## Attachment A – Aquatic Flora and Fauna Review

# Aquatic Flora and Fauna Review

## Longwall 19 Subsidence Management Plan

AWE200141



Prepared for

South32

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Cardno

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# Executive Summary

## Introduction

South32 – Illawarra Metallurgical Coal (South32) plans to extract coal from Longwall 19 in Dendrobium Area 3A (DA3A) of the Dendrobium Mine Area (the Project). Longwall 19 would be located between Wongawilli Creek and Sandy Creek south of DA3A Longwall 8 and south of Fire Trail 6A. This Aquatic Flora and Fauna Assessment (AFFA) has been prepared to support the Subsidence Management Plan (SMP) for Longwall 19. The AFFA focuses on the sections of Wongawilli Creek and its drainage lines and drainage lines of Sandy Creek that may be affected by mining induced ground movements due to longwall extraction. Potential impacts to aquatic flora and fauna are associated with subsidence and fracturing of bedrock resulting in water diversion, groundwater depressurisation and consequent loss of aquatic habitat and biota in watercourses. Sandy Creek, Lake Avon and Lake Cordeaux are located some distance away from the longwalls and would not be affected by extraction. The AFFA includes:

- A review and synthesis of existing information on the aquatic flora and fauna of the Wongawilli Creek and Sandy Creek catchments in the Study Area (area within 600 metres (m) of Longwall 19);
- A field survey in sections of Wongawilli Creek, Sandy Creek and their drainage lines within and adjacent to the Study Area to provide updated detailed local information on aquatic habitat and biota present;
- Assessment of the potential impacts on aquatic flora and fauna (including threatened species) arising directly and indirectly from the proposed mining; and
- Recommendations on impact mitigation measures and monitoring for inclusion within the SMP.

## Existing Environment

Aquatic habitat in Wongawilli Creek, Sandy Creek and their drainage lines within the Study Area for Longwall 19 is largely undisturbed. Wongawilli Creek provides substantial aquatic habitat in the form of pools (up to 100 m long) with important fish habitat such as large boulders and wood debris. Stream banks consisted mainly of well vegetated sandy soil with little erosion or undercutting evident and extensive overhanging vegetation along the stream margin. The main channel of Sandy Creek consists of alternating riffles with sand and gravel bars and moderate size pools. Very little in-stream aquatic macrophytes have been observed, but bank vegetation was extensive and dominated by saw grass and mat rush. Large woody debris and overhanging banks provided extensive aquatic habitat features. Aquatic habitat in drainage lines include small, disconnected and ephemeral pools with limited habitat potential for aquatic flora and fauna. Wongawilli Creek and Sandy Creek, but not their drainage lines, is mapped as Key Fish Habitat. Although some of the biotic indices derived from AUSRIVAS aquatic macroinvertebrate sampling are indicative of degraded habitat or water quality, these more likely reflect natural conditions and the naturally low pH of stream water within the catchment. Suitable habitat for three threatened species, Adams emerald dragonfly (*Archaeophya adamsi*), Sydney hawk dragonfly (*Austrocordulia leonardi*) and Macquarie perch (*Macquaria australasica*) occurs in the Study Area, however, none were detected in the current or previous surveys. Macquarie perch are potentially unable to access Wongawilli Creek in the Study Area due to the presence of natural barriers to fish passage downstream. The waterfall on Sandy Creek downstream of the Study Area almost certainly would prevent Macquarie perch present in Lake Cordeaux from accessing the Sandy Creek catchment within the Study Area.

## Impact Assessment

The mine has been designed to minimise potential impacts to natural features, including watercourses. This includes setting Longwall 19 back from Wongawilli Creek by 175 m. Due to a geological feature underground, Longwall 19 is offset from Sandy Creek by 750 m. The mine has also been designed to reduce the rate of rockbar fracture resulting in flow diversion in Wongawilli Creek to less than 10%. The assessment of potential impacts on aquatic ecology arising from the extraction of Longwall 19 is based on the maximum residual predicted ground movements (including subsidence) and their predicted impacts on physical structure, water availability and water quality characteristics of the above watercourses. Based on these predictions, it is expected that a reduction in the amount and connectivity of aquatic habitat in Wongawilli Creek and drainage lines in the Wongawilli Creek and Sandy Creek catchments would occur due to fracturing of bedrock. An increase in the number of zero flow days in Wongawilli Creek and Sandy Creek following mining induced groundwater depressurisation is also expected to occur and would also result in some reduction in the connectivity of aquatic habitat. Such changes are expected to also impact aquatic biota via reduction in the amount of available habitat and due to habitat fragmentation. Although impacts to aquatic habitat and biota in Wongawilli Creek would be severe at the scale of individual pools if fracturing was to occur, in isolation, impacts associated with extraction of Longwall 19 would be minimal in the context of the upper Avon River and Cordeaux River catchments. However, the extraction of Longwall 19 would be

expected to continue to contribute to the cumulative impact of extraction of other longwalls in DA3A and DA3B that have resulted in reductions in flow and drainage of pools in Wongawilli Creek during low rainfall conditions.

Predictions indicate that the risk of rockbar fracturing associated with flow diversions in Wongawilli Creek is low (less than 10%). Based on this fracture rate, the probability of this occurring due to extraction of Longwall 19 is low (only one rockbar occurs within the Study Area). In the unlikely event fracturing resulting in flow diversion occurred at this rockbar, reductions in the availability of aquatic habitat in Wongawilli Creek would be limited due to the presence of several other flow controlling features (shallow riffle sections, channel restrictions and debris dams) further upstream, and possibly restricted to the 80 m long pool immediately upstream of the rockbar. The drainage of this pool, if it were to occur, represents a relatively small impact to aquatic habitat and associated biota in the section of creek within the Study Area and wider Cordeaux River catchment area. There is likely to be a reduction in longitudinal connectivity resulting from the full or partial drainage of pools. Based on observations to date, this should be temporary and only occur during low flow events. Fracturing and flow diversions are also predicted to occur in drainage lines. However, the aquatic habitat provided by these watercourses is very limited (in terms of permanence and quality) and also abundant in the Study Area and Dendrobium Mine Area. Thus, associated impacts to aquatic habitat and biota would be minimal at the scale of the Study Area. It is noted that some of these drainages have experienced such impacts associated with extraction of previous DA3A and DA3B longwalls. Fracturing is not predicted to occur in Sandy Creek and so impacts to aquatic habitat and biota would not be expected.

It is predicted that extraction of Longwall 19 and other DA3 longwalls could result in an increase in zero flows on Wongawilli Creek from 10% of the time (natural conditions) up to 13 % of the time. On average, this represents an additional 10 days of zero flow (an increase from 37 days to 47 days). On Sandy Creek it could increase from up to 8% of the time (natural conditions) to 13% of the time, representing an additional 18 days of zero flow (an increase from 29 days to 47 days). These do not suggest substantial changes to natural conditions would occur. Pool habitat would be expected to largely persist during periods of zero flow thereby providing refuge for aquatic biota until flow returned. Although pools would eventually dry during extended zero flow periods, it would be unlikely all zero flow days would occur consecutively, but rather be interrupted by periods of flow. Associated impacts to aquatic biota would be expected to be associated primarily with temporary reductions in habitat connectivity. These should be relatively minor assuming flow returned during and following periods of rainfall. Groundwater depressurisation would likely also be temporary and would reduce to a few ML/year by 2055. Assuming flow returns soon after periods of zero flow, reductions in habitat availability and connectivity would be temporary and are not expected to result in substantial impacts to aquatic biota. Impacts to water quality due to mining of Longwall 19 are expected to be minor in stream reaches within subsidence affected areas. This prediction is consistent with changes in water quality observed during extraction of previous DA3A and DA3B longwalls. Thus, associated risks to aquatic habitat and biota is expected to be low.

Although in isolation impacts due to extraction of Longwall 19 represent a relatively small impact to these watercourses, cumulative impacts associated with existing impacts and habitat loss, particularly in Wongawilli Creek, should be considered. This has occurred following reductions in baseflow due to mining induced groundwater depressurisation (albeit manifesting during periods of low rainfall only) associated with mining in Dendrobium DA3A and DA3B. By May 2018 approximately 1.4 km of Wongawilli Creek (representing about 10% of its 12 km total length) had been affected by temporary reductions in flow and pool drainage associated with extraction of coal at Dendrobium Mine. Low rainfall appears the primary process contributing to the low pool water levels observed in Wongawilli Creek. The severe rainfall deficit during 2018 reduced available water in the catchment to the extent that mining effects were obvious. It is expected that during similar drought conditions, pool levels and river flows will remain low, consistent with historically low rainfall. When rainfall increases, surface flows and pool levels have recovered, although there could be a lag while any significant soil moisture deficit is overcome. Although depressurisation impacts may only be evident during low rainfall, with flow and pool water levels returning after rainfall periods, even a temporary loss of habitat and the loss of connectivity of remaining habitat here would likely have resulted in a reduction in the population size of aquatic biota in Wongawilli Creek. Extraction of Longwall 19 would be expected to increase the levels of mining impacts through further groundwater drawdown currently experienced in the Wongawilli Creek catchment. The predicted increases in zero flow days was based on the cumulative effect of the remaining DA3B longwalls and Longwall 19 and applicable to the flow at the gauging station located approximately 1 km downstream of the Study Area near Fire Road 6, however it is probable increases in zero flow days would be greater adjacent to extracted longwalls. The predicted increase in number of zero flow days that would occur suggests that impacts associated with extraction of Longwall 19 and other future DA3A and DA3B longwalls would occur associated with reductions in habitat connectivity during periods of low flow. During these periods isolated pool habitat would provide refuge for aquatic biota until flow returned following rainfall events. This should largely limit impacts to aquatic biota to those

associated with temporary reductions in habitat connectivity, which should be relatively minor in the context of the entire creek.

**Recommendations and Management**

Potential impacts on aquatic habitat and biota within the Study Area would be managed by:

- Impact minimisation, including the proposed setback of the longwall from Wongawilli Creek and identification of triggers that would prompt surveys to assess any impacts on aquatic habitats and their biota identified during and after extraction of the longwalls;
- Monitoring of aquatic habitat and biota during and after mining to determine the nature and extent of any subsidence-induced impacts on aquatic ecology and responses of aquatic ecosystems to any remediation or management works implemented;
- Undertaking additional aquatic ecology studies in response to specific impacts on water quality and availability of aquatic habitats within the watercourses; and
- Implementation of contingent measures such as review of mine layout and appropriate offset distances from creeks, watercourse remediation measures, appropriate control measures to limit deposition of any eroded sediment into the watercourses, and appropriate offset and compensatory measures.

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# 1 Introduction

## 1.1 Background

South32 – Illawarra Metallurgical Coal (South32) is using longwall mining to extract coal from the Dendrobium Coal Mine, situated near Cordeaux approximately 20 kilometres (km) west of Wollongong. Consent for the mine, granted in November 2001, allows extraction from three longwall domains, known as Dendrobium Areas (DA) DA1, DA2 and DA3. DA3, situated to the west of Lake Cordeaux, is currently being mined. A modification to the mine layout of DA3 approved in December 2008 allowed the mine to be expanded and Area 3 to be sub-divided into three smaller domains, DA3A, DA3B and DA3C. DA3A currently comprises Longwalls 6, 7, 8 and 19, which are situated between Wongawilli and Sandy Creeks. Longwalls 6, 7 and 8 were completed from 2010 to 2012. Mining of DA3B Longwalls 9 to 18 commenced in 2013 and Longwall 15 in DA3B is currently being extracted. South32 are proposing to extract coal from Longwall 19 in DA3A (the Project). Longwall 19 would be located between Wongawilli Creek and Sandy Creek south of DA3A Longwall 8 and south of Fire Trail 6A.

Longwall mining is the most common form of coal mining in the Illawarra Region. Longwall mining contrasts with open-cut mining, with the former being undertaken by extracting coal accessed via tunnels. The coal seams are progressively accessed and extracted by longwalls. Longwall mining can affect the surface, principally by the effects of subsidence. Physical impacts such as subsidence induced fracturing of creek beds can cause diversions of surface and sub-surface flows, drainage of pools and increases in groundwater inflows.

The Dendrobium Mine consent conditions require that prior to carrying out any underground mining operations that could cause subsidence a Subsidence Management Plan (SMP) should be prepared and approved by the Department of Planning, Industry and Environment (DPIE). The overall objective of the SMP is to manage any impacts to watercourses, other natural features and built features associated with mine-induced subsidence.

South32 has commissioned Cardno (formerly trading as Cardno Ecology Lab and The Ecology Lab Pty Ltd) to undertake the Aquatic Flora and Fauna Assessment (AFFA) to support the SMP for Longwall 19.

## 1.2 Scope of Works

The work undertaken for the AFFA by Cardno consisted of the following:

- Desktop review and compilation of existing information on aquatic habitat, vegetation and macroinvertebrates, fish, and any listed threatened species and populations, in the Wongawilli Creek and Sandy Creek catchments adjacent to the proposed location of Longwall 19. This information was obtained from investigations that have been underway for several years, as part of existing mining operations in DA3B.
- A field survey in sections of Wongawilli Creek and Sandy Creek and their drainage lines adjacent to proposed Longwall 19. The aim was to update information on local aquatic habitat and biota that may be affected by any subsidence associated with extraction of these longwalls and place it in context of the wider Dendrobium Mine and Metropolitan Catchment Areas.
- Assessment of the potential impacts of the Project on aquatic ecology, including threatened species, and any cumulative impacts, in Sandy Creek and Wongawilli Creek and their tributaries that may experience impacts associated with potential mining subsidence.
- Provide recommendations on measures to avoid and mitigate potential impacts on aquatic ecology and the form and content of the requisite aquatic ecology monitoring plan for these longwalls. This would be implemented to determine the nature and extent of any subsidence induced impacts on aquatic ecology and assess the response of aquatic ecology to any subsequent remediation and management works.

# 2 Relevant Management, Policies and Guidelines

## 2.1 Dendrobium Mine Consent

Schedule 3 of the Dendrobium Mine consent includes several conditions concerning management of potential environmental impacts associated with mine subsidence. These include preparation of a SMP that integrates monitoring and management of potential impacts to natural (e.g. watercourses, swamps), built (e.g. electrical, communications and other infrastructure) and cultural (e.g. aboriginal heritage) features of the environment. With relevance to aquatic ecology the SMP should:

- Identify and assess the significance of all natural features located within 600 m of the edge of secondary extraction;
- Include a minimum of two years of baseline data, collected at appropriate frequency and scale, for all significant natural features;
- Address third and higher order streams individually and address first and second order streams collectively;
- Include a detailed subsidence impact assessment, clearly setting out all predicted subsidence effects, subsidence impacts and environmental consequences;
- Describe a monitoring and reporting program addressing aquatic flora and fauna including any threatened aquatic species and their habitats and ecosystem function; and
- Provide a management plan for avoiding, minimising, mitigating and remediating impacts on watercourses, including a contingency plan focusing on measures for remediating both predicted and unpredicted impacts.

Several conditions also relate specifically to swamps, these are considered by other specialists.

Appendix 4 of the Dendrobium Mine consent also provides a statement of commitments relating to longwall layouts, impact monitoring, avoidance, mitigation and any rehabilitation in DA3. These include a commitment to avoid significant impact to major natural features such as creeks, and a commitment to avoid mining under Wongawilli Creek and Sandy Creek to minimise the potential for major fracturing and loss of surface flow and any associated impacts to aquatic ecology. Pre, during and post mining subsidence impact monitoring of aquatic flora and fauna will also be undertaken in accordance with the approved SMP.

NSW Resources and Energy (formerly the Division of Resources and Energy (DMR)) has prepared guidelines for SMP (now known as Extraction Plan (EP)) applications (DMR 2003). A key component of the application is characterisation of each of the identified surface and sub-surface features that may be affected by the proposed mining. Results of a minimum of one-year pre-mining base-line monitoring of relevant environmental values in areas of environmental sensitivity that may be affected by the proposed mining with reference to applicable guidelines published by the NSW Government should also be included. The applicant should provide the results of a risk assessment, where appropriate, with an emphasis on identifying those subsidence impacts with high-risk levels and/or potentially severe consequences. Areas requiring attention by the applicant when conducting risk assessment include potential subsidence impacts on:

- Wetlands, swamps and water related ecosystems;
- Significant watercourses including surface flows, water quantity and quality and ecological integrity; and
- Threatened and protected species.

## 2.2 Fisheries Management Act 1994

The *Fisheries Management Act 1994* (FM Act) contains provisions for the conservation of fish stocks, key fish habitat (KFH), biodiversity, threatened species, populations and ecological communities. The FM Act regulates the conservation of fish, marine vegetation and some aquatic macroinvertebrates and the development and sharing of the fishery resources of NSW for present and future generations. The FM Act lists threatened species, populations and ecological communities under Schedules 4, 4A and 5. Schedule 6 lists key threatening processes (KTPs) for species, populations and ecological communities in NSW waters and declared critical habitat are listed in a register kept by the Minister of Primary Industries. Impacts to these species, populations, communities, processes and habitats due to the Project need to be considered.

Assessment guidelines to determine whether a significant impact is expected are detailed in Section 220ZZ and 220ZZA of the FM Act.

Another objective of the FM Act is to conserve KFH. These are defined as aquatic habitats that are important to the sustainability of recreational and commercial fishing industries, the maintenance of fish populations generally and the survival and recovery of threatened aquatic species. In freshwater systems, most permanent and semi-permanent rivers, creeks, lakes, lagoons, billabongs, weir impoundments and impoundments up to the top of the bank are considered KFH. Small headwater creeks and gullies that flow for a short period after rain and farm dams on such systems are excluded, as are artificial water bodies except for those that support populations of threatened fish or invertebrates. At a broad scale, KFH relevant to the Project includes the following:

- Permanently flowing rivers and creeks including those where the flow is modified by upstream dam(s), up to the top of the natural bank regardless of whether the channel has been physically modified;
- Intermittently flowing rivers and creeks that retain water in a series of disconnected pools after flow ceases including those where the flow is modified by upstream dam(s), up to the top of the natural bank regardless of whether the channel has been physically modified; and
- Any waterbody if it is known to support or could be confidently expected (based on predictive modelling) to support threatened species, threatened populations or threatened communities listed under the provisions of FM Act.

## 2.3 NSW DPI (Fisheries) Policy and Guidelines for Fish Habitat Conservation and Management

The NSW Department of Primary Industries (DPI) Policy and Guidelines for Fish Habitat Conservation and Management (Update 2013) (NSW DPI 2013a) replaces the Policy and Guidelines for Aquatic Habitat Management and Fish Conservation (NSW DPI 1999) and the former Fisheries NSW Policy and Guidelines for Fish Friendly Waterway Crossings (NSW DPI 2003). These updated policies and guidelines are applicable to all planning and development proposals and various activities that affect freshwater, estuarine and marine ecosystems. The aims of the updated policies and guidelines are to maintain and enhance fish habitat for the benefit of native fish species, including threatened species, in marine, estuarine and freshwater environments. The updated document assists developers, their consultants and government and non-government organisations to ensure their actions comply with legislation, policies and guidelines that relate to fish habitat conservation and management. It is also intended to inform land use and natural resource management planning, development planning and assessment processes, and to improve awareness and understanding of the importance of fish habitats and how impacts can be mitigated, managed or offset. The policies and guidelines outlined in this document are taken into account when NSW DPI assesses proposals for developments and other activities that affect fish habitats. The document contains:

- Background information on aquatic habitats and fisheries resources of NSW;
- An outline of the legislative requirements relevant to planning and development which may affect fisheries or aquatic habitats in NSW;
- General policies and classification schemes for the protection and management of fish habitats and an outline of the information that NSW DPI requires to be included in development proposals that affect fish habitat;
- Specific policies and guidelines aimed at maintaining and enhancing the free passage of fish through instream structures and barriers;
- Specific policies and guidelines for foreshore works and waterfront developments; and
- Specific policies and guidelines for the management of other activities that affect waterways.

NSW DPI considers the ‘sensitivity’ of any KFH that would be affected by the Proposal (NSW DPI 2013a). The term ‘sensitivity’ refers to the importance of the habitat to the survival of fish and its ability to withstand disturbance. In freshwater ecosystems, instream gravel beds, rocks greater than 500 mm in two dimensions, snags greater than 300 mm in diameter or 3 m in length, native aquatic plants, and areas known or expected to contain threatened and protected species are considered highly sensitive KFH. Other freshwater habitats plus weir pools and dams across natural waterways are considered to be moderately sensitive KFH. Ephemeral aquatic habitat that does not support native aquatic or wetland vegetation is considered to be of

minimal sensitivity. It is important to note that aquatic habitats within first and second order gaining streams, sections of stream that have been concrete-lined or piped (excluding waterway crossings) and artificial ponds are not regarded as KFH unless they support a listed threatened species, population or ecological community or 'critical habitat'. NSW DPI may in addition assess development proposals in relation to waterway class (i.e. their ability to provide habitat that is suitable for fish), which in turn determines the appropriate type of any waterway crossings.

## 2.4 Key Threatening Processes

A Key Threatening Process (KTP) is a process that threatens, or may have the capability to threaten, the survival or evolutionary development of species, population or ecological community. KTPs are listed under the FM Act, *Biodiversity Conservation Act 2016* (BC Act) and *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). There are eight listed KTPs under the FM Act, 38 listed under the BC Act and 21 listed under the EPBC Act. Broadly, the KTPs include threats to threatened species, population and ecological communities as well as cause species, population or ecological communities to become threatened.

One KTP listed under the BC Act is directly applicable to the Project: *Alteration of habitat following subsidence due to longwall mining.*

In the final determination for this KTP, the NSW Scientific Committee found that:

- Mining subsidence following longwall mining is frequently associated with cracking of valley floors and creek lines and with subsequent effects on surface and groundwater hydrology.
- Subsidence-induced cracks occurring beneath a stream or other surface water body may result in the loss of water to near-surface groundwater flows. If the water body is located in an area where the coal seam is less than approximately 100 to 120 m below the surface, longwall mining can cause the water body to lose flow permanently. 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. The ability of the water body to recover is dependent on the width of the crack, the surface gradient, the substrate composition and the presence of organic matter. An already-reduced flow rate due to drought conditions or an upstream dam or weir will increase the impact of water loss through cracking.
- Subsidence can cause decreased stability of slopes and escarpments, contamination of groundwater by acid drainage, increased sedimentation, bank instability and loss, creation or alteration of riffle and pool sequences, changes to flood behaviour, increased rates of erosion with associated turbidity impacts, and deterioration of water quality due to a reduction in dissolved oxygen (DO) and to increased salinity, iron oxides, manganese, and electrical conductivity (EC).
- Loss of native plants and animals may occur directly via iron toxicity, or indirectly via smothering. Long-term studies in the United States indicate that reductions in diversity and abundance of aquatic invertebrates occur in streams in the vicinity of longwall mining and these effects may still be evident 12 years after mining.
- In the Southern Coalfields, substantial surface cracking has occurred in watercourses within the Upper Nepean, Avon, Cordeaux, Cataract, Bargo, Georges and Woronora catchments, including Flying Fox Creek, Wongawilli Creek, Native Dog Creek and Waratah Rivulet. The usual sequence of events has been subsidence-induced cracking within the streambed, followed by significant dewatering of permanent pools and in some cases complete absence of surface flow.
- Subsidence associated with longwall mining has contributed to adverse effects on upland swamps. The conversion of perched water table flows into subsurface flows through voids, as a result of mining-induced subsidence may significantly affect the water balance of upland swamps. The timeframe of these changes is likely to be long-term. While subsidence may be detected and monitored within months of a mining operation, displacement of susceptible species by those suited to altered conditions is likely to extend over years to decades as the vegetation equilibrates to the new hydrological regime.

The Department of Environment and Conservation (now the DPIE) has identified several priority actions to promote the abatement of this KTP, including:

- Examine the effects of subsidence from longwall mining on priority ecosystems including streams, wetlands and threatened species, populations and ecological communities.
- Prepare guidelines outlining key factors that should be considered when assessing impacts of new longwall mines on biodiversity.
- Develop recommendations for monitoring impacts of new longwall mines on biodiversity and mitigation methods.
- Ensure rigorous assessment of new mines continues through existing approval processes including the preparation of SMPs.

Consideration of the effect of exacerbation of any KTP on a listed threatened species, population or ecological community must be taken into consideration during any assessment.

# 3 Existing Environment

## 3.1 Desktop Review

### 3.1.1 Physical Setting and Study Area

The proposed Longwall 19 is located within the Metropolitan Catchment Area, which is a special declared area controlled by Water NSW (previously the Sydney Catchment Authority (SCA)) (**Figure 3-1**). The Study Area for the aquatic ecology assessment is the surface environment directly above and within 600 m of the footprint of Longwall 19. The main watercourses within the vicinity of these longwalls are Wongawilli Creek and Sandy Creek, which flow in a northerly direction west and east of the longwall, respectively. Wongawilli Creek is a third order (Strahler stream order) creek that is 12 km long from its confluence with the Cordeaux River to its headwater, with 1.4 km within the Study Area. The majority of Sandy Creek is third order. There are also several other first and second order drainage lines and upland swamps that flow into these watercourses.

Lake Cordeaux is located 0.9 km east and Lake Avon is located 3.1 km west of the proposed longwall. Avon River, Cordeaux River and their upstream lakes have a very low risk of being affected by the Project and are not included in this assessment. Swamps and associated flora and fauna in the Study Area will be assessed by other specialists.

### 3.1.2 Overview of Previous Studies

Numerous studies of aquatic habitat, flora and fauna in the Dendrobium Mine area have been undertaken by Cardno (formerly Cardno Ecology Lab and The Ecology Lab). These included studies in:

- DA1: AEA studies (The Ecology Lab 2001a, b and 2003) and monitoring studies ((The Ecology Lab 2005).
- DA2: AEA studies (The Ecology Lab 2006) and monitoring studies (Cardno Ecology Lab 2009). and
- DA3: AEA studies (The Ecology Lab 2007), including the DA3B AEA (Cardno Ecology Lab 2012a), baseline studies (Cardno Ecology Lab 2011) and ongoing monitoring studies (Cardno Ecology Lab 2012; 2013; 2014; 2015 and 2016 and Cardno 2018a) and most recently in 2019 (Cardno in prep).

In these studies, the primary watercourses considered were in the Wongawilli Creek and Sandy Creek Catchments. Investigations of Wongawilli Creek and Sandy Creek, including sections within the Study Area for Longwall 19, were undertaken as part of the initial aquatic ecology assessment for Dendrobium Area 3 (The Ecology Lab 2007) and of Wongawilli Creek as part of the subsequent SMP for DA3B (Cardno Ecology Lab 2012a). These studies also assessed impacts of predicted mine subsidence on aquatic ecology, including threatened species, in DA3. Information on aquatic ecology in the Study Area and adjacent areas available from these previous studies is reviewed in **Sections 3.1.3** to **3.1.8**. This included the findings of surveys undertaken at existing DA3A and DA3B Sites 2, 3 and X4 on Wongawilli Creek, Sites 11 and 12 on Sandy Creek tributary SC10 and Site 13 on Sand Creek tributary SC10C. All of these sites are within the Study Area for Longwall 19 and may experience impacts associated with mining induced subsidence. Information from other nearby sites in these catchments but that are outside the Study Area has also been reviewed for comparative purposes. These are Sites 1, 4, 5, X5 and X6 on Wongawilli Creek, Sites 7 and 9 on Sandy Creek and Site 8 on Sandy Creek tributary SC7. Investigations undertaken for the current study in November 2019 included additional surveys at each of these sites.

### 3.1.3 Aquatic Habitat and Vegetation

#### *3.1.3.1 Wongawilli Creek*

Detailed investigations of Wongawilli Creek were undertaken as part of the initial investigations for DA3 in July 2007. Four zones with similar habitat characteristics were identified within Wongawilli Creek. The Study Area is located within Zones 2 and 3. Zone 2 is located from 3 km upstream of Cordeaux River to the confluence of tributary WC15. Zone 3 is located from the confluence with WC15 upstream to the large waterfall on Wongawilli Creek at rockbar 36.

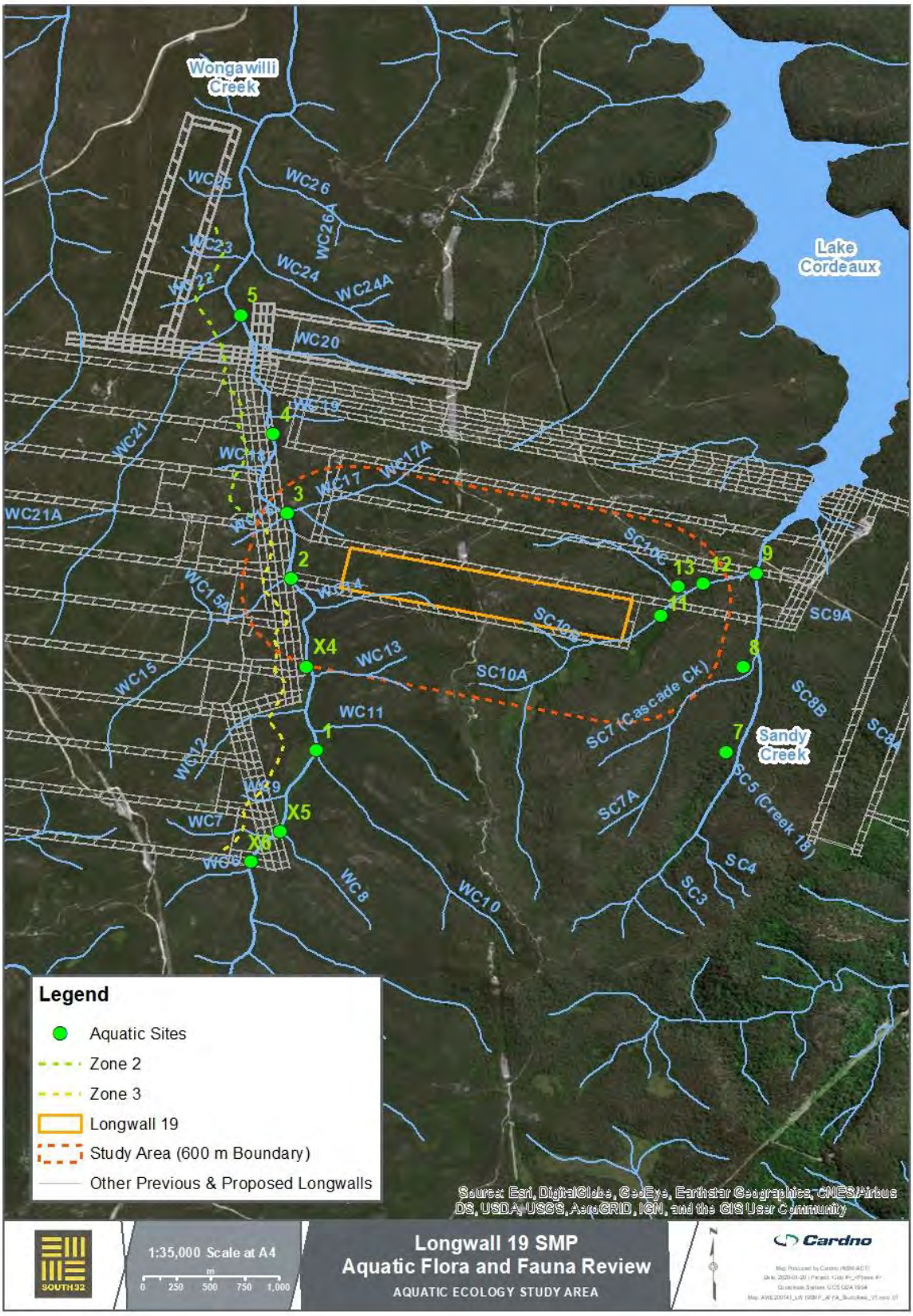



Figure 3-1 Aerial image overlaid with longwall layouts, watercourses and aquatic ecology sites within and adjacent to the Longwall 19 Study Area

The aquatic habitat within Zones 2 and 3 was characterised as follows:

- Riparian vegetation is dominated by dry Eucalypt native forest within an increasingly steep and narrow (moving upstream) valley. This forest vegetation extends to the banks of the creek and partially shades the channel along much of Zone 2 and almost fully shades the channel in Zone 3. Riparian vegetation along the banks includes numerous native grasses, shrubs and trees including saw grass (*Gahnia* sp.), mat rush (*Lomandra* sp.), wattles (*Acacia* sp.), and tea-tree (*Leptospermum* sp.). There is also a variety of native ferns present along the banks of the main drainage and tributaries of this zone.
- The channel morphology of Wongawilli Creek within Zone 2 is characterised by a series of long pools some of which are over 100 m in length, up to 10 m wide and up to 2 m deep. These pools are separated by small sandstone rock bars. There are also accumulations of sand, debris dams and small boulder fields between these long pools. In the large pools, the dominant substratum is sand, with significant areas of bedrock, and boulders. Small gravel beds are present in the upstream sections of some of the pools. Stream banks consisted of sections of well vegetated sandy soil with overhanging vegetation along the edge, and sections of exposed sandy soil with signs of recent natural erosion including undercutting and scouring. There were numerous in-stream habitat features, including large snags and tree roots and some rockbars. The main channel in Zone 3 is characterised by extensive reaches of relatively long, narrow, shallow pools with few holes deeper than 1 metre, and rarely wider than 3 m. These pools are separated by short riffle sections which consist of boulder fields, and gravel-pebble beds. There were also sandbars and some small areas of bedrock along this reach. Within the pools there was some accumulation of detritus including leaf litter and woody debris.
- The distribution of aquatic plants is patchy, with green and brown algae present. The only other submerged plant found was Watermilfoil (*Myriophyllum* sp.) at Site 5. Three emergent plants were recorded in Wongawilli Creek, rush (*Juncus* sp.) at Sites 1 and 3, sedge (*Cyperus* sp.) and *Lomandra* sp. at Site 3. The baseline monitoring (Cardno Ecology Lab 2011) indicated that aquatic macrophytes were relatively scarce covering ≤ 5% of the surface area at the majority of monitoring sites, except for Site 5, where the percentage cover varied from 10% to 40% in spring and 15 % to 80 % in autumn. The percentage cover of aquatic macrophytes at the other sites exceeded 5% on only two occasions in September 2011 and April 2009 at Sites X6 and 3, respectively. Algae were more common, covering ≥ 20% of the area on occasion at all of the sites. Mosses were present on bedrock, boulders and large woody debris and appeared to be more prevalent in spring. The Ecology Lab (2001a) also noted small beds of *Myriophyllum* sp. in most pools and extensive algal growth on hard surfaces.

A description of Wongawilli Creek drainage lines within the Study Area is provided in **Section 3.1.3.3**.

#### *3.1.3.2 Sandy Creek*

Near the Fire Road 6C crossing, Sandy Creek flows over sandstone rockbars forming a series of long shallow pools, short deep pools and alternating short riffles. Approximately 100 m below the crossing is a large waterfall approximately 25 m high. Below the waterfall the creek bed is characterised by a moderate slope with large boulders and sandbars to the high water mark of the dam. This waterfall is downstream of the Study Area for Longwall 19. The reach of Sandy Creek upstream of here and including the confluence with Banksia Creek (SC10) as far as the confluence with Cascade Creek (SC7) is characterised by alternating riffles with sand and gravel bars and moderate size pools. No in-stream aquatic macrophytes have been observed, but bank vegetation was extensive and dominated by saw grass and mat rush. Large woody debris and overhanging banks provided extensive aquatic habitat features. Surrounding riparian vegetation was predominantly eucalypt forest. The waterfall on Sandy Creek is a substantial barrier to fish passage into Sandy Creek from Lake Cordeaux.

A description of Sandy Creek drainage lines within the Study Area is provided in **Section 3.1.3.3**.

#### *3.1.3.3 Existing Aquatic Habitat Mapping*

The July 2007 investigations (The Ecology Lab 2007) mapped four habitat types (adapted from Fairfull and Witheridge 2003) within Wongawilli Creek and Sandy Creek and their drainage lines:

- Unlikely habitat: Ephemeral drainage lines that only contain flow during and immediately after significant rainfall. Permanent or semi-permanent pools that could provide refuge for aquatic biota during prolonged dry weather are absent.
- Minimal habitat: Watercourses that contain some small semi-permanent refuge pools which are unlikely to persist through prolonged drought. Flow connectivity would only occur during and following significant

rainfall. These pools may provide habitat for some aquatic species including aquatic macroinvertebrates and freshwater crayfish.

- Moderate habitat: Watercourses that contain some larger permanent and semi-permanent refuge pools, which would persist through prolonged drought, although become greatly reduced in extent. These watercourses should support a relatively diverse array of aquatic biota including some fish, freshwater crayfish and aquatic macroinvertebrates. There may also be some aquatic plant species present.
- Significant habitat: Watercourses that contain numerous large, permanent pools and generally have flow connectivity except during prolonged drought. They provide extensive and diverse aquatic habitat for aquatic flora and fauna.

It was found that:

- Wongawilli Creek and Sandy Creek provide significant aquatic habitat.
- Four drainage lines of Wongawilli Creek are located in the Study Area. Wongawilli Creek drainage line WC15 provides moderate aquatic habitat, WC13, WC14 and WC17 provide minimal aquatic habitat. WC15 flows out of Swamp 14 and is characterised by a series of permanent pools amongst sandstone boulders and small waterfalls. These pools would provide habitat for some fish and invertebrates throughout prolonged dry periods. This series of waterfalls is an effective barrier to passage of Macquarie perch (*Macquaria australasica*) upstream within this tributary.
- Two drainage lines of Sandy Creek are located in or on the edge of the Study Area. SC10 joins Sandy Creek approximately 50 m upstream of the Fire Road 6C crossing with approximately 3.0 km (including tributaries of SC10) located within the Study Area. The reach of SC10 has a relatively level gradient, with long pools separated by small sandstone rockbars with falls of less than 2 m. The creek bed consisted of a mixture of bedrock, boulder, sand and detritus. The bank vegetation was dominated by native shrubs and grasses with some ferns. Surrounding vegetation consisted of sparse eucalypt woodland with a dense under-story of native shrubs and grasses. The relatively deep pools (up to 2 m) provide permanent refuge SC10 provides moderate aquatic habitat. Since this initial investigations SC10 and its drainage line SC10C have experienced impacts associated with previous mining in DA3A that have resulted in changes in aquatic habitat here (**Section 3.1.9**). The second drainage line, Cascade Creek (SC7), joins Sandy Creek approximately 700 m upstream of the Fire Road 6C crossing and is adjacent to the southeast border of the Study Area for Longwall 19. SC7 flows mainly over sandstone bedrock with some sand and gravel bars. The creek banks are well vegetated with overhanging native ferns, shrubs and grasses and contain large amounts of woody debris. Approximately 200 m upstream of the confluence with Sandy Creek is a waterfall consisting of a series of cascades over bedrock with a boulder filled pool at the base. It is expected that aquatic habitat would be restricted to a few permanent pools during periods of extended dry weather and that these would provide refuge for some fish and invertebrate species and SC7 provides moderate aquatic habitat.

These findings were used to inform the detailed KFH mapping using the updated classifications in NSW DPI (2013a) during the current assessment (**Section 3.2.2.1**)

The broad scale KFH map for Wollongong available on the NSW DPI website indicates that Wongawilli Creek and Sandy Creek are KFH (NSW DPI 2017a). The drainage lines that traverse the Study Area are not identified as KFH by this map.

### 3.1.4 Water Quality

The limited *in-situ* water quality measurements taken in Wongawilli Creek during the baseline aquatic ecology monitoring showed EC levels were generally within the ANZECC/ARMCANZ (2000) guideline default trigger values (DTVs) (30 to 350 (µS/cm) for upland rivers in south-east Australia (Cardno Ecology Lab 2009 and 2011). EC measurements below the lower DTV were recorded at Sites X5, X4 and 4, but only on one occasion. The pH of the water at all sites was generally below the DTVs (pH 6.5 to 8.0). It should be noted that this is typical for watercourses that flow through Hawkesbury sandstone environments. The DO levels at all the sites on the creek fell below the lower DTV (90 % saturation) during some surveys, more commonly at the downstream sites (2, 3, 4, 5 and X4) than upstream sites (X6, X5 and 1). DO levels in excess of the upper DTV (110 % saturation) were recorded at Sites X6, 3 and 4 in September 2010 and at Sites 1, 2, 3 and 4 in April 2009. In spring, the turbidity measurements taken at Sites X6, X5 and 5 were frequently below the lower DTV (2 ntu), as were the measurements taken at Sites 1 and X4 in autumn. Turbidity readings in excess of the upper DTV (25 ntu) were recorded at Sites 3 and 4, but only in

October/November 2011. Water quality in Sandy Creek and its drainage lines during the DA3A monitoring period was comparable to that in Wongawilli Creek (Cardno 2015). EC was generally within DTVs except for a few occasions when it was marginally below. DO was on occasion marginally below the DTVs. As is the case in Wongawilli Creek, pH in Sandy Creek also appears naturally low, with values often below the lower DTV (Cardno 2015). In both creeks, turbidity levels are low and often below the lower DTV (2 ntu).

While water quality measures have often been found outside DTVs, the relatively remote and undisturbed catchment area does not suggest influence by any anthropogenic disturbance. Turbidity values below 2 ntu are not cause for concern, and most likely reflect the relatively low organic content of the water. Also, low pH levels have been recorded generally across the Dendrobium Mine area, and appear to occur naturally, most likely associated with local geology and its influence on water chemistry. The natural water quality of these creeks should be taken in to consideration when interpreting the results of macroinvertebrate sampling.

### 3.1.5 Macroinvertebrates

The several AUSRIVAS surveys undertaken in Wongawilli Creek and Sandy Creek have indicated a relatively large among of variability in biotic indices. During sampling as part of the DA3A and DA3B monitoring, assemblages on Wongawilli Creek and Sandy Creek ranged from more diverse than AUSRIVAS reference condition (AUSRIVAS Band X) to severely impaired (Band C) (**Appendix B**). AUSRIVAS Band scores are derived from the OE50 Taxa Scores, which is a biotic index of habitat and water quality (**Section 3.2.2.4**). The Stream Invertebrate Grade Number Average Level (SIGNAL2) indices, a biotic index of water pollution, suggested severe to mild water pollution in both creeks. However, while these results suggest potential anthropogenic disturbance to habitat and / or water quality, there is no other evidence to support this. It is possible that the naturally low pH levels in this watercourse, and others that traverse the Dendrobium Mine area (**Section 3.1.4**), may be influencing the type of macroinvertebrates that are present. Other measures of water quality, such as naturally occurring levels of some heavy metals, may also influence the type of macroinvertebrates, and other organisms, present (Cardno Ecology Lab 2012a; b; Ecoengineers 2006).

Overall there was little difference in biotic indices between sites within and outside of the Study Area in each of the Wongawilli Creek and Sandy Creek catchments (**Table 3-1**). The number of taxa, OE50 Taxa Score and SIGNAL2 Index tended to be greater at sites on Wongawilli Creek and Sandy Creek outside of the Study Area. The two exceptions were OE50 Taxa Score in Wongawilli Creek in autumn and in Sandy Creek in spring. However, in each cases differences between sites inside and outside the Study Area were marginal, and do not suggest substantial differences in aquatic habitat and water quality inside and outside of the Study Area.

Table 3-1 Mean AUSRIVAS data from sites within and outside the Study Area in each of Wongawilli Creek and Sandy Creek from 2008 to 2017. Note not all sites sampled on each occasion, see **Appendix B** for further detail. SE = standard error.

| Catchment and Sites | Spring | | | Autumn | | |
|---|---|---|---|---|---|---|
| | No. of Taxa | OE50 Taxa Score | SIGNAL2 Index | No. of Taxa | OE50 Taxa Score | SIGNAL2 Index |
| **Wongawilli Creek** | | | | | | |
| Within Study Area: Sites 2, 3 and X4 | | | | | | |
| Mean | 16.5 | 0.72 | 4.7 | 16.4 | 0.87 | 4.5 |
| SE | 1.2 | 0.04 | 0.1 | 1.2 | 0.05 | 0.1 |
| Outside Study Area: Sites 1, 4, 5, X5 and X6 | | | | | | |
| Mean | 19.3 | 0.78 | 4.8 | 17.8 | 0.85 | 4.7 |
| SE | 1.1 | 0.04 | 0.1 | 1.2 | 0.05 | 0.1 |
| **Sandy Creek** | | | | | | |
| Within Study Area: Sites 11, 12 and 13 | | | | | | |
| Mean | 16.0 | 0.75 | 4.3 | 15.6 | 0.77 | 4.2 |
| SE | 0.5 | 0.03 | 0.1 | 0.5 | 0.03 | 0.1 |
| Outside Study Area: Sites 7, 8 and 9 | | | | | | |
| Mean | 16.8 | 0.74 | 4.6 | 17.2 | 0.83 | 4.6 |
| SE | 0.6 | 0.03 | 0.1 | 0.6 | 0.02 | 0.1 |

### 3.1.6 Fish

Numerous fish surveys have been undertaken in Wongawilli Creek previously. In particular, in autumn 2008 and summer 2009, targeted backpack electrofishing surveys were undertaken in the reaches of Wongawilli Creek identified as containing potential habitat for Macquarie perch (Cardno Ecology Lab 2009), including that within the Study Area. Climbing galaxias (*Galaxias brevipinnis*), Australian smelt (*Retropinna semoni*) and freshwater crayfish (*Euastacus* sp.) were caught in the reach of the creek immediately downstream of Fire Road 6, just downstream of the Study Area. The deeper pool sections immediately upstream of this road and within the Study Area contained Australian smelt and longfinned eel (*Anguilla reinhardtii*). Further upstream, large numbers of climbing galaxias and freshwater crayfish were caught. In 2001, fish occurring in pools and riffles from the upstream limit of boat passage back down to the road crossing were sampled using an electrofisher (The Ecology Lab 2001a, b). Australian smelt, freshwater eels (*Anguilla* sp.), mountain galaxias and climbing galaxias were caught upstream of the major barriers. No Macquarie perch were caught during these surveys, although this species has been recorded in Wongawilli Creek in pools just upstream and downstream of Fire trail 6A (NSW DPI (Fisheries), pers. com.; The Ecology Lab, 2001a, b; MPR 2006a; b). On 31 October 2011, eight individuals of this species were observed in the pool immediately upstream of fire trail 6A (Matt Richardson, Niche pers. comm.). This species has not, however, been caught any farther upstream in Wongawilli Creek despite extensive subsequent sampling for the ongoing DA3A and DA3B investigations (Cardno 2012 and 2016) nor during targeted surveys in Donalds Castle Creek downstream of the Study Area in September 2016 (Cardno 2018b).

There are three significant barriers to fish passage on Wongawilli Creek downstream of the Study Area. The largest being rockbar-waterfall (WC RB 1) located just upstream of the confluence with Cordeaux River. This waterfall has a series of sandstone steps up to 2 m high and a total fall in elevation of approximately 15 m and would therefore pose a hindrance to the upstream passage of species such as Macquarie perch, but less so freshwater eels and galaxiids which are more adept at passing such barriers. The other barriers are the rockbars (WC-RB 11 & 12) located upstream of Fire Road 6. During periods of low to moderate flow, the shallow flow and vertical fall of these rockbars would create a major barrier to the upstream passage of Macquarie perch. During large floods, these rockbars are likely to be submerged for short periods, so it is possible that Macquarie perch and other fish are able to move further upstream at these times. However, the apparent absence of Macquarie perch upstream of these rockbars suggests it is possible that this species is unable to pass this natural barrier and access the section of Wongawilli Creek within the Study Area, at least not in any appreciable numbers.

Several fish surveys were also undertaken in the Sandy Creek Catchment during 2008 to 2014 (Cardno 2015). Galaxiids (*Galaxias* sp.), including at least one specimen of climbing galaxias (*Galaxias brevipinnis*), and freshwater crayfish were caught. The waterfall on Sandy Creek upstream of its confluence with Lake

Cordeaux is almost certainly an absolute barrier to the passage of Macquarie perch into the Sand Creek Catchment upstream of here and within the Study Area for Longwall 19.

In the wider catchment areas, a survey of Lake Cordeaux, undertaken in 1994 using gill nets and electro-fishing, indicated that three native fish species, longfinned eel, Australian smelt, Macquarie perch and goldfish (*Carassius auratus*), an invasive species, were present (Gehrke and Harris 1996). During subsequent surveys, Australian smelt, numbers of goldfish, longfinned eels, mountain galaxias and shortfinned eels and a single Macquarie perch were caught (Growns and Gehrke 2001). Freshwater crayfish (*Euastacus* sp.) were also caught in Lake Cordeaux (Growns and Gehrke 2001). During the third survey, undertaken when Macquarie perch are known to migrate from reservoirs to spawning habitats in creeks, four specimens were caught in Lake Cordeaux, but none were found in the creeks entering the lake. This was despite the presence of habitats suitable for spawning in Goondarrin and Kembla Creeks (Creese and Hartley 2003). It is possible that a low storage level in the dam at the time of sampling may have prevented Macquarie perch from accessing these spawning areas. In Lake Avon, Macquarie perch, longfinned eel, and Brown trout (*Salmo trutta*) have been recorded, and it is thought that a further 12 species may be present (Cardno Ecology Lab 2012a).

Aside from the listed threatened Macquarie perch, all species of fish identified from the Study Area are widespread and abundant, and currently have no cause for conservation concern. No non-native species of fish have been identified in the Study Area.

### 3.1.7 Listed Threatened Species, Populations and Ecological Communities

#### *3.1.7.1 Information Sources*

A search for information on records and distributions of threatened species, populations and ecological communities listed under the FM Act, EPBC Act and BC Act in the Wongawilli Creek and Sandy Creek catchments was undertaken to update searches completed for previous assessments for DA3 (The Ecology Lab 2007; Cardno Ecology Lab 2011). The search used the following resources:

- The Department of the Environment and Energy (DEE) Protected Matters Search Tool (DEE 2018) was used to determine whether any Matters of National Environmental Significance (MNES) listed under schedules of the EPBC Act occurred in a 10 km radius from the centre of Longwall 19;
- The DPIE managed BioNet searched for records of BC Act listed flora and fauna within the Sydney – Cataract sub-region held in the Atlas of NSW Wildlife. The Atlas of Living Australia (ALA 2019) was also searched for records of species of fish (including invertebrates and vertebrates) listed under the FM Act occurring in the catchments of Wongawilli Creek and Sandy Creek; and
- Species distribution maps contained in the NSW DPI Fish Communities and Threatened Species Distributions of NSW (NSW DPI 2016a) were examined for the occurrence of threatened species listed under the FM Act in the upper catchments of Cordeaux River and Avon River.

The desktop search indicated several species that occur, or have potential to occur, in the Study Area (**Sections 3.1.7.2** to **3.1.7.5**). Amphibians, aquatic mammals, reptiles and Giant dragonfly (*Petalura gigantea*) are being considered by other specialists and were excluded from the search.

#### *3.1.7.2 Macquarie Perch*

Macquarie perch is listed as endangered under the EPBC Act and the FM Act. In addition to reaches of Wongawilli Creek downstream of the Study Area (**Section 3.1.6**) it has been recorded also in Lake Avon and Lake Cordeaux (ALA 2019) and previously recorded, or potentially present, in the upper reaches of Cordeaux and Avon Rivers (NSW DPI 2016a) in Dendrobium Area 3. Outside of these areas, Macquarie perch are found in the Murray-Darling Basin, particularly the upstream reaches of the Lachlan, Murrumbidgee and Murray rivers, and parts of south-eastern coastal NSW, including the Hawkesbury and Shoalhaven catchments.

Macquarie perch prefer clear water and deep, rocky holes with extensive cover in the form of aquatic vegetation, large boulders, debris and overhanging banks (NSW DPI 2016b). They spawn in spring or summer and lay their eggs over stones and gravel in shallow, fast-flowing upland streams or flowing parts of rivers. Macquarie perch is an active predator of macroinvertebrates. While other large-bodied percichthyids are generally higher-order ambush predators that may have limited range, the Macquarie perch tends to have a relatively larger linear (along shore) diel range (Ebner *et al*. 2010). A study in a Canberra reservoir

found that Macquarie perch have a mean linear diel range of 516 m (± 89 S.E.) which suggests that discontinuous and small pools would not provide suitable habitat for this species (Ebner *et al*. 2010).

The draft National Recovery Plan for Macquarie perch has recently been released (Commonwealth of Australia 2017). This contains background information on the biology, ecology, distribution and populations, decline and threats and recovery objectives and strategies and associated actions for this species. Identified threats include:

- Habitat degradation;
- Alien (non-native) fish;
- Barriers to fish movement;
- Altered flow and thermal regimes;
- Disease;
- Illegal / incidental capture;
- Chemical water pollution; and
- Climate change.

Recovery Strategies are:

- Conserve existing Macquarie perch populations;
- Protect and restore Macquarie perch habitat;
- Investigate threats to Macquarie perch populations and habitats;
- Establish additional Macquarie perch populations;
- Improve understanding of the biology and ecology of the Macquarie perch and its distribution and abundance; and
- Increase participation by community groups in Macquarie perch conservation.

The public comment period closed 1 September 2017.

The following Priority Action Statements for Macquarie perch (NSW DPI 2017b) exist:

- Advice to consent and determining authorities;
- Collate and review existing information;
- Community and stakeholder liaison, awareness and education;
- Compliance / enforcement;
- Enhance, modify or implement Natural Resource Management planning processes to minimize adverse impacts on threatened species;
- Habitat rehabilitation;
- Pest eradication and control;
- Research / monitoring;
- Stocking / translocation; and
- Survey / mapping.

Actions directly applicable to the Project include the provision of advice on the distribution of Macquarie perch to determining authorities to ensure appropriate consideration during development assessment processes, and the undertaking of targeted surveys to determine the current distribution and abundance of Macquarie perch.

#### 3.1.7.3 Australian Grayling

Australian grayling is listed as a vulnerable species under the EPBC Act and is a protected species under the FM Act. It occurs in coastal streams and rivers on the eastern and southern flanks of the Great Dividing Range from Sydney southwards to the Otway Ranges in Victoria, and Tasmania (NSW DPI 2006). Australian grayling has been recorded in the Grose River, but there are no records of this species from the upper Nepean Catchment. They have also been recorded in estuarine areas. The life cycle of

Australian grayling is dependent upon migration to and from the sea (McDowall 1996). Spawning occurs in late summer or autumn and larvae are swept downstream to the sea (NSW DPI 2006). Juvenile fish return to freshwater when they are about six months old and remain in rivers and streams for the rest of their life. Australian Grayling has undergone a considerable decline in its distribution and abundance and, although it was historically present in the Hawkesbury-Nepean, it is now restricted to the coastal rivers of southern New South Wales (Morris *et al*. 2001; NSW DPI 2016a). The decline of this species has been attributed to dams, weirs and culverts preventing it from migrating to and from the sea and completing its life cycle. As Australian grayling is highly unlikely to occur within the Study Area, further consideration of this species is not considered necessary.

#### 3.1.7.4 Sydney Hawk Dragonfly

The Sydney hawk dragonfly (*Austrocordulia leonardi*) is listed as endangered under the FM Act. It is extremely rare, having been collected in small numbers at only a few locations in a small area to the south of Sydney, between Audley and Picton (NSW FSC 2004). The species is also known from the Hawkesbury-Nepean, Georges River and Port Hacking drainages. It was discovered in 1968 from Woronora River and Kangaroo Creek, south of Sydney, and has subsequently been found in the Nepean River at Maldon Bridge near Picton and further upstream at Nepean Dam (ALA 2019). There are no records for this species within the Study Area or the Cordeaux and Lake Avon catchments. Extensive sampling has failed to discover further specimens in other areas suggesting that it has a highly restricted distribution within the catchment of the Nepean River (NSW DPI 2007).

Most of the lifecycle of this species is spent as an aquatic larva, with adults living for only a few weeks. The larvae appear to have specific habitat requirements, being found under rocks in deep, cool, shady pools (NSW DPI 2007). Relative environmental stability appears to be an important habitat feature, with rapid variation in water level and flow rate likely to have a negative effect on the suitability of habitat for larvae.

No Recovery and Threat Abatement Plans exist for this species. Several conservation and recovery actions for Sydney hawk dragonfly are included in NSW DPI (2007):

- Allocate and manage environmental water through water sharing planning processes, to lessen the impacts of altered flows;
- Prevent sedimentation and poor water quality by using conservation farming and grazing practices, conserve and restore riparian (river bank) vegetation and use effective erosion and sediment control measures;
- Rehabilitate degraded habitats. Protect riparian vegetation and encourage the use of effective sediment control measures in catchments where the dragonfly may occur;
- Protect the few remaining sites with the potential to support the species, and address key threats such as habitat degradation and water quality decline;
- Conduct further research into the species' biology, ecology and distribution; and
- Implement the Protected, Threatened and Pest Species Sighting Program and report any sightings to NSW DPI.

#### 3.1.7.5 Adams Emerald Dragonfly

Adams emerald dragonfly (*Archaeophya adamsi*) is listed as endangered under the FM Act. It is extremely rare, having been collected only in small numbers at a few locations in the greater Sydney region (NSW DPI 2013b). Specimens have been collected at five localities: Somersby Falls and Floods Creek in Brisbane Waters National Park near Gosford; Berowra Creek near Berowra and Hornsby; Bedford Creek in the Lower Blue Mountains; and Hungry Way Creek in Wollemi National Park. There are no records for this species

within the Study Area or the Cordeaux and Lake Avon catchments (ALA 2019). There are no records of Adam's emerald dragonfly occurring south of Sydney, despite active collecting in the Hawkesbury-Nepean River catchment (NSW FSC 2008). This species was not collected by Cardno during the baseline surveys of aquatic macroinvertebrates in Wongawilli, Sandy, Donalds Castle or Native Dog Creeks as part of the Dendrobium Mine area studies, but aquatic habitat that appears suitable for this species does occur within these watercourses (Cardno Ecology Lab 2011).

The larvae of Adam's emerald dragonfly inhabit small creeks with gravel or sandy bottoms in narrow, shaded riffle zones with moss and lush riparian vegetation (NSW Fisheries 2012). The larvae live for approximately seven years before metamorphosing into adults that probably live for only a few months. They are thought to have a low natural rate of recruitment and limited dispersal abilities.

No Recovery and Threat Abatement Plans exist for this species. Conservation and recovery actions (NSW DPI 2007) for Adams emerald dragonfly are:

> Rehabilitate degraded habitats. Protect riparian vegetation and encourage the use of effective erosion and sediment control measures in catchments where the dragonfly may occur;

> Protect the few remaining sites that still support the species, and address key threats such as habitat degradation and water quality decline from expanding development;

> Conduct further research into the biology and distribution of the species; and

> Report any sightings to NSW DPI.

#### *3.1.7.6 Likelihood of Occurrence*

**Table 3-2** assesses the likelihood of occurrence of Listed Threatened Species in the Study Area.

Table 3-2 Likelihood of Occurrence of Listed Threatened Species in the Study Area

| Species and Listing | Likelihood of Occurrence |
|---|---|
| Macquarie perch<br>(endangered under FM Act and EPBC Act) | Occurs in Avon River and Cordeaux River and the reach of Wongawilli Creek just upstream of Fire Road 6 and downstream of the Study Area. Suitable pool habitat exists within the Study Area and upstream but it has not been caught during numerous surveys in Wongawilli Creek and Sandy Creek in the Study Area, possibly due to the presence of natural barriers to fish movement further downstream.<br>Very unlikely to occur in Sandy Creek and drainage lines in the Study Area. |
| Adams emerald dragonfly<br>(endangered under FM Act) | Unlikely to occur within the Study Area. No records within, or adjacent to the Study Area despite extensive sampling, though suitable microhabitat appears to exist in creeks and drainage lines. |
| Sydney hawk dragonfly<br>(endangered under FM Act) | Unlikely to occur within the Study Area. Records from the adjacent Nepean Catchment though no records within the catchments of Wongawilli Creek and Sandy Creek despite extensive sampling, though suitable microhabitat appears to exist in creeks and drainage lines. |
| Australian grayling<br>(endangered under FM Act and vulnerable under EPBC Act) | Does not occur in the Study Area. Present in coastal rivers of southern NSW outside of the Study Area. |

### 3.1.8 Critical Habitat

The Study Area does not contain any critical habitats listed under the FM Act, BC Act or EPBC Act.

### 3.1.9 Existing Mining Impacts to Watercourses

Cardno (2018b) undertook a review of existing mining impacts that have occurred due to previous and existing mining in the upper Avon and Cordeaux River catchments. These include the following mining in the Metropolitan Special Area:

> Longwall mines: Dendrobium Areas 1, 2, 3A, Dendrobium DA3B Longwalls 9 to 13, Elouera Mine, Cordeaux Mine, Kemira Mine; and

> Bord and pillar mines: Nebo Mine and Wongawilli Mine.

Subsidence induced impacts (fracturing, flow diversions and/or reductions in pool water levels) have been observed in watercourses overlying each of the previous mine areas. To provide an indication of the cumulative impact of these mines on aquatic ecology in these and the upper Avon and Cordeaux River catchments, the length of watercourse known or expected to experience subsidence related impacts was calculated by the Illawarra Coal Environmental Field Team (ICEFT). As of May 2018, of the 716 km of watercourses (first order and above) mapped within the upper Avon and Cordeaux River catchments, direct mining impacts (fracturing, flow diversions and/or pool water loss) had or were highly likely to have occurred in approximately 36 km of watercourses located directly above longwall mining. This included first, second and higher order streams within the Wongawilli, Sandy and Donalds Castle Creek Catchments.

The most recent impacts observed (associated with mining in DA3) include fracturing, flow diversions, reductions in pool water levels in SC10C (a tributary of Sandy Creek) and WC17 (a tributary of Wongawilli Creek) in DA3A. Both these drainage lines are within the Study Area for Longwall 19. Fracturing of bedrock and flow diversions have also been experienced in WC15, which is also within the current Study Area. Impacts have not been experienced in WC13, WC14, WC16, SC10, SC10A or SC10B, which are within the current Study Area but are not located directly above and have not been impacted by previous DA3A and DA3B longwalls. Only WC13 is located directly above Longwall 19, though SC10 and SC10B are adjacent to Longwall 19. Outside of the Study Area, such impacts have also been observed and in WC21 (a second order tributary of Wongawilli Creek) and in upper Donalds Castle Creek in DA3B. In each case there was an associated loss of aquatic habitat and likely also biota.

Impacts occurring in SC10C were assessed in detail in Cardno (2015). Fracturing of bedrock and reductions in pool water levels and flow occurred here in December 2011, and in early 2013 low pool water levels were evident throughout SC10C. These changes were attributed to the extraction of Longwalls 7 and 8 which took place below SC10C and the adjacent area between May 2011 and December 2012. During the 2013 and 2014 aquatic ecology surveys, the only water present in SC10C was a small, shallow pool at Site 13. The complete drainage of all but one pool in SC10C resulted in a direct loss of aquatic habitat and likely some biota. Other impacts to aquatic ecology associated with the physical impacts include the loss of longitudinal connectivity. The impact to aquatic ecology due to desiccation of aquatic macrophytes was considered minimal, as very little in-stream aquatic vegetation has been identified in SC10C. A reduction in abundance of Leptoplebiidae (a pollution sensitive Family of mayfly in the Order Odonata) and an increase in abundance of Chironomidae (consisting of three pollution tolerant Subfamilies: Chironominae, Orthocladiinae and Tanypodinae) was also detected, indicating associated impacts to aquatic biota. The impacts to aquatic ecology observed in SC10C were localised to the areas directly affected by physical mining impacts and were considered relatively minor in the context of the Sydney Catchment Area. This watercourse was visited last in 2014. During the current study there was evidence of a recovery in flow and pool water levels in SC10C (**Section 3.2.2.2**).

Approximately 77 km of watercourse is located above previous bord and pillar mining. Based on observations of impacts due to longwall mining there is potential for these to have also experienced direct subsidence related impacts similar to that experienced above longwall mining. The most severe watercourse impacts described above (fracturing and flow diversions resulting in part or complete drainage of pools and loss of surface water) tend to occur when watercourses are directly mined under. However, such impacts may also occur in watercourses that are not directly mined under. A further 18 km of watercourse located directly downstream of longwall mining is expected to have experienced indirect impacts (including reductions in pool water levels and flow). Fracturing of rockbars was observed in Donalds Castle Creek, LA4 (tributary of Lake Avon) and WC15 100 m to 300 m from DA3B longwalls. Fracturing has been observed up to approximately 400 m outside of previously extracted longwalls in the Southern Coalfield (MSEC 2018).

Collectively, the length of watercourse that has experienced indirect and direct mining impacts is estimated to be 16% of that present in the upper Avon and Cordeaux River catchments. The majority of this would be first and second order drainage lines. However, impacts of groundwater depressurisation have recently been observed in Wongawilli Creek. During inspections in May 2018, a reduction in flow and a series of disconnected pools were observed within an approximate 1,400 m section of Wongawilli Creek located partly within the Study Area for Longwall 19 and representing about 10% of the total 12 km length of Wongawilli Creek. This section included Pool 41 to Pool 44 (Pool 36 lies within this extent). Surface flow was observed just downstream of the confluence with Wongawilli Creek tributary WC21. Although fracturing in one rockbar at Pool 43a in Wongawilli Creek was observed during extraction of Longwall 9 in December 2012, this is not considered to be the cause of the reduced flow and reduction in pool water levels here. Rather, assessment of flow and water level data with rainfall and rates of pool water recession from before and after commencement of mining and the timing of fracturing suggest mining induced groundwater depression coinciding with low rainfall explain the low flow and water levels observed in Wongawilli Creek (HGeo2018). Low pool water levels were not restricted to Pool 43a but were also observed in Pool 49. Pool water levels also begun to decline 2 years before the fracture was observed. The pool recession rate, calculated as the

decline in pool level between consecutive observations averaged over the number of days, was not greater after the observation of the fracture. Mining is considered to be the primary cause of reductions in groundwater levels in the lower Hawksbury Sandstone and upper Bulgo Sandstone. This has contributed to a reduction in baseflow in Wongawilli Creek, which was most noticeable during periods of low rainfall and greater evapotranspiration that occurred in 2018. Extraction of each individual longwall would be expected to contribute to reductions in groundwater levels. Hydrosimulations (2018) in HGeo(2018) estimated baseflow capture of approximately 0.3 ML/d in Wongawilli Creek, this would be a significant fraction of flow under conditions of very low rainfall such as those that have occurred during 2018 with typical surface flow below 1 ML/day (HGeo2018). It is noted that a significant mining effect on surface flow in Wongawilli Creek was not apparent approximately 3 km downstream at gauge WWL.

Pool water levels and flow is also restored following rainfall events, thus impacts to the availability and connectivity of aquatic habitat is temporary. During aquatic ecology surveys throughout 2019 water and flow was present in the sections of Wongawilli Creek previously affected by reductions in water levels and flow, albeit water levels appeared reduced slightly during the current survey in November 2019. Nevertheless, temporary reductions in flow and pool water levels would be expected to affect aquatic biota. Such as the changes observed in SC10C in the Sandy Creek catchment. Changes in the abundance of several macroinvertebrate taxa have also been observed in WC21 and Donalds Castle Creek and have been attributed to reductions in pool water levels observed here (Cardno 2018a). Temporary reductions in longitudinal connectivity would also be expected to affect fish and aquatic macroinvertebrates by limiting movement in search of food and refuge. It may also result in reduction in genetic transfer, particular if it coincides with migration as part of reproduction. Species of freshwater eel (*Anguilla* sp.), for example, undertake long distance reproductive migration that could be hindered during times of low flow and pool water level. As well as direct habitat loss, associated reductions in water quality could also affect the type and number of macroinvertebrates and other aquatic biota (fish, large mobile invertebrates and aquatic macrophytes) in watercourses. However, the changes in water quality observed that are associated with mining (reduced DO and elevated EC) have been relatively minor. Changes in macroinvertebrates appear to be localised to the areas of watercourse directly affected by physical mining impacts and habitat loss. They do not appear to persist downstream once water reappears (Cardno 2018a).

In addition to the Project, future mining is proposed in DA3B (Longwalls 15 to 18) and in Area 5 and Area 6. These are located within the upper Avon River and Cordeaux River Catchments (including catchments of Wongawilli Creek, Donalds Castle Creek and tributaries of Lake Avon and Lake Cordeaux). Further, approximately 37 km (5%) of watercourse is located above the proposed Area 5 and Area 6 longwalls and would be expected to experience direct mining induced impacts comparable to that observed above previous mine areas.

## 3.2 Field Surveys

### 3.2.1 Rationale

Field surveys were undertaken 26 and 27 November 2019 at sites 1 to 5, X5 and X6 on Wongawilli Creek and sites 7 to 8 and 12 on Sandy Creek (**Figure 3-1**).

The surveys included the following components:

- Classification and mapping of aquatic habitat in rivers, creeks and drainage lines within, and adjacent to the Study Area using classification criteria in NSW DPI (Fisheries) (2013a); and
- Surveys of aquatic macroinvertebrates and fish. This included consideration of Sydney hawk dragonfly and Adam's emerald dragonfly.

Aquatic habitat was also assessed in several drainage lines of these watercourses that traverse the Study Area and at Site 11 on SC10C.

The primary objective of the field studies was to update the findings of the previous studies undertaken in these areas, characterise the aquatic ecology of the Study Area and place it in context of the wider catchment area. In particular, at sites 8, 9, 12 and 13 in the Sandy Creek Catchment that were visited last in 2014 as part of the now complete DA3A investigations (Cardno 2015).

### 3.2.2 Methods

#### *3.2.2.1 Key Fish Habitat*

Wongawilli Creek and the third order section of Sandy Creek (outside of the Study Area) is KFH (**Section 3.1.3**). First and second order watercourses within the Study Area are not mapped by NSW DPI as KFH, though they may still contain, or constitute, sensitive KFH as described in NSW DPI (2013a) (**Section 3.1.3.3**). The occurrence of sensitive fish habitat in the Study Area was assessed using the criteria in NSW DPI (2013a) relevant to freshwater habitat (**Table 3-3**).

Mapping was done initially as a desktop exercise with the aid of existing information from previous mapping (**Section 3.1.3.3**), with ground-truthing undertaken in during November 2019. Where sections of drainage lines could not be accessed, KFH type was inferred based on the findings from other drainage lines in the Study Area.

Table 3-3 Classification of KFH according to sensitivity (NSW DPI 2013a)

| Classification | Habitat Type |
|---|---|
| Type 1 – highly sensitive KFH | Instream gravel beds, rocks greater than five hundred millimeters in two dimensions, snags (wood debris) greater than three hundred millimeters in diameter or three meters in length, native aquatic plants, and areas known or expected to contain threatened and protected species |
| Type 2 – Moderately sensitive KFH: | Freshwater habitats other than those defined in Type 1 |
| Type 3 – Minimally sensitive KFH | Ephemeral aquatic habitat not supporting native aquatic or wetland vegetation |
| Not considered KFH | First and second order streams on gaining (those where streams are coming together and becoming progressively larger) streams (based on the Strahler method of stream ordering) |

#### *3.2.2.2 Aquatic Habitat and Vegetation*

The condition of the aquatic habitat at each site was assessed using a modified version of the Riparian, Channel and Environmental Inventory method (RCE) (Chessman *et al*. 1997) (**Appendix Ci**). This assessment involves evaluation and scoring of the characteristics of the adjacent land, the condition of riverbanks, channel and bed of the watercourse, and degree of disturbance evident at each site. The occurrence of key aquatic habitat (e.g. gravel beds, pools, macrophytes, riffles, and woody debris) in these watercourses was also identified along with surrounding land uses.

Notes were also taken on the presence of the following features:

- Surrounding vegetation and riparian vegetation;
- Barriers to fish passage;
- The species and percent cover (in an approximate 100 m reach) of in-stream aquatic vegetation present at each site; and
- The presence of algae or flocculent on the surface of macrophytes was also be noted, if present.

#### *3.2.2.3 In-situ Water Quality*

At each site, two replicate measurements of DO, EC, oxidation-reduction potential (ORP), pH, temperature and turbidity of the water were taken from just below the surface of the water using a YSI multiprobe. The measurements taken would be used to assist in interpretation of the results of biotic sampling. The EC, DO, pH and turbidity measures were also compared with the ANZECC (2000) DTVs for slightly disturbed upland rivers in south-east Australia. Specific guidelines are not available for temperature and ORP measures.

#### *3.2.2.4 AUSRIVAS Macroinvertebrates*

##### 3.2.2.4.1 Field and Laboratory Methods

At each site, samples of aquatic macroinvertebrates associated with the pool edge habitat were collected by using dip nets (250 µm mesh) to agitate and scoop up material from vegetated areas of the river bank.

Samples were collected over a period of 3 to 5 minutes from a 10 m length of habitat along the river, in accordance with the AUSRIVAS Rapid Assessment Method (RAM) (Turak *et al*. 2004). If the required habitat was discontinuous, patches of habitats with a total length of 10 m were sampled. Each RAM sample was rinsed from the net onto a white sorting tray from which animals were picked using forceps and pipettes. Each tray was picked for a minimum period of forty minutes, after which they were picked at ten-minute intervals for either a total of one hour or until no new specimens were found. Samples were preserved in alcohol and transported to the laboratory for identification and subsequent derivation of biotic indices and assessment of habitat and water quality using the AUSRIVAS modelling software.

AUSRIVAS samples were sorted under a binocular microscope (at 40 X magnification) and identified to family level with the exception of Oligochaeta and Polychaeta (to class), Ostracoda (to subclass), Nematoda and Nemertea (to phylum), Acarina (to order) and Chironomidae (to subfamily). Up to ten animals of each family were counted, in accordance with the latest AUSRIVAS protocol (Turak *et al*. 2004). There is a possibility, albeit unlikely, that two threatened aquatic macroinvertebrate species (Adams emerald dragonfly and Sydney hawk dragonfly) occur in the Study Area. Therefore, if any individuals of the family Austrocorduliidae and Gomphomacromiidae were found these would have been identified to species level. However, no specimens from these families were found (**Section 3.2.3.4**).

#### 3.2.2.4.2 AUSRIVAS Model

The AUSRIVAS protocol uses an internet-based software package to determine the environmental condition of a waterway based on predictive models of the distribution of aquatic macroinvertebrates at reference sites (Coysh *et al.* 2000). The ecological health of the creek is assessed by comparing the macroinvertebrate assemblages collected in the field (i.e. 'observed') with macroinvertebrate assemblages expected to occur in reference waterways with similar environmental characteristics. The data from this study were analysed using the NSW models for pool edge habitat sampled in spring. The AUSRIVAS predictive model generates the following indices:

- OE50Taxa Score – The ratio of the number of macroinvertebrate families with a greater than 50% predicted probability of occurrence that were actually observed (i.e. collected) at a site to the number of macroinvertebrate families expected with a greater than 50% probability of occurrence. OE50 taxa scores provide a measure of the impairment of macroinvertebrate assemblages at each site, with values close to 0 indicating an impoverished assemblage and values close to 1 indicating that the condition of the assemblage is similar to that of the reference streams.
- Overall Bands derived from OE50Taxa scores that indicate the level of impairment of the assemblage. These bands are graded as described in **Table 3-4**.

Table 3-4 AUSRIVAS Bands and corresponding OE50 Taxa Scores for AUSRIVAS edge habitat sampled in spring

| Band | Description | Spring OE50 Score |
|---|---|---|
| X | Richer invertebrate assemblage than reference condition | >1.16 |
| A | Equivalent to reference condition | 0.84 to 1.16 |
| B | Sites below reference condition (i.e. significantly impaired) | 0.52 to 0.83 |
| C | Sites well below reference condition (i.e. severely impaired) | 0.20 to 0.51 |
| D | Impoverished (i.e. extremely impaired) | ≤0.19 |

The SIGNAL2 biotic index (Stream Invertebrate Grade Number Average Level) developed by Chessman (2003) was also used to determine the environmental quality of sites on the basis of the presence or absence of families of macroinvertebrates. This method assigns grade numbers between 1 and 10 to each macroinvertebrate family, based largely on their responses to chemical pollutants. The sum of all grade numbers for that site was then divided by the total number of families recorded in each site to obtain an average SIGNAL2 index. The SIGNAL2 index therefore uses the average sensitivity of macroinvertebrate families to present a snapshot of biotic integrity at a site. SIGNAL2 values are as follows:

- SIGNAL > 6 = Healthy habitat;
- SIGNAL 5 – 6 = Mild pollution;
- SIGNAL 4 – 5 = Moderate pollution; and

> SIGNAL < 4 = Severe pollution.

#### *3.2.2.5 Fish*

Fish were sampled using a backpack electrofisher (model LR-24 Smith-Root) and baited traps. At each site, four baited traps were set for approximately one hour in a variety of habitats, such as amongst aquatic plants and snags, in deep holes and over bare substratum. Bait traps were approximately 30 cm x 30 cm x 40 cm with 0.3 cm aperture mesh and a 3 cm opening and were unbaited. The backpack electrofisher was operated around the edge of pools and in riffles (if present), with four two minute shots being performed at each site. Fish stunned by the current were collected in a scoop net, identified and measured. All captured fish would be handled with care to minimise stress and be released as soon as possible.

### 3.2.3 Results

#### *3.2.3.1 Key Fish Habitat*

Wongawilli Creek (**Appendix D-i** to **iii**) and Sandy Creek (**Appendix D-iv**) provide Type 1 – Highly sensitive KFH, and contain areas of aquatic plants, large rocks, large wood debris. It is noted that Sandy Creek is slightly smaller (in terms of channel width, water and pool depth) and provides less abundant and diverse fish habitat than Wongawilli Creek (**Figure 3-2**).

First and second order streams, including and the first and second order drainage lines of Wongawilli Creek (WC13 to WC17) and Sandy Creek (SC7, SC10 and SC10A to C) within the Study Area, are not KFH (**Section 3.2.2.1**). Nevertheless, lower sections of these drainage lines near the main creek channels, in particular SC10C (**Appendix D-v**) provide somewhat permanent aquatic habitat in the form of larger pools connected by flow. Further upstream of here and in the other drainage lines with aquatic habitat becomes increasingly limited as baseflow reduces due to the smaller sub-catchment areas. While these areas may contain some rocks and wood debris, they would have intermittent flow, with disconnected pools that would provide sporadic refuges for aquatic fauna such as fish and freshwater crayfish, if present. Furthermore, several substantial natural barriers to fish passage (such as waterfalls, cascades, and low flow over rock bars) were present on these drainage lines which generally have much steeper grades than the larger creeks. This would limit the number and type of fish species present to those capable of passing such barriers, such as climbing galaxiid. Iron precipitate was present throughout SC10C (**Appendix D-vi**) and in sections of SC10. SC10C previously experienced reductions in flow associated with subsidence induced fracturing of bedrock and flow diversions in December 2011 (Cardno 2015). Throughout 2011 to 2014 low pool water levels were observed in SC10C with a concurrent change in macroinvertebrate indicators suggestive of an impact to aquatic ecology (Cardno 2015). Greater flow was observed here during the current investigations, which may suggest a degree of recovery in aquatic habitat. Further investigation would need to be undertaken to ascertain the degree of recovery in macroinvertebrates. It is possible the accumulation of iron precipitate in the watercourses hinder recovery of some aquatic biota even if flow returns to pre-mining condition.

#### *3.2.3.2 Aquatic Habitat and Vegetation*

Results of the RCE assessment are provided in **Appendix C-ii**. Total scores raged from 46 to 51 on Wongawilli Creek and from 46 to 50 on Sandy Creek. These are relatively high and indicative of largely undisturbed systems. All sites scored high (i.e. 4, no evidence of disturbance) in categories associated with the condition of riparian vegetation and channel morphology. While there was some evidence of sediment accumulation, this appears to be a natural occurrence given the undisturbed nature of the surrounding environment.

The riparian and surrounding vegetation in the reaches of Wongawilli Creek and Sandy Creek was comparable to that observed during previous investigations. It is dominated by dry Eucalypt forest which extends to the banks of the creeks. Along the banks there are numerous native grasses, shrubs and trees including saw grass (*Gahnia* sp.), mat rush (*Lomandra* sp.), wattles (*Acacia* sp.), and tea-tree (*Leptospermum* sp.). Stream banks consisted mainly of well vegetated sandy soil with little erosion or

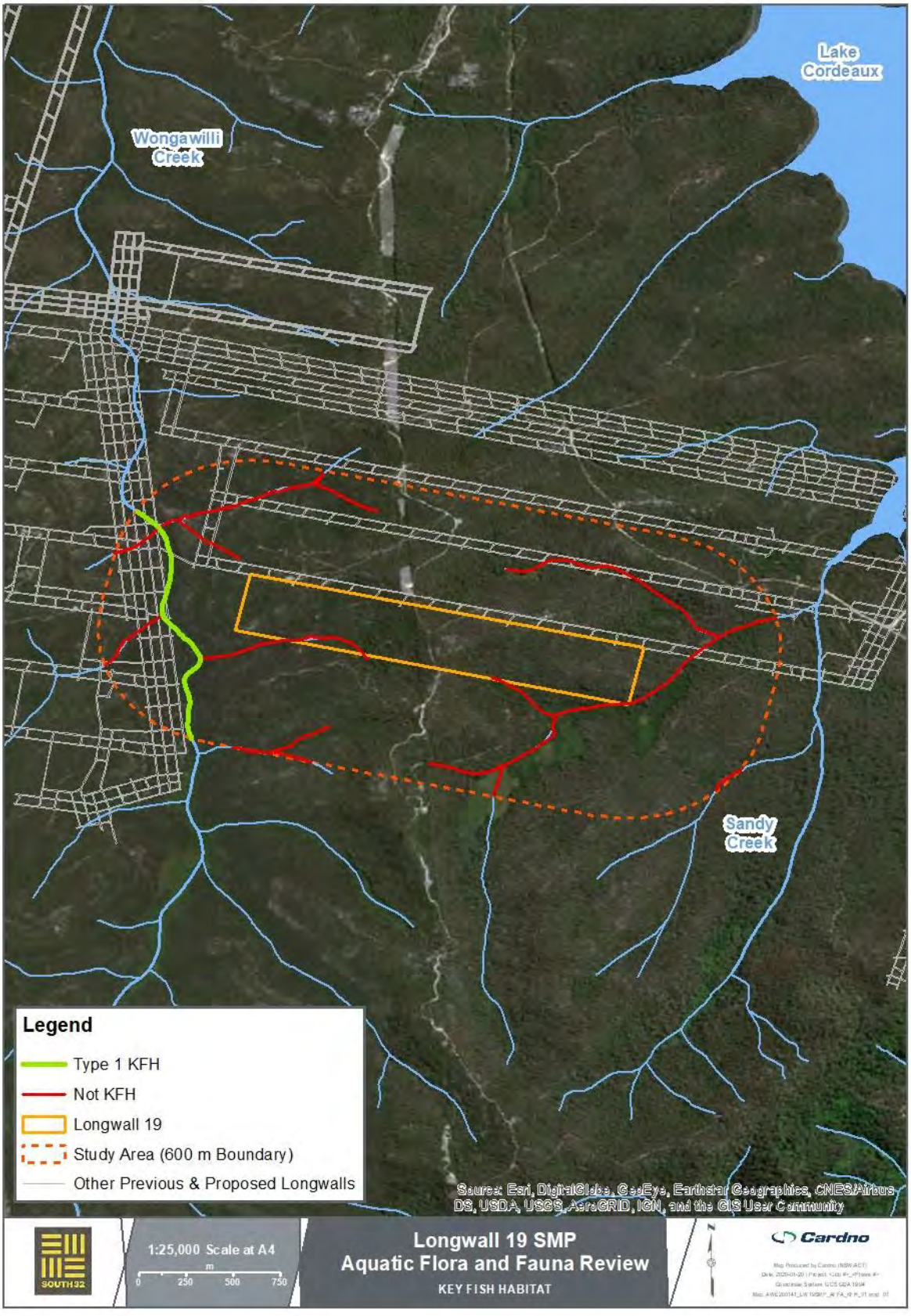



Figure 3-2 Key fish habitat mapped within the Study Area

undercutting evident and extensive overhanging vegetation along the stream margin. There were numerous in-stream habitat features, including snags and tree roots. The water within both creeks appeared very clear and there was no sign of contamination such as odour, emulsion, or discolouration. Riparian vegetation and bank structure along drainage lines consisted of a series of relatively small permanent pools with sand substratum and some areas of bedrock, boulder and gravel. These pools are connected by narrow channels with a mainly sand substratum with small sections of gravel riffles and some sandstone rockbars with small cascades up to 1 m high. It is expected that this connectivity between pools would not persist through extended dry periods. While this would limit the amount of aquatic habitat available for aquatic flora and fauna. Nevertheless, the abundance of this habitat means that, cumulatively, it provides a substantial contribution to overall aquatic habitat in the Study Area and wider Cordeaux Catchment. The only aquatic macrophyte observed was *Myriophyllum* sp. at Site 5 (coverage of approximately 10% over a 100 m stretch of creek channel) on Wongawilli Creek and some filamentous algae in Wongawilli Creek. Filamentous algae can be indicative of nutrient enrichment, though there is no other evidence of this and the catchment is almost entirely undisturbed.

#### *3.2.3.3 In-situ Water Quality*

The findings of the water quality sampling on Wongawilli Creek and Sandy Creek are presented in **Table 3-5**, the main findings were:

- Temperature ranged from 15.7 to 17.4 °C and was comparable between Wongawilli Creek and Sandy Creek;
- EC was within DTVs and ranged from 78 to 117 µS/cm;
- pH ranged from 5.3 to 6.1 and was slightly greater in Wongawilli Creek. It was below the lower DTV on each occasion;
- DO ranged from 85.4 % to 99.5 % saturation and was within DTVs at each site on Wongawilli Creek except Site 1. It was within DTVs at Site 7 on Sandy Creek and Site 8 on SC7 and slightly below the lower DTV at Site 9 on Sandy Creek and Site 12 on SC10, and
- Turbidity ranged from 0.2 to 2.7 NTU and was below the lower DTV at each site.

Measures of water quality on Wongawilli Creek and Sandy Creek were comparable with those measured previously on these creeks by Cardno. Naturally low pH, DO and turbidity is not cause for concern (**Section 3.1.4**).

Table 3-5 Mean in-situ water quality measures from each sampling site. Grey shading indicates value outside of DTV.

| Measure | DTV | 1 | 2 | 3 | 4 | 5 | X4 | X5 | X6 | 7 | 8 | 9 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp (°C) | | 15.7 | 17.1 | 17.3 | 16.3 | 16.7 | 16.4 | 16.9 | 16.5 | 15.9 | 16.6 | 17.4 | 17.4 |
| Cond (µS/cm) | 30-350 | 91 | 99 | 117 | 99 | 78 | 95 | 86 | 79 | 110 | 112 | 94 | 84 |
| pH | 6.5-8.0 | 5.5 | 5.6 | 5.7 | 5.9 | 5.9 | 5.8 | 5.9 | 5.9 | 5.4 | 5.7 | 6.1 | 5.3 |
| ORP (mV) | | 189 | 183 | 187 | 176 | 128 | 123 | 134 | 132 | 194 | 152 | 175 | 237 |
| DO (%Sat) | 90-110 | 85.4 | 92.1 | 94.5 | 90.8 | 95.8 | 91.2 | 92.7 | 91.9 | 99.5 | 96.4 | 88.0 | 87.4 |
| Turbidity (NTU) | 2-25 | 0.4 | 0.5 | 1.7 | 0.4 | 0.4 | 0.2 | 0.3 | 0.3 | 2.4 | 0.8 | 1.4 | 1.2 |

Standard errors <0.01 in each case, n = 2. Default Trigger Values (DTV) taken from ANZECC/ARMCANZ (2000) guidelines for slightly disturbed upland rivers in southeast Australia.

#### *3.2.3.4 AUSRIVAS Macroinvertebrates*

The macroinvertebrate taxa identified from each AUSRIVAS sample are provided in **Appendix E**. The number of taxa, OE50 Taxa Scores and SIGNAL2 Indices for each of the AUSRIVAS samples are provided in **Table 3-6**. The number of taxa found at each site ranged from 11 to 30 with fewer tending to be found on Sandy Creek than in Wongawilli Creek. OE50 Taxa Scores ranged from 0.47 (Band C) to 1.14 (Band A) and SIGNAL2 Indices ranged from 3.7 (indicative of severe water pollution) to 5.5 (indicative of mild water pollution). SIGNAL2 Indices ranged from 3.7 (indicative of severe water pollution) to 5.5 (indicative of mild water pollution). While these scores may indicate some form of water pollution, pollution sensitive taxa were caught, including leptophlebiids (SIGNAL2 Score: 8), which were present at each site sampled. It is noted

also that while several relatively pollution tolerant taxa were caught, these would also be expected to be present in un-polluted water. No. of Taxa and SIGNAL2 Indices on Wongawilli Creek are within the range of values sampled previously in this creek as part of the DA3A and DA3B aquatic ecology monitoring (**Section 3.1.5**). Those from the Sandy Creek catchment are also comparable to those from across from previous sampling in the DA3A and DA3B areas (Cardno Ecology Lab 2013; 2014; 2015; 2016). As appeared to be the case in these previous investigations, low SIGNAL2 Indices are more likely reflective of natural water quality, rather than any anthropogenic disturbance. Neither Adams emerald dragonfly or Sydney hawk dragonfly were identified in the AUSRIVAS samples.

Table 3-6 Total number of taxa, OE50 Taxa Scores and SIGNAL2 Indices for each of the AUSRIVAS samples collected in November 2019

| Catchment: | Wongawilli Creek | | | | | | | | | | Sandy Creek | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AUSRIVAS Index | 1 | 2 | 3 | 4 | 5 | X4 | X5 | X6 | 7 | 8 | 9 | 12 |
| Number of Taxa | 11 | 15 | 19 | 24 | 30 | 16 | 15 | 15 | 15 | 11 | 13 | 11 |
| OE50 Taxa Score | 0.47 | 0.65 | 0.81 | 1.14 | 0.85 | 0.87 | 0.75 | 0.75 | 0.96 | 0.56 | 0.80 | 0.77 |
| Band Score | C | B | B | A | A | A | B | B | A | B | B | B |
| SIGNAL2 Index | 3.7 | 4.5 | 4.7 | 4.7 | 4.3 | 4.7 | 5.5 | 4.2 | 4.2 | 4.4 | 4.1 | 3.8 |

#### *3.2.3.5 Fish*

The total number of each species of fish and freshwater crayfish caught or observed whilst backpack electrofishing at each site is presented in **Table 3-7**.

Table 3-7 Total numbers of each species of fish species caught and whether freshwater crayfish were observed whilst electrofishing at sites within the Study Area. Obs = observed

| | Wongawilli Creek | | | | | | | | | | Sandy Creek | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | 1 | 2 | 3 | 4 | 5 | X4 | X5 | X6 | 7 | 8 | 9 | 12 |
| Galaxiid (*Galaxias* sp.) | 2 | | 1 | | 1 | 1 | | | | | | |
| Freshwater crayfish (*Euastacus* sp.) | | Obs | | Obs | Obs | | | | | | Obs | |

No fish were caught in bait traps. Galaxiids were caught at Sites 1, 3, 5 and X4 on Wongawilli Creek and freshwater crayfish observed at Sites 2, 4 and 5 on Wongawilli Creek and Site 9 on Sandy Creek. Numbers were comparable with those caught in these watercourses previously (Cardno Ecology Lab 2013; 2014; 2015; 2016a, b; 2018a).

## 3.3 Summary

The findings of the current and previous investigations indicated that aside from previously observed impacts associated with previous longwall extraction in DA3A and DA3B Wongawilli Creek and Sandy Creek and their drainage lines within the Study Area for Longwall 19 are largely undisturbed. Although some of the biotic indices derived from AUSRIVAS aquatic macroinvertebrate sampling are indicative of degraded habitat or water quality, these more likely reflect natural conditions and the naturally low pH of stream water within the catchment), rather than any anthropogenic disturbance. Wongawilli Creek and lower reaches of Sandy Creek provide the most substantial habitat for native fish, aquatic plants and macroinvertebrates. The upper reaches of Sandy Creek and the lower reaches of the larger drainage lines also provide important aquatic habitat in the form of larger pools. The listed threatened Macquarie perch is likely to be present in Wongawilli Creek downstream of the Study Area, though the presence of natural barriers and its apparent absence in this and previous targeted surveys upstream of here suggests it is unlikely to occur in the section of creek within the Study Area. Based on previous surveys, natural barriers to fish movement and habitat requirements, this species is highly unlikely to occur in Sandy Creek and its drainage lines. Other threatened species (Australian grayling, Adams emerald dragonfly and Sydney hawk dragonfly) do not, or are highly unlikely to, occur in the Study Area. There is very little evidence of invasive plant species instream or within the riparian zone. The current and previous investigations indicate that the aquatic ecology in sections of these watercourses in the Study Area are comparable with that present throughout the larger catchment

area. The crossing of Fire Road 6 is the only major artificial structure that would hinder fish passage along the creek.

Sections of Wongawilli Creek, drainage lines of Wongawilli Creek and Sandy Creek tributary SC10C within the Study Area for Longwall 19 have experienced impacts associated with past and current mining-related impacts in DA3A and DA3B (**Section 3.1.9**). At the time of the current study, limited reductions in water levels in Wongawilli Creek were observed and there appeared some recovery in flow and pool water levels in SC10C, albeit there was extensive iron precipitate build up in SC10C that may be affecting aquatic biota here.

# 4 Assessment of Impacts

## 4.1 Predicted Ground Movements

South32 have reduced the potential for mining induced impacts to Wongawilli Creek by setting the proposed longwall back a minimum of 175 m. Due to a geological constraint, Sandy Creek is a minimum of 750 m from the proposed Longwall 19. The mine has also been designed so that predicted valley closure (reduction in the horizontal distance between valley sides) is no greater than 210 mm. Based on monitoring data from Dendrobium Mine, this is likely to reduce the rate of rockbar fracture resulting in flow diversion and a reduction pool water levels to less than 10% (MSEC 2020). This is an average value based on data from Dendrobium Mine (and across the Southern Coalfield) and fracture rates also depend on many factors, including other ground movements and importantly, existing natural compressive strains present in the bedrock.

The extraction of coal from the proposed longwalls will result in vertical and horizontal movements of the rock and soil mass directly above and immediately adjacent to the extracted coal seam (i.e. subsidence). Subsidence that occurs under surface watercourses is likely to result in fracturing of the streambed and banks, movements of joints and bedding plates in the streambed, uplift and buckling of rock strata in the streambed. Fracturing of bedrock and diversion of surface flows in watercourses depends on the magnitude of subsidence movements, valley-related upsidence and closure movements (MSEC 2020). MSEC (2020) assess ground movements that would occur in watercourses within 600 m of the longwalls (fracturing has been observed up to approximately 400 m outside of previously extracted longwalls in the Southern Coalfield). Ground movements can also lead to tilting of streambeds that can, in turn, lead to erosion of the streambed and banks and increased instream sediment load, changes in flow rates and migration of stream channels. Subsidence may also allow the release of gas from sub-surface strata that could affect water quality and, in some cases, lead to dieback of riparian vegetation. Subsidence can potentially result in increased levels of ponding in locations where the mining induced tilts oppose and are greater than the natural drainage line gradients that exist before mining. The potential for changes to the level of ponding, flooding and scouring of banks along watercourses depends on whether the net vertical movements brought about by longwall mining alters the gradients of the watercourses. Mining can also potentially result in an increased likelihood of scouring of the banks in the locations where tilts considerably increase natural gradients. Mining induced tension and compression can also result in dilation and bed separation in the topmost bedrock.

The location of watercourses relative to Longwall 19 and ground movements predicted to occur in each is summarised as follows:

- The maximum predicted movements of Wongawilli Creek would include less than 20 mm vertical subsidence, 150 mm upsidence and 210 mm closure (this a cumulative assessment of closure based on extraction of longwalls in DA3A, DA3B and DA3C). Based on this, the rate of fracturing resulting in surface water flow diversions for the rockbars located within the Study Area would be less than 10%. Minor fracturing could also occur along the creek, at distances up to approximately 400 m from the proposed Longwall 19. Approximately 0.9 km of Wongawilli Creek is within 400 m of the proposed Longwall 19. The predicted changes in grade along the creek would be < 0.05%, or 1 in 2000. The average natural grade of the section of Wongawilli Creek within the Study Area is approximately 0.36% or 1 in 278.
- Drainage lines are located across the Study Area, with two (SC10B and WC14) located partly above Longwall 19. Drainage lines within the Study Area could experience subsidence of between 50 mm and 2,750 mm. The maximum predicted change in grade is 3.0% or 1 in 33. The natural gradients of the drainage lines vary from 10 to 20%. The potential for fracturing of drainage lines within the Study Area is expected to be similar to that observed above and adjacent to the existing longwalls in Area 3B. It is expected that fracturing of the bedrock would occur along the sections of the drainage lines that are located directly above the proposed Longwall 19 and the adjacent previously extracted Longwalls 7 and 8. Fracturing can also occur outside the extents of the longwalls, with minor and isolated fracturing occurring at distances up to approximately 400 m. Surface water flow diversions are likely to occur along the sections of drainage lines that are located directly above and adjacent to the longwalls. It is possible that localised increased ponding could develop in some isolated locations, where the natural grades are small and where the drainage lines exit the mining area. Impacts resulting from changes in surface water flows are expected to be small in comparison with those which occur during natural flood conditions

The maximum predicted movements of Sandy Creek, located at least 750 m from Longwall 19, would be less than 20 mm vertical subsidence, upsidence and closure (MSEC 2020). It is not expected to experience

measurable tilts, curvatures or strains. It is unlikely that Sandy Creek would experience adverse physical impacts such as fracturing due to the mining of Longwall 19. Thus, such impacts to the main channel of Sandy Creek are not considered further. Lake Cordeaux and Lake Avon are located at minimum distances of 0.9 km and 3.1 km, respectively, from the proposed Longwall 19. At these distances, the reservoirs are not predicted to experience measurable conventional or valley related effects. Longwall extraction would result in less than 1 ML/day of water loss from each of Lake Cordeaux and Lake Avon (SLR 2020) Water quality effects on stored waters of the reservoirs are expected to be negligible and undetectable (HGeo 2020). Thus, impacts to these features are not considered further.

## 4.2 Impacts on Aquatic Ecology

Physical impacts such as creek bed fracturing may cause diversion of surface and sub-surface flows, drainage of pools and increases in groundwater inflows. These changes, in turn, may have adverse effects on aquatic flora and fauna via reductions in the amount of aquatic habitat, desiccation of fringing vegetation and reductions in longitudinal connectivity. The impact of changes in surface and sub-surface flows on the availability of aquatic habitats is likely to be greater if it coincides with periods of low or no flow. The duration of these impacts on aquatic habitats depends on the characteristics of the watercourses, such as substratum type, and subsequent flow events. In some cases, cracks in bedrock may be filled partially or completely by alluvial deposits during subsequent flow events. Aquatic habitat can also be adversely affected by changes in water quality resulting from mine subsidence impacts. The assessment of impacts to aquatic habitat was undertaken with consideration of amount (linear length) of watercourse that would be affected by physical mining impacts, their severity, and the amount of comparable watercourse present in the wider catchment that would remain unaffected by the mining.

The assessment of potential impacts on aquatic ecology arising from the extraction of Longwall 19 was based on the maximum predicted movements for the sections of Wongawilli Creek and the drainage lines that flow through the Study Area and their predicted impacts on the physical (MSEC 2020) and surface water (HGeo 2020) and groundwater (SLR 2020) characteristics of the waterways. **Table 4-1** summarises the predicted geophysical, water availability and quality impacts to watercourses predicted due to subsidence associated with extraction of Longwall 19 and the associated consequences for aquatic habitat and biota in the Study Area.

### 4.2.1 Aquatic Habitat

#### *4.2.1.1 Ponding, Flooding and Scouring of Stream Banks*

Predictions indicate that tilt will result in very small (< 0.05%) changes in the gradients of the reaches of Wongawilli Creek within the Study Area. Changes of this magnitude are unlikely to cause significant increases in the levels of ponding, flooding or scouring of banks along these creeks. There is a possibility of localised changes in ponding or flooding in areas where maximum predicted changes in slope of the ground coincide with existing pools, steps or cascades along these watercourses. These could result in changes in the availability of aquatic habitat but these are likely to be localised. Predicted changes in grade in drainage lines are greater than their natural grade, though any changes in availability of aquatic habitat resulting from mining induced tilt will likely be negligible due the large variability in grade and natural flows within these ephemeral systems.

#### *4.2.1.2 Fracturing and Flow Diversions*

While there is a degree of uncertainty around the predicted rate of rockbar fracturing when applied to individual circumstances (i.e. discrete sections of particular watercourse) (**Section 4.1**), it is possible to make an assessment of the associated impact to aquatic ecology based on predicted fracture rate. The likelihood of significant fracturing resulting in flow diversions in Wongawilli Creek is low (≤ 7 %) (MSEC 2020). Only one major flow controlling rockbar occurs within 600 m of Longwall 19 (**Figure 4-1**) Given the low overall fracture rate, it is therefore unlikely fracturing associated with flow diversions would occur in the section of Wongawilli Creek within the Study Area (**Table 4-1**). The severity of associated impacts to aquatic habitat and biota, in the unlikely event such fracturing did occur, would depend on the magnitude of associated upstream pool water level reductions and the size of the affected pools. Recent (February 2020) detailed mapping of creek features in this section of Wongawilli Creek by ICEFT identified several shallow riffle sections, channel restrictions and debris dams that also control flow and that influence the number and length of pools in the creek (**Figure 4-1**). Thus, even in the unlikely event that the major flow controlling rockbar were to fracture resulting in flow diversions, the amount of pool habitat affected by reductions in water levels would be limited (**Table 4-1**). At the scale of the entire watercourse and the upper Avon and Cordeaux River catchments, the potential loss of habitat would be relatively minor and largely if not entirely restricted to the 80 m long pool immediately upstream of the major rockbar.

Table 4-1 Predicted physical impacts and associated impacts to aquatic ecology in watercourses in the Study Area due to proposed Longwall 19

| Watercourse | Attribute | Predicted Physical and Water Quality Impacts | Predicted Impacts on Aquatic Habitat and Biota |
|---|---|---|---|
| Wongawilli Creek | Ponding, flooding and scouring of stream banks due to subsidence induced tilt | Localised changes in the levels of ponding or flooding are possible where the maximum changes in grade coincide with existing pools, steps or cascades along the creek. It is not anticipated that these changes would result in adverse impacts on the creek since the predicted changes in grade are less than 0.05%. The natural grade is 0.36% or 1 in 278.<br>Adverse changes in the potential for ponding, flooding or scouring of the banks along the creek due to the mining-induced tilt are unlikely. | Measurable effects on the availability and connectivity of most aquatic habitats are unlikely. There is potential for minor, localised changes in the availability of aquatic habitat in some pools. Associated impacts to aquatic biota, if they occur, are therefore expected to be minor and localised. |
| | Fracturing of bedrock and diversion of surface flows due to subsidence induced strain | The overall likelihood of significant fracturing resulting in surface water flow diversions at the rockbars along Wongawilli Creek is 7% (based on the rate of rockbar fractures experienced in DA3B due to extraction of Longwalls 9 to 12).<br>Minor fracturing could occur along the creek at distances up to approximately 400 m from the proposed longwall (0.9 km of watercourse length).<br>Fracturing and flow diversions are not predicted to occur in Sandy Creek. | Risk to aquatic biota due to loss of habitat associated with flow diversions would depend on the number of rockbars that would be affected and the size of the associated upstream pools (where water may be lost from a pool following any fracturing of controlling rockbars). One major flow controlling rockbar is located on Wongawilli Creek within 600 m of Longwall 19, at the northern (downstream extent) of the Study Area. Flow in this section of the creek is also controlled by shallower riffle sections, narrow sections of channel and debris dams (**Figure 4-1**). Together, these features influence the number and size of pool sections in the creek. A total of 32 pools with length up to 160 m (total of 1,164 m of pool habitat) have been identified in this section of creek. Based on the predicted fracture rate, it would be unlikely the major rockbar would experience fracturing associated with flow diversions. In the unlikely event this did occur, the length of aquatic habitat that would be affected due to flow diversions is expected to be limited due to the presence of the other flow controlling structures in this section of creek. The pool immediately upstream of the major rockbar is approximately 80 m long. If it were to occur, the drainage of this pool represents a relatively small impact to the availability of aquatic habitat in this section of creek and the wider Cordeaux River catchment.<br>Some reduction in the population size of aquatic biota associated with pool habitat (fish and many macroinvertebrates) would be expected. Though given the limited amount of pool habitat that would be affected, impacts to aquatic habitat and biota as a direct result of pool drainage would be relatively minor.<br>A complete drainage of a pool or section of pool would reduce longitudinal connectivity in the creek and impact the ability of aquatic biota to move in search of food and refuge. Ongoing reductions in connectivity could alter the fish assemblage in Wongawilli Creek, particularly in upstream sections that are fragmented from connected waterways downstream. Freshwater eels (*Anguilla* sp.), which undertake long distance migrations, may reduce in abundance within disconnected |

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| | | sections upstream following impacts to connectivity. However, based on the low rate of fracture that would result in flow diversions and the size range of associate pools, the probability of fracturing resulting in large reduction in pool habitat is expected to be low. In isolation, impacts associated with extraction of Longwall 19 would also be expected to be relatively minor in the context of the Avon and Cordeaux River catchments. |
| Water Quality and Availability | Zero flow or 'cease-to-flow' conditions are estimated to occur in Wongawilli Creek up to 10 % of the time under natural conditions (HGeo 2020). Groundwater modelling suggests that this would increase to up to 28% of the time due to extraction of all DA3A, DA3B and DA3C longwalls. However, these are conservative predictions and considered highly unlikely (SLR 2020, HGeo 2020). Based on field observations up to the end of extraction of Longwall 14, cease to flow days were estimated to have occurred up to 13 % of the time (an increase of approximately 3 %) in the reach of Wongawilli Creek between gauges WWU and WWL and adjacent to DA3A and DA3B longwalls.<br><br>Extraction of remaining DA3A, DA3B and DA3C longwalls (including Longwall 19) is expected to result in a comparable increase in the number of zero flow days in the reach of Wongawilli Creek adjacent to Longwalls 15 to 19. Conservatively, it is considered possible this extension in affected creek length would be accompanied by an additional increase in zero flow days of 2 %, resulting in zero flow days up to 15 % of the time (HGeo 2020) in this reach between DA3A and DA3B. This suggests that as a result of mining remaining longwalls, the number of zero flow days would increase from 47 days to 55 days per year in Wongawilli Creek adjacent to where all longwalls would be extracted.<br><br>Based on groundwater model predictions of baseflow reduction, an increase in the number of days with zero flows from up to 8% of the time (natural conditions) to 40% is predicted at Sandy Creek gauge SCL2 due to extraction of all DA2 and DA3A longwalls. This is considered a conservative prediction and an increase to up to 13 % of the time is considered more likely based on field observations at other watercourses (HGeo 2020). This suggests that as a result of mining remaining longwalls, the number of zero flow days would increase from 29 days to 47 days per year in Sandy Creek.<br><br>In the case of watercourses that are not directly above or very close to longwall panels, such increases in zero flow days are expected to be largely temporary (albeit persist for a few | The severity of any impact on aquatic biota would depend on several factors, including the timing and duration of zero flow periods. An overall reduction in base flow and increase in the number of zero flow days would impact aquatic habitat and biota in Wongawilli Creek and Sandy Creek. Although substantial reductions in baseflow that would result in relatively severe impacts to aquatic ecology are not expected. Nevertheless, the expected increase in zero flow days would reduce longitudinal connectivity in the watercourses and possibly also the amount of aquatic habitat available to biota if pool levels also decrease during these periods. If pools do not drain completely then these would provide refuge for aquatic biota until flow returns. It is expected that such impacts to aquatic habitat and biota would be restricted to sections of Wongawilli Creek adjacent to mining, as there would be negligible impact to the overall yield of the Cordeaux River catchment.<br><br>Impacts to aquatic habitat and biota due to changes in water quality appear unlikely as only minor changes in water quality are expected. |

| | | | |
|---|---|---|---|
| | | decades). The potential incremental decrease in stream baseflow as a result of Longwall 19 extraction equates to 2% and 9% of the cumulative (whole mine) losses over the period 2020 to 2035 for Wongawilli Creek and Sandy Creek respectively. After 2035, both the cumulative and incremental groundwater losses are expected to decline to 0.05 ML/day or less.<br>Impacts to water quality due to mining are expected to be minor in stream reaches within subsidence affected areas (HGeo 2020). Effects are likely to include slight and temporary changes in water salinity, pH and iron content with local discolouration of streambeds and rock faces by iron hydroxide. | |
| Drainage Lines | Ponding, flooding and scouring of stream banks due to subsidence induced tilt | Although predicted changes in grade (3%) are larger as a proportion of the natural grade (10% to 20%), compared with that for creeks, it is unlikely that there would be large-scale adverse changes in the levels of ponding or scouring of the banks along these drainage lines due to subsidence induced tilt. It is possible that localised increased ponding could develop in some isolated locations, where the natural grades are small and where the drainage lines exit the mining area. | Localised changes in habitat availability and connectivity may occur along the drainage lines due to tilt but these effects will be difficult to detect due the large variability in grade and natural flows within these ephemeral systems. The impacts resulting from the changes in surface water flows are expected to be small in comparison with those which occur during natural flooding conditions. Consequently, impacts to aquatic habitat and biota due to tilt, if any, are expected to be minor and localised. |
| | Fracturing of bedrock and diversion of surface flows due to subsidence induced strain | Fracturing is expected to occur along the sections of the drainage lines that are located directly above the proposed Longwall 19. Fracturing can also occur outside the extents the proposed longwalls, with minor and isolated fracturing occurring at distances up to approximately 400 m. Surface water flow diversions are also likely to occur along the sections of drainage lines that are located directly above the proposed longwalls.<br>In times of heavy rainfall, the majority of the runoff would flow over the fractured bedrock and soil beds and would not be diverted into the dilated strata below. In times of low flow, however, surface water flows can be diverted into the dilated strata below the beds. | Fracturing induced flow diversions in the highly ephemeral drainage lines directly above the longwalls would result in a reduction in the amount of aquatic habitat. However, smaller drainage lines such as these are limited in habitat value for aquatic biota. Flow diversions would reduce the volume and duration of flow in these ephemeral drainage lines. Approximately 0.5 km of first and second order drainage lines occur directly above Longwall 19 and a further approximate 3.0 km within the Study Area. These lengths represent a very small proportion of that present in the wider Cordeaux River Catchment. The majority of these watercourses have previously been impacted by extraction of longwalls from DA3A and DA3B. |
| | Water quality | Impacts to water quality due to mining are expected to be minor in stream reaches within subsidence affected areas (HGeo 2020). Effects are likely to include temporary changes in water salinity, pH and iron content with local discolouration of streambeds and rock faces by iron hydroxide. | Minor impacts to water quality are unlikely to represent substantial risks to aquatic habitat and biota in drainage lines. |

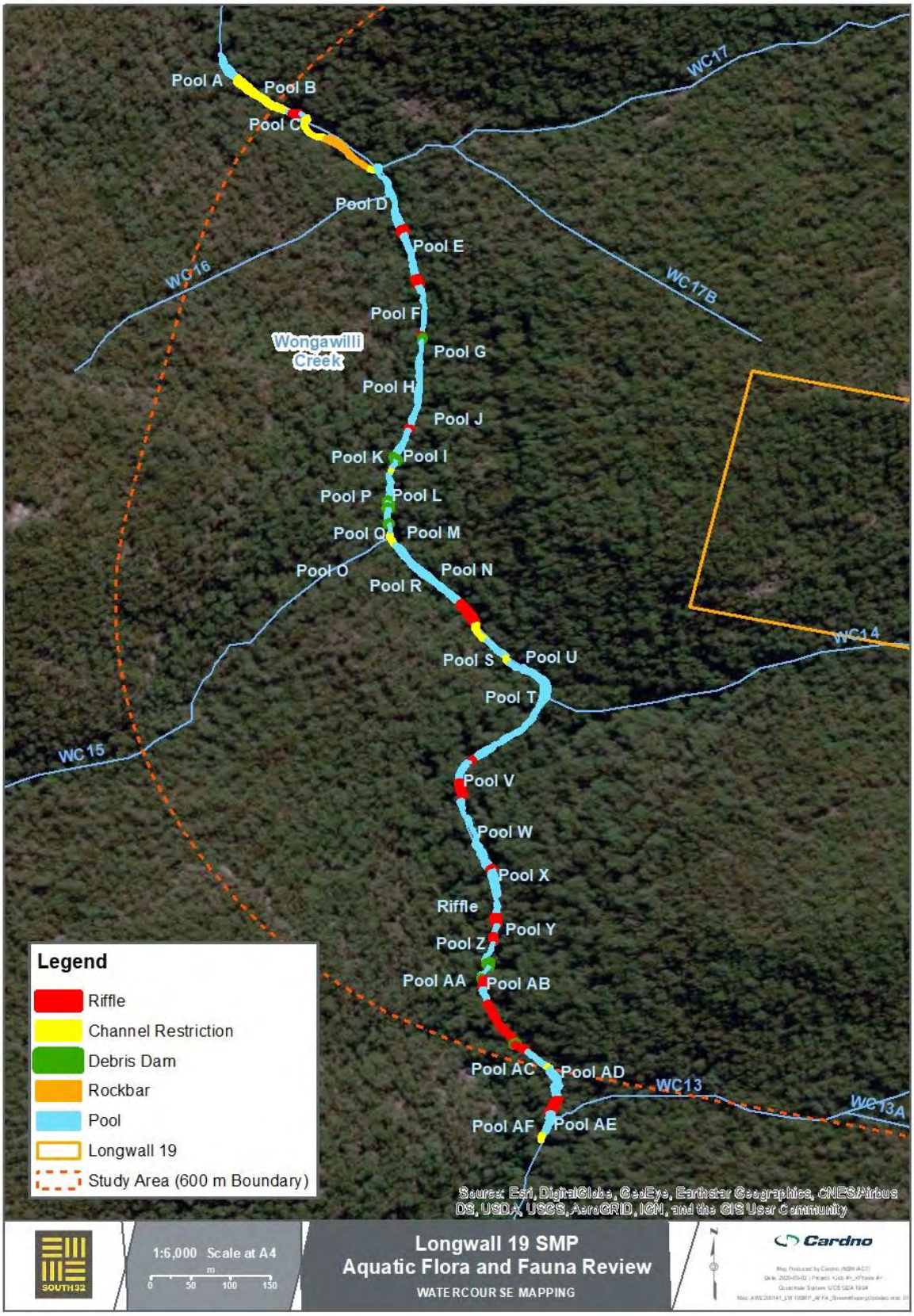



Figure 4-1 Location of pools and flow controlling structures (shallow riffle sections, channel restrictions, debris dams and the major rockbar) mapped within Wongawilli Creek within the Study Area

A total of 1,165 m of linear pool habitat was mapped in the section of Wongawilli Creek in the Study Area. Fracturing may occur along the creek at distances up to approximately 400 m from the proposed longwalls. Though this would be minor and isolated and not expected to cause any significant diversion of surface flows, it could cause localised reductions in the availability of aquatic habitat. Approximately 0.9 km of Wongawilli Creek is within 400 m of the longwalls and thus may be affected by such impacts.

Drainage lines directly above Longwall 19 would be most at risk of flow diversions and reductions in aquatic habitat due to a greater potential for subsidence and fracturing to occur here. Smaller drainage lines such as these typically support limited aquatic ecology (i.e. consist of few disconnected pools, if any) and experience flow during and soon after rainfall only. Flow diversions would reduce the volume and duration of ephemeral flows, however, there would not be any fundamental change in habitat type (i.e. it would still be ephemeral watercourse). Approximately 0.5 km of drainage lines WC14 and SC10B occur directly above Longwall 19 and would be at high risk of such impacts. Minor and isolated fracturing may also occur in drainage lines up to approximately 400 m from these longwalls. Due to the limited aquatic habitat supported by these drainage lines described above, the limited nature of associated flow diversions that would occur here and the abundance of ephemeral drainage line habitat in the wider catchment, potential consequences to aquatic ecology would be minor. Localised changes in habitat availability and connectivity would also be difficult to detect due to the large variability in grade and natural flows within these ephemeral systems. It is noted also that most other drainage lines within the Study Area (WC15, WC16, WC17 and SC10C) have experienced impacts (fracturing, flow diversions and reductions in availability of aquatic habitat) due to extraction of previous DA3A and DA3B longwalls.

#### *4.2.1.3 Water Availability*

Where stream flow is partly sustained by the discharge of groundwater from adjacent aquifers (baseflow), groundwater drawdown or depressurisation due to mining can lead to a reduction in baseflow and additional cease to flow/pool dry days. Based on previous field observations it is predicted that extraction of Longwall 19 and other DA3 longwalls could result in an increase in zero flows on Wongawilli Creek from 10% of the time (natural conditions) up to 13 % of the time (**Table 4-1**) (HGeo 2020). On average, this represents an additional 10 days of zero flow (an increase from 37 days to 47 days). On Sandy Creek it could increase from up to 8% of the time (natural conditions) to 13% of the time, representing an additional 18 days of zero flow (an increase from 29 days to 47 days). The estimated increase in number of zero flow days is that associated with mining. Despite these mining effects, zero flow days would likely be evident only during periods of drought comparable to that which occurred in 2017 to 2019.

While reductions in availability and connectivity of aquatic habitat could occur and be associated with potential impacts to aquatic biota in these pools, these changes do not suggest substantial changes to natural conditions would occur. Pool habitat would be expected to largely persist during zero flow days, thereby providing refuge until flow returned. Although pools would eventually dry during extended zero flow periods, it would be unlikely all zero flow days would occur consecutively, but rather be interrupted by periods of flow. This should limit impacts to aquatic biota to those associated with temporary reductions in habitat connectivity, which should be relatively minor in the context of the entire creek. Nevertheless, some associated baseflow reduction resulting in the temporary drying of some pools and reduced longitudinal connectivity would be expected, which could manifest in a reduction in the population sizes of aquatic biota (**Table 4-1**). It is noted that this is not expected to be a permanent effect and would reduce in magnitude substantially after 2035 (SLR 2020).

### 4.2.2 Aquatic Biota

#### *4.2.2.1 Ponding, Flooding and Scouring of Stream Banks*

Localised changes in availability of aquatic habitat due to ponding, flooding and scouring of stream banks as a result of subsidence induced tilt are expected to have no more than minor and localised impacts on aquatic habitat (**Section 4.2.1.1**), and thus biota.

#### *4.2.2.2 Fracturing and Flow Diversions*

Drainage of pools and loss of aquatic habitat following fracturing leading to flow diversion is likely to have localised, significant impact on aquatic biota, particularly on aquatic plants and sessile animals. The survival of mobile organisms is difficult to predict, it will depend on individual taxon tolerance and response to desiccation and changing water level, their ability to migrate to nearby unaffected areas, weather conditions, the underlying substratum and duration of exposure. Simple experimental observations have indicated variable responses to exposure to air among aquatic macroinvertebrate taxa. Net-spinning caddisfly (Hydropsychidae) larvae respond by commencing crawling before substratum stones dried out, but cased caddis-fly (Conoesucidae) larvae do not move until stones are dry and then they simply drop off (Bergey

2000). This suggests that net-spinning caddis fly larvae may be able to move away from receding water levels, whereas cased caddisfly larvae are more likely to fall into crevices where they desiccate. Gastropod molluscs also differ in their responses to exposure. Physids migrate off stones, and potamopyrgids migrate onto the underside. Streams with soft-sediment substratum may retain moisture within interstices and thus prolong the survivorship of stranded animals. In streams with bedrock substratum with fewer natural refuges except larger cracks and cavities, few organisms may survive complete pool drainage. The tolerance of aquatic biota to exposure is also likely to be longer on cool and rainy days than on hot days. More mobile biota such as freshwater crayfish may be able to relocate to other areas of aquatic habitat. These species can also withstand prolonged periods of drought by retreating into their burrows (NSW DPI 2006). Species of fish, such as freshwater eels and climbing galaxias, may be able to relocate provided sufficient damp surfaces are available (McDowall 1996). Other species of fish could become isolated and asphyxiate following reductions in water levels and exposure to air.

Based on predictions of fracture and flow diversion the likelihood of extensive reductions in Wongawilli Creek pool habitat is low (**Section 4.2.1.2**). In the unlikely fracturing and loss of pool water did occur in the pool immediately upstream, some reduction in the population size of aquatic biota associated with pool habitat (fish and many macroinvertebrates) would be expected. Though given the limited amount of pool habitat that would be affected, impacts to aquatic habitat and biota as a direct result of pool drainage would be relatively minor. While the loss of associated aquatic biota represents a severe impact to aquatic biota at the scale of individual pools, at the scale of an entire watercourse and the upper Avon and Cordeaux River catchments, impacts to the population size of affected aquatic biota associated with extraction of Longwall 19 would be relatively minor. A complete drainage of a pool or section of pool would reduce longitudinal connectivity in the creek and impact the ability of aquatic biota to move in search of food and refuge. Ongoing reductions in connectivity could alter the fish assemblage in Wongawilli Creek, particularly in upstream sections that are fragmented from connected waterways downstream. Freshwater eels (*Anguilla* sp.), which undertake long distance migrations, may reduce in abundance within disconnected sections upstream following impacts to connectivity. Reductions in connectivity and associated impacts to aquatic biota should, however, be limited and temporary assuming flow returns to the pool following rainfall.

#### *4.2.2.3 Water Availability*

The expected increase in number of zero flow days in Wongawilli Creek would result in some reduction in the amount of aquatic habitat available to aquatic biota, with potential associated reductions in population size. There would also be some reduction in longitudinal connectivity in the watercourse while aquatic biota are unable to move between disconnected pools. Substantial increases in the number of zero flow days in Wongawilli Creek and Sandy Creek are not expected, however, and substantial impacts to aquatic biota associated with fragmentation of habitat and hindrance of movement through the watercourse should not occur as long as flow returned soon afterwards. It would also not be expected that all additional low and zero flow days would necessarily occur consecutively, which should limit the severity of impacts to aquatic biota.

#### *4.2.2.4 Changes in Water Quality*

Fracturing of the stream substrate can result in the development of ferruginous springs (iron staining), alteration of water quality parameters and the mobilisation of trace metals which may in turn affect the health of aquatic ecosystems (HGeo 2020). The destabilisation of surrounding soils due to subsidence could also increase the potential for mobilisation and transport of sediments into watercourses during rainfall events. Impacts to water quality in stream reaches within subsidence affected areas due to mining of Longwall 19 are expected to be minor (HGeo 2020). Effects are likely to include slight and temporary changes in water salinity, pH and iron content with local discolouration of streambeds and rock faces by iron hydroxide. Thus, associated risks to aquatic habitat and biota is expected to be low.

### 4.2.3 Threatened Species

Sydney hawk dragonfly and Adams emerald dragonfly were not found in the AUSRIVAS samples collected during the current study nor have any been found in the samples collected as part of several previous studies within, and adjacent to, the Study Area. While suitable microhabitat for this species occurs in the Study Area, the absence of this species in the numerous collected samples, and its known distribution outside of the Study Area, provides sufficient evidence that it does not currently occur here. Australian grayling also does not occur in the Study Area, thus, assessments of significance for these species were not considered necessary.

Macquarie perch have previously been recorded in the lower reach of Wongawilli Creek downstream of the Study Area. Though habitat (larger pools) suitable for this species does occur in Wongawilli Creek within the Study Area, none have been found during the several fish surveys here and farther upstream. The presence

of a natural barrier to movement of this species on Sandy Creek just upstream of its confluence with Lake Cordeaux would also prevent this species utilising the vast majority of this watercourse. Nevertheless, as a precautionary measure an assessment of significance was undertaken for this species in accordance with the Threatened Species Assessment Guidelines (DECC 2007) (**Appendix F**).

The guidelines specify the important factors that must be taken into considered when assessing potential impacts on threatened species, populations, or ecological communities. The factors requiring consideration are:

- How is the Project likely to affect the lifecycle of a threatened species and/or population?
- How is the Project likely to affect the extent and composition of a threatened ecological community?
- How is the Project likely to affect the habitat of a threatened species, population or ecological community?
- Will the Project affect any critical habitat?
- Is the Project consistent with the objectives or actions of a recovery plan or threat abatement plan?
- Is the Project part of a KTP or is it likely to exacerbate a KTP?

The potential for adverse effects on the lifecycle of threatened fish species depends on whether the works are likely to cause loss or degradation of habitat, reduction in water quality, limit their foraging activities and disrupt their reproduction and recruitment. The assessment presented in **Appendix F** indicated the risk of Macquarie perch being impacted by the Project as unlikely. Further monitoring of the Macquarie perch population has been incorporated into the monitoring plan for Longwall 19 as a precautionary measure.

### 4.2.4 Cumulative Impacts

Based on predicted ground movements and associated impacts to water availability and quality (**Section 4.1** and **Table 4-1**), associated impacts to aquatic habitat and biota due to extraction of Longwall 19 are expected to be relatively minor compared with impacts that have occurred in the wider upper Avon and Cordeaux River catchments due to historic and current mining (**Section 4.2**). Due to their proximity to Wongawilli Creek, potential impacts associated with Longwall 19 do, however, represent a relatively greater risk to aquatic habitat and biota in this watercourse. The extraction of this longwall would also contribute to the predicted cumulative reductions to base flow in Wongawilli Creek due to potential additional groundwater depressurisation that would occur. Along with extremely low rainfall conditions, this appears to be the cause of extensive but temporary reduced flow and pool water levels further upstream on Wongawilli Creek associated with DA3B longwalls, rather than fracturing induced flow diversions (**Section 4.2**).

# 5 Recommendations

Four approaches would be used to manage potential impacts on aquatic ecology within the Study Area from Longwall 19:

- Impact minimisation;
- Aquatic ecology monitoring;
- Additional aquatic ecology studies that would be triggered by specific impacts on physical and water quality characteristics of the watercourses; and
- Contingent measures should impacts exceed predictions.

## 5.1 Impact Minimisation

The potential impacts from the extraction of Longwall 19 on aquatic habitats and biota in the watercourses in the Study Area will be minimised by designing the longwall layout so that mining will not occur under Wongawilli Creek or Sandy Creek and by setting the nearest longwall at least 175 m back from Wongawilli Creek. The mine has also been designed to minimise valley closure so that the predicted rate of rockbar fracturing resulting in flow diversions is low (less than 10%). Temporary erosion and sediment control measures such as sediment fences, sandbag weirs, temporary drains, and temporary silt traps should be installed prior to any minor surface works (e.g. road construction and clearing of vegetation) in the vicinity of watercourses and swamps to prevent the input of sediment into watercourses and perched aquifer systems during rainfall events.

## 5.2 Monitoring

### 5.2.1 Background

An aquatic ecology monitoring program would be implemented to:

- Determine the nature and extent of any subsidence-induced impacts on aquatic ecology due to extraction of Longwall 19; and
- Assess the response of aquatic ecosystems to any stream remediation and management works implemented.

A comprehensive monitoring plan designed to assess the potential impacts of mine subsidence on aquatic habitat and biota within watercourses of Dendrobium Area 3 was outlined in The Ecology Lab (2007). This monitoring plan was prepared in accordance with the Dendrobium Consent, the Director General's Requirements (DoP) to modify the Dendrobium Area 3 mine area and in support of the SMP application for Dendrobium DA3A and DA3B. The monitoring plan indicated that baseline sampling would be conducted in impact and control locations four times within a 12 months period, prior to the commencement of longwall mining and that during-extraction and post-extraction monitoring would be undertaken at the same seasonal periods to determine the extent and nature of any impacts and recovery. The plan also advocated a temporally staged monitoring approach be adopted and that impact and control locations relevant to each of Areas A, B and C be monitored over a 12-month period prior to that area's development. The strategic review of the impacts of underground mining in the Southern Coalfield, recommends that baseline studies be conducted at sufficient intensity over a minimum period of 18 to 24 months to gain a better understanding of the variability and seasonality in distribution of flora and fauna, prior to any mining activity (NSW DoP 2008). The review also recommended that replicate surveys be undertaken at sites directly above the mine and at comparable control sites outside the direct impact zone, so that changes and fluctuations due to mining can be distinguished from those due to natural variability.

The Independent Expert Panel for Mining in the Catchment was established in late February 2018 to provide informed expert advice to the (then) Department of Planning and Environment, now the Department of Planning, Industry and Environment) on the impact of mining activities in the Greater Sydney Water Catchment Special Areas, with a focus on risks to the quantity of water and swamps. Part 1 (IEPMC 2019a) reviewed specific mining activities at the Metropolitan and Dendrobium coal mines and Part 2 (IEMPC 2019b) focused on the impacts of mining on water quantity and swamps, including cumulative impacts, and includes review and update of relevant findings of the strategic review (NSW DoP 2008). Recommendations specific to monitoring of aquatic ecology were not included, though several recommendations relevant to

monitoring of groundwater and surface water and the development of associated TARPs will assist in the future assessment and identification of causes of potentially impacts to aquatic ecology.

### 5.2.2 Sites and Timing

Two types of monitoring sites have been incorporated into the plan: 'impact' sites that may be subject to mine subsidence impacts during and after longwall extraction and 'control' sites that will provide a measure of the background environmental variability within the catchments as distinct from any mine subsidence impacts. Monitoring sites have been established previously for DA3A. Impact sites applicable to monitoring potential impacts associated with Longwall 19 are Sites 2, 3 and X4 on Wongawilli Creek, Site 12 on SC10 and Site 13 on SC10C. Monitoring should also recommence at Site 11 on SC10 approximately 250 m upstream of the confluence with SC10C. Sites X7 and X8 on Wongawilli Creek and sites 9 and 7 on Sandy Creek and Site 8 on SC7 would provide control data. Sites X7 and X8 have recently been established within the DA3B monitoring program to provide further control data for Wongawilli Creek and would also provide suitable control data for Longwall 19.

Ideally, baseline surveys at impact and control sites would be undertaken over a 24-month period prior to the commencement of longwall mining and during and post-extraction monitoring to determine the extent and nature of any impacts and recovery. This would provide a better measure of background temporal variability and provide more confidence regarding potential changes occurring several years into the future. Assuming extraction of Longwall 19 begins in February 2023, monitoring specific to this longwall should be undertaken twice in autumn 2021 and twice in spring 2021 in conjunction with the biennial DA3B monitoring also planned for 2021 to supplement the baseline data currently available from previous monitoring events. There would also be merit in undertaking further baseline monitoring for Longwall 19 in 2022. Ongoing monitoring for Longwall 19 could be incorporated into the ongoing biennial monitoring for DA3B Longwalls.

### 5.2.3 Indicators and Methods

The following indicators of aquatic ecology would be monitored at each site:

- Aquatic habitat;
- *In situ* water quality;
- Aquatic macrophytes;
- Aquatic macroinvertebrates; and
- Fish.

#### *5.2.3.1 Aquatic Habitat*

During the first baseline survey, the condition of the aquatic habitat at each site was assessed using a modified version of RCE (Chessman *et al.* 1997). This assessment involved evaluation and scoring of the characteristics of the adjacent land, the condition of riverbanks, channel and bed of the watercourse, and degree of disturbance evident at each site. Any changes in the condition of the aquatic habitat would be recorded during the subsequent surveys.

During each survey, a comprehensive photo record of each site would be taken to gain an understanding of environmental variation within the watercourses. This would be done by taking standardised photos, using a 2 m tall x 1 m wide T-bar, from the top of the site looking downstream, the middle of the site looking upstream, the middle of the site looking downstream, and the bottom of the site looking upstream.

#### *5.2.3.2 Water Quality*

At each site, two replicate measurements of DO, EC, ORP, pH, temperature and turbidity of the water would be taken from just below the surface of the water. The measurements taken would be used to help interpret differences in biotic assemblages. The EC, DO, pH and turbidity measures would also be compared with the ANZECC (2000) DVTs for slightly disturbed upland rivers in south-east Australia. Specific guidelines are not available for temperature and ORP measures.

A more comprehensive assessment of changes in surface water quality at selected sites would be undertaken by ICEFT and other specialist consultants.

#### *5.2.3.3 Aquatic Macrophytes*

At each site where instream aquatic macrophytes are present, their species composition and total area of coverage would be recorded. Features such as the presence of algae or flocculent on the surface of macrophytes would also be noted

#### *5.2.3.4 Aquatic Macroinvertebrates*

Two methods would be used to sample aquatic macroinvertebrates: the AUSRIVAS protocol for NSW streams (Turak *et al.* 2004) and artificial aquatic macroinvertebrate collectors, a quantitative method developed by Cardno for freshwater environmental impact assessment.

##### 5.2.3.4.1 AUSRIVAS

At each site, samples of aquatic macroinvertebrates associated with the pool edge habitat would be collected by using dip nets (250 µm mesh) to agitate and scoop up material from vegetated areas of the river bank. Samples would be collected over a period of 3 to 5 minutes from a 10 m length of habitat along the river, in accordance with the AUSRIVAS Rapid Assessment Method (RAM) (Turak *et al.* 2004). If the required habitat was discontinuous, patches of habitats with a total length of 10 m would be sampled. Each RAM sample would be rinsed from the net onto a white sorting tray from which animals are picked using forceps and pipettes. Each tray would be picked for a minimum period of forty minutes, after which they would be picked at 10 minute intervals for either a total of one hour or until no new specimens are found. These samples would be preserved in alcohol and transported to the laboratory for identification.

In accordance with the AUSRIVAS protocol, RAM samples would be sorted under a binocular microscope (at 40 X magnification), macroinvertebrates identified to family level and up to ten animals of any one taxon counted (Turak *et al.* 2004). A randomly chosen 10% of the RAM sample identifications would be checked by a second experienced scientist to validate macroinvertebrate identifications.

Data would be analysed using the spring AUSRIVAS predictive models for the edge habitat (Coysh *et al.* 2000). The AUSRIVAS methodology and predictive model requires that sampling be done in autumn (15 March to 15 June) and/or spring (15 September to 15 December).

AUSRIVAS models generate the following indices:

- OE50Taxa Score - This is the ratio of the number of macroinvertebrate families with a greater than 50% predicted probability of occurrence that were actually observed (i.e. collected) at a site to the number of macroinvertebrate families expected with a greater than 50% probability of occurrence. OE50 taxa values range from 0 to 1 and provide a measure of the impairment of macroinvertebrate assemblages at each site, with values close to 0 indicating an impoverished assemblage and values close to 1 indicating that the condition of the assemblage is similar to that of the reference streams.
- Overall Bands - These indicate the level of impairment of the assemblage and are derived from OE50Taxa scores. These bands are graded as follows:
    - Band X = Richer invertebrate assemblage than reference condition.
    - Band A = Equivalent to reference condition.
    - Band B = Sites below reference condition (i.e. significantly impaired).
    - Band C = Sites well below reference condition (i.e. severely impaired).
    - Band D = Impoverished.

The revised SIGNAL2 biotic index (Stream Invertebrate Grade Number Average Level) developed by Chessman (2003) would also be used to determine the environmental quality of sites on the basis of the presence or absence of families of macroinvertebrates. This method assigns grade numbers to each macroinvertebrate family or taxa found, based largely on their responses to chemical pollutants. The sum of all grade numbers for that habitat is then divided by the total number of families recorded in each habitat to calculate the SIGNAL2 index. The SIGNAL2 index therefore uses the average sensitivity of macroinvertebrate families to present a snapshot of biotic integrity at a site. SIGNAL2 values greater than 6, between 5 and 6, 4 and 5 and less than 4 indicate that the quality of the water is clean, doubtful, mildly, moderately or severely degraded, respectively.

#### 5.2.3.4.2 Artificial Macroinvertebrate Collectors

Eight replicate artificial collector units, consisting of 24 cm long x 3 cm diameter bundles of 18 wooden chopsticks held together with plastic cable ties, would be deployed at each monitoring site. The collectors would be attached to vegetation with nylon twine and submerged at least 1 meter apart at the edge of pools in 30 to 60 cm of water. The collectors would be retrieved six weeks after being deployed. During retrieval the collectors would be carefully cut away from their anchors, placed into plastic bags, labeled and preserved in 70% ethanol for subsequent laboratory identification and analysis.

The aquatic macroinvertebrates that colonise each bundle of chopsticks would be rinsed onto a 0.5 mm mesh sieve and examined in the laboratory using a binocular microscope. The samples would be sorted and macroinvertebrates identified to family (most invertebrate taxa), sub-family (chironomids) or class (flatworms and leeches) level and counted. Mayflies, damselflies and stoneflies would be identified to genus, where possible. Genus level taxonomic resolution may be more appropriate when attempting to detect an environmental impact on aquatic ecology, as some taxa within the same family may response differently to disturbance. SIGNAL2 scores would also be calculated for the macroinvertebrate assemblages that developed on the artificial collectors.

#### *5.2.3.5 Threatened Species*

As there is a possibility, albeit unlikely, that two threatened aquatic macroinvertebrate species (Adams emerald dragonfly and Sydney hawk dragonfly) occur in watercourses within the Study Area, all the dragonfly larvae collected would be identified to family level. Any individuals of the genera Austrocorduliidae and Gomphomacromiidae found would be identified to species level, if possible. If there is any uncertainty as to their identification, specimens will be referred to a specialist taxonomist. The presence of either one or both of these threatened species would trigger further investigations into the species and its habitats in relation to potential subsidence impacts.

#### *5.2.3.6 Fish*

Fish would be sampled using and baited traps. At each site, eight baited traps would be deployed for 30 to 45 minutes in a variety of habitats, such as amongst aquatic plants and snags, in deep holes and over bare substratum. Fish caught would be collected in a scoop net, identified and measured. Native species would be released unharmed. Non-native species, if any, would not be returned to the water in accordance with Cardno's Scientific Research Permit. Previous monitoring in DA3B has indicated that baited traps capture the same or comparable number of species of fish at each of the monitoring sites compared with backpack electrofishing.

#### *5.2.3.7 Statistical Analysis*

The aim of the statistical analyses would be to identify differences in the selected indicators of aquatic ecology at the Impact sites that are in a different direction, or of a different magnitude, to those at the Controls. Statistically significant differences provide evidence that an impact may have occurred. Evidence would be assessed by examining data from before with those collected after commencement of longwall extraction. Spatial and temporal changes in macroinvertebrate abundance data from artificial collectors would be examined using Generalised Linear Mixed Modelling (GLMM). This technique is more appropriate than distance-based methods (e.g. permutational analysis of variance - PERMANOVA) for analysis of univariate data. Spatial differences and temporal changes, and their interaction, in macroinvertebrate assemblages sampled using artificial collectors would be examined (PERMANOVA+). Multivariate patterns in the data would also be examined using the unconstrained ordination technique Principal Coordinates Analysis (PCO). This will provide a graphical representation of assemblages based on their similarity within and among places or times sampled. In these plots, samples which have similar sets of organisms are grouped closer together than ones containing different sets of organisms.

## 5.3 Additional Aquatic Ecology Studies

The aquatic ecology monitoring program outlined in **Section 5.2** has been designed to detect and determine the extent and nature of impacts on aquatic habitat and biota resulting from mining induced subsidence impacts within watercourses. It incorporates monitoring events throughout the duration of mining regardless of observed physical and chemical impacts within watercourses. Physical-chemical impacts detected within watercourses by routine surface monitoring by ICEFT that may require further investigation into potential impacts on the aquatic ecology include:

> Rockbar fracture resulting in water loss in a pool within Wongawilli Creek;

- Reductions in flow in Wongawilli Creek or Sandy Creek that exceed expected increases in the number of zero flow days (HGeo 2020); and
- Significant change in water chemistry (particularly pH, dissolved oxygen, turbidity, or metal concentration) in Wongawilli Creek or Sandy Creek.

Other observations made during routine surface monitoring that may require further investigation of the aquatic ecology would include:

- Fish/crayfish kills; and
- Die-off of macrophyte beds (if present).

Trigger values for aquatic ecology monitoring parameters are contained in the Area 3A Watercourse Impact Monitoring Management and Contingency Plan (S32 2020). These are based on the duration of reductions in aquatic habitat that may occur in watercourses due to mining impacts.

## 5.4 Contingent Measures

In the event that the impacts due to the extraction Longwall 19 on aquatic habitats and biota in Wongawilli Creek and Sandy Creek are greater than predicted, the following contingent measures could be implemented:

- Implementing watercourse remediation measures, such as backfilling or grouting, in areas where fracturing of controlling rock bars and/or the creek bed leads to diversion of creek flow and drainage of pools; and
- Implementing appropriate control measures, such as installation of sediment fences down slope of areas where subsidence has led to erosion and stabilisation of areas prone to erosion and soil slumping using rock, brush matting or vegetation, to limit the potential for deposition of eroded sediment into the watercourses.

If these management strategies prove ineffectual, appropriate offset and compensatory measures would be implemented.

# 6 Conclusion

The layout design for Longwall 19 includes measures to minimise potential impacts on aquatic habitat and biota. This includes set back of the longwall from major watercourses and significant features and a mine designed to reduce the probability of physical mining impacts occurring. Nevertheless, monitoring of nearby longwall mining indicates that impacts to aquatic habitat, vegetation, macroinvertebrates or fish may occur following predicted mine subsidence and associated fracturing in watercourses in and adjacent to Longwall 19. Due to the presence of numerous flow restricting features in Wongawilli Creek, in the unlikely event the major flow controlling rockbar fractures and results in flow diversions, impacts to pool habitat are expected to be restricted to the 80 m pool immediately upstream of this rockbar. In the context of the wider catchment area, such impacts would be relatively minor. However, the cumulative effect with mining operations in the wider catchment should be considered, in particular, mining related reductions in flow and pool water levels in Wongawilli Creek within the Study Area for Longwall 19. While in isolation, the potential impacts associated with Longwall 19 appear to represent a relatively minor additional impact on aquatic habitat and biota compared to those that have occurred with previous and existing mines in the upper Avon and Cordeaux River catchments, they represent a relatively greater impact to Wongawilli Creek. This is most likely to result in additional zero flow days in the creek, with associated further reductions in longitudinal connectivity and associated impacts to aquatic biota.

No significant impacts to the threatened Macquarie perch, Sydney hawk dragonfly or Adams emerald dragonfly are expected as these species are unlikely to occur in drainage lines that traverse the Study Area that would be most susceptible to mining related subsidence impacts. Although Macquarie perch is expected to occur in the lower reaches of Wongawilli Creek downstream of the Study Area, it does not appear to be present in sections of Wongawilli Creek that would be directly affected by extraction of Longwall 19.

Implementation of the proposed aquatic ecology monitoring program will assist to determine the magnitude and extent of impacts to aquatic ecology associated with extraction of Longwall 19. This includes impacts to aquatic habitat and biota associated with predicted fracturing in watercourses. The detection of physical impacts, such as rockbar fractures resulting in water loss in a pool within Wongawilli Creek or significant changes in water chemistry, would trigger investigations into potential impacts on aquatic ecology. Observations of fish/crayfish kills or die-off of any macrophyte beds would also trigger further monitoring to determine the nature and extent of secondary impacts on aquatic ecology. The level of impact found would determine the type of response. The implementation of such management measures would help reduce impacts on aquatic ecology.

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# APPENDIX A

## SITE COORDINATES

| Site | Watercourse | Easting | Northing |
|---|---|---|---|
| 1 | Wongawilli Creek | 291156 | 6191184 |
| 2 | Wongawilli Creek | 290977 | 6192444 |
| 3 | Wongawilli Creek | 290939 | 6192926 |
| 4 | Wongawilli Creek | 290844 | 6193506 |
| 5 | Wongawilli Creek | 290625 | 6194378 |
| 7 | Sandy Creek | 293661 | 6191227 |
| 8 | Sandy Creek | 293747 | 6191856 |
| 9 | Sandy Creek | 293812 | 6192547 |
| 11 | SC10 | 293240 | 6192222 |
| 12 | SC10 | 293489 | 6192462 |
| 13 | SC10C | 293335 | 6192439 |
| X4 | Wongawilli Creek | 291083 | 6191801 |
| X5 | Wongawilli Creek | 290950 | 6190581 |
| X6 | Wongawilli Creek | 290775 | 6190356 |

# APPENDIX

# B

## PREVIOUS AUSRIVAS RESULTS

| Spring | | | | Autumn | | | |
|---|---|---|---|---|---|---|---|
| Date | No. of Taxa | OE50 Taxa Score | SIGNAL2 Index | Date | No. of Taxa | OE50 Taxa Score | SIGNAL2 Index |
| **Site 1** | | | | | | | |
| Sep-08 | 20 | 0.84 | 4.5 | Mar-09 | 21 | 0.93 | 4.6 |
| Nov-08 | 23 | 0.99 | 4.6 | May-09 | 24 | 0.93 | 4.8 |
| Sep-10 | 19 | 0.83 | 4.6 | Mar-10 | 18 | 1.15 | 4.1 |
| Nov-10 | 16 | 0.72 | 5.4 | May-10 | 16 | 0.92 | 4.7 |
| Sep-11 | 11 | 0.35 | 5.5 | Apr-11 | 16 | 0.63 | 4.2 |
| Oct-11 | 19 | 0.90 | 4.2 | Jun-11 | 12 | 0.65 | 5.2 |
| Sep-12 | 21 | 0.67 | 4.1 | May-12 | 17 | 0.87 | 5.1 |
| Nov-12 | 13 | 0.66 | 4.6 | Jun-12 | 20 | 0.93 | 5.5 |
| Sep-13 | 12 | 0.41 | 5.5 | Apr-13 | 18 | 0.97 | 5.0 |
| Nov-13 | 15 | 0.67 | 4.9 | Jun-13 | 13 | 0.80 | 4.4 |
| Sep-14 | 13 | 0.67 | 5.1 | Mar-14 | 14 | 0.83 | 4.6 |
| Nov-14 | 17 | 0.72 | 4.9 | Apr-14 | 12 | 0.80 | 4.3 |
| Oct-15 | 14 | 0.66 | 4.8 | May-15 | 12 | 0.58 | 5.4 |
| Nov-15 | 19 | 0.65 | 4.9 | Jun-15 | 9 | 0.62 | 5.8 |
| Sep-17 | 19 | 0.70 | 4.2 | Apr-17 | 6 | 0.28 | 6.0 |
| Nov-17 | 16 | 0.91 | 4.6 | Jun-17 | 14 | 0.28 | 4.4 |
| **Site 2** | | | | | | | |
| Sep-10 | 15 | 0.71 | 4.8 | Mar-10 | 19 | 1.06 | 3.9 |
| Nov-10 | 16 | 0.81 | 4.2 | May-10 | 15 | 0.77 | 4.1 |
| Sep-11 | 18 | 0.52 | 4.5 | Apr-11 | 20 | 1.16 | 4.4 |
| Oct-11 | 18 | 0.89 | 4.5 | Jun-11 | 19 | 0.97 | 4.4 |
| Sep-13 | 15 | 0.70 | 5.4 | Apr-13 | 24 | 0.77 | 4.7 |
| Nov-13 | 20 | 0.82 | 5.4 | Jun-13 | 14 | 0.82 | 5.3 |
| Sep-15 | 15 | 0.70 | 5.4 | May-15 | 24 | 0.77 | 4.7 |
| Nov-15 | 20 | 0.82 | 5.4 | Jun-15 | 14 | 0.82 | 5.3 |
| Sep-17 | 17 | 0.89 | 4.6 | Apr-17 | 12 | 0.74 | 4.9 |
| Nov-17 | 21 | 0.57 | 4.7 | Jun-17 | 19 | 0.74 | 5.0 |
| **Site 3** | | | | | | | |
| Sep-08 | 20 | 0.85 | 4.4 | Mar-09 | 22 | 1.02 | 4.8 |
| Nov-08 | 20 | 0.89 | 4.7 | May-09 | 19 | 1.02 | 4.6 |
| Sep-10 | 21 | 0.92 | 4.6 | Mar-10 | 20 | 1.25 | 4.4 |
| Nov-10 | 23 | 0.68 | 4.8 | May-10 | 16 | 1.05 | 4.1 |
| Sep-11 | 14 | 0.59 | 4.8 | Apr-11 | 14 | 0.82 | 4.1 |
| Oct-11 | 23 | 0.91 | 5.0 | Jun-11 | 20 | 0.95 | 4.6 |
| Sep-12 | 17 | 0.81 | 4.5 | May-12 | 14 | 0.87 | 3.8 |
| Nov-12 | 18 | 0.71 | 5.1 | Jun-12 | 15 | 0.86 | 4.8 |
| Sep-13 | 15 | 0.70 | 4.4 | Apr-13 | 17 | 0.70 | 4.4 |
| Nov-13 | 20 | 0.86 | 4.7 | Jun-13 | 14 | 0.77 | 4.3 |
| Sep-14 | 15 | 0.69 | 4.0 | Mar-14 | 20 | 1.08 | 4.5 |
| Nov-14 | 20 | 0.95 | 4.9 | Apr-14 | 19 | 1.07 | 4.8 |
| Oct-15 | 17 | 0.66 | 4.7 | May-15 | 16 | 0.69 | 5.2 |
| Nov-15 | 18 | 0.70 | 4.8 | Jun-15 | 17 | 0.85 | 4.9 |

| Spring | | | | Autumn | | | |
|---|---|---|---|---|---|---|---|
| Date | No. of Taxa | OE50 Taxa Score | SIGNAL2 Index | Date | No. of Taxa | OE50 Taxa Score | SIGNAL2 Index |
| Sep-17 | 15 | 0.52 | 4.8 | Apr-17 | 18 | 0.90 | 4.1 |
| Nov-17 | 17 | 0.77 | 4.8 | Jun-17 | 16 | 0.90 | 4.3 |
| **Site 4** | | | | | | | |
| Sep-08 | 19 | 0.87 | 4.9 | Mar-09 | 17 | 1.03 | 5.2 |
| Nov-08 | 23 | 0.98 | 4.6 | May-09 | 22 | 1.03 | 4.9 |
| Sep-10 | 19 | 0.73 | 4.4 | Mar-10 | 18 | 1.03 | 4.2 |
| Nov-10 | 25 | 1.06 | 4.8 | May-10 | 13 | 0.82 | 3.8 |
| Sep-11 | 14 | 0.60 | 4.9 | Apr-11 | 23 | 0.98 | 4.5 |
| Oct-11 | 22 | 0.80 | 4.5 | Jun-11 | 17 | 0.77 | 4.9 |
| Sep-12 | 19 | 0.82 | 4.0 | May-12 | 20 | 0.77 | 5.0 |
| Nov-12 | 19 | 0.93 | 4.7 | Jun-12 | 23 | 0.97 | 5.0 |
| Sep-13 | 16 | 0.64 | 4.9 | Apr-13 | 21 | 1.09 | 4.8 |
| Nov-13 | 18 | 0.81 | 4.8 | Jun-13 | 18 | 0.87 | 4.4 |
| Sep-14 | 21 | 0.85 | 5.2 | Mar-14 | 22 | 1.22 | 4.3 |
| Nov-14 | 20 | 0.81 | 4.7 | Apr-14 | 16 | 0.77 | 4.1 |
| Oct-15 | 16 | 0.77 | 5.6 | May-15 | 14 | 0.67 | 4.5 |
| Nov-15 | 24 | 0.87 | 5.1 | Jun-15 | 14 | 0.97 | 4.4 |
| Sep-17 | 21 | 0.93 | 4.4 | Apr-17 | 16 | 0.97 | 4.1 |
| Nov-17 | 15 | 0.62 | 4.9 | Jun-17 | 10 | 0.97 | 4.2 |
| **Site 5** | | | | | | | |
| Sep-08 | 25 | 0.81 | 4.5 | Mar-09 | 29 | 0.87 | 4.6 |
| Nov-08 | 25 | 1.12 | 5.0 | May-09 | 23 | 0.87 | 4.2 |
| Sep-10 | 21 | 0.82 | 4.1 | Mar-10 | 24 | 1.30 | 4.4 |
| Nov-10 | 24 | 0.94 | 4.5 | May-10 | 22 | 1.08 | 4.5 |
| Sep-11 | 22 | 0.78 | 5.0 | Apr-11 | 20 | 0.60 | 4.8 |
| Oct-11 | 14 | 0.71 | 4.2 | Jun-11 | 16 | 0.93 | 4.5 |
| Sep-12 | 20 | 0.78 | 5.7 | May-12 | 22 | 0.86 | 4.5 |
| Nov-12 | 17 | 0.43 | 4.5 | Jun-12 | 19 | 0.96 | 4.6 |
| Sep-13 | 24 | 0.92 | 4.6 | Apr-13 | 23 | 1.15 | 4.8 |
| Nov-13 | 21 | 0.82 | 4.8 | Jun-13 | 16 | 0.98 | 4.4 |
| Sep-14 | 31 | 0.96 | 4.5 | Mar-14 | 28 | 0.98 | 5.0 |
| Nov-14 | 30 | 0.89 | 5.3 | Apr-14 | 25 | 0.77 | 4.8 |
| Oct-15 | 18 | 0.71 | 5.2 | May-15 | 23 | 0.80 | 5.3 |
| Nov-15 | 25 | 0.81 | 5.3 | Jun-15 | 17 | 0.92 | 5.1 |
| Sep-17 | 17 | 0.64 | 4.7 | Apr-17 | 18 | 0.70 | 4.9 |
| Nov-17 | 21 | 0.57 | 5.2 | Jun-17 | 23 | 0.70 | 4.5 |
| **Site X4** | | | | | | | |
| Sep-10 | 10 | 0.75 | 4.4 | Mar-10 | 18 | 1.12 | 3.9 |
| Nov-10 | 9 | 0.58 | 3.9 | May-10 | 17 | 1.02 | 4.4 |
| Sep-11 | 18 | 0.67 | 4.8 | Apr-11 | 17 | 0.65 | 4.6 |
| Oct-11 | 15 | 0.48 | 4.7 | Jun-11 | 15 | 0.65 | 3.9 |
| Sep-13 | 11 | 0.69 | 4.9 | Apr-13 | 11 | 0.82 | 4.0 |
| Nov-13 | 11 | 0.49 | 4.9 | Jun-13 | 11 | 0.72 | 4.1 |

| Spring | | | | Autumn | | | |
|---|---|---|---|---|---|---|---|
| Date | No. of Taxa | OE50 Taxa Score | SIGNAL2 Index | Date | No. of Taxa | OE50 Taxa Score | SIGNAL2 Index |
| Oct-15 | 11 | 0.49 | 5.7 | May-15 | 12 | 0.77 | 3.8 |
| Nov-15 | 11 | 0.61 | 4.9 | Jun-15 | 10 | 0.72 | 4.9 |
| Sep-17 | 13 | 0.69 | 4.3 | Apr-17 | 9 | 0.65 | 4.0 |
| Nov-17 | 16 | 0.75 | 4.7 | Jun-17 | 13 | 0.68 | 4.8 |
| **Site X5** | | | | | | | |
| Sep-10 | 19 | 1.09 | 5.2 | | | | |
| Nov-10 | 19 | 0.70 | 5.0 | | | | |
| Sep-17 | 16 | 0.75 | 5.1 | Apr-17 | 10 | 0.55 | 5.0 |
| Nov-17 | 16 | 0.67 | 4.8 | Jun-17 | 12 | 0.74 | 4.5 |
| **Site X6** | | | | | | | |
| Sep-10 | 18 | 0.96 | 4.6 | | | | |
| Nov-10 | 25 | 1.14 | 4.7 | | | | |
| Sep-17 | 14 | 0.50 | 4.8 | Apr-17 | 15 | 0.64 | 4.4 |
| Nov-17 | 19 | 0.88 | 4.3 | Jun-17 | 14 | 0.74 | 4.6 |
| **Site 7** | | | | | | | |
| Sep-08 | 22 | 1.15 | 4.4 | Mar-09 | 17 | 0.92 | 4.1 |
| Nov-08 | 17 | 1.05 | 4.5 | May-09 | 17 | 0.92 | 4.6 |
| Sep-10 | 20 | 0.96 | 4.6 | Mar-10 | 11 | 0.69 | 4.4 |
| Nov-10 | 14 | 0.64 | 4.3 | May-10 | 25 | 0.88 | 5.1 |
| Sep-11 | 15 | 0.71 | 4.6 | Apr-11 | 19 | 0.72 | 4.7 |
| Oct-11 | 16 | 0.70 | 4.5 | Jun-11 | 20 | 0.93 | 4.6 |
| Sep-12 | 13 | 0.50 | 4.3 | May-12 | 20 | 1.01 | 4.9 |
| Nov-12 | 14 | 0.64 | 3.9 | Jun-12 | 15 | 0.83 | 5.1 |
| Sep-13 | 15 | 0.73 | 4.8 | Apr-13 | 12 | 0.64 | 3.9 |
| Nov-13 | 13 | 0.67 | 4.3 | Jun-13 | 13 | 0.83 | 4.6 |
| Sep-14 | 15 | 0.82 | 5.3 | Mar-14 | 18 | 0.80 | 4.8 |
| Nov-14 | 16 | 0.82 | 4.8 | Apr-14 | 11 | 0.52 | 5.1 |
| **Site 8** | | | | | | | |
| Sep-08 | 21 | 0.88 | 5.1 | Mar-09 | 10 | 0.74 | 4.0 |
| Nov-08 | 23 | 1.09 | 4.7 | May-09 | 19 | 0.74 | 4.6 |
| Sep-10 | 15 | 0.79 | 4.8 | Mar-10 | 14 | 0.93 | 4.4 |
| Nov-10 | 14 | 0.64 | 4.6 | May-10 | 17 | 0.98 | 4.1 |
| Sep-11 | 16 | 0.79 | 4.9 | Apr-11 | 14 | 0.65 | 4.9 |
| Oct-11 | 17 | 0.59 | 4.7 | Jun-11 | 20 | 0.79 | 4.7 |
| Sep-12 | 14 | 0.50 | 3.0 | May-12 | 18 | 0.75 | 5.3 |
| Nov-12 | 13 | 0.53 | 4.5 | Jun-12 | 17 | 1.01 | 4.9 |
| Sep-13 | 15 | 0.74 | 4.8 | Apr-13 | 13 | 0.62 | 4.2 |
| Nov-13 | 12 | 0.61 | 4.8 | Jun-13 | 16 | 0.89 | 4.2 |
| Sep-14 | 16 | 0.67 | 4.6 | Mar-14 | 22 | 0.97 | 4.6 |
| Nov-14 | 17 | 0.64 | 4.8 | Apr-14 | 17 | 0.76 | 5.4 |
| **Site 9** | | | | | | | |
| Sep-08 | 24 | 0.96 | 4.5 | Mar-09 | 21 | 1.02 | 4.5 |
| Nov-08 | 26 | 1.04 | 4.9 | May-09 | 17 | 1.02 | 4.4 |

| Spring | | | | Autumn | | | |
|---|---|---|---|---|---|---|---|
| Date | No. of Taxa | OE50 Taxa Score | SIGNAL2 Index | Date | No. of Taxa | OE50 Taxa Score | SIGNAL2 Index |
| Sep-10 | 17 | 0.75 | 4.6 | Mar-10 | 14 | 0.64 | 4.1 |
| Nov-10 | 21 | 0.75 | 4.7 | May-10 | 24 | 0.92 | 4.3 |
| Sep-11 | 10 | 0.48 | 4.7 | Apr-11 | 19 | 0.71 | 5.1 |
| Oct-11 | 14 | 0.70 | 3.9 | Jun-11 | 19 | 0.83 | 4.6 |
| Sep-12 | 22 | 0.75 | 4.5 | May-12 | 20 | 1.11 | 4.6 |
| Nov-12 | 20 | 0.70 | 5.1 | Jun-12 | 16 | 0.83 | 4.9 |
| Sep-13 | 13 | 0.56 | 4.8 | Apr-13 | 17 | 0.92 | 4.1 |
| Nov-13 | 17 | 0.75 | 4.6 | Jun-13 | 16 | 0.74 | 5.3 |
| Sep-14 | 23 | 0.67 | 4.8 | Mar-14 | 23 | 0.92 | 4.6 |
| Nov-14 | 15 | 0.56 | 4.5 | Apr-14 | 19 | 0.83 | 5.1 |
| **Site 11** | | | | | | | |
| Sep-08 | 16 | 0.86 | 5.0 | | | | |
| Nov-08 | 20 | 1.05 | 4.6 | | | | |
| Sep-10 | 22 | 1.05 | 4.2 | | | | |
| Nov-10 | 10 | 0.38 | 4.5 | | | | |
| **Site 12** | | | | | | | |
| Sep-08 | 18 | 0.77 | 4.2 | Mar-09 | 17 | 0.80 | 4.5 |
| Nov-08 | 17 | 1.05 | 4.7 | May-09 | 18 | 0.80 | 4.2 |
| Sep-10 | 17 | 0.77 | 4.8 | Mar-10 | 12 | 0.55 | 4.3 |
| Nov-10 | 19 | 0.96 | 4.8 | May-10 | 15 | 0.65 | 4.5 |
| Sep-11 | 15 | 0.64 | 4.7 | Apr-11 | 19 | 0.74 | 4.4 |
| Oct-11 | 20 | 0.77 | 4.2 | Jun-11 | 19 | 0.92 | 4.6 |
| Sep-12 | 14 | 0.48 | 3.7 | May-12 | 16 | 0.74 | 4.3 |
| Nov-12 | 14 | 0.67 | 4.0 | Jun-12 | 12 | 0.64 | 4.6 |
| Sep-13 | 14 | 0.77 | 4.6 | Apr-13 | 13 | 0.55 | 4.8 |
| Nov-13 | 16 | 0.86 | 4.6 | Jun-13 | 14 | 0.64 | 4.4 |
| Sep-14 | 19 | 0.70 | 4.3 | Mar-14 | 17 | 0.74 | 4.6 |
| Nov-14 | 17 | 0.67 | 4.1 | Apr-14 | 17 | 0.69 | 4.4 |
| **Site 13** | | | | | | | |
| Sep-08 | 18 | 0.86 | 4.4 | Mar-09 | 18 | 1.11 | 4.3 |
| Nov-08 | 18 | 0.86 | 4.2 | May-09 | 17 | 1.11 | 4.4 |
| Sep-10 | 20 | 0.86 | 4.5 | Mar-10 | 11 | 0.55 | 4.7 |
| Nov-10 | 14 | 0.67 | 3.9 | May-10 | 14 | 0.92 | 4.2 |
| Sep-11 | 15 | 0.64 | 4.1 | Apr-11 | 19 | 0.92 | 4.3 |
| Oct-11 | 14 | 0.70 | 4.1 | Jun-11 | 18 | 0.83 | 4.2 |
| Sep-12 | 15 | 0.70 | 4.5 | May-12 | 19 | 0.92 | 3.8 |
| Nov-12 | 15 | 0.67 | 4.1 | Jun-12 | 15 | 0.83 | 3.9 |
| Sep-13 | 14 | 0.73 | 3.7 | Apr-13 | 12 | 0.55 | 3.3 |
| Nov-13 | 13 | 0.67 | 3.9 | Jun-13 | 15 | 0.92 | 3.5 |
| Sep-14 | 15 | 0.67 | 3.6 | Mar-14 | 18 | 0.92 | 4.0 |
| Nov-14 | 10 | 0.48 | 4.3 | Apr-14 | 9 | 0.46 | 3.1 |

# APPENDIX C

## RCE CRITERIA AND RESULTS

### i) River, Channel and Environmental (RCE) Criteria

| Descriptor and category | Score |
|---|---|
| 1. Land use pattern beyond the immediate riparian zone | |
| Undisturbed native vegetation | 4 |
| Mixed native vegetation and pasture/exotics | 3 |
| Mainly pasture, crops or pine plantation | 2 |
| Urban | 1 |
| 2. Width of riparian strip of woody vegetation | |
| More than 30 m | 4 |
| Between 5 and 30 m | 3 |
| Less than 5 m | 2 |
| No woody vegetation | 1 |
| 3. Completeness of riparian strip of woody vegetation | |
| Riparian strip without breaks in vegetation | 4 |
| Breaks at intervals of more than 50 m | 3 |
| Breaks at intervals of 10 - 50 m | 2 |
| Breaks at intervals of less than 10 m | 1 |
| 4. Vegetation of riparian zone within 10 m of channel | |
| Native tree and shrub species | 4 |
| Mixed native and exotic trees and shrubs | 3 |
| Exotic trees and shrubs | 2 |
| Exotic grasses / weeds only | 1 |
| 5. Stream bank structure | |
| Banks fully stabilised by trees, shrubs etc. | 4 |
| Banks firm but held mainly by grass and herbs | 3 |
| Banks loose, partly held by sparse grass etc. | 2 |
| Banks unstable, mainly loose sand or soil | 1 |
| 6. Bank undercutting | |
| None, or restricted by tree roots | 4 |
| Only on curves and at constrictions | 3 |
| Frequent along all parts of stream | 2 |
| Severe, bank collapses common | 1 |
| 7. Channel form | |
| Deep: width / depth ratio < 7:1 | 4 |
| Medium: width / depth ratio 8:1 to 15:1 | 3 |
| Shallow: width / depth ratio > 15:1 | 2 |
| Artificial: concrete or excavated channel | 1 |

| Descriptor and category | Score |
|---|---|
| 8. Riffle / pool sequence | |
| Frequent alternation of riffles and pools | 4 |
| Long pools with infrequent short riffles | 3 |
| Natural channel without riffle / pool sequence | 2 |
| Artificial channel; no riffle / pool sequence | 1 |
| 9. Retention devices in stream | |
| Many large boulders and/or debris dams | 4 |
| Rocks / logs present; limited damming effect | 3 |
| Rocks / logs present, but unstable, no damming | 2 |
| Stream with few or no rocks / logs | 1 |
| 10. Channel sediment accumulations | |
| Little or no accumulation of loose sediments | 4 |
| Some gravel bars but little sand or silt | 3 |
| Bars of sand and silt common | 2 |
| Braiding by loose sediment | 1 |
| 11. Stream bottom | |
| Mainly clean stones with obvious interstices | 4 |
| Mainly stones with some cover of algae / silt | 3 |
| Bottom heavily silted but stable | 2 |
| Bottom mainly loose and mobile sediment | 1 |
| 12. Stream detritus | |
| Mainly un-silted wood, bark, leaves | 4 |
| Some wood, leaves etc. with much fine detritus | 3 |
| Mainly fine detritus mixed with sediment | 2 |
| Little or no organic detritus | 1 |
| 13. Aquatic vegetation | |
| Little or no macrophyte or algal growth | 4 |
| Substantial algal growth; few macrophytes | 3 |
| Substantial macrophyte growth; little algae | 2 |
| Substantial macrophyte and algal growth | 1 |

### ii) Results of the RCE assessment

| Catchment: | Wongawilli Creek | | | | | | | | | | | | Sandy Creek | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RCE Category | 1 | 2 | 3 | 4 | 5 | X4 | X5 | X6 | 7 | 8 | 9 | 11 | 12 | 13 |
| Land use pattern beyond the immediate riparian zone | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Width of riparian strip of woody vegetation | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Completeness of riparian strip of woody vegetation | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Vegetation of riparian zone within 10 m of channel | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Stream bank structure | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Bank undercutting | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 4 |
| Channel form | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Riffle/pool sequence | 4 | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 |
| Retention devices in stream | 4 | 4 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Channel sediment accumulations | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 2 | 2 | 4 | 3 | 3 | 4 |
| Stream bottom | 4 | 2 | 2 | 2 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 4 | 4 | 4 |
| Stream detritus | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Aquatic vegetation | 3 | 4 | 4 | 4 | 3 | 4 | 3 | 4 | 4 | 3 | 3 | 3 | 3 | 3 |
| Total | 48 | 46 | 46 | 46 | 47 | 50 | 50 | 51 | 46 | 46 | 48 | 48 | 48 | 50 |

# APPENDIX

# D

## SITE PHOTOGRAPHS


i) Site 2


ii) Site 3


iii) Site X4


iv) Site 9


v) Site 12


vi) Site 13

# APPENDIX

# E

## AUSRIVAS RESULTS NOV 2019

| Taxon (max. 10 individuals counted) | 1 | 2 | 3 | 4 | 5 | X4 | X5 | X6 | 7 | 8 | 9 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dugesiidae | | | | | 1 | | | | | | | |
| Oligochaeta | 1 | | | | | | | | | | | |
| Copepoda | | | 3 | | | | | | 3 | 1 | | 1 |
| Ostracoda | | | | | 1 | | | | | | | |
| Atyidae | | | | 2 | 4 | | | 4 | | | | |
| Parastacidae | | | | | | | | | | | | 1 |
| Hydracarina | 7 | 2 | 10 | 8 | 10 | 7 | 10 | 9 | 2 | 5 | 7 | 1 |
| Caenidae | | | 1 | 4 | | | | | | | | |
| Baetidae | | | | 1 | 1 | | 2 | 3 | | | 2 | |
| Oniscigastridae | | 1 | | | | | | | | | | |
| Leptophlebiidae | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Coenagrionidae | | | | | 2 | | | | | | | |
| Protoneuridae | | | | | | | | | 2 | | 1 | |
| Megapodagrionidae | | | | | 1 | | | | 5 | 4 | | |
| Synlestidae | | | 8 | | | 1 | 2 | | | | | |
| Gomphidae | | | | 2 | 2 | | | 1 | | | | |
| Aeshnidae | | | | 1 | 7 | | | | | | | |
| Telephlebiidae | | | | 1 | 4 | 2 | | | | | 1 | |
| Austrocorduliidae | | | 1 | 2 | | | | | | | | |
| Cordulephyidae | | | | 3 | 3 | | | | | | | |
| Hemicorduliidae | | 1 | | | 8 | | | | 2 | 1 | | |
| Gripopterygiidae | | | 3 | 7 | 10 | | | 2 | | | | |
| Mesoveliidae | | 1 | | | 2 | | | | | | | |
| Hydrometridae | | | | | 1 | | | | | | | |
| Veliidae | | | 3 | 1 | 3 | 1 | | | 10 | 1 | 1 | |
| Gerridae | | | 2 | 2 | | | | 1 | | | 2 | |
| Nepidae | | | | | 5 | | | | | | | |
| Gelastocoridae | | | | | | | | | | | | |
| Corixidae | | | | | | | | | | | | |
| Notonectidae | 1 | 3 | 2 | 1 | 4 | 1 | | 3 | 4 | 6 | 6 | 1 |
| Dytiscidae | 1 | | | 3 | 4 | 8 | | 2 | | | 5 | 1 |
| Gyrinidae | | | 1 | 1 | 1 | 2 | 4 | | 2 | 1 | | |
| Hydrochidae | | | | | 2 | 1 | | 1 | | | | |
| Hydrophilidae | | 1 | 2 | 2 | | 1 | | | 1 | | | 2 |
| Scirtidae | | 1 | | 1 | | 2 | | | 4 | | | |
| Elmidae | | | | | 1 | | 2 | | | | | |
| Psephenidae | | | | | | | | | | | | |
| Curculionidae | | | | | | | | 1 | | | | |
| Dixidae | | 1 | | | 1 | | 2 | | | | | |
| Culicidae | 1 | 7 | 4 | 1 | 2 | 2 | 1 | | | | 3 | |
| Chironomidae/Aphroteniinae | | | | | | | 1 | | | | | |
| Chironomidae/Chironominae | 1 | 2 | 4 | | | | 2 | 2 | 1 | | 1 | 5 |
| Chironomidae/Tanypodinae | 3 | 9 | 7 | 7 | 10 | 4 | 2 | 5 | 2 | 2 | | 2 |
| Ceratopogonidae | | 1 | 1 | 2 | | | 1 | | 3 | 6 | 2 | 3 |
| Tipulidae | 1 | | | 3 | | | | | | | | |
| Hydroptilidae | | | | | 1 | | | | | | | |
| Philopotamidae | | | 2 | | | | 1 | | | | | |
| Hydropsychidae | | | | | | | | | | | | |
| Ecnomidae | 1 | | 9 | | 1 | | 2 | 1 | | | | |
| Conoesucidae | | | | | | | | | | | | |
| Helicopsychidae | | | | | | 1 | | | | | | |
| Odontoceridae | | 7 | | 2 | 6 | 2 | | | | | | |
| Philorheithridae | | | | | | | | | | | | |
| Leptoceridae | 10 | 10 | 10 | 10 | 10 | 10 | 9 | 2 | 7 | 9 | 5 | 7 |
| Pyralidae | | | | | | | | | | | | |

# APPENDIX

# F

## AOS *M. AUSTRALASICA*

## Assessment of Significance (FM Act) – Macquarie perch

***a) In the case of a threatened species, whether the action proposed is likely to have an adverse effect on the life cycle of the species such that a viable local population of the species is likely to be placed at risk of extinction***

Macquarie perch has been recorded in the Dendrobium Mine area in the mid to lower reaches of Wongawilli Creek, including pools just upstream and downstream of Fire trail 6A (NSW DPI (Fisheries), pers. com.; The Ecology Lab, 2001 and pers. obs. 2005; MPR 2006b; Matt Richardson, Niche, pers. obs. 2011). However, this species was not caught further upstream in Wongawilli Creek despite extensive sampling (Cardno 2012 and 2016). It has been recorded also in Lake Avon and Lake Cordeaux and previously recorded, or potentially present, in the upper reaches of Cordeaux and Avon Rivers (NSW DPI 2016a). The steep bedrock cascade features directly upstream of the crossing at Fire Road No. 6 would pose a significant barrier to the upstream passage of the Macquarie perch populations within the lower to mid reaches of Wongawilli Creek. The presence of a large waterfall on Sandy Creek downstream of the Study Area would also prevent this species utilising the Sandy Creek catchment within the Study Area.

Life history studies of Macquarie perch have been largely carried out on western drainage populations. These populations are known to spawn just above riffles in shallow upland streams in October to January when water temperatures rise to around 16 C. Eastern populations, however, inhabit rivers with very different hydrological conditions to the inland populations and very little is known of their life cycle. The eggs are adhesive and stick to gravel. Hatching commences 13 days after fertilisation and is completed by 18 days after fertilisation at water temperatures of 11 to 18°C Newly-hatched larvae shelter amongst pebbles. In impounded waters, hatched fish move back downstream to the lake habitat from their upstream spawning sites.

The lifecycle of Macquarie perch could be adversely affected if mining results in changes in levels of ponding, flooding or scouring of river banks, fracturing of rock bars and diversion of surface flows and these, in turn, lead to drainage of pools, loss of habitat, and reductions in habitat connectivity and/or water quality. The subsidence predictions indicate that extraction of the proposed longwalls is unlikely to result in the fracturing of the major flow controlling rockbar in Wongawilli Creek. In the unlikely event this did occur, the length of aquatic habitat that would be affected due to flow diversions is expected to be limited due to the presence of the other flow controlling structures in this section of creek. The pool immediately upstream of the major rockbar is approximately 80 m long. Groundwater depressurisation could result in a further increase in the number of zero flow days in Wongawilli Creek from 29 days to 47 days per year. Such increases do not represent substantial changes from natural conditions, though it is possible some pools may dry during extended drought periods.

In any case, while suitable Macquarie perch habitat (woody debris, rocks and boulders) is present within the section of Wongawilli Creek within the Study Area that could be affected, Macquarie perch do not appear to be able to access this habitat due to the presence downstream natural barriers to fish passage associate impacts to this species are unlikely. Also given the extensive amount of potential habitat available for this species further downstream and in Avon and Cordeaux rivers, it is highly unlikely that mining would have any adverse effects on the life cycle of Macquarie perch in the Avon / Cordeaux River Catchment or place a viable local population at risk of extinction. Macquarie perch are considered very unlikely to occur in Sandy Creek and drainage lines due to the presence of a substantial downstream natural barrier to movement, and, thus, would not be affected by any mining induced impacts here. Likewise, any impacts to water quality in these creeks and rivers due to the project are expected to be minor and localised and thus not affect Macquarie perch.

***b) In the case of an endangered population, whether the action proposed is likely to have an adverse effect on the life cycle of the species that constitutes the endangered population such that a viable local population of the species is likely to be placed at risk of extinction.***

No endangered populations of Macquarie perch have been listed on the Schedules of the FM Act.

***c) In the case of an endangered ecological community or critically endangered ecological community, whether the proposed action is likely to:***

***i) Have an adverse effect on the extent of the ecological community such that its local occurrence is likely to be placed at risk of extinction, or***

***ii) Substantially and adversely modify the composition of the ecological community such that its local occurrence is likely to placed at risk of extinction.***

Macquarie perch is not part of a listed endangered ecological community.

***d) In relation to the habitat of a threatened species, population or ecological community:***

***i) The extent to which habitat is likely to be removed or modified as a result of the action proposed;***

***ii) Whether an area of habitat is likely to become fragmented or isolated from other areas of habitat as a result of the proposed action;***

***iii) the importance of the habitat to be removed, modified, fragmented or isolated to the long-term survival of the species, population or ecological community in the locality.***

Subsidence predictions indicate a low probability of occurrence of significant fracturing resulting in flow diversions in Wongawilli Creek. The sections of Wongawilli Creek and Sandy Creek within the Study Area also does not appear to be accessible to Macquarie perch. Thus there are unlikely to be any reduction in Macquarie perch habitat availability, quality or connectivity here due to fracturing. Although fracturing and flow diversions are likely to result in more severe impacts

to habitat in drainage lines, these are very unlikely to provide habitat for Macquarie perch. Thus, it is highly unlikely that mining would lead to removal, fragmentation or isolation of a Macquarie perch population.

**e) Whether the action proposed is likely to have an adverse effect on critical habitat (either directly or indirectly).**

There is no listed critical habitat for Macquarie perch listed on the NSW Register of Critical Habitat.

**f) Whether the action proposed is consistent with the objectives or actions of a recovery plan or threat abatement plan.**

The draft National Recovery Plan for Macquarie perch has recently been released (Commonwealth of Australia 2017). This contains background information on the biology, ecology, distribution and populations, decline and threats and recovery objectives and strategies and associated actions for this species. The objectives are:

- Conserve existing Macquarie perch populations;
- Protect and restore Macquarie perch habitat;
- Investigate threats to Macquarie perch populations and habitats;
- Establish additional Macquarie perch populations;
- Improve understanding of the biology and ecology of the Macquarie perch and its distribution and abundance; and
- Increase participation by community groups in Macquarie perch conservation.

Identified threats include:

- Habitat degradation;
- Invasive fish;
- Barriers to fish movement;
- Altered flow and thermal regimes;
- Disease;
- Illegal and incidental capture;
- Chemical water pollution;
- Climate change.

The following Priority Action Statements for Macquarie perch (NSW DPI 2017) exist:

- Advise consent and determining authorities;
- Collate and review existing information;
- Community and stakeholder liaison, awareness and education;
- Compliance / enforcement;
- Enhance, modify or implement Natural Resource Management planning processes to minimize adverse impacts on threatened species;
- Habitat rehabilitation;
- Pest eradication and control;
- Research / monitoring;
- Stocking / translocation; and
- Survey / mapping.

Potential impacts to Macquarie perch associated with the Project (primarily loss of habitat following significant fracturing leading to flow diversions and reductions in pool water levels) are unlikely. The Project is not expected to interfere with these objectives and the recovery of the species.

**g) Whether the action proposed constitutes or is part of a key threatening process or is likely to result in the operation of, or increase the impact of, a key threatening process.**

One KTP listed under the BC Act is directly applicable to the Project: *Alteration of habitat following subsidence due to longwall mining.*

While the Project is expected to exacerbate this KTP, associated impacts to Macquarie perch due to subsidence are unlikely. Macquarie perch is very unlikely to be found in the Study Area where fracturing and flow diversions could occur.

**2) Assessment of Significance Based on Significant Impact Criteria for Endangered Species (EPBC Act) – Macquarie perch**

**An action is likely to have a significant impact on an endangered species if there is a real chance or possibility that it will:**

**a) Lead to a long-term decrease in the size of a population**

Macquarie perch has been recorded in the Dendrobium Mine area in the mid to lower reaches of Wongawilli Creek, including pools just upstream and downstream of Fire trail 6A (NSW DPI (Fisheries), pers. com.; The Ecology Lab, 2001 and pers. obs. 2005; MPR 2006b; Matt Richardson, Niche, pers. obs. 2011). However, this species was not caught further upstream in Wongawilli Creek despite extensive sampling (Cardno 2012 and 2016). It has been recorded also in Lake Avon and Lake Cordeaux and previously recorded, or potentially present, in the upper reaches of Cordeaux and Avon Rivers (NSW DPI 2016a). The steep bedrock cascade features directly upstream of the crossing at Fire Road No. 6 would pose a significant barrier to the upstream passage of the Macquarie perch populations within the lower to mid reaches of Wongawilli Creek. The presence of a large waterfall on Sandy Creek downstream of the Study Area would also prevent this species utilising the Sandy Creek catchment within the Study Area.

Life history studies of Macquarie perch have been largely carried out on western drainage populations. These populations are known to spawn just above riffles in shallow upland streams in October to January when water temperatures rise to around 16 C. Eastern populations, however, inhabit rivers with very different hydrological conditions to the inland populations and very little is known of their life cycle. The eggs are adhesive and stick to gravel. Hatching commences 13 days after fertilisation and is completed by 18 days after fertilisation at water temperatures of 11 to 18°C Newly-hatched larvae shelter amongst pebbles. In impounded waters, hatched fish move back downstream to the lake habitat from their upstream spawning sites.

The subsidence predictions indicate that extraction of the proposed longwalls is unlikely to result in the fracturing of the major flow controlling rockbar in Wongawilli Creek. In the unlikely event this did occur, the length of aquatic habitat that would be affected due to flow diversions is expected to be limited due to the presence of the other flow controlling structures in this section of creek. The pool immediately upstream of the major rockbar is approximately 80 m long. Groundwater depressurisation could result in a further increase in the number of zero flow days in Wongawilli Creek from 29 days to 47 days per year. Such increases do not represent substantial changes from natural conditions, though it is possible some pools may dry during extended drought periods.

In any case, while suitable Macquarie perch habitat (woody debris, rocks and boulders) is present within the section of Wongawilli Creek within the Study Area that could be affected, Macquarie perch do not appear to be able to access this habitat due to the presence downstream natural barriers to fish passage associate impacts to this species are unlikely. Also given the extensive amount of potential habitat available for this species further downstream and in Avon and Cordeaux rivers, it is highly unlikely that mining would have any adverse effects on the life cycle of Macquarie perch in the Avon / Cordeaux River Catchment or place a viable local population at risk of extinction. Macquarie perch are considered very unlikely to occur in Sandy Creek and drainage lines due to the presence of a substantial downstream natural barrier to movement, and, thus, would not be affected by any mining induced impacts here. Likewise, any impacts to water quality in these creeks and rivers due to the project are expected to be minor and localised and thus not affect Macquarie perch.

**b) Reduce the area of occupancy of the species**

As described above, Macquarie perch is not expected to occur within the Study Area where fracturing, flow diversions and or reductions in flow could occur. The Project would also not require any crossings over Avon River and Cordeaux River that could hinder fish passage and any impacts to water quality are expected to be localised and miner. Thus, reductions in the occupancy of this species die to the Project are unlikely.

**c) Fragment an existing population into two or more populations**

As described in a) and b), potential impacts to Macquarie perch due to the Project are unlikely. No structures that may hinder fish passage would be installed. Macquarie perch is not expected to occur within the Study Area where fracturing and flow diversions could occur.

**d) Adversely affect habitat critical to the survival of a species**

As described in a), potential impacts to Macquarie perch habitat are unlikely. Critical breeding habitat (shallow flowing sections of rivers) is likely to be present throughout Avon River and Cordeaux River though the Project would not result in any impacts here.

**e) Disrupt the breeding cycle of a population**

It is highly unlikely that mining would have any adverse effects on the life cycle of Macquarie perch in Avon River or Cordeaux River or place a viable local population at risk of extinction. Macquarie perch are considered very unlikely to occur in the Study Area, and, thus, would not be affected by any mining induced impacts here. The population in Wongawilli Creek is located downstream of the proposed mining where no fracturing would occur and is not expected to be affected by the project. Likewise, any impacts to water quality in these creeks and rivers due to the project are expected to be minor and localised not affect Macquarie perch.

**f) Modify, destroy, remove or isolate or decrease the availability or quality of habitat to the extent that the species is likely to decline**

As described in (a) – (d) potential impacts to Macquarie perch and their habitat due to the Project are unlikely and not expect to affect its forage, resting or spawning habitat to the extent that the species is likely to decline.

**g) Result in invasive species that are harmful to an endangered species becoming established in the endangered species' habitat**

Invasive species that may predate on Macquarie perch eggs or young fish and/or potentially compete with Macquarie perch for food and habitat include redfin perch (*Perca fluviatilis*), rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), wild goldfish (*Carassius auratus*), eastern gambusia (*Gambusia holbrooki*) and carp (*Cyprinus carpio*). The Project does not include any vectors that may introduce/further introduce these species to Macquarie perch habitat within the Study Area.

**h) Introduce disease that may cause the species to decline**

The invasive species listed in g) may carry disease or parasites that could infect Macquarie perch. However, the Project would not result in the introduction or further introduction of these species to the Study Area.

**i) Interfere substantially with the recovery of the species**

The draft National Recovery Plan for Macquarie perch has recently been released (Commonwealth of Australia 2017). This contains background information on the biology, ecology, distribution and populations, decline and threats and recovery objectives and strategies and associated actions for this species. The objectives are:

- Conserve existing Macquarie perch populations;
- Protect and restore Macquarie perch habitat;
- Investigate threats to Macquarie perch populations and habitats;
- Establish additional Macquarie perch populations;
- Improve understanding of the biology and ecology of the Macquarie perch and its distribution and abundance; and
- Increase participation by community groups in Macquarie perch conservation.

Identified threats include:

- Habitat degradation;
- Invasive fish;
- Barriers to fish movement;
- Altered flow and thermal regimes;
- Disease;
- Illegal and incidental capture;
- Chemical water pollution;
- Climate change.

The following Priority Action Statements for Macquarie perch (NSW DPI 2017) exist:

- Advise consent and determining authorities;
- Collate and review existing information;
- Community and stakeholder liaison, awareness and education;
- Compliance / enforcement;
- Enhance, modify or implement Natural Resource Management planning processes to minimize adverse impacts on threatened species;
- Habitat rehabilitation;
- Pest eradication and control;
- Research / monitoring;
- Stocking / translocation; and
- Survey / mapping.

Potential impacts to Macquarie perch associated with the Project (primarily substantial loss of habitat following significant fracturing leading to flow diversions and reductions in pool water levels and reductions in flow and pool water levels

following groundwater depressurisation) are unlikely. The Project is not expected to interfere with these objectives and the recovery of the species.

## Attachment B – Groundwater Assessment

# DENDROBIUM MINE LONGWALL 19

## Groundwater Assessment

**Prepared for:**

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# BASIS OF REPORT

This report has been prepared by SLR Consulting Australia Pty Ltd (SLR) with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with South32 (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

This report is for the exclusive use of the Client. No warranties or guarantees are expressed or should be inferred by any third parties. This report may not be relied upon by other parties without written consent from SLR.

SLR disclaims any responsibility to the Client and others in respect of any matters outside the agreed scope of the work.

# DOCUMENT CONTROL

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## APPENDICES

Appendix A Model Timing
Appendix B Aquifer Permeability Data Summary
Appendix C Simulated Extent of Connected Fracturing and Surface Cracking
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# 1 Introduction

The Dendrobium Mine is located approximately 12 kilometres (km) west of Wollongong (NSW) in the Southern Coalfields and within the Metropolitan Special Catchment Area managed by WaterNSW. The mine is operated by Illawarra Metallurgical Coal (IMC), a subsidiary of South32. **Figure 1** shows that the designated areas of extraction at Dendrobium are:

- Area 1, the easternmost and lying adjacent to the Cordeaux Reservoir and close to the Illawarra Escarpment;
- Area 2, immediately to the west and south of Cordeaux Reservoir;
- Area 3A, to the west of Cordeaux Reservoir and adjacent to Wongawilli Creek;
- Area 3B, further west, between Wongawilli Creek and Avon Reservoir; and
- Area 3C, to the north of Areas 3A and 3B, between Donalds Castle Creek and Lake Cordeaux.

Coal is extracted from the Wongawilli Seam by longwall mining. Previous workings in the Wongawilli Seam are located to the south at Elouera and Nebo (also referred to as 'Wongawilli'), and to the east at Kemira. The overlying Bulli Seam has been mined at Mt Kembla, partially coincident and to the east of Area 1.

HydroSimulations SLR Consulting Pty Ltd (SLR) was engaged by IMC to prepare an assessment of potential groundwater impacts of the extraction of the proposed Longwall 19 within Area 3A. Prior to approval being given to mine this longwall panel, IMC is required to prepare a Subsidence Management Plan (SMP) outlining the potential impacts that may occur to identified features of significance within and near to this area (see **Section 1.3**). This assessment provides information about predicted groundwater behaviour in response to mining and subsidence for consideration by NSW Department of Planning, Industry and Environment (DPIE) in the assessment of the SMP. Some of the information provided is in response to previous comments and recommendations from the Independent Expert Panel for Mining in the Catchment (IEPMC).

## 1.1 Historical and approved mining at Dendrobium

Longwall mining has occurred at Dendrobium Mine since early 2005 (**Table 1-1**). Area 1 (Longwalls 1 and 2) was completed in 2007, then Area 2 (Longwalls 3, 4, and 5) in 2009. Longwalls 6, 7 and 8 were previously extracted from Area 3A between 2010 and 2012. Mining of Area 3B has been undertaken since February 2013. Four of the ten proposed longwalls remained to be mined in Area 3B following the completion of mining at Longwall 14 in April 2019, although the current panel (Longwall 15) is schedule for completion in January 2020. **Figure 2** shows the location of the mining areas and longwalls at Dendrobium and the relative location of nearby reservoirs and watercourses.

Longwall widths and cutting heights increased from Area 1 to Area 3B (**Table 1-1**). Maximum cutting heights were approximately 3.7 m in Area 1, and 3.5-3.9 m in Areas 2 and 3A. Earlier Area 3B longwalls had maximum cutting heights between 3.95 and 4.5 m. Recent SMP approvals stipulate that Longwalls 14 to 16 must have a maximum cutting height of no more than 3.9 m. A maximum cutting height of 3.9 m is proposed for Longwall 19.

## Table 1-1 Historical and Proposed Longwall Dates and Dimensions

| Area | Panel | Date | Date | Days | LW width | Void width | Length | Cutting height | | Cover Depth | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Historical*** | | Start | End | | [m] | [m] | [m] | Mean [m] | Max. [m] | Min. [m] | Mean [m] | Max. [m] |
| 1 | 1 | 30/03/05 | 15/12/05 | 261 | 237 | 247 | 1750 | 3.2 | 3.7 | 170 | 262 | 316 |
| 1 | 2 | 09/02/06 | 22/01/07 | 348 | 237 | 247 | 2000 | 3.24 | 3.70 | 162 | 264 | 320 |
| 2 | 3 | 30/03/07 | 22/11/07 | 238 | 235 | 245 | 1560 | 3.34 | 3.66 | 138 | 211 | 282 |
| 2 | 4 | 17/12/07 | 30/09/08 | 289 | 235 | 245 | 1950 | 3.65 | 3.75 | 159 | 249 | 310 |
| 2 | 5 | 04/12/08 | 18/12/09 | 380 | 235 | 245 | 2300 | 3.57 | 3.80 | 213 | 252 | 293 |
| 3A | 6 | 9/02/10 | 28/03/11 | 413 | 238.5 | 248.5 | 2610 | 3.7 | 3.90 | 287 | 345 | 389 |
| 3A | 7 | 04/05/11 | 23/01/12 | 265 | 238.5 | 248.5 | 2220 | 3.46 | 3.60 | 288 | 338 | 379 |
| 3A | 8 | 24/02/12 | 29/12/12 | 310 | 295 | 305 | 2220 | 3.38 | 3.50 | 261 | 321 | 373 |
| 3B | 9 | 09/02/13 | 02/06/14 | 479 | 295 | 305 | 2150 | 3.45 | 3.70 | 314 | 381 | 409 |
| 3B | 10 | 20/01/14 | 20/01/15 | 366 | 295 | 305 | 2200 | 3.93 | 4.50 | 325 | 383 | 406 |
| 3B | 11 | 18/02/15 | 05/01/16 | 322 | 295 | 305 | 2190 | 3.86 | 3.95 | 327 | 381 | 404 |
| 3B | 12 | 22/01/16 | 31/01/17 | 377 | 295 | 305 | 2590 | 3.93 | 3.95 | 329 | 376 | 404 |
| 3B | 13 | 04/03/17 | 19/04/18 | 411 | 295 | 305 | 2210 | 3.86 | 3.95 | 299 | 375 | 400 |
| 3B | 14 | 22/05/18 | 26/02/19 | 223 | 295 | 305 | 1980 | 3.89 | 3.90 | 325 | 378 | 395 |
| 3B | 15 | 08/04/2019* | Jan-2020 | 243 | 295 | 305 | 1963 | | 3.9 | 324 | 370 | 390 |
| ***Proposed*** | | Start | End | | [m] | [m] | [m] | Mean [m] | Max. [m] | Min. [m] | Mean [m] | Max. [m] |
| 3B | 16 | Feb-2020 | Nov-2020 | 274 | 295 | 305 | 1874 | | 3.9 | 280 | 350 | 390 |
| 3B | 17 | Dec-2020 | Sep-2021 | 274 | 295 | 305 | 2013 | | 3.9 | 279 | 345 | 385 |
| 3B | 18 | Oct-2021 | Aug-2022 | 304 | 295 | 305 | 1928 | | 3.9 | 248 | 332 | 375 |
| 3C | 21 | Oct-2022 | Jan-2023 | 92 | 245 | 256 | 820 | | 3.9 | 338 | 369 | 404 |
| **3A** | **19** | **Feb-2023** | **Sep-2023** | **212** | **295** | **305** | **1760** | | **3.9** | **278** | **330** | **370** |
| 3C | 20 | Oct-2023 | Apr-2024 | 183 | 245 | 256 | 2000 | | 3.9 | 296 | 338 | 382 |

Width and length all in metres (m). * proposed start date.

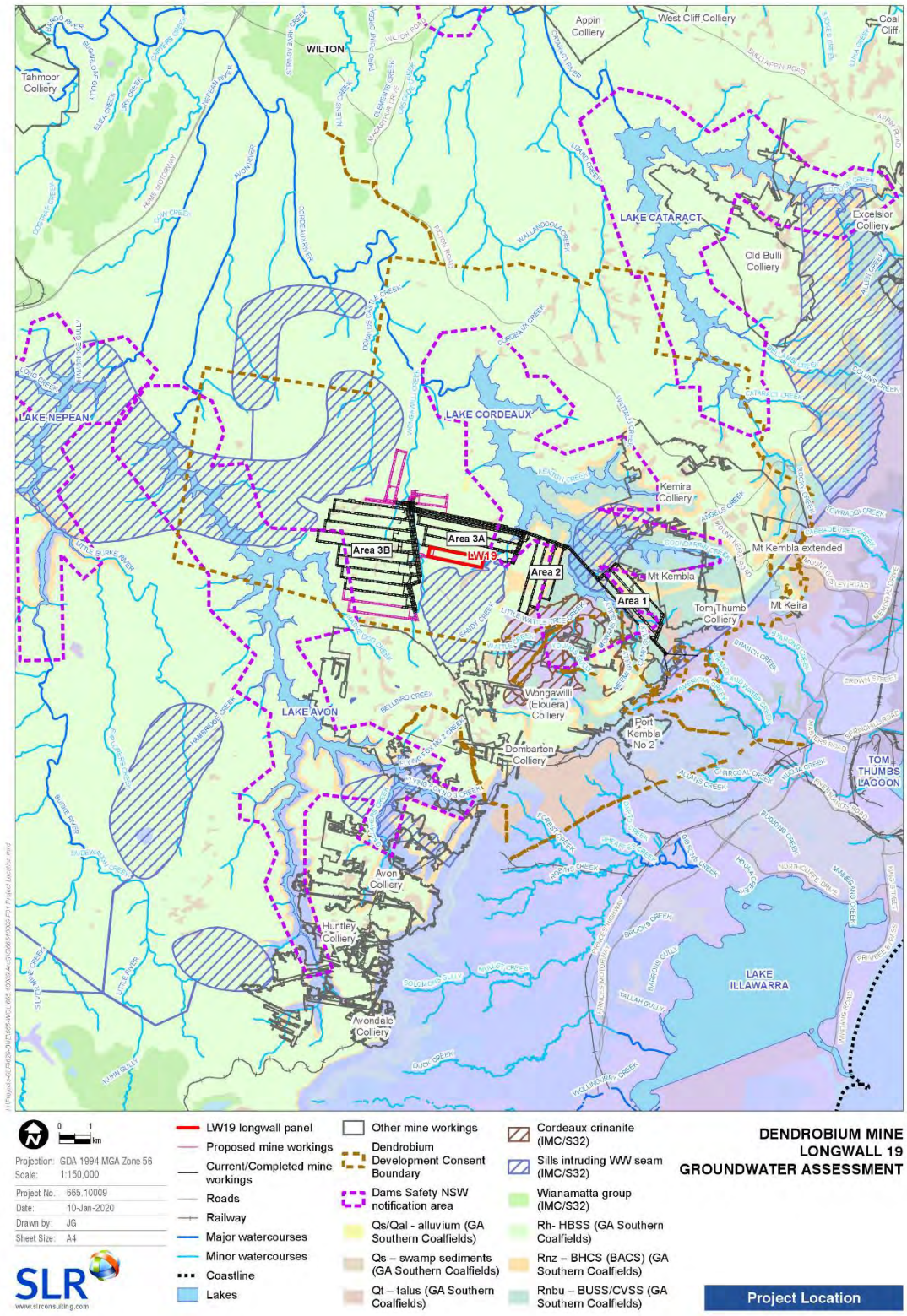



**Figure 1 Project Location**

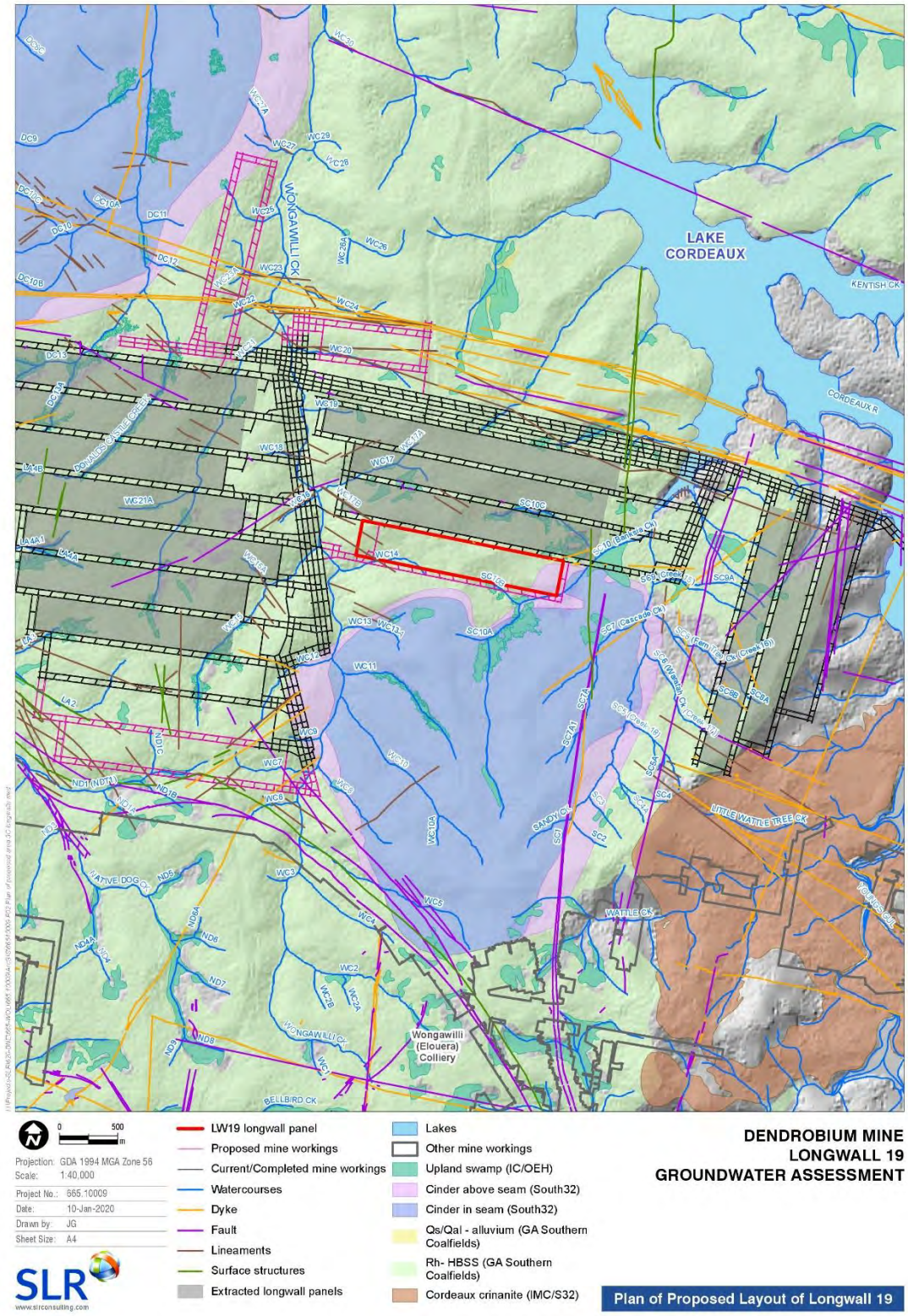



**Figure 2 Plan of Proposed Layout Longwall 19**

## 1.2 Proposed Mining

This study incorporates IMC's proposal for Dendrobium Longwall 19. The planned timing and dimensions of the proposed longwall is presented in **Table 1-1**, along with planned longwalls in Area 3B (Longwalls 16-18) and Area 3C (Longwalls 20-21).

### 1.2.1 Area 3A (Longwall 19)

Longwall 19 in Area 3A is proposed for extraction after longwalls in Area 3B and after extraction of Longwall 21 in Area 3C. It is located immediately south of the previously mined Longwall 8 (Area 3A). As shown on **Figure 1**, Longwall 19 is positioned over 0.9 km south-west of Lake Cordeaux at its closest point, with the eastern ends of historical Longwalls 6 - 8 positioned between Longwall 19 and the lake. Longwall 19 is also located over 3.1 km east to north-east of Lake Avon at its closest point, with the historical and approved workings that are currently being undertaken and proposed in Area 3B between Longwall 19 and the lake.

Longwall 19 is partially overlain by two minor tributaries, WC14 and SC10, as shown on **Figure 2**. WC14 is a minor tributary of Wongawilli Creek, while SC10 is a tributary of Sandy Creek (Lake Cordeaux catchment). Wongawilli Creek overlies the roadways that will be utilised to extract coal from Longwall 19 with the centreline of Wongawilli Creek being located 175 m from the longwall.

There are no overlying historical workings associated with or near Longwall 19.

The cutting height of Longwall 19 is likely to be less than then maximum 3.9 m started in **Table 1-1**. The Wongawilli Coal seam is known to be thinning toward the south in Area 3A and is likely to be 3.5-3.7 m thick through Longwall 19. For conservatism, 3.9 m has been adopted as the cutting height in the modelling and impact assessment.

### 1.2.2 Area 3B (Longwalls 16-18)

These longwalls are proposed to be over 300 m from the Lake Avon Full Storage Level (FSL), as in Schedule 4 Condition 8 of the SMP approval. Some of these longwalls have also been shortened at their eastern end to avoid mining under tributaries of Wongawilli Creek (i.e. WC15).

Longwalls 16 to 18 extend into the Dams Safety NSW Avon Notification Area. There are no overlying historical workings associated with or near Longwalls 16-18, although Longwall 18 is close to old workings at Elouera Colliery.

### 1.2.3 Area 3C (Longwalls 20-21)

Longwalls 20 and 21 both have a void width of 256 m (**Table 1-1**). Cutting heights are similar to recent, with a maximum of 3.9 m as imposed by the most recent Area 3B SMP approval.

**Figure 1** shows that these longwalls are distant from WaterNSW's reservoirs, being at least 1.5 km from Lake Cordeaux and 2.9 km from Lake Avon and are therefore outside of Dams Safety NSW Notification Areas. Longwall 20 is 240 m east of Wongawilli Creek at its closest point. Longwall 21 is proposed to be 120 m west of Wongawilli Creek, and 575 m east of Donalds Castle Creek at their closest points. The likely effects of these longwalls on the groundwater system were described in HydroSimulations (2019b).

There are no overlying historical workings associated with or near Longwalls 20 and 21.

## 1.3 Scope of Work

Numerical modelling has formed part of previous groundwater assessments carried out by Coffey (2012b) and HydroSimulations (2014, 2016a, 2018, 2019a and 2019b). A detailed regional groundwater model has been developed for previous assessments in Areas 3B and 3C, most recently updated for the Longwall 17 and the Longwall 20-21 SMP (HydroSimulations, 2019a, 2019b).

### 1.3.1 Requirements and Conditions

**Table 1-2** outlines the conditions within Schedule 3 of the Consolidated Dendrobium Consent DA 60-03-2001 that are relevant to groundwater and the sections of this report that address them.

This assessment focuses on predicting the potential impacts of Longwall 19, on groundwater, watercourses and reservoirs. For this assessment, historical mining and mining at proposed Longwalls 16-18 and 20-21 has been simulated to provide an understanding of the potential cumulative impacts that may be experienced with the addition of Longwall 19.

**Table 1-2 Groundwater related SMP Requirements and Conditions**

| Condition | | Detail | Section Reference |
|---|---|---|---|
| **Watercourse Impact Management** | | | |
| 2 | The Applicant shall ensure that underground mining operations do not cause subsidence impacts at Sandy Creek and Wongawilli Creek other than "minor impacts" to the satisfaction of the Secretary. | "Minor Impacts" refer to minor fracturing, gas release, iron staining and minor impacts on water flows, water levels and water quality. | Predictions of loss of surface water provided in **Section 5.2** |
| 3 | The Applicant shall ensure the development does not result in reduction (other than negligible reduction) in the quality or quantity of surface water or groundwater inflows to Lake Cordeaux or Lake Avon or surface water inflow to the Cordeaux River at its confluence with Wongawilli Creek, to the satisfaction of the Secretary. | | Predictions of loss of surface water provided in **Sections 5.2** |
| **Groundwater Model** | | | |
| 18 | The Applicant must regularly review and update the Area 3B Groundwater Model to the satisfaction of the Secretary. The model must: | (a) include detailed consideration of surficial aquifers, swamps and watercourses; | **Section 4.2** outlines the stratigraphic units included in the groundwater model. This includes a representation of swamps. **Section 4.4.2** describes the representation of watercourses. |
| | | (b) include all available data on groundwater levels; | **Section 4.6.3** |

| | | | |
|---|---|---|---|
| **Groundwater Model** | | | |
| | | (c) model baseflow contributions for all sub-catchments from baseline (i.e. prior to the extraction of Longwall 9) until 30 years post-mining, using 5-yearly increments; | **Section 5.2**. |
| | | (d) provide adequate water table contour plots, drawdown plots and pore pressure vertical section plots for predicted and observed conditions; | **Section 5.3**.<br>The detail presented in these has been increased from previous assessments, in line with IEPMC's request of 28/11/2019. |
| | | (e) take into consideration the findings of any independent report on groundwater commissioned by the Department, or advice from the Independent Expert Panel, and the report required under condition 19(c) of this approval; and | IEPMC report<br><br>**Section 2.6.3**. |
| | | f) be peer reviewed by a suitably qualified, experienced and independent expert, who is approved by the Secretary. | Review by Kalf and Associates (KA) [KA, 2019]. Comments made by KA are incorporated into this report. |
| **Groundwater Monitoring Program** | | | |
| 5 | Prior to the extraction of Longwall 16, the Applicant must review the Watercourse Impact Monitoring, Management and Contingency Plan for Area 3B prepared under condition 4 of Schedule 3 of the development consent (DA 60-03-2001) to provide for achievement of the performance measures listed in Table 1 in consultation with WaterNSW, to the satisfaction of the Secretary. The revised plan must include: | (a) a program of long-term groundwater monitoring, to be developed in consultation with WaterNSW, to monitor groundwater levels at specific locations and depths until post-mining groundwater levels have stabilised; | This report in general. Specific reference to **Sections 5.2**.<br><br>Long-term monitoring plan currently being developed by SLR. |
| | | (b) and (c) | Not relevant to this groundwater assessment. |
| | | (d) a program to monitor the impact of the development on:<br>- groundwater levels, yield and quality (particularly any potential loss of flow to, or flow from,<br>- SCA (WaterNSW) water storages);<br>- coal seam aquifers and overlying aquifers;<br>- groundwater springs and seeps; and | Provided separately. |

| | | | |
|---|---|---|---|
| **Groundwater Monitoring Program** | | | |
| | | (e) consideration of the requirements of the latest version (or subsequent replacement) of SCA's The Design of a Hydrological and Hydrogeological Monitoring Program to Access the Impacts of Longwall Mining in SCA (WaterNSW) Catchment. | Provided separately. |

SLR has also considered the additional Conditions, relevant to this groundwater assessment, that were imposed on the mining of Area 3B in 11 July 2019, as listed in **Table 1-3**.

### Table 1-3 Additional Area 3B SMP requirements regarding the Groundwater Model (11/07/2019)

| Condition | | Detail | Section Reference |
|---|---|---|---|
| **Groundwater Model** | | | |
| 7 | Prior to the extraction of Longwall 16, unless otherwise agreed by the Secretary, the Applicant must review and update the Area 3B Groundwater Model to the satisfaction of the Secretary.<br>The updated model must: | (a) provide adequate water table contour plots, drawdown plots and pore pressure vertical section plots for predicted and observed conditions; | **Section 4.6** (Calibration) and **Section 5.3** (Predictions). |
| | | (b) take into consideration the findings of any independent report on groundwater commissioned by DPIE, or advice from the IEPMC, and the report required under condition 19(c) [sic 14(c)] of this approval; | Incorporated throughout |
| | | (c) be peer reviewed by a suitably qualified, experienced and independent expert, who is approved by the Secretary. | Review by Kalf and Associates (KA) [KA, 2019]. Comments made by KA are incorporated into this report. |
| **Groundwater Monitoring and Height of Cracking** | | | |
| 14 | The Applicant must undertake a comprehensive program of groundwater monitoring and assessment… to the satisfaction of the Secretary, including: | (a) undertaking detailed geotechnical and hydrological investigations of the height of connective cracking in Longwalls 6 to 12, prior to the extraction of Longwall 14; | Details provided separately. |
| | | (b) installing a combination of extensometers and multi-level piezometers directly above Longwalls 14, 15 and 16, in consultation with Water NSW and OEH, prior to the extraction of Longwall 15; | Provided separately. |

| Condition | | Detail | Section Reference |
|---|---|---|---|
| | | (c) engaging a suitably qualified, experienced and independent expert, who is approved by the Secretary, to prepare and submit a report to the Department prior to the extraction of Longwall 15, unless otherwise agreed by the Secretary, which includes:<br>- a model describing the measured height of connective cracking across Longwalls 6 to 12;<br>- detailed predictions of the height of cracking for Longwalls 14 to 18, and associated impacts on sensitive surface features, including watercourses, swamps and Avon Reservoir;<br>- an analysis of the extent of surface cracking and potential connections with horizontal partings; and<br>- consideration of the findings and recommendations of any independent report on groundwater commissioned by DPE; | Provided separately. |
| | | (d) an assessment of the height of connective fracturing and the extent of surface cracking before and after the extraction of Longwalls 14 and 15 and 16. | Provided separately. |

Recommendations previously incorporated from the DPIE-commissioned study into the Height of Connected Fractures (PSM, 2017) for the Longwall 20-21 and Longwall 17 groundwater assessments (HydroSimulations, 2019a and 2019b), have been retained for the groundwater model utilised in this study. Details on the findings of the Height of Connected Fracture Study are outlined in **Section 2.6.3** of this report.

### 1.3.2 Summary of relevant IEPMC recommendations

In 2018, the IEPMC was formed to provide informed expert advice to the DPIE on the impact of mining activities in the Greater Sydney Water Catchment Special Areas, with a particular focus on risks to the quantity of water in the Catchment. The IEPMC released an initial report in late 2018, and an updated and extended report in 2019 (IEPMC 2019a and 2019b), and the relevant recommendations are summarised in **Table 1-4**.

## Table 1-4 Recommendations of IEPMC

| Recommendation | | | Detail / Response | Where dealt with |
|---|---|---|---|---|
| **p.35** | **2.3.4** | There is a need to consider the ability of geological structures to transmit effects over distance beyond the angle of draw, e.g. as noted at Springvale Mine. | This effect not yet seen at Dendrobium – impacts on shallow piezometers at Dendrobium have all been within 120 m (Watershed HydroGeo, 2019a). Recommend that the position of structures be considered in EOP reporting re: swamp piezometers when analysing hydrographs. | Mapped geological structure in **Section 2.1**.<br>MSEC (2019) describes differences between lineaments at Springvale and those around Dendrobium. |
| **p.47** | **Para 3.** | The Panel foresees that faulting, basal shear planes, lineaments and the potential to unclamp and reactivate fault planes will need to be very carefully considered. | Investigations are currently underway at major geological structures in Area 3B, however these are not relevant to Longwall 19.<br>Basal shears are modelled around the deeper valleys near Longwalls 20 and 21, e.g. along Wongawilli Creek. | Minor geological structures around Longwall 19 are discussed in **Section 2.1**.<br>Modelling of off-goaf effects in **Section 4.5.3** and **Section 4.9.2**. |
| **Groundwater Impacts at Dendrobium Mine** | | | | |
| **p.9** | **6** | Notwithstanding that uncertainty is associated with both the Tammetta and the Ditton height of complete drainage equations, it is recommended to err on the side of caution and defer to the Tammetta equation until field investigations quantify the height of complete drainage AND/OR geomechanical modelling of rock fracturing and fluid flow is utilised. | The method used here is as conservative as that recommended by IEPMC in that the Tammetta method is used as a starting point, and then seam-to-surface connection is simulated for 300 m wide panels. | See discussion of model representation of the height of fracturing in **Section 2.6** and text describing the 'stacked Drains' method in **Section 4.5.1.** |
| **p.5** | **s4.3.1** | "geomechanical modelling is generally restricted to two dimensions and the results translated into a three-dimensional groundwater flow model for separate (uncoupled) predictive purposes." | This update to the model also relies in part on geomechanical modelling by SCT as described in HydroSimulations (2019c) for other proposed areas of the Dendrobium Mine. | |
| | **8** | Groundwater models should:<br>i. continue to be updated<br>ii. be migrated from MODFLOW-SURFACT to MODFLOW-USG only if significant benefits can be demonstrated | i) the model has been updated numerous times, with additional layering, parameters and methods for deformation. A more advanced modelling platform is being developed as part of a long-term project. | This report presents updates to the model, detailed in **Section 4**. |

| Recommendation | | | Detail / Response | Where dealt with |
|---|---|---|---|---|
| | | iii. be underpinned by unified material properties (for common stratigraphic layers) unless differences can be demonstrated to exist through measurements | ii) HydroSimulations do not agree that specific software should be specified. Both SURFACT and USG have advantages and disadvantages and have been verified to give essentially the same results.<br>iii) Differences in material properties may exist between the two sites identified by IEPMC, however more analysis should be done on Southern Coalfield material properties. The parameters of this model rely heavily on the extensive Dendrobium packer test dataset. | Further details on model development and evolution is described through Coffey (2012), HydroSimulations (2014, 2016, 2018, 2019a, 2019b, 2019c). |
| **Surface Water Impacts at Dendrobium Mine** | | | | |
| **p.1** | **17** | ii. installation of weirs and/or flumes at selected sites agreed by WaterNSW and the Dendrobium Mine. ... sites should… include catchments …potentially affected by Longwall 16 to Longwall 18. | New surface water sites have been installed. | **Section 2** |
| | **17** | iv. additional basal shear monitoring, implemented as a priority between the Avon Dam and Longwalls 14 to 18 before mining commences. The sites should be designed to complement the … strategy (geotechnical and groundwater) at S2313 and S2314. | Aside from S2313 and S2314, new monitoring holes installed between Area 3B and Lake Avon, including S2376, S2377, S2378, S2379, S2435, S2436.<br>Work by HGEO and SCT has been reviewed for this assessment, including HGEO (2019). | See network of "Avon monitoring" sites on **Figure 23**. Data from these sites are used to inform uncertainty scenarios in **Section 4.9.2**. |

## 1.4 Water Management

Water use in NSW is managed by the DPIE and regulated through Water Sharing Plans (WSP). The Dendrobium Mine lies within the Nepean Sandstone Groundwater Source of the *Greater Metropolitan Region Groundwater Sources WSP* (NSW Office of Water, 2011) , which is the instrument through which groundwater is managed by the NSW Government. Specifically, the Dendrobium mining area is in Management Zone 2 of that Groundwater Source. This Groundwater Source has been classified as 'Highly Productive'.

Surface Water in this area is managed under the *Greater Metropolitan Region Unregulated River Water Sources WSP* (DPI Water, 2016).

## 1.5 Structure of this Report

This report primarily presents the results of predictive groundwater modelling undertaken to assess potential impacts of Longwall 19 to groundwater sources surrounding Dendrobium Mine. For context, brief discussions of site geology, hydrogeology and the conceptual groundwater model have been included. Further detail of the rainfall, evaporation, topography, geology, as well as detailed descriptions of the conceptual and numerical groundwater models can be accessed through the following reports:

- Coffey, 2012a and 2012b;
- HydroSimulations, 2014;
- HydroSimulations, 2016a;
- HydroSimulations, 2016b;
- HydroSimulations, 2018;
- HydroSimulations, 2019a;
- HydroSimulations, 2019b;
- End of Panel reports:
  - Groundwater: e.g. HydroSimulations 2012-2016 and HGEO, 2017-2019; and
  - Surface Water and Shallow Groundwater, e.g. EcoEngineers 2013-14, HydroSimulations, 2016c and HGEO, 2017-2019.

Additionally, a related but different groundwater model was developed for the recent Dendrobium Extension EIS and described in HydroSimulations (2019c). Relevant elements of that have been transposed to this model.

New information, analysis and interpretation, as well as changes to groundwater modelling are described in this report. This structure is as follows:

**Table 1-5 Outline of report structure**

| Section | Title | Contents |
|---|---|---|
| 1 | Introduction | Description of Dendrobium Mine operations and scope of work. |
| 2 | Hydrogeology | A summary and discussion of key facets of the groundwater system, including discussion of relevant points from PSM (2017) and IEPMC (2018 and 2019). |
| 3 | Conceptual model | Summarises the data analysis and the conceptual model developed, which then leads to the design and operation of the numerical model in the following sections. |
| 4 | Model construction and calibration | Describes changes to the groundwater model to meet relevant conditions as well as other modifications. |
| 5 | Model results | Presents output from the updated model, including predicted groundwater inflow, groundwater level and pressure hydrographs/maps/profiles, and incidental take from surface water features. |
| 6 | Monitoring | Reference to works underway to review the monitoring program. |
| 7 | Conclusions | Includes assessment of Longwall 19 and Dendrobium Mine against the Aquifer Interference Policy (2012). |

# 2 Hydrogeological Setting

The hydrogeological setting of the Dendrobium area is described in previous reporting, such as HydroSimulations, 2016a and 2016b, and 2019c. This section includes a summary of an updated conceptual model of hydrogeology around the Dendrobium Mine based on interpretation of new data collected since these reports, including additional investigative bore holes over and adjacent the mining area as well as the IEPMC (2018 and 2019) reports and DPE's independent 'Height of Fracturing Study' (Pells Sullivan Meynink [PSM], 2017). An integration of the data and analysis is then provided as a conceptual model of geotechnical/groundwater effects in **Section 2.8**.

## 2.1 Geology

### 2.1.1 Stratigraphy

Dendrobium Mine is located within the (Southern) Sydney Basin, part of the Southern Coalfield. The stratigraphy of the Southern Coalfield is presented in **Figure 1**, based on the Southern Coalfield Regional 1:100,000 Geology Map (Moffit 1999) and site-specific data. The Sydney Basin primarily comprises Permo-Triassic sedimentary rock sequences and is underlain by undifferentiated sediments of Carboniferous and Devonian age.

Within the mine area the geology comprises isolated occurrences of Quaternary sediments, as well as upland swamp deposits in localised areas of broad and gently sloping headwater valleys. Triassic stratigraphy can also occur at surface and includes the Hawkesbury Sandstone and underlying Narrabeen Group, as shown in **Table 2-1**. The Permian aged Illawarra Coal Measures underlie the Triassic Narrabeen Group. The Illawarra Coal Measures comprise interbedded sandstone, shale and coal seams, including the two main economic coal seams - the Bulli Seam and Wongawilli Seam. The vertical separation between the historically-mined Bulli and Wongawilli seams is about 30-50 m in the Dendrobium area.

Igneous intrusions have also been mapped in the mine area based on site geological drill data. This includes the Cordeaux Crinanite around Area 2/3A, as well as sills and associated cindering to the north and west of Area 3B, around Area 5, and south of Area 3A (**Figure 1** and **Figure 2).** Relevant to Longwall 19, immediately south of Longwall 19 the Wongawilli Seam has been intruded and the coal replaced by syenite in this area. In addition, a north-south trending dyke (DD1) is located 250 m east of Longwall 19, and extending into Longwall 8, and there is an unnamed dyke, oriented east-west at the eastern end of Longwall 19.

**Table 2-1 Summary of Regional Geology**

| Period | Group | Sub-Group | Formation/ Unit | Description | Typical Thickness (m) |
|---|---|---|---|---|---|
| Quaternary | - | - | Alluvium | Includes Quaternary alluvium (Qa), Quaternary sand (Qs) and talus (Qt) in isolated occurrences. Swamp deposits also occur in localised areas in headwater valleys. | - |
| Tertiary | - | - | Volcanics/ Intrusions | Includes Cordeaux Crinanite (dyke), comprising olivine analcime dolerite, camptonite and teschenite. | ~ 30 |
| Triassic | - | - | Volcanic intrusions | Syenite, diorite and gabbroic plugs, intrusive complexes and associated sills (Moffit 1999). | - |
| | - | - | Hawkesbury Sandstone (HBSS) | Massive or thickly bedded quartzose sandstone with siltstone, claystone and grey shale lenses up to several metres thick (Bowman, 1974; Moffitt, 1999). | < 120 |

| Period | Group | Sub-Group | Formation/ Unit | | Description | Typical Thickness (m) |
|---|---|---|---|---|---|---|
| | Narrabeen Group | - | Newport Formation (NPFM) | | Fine-grained sandstone (less than 3 m thick) interbedded with light to dark grey, fine-grained sandstones, siltstones and minor claystones (Bowman, 1974). | 10 |
| | | - | Garie Formation (GRFM) | | Cream, massive, kaolinite-rich pelletal claystone, which grades upwards to grey, slightly carbonaceous claystone containing plant fossils at the base of the Newport Formation (Moffitt, 1999). | 3 |
| | | Clifton Sub-Group | Colo Vale Sandstone (CVSS) | Bald Hill Claystone (BHCS) | Massive chocolate coloured and cream pelletal claystones and mudstones, and occasional fine-grained channel sand units (Moffitt, 1999). | 12 |
| | | | | Bulgo Sandstone (BGSS) | Thickly bedded sandstone with intercalated siltstone and claystone bands up to 3m thick (Moffitt, 1999). | 95 |
| | | | | Stanwell Park Claystone (SPCS) | Red-green-grey shale and quartz sandstone (Moffitt, 1999; BHP Billiton, 2013) | 20 |
| | | | | Scarborough Sandstone (SBSS) | Quartz-lithic sandstone, pebbly in part (Moffitt, 1999). | 30 |
| | | | Wombarra Formation (WBFM) | Wombarra Claystone (WBCS) | Grey shale and minor quartz-lithic sandstone (Moffitt, 1999; BHP Billiton, 2013) | 25 |
| | | | | Coal Cliff Sandstone (CCSS) | Fine to medium grained quartz-lithic sandstone (Moffitt, 1999). BHPB (2013) suggests CCSS is a sub-unit or facies grading into the Wombarra Formation. | 15 |
| Permian | - | - | Volcanic intrusions | | Basalt, dolerite and volcanic breccia (Moffit 1999) | - |
| | Illawarra Coal Measures | | | | Coal interbedded with siltstone, claystone, quartz-lithic sandstone and minor conglomerate (Moffitt, 1999). Includes the Bulli seam (BUSM/BUCO), Balgownie Coal, Wongawilli seam (WWSM/WWCO) and Tongarra Coal, plus Loddon/Lawrence Sandstones (LRSS) and Kembla Sandstone (KBSS). | 200 - 300 |

### 2.1.2 Structural Geology

The dip of the sediment strata in this area is predominantly to the north, with some westerly dip toward a regional south-to-north syncline which is located in the centre of Area 3B (near Donalds Castle Creek). **Figure 2** shows the geological structures that have been mapped around the proposed footprint of Longwall 19. Compared to the north side of Area 3A, there are few structures mapped. Two NW-SE oriented surface lineaments (DL3_1 and DL3_2) to the west of Longwalls 8 and 19, i.e. between Area 3A and Wongawilli Creek. One major structural feature is the Elouera Fault. This major structural zone is mapped from Elouera Colliery to the south of Dendrobium (**Figure 2**) running northwest between Elouera Colliery and Dendrobium Area 3B roughly parallel to Native Dog Creek and toward Lake Avon. IMC commissioned a number of investigations of subsurface conditions within the fault zone, and these are ongoing. Findings from HGEO (2019a) are summarised as follows:

- The fault offsets the Wongawilli Seam by up to 40 m. The fault is identified within the Colo Vale Sandstone as a zone with breccia, fault gouge and higher fracture density. The fault has not been identified in surface mapping.

- The permeability of the fault zone has been measured via packer testing at a number of bores drilled specifically for investigating the fault zone. Full details on the test results are included in HydroSimulations (2019c), a summary of the findings are included below:
  - Despite the presence of the fault zone being evident In the Colo Vale Sandstone, the permeability of this unit is similar to that measured elsewhere around Area 3B. There is no evidence that mining at Elouera resulted in significant changes in permeability within the fault zone.
  - There are local increases in permeability in the Hawkesbury Sandstone and Bald Hill Claystone below the floor elevation of the adjacent Native Dog Creek valley in some bores in this area. These higher permeability zones are not associated with stratigraphic displacement.

## 2.2 Climate

Average annual rainfall is approximately 1200 mm/yr and average potential evaporation is 1430 mm/yr (from Bureau of Meteorology [BoM] records). Conditions in the mining area have been very dry with rainfall being below average for an extended period since early 2017. BoM's Drought Statement indicates that the 34-month period from January 2017 to October 2019 for the state of NSW compared to other 34-month periods commencing in January had the driest average on record (BoM, 2019). The statement reports that rainfall in NSW for this period has been 35 % below average.

Streams WC14 and SC10 (see **Figure 2**) are partially located above Longwall 19. The longwall panel is located 175 m from the centreline of Wongawilli Creek, and 0.9 km from Lake Cordeaux and 3.1 km from Lake Avon. The following sections outline monitoring, natural groundwater-surface water interaction and the effects on streamflow from historical mining at Dendrobium. See HGEO (2018) and IMC (2017) for more detail on swamps.

### 2.2.1 Monitoring

In the past year, IMC has installed gauging stations on the following watercourses (shown on **Figure 23**):

- LA2 – installed 01/02/2019.
- LA3 – installed 31/01/2019.
- WC12 – installed 14/02/2019.
- NDT1 – installed 28/02/2019.
- LC5 – installed 13/02/2019.

These are distant from Longwall 19. This addresses Condition 5 of Schedule 4 of the SMP conditions regarding the need for further monitoring of these streams around the southern part of Area 3B. See HydroSimulations (2016a) and HGEO (2017) for more detail on surface water monitoring.

### 2.2.2 Baseflow Estimates

IMC has been monitoring stream level and flow around Areas 3A and 3B since late 2007. The Dendrobium area baseflow indices (BFI) have been estimated and converted to baseflow yield (mm/yr), and % long-term average rainfall is summarised from a range of sources. The results by Advisian (2016) represent the regional average.

The results suggest that baseflows in the Dendrobium area are equivalent to approximately 2-60 mm/yr (with a mean of about 20-50 mm/yr), or approximately 1-4% of long-term average (LTA) rainfall.

**Table 2-2 Summary of Calculated BFI and Baseflow Yield**

| Source | Watercourse | BFI | Baseflow yield (mm/yr) | %LTA rainfall |
|---|---|---|---|---|
| HydroSimulations (2016b) | Wongawilli Creek | 10-16% | 31 to 50 | 2.5 to 4.2 |
| HydroSimulations (2016b) | Donalds Castle Creek | 1-6% | 1.5 to 10 | 0.1 to 1 |
| HydroSimulations (2016b) | Sandy Creek | 8-20% | 22 to 55 | 1.8 to 4.6 |
| HydroSimulations (2016b) | - | 15%<br>(10-40%) | 40<br>(25-110) | 4<br>(2.5-11%) |
| Advisian (2016) | - | 10% | - | - |

### 2.2.3 Baseflow Depletion

Mining-induced subsidence and depressurization can result in reductions in low-flows and increases in the duration of cease-to-flow conditions in creeks and rivers within affected areas. Reports such as HydroSimulations (2016a,b) and McMahon (2015) discuss the loss of surface flow in undermined headwater streams such as WC21, DC13S1, DCS2 (HydroSimulations, 2016c; HGEO, 2017). However, changes in surface water flow are not as easily discernible at the major downstream gauges (e.g. Donalds Castle Upper [DCU], Wongawilli Creek Lower [WWL]). This is likely a result of gauging accuracy and the relatively small magnitude of loss compared to total flow at the downstream gauging stations.

This 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), as discussed in Section 3.6 of HydroSimulations (2016d). 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 3A is typically 330 m deep, and typically >350 m deep in Area 3B and 3C (**Table 1-1**). In the area around Longwall 19, the depth of cover is typically 340 to 400 m above the coal seam.

This understanding is routinely re-assessed during the End-of-Panel process. The most recent End-of-Panel report (HGEO, 2018) indicates no discernible effect at stream gauge WWL despite the reach of Wongawilli Creek adjacent to Longwalls 6-11 experiencing 'discontinuous flow' at times during 2018 and 2019.

## 2.3 Groundwater Monitoring

The Dendrobium Mine groundwater monitoring network comprises a substantial number of multilevel vibrating wire piezometers (VWPs) positioned in various geologic units in and around the mine footprint to monitor groundwater levels. A total of 694 sensors within 154 VWPs were active at the time of writing. The Hawkesbury Sandstone is the most intensely monitored geologic unit with 298 sensors positioned within 107 VWPs.

The monitoring points closest to Longwall 19 include: S1885, S1934, S1388, S1879, S1888, S1890 and S1907, S1099 and S1096. Details on the VWPs are included in **Table 2-3**. Details on the full groundwater monitoring network are included in HydroSimulations (2019c), and the location of observation points used for the modelling are discussed in **Section 4.6**.

Currently, water level measurements are collected at the VWPs on a daily to sub-daily basis. Shallow and swamp groundwater levels are also monitored using a system of open standpipe bores. Groundwater quality measurements are taken using pumps installed within purpose built boreholes and within the same borehole as several of the VWP around the site. Groundwater is currently assessed for salinity, pH, major ion compositions (i.e. $HCO_3$, Na), minor ion composition (i.e. Ba, Sr, Li) as well as a range of isotopes.

## Table 2-3 Summary Details of VWPs near Longwall 19

| Area | S-Index | Bore Name | Easting (GDA94 Zone 56) | Northing (GDA94 Zone 56) | Collar RL (mAHD) | Total depth (mbgl) | No. Sensors | No. Piezometers by Geology | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | HBSS | BHCS/BACS | BGSS | SBSS | WBCS | CCSS | BUSM | WWSM | TGSM |
| 3A | S1096 | AIS Kemira DDH 19 | 292699.6 | 6191120.9 | 435.1 | | 1 | | | | | | | | 1 | |
| 3A | S1099 | AIS Kemira DDH 22 | 292040.9 | 6191530.9 | 429.9 | | 1 | | | | | | | | 1 | |
| 3A | S1388 | DDH 29 | 292128.9 | 6192392.9 | 427.6 | | 1 | | | | | | | | 1 | |
| 3A | S1879 | DDH 92 | 291440.3 | 6192133.4 | 379.7 | 368.5 | 12 | 3 | | 3 | 3 | 1 | | 1 | 1 | |
| 3A | S1885 | DDH 93 | 291504.4 | 6192667.9 | 420.0 | 420.4 | 12 | 3 | | 3 | 3 | 1 | | 1 | 1 | |
| 3A | S1888* | DDH 96 | 292486.5 | 6191987.4 | 381.3 | 320.5 | 8 | 2 | | 2 | 2 | | | 1 | 1 | |
| 3A | S1890 | DDH 98 | 292637.3 | 6192490.5 | 407.1 | 347.5 | 8 | 2 | | 2 | 2 | | | 1 | 1 | |
| 3A | S1907* | DDH 103 | 293212.2 | 6191943.1 | 371.9 | 371.9 | 8 | 2 | | 2 | 2 | | | 1 | 1 | |
| 3A | S1934 | DDH 115 | 292128.0 | 6192398.0 | 427.5 | 114.2 | 4 | 2 | | 2 | | | | | | |

Note: * Historical data only due to recent instrument errors

## 2.4 Groundwater Users (Registered Bores)

The Dendrobium mining area lies entirely within the WaterNSW Metropolitan Special Area and therefore registered 'groundwater works' (typically bores) are typically distant from the Dendrobium Mine (**Figure 3**). The nearest are listed in **Table 2-4** (data from the 'Pineena' database).

**Table 2-4 Bores (GW works) nearest Dendrobium Mine**

| GW work number | Distance from Dendrobium Mine | Distance from Longwall 19 | Comment |
|---|---|---|---|
| GW112386 | 1.9 km north of Area 2 | 3.25 km NNE | Monitoring bore installed by the WaterNSW on western edge of L. Cordeaux. |
| GW040945 | 7.2 km WNW of Area 3B | 11.5 km WNW | WaterNSW test bore drilled to investigate groundwater supply near L. Avon dam. |
| GW068119 and a number of others | 4.5 km south of Areas 1-2 | 7.8 km SE | GW068119 and nearby private bores are located on the coastal plain, and in the lower Permian units (e.g. Shoalhaven Group). |
| GW102528 | 10.5 km north of Areas 3B | 12.8 km NNW | Domestic/stock bore completed in the Hawkesbury Sandstone, just south of Wilton. |

All other Groundwater Works are further from Longwall 19 and the greater Dendrobium mine workings, with most of them along the coastal plain. In line with the requirements of the Aquifer Interference Policy (2012), an assessment of drawdown at these GW works, based on the modelling, is presented in **Section 5.3.4**.

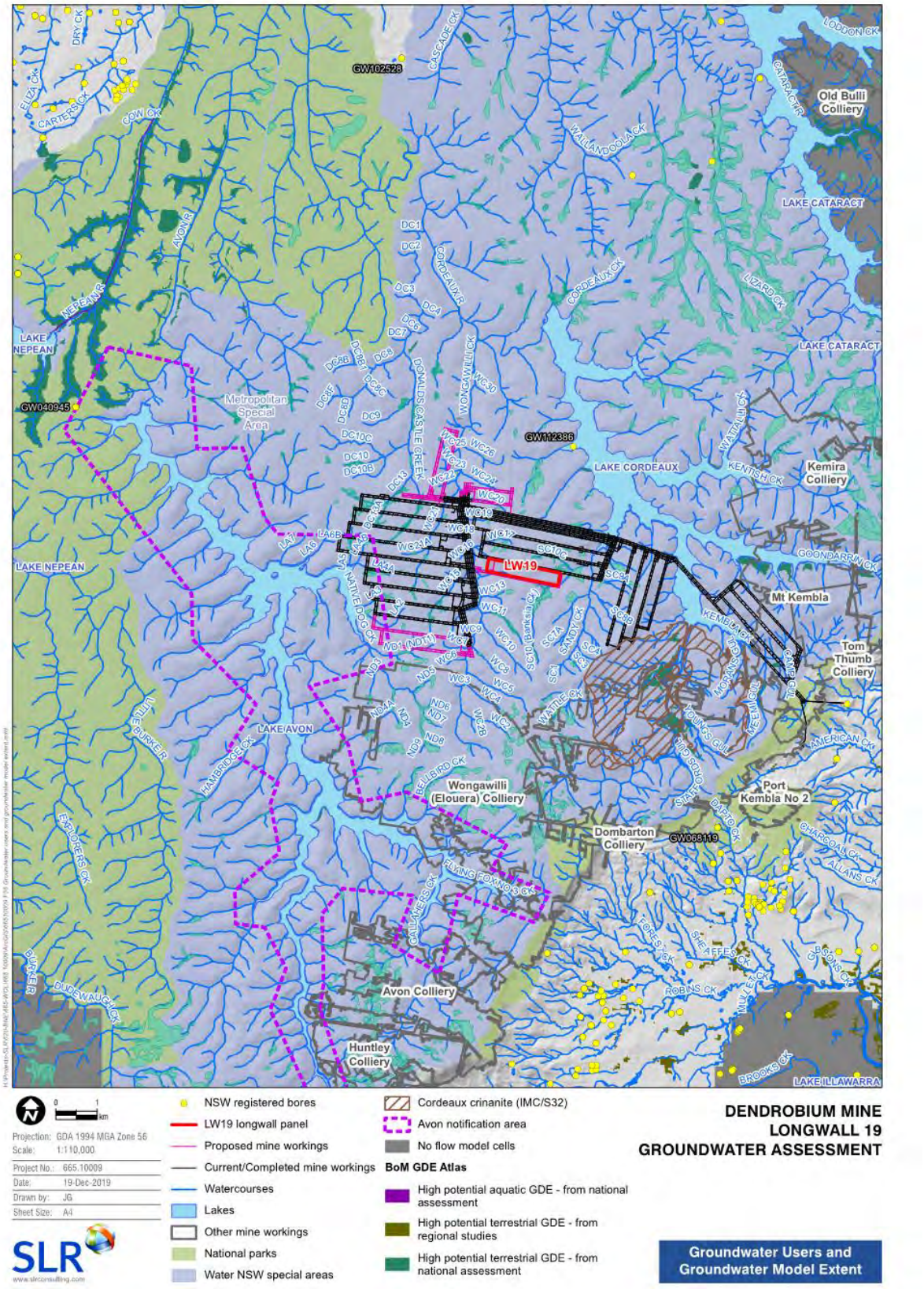



**Figure 3 Groundwater Users and Groundwater Model Extent**

## 2.5 Groundwater Flow, Recharge and Discharge

Regionally, groundwater within the Hawkesbury Sandstone flows from the south-east towards the north-west. Regional groundwater levels within the Permian coal measures generally flow towards the north but are locally influenced by mine activities in the area. Interpolated groundwater flow contours developed from numerical modelling are presented later in **Section 5.3.1**.

Groundwater level monitoring from two of the monitoring bores located near Longwall 19, S1879 and S1907 are presented in **Figure 4** and **Figure 5**, respectively. bore S1879 is located approximately 0.8 km east of Longwalls 13 to 15 and 0.6 km south of Longwall 8. Bore S1907 is located over 3 km east of Longwalls 13 to 15, 0.4 km south of Longwall 8 and 1.5 km west of Longwall 5.

**Figure 4** shows groundwater levels within the Hawkesbury Sandstone currently (November 2019) range between 341 mAHD and 374 mAHD, with sensors at different levels in the Hawkesbury Sandstone showing a downward gradient. In contrast, groundwater heads within the Bulli Seam (BUCO) are currently (November 2019) at around 94 mAHD at S1879 and 140 mAHD at S1907. Likewise, in the Wongawilli Seam (WWCO) groundwater head is at around 80 mAHD at S1897 and 126 mAHD at S1907. The historical trends for the two VWPs show depressurisation of the coal seams over time in response to depressurisation with historical mine progression in the region. Depressurisation is greatest in S1879 compared to S1907 due to its closer proximity to historical mining at longwalls 13 to 15.

Note that some periods of erroneous or suspect data are present in the records shown on **Figure 4**, as is typical of VWP data. This includes a number of spikes in data in late 2007, a spike in the BGSS-210 VWP in mid-2009, and a longer period of suspect data in the BUCO-292 VWP in late 2017.

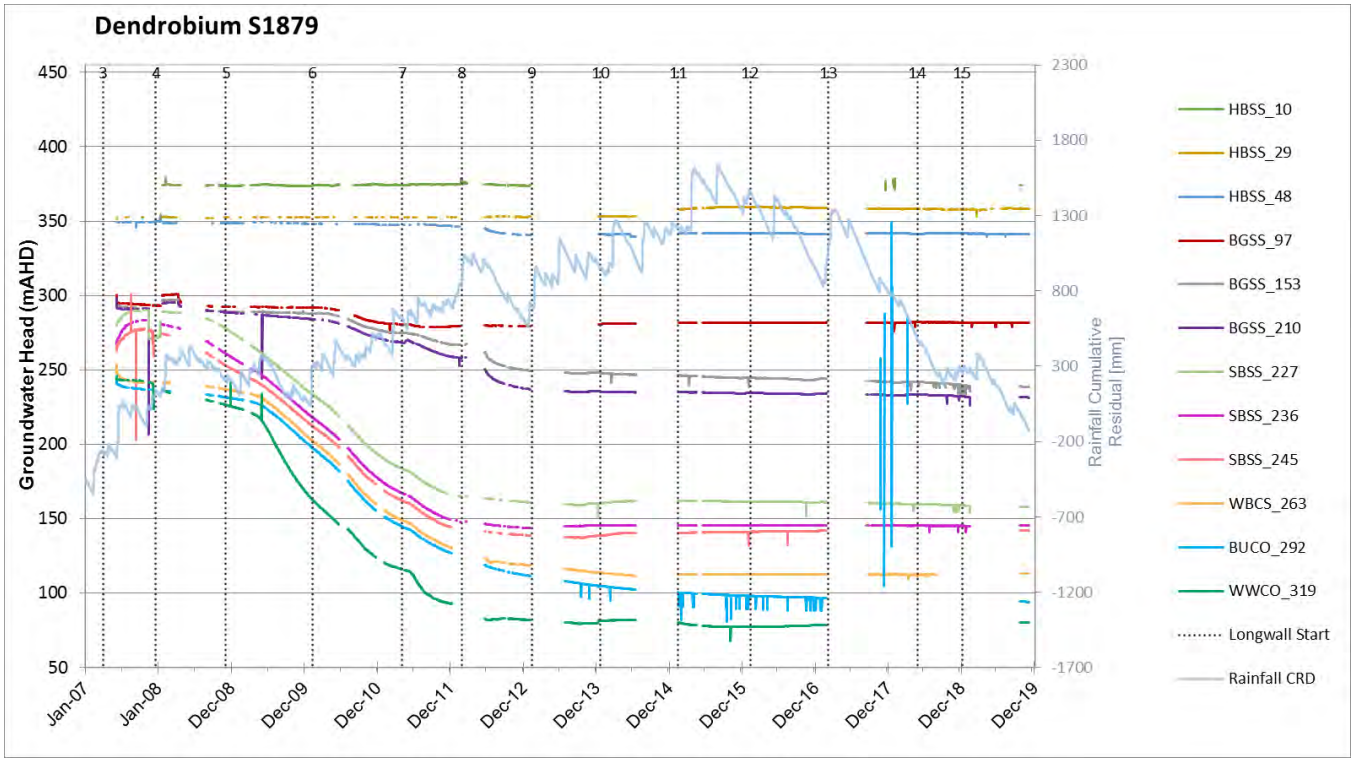



**Figure 4 Hydrograph – VWP S1879**

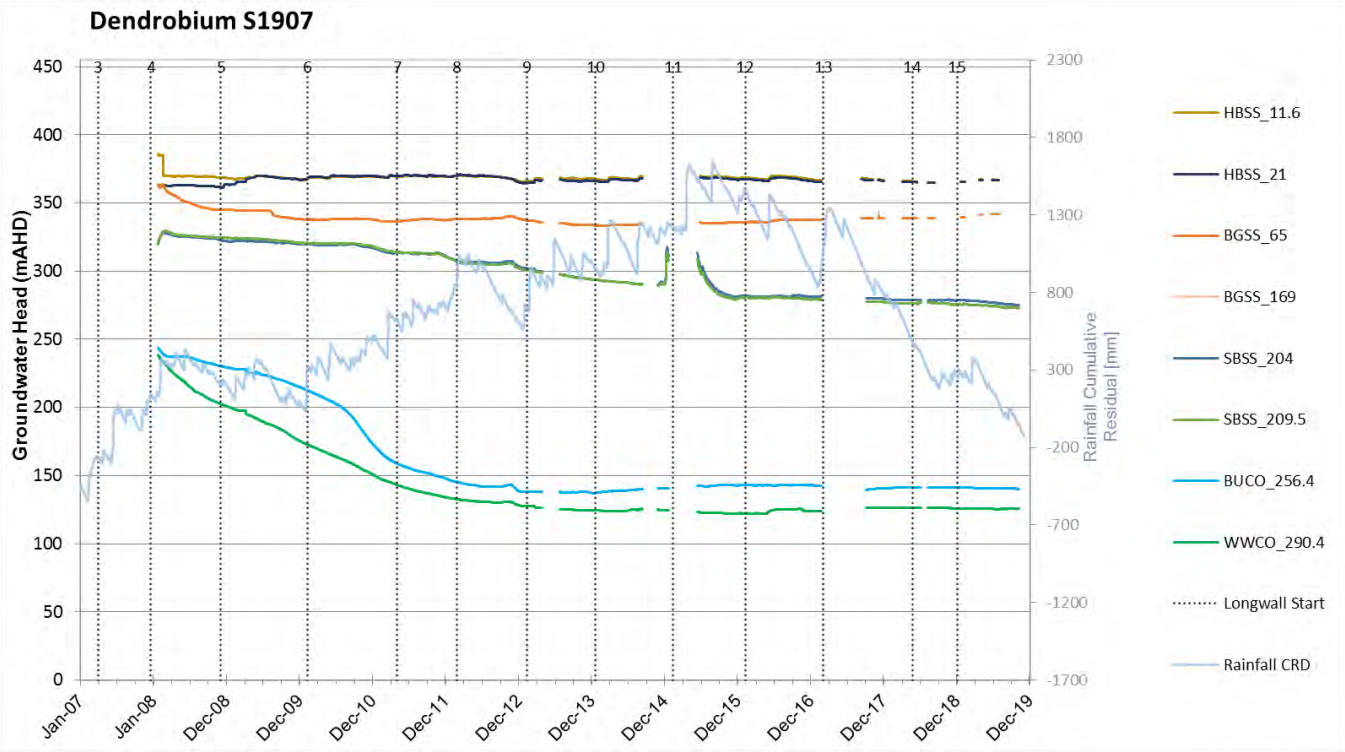



**Figure 5 Hydrograph – VWP S1885**

Groundwater within the Hawkesbury Sandstone and Narrabeen Group as well as the Permian coal measures is recharged from rainfall and water bodies where the lithologies occur at outcrop, as well as potential downward leakage from overlying strata. Estimates of average or long-term rainfall recharge to surficial strata (i.e. Hawkesbury Sandstone) have been obtained from a number of literature sources and from analysis of Dendrobium data. The method of analysis has been added to the table where this is known. The average recharge as calculated by the water balance model for the areas of rock outcrop is equivalent to about 7 % of long-term average rainfall. According to Advisian (2016), 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.

**Table 2-5 Summary of Recharge and Baseflow Estimates**

| Process | Analysis Method | Recharge | |
|---|---|---|---|
| | | % LTA rain | mm/yr |
| HydroSimulations, 2016b | Chloride mass balance baseflow separation, water table fluctuation. | 6.5 % | 65 |
| HydroSimulations, 2016b | Chloride mass balance in shallow groundwater. | 3 - 8.5 % | 40-100 |
| Crosbie, 2015 | Baseflow separation, water table fluctuation. | 6 % | |
| DPI, 2011 | - | 6 % | |
| Coffey, 2012a,b | - | 5 % | 50 |
| Pells, 2013 | - | 5 % | 50 |
| URS, 2007 | Water table fluctuation | 3-10 %* | |

**Note:** LTA: Long-term Average; BFI : Baseflow Index. * URS stated that local variation might be 2-16%, but "realistic range" is 3-10%.

Groundwater discharge from the Hawkesbury Sandstone and Narrabeen Group includes downward seepage, direct bore abstraction, baseflow discharge where incised creeks and gradients enable this, as well as potential evapotranspiration in shallow groundwater areas. Groundwater discharge from the Permian coal measures includes downward seepage and extraction through mine activities and direct bore abstraction.

## 2.6 Hydraulic Properties

### 2.6.1 *In situ* Properties

The set of pre-mining hydraulic conductivity data is presented in **Appendix B**. **Figure B1** shows the packer test data, which measures *in situ* horizontal hydraulic conductivity (Kh), and **Figure B2** shows the vertical hydraulic conductivity (Kv) data as determined by (laboratory) core testing. These Kh and Kv data are classified according to the stratigraphic unit tested. **Figure B3** shows the variation in Kh by mine area and by depth. In general, the different stratigraphic units are slightly deeper in Area 3C than in Areas 3A and 3B, which are deeper than Area 2. This leads to generally lower Kh in Area 3C than in other recent mining areas.

These datasets have been used to inform and constrain the permeability parameters used in the groundwater model (**Section 4.7**). More discussion of recent pre- and post-mining assessments of permeability around the shore of Lake Avon is described in **Section 2.6.5**.

### 2.6.2 Height of Connected Fracturing above the Seam

There are a number of published methods for estimating the height of connected fracturing above longwall panels. The vertical height to which connected fracturing occurs and the models for estimating this were the subject of the IEPMC (2018) as well as PSM (2017) and the associated peer reviews (Mackie, 2017; Galvin, 2017a). A brief assessment of these models is presented below.

These models rely on one or more longwall geometry parameters to estimate the height of connected fracturing:

- W = panel (void) width [m];
- T = mining or cutting height [m]; and
- D = depth of cover [m].

Three of the recent models are Mills (2011), the Ditton 'Geology' Model (Ditton and Merrick, 2014) and the 'Collapsed Zone' (*H*) of Tammetta (2012). The Mills (2011) method relies on panel width, while the other two most recent models (Ditton and Tammetta) use more of the geometric parameters. These two models have been the subject of review and assessment in recent times. In some instances, based on longwall geometry, the Ditton and Tammetta models produce very similar results and both models provide a good match to observation/inference (e.g. above Tahmoor Longwall 10A; SCT, 2014). However, at Dendrobium the models diverge, e.g. at bore S2220 above Longwall 9 (in Area 3B) the Tammetta H would be 20 m below the surface, while the Ditton A-zone would be 115 m below and the Ditton B-zone would be 80 m below. The estimates from the two algorithms tend to diverge for mining thicknesses greater than about 3 m.

While PSM (2017) indicated that neither of these empirical models was robust, no alternative method was suggested. The result is that while they are not universally accepted, these methods still provide useful estimates (Galvin, 2018b, IEPMC, 2018). HydroSimulations has used both the Ditton 'Geology Model' (Ditton and Merrick, 2014) and the 'Height of Complete Groundwater Drainage' (Tammetta, 2012) in previous assessments.

PSM made the conclusion that there was connective fracturing between the seam and surface above Longwall 9; therefore this condition has been represented in the modelling presented here. As a result, the adopted conceptual model (and the numerical model) assumes the profile of connected fracturing shown in **Appendix C**. This shows the simulated height of this zone intersecting the surface cracking zone, if not ground surface, for most of the area within the longwall footprint at Dendrobium, specifically for longwalls with a void width of >300 m. For longwalls that are narrower, the conceptual and numerical models rely on the use of the Tammetta (2012) method to estimate the height of connected fracturing, which is consistent with the finding of IEPMC (2018 and 2019a) that the more conservative Tammetta method be adopted in cases where other data is not available.

These assumptions mean that the modelling-based assessment is conservative – more detail is presented in **Section 4.5**. With respect to conditions at Dendrobium, this should be revised in the near future – IMC are currently completing analysis of recent centre-line goaf hole investigations in Areas 3A and 3B.

### 2.6.3 DPE 'Height of Fracturing Study' (PSM, 2017) and IEPMC (2018 and 2019a)

In 2016 DPE commissioned an independent 'Height of Fracturing Study' to assess the height of fracturing and related behaviour above longwalls at the Dendrobium Mine. This study was carried out by PSM, with peer review by Emeritus Professor Jim Galvin and Dr Col Mackie.

HydroSimulations reviewed the PSM study and associated reviews, providing comment to IMC and DPE (HydroSimulations, 2017). A summary of the implications for groundwater modelling is presented in **Table 2-6**.

**Table 2-6 Summary of implications for groundwater modelling**

| #. | Issue | Action/Recommendation |
|---|---|---|
| 1 | Accounting for structures, specifically Elouera Fault | South32 maps structures in the mining area and has commissioned studies to investigate the role of structures within and around Area 3B longwalls. Additional studies on the Elouera Fault are underway and continuing; we have reviewed HGEO (2019b), which as yet does not point to significant and broad changes to permeability. However, this needs to be considered further in future, as more data becomes available, especially as part of any assessment specific to Longwall 18. |
| 2 | Valley-bulging (valley-closure) around lakes | Suggestions for incorporation into modelling are that this be dealt with by increasing the hydraulic conductivity of the strata along valley walls and beneath valley floors.<br>The modelled increase in hydraulic conductivity used to represent this mechanism is described in **Sections 2.6.5** and **Section 4.5.3**. |
| 3 | Accounting for basal shears | Increased permeability resulting from basal shears around ends of Area 3B longwalls and the potential to connect to Lake Avon has been incorporated into the model. Based on advice from SCT, and the PSM study, these occur around the claystones (BHCS and SPCS).<br>PSM stated that "based on its general experience in sedimentary rock geological terrains, this shearing is likely to be continuous throughout the Dendrobium Mine region."<br>Basal shears are not modelled explicitly as discrete features, as the evidence from packer testing around Area 3B and Lake Avon does not support these being the primary potential groundwater pathways in off-goaf areas. Rather, broader deformation or valley closure (see previous and following points) that causes a change in horizontal hydraulic conductivity is simulated. |

| #. | Issue | Action/Recommendation |
|---|---|---|
| 4 | Off-goaf fracturing | The groundwater model needs to simulate off-goaf Kh enhancement, although this may be accounted for via the 'valley-bulging' mechanism described earlier (#2). Enhancement has been represented as:<br>• occurring up to 600 m from longwalls;<br>• being an increase of 2-3 times as a minimum, but up to 15 times based on recent testing at S2314A (*more discussion of this in HGEO, 2019b and* ***Section 2.6.5***). PSM's claim of up to 3 orders of magnitude remains unsupported by data or literature; and<br>• being applied as declining with distance, based on S2313 and S2314A data. |
| 5 | Representation of fracturing through to surface in Area 3B | Neither the Tammetta (2013) or Ditton (Ditton and Merrick, 2014; DGS, 2016) models are supported by the PSM study or reviews, although IEPMC (2019a) consider the Tammetta (2013) method to be an appropriate tool for assessments, in the absence of other more site-specific data.<br>There is clearly some form of fracturing to the surface above Area 3B and 3A panels (HGEO, *pers.comm.*), although the specific mode of fracturing is subject to some dispute. PSM assert there is vertical connection from seam to surface above Area 3B (based on their review of the Longwall 9 investigations by PB, 2015); however we do not consider that all of the water budgets, groundwater levels and inflow chemistry consistently support this conceptual model (see **Sections 2.7**.<br>However, to carry out a highly conservative assessment of impacts, the baseline model now incorporates seam-to-surface connection, while maintaining calibration (where possible) to inflow and groundwater levels. |
| 6 | Geotechnical modelling | Geotechnical modelling could be done prior to groundwater modelling (e.g. FLAC) or coupled (e.g. COSFLOW).<br>Geotechnical modelling has been used in other parts of Dendrobium Mine (HydroSimulations, 2019c). HydroSimulations previously found that FLAC modelling produces estimates of strata permeability that are significantly greater than would be used in a calibrated groundwater flow model (possibly because they focus on fracture, not bulk, permeability). Therefore, we have used a method to incorporate the outputs of such modelling in the groundwater model, chiefly around up-scaling from the fine detail of local-scale geotechnical models to regional groundwater models.). |

### 2.6.4 Surface Cracking

Packer testing in the Longwall 9 boreholes (PB, 2015; PSM, 2017) shows fracturing through the vertical profile, with no separation between fracturing from the panel and from the surface (i.e. no obvious 'Constrained Zone'). Therefore, it is difficult to assess the depth of the surface influenced (unconfined) cracking zone (a complication also noted by Advisian, 2016).

Surface cracking specifically related to the unconfined nature of the surface strata has been measured down to 15-20 m above the Bulli Seam Operations (Appin) Mine, and Advisian (2016) state that it could extend to 10-15 m (Table 4.2 of that report). Given the different longwall geometry and depths of cover at Dendrobium Mine, especially in Area 3B, the discrete surface cracking zone due to the unconfined nature of the surface strata can overlap with the fracturing from the seam to the surface.

While it is likely that longwall width, topographic relief (slope) and geological conditions, instead of cutting height alone, will govern this depth, 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 Mines, including field testing by SCT (2018). Above Longwall 19, this would mean depths of around 40 m (maximum extraction height of 3.9 m), as also estimated for longwalls in Areas 1, 2 and 3A (as shown in **Appendix C**). For Longwalls 10-12, in Area 3B, however, the depth of surface cracking zone is expected to exceed 40 m due to the greater cutting heights in those longwalls (**Table 1-1**).

The cross-sectional charts in **Appendix C** suggest that the surface cracking zone (extending downward from surface) will likely intersect the zone of connected fracturing (extending up from the goaf) with resultant condition of seam-to-surface connection.

### 2.6.5 Off-Goaf Deformation and Valley Closure

Ground movement can occur at some distance away from the longwall panels themselves. This can take the form of valley closure or valley-bulging. It is our understanding that these two geotechnical phrases refer to the same or similar processes, with PSM (2017) favouring 'valley-bulging' while others prefer the term 'valley closure'.

#### 2.6.5.1 Valley Closure or Valley Bulging

Valley closure subsidence relates to valley and horizontal compressive stress. Zhang (2014) thesis discussed the influence of longwall mining on the redistribution of horizontal in-situ stress, and contribution to pressure to the valley walls and bedding plane shearing. The contribution of pressure and shear was found to be influenced by the position of the longwall panel in relation to the proximity to the valley centreline, depth of cover and presence of bedding planes. Zhang concluded that other factors such as valley geometry (slope angle) and presence of geological structures were less significant.

The presence of basal shear planes, discussed by various geotechnical engineers (Walsh *et al*., SCT, PSM) has a potential role in connecting features to the goaf. The mobilisation of such features and enhanced permeability that may result from them might be taken into account by the more general 'off-goaf deformation' or valley closure described above, however given the conjecture about specific or discrete features connecting reservoirs (namely, Lake Avon) to the zone of connected fracturing above the goaf, this has warranted additional consideration.

SCT (2015) provided discussion on the presence and behaviour of horizontal planar feature' basal shears associated with claystones (i.e. Bald Hill Claystone) and floors or valleys adjacent to longwall mining. **Figure 6** shows the general conceptualisation developed by SCT. Packer testing of a potential basal shear zone by SCT (2017) indicated a horizontal hydraulic conductivity of about $2E^{-6}$ m/s (0.17 m/day) across a 6 m test interval. Recent work by SCT (2019) at Sandy Creek (near to Longwall 19) presents data on two basal shears. One was shown to have a hydraulic conductivity 2-3 times as permeable as the background hydraulic conductivity, while the hydraulic conductivity of other shear was indistinguishable from the surround strata. SCT concluded that basal shear horizons may not show a universally high hydraulic conductivity, due to factors of overburden depth, shear magnitude and weathering.

Recent downhole packer testing of pre- and post-mining conditions at a number of boreholes between Area 3B longwalls and Lake Avon has indicated the following in terms of changes to horizontal permeability (**Table 2-7**). This dataset has been revised and updated due to continuing investigations by IMC. The latest reference to cover this work is HGEO (2019b), and this is relied on for this assessment. Locations are shown on **Figure 23**.

### Table 2-7 Recent pre- and post-mining packer test locations near Lake Avon

| Site | Bore(s) | Location | Pre- to post-mining Kh [m/day] | Change | Comment |
|---|---|---|---|---|---|
| AD1 | S2313 and S2331 | 150 m from Longwall 12 | 2.9E-03 to 5.00E-03 | x 2 | |
| AD2 | S2314 and S2314A | 210 m from Longwall 13 | 3.04E-02 to 2.10E-01 | x 15 | |
| AD3 | S2377 and S2377**B** | 104 m from Longwall 14 | 1.20E-02 to 1.50E-01 | x 12 | Post-mining re-drill in Dec-2017 |
| AD3 | S2377 and S2377**C** | 104 m from Longwall 14 | 1.20E-02 to 5.70E-03 | x 0.5 | Second re-drill in Sept-2018, suggesting further change in Kh. |
| AD4 | S2378 and S2378B | 105 m from Longwall 15 | 2.80E-03 to 1.30E-02 | x 5 | |
| AD6 | S2314 and S2376 | 10 m from Longwall 13 | 3.04E-02 to 2.90E-02 | x 1 | |
| AD7 | S2314 and S2435 | 320 m from Longwall 14 | 3.04E-02 to 3.10E-01 | x 10 | |
| | General | Not specified | | "larger" | PSM, 2017. No data cited. |
| | General | Hawkesbury Sandstone within 200 m | | → 5E-2 m/day | HGEO, 2018b |

Data is from Table 2 of HGEO (2019b)

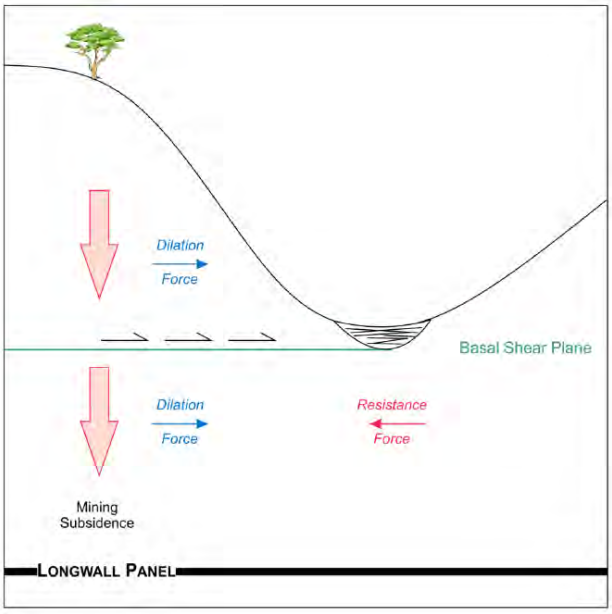
Analysis of the testing results led to HGEO recommending that despite some pre- and post-mining boreholes showing little to no change in Kh, due to the limited dataset, the modelling should use an absolute Kh. Previously this was estimated to be 5E-2 m/d, rather than a multiplier in order to make a conservative estimate of impacts on surrounding waterbodies (e.g. Lake Avon). This has been changed slightly in this study to 6E-2 m/day based on the results in HGEO (2019b) and **Table 2-7**. Based on this, the conceptual model for enhancement of horizontal permeability is:

- For conservatism, we will ignore the apparent reduction in permeability (Kh) that has been inferred or measured in some boreholes, and that there appear to be some transient effects, as at AD3 which has been drilled twice, almost a year apart, following nearby longwall extraction.
- Occurring up to a maximum of 600 m from longwalls.
- Being applied as declining with distance, based on S2331 vs 2313 and S2314 vs S2314A data, although there is a hypothesis that the effects might be greater at approximately 100-300 m from longwalls, with smaller changes to permeability within 100 m and beyond 300-400 m.
- Specifically, enhancement to approximately 6E-2 m/d (when averaged over significant thickness, like those of the groundwater model layers) within 300 m.
- Beyond 300 m, Kh change could be an increase of up to 15 times based on testing at S2314A but based on other bores is likely to be an increase of 2-3 times.

PSM's claim of Kh increases of '1-3 orders of magnitude', specifically the upper part of that range, was not supported by data from Dendrobium Mine or literature. The model could be modified in future if further data is supplied to support a change of 3 orders of magnitude, however so far, additional data has suggested that Kh can change but also may only increase mildly or even show no systematic increase (HGEO, 2019b).

Given the uncertainty and differences in packer test results, the regional groundwater model has been run multiple times to test the sampled Kh and the potential effects of this on losses from reservoirs. **Section 4.9.2** provides additional detail on this.

**A)**




**B)**

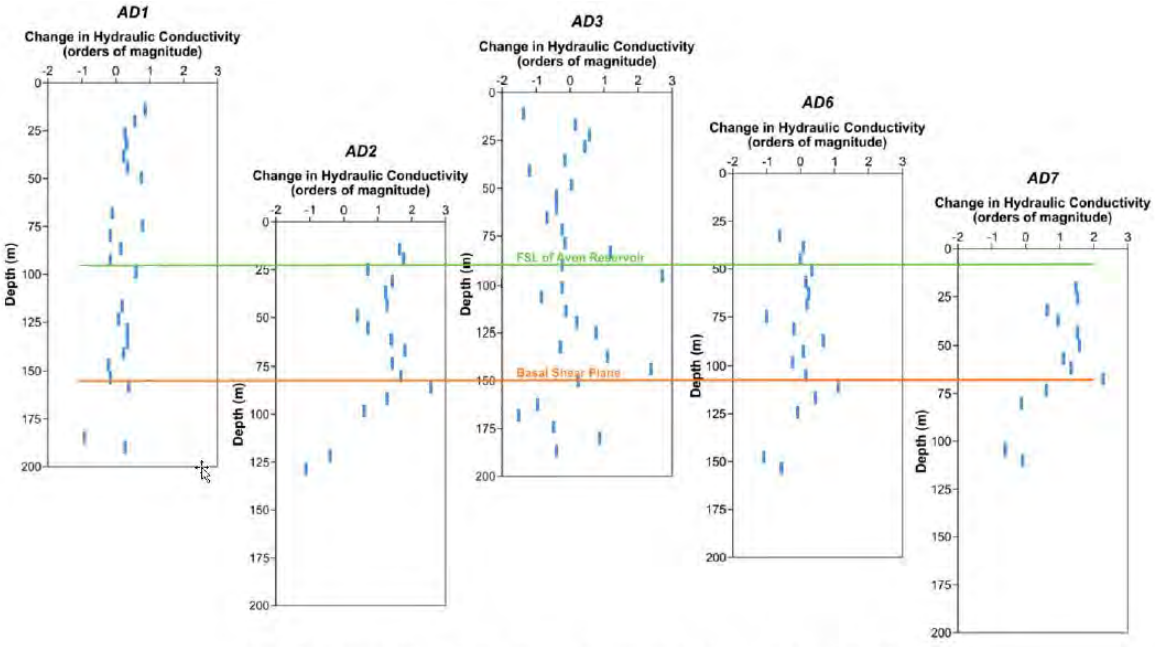



Figure 4: Changes in Hydraulic Conductivity Indicated by Packer Testing Pre to Post Mining

**Figure 6 A) SCT (2015) Basal Shear Conceptual Model and B) Analysis of Kh Changes**

## 2.7 Water Quality

More than 2,740 water samples have been collected and analysed at Dendrobium Mine since 2004, providing an extensive database with which to assess mine water chemistry against baseline surface water and groundwater chemistry. IMC provides regular reports on water quality data and analysis (e.g. HGEO, 2017d), and the following discussion is based on that.

### 2.7.1 Groundwater Quality

Groundwater quality is highly variable depending on the geological unit and sampling depth. A summary of electrical conductivity (EC) data is presented in **Table 2-8**

**Table 2-8 Summary of Electrical Conductivity (EC) Variation at Dendrobium**

| Type | Site Name | Electrical Conductivity (uS/cm) | | | | |
|---|---|---|---|---|---|---|
| | | 5th percentile | Median | 95th percentile | Mean | N |
| Rain | Rain | 72 | 85 | 103 | 86 | 28 |
| Surface Water | Wongawilli Ck (FR6) | 67 | 94 | 130 | 96 | 596 |
| | Donalds Castle Ck (FR6) | 73 | 108 | 149 | 110 | 715 |
| | Sandy Ck | 66 | 87 | 112 | 90 | 124 |
| | Lake Cordeaux | 72 | 94 | 113 | 93 | 249 |
| | Lake Avon | 56 | 70 | 78 | 69 | 67 |
| Groundwater | Hawkesbury Sst | 70 | 123 | 357 | 157 | 275 |
| | Bald Hill Claystone | 153 | 200 | 247 | 200 | 2 |
| | Bulgo Sst | 137 | 400 | 2058 | 557 | 67 |
| | Scarborough Sst | 468 | 550 | 763 | 555 | 109 |
| Pre-longwall seeps | Area 1 seep | 2981 | 3340 | 7907 | 4543 | 7 |
| | Area 2 seep | 876 | 1355 | 1886 | 1310 | 231 |
| | Area 3A seep | 1029 | 2240 | 2791 | 1956 | 58 |
| | Area 3B seep | 829 | 2040 | 3699 | 2130 | 55 |
| Post-Longwall goafs | Area 1 goaf | 1700 | 2350 | 2579 | 2246 | 182 |
| | Area 2 goaf | 1015 | 1560 | 1882 | 1510 | 628 |
| | Area 3A goaf | 738 | 857 | 1223 | 919 | 162 |
| | Area 3B goaf | 1786 | 1930 | 2235 | 1942 | 51 |

As shown in **Table 2-8**, in general, the salinity of groundwater increases with stratigraphic age, reflecting the longer groundwater residence times in the deeper units. The Hawkesbury Sandstone hosts water that is generally fresh (EC < 1,000 µS/cm), with a mixed major ion composition. The relatively fresh nature of groundwater in Hawkesbury Sandstone is indicative of relatively recent rainfall recharge via fracture networks in the weathered zone. Groundwater in progressively deeper stratigraphic units (Bulgo Sandstone, Scarborough Sandstone), becomes both more saline and dominated by Na+ and HCO3- ions. There is a corresponding increase in the concentration of minor and trace ions.

Deep groundwater samples are collected from development roadway roof seepages and mining faces which have not been impacted by the formation of the goaf during mining. Roof seepage samples are considered representative of the Wongawilli seam and adjacent shales. Deep groundwater in the Wongawilli seam is geochemically dominated by Na+ and HCO3- ions, across the three existing mine areas, and spatial variation in salinity (EC) can primarily be related to changes in the concentrations of these two major ions. Spatial variations are evident; the highest salinities are in Area 1 and the western end of Area 3B. Based on data from Area 3B mine workings, the salinity of roof drippers increases from east to west, i.e. fresher near Longwall 20 (EC = 2,000-3,000 uS/cm), and slightly more saline near Longwall 21 (EC = 3,000-4,000 uS/cm).

### 2.7.2 Water Source Discrimination

Background and operational water quality monitoring carried out at Dendrobium to date has shown a number of dissolved constituents that are useful in discriminating ("fingerprinting") waters derived from different sources (HGEO, 2017d). The most useful indicators are:

- Tritium (indicating the average time elapsed since the water fell as rain).
- Electrical Conductivity (EC, an indicator of salinity or total dissolved salts).
- Na/Cl ratio (an indicator of sodium enrichment as a function of aquifer processes).
- Si (dissolved silica derived from weathering of silicate minerals).
- Li, Ba, Sr (minor or trace ions liberated during weathering or dissolution).

Of these, tritium, EC and Na/Cl are identified as the most useful indicators for routine monitoring and reporting. In addition, the Li/Cl ratios allow discrimination of some deep groundwater sources. Tritium typically identifies waters derived from rain within the last ~50 to 70 years (or mixing with a young source). IMC is currently investigating other isotopic tracers such as 14C, 36Cl, 7Li/6Li and 87Sr/86Sr to better understand mine inflow pathways and water-rock interactions.

Analysis of these indicators shows that deeper groundwaters have distinctly different characteristics in terms of dissolved metal ions. The deeper groundwater (e.g. mine seepage) is characteristically higher in minor ions such as Li, Ba and Sr compared to surface water and shallow groundwater (when normalised to chloride). These characteristics reflect long residence times and equilibrium established with the host groundwater minerals. Furthermore, different mine areas can be distinguished using water fingerprinting. Mine seepage and goaf drainage from Areas 3A and 3B have distinctly higher Li/Cl ratios than seepage and goaf water from Areas 1 and 2. This suggests that groundwater parameters within the coal measures are spatially variable and that variability is reflected initially in seepage samples, and subsequently in goaf water compositions.

### 2.7.3 Modern Water in Mine Inflow

Estimates reported in IEPMC, 2018, made via hydrograph separation, from HGEO (2017) and Mackie (2017), indicated up to 78 % or even 90 % of inflow to Area 2 could be due to direct rainfall/surface water ingress. In contrast, for Area 3B contribution is likely much lower than Area 2 based on analysis by HGEO (2018a) of inflow hydrographs that indicated in the past two years 10-20 % of total inflows occurred following rainfall peaks (**Section 2.8**).

Contribution of modern water to mine workings is the subject of further and on-going investigation, as recommended by IEPMC (2018 and 2019a). The site groundwater database currently includes over 700 analyses of tritium, providing an indication of the presence of modern water (<70 years) in any given sample. Analysis of the results is currently being undertaken by HGEO. Initial estimates for Area 3A where Longwall 19 occurs has approximately 11 – 25 % contribution of modern water to mine inflows (HGEO pers. comm.).

In order to simulate and predict the effects of longwalls height of connected fracturing, the groundwater model relies on the conservative position that there is connection from the seam to the surface fracturing zone, as suggested by PSM (2017) for the strata above > 300 m wide longwalls (see **Table 1-1**), and consistent with the recommendations of the IEPMC (2018 or 2019a).

## 2.8 Mine Inflow

Groundwater inflow to the mine workings is inferred from the detailed site water balance that is maintained by the IMC Water Balance Officer at Dendrobium. **Figure 7** presents the mine inflow for each of the four historical areas in relation to the total inflow and to rainfall trends. Each area has a somewhat different character of inflow. These are discussed by various authors (e.g. HydroSimulations, 2016a,b; Mackie, 2017; IEPMC, 2018), with a summary in **Table 2-9.**

**Table 2-9 Summary of trends in mine inflow**

| Mine area | Comment on apparent trends in inflow |
|---|---|
| Area 1 | After two significant peaks correlating to rainfall events in 2007-2008, inflow has been relatively consistent, typically fluctuating between ~200 and ~800 $m^3$/day. Since those early peaks there has been a weak correlation with residual rainfall trends (also identified by Ziegler and Middleton, 2011), with broad inflow peaks delayed by several months. This mild correlation appears to continue into 2016, other than an unexplained peak (up to 1,900 $m^3$/day) in September 2016.<br>** as of September 2016, the flow meter in Area 1 failed, and is no longer operable. Due to the low rate of inflow in this old area, an average inflow (330 $m^3$/d) is reported by IMC.* |
| Area 2 | Highly variable inflow, with a baseline inflow of between ~200 and 1,000 $m^3$/day and peaks of between 4,000 and 9,000 m3/day that are strongly correlated with very large rainfall events, a trend confirmed by the IEPMC (2019). The largest inflow peaks in recent times were 6,400 $m^3$/day (2014), 4,600 $m^3$/day (2015) and 4,500 $m^3$/day (2017). Outside these short peaks the inflow tends to be in the range 500-1,000 $m^3$/day has and that has declined since 2015. Peak inflow is delayed by 8 to 10 days after a significant rainfall event. |

| Mine area | Comment on apparent trends in inflow |
|---|---|
| Area 3A | Inflow increased linearly with area mined during active mining (2010 to 2012). This hydrograph appeared to be more correlated to rainfall, including to individual events, during mining, i.e. Longwalls 6-8 and the first 'half' of Longwall 9.<br>From mid-2012 to 2017 inflows fluctuated between ~1,000 and ~4,000 $m^3$/day, with average inflows correlated with residual rainfall trends. Since 2013 (when mining moved to Area 3B) average inflow has reduced from about 3,000 to 1,050 $m^3$/day (2017), and again further to 700 m3/day in the past year (2019), possibly correlated with recent dry conditions. Recent spikes in inflow (late 2017 and mid-2018) are not well correlated with rainfall.<br>It is possible that the weakened correlation of inflow to rainfall trend in this area from about August 2013 is associated more with the onset of mining in Area 3B, rather than the cessation of mining in Area 3A. |
| Area 3B | Area 3B is the lowest point in the mine (by elevation), lying across the axis of a large syncline, and water naturally drains toward the Area 3B sump at TG9 (Longwall 9). IEPMC (2019a) report that the correlation to rainfall is 'moderate' to 'weak' and we generally agree with this, at least from Longwall 12.<br>HGEO (2018c) noted: *Groundwater ingress to Area 3B has increased steadily since the start of mining (2013), and correlates approximately with the total area mined. However, the overall rate of increase appears to have slowed during the mining of Longwalls 12 and 13, representing a possible departure from the area-inflow relationship, as was seen at Area 3A after Longwall 7.*<br>*As of Longwall 12 there is an apparent correlation between periods of high inflow to Area 3B and periods of high rainfall with a lag time of between two and three months. Peak inflow rates to Area 3B following high rainfall events is 1-2 ML/day higher than during low rainfall periods. The inflow peak that followed the high rainfall event of early 2017 accounts for approximately 20% of the total inflow for the 2017 year. The peak component in 2016 was approximately 12%.* |

Correlation to rainfall trends in Area 3B are possible due to review of hydrograph behaviour. But these are not considered completely definitive when considering the use of chemical methods to assess the relationship to rainfall (**Section 2.7.2** and **2.7.3**).

Based on IMC's mine water balance, the average inflow for each mine area for the 12 months to the end of November 2019 is summarised in **Table 2-10**.

### Table 2-10 Summary of Dendrobium Mine Inflow Dec-2018 to Nov-2019

| Statistic | Area 1* | Area 2 | Area 3A | Area 3B | Total |
|---|---|---|---|---|---|
| Mean | 0.33 | 0.63 | 0.71 | 4.02 | **5.7** |
| Minimum | -- | 0.01 | 0.06 | 0.17 | **0.5** |
| Maximum | -- | 3.90 | 2.01 | 7.18 | **8.2** |

Units in ML/d. *Area 1 flow meter failed in early 2017, therefore this is an average of the historical record.

The total inflow during the past 12-months was approximately 2,075 ML. This is less than the groundwater entitlement currently held for the Dendrobium Mine. The past year's total inflow of 5.7 ML/day is lower than recent years, where inflow during 2017 averaged approximately 7 ML/day.

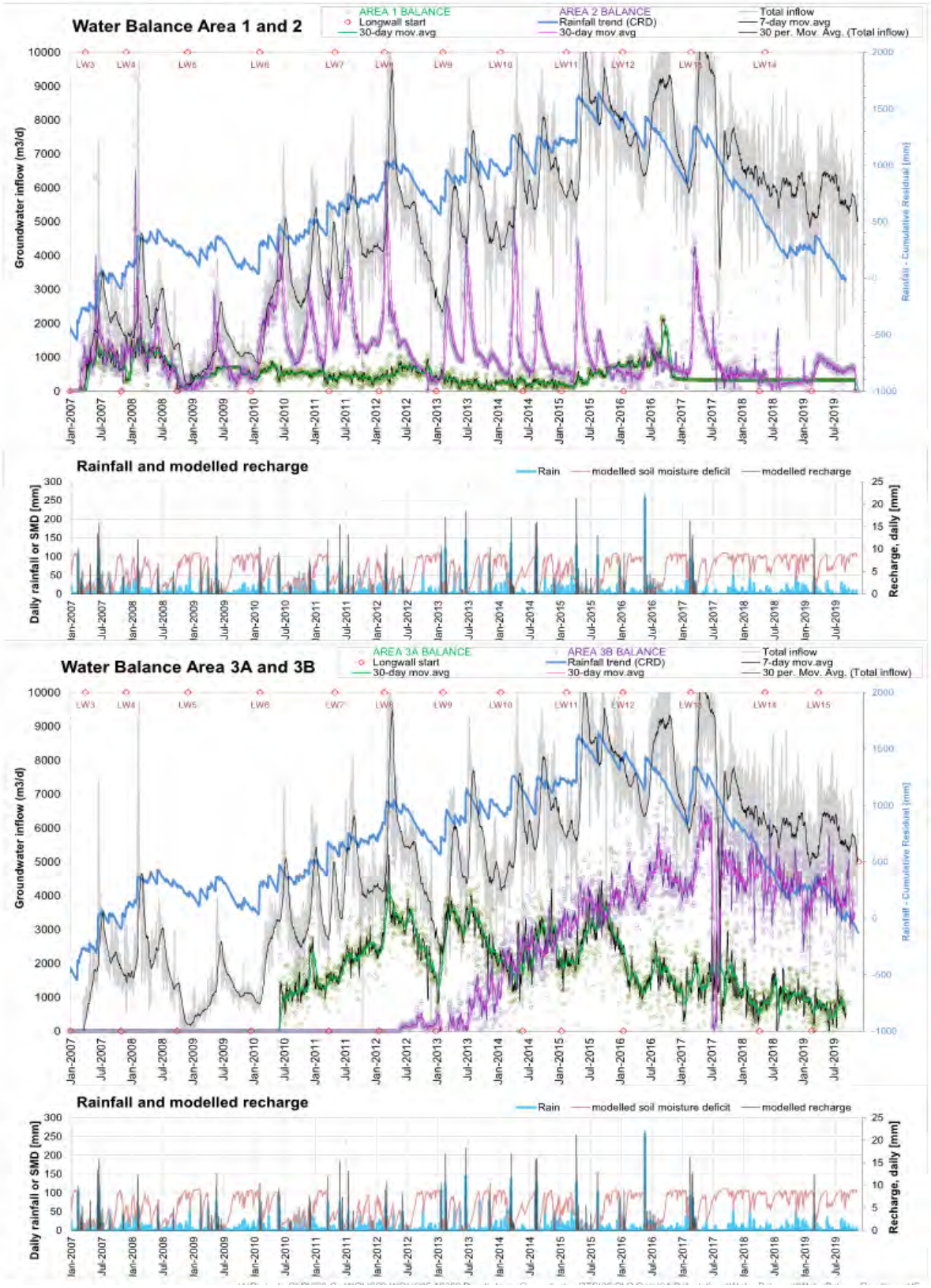



**Figure 7 Groundwater Inflow Trends by Mine Area**

# 3 Hydrogeological Conceptual Model

## 3.1 Effects of Longwall Mining (HydroSimulations 2019c)

The effects of longwall mining reported here have been derived from HydroSimulations (2019c).

To develop roadways and then extract a longwall panel, the coal seams must be dewatered, and this dewatering generally continues during operations to prevent flooding of roadways and longwalls and to maintain air circulation. Dewatering draws groundwater from the surrounding geological strata and potentially from surface water. In regulatory terms, this can constitute capture ("take") from one or more water sources.

After the panels of coal are extracted the overlying strata immediately above the extracted seam collapses into the void (forming the goaf). The strata above the goaf deform and fracture in response, and some level of subsidence can occur at the ground surface.

Subsidence at the surface reduces the volume of material available to offset the extracted coal. MSEC (2017) calculated subsidence of 0.8 m (pillar) and 2.5 m (centre) for the End of Panel report for Longwall 12, with an average subsidence of 1.5 m for a mined height of 3.9 m (about 40%). This creates a void space of 2.4 m (calculated as 3.9 m – 1.5 m). 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. Another conceptual model was provided by the Department of Planning (2008) and other authors have developed similar or alternative conceptual schemes. The zones adopted by HydroSimulations, both in terms of the geomechanical behaviour and groundwater response, are listed in **Table 3-1**.

Based on review of the existing conceptual models (e.g. Booth, 1986 and 2002; Holla and Barclay, 2000; Guo et al., 2007; Mills, 2011; Tammetta, 2012; Ditton and Merrick, 2014), as well as analysis of data from Dendrobium, and discussion between HGEO, SCT, HydroSimulations and IMC, a conceptual model diagram has been developed (**Figure 8**). This is consistent with **Table 3-1** and is based mainly on the geotechnical zones proposed by Mills (2011), but with consideration of other published works. It is likely that in reality, the conceptual zones are not clearly distinguished, and would occur as a continuum with gradual changes between zones.

**Figure 8**, the summary in **Table 3-1**, and the following supporting text in this section describe our 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 8**.

The strata in the connected part of the fractured zone ①② would have a substantially higher vertical hydraulic conductivity⑱ than the undisturbed host rocks ⑤. This would encourage groundwater to move out of rock storage (elastic storage and drainable porosity) and drain downwards towards the goaf ⑬⑭⑮. Fracturing becomes gradually less well-connected (i.e. declining continuity between separate fractures) with increasing height above the seam, tending toward being vertically 'disconnected' ③; Kh increases due to the parting of bedding planes being enhanced more than Kv due to reduced frequency of (sub-)vertical fractures to act as vertical pathways.

### Table 3-1 Conceptual Zones of Deformation adjacent to Longwalls

| Conceptual Zone | | | Mills (2011) | Tammetta (2012) | Ditton (2014) | Geometry |
|---|---|---|---|---|---|---|
| ⑦ | Surface Fracture Zone (i.e. surface cracking) | | | | D-zone | Depth of increased surface fracturing (due to lower depth of cover/confinement) <=20 m, with enhanced horizontal hydraulic conductivity. At Dendrobium, this may occur from the surface down to the Fractured Zone. |
| ③ | Zones of mostly horizontal shear offset from the longwall panel footprint | | | Disturbed Zone | | Offset from goaf, extending approx. 500 m from longwall edge (but subject to ongoing assessment). |
| | Constrained Zone | | Zone of no disturbance (#5) | | C-zone | Based on packer tests, not considered to occur above Area 3B or Area 3A (HGEO, pers. comm.). |
| ③ | Fractured Zone | upper zone of Disconnected Fracturing | Zone of stress relaxation (#4)<br>Zone of bedding plane dilation, some fracturing (#3) | | B-zone | • 1.6 x panel width (W) (Mills, 2011);<br>• B/B95 – Ditton and Merrick (2014). |
| ② | | lower zone of Connected Fracturing | Zone of large downward movement (#2) | Collapsed Zone | A-zone | • 1 x panel width (W) (Mills, 2012)<br>• H – Tammetta (2012) or<br>• A/A95 – Ditton and Merrick (2014). |
| ① | Caved Zone | | Zone of chaotic disturbance (#1) | | | • 5-10 x t (Forster & Enever, 1992; Guo et al., 2007).<br>• 5-20 m (Mills, 2011). |
| | Mined Zone (extracted seam) | | | | | Mined seam thickness (t) listed in **Section 1.1**. |
| ⑧ | Buckling/heaving of 'floor' strata, caused by unloading after panel extraction (Meaney, 1997; Karacan et al., 2011) | | | | | Assumed to be in the order of 10-30 m. |

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

As a result, the vertical movement of groundwater would be enhanced but may not be significantly greater than under natural conditions ⑫. This is borne out by observations:

- at the Tahmoor Longwall 10A "HoF" (height of fracture investigation) borehole (SCT, 2014), it was clear that a downward gradient existed in the lower Hawkesbury Sandstone, but the vertical connectivity was not sufficient to alter groundwater levels in the mid/upper Hawkesbury Sandstone to any observable degree; and
- at Dendrobium, where water levels in shallow strata have been more affected than those at Tahmoor Longwall 10A, but positive pressures can still be maintained in the shallow strata, indicating an indirect connection (or a slow or low transmissivity pathway) to the fractured zone and goaf. That is, any fracturing below is insufficiently continuous or connected, or insufficiently transmissive, to cause drainage of groundwater from the upper zone via recharge or other sources.

At distances exceeding approximately 500 m from the mine, strata are assumed to be relatively unaffected ⑤, although minor enhancements to Kh may arise at specific horizons due to shearing along bedding planes. This enhancement is considered more likely in the upper parts of the strata offset from longwalls; in the lower sections above chain pillars the compression of overlying strata ⑥ is likely to restrict the potential for secondary porosity to develop, and may even reduce Kh in these areas.

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. some degree of fracturing is observed through the sequence above these longwalls.

In the surface 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 near to the subsidence trough.

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, 2017a).

Surface fracturing is likely to result in persistent or permanent changes to hydrology ⑨, such as WC21 ceasing to flow during recession periods. Leakage of water into the surface fracturing zone can result in effects on water quality (McNally and Evans, 2007).

Surface water flow that is redirected into and through near-surface fractures ⑨ may either be returned to surface drainage somewhere down-gradient ⑩, (in which case the net loss from the catchment is minimal), migrate downwards towards the goaf ⑬, or some combination of both. IMC are monitoring water flows and planning tracer tests to further investigate this behaviour. Recent analysis (**Section 2.1**) indicates that the return of surface flows is very plausible, i.e. this appears to be occurring in the Donalds Castle Creek catchment, despite significant localised flow reductions immediately above extracted longwall panels.

The strata movements and deformation that accompany subsidence would alter the hydraulic and storage characteristics of the host strata. 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 (Tammetta, 2016).

Fractures that are directly connected to the goaf would rapidly depressurise and form a pathway for seepage of pore water downwards towards the goaf. This does not mean that these areas contain no groundwater, but that there can be free drainage through the cracks and 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.
The zones of enhanced K, i.e. the deformation zones ①②③⑦, above the mine void/goaf on **Figure 8** is a schematic representation of monitoring data of post mining strata conditions at Dendrobium Mine and the conceptualised 'likely' case for the remainder of Area 3B. There are a number of models for estimating the height of the zone of connected fracturing (discussed briefly in Section 2.7, PSM (2017)). There are also methods and schemes for estimating change in K (e.g. Tammetta, 2014; Guo et al., 2007), and both height and K are tested during groundwater model calibration (**Sections 4.5 to 4.6**).

Basal shear planes ④, as identified in the analysis of Walsh et al. (2014) and SCT (2015), can extend laterally in strata at an elevation of or just beneath the base of incised valleys. These features can be natural or a result of or enhanced by mining subsidence. It is possible that shear planes may act as a conduit for groundwater flow ⑪, and that these might enhance horizontal connection between watercourses and waterbodies (specifically the Avon and Cordeaux Reservoirs) with the fractured zone extending upward from the longwall goaf, therefore potentially providing a rapid and transmissive pathway for surface water to enter the mine. It is unclear at what distance such shear planes might be able to connect a valley, including a reservoir, with the fractured zone above the goaf. However, data from Sandy Creek indicated that shear planes were mobilised when Longwall 8 was some 670 m from the valley (Walsh *et al*., 2014), so conceptually there may be connection when the longwall edge is about 600 m from a watercourse or reservoir.

More recent testing at the Lake Avon monitoring bores (see SCT, 2015; HGEO, 2019b), did not consistently detect such shear zones (i.e. highly permeable discrete zones) in the pre- or post-mining strata. SCT detected one at S2314, although "it is not considered to be a significant conduit for flow from the reservoir into the mine" (SCT, 2017). The development and/or enhancement of shear planes resulting from mining is the subject of ongoing research at Dendrobium.

Aside from the discrete basal shear features ⑪, there is potential for the modification or enhancement of Kh ④⑱ beyond the mine footprint. The extraction of a longwall results in the collapse and subsidence of overlying strata, causing both vertical and horizontal movement of overlying and nearby strata. Outside the longwall footprint, where such horizontal movements occur, the effect can be an enhancement of Kh through horizontally-bedded strata, especially in areas where the topographic relief is such that parts of the landscape (strata) are not supported or buttressed against such horizontal movements (SCT, 2015). Hydraulic conductivity testing at bores located between Area 3B longwalls and Lake Avon suggests that Kh might be enhanced 2-3 times, or more, the host (pre-mining) value (~0.3 log units) (**Section 2.6.5.1**). However, this is not definitive and possibly not significant as often the post-mining permeabilities measured at Lake Avon monitoring sites have been within the expected range of (pre-mining) Kh.

While the degree of enhancement of Kh in areas offset from a longwall is unclear and subject to on-going research, it is considered prudent that the effects of an increase in Kh are modelled (Section 4.5.3). The distance from the longwall footprint that this effect occurs is not clear – bores S2313-S2331 are approximately 80 m from the nearest longwall edge. For the purpose of modelling, HydroSimulations has assumed that this effect could occur with declining significance to about 600 m from the edges of the longwall footprint.

Within the mine workings, 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 and beneath 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 8**) 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 connection to the surface (**Sections 2.7.3)** 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 is significantly greater (median = 365 m), such that the 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. Depth of cover at Longwall 19 is similar to that of Area 3B, at about 350 m.

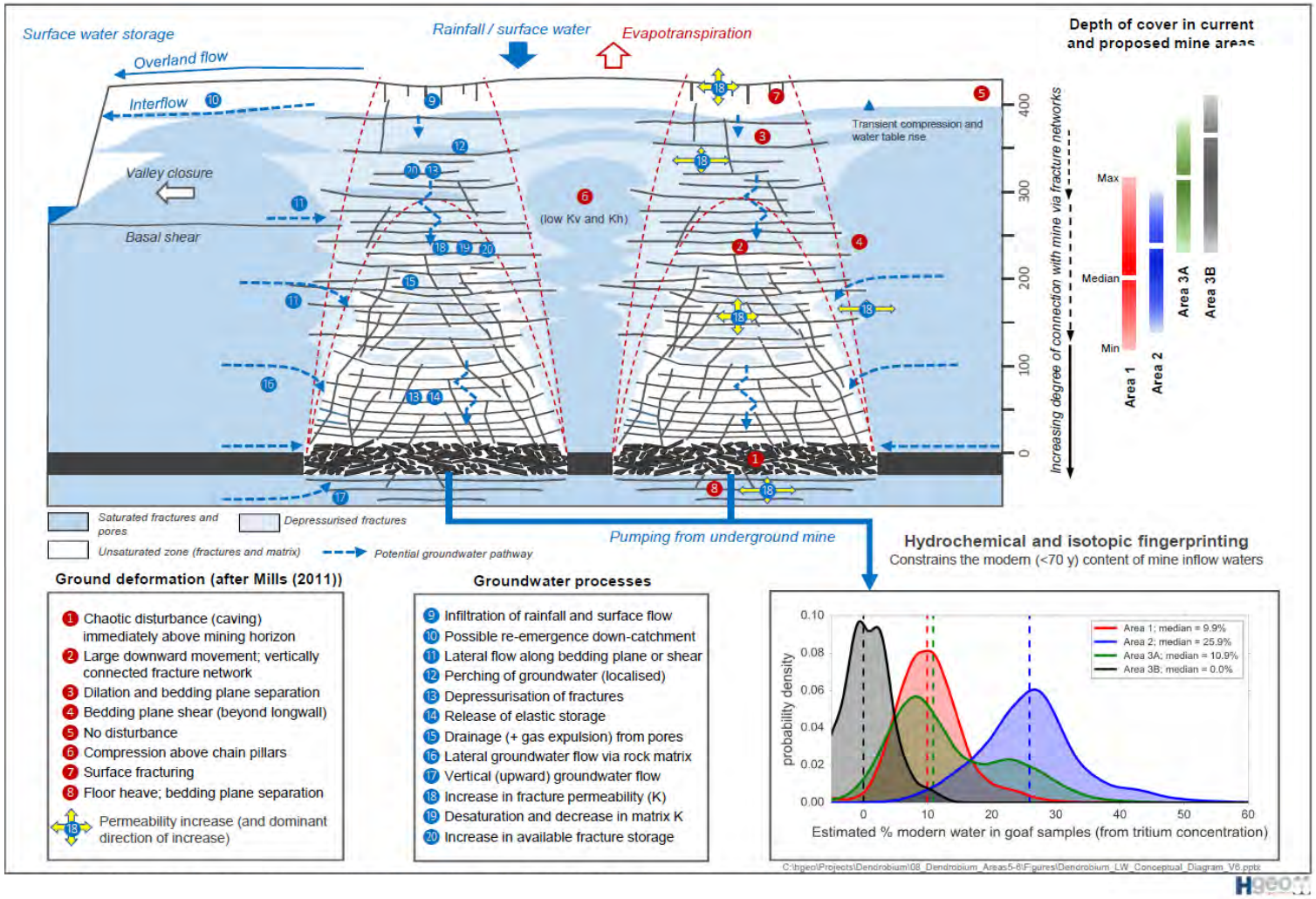



**Figure 8 Conceptual Model: Geotechnical and Hydrogeological Effects of Mining**

## 3.2 Influence on Groundwater Levels

In general, the greatest drawdown effects occur in the strata 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, and into the lower Hawkesbury Sandstone. 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 disconnected ③), the degree of drawdown becomes less towards the surface. Drawdown in the mid Hawkesbury Sandstone is about 10-20 m, and in the shallower horizons of the Hawkesbury Sandstone it has been observed to be <5 m (e.g. at S2192-S2220 directly overlying Longwall 9).

Drawdown in Hawkesbury Sandstone decreases with distance from the extracted panels to approximately 5-10 m at a distance of 1 km from the longwall (based on observations in HydroSimulations (2014b) or review of DEN131-S2009). Deeper in the sequence, e.g. the Bulli Seam, the 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.

There are no areas in the Dendrobium Mine where inflow has ceased, although Area 3A currently appears to be declining linearly toward 0.5 ML/d. It is expected that drawdown would persist until inflow ceases, and the mine re-fills and an equilibrium is re-established. 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.

## 3.3 Effects of Structure: Lineaments

Geological structures are mapped on **Figure 2** and discussed in **Section 2.3.**

At Dendrobium, lineaments are rarely successfully correlated with a structural feature (fault, dyke) at seam level. Further, they have not caused difficulties to mine operations at Dendrobium, nor are mapped lineaments known to interact with water features (e.g. swamps, waterfalls) in a manner that suggest they exacerbate the risk of mining to such features or exacerbate the distance to which impacts manifest themselves (**Section 2.1**).

For reasons noted in Hebblewhite (2019), the Western Coalfield is different to the Southern Coalfield, and the experience at Dendrobium is different to that identified by IEPMC (2018 or 2019a) at Springvale Mine. MSEC (2019) has indicated that subsidence anomalies along or around lineaments are obvious at Springvale Mine (in the Western Coalfield), with LiDAR mapping showing up to 30% more subsidence along these features, but that this behaviour is not evident at Dendrobium.

Therefore, based on current data, there is no need to explicitly represent such features in the regional groundwater model. However, if the extraction of these panels is approved, then there will be more investigation of geological conditions, including structures, by IMC, and further knowledge can be incorporated into modelling as required.

# 4 Groundwater Model

This section briefly describes the key aspects of the model used for this assessment of Longwall 19. Some changes have been made to this model that makes it not directly comparable to the groundwater model utilised in the Longwall 17 and Longwalls 20 and 21 Groundwater assessments (HydroSimulations, 2019a and 2019b). Namely, these modifications include changes to the simulation of drain boundary conditions used to represent the height of connected fractures above longwalls and increase in the horizontal hydraulic conductivity within the Bulli and Wongawilli Coal Seams and some areas of the Hawkesbury Sandstone. These changes are discussed below in **Sections 4.5.1** and **Section 4.7**.

As noted previously, another different groundwater model has been developed for the recent Dendrobium Extension EIS (HydroSimulations, 2019c). That model is not used for this work. A decision was made to continue with the model previously used for Area 3B and 3C because of the existing workflows and to maintain greater similarity with recent SMP applications. Elements of the HydroSimulations (2019c) model have been used to revise the Area 3B model.

## 4.1 Model Mesh

The MODFLOW-USG model mesh or grid is identical to that of Coffey (2012), with resolution varying between 50 m and 215 m (finest resolution in Longwalls 13-18 and nearest Lake Avon). There are 239 rows and 225 columns in the mesh, giving a total of 53,775 cells per layer. The active extent of the model is shown on **Figure 3**.

IEPMC (2018 and 2019a) noted that the migration to an 'unstructured' model mesh in MODFLOW-USG had 'stalled'. The development of an unstructured model was completed in HydroSimulations (2019c) but the structured mesh model has been employed here for easier comparison against recent Area 3B and 3C SMP applications.

## 4.2 Model Geometry and Hydrostratigraphy

**Table 4-1** and **Figure 9** present the model layering and stratigraphy adopted in this project. This is the same as that used for HydroSimulations (2018). The geological layering within the model is based on the geological model supplied by IMC which is defined by hundreds of exploration drill logs. As noted in HydroSimulations (2018), an additional model layer was added in 2017-18 to better accommodate the swamps at the surface above the Hawkesbury Sandstone or Narrabeen Group units.

There is a total of 914,175 cells, of which 501,447 are active. The MODFLOW-USG is written to taken advantage of the fact that only the 'active' nodes are written by Groundwater Vistas to the MODFLOW input files – the model layers do not have to be extensive across the entire model domain.

## Table 4-1 Model Layer Assignment

| Layer | Stratigraphy | Secondary Lithology | Comment |
|---|---|---|---|
| 1* | Swamps | | Uniform 2 m thickness |
| 2 | Hawkesbury Sandstone (upper) | Swamps | Mean thickness 80 m |
| 3 | Hawkesbury Sandstone (middle) | Swamps | |
| 4 | Hawkesbury Sandstone (lower) | Swamps / Crinanite | Mean thickness 25 m |
| 5 | Bald Hill Claystone | Garie/Newport Formations / Swamps / Crinanite | Mean thickness 20 m |
| 6 | Bulgo Sandstone (upper) | Crinanite | Mean thickness 40 m |
| 7 | Bulgo Sandstone (lower) | Crinanite | Mean thickness 74 m |
| 8 | Stanwell Park Claystone | Colo Vale Sandstone (Area 3B and west) / Crinanite | Mean thickness 10 m |
| 9 | Scarborough Sandstone | Crinanite | Mean thickness 38 m |
| 10 | Wombarra Claystone | Crinanite | Mean thickness 27 m |
| 11 | Coalcliff Sandstone | Wombarra Formation (Area 3B and west) | Mean thickness 15 m |
| 12 | Bulli Coal Seam | | Mean thickness 3 m |
| 13 | Lawrence & Loddon Sandstones | | Mean thickness 27 m |
| 14 | Wongawilli Coal Seam | | Mean thickness 21 m |
| 15 | Kembla Sandstone | | Mean thickness 53 m |
| 16 | Lower Permian Coal Measures | | Mean thickness 167 m |
| 17 | Shoalhaven Group and older | | Mean thickness 250 m |
| *swamps simulated in model Layer 1 or the uppermost active layer | | | |

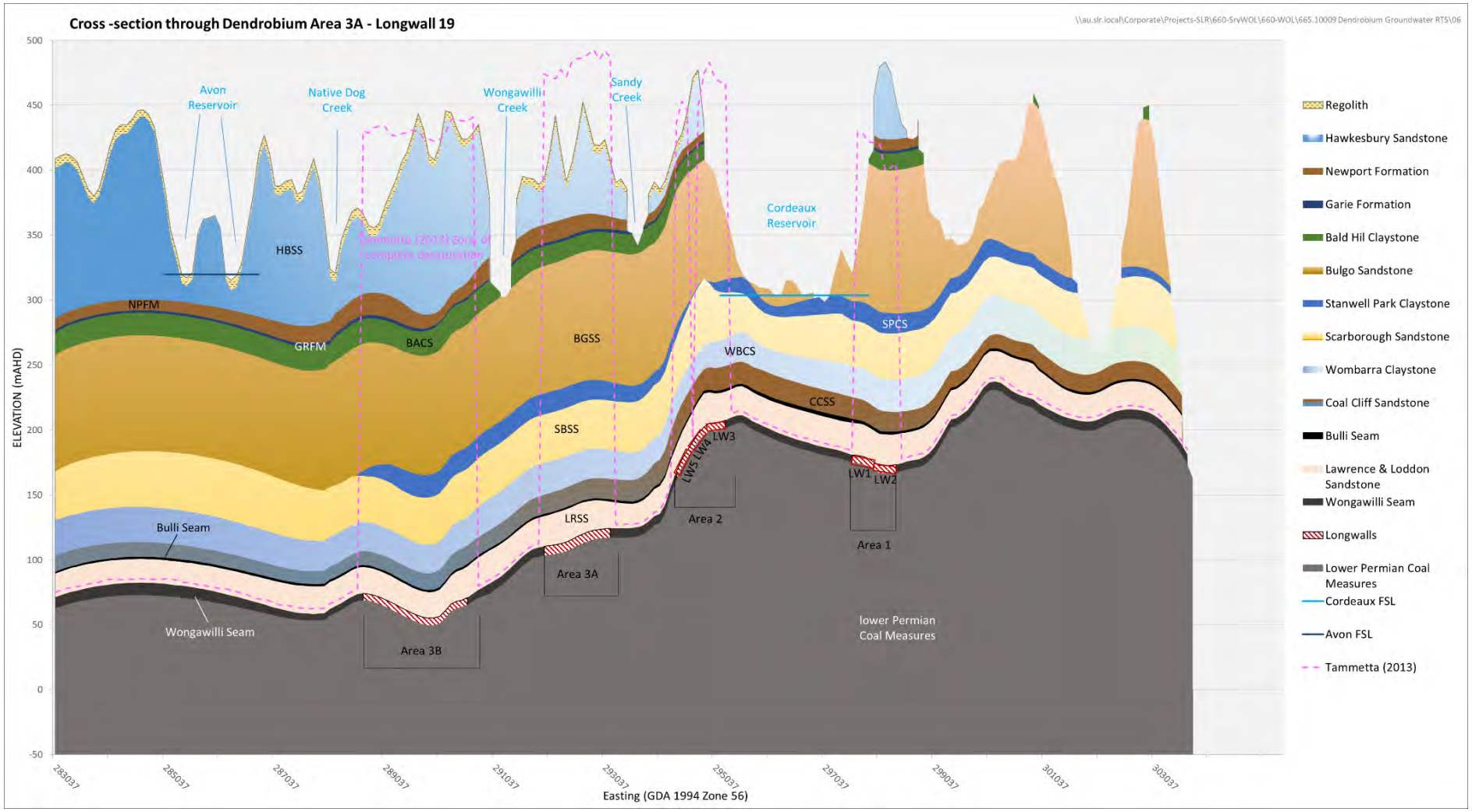



**Figure 9 Geological Cross-Section Through Dendrobium Mine**

## 4.3 Model Temporal Discretisation

The temporal discretisation is the same as in the Longwall 17 and Longwalls 20 and 21 groundwater models (HydroSimulations, 2019a, 2019b). The changes to the HydroSimulations (2016) discretisation included the addition of more 'stress periods' in order to better represent longwall progression. This has allowed the simulation of progressive extraction for Longwalls 13-21 with extraction of each of those longwalls across 3-4 stress periods. A table outlining the temporal discretisation is shown in **Appendix A**.

Furthermore, to capture the dynamics of very high rainfall periods, such as those leading to the 'inflow' events observed in Area 2 (**Section 2.8**), the key events have been identified and a series of shorter stress periods defined. These stress periods are designed to capture the intense rainfall event (e.g. a period of a few days or a week), the following period where the main inflow is measured, and then the recession period after that. Fifteen such high rainfall/inflow sequences or events are included in the model time period (**Appendix A**).

The third change to the model timing was in relation to SMP Condition 16 (**Table 1-3**), requiring model estimates of incidental baseflow capture for regular intervals to a point 30-years post-mining.

The downside to capturing this detail is a longer set of stress periods: 199, compared to 90 in the HydroSimulations (2016) model (for Longwall 14-15) to cover a similar total period, resulting in large model input and output files and longer model run times.

## 4.4 Boundary Conditions

Almost all the boundary conditions remain identical to the HydroSimulations (2018) model. A summary of the boundary conditions is presented below, with emphasis on any changes.

### 4.4.1 Lakes – 'River' Boundaries

'River' boundary conditions have been employed to represent the reservoirs, as in Coffey (2012) and HydroSimulations (2014). The historical record of water levels in the Avon and Cordeaux Reservoirs has been employed, as in HydroSimulations (2016a), but updated to include more recent data.

### 4.4.2 Watercourses

As in HydroSimulations (2018), River boundaries have been employed to represent watercourses. The River package included variable stream stages, based on a timeseries of runoff from the water balance model (**Section 4.4.4**), for simulating gaining/losing conditions.

Watercourses were previously simulated (HydroSimulations 2014, 2016a) using the MODFLOW 'Stream-Flow Routing' [SFR1] package (Prudic *et al*., 2004). The River package was used instead because it increases the speed of the model simulation and assisted with the priority given to incorporating the off-goaf and surface cracking processes and the long model testing/calibration process. IEPMC (2018) also noted that the approach of using the River package is appropriate.

### 4.4.3 Recharge

The MODFLOW Recharge (RCH) package is used to simulate diffuse rainfall recharge, as per previous modelling. As in HydroSimulations (2016a, 2018), temporal variation in rainfall recharge 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.

The water balance model has been calibrated to match estimates of average or long-term recharge obtained from a number of literature sources as discussed in **Section 2.5**. The average recharge as calculated by the water balance model for the areas of rock outcrop is equivalent to about 7 % of long-term average rainfall. As discussed in **Section 2.5,** recharge to the Hawkesbury Sandstone is within a range of 0-8.5% of LTA rainfall (Advisian 2016). Within the groundwater model, recharge is zoned in the model in a similar fashion to that in Coffey (2012) and HydroSimulations (2014, 2016a), based on average rainfall declining from the coast/escarpment to the northwest.

Estimates of rainfall recharge to the basal sands and gravels within swamps are not available but are conceptualised as being significantly more than that to the rock outcrop. As a result, the water balance model for the swamp areas was set to produce a timeseries of recharge of about 330 mm/year, equivalent to 25-30% of long-term average rainfall.

#### 4.4.3.1 Enhanced Recharge Above Longwalls

Conceptually, the presence of subsidence cracking at the surface and increased permeability/porosity in near surface strata could lead to increased infiltration of rainfall to shallow groundwater systems above and around the footprint of longwalls (McNally and Evans, 2007; Advisian, 2016).

The issue with modelling this process is that the degree of enhancement is unknown. HydroSimulations is not aware of any estimates of the increase in recharge. HydroSimulations inspected water quality and water level data from bores to assess whether freshening or increased water table rise were discernible in shallow groundwater, and whether this would allow some quantification of any change. Such freshening was not discerned within the electrical conductivity dataset. While inspection of water table fluctuation does show changes in the post-mining environment, the fluctuation of water tables is governed by recharge, porosity and permeability, and it is likely that all of these parameters are modified by longwall mining, making it difficult to quantify.

During the model calibration process in HydroSimulations (2018), HydroSimulations tested infiltration recharge being enhanced by 2-5 times (i.e. 12-30% of long-term average rainfall) for the area above extracted longwalls. The impact assessment models presented in this assessment (**Section 4.8**) use a factor of 2.5. There is uncertainty about the magnitude of this conceptual process.

### 4.4.4 Evapotranspiration

The water balance model described in the previous section also provides estimates of evapotranspiration in the soil zone, and whether there is an excess of potential evaporation on each day during the sequence. The excess evaporation is then averaged across model stress periods and applied to the MODFLOW model via the Evapotranspiration 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.

In previous modelling, rooting depths ('extinction depths') were set at 1.9 m for swamps (which aligns with swamp sediment depth data) and 3-6 m for other areas. Based on information in SMI Environment Centres (2019), the vertical extent of roots within swamp deposits is likely to be shallower, in the range of 0.4-0.8 m, and so 0.8 m has been adopted in the revised groundwater model. The extinction depth for the treed areas is lower than in HydroSimulations (2016), based on calibration to shallow groundwater levels.

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

## 4.5 Modelling of Deformation and Fracturing

Within groundwater models, simulation of mining-induced changes to the hydraulic properties of rock strata within and above the mined zone has typically been limited to simulating the connected fracture zone. The three methods for simulating the connected fractured zone in groundwater models known to HydroSimulations at the time of preparing the original groundwater model that the model presented here has been adapted from are discussed in **Section 4.5.1**.

Additionally, other zones and mechanisms are simulated in this groundwater model, based on conditions of approval (**Section 1.3**, **Table 1-3**) and the DPE study (**Sections 2.6.3** to **Section 2.6.5**), and the representation of these is discussed in **Section 4.5.2**.

All the methods tested, and the combination of methods for different processes, have some weakness, either in conceptual terms or with software or practical ability (e.g. model stability, model performance). This is not to say that these hurdles cannot be overcome in the future, although model practicality is an important requirement.

### 4.5.1 Zone of Connected Fracturing

The development of a network of fractures extending up from the longwall as a result of mining subsidence is typically simulated in three ways, as tabulated below. The Part 2 Report of IEPMC (2019b) contains a similar summary (in Section 3.3.1 of that report), also describing the strengths and weaknesses of each method.

### Table 4-2 Typical Methods Used to Simulate Fracturing

| Method | Description | Advantages | Disadvantages |
|---|---|---|---|
| Time-varying hydraulic properties | Time-varying material properties (within the MODFLOW TVM or TMP packages) can be used to simulate the zones of fracturing and deformation within mine workings and the other fractured zones above longwall panels. Specifically, this package is used to increase hydraulic conductivity (horizontal – Kh and vertical - Kv) as well as storage properties (Sy) due to mining. Changes to specific storage (Ss) are also possible. | The main advantage of this method is that it represents the change in permeability and porosity properties, and the degree of enhancement of these properties can be calibrated by using mine inflow and heads. This then allows a more 'seamless' simulation of the longwall extraction phase, the period after that when mine workings remain dewatered, and the post-closure period. | Requires a method for estimating/calibration Kh, Kv and porosity properties.<br>Model stability is frequently an issue, especially if using pseudo-soils or upstream weighting numerical methods. Models where the height of the connected fracture zone is relatively low compared to overburden thickness seem to be more stable.<br>Some practitioners do not like the idea of simulating the fracture network as an equivalent porous medium governed by Darcian flow. |
| 'Stacked Drains' | A set of Drain boundary conditions are set through the strata above longwall panels to represent the depressurisation and drainage of groundwater in this zone.<br>The Drains are set in each model layer up to a user-specified height, with conductance terms used to represent permeability.<br>The Drains are activated as each longwall is extracted. The Drains could be left active into the future to provide conservative estimates of the effects of the mine on the catchment water balance, or can be inactivated when mine dewatering ceases. | This method does not require an estimate of enhanced permeability or porosity to be made, although some would argue that the conductance term needs to be estimated.<br>Models using this method tend to be significantly faster and more stable than those employing the other two methods. This is an important factor in the subsequent use of this method in this study. | This method is a short-cut, in that it fixes the groundwater pressures within a user-specified zone, rather than allowing the numerical model to simulate groundwater pressures in response to changes in permeability and porosity. Changes to hydraulic properties may still need to be simulated using another method, in conjunction with the 'Stacked Drains'.<br>Because this method fixes groundwater heads, it does not allow groundwater pressures to build up in the goaf and fractured zone after mine dewatering has ceased, unless the 'Stacked Drains' are removed altogether. Because of this weakness in honouring the conceptualised changes in hydraulic properties, this method must be replaced with one of the other two methods to more appropriately simulate the long-term recovery of the groundwater system. |

| Method | Description | Advantages | Disadvantages |
|---|---|---|---|
| Connected Linear Networks (CLN) | CLNs are a feature of the most recent versions of MODFLOW, and allow a discrete conduit with a size independent to the main model grid, to be represented.<br>CLNs can be used to simulate horizontal, vertical and angled conduits. This method was employed in HydroSimulations (2016a) to simulate the vertical conduits connecting the mined seam to the overlying strata. | The chief advantage is that it can simulate the interaction between the two conceptualised flow domains – the host strata in the groundwater model cells and the fracture network developed through the strata.<br>Like the time-varying properties method, this method should be applicable to both active mining and post-closure period. | Requires estimates of geometry of the CLN. Each CLN should represent the bulk volume of connected fractures, but that is a difficult parameter to estimate, as is the conductivity of the conduit.<br>Model stability was an issue in HydroSimulations (2016b), although less so in the testing conducted in this phase of work. |

For the modelling, two rules have been applied to carry out a conservative impact assessment, as per discussion with the model Peer Reviewer (Dr. Frans Kalf of Kalf and Associates) in 2018. These were that:

- The Tammetta (2012) empirical model has been used to estimate the height of connected fracturing for all modelled longwalls, based on the local conditions (panel width, depth of cover, cutting height). The Tammetta model has been used as it is typically the more conservative (Galvin, 2017b); and
- Seam-to-surface connection has been enforced for all model cells that lie along the centre-line of any 305 m wide panels (**Table 1-1**), consistent with the interpretation by PSM (2017) for Longwall 9.

The resultant modelled profile of seam, surface and the height or depth of the main fracturing zones are shown in **Appendix C**. There are areas where the Tammetta H will intersect the surface cracking zone or ground surface, even without the imposition of seam-to-surface fracturing for the 305 m wide longwalls.

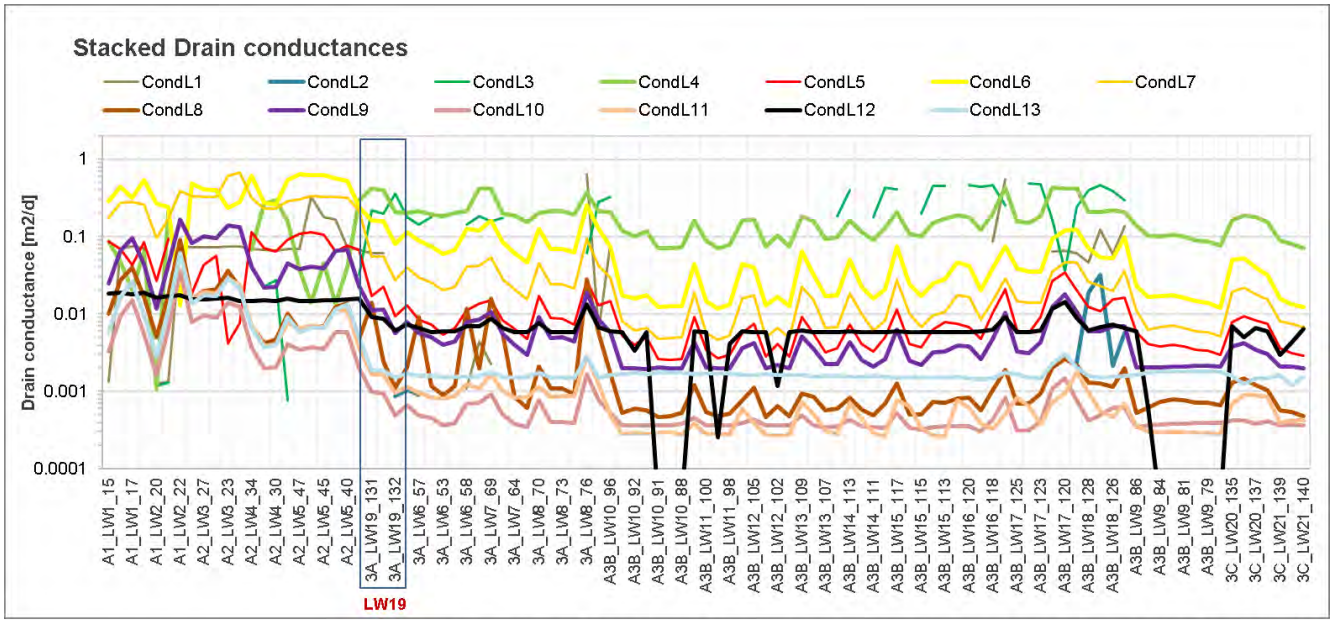
The chief issue encountered in this project is that while each method could be calibrated to inflow during the active longwall extraction phase in each separate mine area (see discussion in **Section 4.6.4**), all methods struggled to match the period after longwalls had been extracted but while dewatering still occurs. Specifically, the very peaky inflow to Area 2 (after Longwall 5) and muted peaks in Area 3A (after Longwall 8) were difficult to simulate – as a result of the time taken to achieve the current degree of calibration, the 'Stacked Drains' method has been employed because model run times are about half that of other methods, the model is much more stable, and because early on it gave better results for matching the peakiness of Area 2 inflows. Discussion with the Peer Reviewer has confirmed that the use of 'Stacked Drains' to simulate the connected fracture zone should provide a conservative impact assessment.

#### 4.5.1.1 Drain Conductance

In previous versions of the Area 3B/3C model (HydroSimulations, 2018; 2019a; 2019b) the 'Stacked Drains' have been set with a conductance that declines with height above the mined seam, with conductances varying, as a result of calibration, from 13 above the seam down to 2 $m^2/d$. As part of the modelling for the Dendrobium Extension EIS, HydroSimulations (2019c) describes 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), with inputs to this method being obtained from review of SCT's FLAC2D modelling of 305 m wide longwall panels. This is consistent with the recommendations and discussion in IEPMC's Part 1 and Part 2 reports (IEPMC 2019a, 2019b).

Full details of the calculations are available in HydroSimulations (2019c). As part of the update to the model used in this groundwater assessment, the stacked Drains conductances as calculated for HydroSimulations (2019c) have been transposed directly into this model. That is, those estimated for Longwall 19 in HydroSimulations, 2019c are applied to the various sections of Longwall 19 in this model, and similarly for the other Area 1, 2, 3A, 3B and 3C longwalls.

Drain conductances calculated in HydroSimulations (2019c) and now used in this model are summarised in **Figure 10**. The X-axis shows Mine area (e.g. Area 1, 2, 3A, 3B, 3C), longwall ID (e.g. Longwall 1, Longwall 19) and then a number used to group sections of each panel. Each panel is typically broken into three or four such sections for this purpose.




E:\DENDROBIUM\Model\GWModel\Construction\FracZone\[FracZone_DND4v71_Dend_StackedDRNs_Tammetta_IwrBUSM.xlsm]FIGURE

**Figure 10 Model 'Stacked Drain' Conductances Used to Simulate Connected Fracturing**

More discussion of the effect of this change on model calibration is presented in **Section 4.6.4**.

### 4.5.2 Surface Cracking Zone

The simulated surface cracking zone depth was set at 10 x longwall cutting height (t) above longwall panels (**Section 2.6.4**). This means that the surface cracking zone above Dendrobium is simulated as being about 34 m (Area 1), up to 45 m (Longwalls 10-12) in Area 3B, and about 39 m for proposed Longwall 19 in Area 3A (**Appendix C**). There will be some difference in the model application given the granularity (thickness) of model layers compared to the scale of 10 x t.

This representation of the surface cracking zone was set as having a horizontal hydraulic conductivity as 3 times that of the host material and vertical hydraulic conductivity that is 50% greater than the host strata. Higher factors were initially tried during model calibration, and these resulted in less peaky inflow hydrographs. It is hypothesised that higher factors could be used successfully in conjunction with lower 'host' (natural) hydraulic conductivities, although this should be tested after the recommended further analysis of hydraulic conductivity (see Recommendations, Section 7.1).

### 4.5.3 Off Goaf (Valley Closure and Strata Deformation)

This has been simulated by increasing horizontal hydraulic conductivity of the strata between the longwalls and the nearest 'deep' valley (**Figure 6**). This has been done by selected model cells within a certain distance or buffer (less than 100 m from the longwall, less than 300 m and less than 600 m) and assigning a Kh value or Kh multiplier to each buffer area, with the multiplier declining with distance from the longwall. The modelled timing of the permeability enhancement is simplistic, with the enhancement due to a group of longwalls being imposed at one time, e.g. Longwalls 9-13 are imposed in stress period 106, while Longwalls 14-15 are imposed in stress period 117. It could be possible to improve this in the future.

Initially, the factors selected were x15, x5 and x3, however given the issues during calibration to do with enhanced permeability flattening the inflow hydrograph, the model was then run using factors of x4, x3 and x2. Subsequently, HGEO (2018b) revised the estimate 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, and so an absolute value of 5E-2 m/d was simulated for cells lying within 300 m, with multipliers of x2 used beyond 300 m. The Kh value for the zone closer than 300 m has been increased slightly to 6E-2 m/d for this current study, based on additional data presented in HGEO (2019b), as described in **Section 2.6.5.1**. Kh enhancement is simulated in the strata from the base of the nearest valley, e.g. in the lower Hawkesbury Sandstone around the Lake Avon shoreline west of Area 3B or along Wongawilli Creek around Longwalls 20 and 21, and above.

### 4.5.4 Underlying (Floor) Strata

Deformation (buckling) in floor strata is caused by unloading. This has been simulated with a horizontal hydraulic conductivity factored up to 5, and vertical hydraulic conductivity increased by a factor of 2. This has been applied to the model layer immediately below the mined seam.

### 4.5.5 Distribution of Increased Porosity

The extraction of the longwall results in an increase in porosity in the subsurface (i.e. removal of 3.9 m of coal). As discussed in **Section 3.1**, subsidence at the surface reduces the volume available. MSEC (2017) calculated subsidence of 0.8 m (pillar) and 2.5 m (centre) for End of Panel for Longwall 12. This equated to an average subsidence of 1.5 m for a mined height of 3.9 m, creating a void space of around 2.4 m. The subsequent deformation in the strata between the seam floor and the surface results in some re-distribution of that porosity through the sequence. For example, with a depth of cover of 350 m, the average increase in porosity can be calculated at 0.7 % (calculated as 2.4 m / 350 m). Most of this increase in porosity would apply at depth.

Advisian (2016) made the following summary: “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).

In the current model, the Sy increase has been concentrated on the mined seam, the caved zone and the lower parts of the connected fractured zone, as outlined in **Table 4-3**. **Table 4-3** shows good agreement between the ‘calculation’ of void space created and the example distribution of void space in the groundwater model. It is acknowledged that porosity can be created or enhanced higher in the profile, and possibly in a non-systematic fashion (e.g. as in PB, 2015). However, it is assumed most of the Sy enhancement will occur in the zones near the mined seam (as per Advisian, above) and that as long as the model approximates the total porosity enhancement, then the role of this in delaying the recovery of groundwater levels should be taken into account.

**Table 4-3 Modelled Enhancement of Porosity / Specific Yield**

| Modelled Porosity Enhancement | | | | | |
|---|---|---|---|---|---|
| Layer | Thickness* | Host | | Post-Mining | |
| | | Sy | Void (m) | Sy | Void (m) |
| Wombarra Fm (L11) | 15 | 0.004 | 0.06 | 0.033 | 0.495 |
| Bulli Seam (L12) | 2.5 | 0.016 | 0.04 | 0.06 | 0.15 |
| LRSS (L13) | 28 | 0.005 | 0.14 | 0.05 | 1.5 |
| Wongawilli Seam (L14) | 4** | 0.015 | 0.06 | 0.15 | 0.6 |
| **Total Void (m)** | - | - | 0.3 | - | 2.65 |
| **Difference (m)** | = 2.65 - 0.3<br>= 2.3 | | | | |

**Note:** ** working section only

### 4.5.6 Other Workings

Within roadways and bord and pillar areas, horizontal hydraulic conductivity was set to 10 m/day, and vertical hydraulic conductivity to 0.002 m/day.

## 4.6 Model Calibration

### 4.6.1 Approach

Manual calibration methods were used to alter the hydraulic conductivity (horizontal and vertical), and specific yield of modelled layers or zones. The model is parameter-rich, with many host permeabilities and storage parameters, recharge, boundary condition conductances to be modified. In addition, the height / depth / lateral extent of the various zones of deformation and the degree of deformation within those all work in different ways to affect model behaviour.

Calibration has focussed on replicating observed mine inflow and groundwater levels, while constraining the hydraulic conductivity with the large dataset of packer and core test results available at Dendrobium and supported by data from neighbouring mines (Appin, Tahmoor).

A key difference in this model, compared to the previous HydroSimulations and Coffey models is that calibration has been attempted separately for inflow to each mine area (Areas 1, 2, 3A and 3B). This is viewed as important given the different character of inflow to each area.

Given the size and complexity of the model, and timeframe between the release of the PSM study (in September, 2017) and requirement for model update in late 2017 (as in Section 1.3), HydroSimulations used a local-scale model, based on the regional model but with boundaries much closer to the Dendrobium Mine, in order to test different methods for representing connected fracturing, as well as different heights/parameters within deformed zones. The results of this were then passed back to the regional model for the overall 'impact assessment'. The model was revised in early 2018 based on Agency and Peer Review (Kalf and Associates, 2018) comments to make it more conservative with respect to subsidence and deformation processes.

### 4.6.2 Model Performance

The full regional model takes about 15-20 hours to run with the 'Stacked Drains' implementation of the connected fractured zone, and about 30-50 hours with other methods.

The head closure criterion specified in the MODFLOW-USG SMS solver was set at 0.05 m. The mass balance error at the end of the MODFLOW-USG simulation was reported as <0.05%. The model uses the 'upstream weighting' method for simulating unsaturated conditions (similar to the 'pseudo-soil' function in MODFLOW-SURFACT), although testing was conducted with this and with the Richards Equation for unsaturated flow. Some previous versions of the model have used Richards Equation (e.g. HydroSimulations, 2014; 2016a).

In previous models (HydroSimulations 2019a, 2019b), the statistical calibration to groundwater levels and the calibration to inflows declined with the incorporation of a conservative height of connected fracturing and off-goaf / valley-bulging mechanism.

For the purpose of this model, revised conductances were applied to the stacked drains simulating the height of connected fractures over Dendrobium to be consistent with the parameters used in HydroSimulations 2019c. In addition, the horizontal hydraulic conductivities for the two coal seams have been increased in line with the analysis of drillstem test data presented in HydroSimulations 2019c. These changes have improved calibration to modelled inflows and groundwater levels.

A comparison of the revised model outputs prepared for this report and the observed data for both groundwater levels and mine inflows is presented below.

### 4.6.3 Groundwater Levels

The locations of boreholes and piezometers used for groundwater level calibration are mapped in **Figure 23** (with more detailed maps in **Appendix D**). As per Condition of Approval 18(b) (**Table 1-3**), a large dataset of groundwater levels has been collated across a total of 694 target instruments (bores, piezometers) at which over 40,000 observations have been used to assess model calibration to groundwater levels.

Of those sites/piezometers, 615 are piezometers in 'deep' bores. From the sub-daily or daily data recorded at those sites, HydroSimulations/SLR have aggregated those data into over 39,000 aggregated medians by model stress period. The modelled heads are plotted against observed heads on **Figure 11**. With respect to the scatter on the X:Y plot shown on this figure, the key reasons for the scatter are:

- difficulty in matching the timing of drawdown. The model may match the pre-mining head quite well, and also the final post-mining head reasonably well, but during the period of drawdown, it is easy for the model to be out by 100 m or more because it either draws down too quickly or too slowly compared to observed;
- longwall progression and therefore 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;
- incorrect or suspect data which has not been identified;
- incorrect or imperfect parameterisation of the model re: K and S parameters, either on a local or larger-scale; and

- the 'Stacked Drains' method fixes the head in the connected fracture zone around zero pressure – pressures are often maintained (see **Figure 21** and **Figure 22**) but the preference is that the model configuration be such that a conservative impact assessment is achieved.

HydroSimulations/SLR have used water levels from 98 'shallow' piezometers, almost all of which are located in swamp deposits (as mapped for IMC or based on OEH mapping), although some are not located in such features. From this dataset, given that these shallow bores are responsive to short-term rainfall events, we have derived target values for calibration by taking a value within the first third, second third and last third of each month resulting in over 2,500 'targets' for calibration.

The size of the dataset has meant that data 'cleaning' or the application of 'weights' has not occurred. We have made steps to have clearly erroneous data corrected (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).

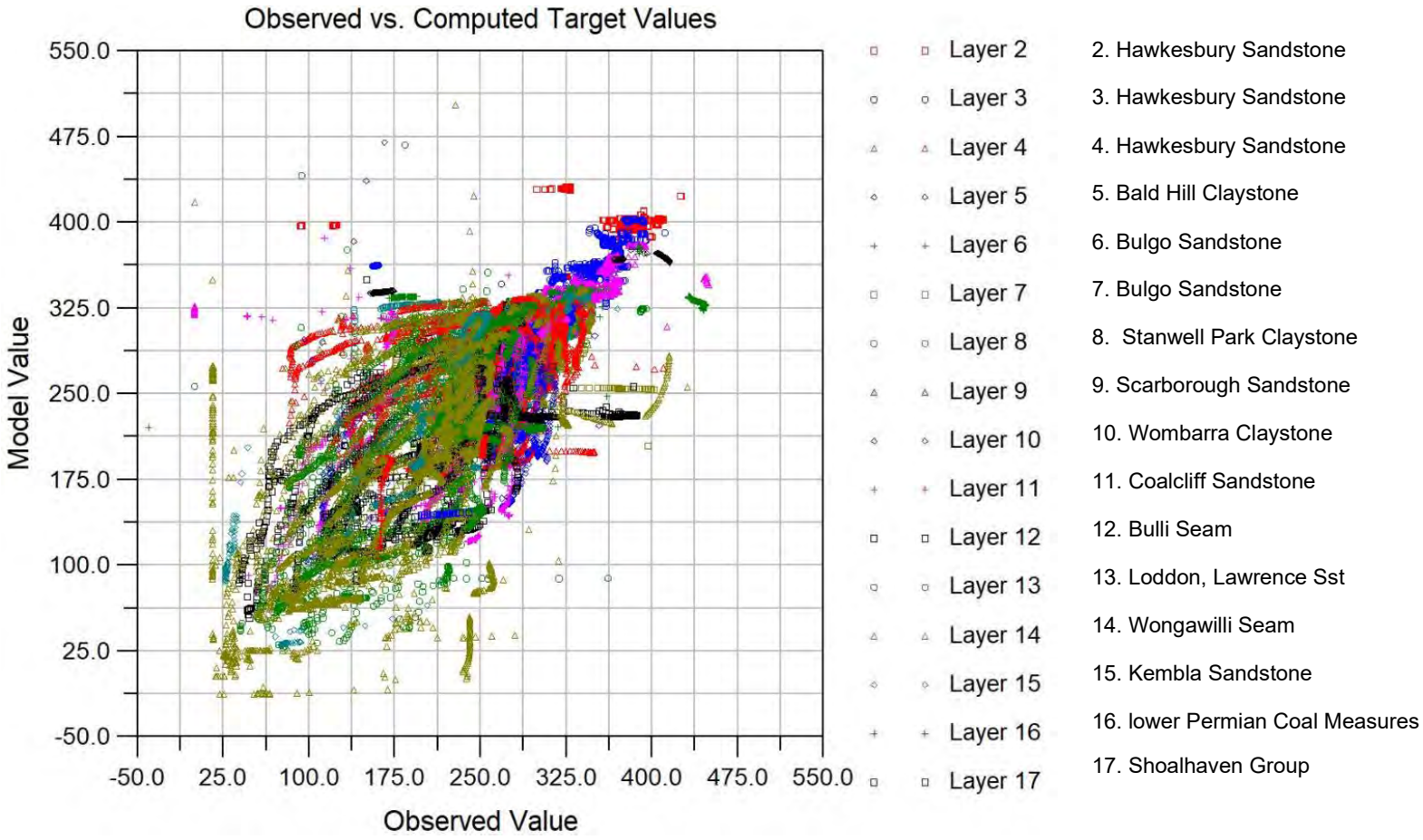



**Figure 11 Summary of Groundwater Level Calibration**

The RMS error is 52.40 m and the SRMS error for the correlation between observed data and the transient model groundwater levels is 10.7%. This value is just outside the often-quoted example of 10 % (MDBC, 2001; Barnett et al., 2012), however 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 -3.6 m, a significant improvement from the mean residual of -22 m produced by the groundwater model used in the Longwall 20 and 21 groundwater assessment (HydroSimulations, 2019b).

Calibration hydrographs for the entire dataset are presented in **Appendix D**. The match between modelled and observed hydrographs is generally good, with the main issue being that while the overall scale of drawdown is often quite well matched, the timing of drawdown is not always matched, and this can lead to large residuals in the calibration. This could be due to the real timing of mine development versus the 'blocky' timing of model stress periods but is more likely related to local-scale variation in permeability and porosity, or geotechnical behaviour that cannot be captured in a regional model (e.g. multiple caving/subsidence events related to (multiple) longwall extraction).

Modelled groundwater levels are plotted against observed pressures for eight sites in or near Area 3A (S2442A, S2243, S1870, S1879), as well as within Area 3B (S2398, S2412) and on the eastern bank between Lake Avon and Area 3B (S2314, S2435, S2436). Locations marked on **Figure 23**. Hydrographs for each of these bores are provided on **Figure 12** to **Figure 20**. Observed groundwater levels are plotted in solid lines, with a corresponding modelled series in a dashed line of the same colour. Some of the bores were installed recently (e.g. S2442 on **Figure 12**), especially those around the Lake Avon shoreline or centre-line goaf holes in response to comments by agencies, so in some instances only a short record of data is available. Other bores (e.g. S1870, **Figure 14**) have longer records.

From **Figure 12** to **Figure 20**, the key features are:

- Relatively good correlation between observed and modelled head values for the Hawkesbury Sandstone) at all bores.
- The model captures the timing of drawdown well particularly at bore S2412. The timing is well correlated for bores S1879 and S1870 however the model simulates drawdown that progresses more quickly and linearly during the period 2008-2010 than what was observed. Observed data shows an initial sharp decline in groundwater levels followed by a period of gradual groundwater level decrease before more rapid declines again after mid-2010;
- The modelled water levels in the coal seams at bores S1870, and Hawkesbury Sandstone at S2443 and S2442A show rapid peaks in groundwater levels beyond the simulated ground surface during the historic period of the model. These increases are a model artefact and something that is due to changes in the simulation of specific yield (i.e. when simulating coal extraction and subsidence).
- For the bores adjacent to Lake Avon (S2314, S2435, S2436 and S2436C) modelled groundwater levels within the Hawkesbury sandstone are responsive to rainfall recharge, as has been observed, and the model captures groundwater levels well particularly for the mid Hawkesbury Sandstone and Bald Hill Claystone. The model overestimates the degree of drawdown at the 128 m deep Hawkesbury Sandstone sensor at S2314, yet overall groundwater levels are consistent.

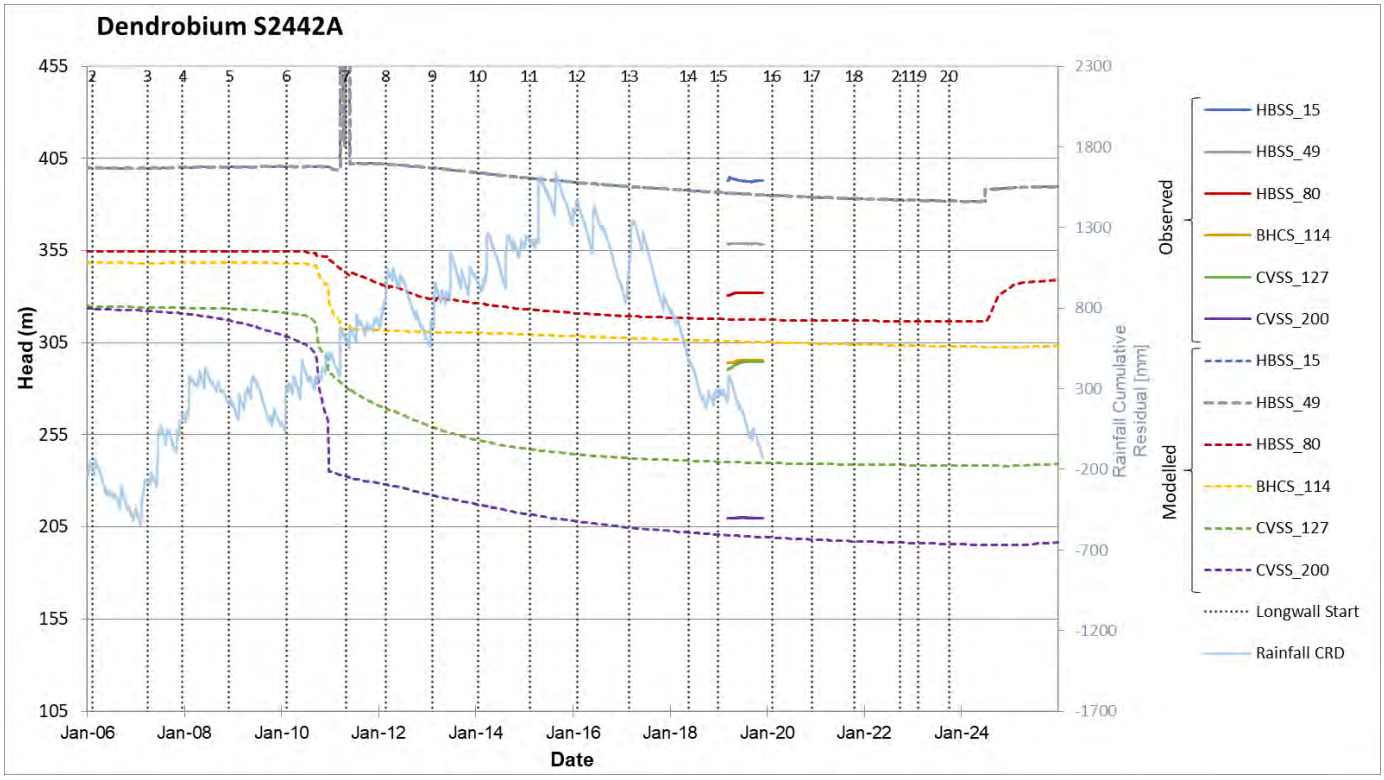



**Figure 12 Comparison of Observed and Modelled Groundwater Levels at Bore S2442A**

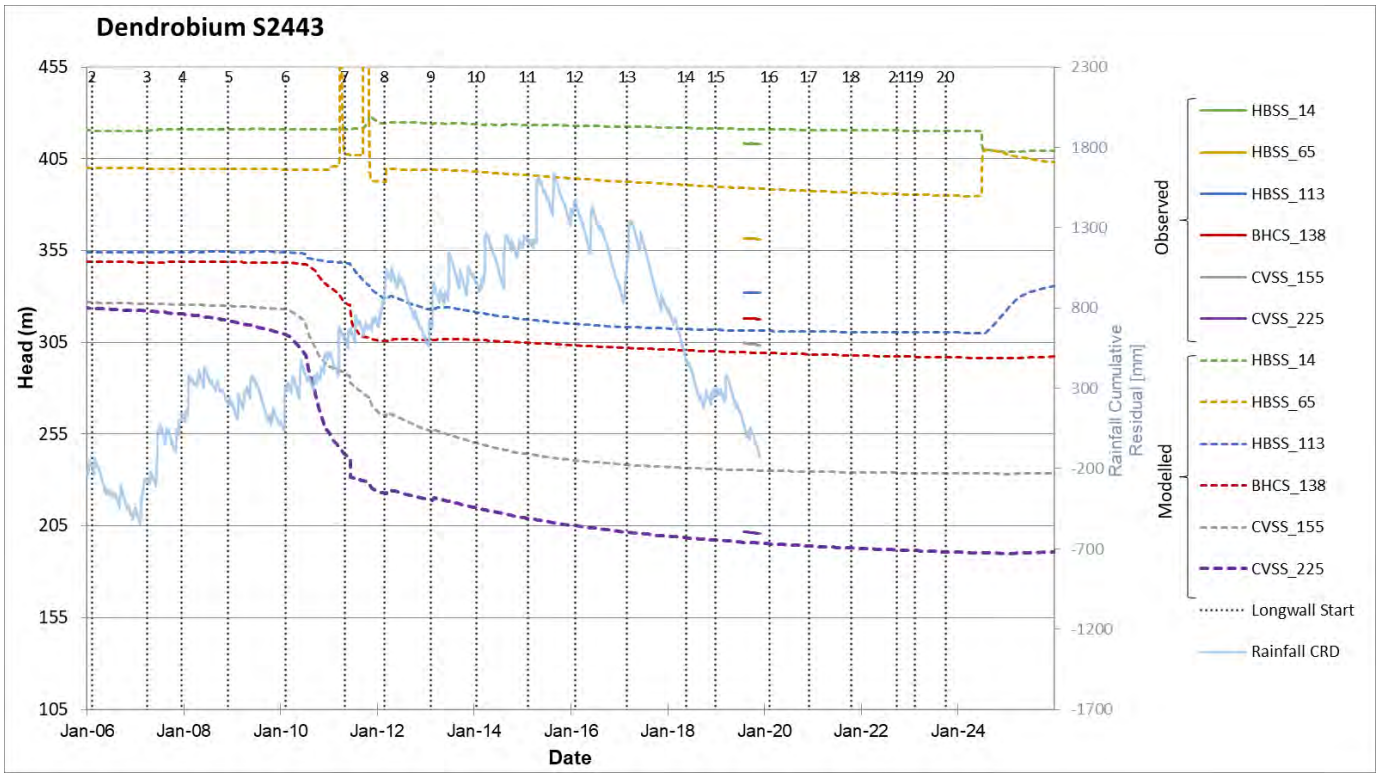



**Figure 13 Comparison of Observed and Modelled Groundwater Levels at Bore S2243**

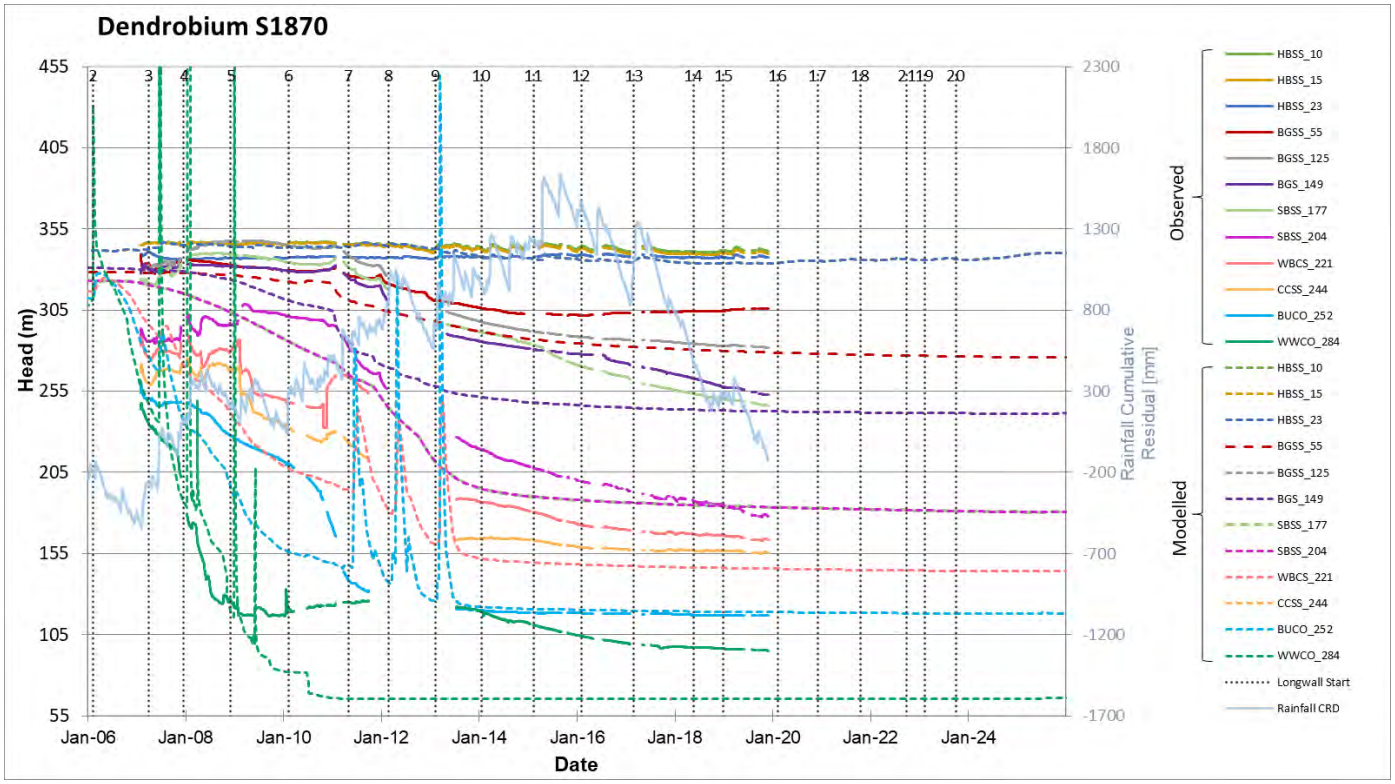



**Figure 14 Comparison of Observed and Modelled Groundwater Levels at Bore S1870**

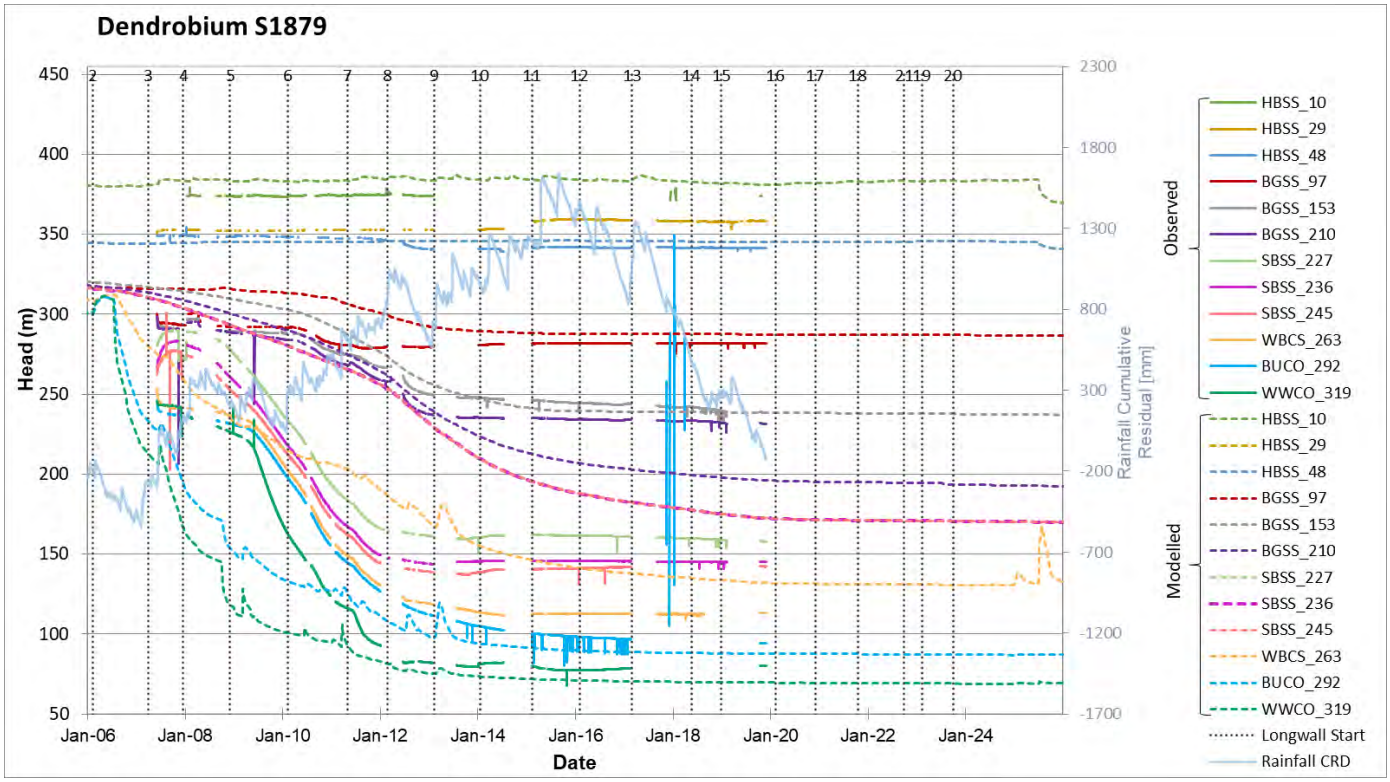



**Figure 15 Comparison of Observed and Modelled Groundwater Levels at Bore S1879**

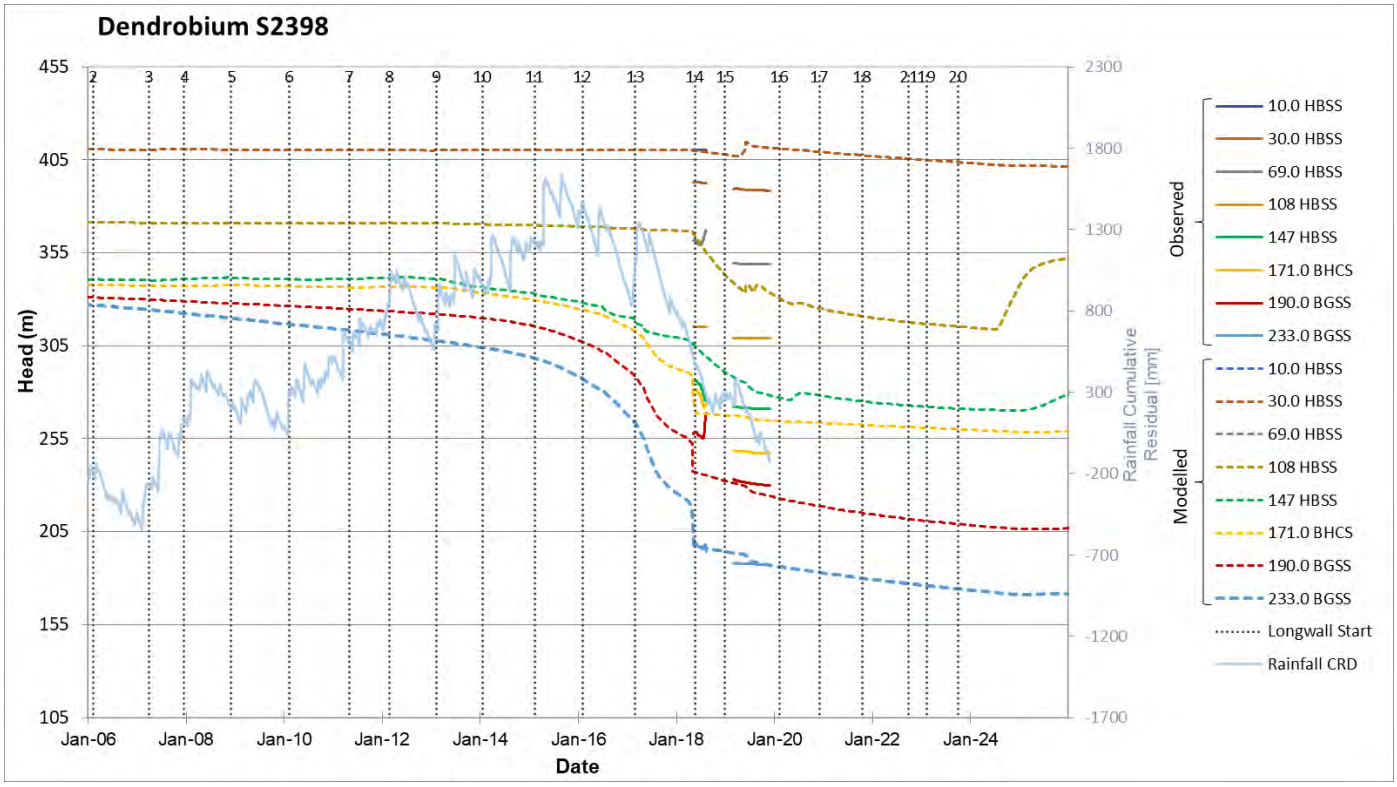



**Figure 16 Comparison of Observed and Modelled Groundwater Levels at Bore S2398**

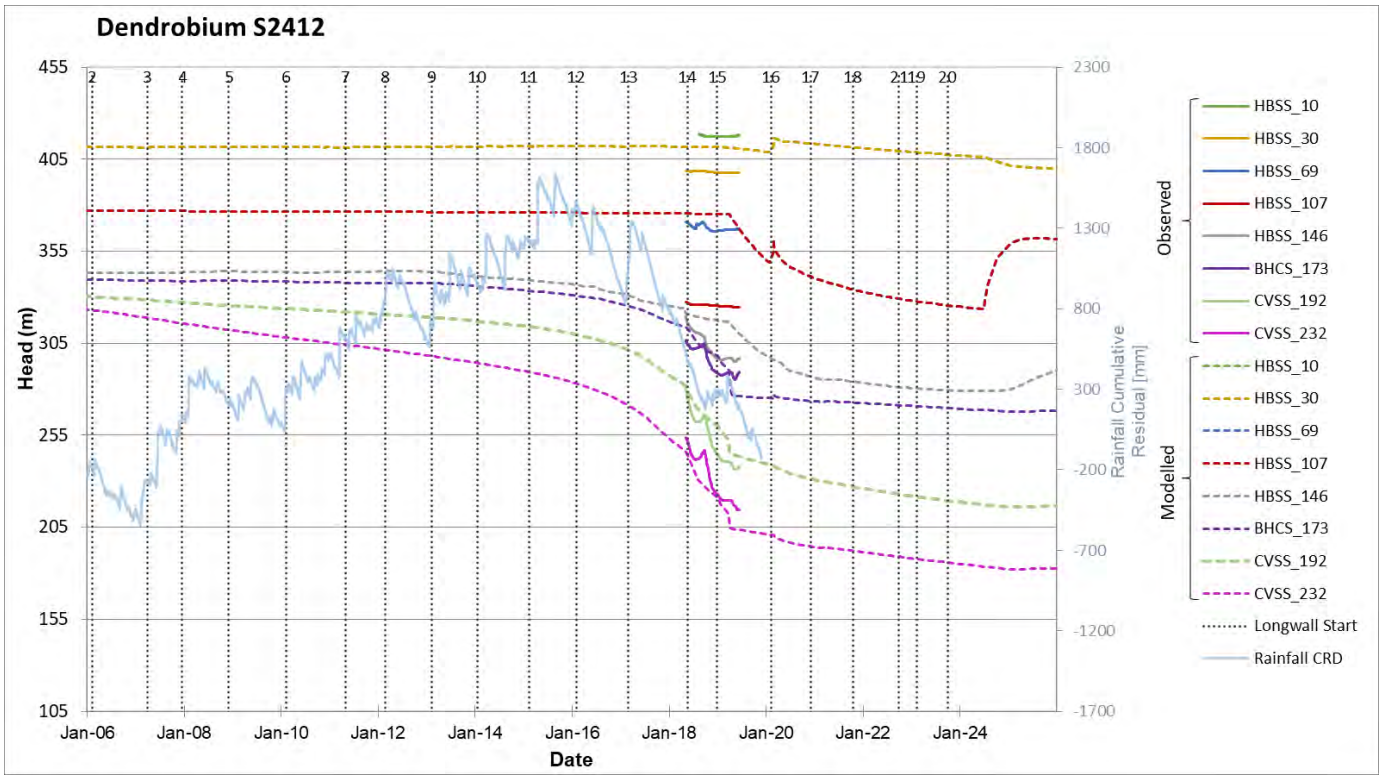



**Figure 17 Comparison of Observed and Modelled Groundwater Levels at Bore S2412**

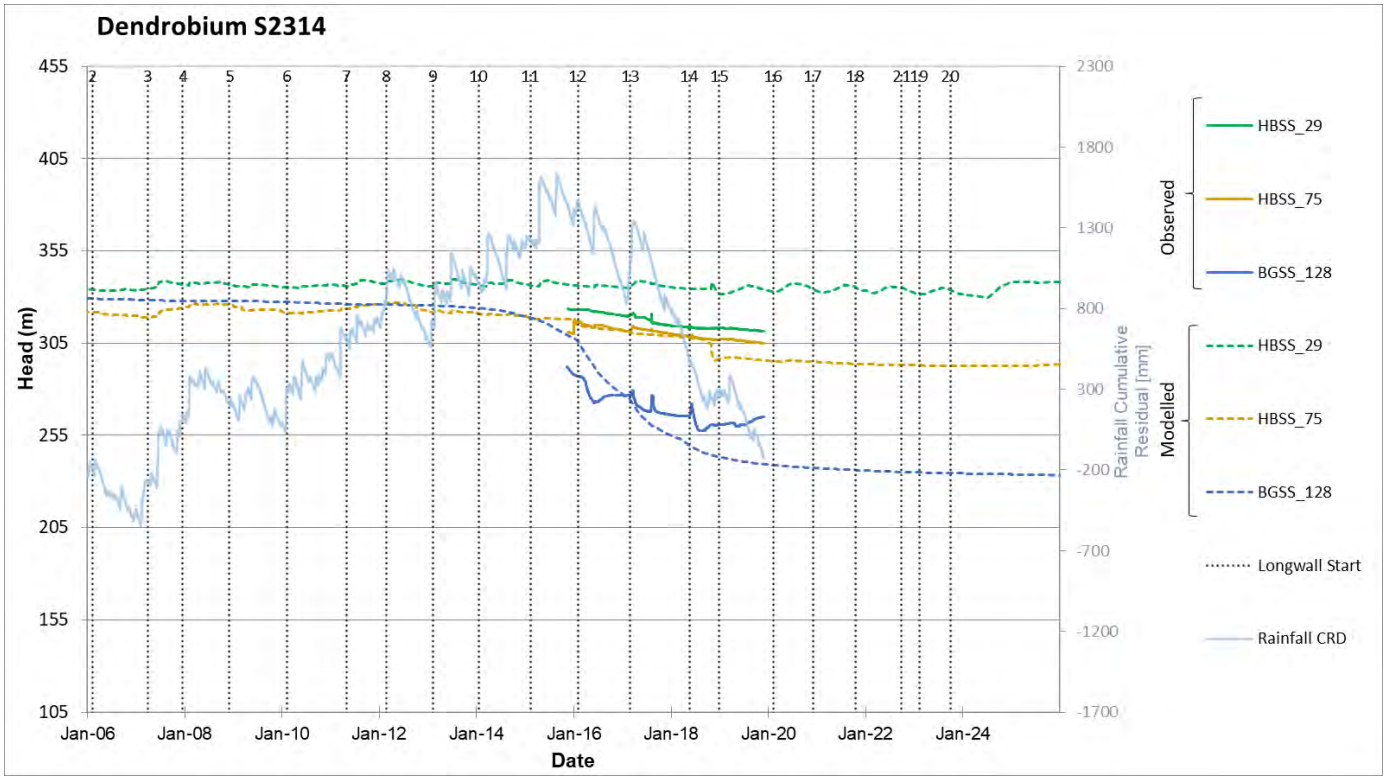



**Figure 18 Comparison of Observed and Modelled Groundwater Levels at Bore S2314**

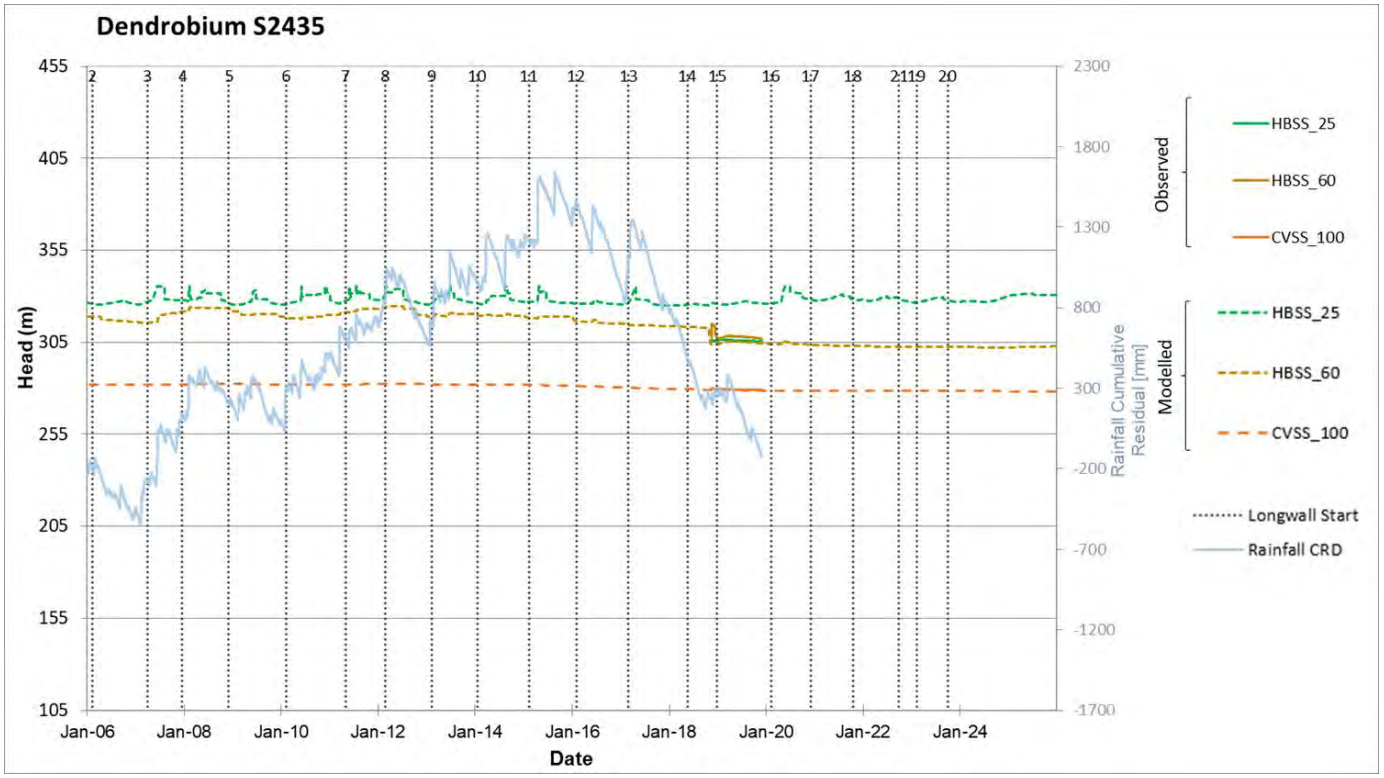



**Figure 19 Comparison of Observed and Modelled Groundwater Levels at Bore S2435**

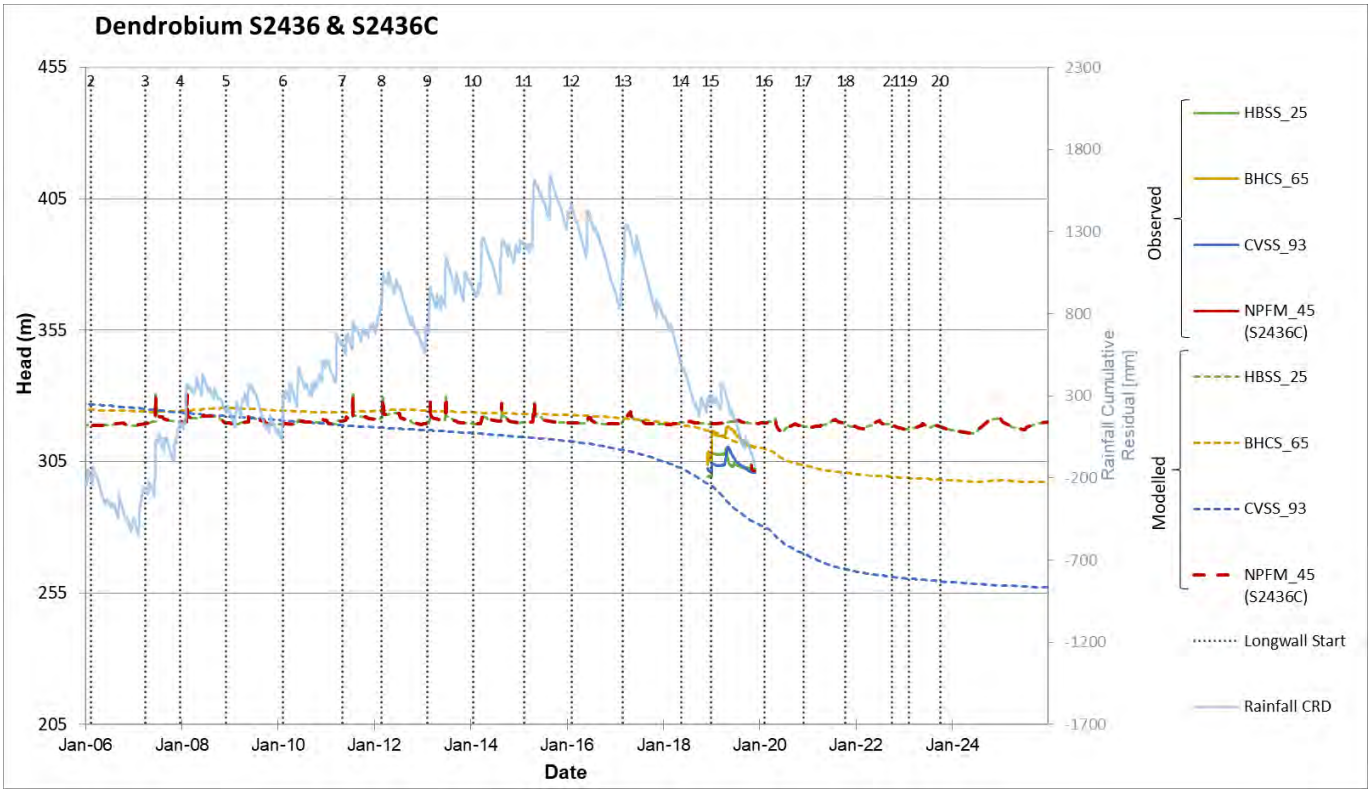



**Figure 20 Comparison of Observed and Modelled Groundwater Levels at Bore S2436**

A second method of assessing groundwater level calibration is via comparison of groundwater pressure vertical profiles. Observed and modelled pressures for two sites are presented: the paired site S2194 between Longwall 17 and Lake Avon (**Figure 21**) and S1927 at Longwall 14 (**Figure 22**). On these plots recorded or observed pressures for specific dates are plotted as solid lines, with a corresponding modelled series in a dashed line of the same colour. From these it can be seen that:

- Pre-mining pressures are relatively well matched at both sites, being better at S1927 in Longwall 9, **Figure 21** (blue and green series).
- The upper piezometers at bore S2194 show the maintenance of pressures in the range 5-20 $mH_2O$ (the piezometers at 10 to 55 m) to about 45 to 70 m (in the piezometers at 111 and 150 m). The simulated post-mining pressure heads in the Bulgo and Wongawilli Coal Seams show divergence from the observed data with simulated pressure heads ranging between 145 and 195 $mH_2O$, whereas the observed fall between 20 to 80 $mH_2O$.).
- **Figure 22** shows that as mining approached S1927, pressures in the units below the upper Hawkesbury Sandstone, dropped significantly, especially in the sandstones.

Overall, the model overestimates the degree of drainage of groundwater from the strata above and around the longwalls. This is due to the 'Stacked Drains' method. In reality, areas where fracturing is not connected and/or where host permeabilities are low, drainage would be delayed or even incomplete.

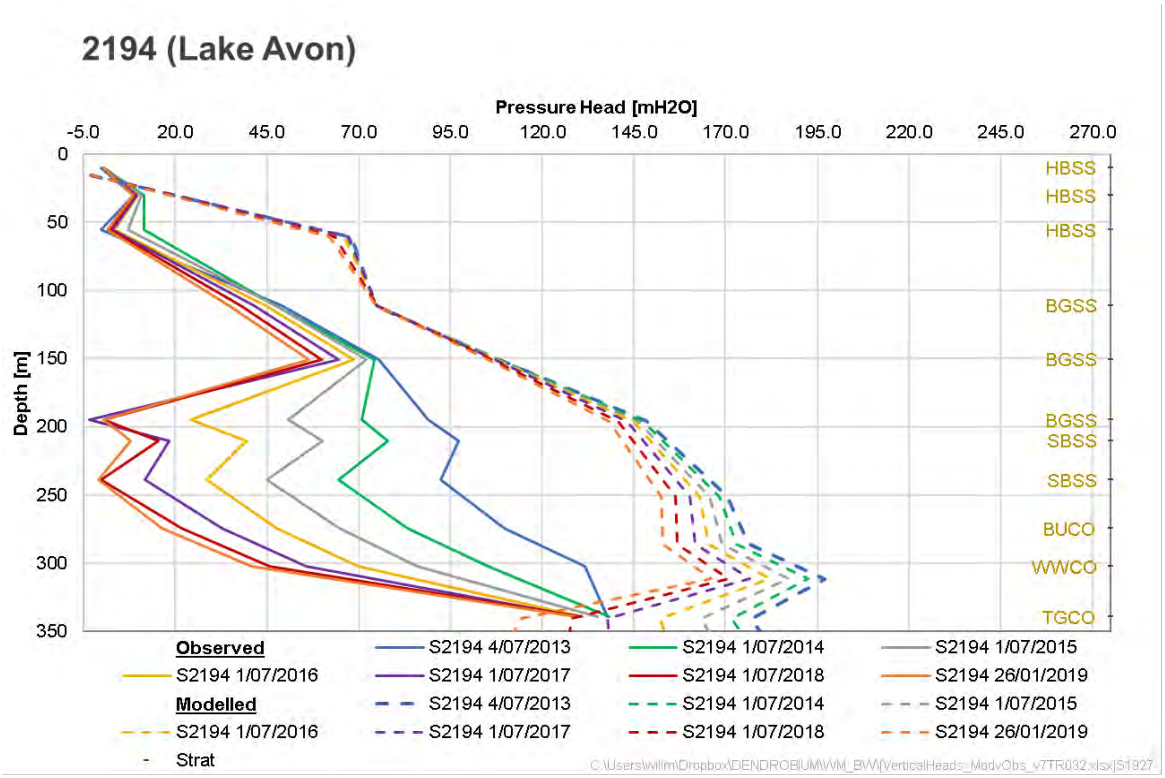



**Figure 21 Modelled and Observed Groundwater Levels: Lake Avon**

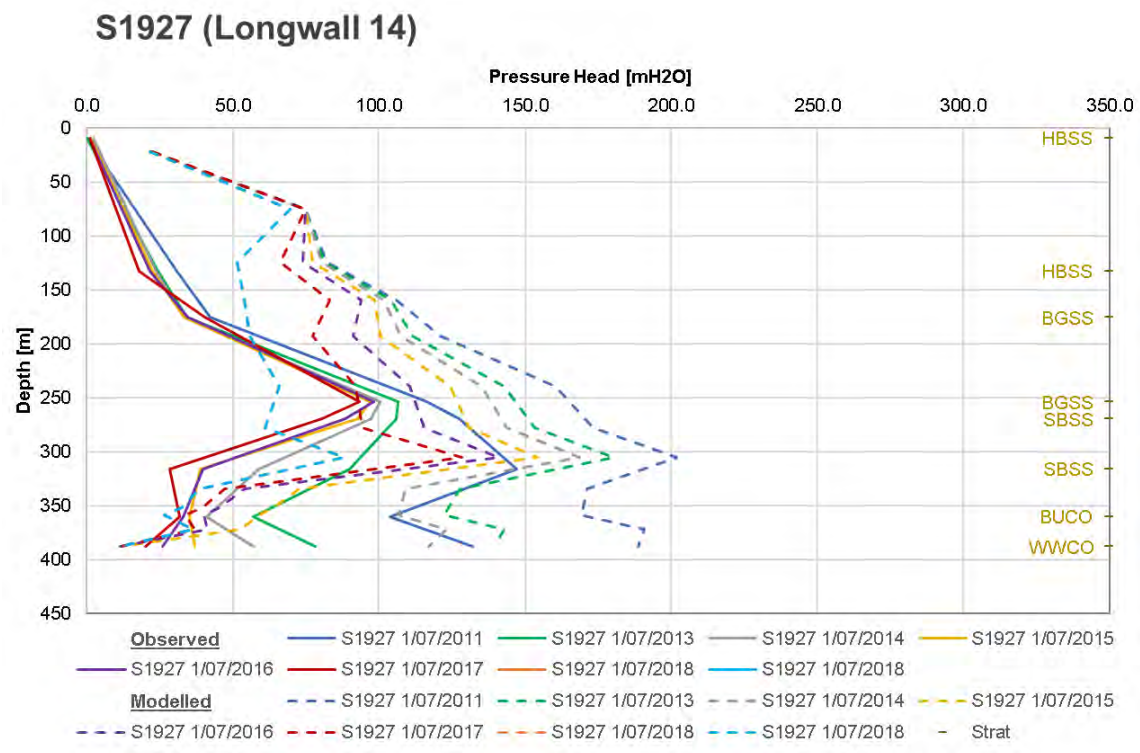



**Figure 22 Modelled and Observed Groundwater Pressures: Area 3B, Bore S1927**

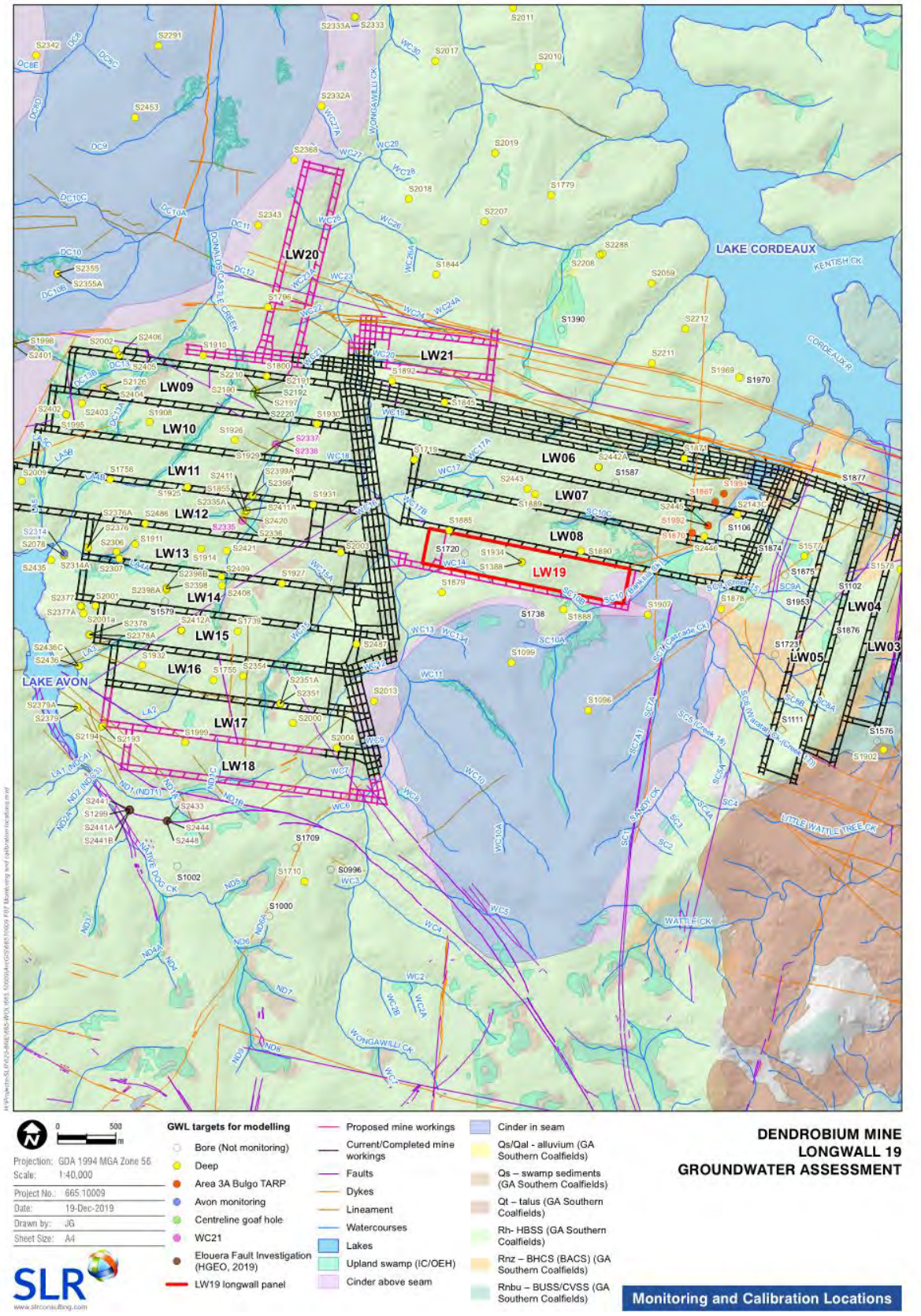



**Figure 23 Groundwater Monitoring and Calibration Locations**

### 4.6.4 Mine Inflow

**Figure 24** and **Figure 25** present the model calibration to the 'observed' groundwater inflow to the underground mine, as calculated by IMC's site water balance. The groundwater model results have been calculated considering time-weighted averages, with reference to model output times (**Section 4.3** and Mackie, 2013).

Comments on **Figure 24** are as follows:

- Area 1 – modelled inflows are consistent with observed inflows. During 'active' extraction, inflow peaks are matched relatively well with some underprediction during Longwalls 1 and 2, and overprediction during Longwalls 3 and 4 extraction in Area 2. The consistent long-term trend is matched appropriately, although the modelled inflow fails to capture a peak in observed inflow following the extraction of Longwall 12 in Area 3B.
- Area 2 – as described in **Section 2.8**, inflows to Area 2 exhibit a strong correlation to rainfall. The model captures the general trend and the long-term average of recorded groundwater inflow to Area 2, however, fails to capture the peaks associated with intense rainfall events that have been observed throughout the monitoring period.
- Area 3A – the model simulated the progressive increase in inflow to Area 3A associated with longwall extraction in line with the observations. Large peaks observed between 2015 and 2016 are not captured well, however the modelled post-mining decline in inflows matches the general observed trend for this period.
- Area 3B – observed and simulated inflows to Area 3B show the best correlation of all areas at Dendrobium. The modelled dataset matches the linear increase in observed inflows between 2012 and 2017 almost exactly. After this point the two diverge with the model overestimating inflows by approximately 5-7 ML/d during the extraction of Longwalls 14 and 15.

The correlation between observed and modelled inflows presented here show a substantial improvement compared to inflows presented previously in HydroSimulations 2019a and 2019b. In these groundwater assessments, modelled inflows were over-predicted and did not capture specific peaks or trends as seen in the observed data.

Overall, the modelled total mine inflow **Figure 25A** appears to be a good match to observed and is generally consistent with the observed data, and therefore should be considered conservative with respect to volumetric impacts, such as groundwater take and baseflow capture from watercourses.

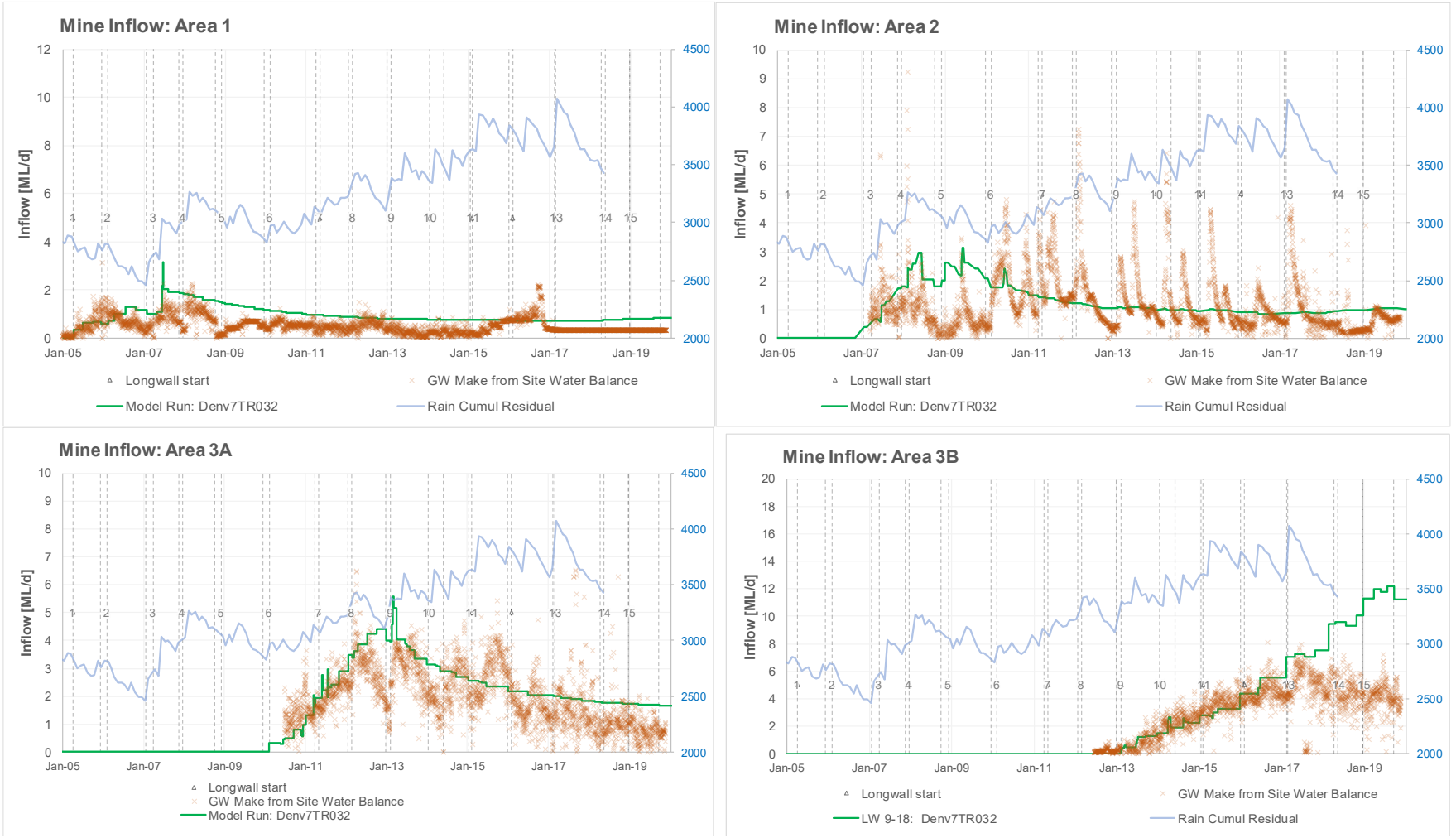
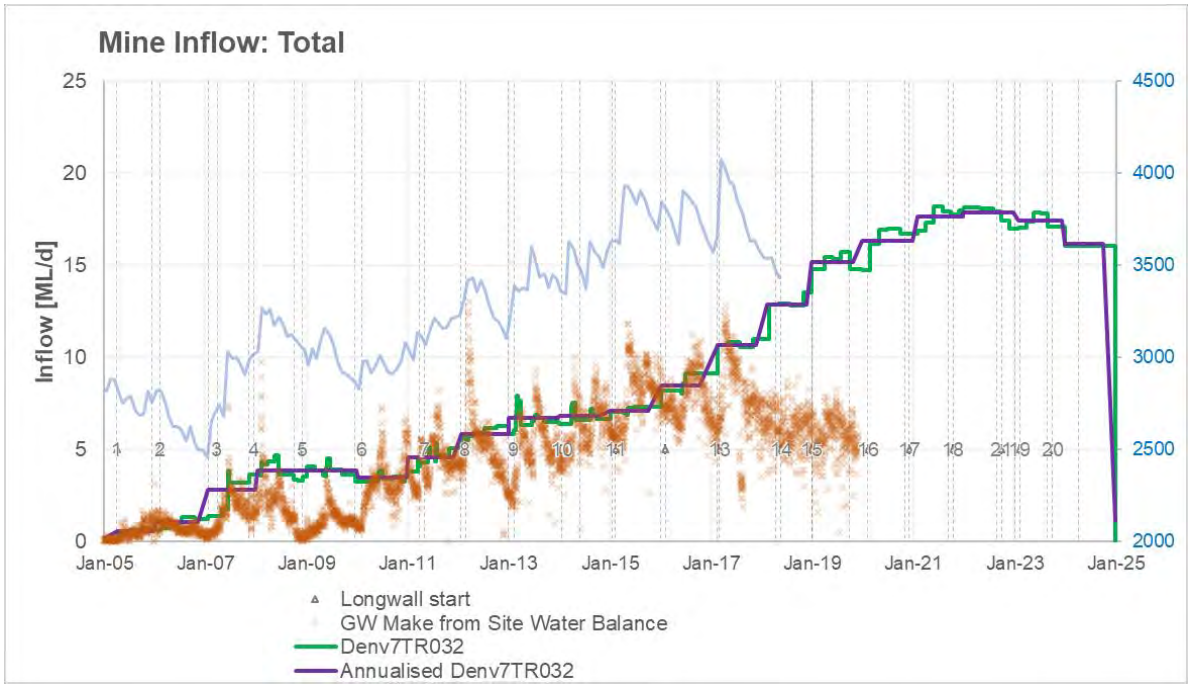
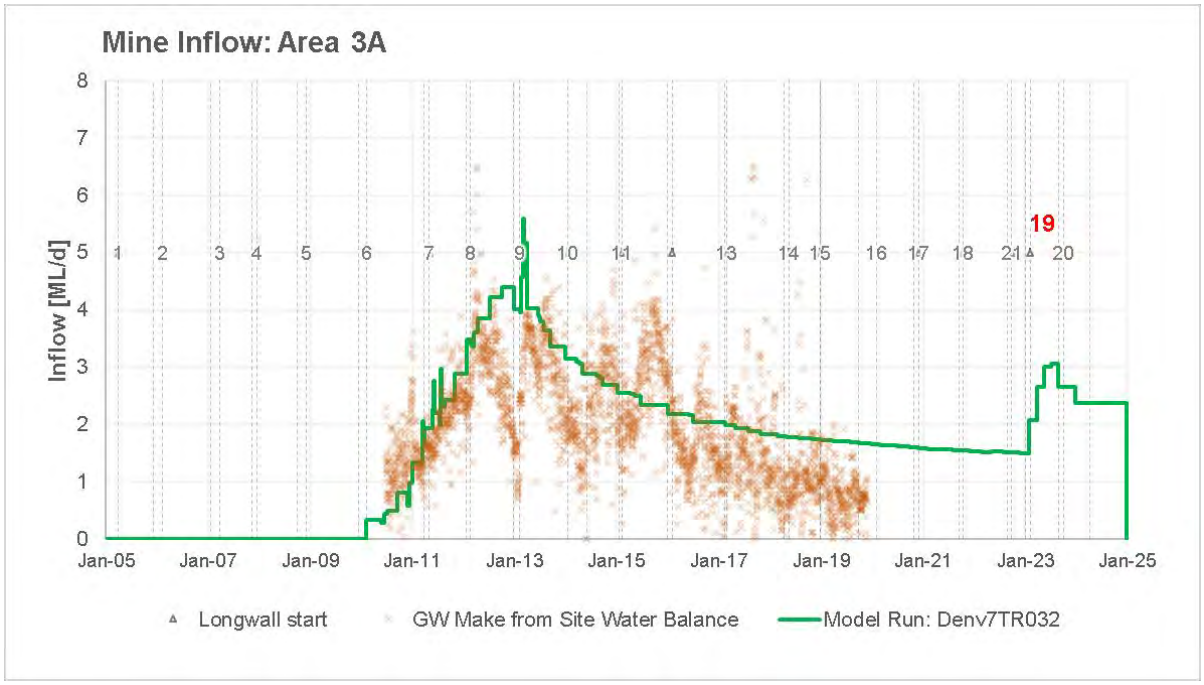



**Figure 24 Mine Inflow Calibration – By Mine Area**

**A)**




**B)**




\\au.slr.local\Corporate\Projects-SLR\660-SrvWOL\660-WOL\665.10009 Dendrobium Groundwater RTS\06 SLR Data\04 Calculations\Hydrographs\[VerticalHeads_ModvObs_v7TR032.xlsx]S1927

**Figure 25 Mine Inflow Calibration and Prediction: A) Whole of Mine and B) Area 3A with Longwall 19**

## 4.7 Calibrated Model Parameters

**Table 4-4** presents the calibrated model aquifer parameters. Apart from key adjustments made to the Bulli and Wongawilli Coal Seams (as discussed below), these are the same as in HydroSimulations (2018, 2019a and 2019b).

### Table 4-4 Calibrated Model Parameters

| Layer | Hydrostratigraphic Unit | Kh (m/d) | Ky (m/d) | Ky/Kh | Ss (m-1) | Sy |
|---|---|---|---|---|---|---|
| 1-4 | Swamps | 1.00 | 5.00E-02 | 0.050 | 0.01 | 0.3 |
| 2 | upper Hawkesbury Sandstone | 2.50E-02 | 1.20E-05 | 0.001 | 5.00E-03 | 0.05 |
| 3 | mid Hawkesbury Sandstone | 9.00E-03 | 1.00E-04 | 0.011 | 1.00E-06 | 0.025 |
| | (deeper, under ridge lines) | 9.00E-03 | 1.00E-05 | | | |
| 4 | lower Hawkesbury Sandstone | 2.00E-02 | 3.00E-05 | 0.002 | 1.00E-06 | 0.012 |
| | | 7.00E-03 | 1.00E-05 | 0.01 | | |
| 5 | Crinanite (upper) | 5.00E-02 | 3.00E-03 | 0.06 | 5.00E-04 | 0.01 |
| | Bald Hill Claystone | 1.50E-03 | 3.00E-06 | 0.002 | 1.00E-06 | 0.006 |
| | | 3.00E-4 | 3.00E-06 | 0.01 | | |
| 5-11 | Crinanite | 1.00E-04 | 5.00E-05 | 0.5 | 9.00E-06 | 0.003 |
| 6 | Bulgo Sandstone (upper) (Area 2) | 2.00E-02 | 2.00E-05 | 0.017 | 9.00E-07 | 0.008 |
| | | 6.00E-03 | 2.00E-06 | 0.001 | 9.00E-07 | 0.008 |
| | | 8.00E-04 | 1.00E-06 | 0.001 | | |
| | (deepest, west/north) | 3.00E-04 | 1.00E-06 | 0.003 | | |
| 7 | Bulgo Sandstone (lower) (Area 2) | 1.00E-02 | 2.00E-05 | 0.002 | 8.00E-07 | 0.007 |
| | | 6.00E-03 | 6.00E-06 | 0.001 | | |
| | | 8.00E-04 | 3.00E-06 | 0.004 | | |
| | (deepest, west/north) | 1.00E-04 | 2.00E-06 | 0.02 | | |
| 8 | Stanwell Park Claystone | 6.00E-04 | 4.00E-06 | 0.007 | 7.00E-07 | 0.005 |
| | Stanwell Park Claystone – sandy facies | 1.00E-03 | 3.25E-05 | 0.033 | | |
| | (deepest, west/north) | 6.00E-05 | 2.00E-06 | 0.033 | | |
| 9 | Scarborough Sandstone | 4.00E-03 | 5.00E-06 | 0.001 | 6.00E-06 | 0.01 |
| | | 4.00E-04 | 1.00E-06 | 0.003 | | |
| | (deepest, west/north) | 1.00E-04 | 1.00E-06 | 0.01 | | |
| 10 | Wombarra Claystone | 3.00E-04 | 5.00E-06 | 0.017 | 5.00E-07 | 0.0035 |
| | | 7.00E-05 | 5.00E-06 | | | |
| 11 | Coalcliff Sandstone | 4.00E-04 | 7.00E-06 | 0.018 | 4.00E-07 | 0.004 |
| 12 | Bulli Coal Seam | 2.00E-02 | 2.50E-05 | 0.036 | 1.00E-06 | 0.016 |
| 13 | Lawrence & Loddon Sandstones | 3.00E-04 | 9.00E-06 | 0.03 | 3.00E-07 | 0.005 |
| 14 | Wongawilli Coal Seam | 4.00E-02 | 9.00E-06 | 0.002 | 1.00E-06 | 0.015 |
| | | 9.00E-03 | 7.00E-06 | | | |
| 15 | Kembla Sandstone | 2.50E-04 | 3.00E-05 | 0.12 | 3.00E-07 | 0.0045 |
| 16 | lower Permian coal measures | 8.00E-05 | 1.28E-05 | 0.16 | 3.00E-07 | 0.004 |
| 17 | Shoalhaven Group | 1.00E-05 | 1.80E-06 | 0.18 | 3.00E-07 | 0.004 |

**Note:** 1. Kh – Hydraulic conductivity (horizontal); Kv – Hydraulic conductivity (vertical); Kv/Kh – Ratio of vertical to horizontal hydraulic conductivity; Ss – Specific storage; Sy – Specific yield

Model parameters are all within expected ranges based on analysis of the packer and core testing databases (i.e. close to arithmetic mean and harmonic mean for horizontal and vertical hydraulic conductivities respectively) and do not represent a marked departure from previous modelling (see Coffey, 2012a; HydroSimulations, 2014, 2016a, 2016b, 2019c). Two of the main adjustments include:

- Hydraulic conductivity of the Bulli and Wongawilli Seam has been increased to be consistent with the analysis of drillstem test data presented in HydroSimulations, 2019c.
- Horizontal hydraulic conductivity for some areas of the Hawkesbury Sandstone have been increased to better represent pre-mining Kh data from bores S2377 (AD3) and S2378 (AD4) (HGEO, 2019b).

## 4.8 Model Review

The Dendrobium Regional Groundwater Model has evolved from that of Coffey (2012) through numerous iterations and updates (HydroSimulations, 2014, 2016, 2018, 2019a and 2019b), and further work to improve the model is on-going, as recommended by IEPMC (2018 and 2019a).

The model, as reported on in SMP applications for Dendrobium has been reviewed a number of times by NSW Government Agency staff (e.g. WaterNSW, Dams Safety NSW, OEH and DPE) and the IEPMC.

The Dendrobium Regional Groundwater Model has been the subject of multiple Peer Reviews by Kalf and Associates (the latest in 2018), who has made specific comments and recommendations about the analysis of data, the development of the conceptual model, as well as features of the numerical model including the need for conservative representation of the zone of connected fracturing and reviewed the method for including basal shears and valley closure processes.

Kalf and Associates is engaged on an on-going basis for review of the model described in this report and for future model development, including the development of an unstructured model which will be documented in a separate report.

## 4.9 Predictive Modelling

### 4.9.1 Model Scenarios

The mine plan and schedule for Longwall 19 is presented in **Table 1-1** and **Appendix A**. To assess the effects of the proposed Longwall 19 a number of predictive scenarios have been applied and these are summarised in **Table 4-5**.

**Table 4-5 Summary of Predictive Scenario Design**

| Scenario | Model Run | Name | Dendrobium | Connected Fractured Zone Method | Other Mines | Comment |
|---|---|---|---|---|---|---|
| A | v7TR032 | Full Impact | All completed/ current and proposed longwalls for Areas 1, 2, 3A, 3B and 3C (Longwall 20-21) | 'Stacked Drains', with connected fracturing as per calibration (Appendix C) | All | Comparison against B gives incremental impacts of Longwall 19.<br>Comparison against C gives impacts of Dendrobium. |
| B | v7TR033 | Full Impact without Longwall 19 | As above but excluding Longwall 19. | As above | All | Comparison against C gives impacts of Dendrobium without Longwall 19. |

| Scenario | Model Run | Name | Dendrobium | Connected Fractured Zone Method | Other Mines | Comment |
|---|---|---|---|---|---|---|
| C | v7TR034 | No Dendrobium | None | As above | All | Represents impact of other mines. |
| D | v7TR035 | Baseline (Null) | None | N/A | None | Represents pre-mining conditions.<br>Important to note the long history of mining in this area. |

Each predictive run simulates the period to 2200 (as per Condition of Approval), as outlined in **Appendix A**.

All the runs in **Table 4-5** were carried out, and results of these compared to assess the effects of Dendrobium (as a whole) and the incremental effects of Longwall 19.

### 4.9.2 Uncertainty Analysis

Further scenarios to assess the uncertainty associated with a particular prediction ('deterministic scenarios', as per the IESC Uncertainty Guidelines of Middlemis and Peeters, 2019) have been carried out. These are focussed on losses from the reservoirs that might be caused by mining at Dendrobium. A summary of these is as shown in **Table 4-6**, with further discussion provided in **Section 2.6.5**.

The post-mining Kh values in **Table 4-6** are applied to all model cells at or above valley bottoms within the specified distance of extracted longwalls. For example, in the base case model, around the shoreline of Lake Avon, all Hawkesbury Sandstone model cells within 300 m of Dendrobium Area 3B longwalls are simulated with a post-mining Kh of 0.06 m/d, while in the Case 2 scenario, which is based on the AD7 monitoring site, the post-mining Kh in the Hawkesbury Sandstone within 300m of extracted panels is increased to 0.301 M/day.

**Table 4-6 Summary of Deterministic Scenarios focussing on reservoir losses**

| Case | Base (Case 1) | Case 2 | Case 3 | Case 4 | Case 5 | Case 6 | Case 7 |
|---|---|---|---|---|---|---|---|
| Model run | V7TR032 | v7TR036 | V7TR038 | V7TR039 | V7TR040 | V7TR041 | v7TR037 |
| Post-mining Kh <300m | 6.0E-2 | 3.01E-01 | 2.09E-01 | 2.92E-02 | 1.30E-02 | 5.70E-03 | 5.00E-03 |
| Basis (refer to Table 2 of HGEO, 2019b) | synthesis of AD data | (from AD7) | (from AD2) | (from AD6) | (from AD4) | (from AD3) | (from AD1) |
| Post-mining Kh 300-600m | Host Kh x 2 | Host Kh x 2 | Host Kh x 2 | Host Kh x 2 | Host Kh x 2 | Host Kh x 2 | Host Kh x 2 |

All seven cases have been run using the regional model, and the reservoir losses calculated (**Section 5.2.1 and 5.2.2**). This approach is more consistent with the approach used by SCT and HGEO (e.g. HGEO, 2019b).

### 4.9.3 Model Performance

As noted previously, the predictive model run times were about 20 hours. The conjunctive use of 'Stacked Drains' (for the connected fracture zone) has meant that model speed has improved on previous versions of the model, yet the run time remains somewhat impractical.

All predictive runs had overall mass balance errors of <0.04% which is acceptable based on the recommended threshold of 1-2% of Barnett *et al.* (2012). Some timesteps, typically those at the beginning of a stress period, have higher mass balance errors. This is due to the enhancement of specific yield, Kh or Kv in many cells, and often in cells containing the 'Stacked Drains' in those periods.

### 4.9.4 Simulated Groundwater Balance

The modelled regional groundwater balance is summarised in **Table 4-7** to provide context to the major processes represented by the groundwater model. The water balance presented here is the average from 1990-2053. The end date is chosen based on DPIE's condition requesting model estimates of specific fluxes for a period to 30 years after the proposed end of mining. The groundwater balance includes simulated mining at Dendrobium (including Longwall 19), historical mining around Dendrobium, and the parts of approved Tahmoor Mine and the Appin/BSO Mine that lie within the active model domain (see **Figure 3**).

**Table 4-7 Modelled Water Balance**

| MODFLOW Component | Process | In [ML/d] | Out [ML/d] |
|---|---|---|---|
| Recharge | Rainfall recharge | 140.4 | 0.0 |
| River leakage | Watercourses, reservoirs | 70.2 | 50.6 |
| EVT | Evapotranspiration from groundwater | 0.0 | 190.7 |
| Drains | Mine inflow/dewatering | 0.0 | 8.1 |
| Head dep bounds | Regional groundwater flow | 2.4 | 0.0 |
| Constant head | Flow to ocean, estuaries | 0.1 | 0.1 |
| Storage | Groundwater storage | 91.0 | 55.6 |
| | **Total** | **304.0** | **305.1** |

**Note:** ET is high because it represents spring flow along escarpment. Results are from model run v7TR032

Rainfall recharge and then inflow from watercourses are the dominant inputs, while evapotranspiration and baseflow to watercourses/springs are the dominant outputs. Mine inflow constitutes approximately 6% of the recharge.

# 5 Model Results

Given the amount of model output that could be generated, only the key results have been discussed in detail in the following sections. This includes:

- mine inflow predictions (**Section 5.1**) show mine inflow through time, including through all proposed longwalls for Areas 3A, 3B and 3C;
- whole-of-mine and incremental effects of Longwall 19 on leakage from Lake Avon (**Section 5.2.1**);
- whole-of-mine and incremental effects of Longwall 19 on leakage from Lake Cordeaux (**Section 5.2.2**);
- surface water take from watercourses (**Section 5.2.3**) as per Condition 18(c) (**Table 1-2**); and
- groundwater level and pressure results presented in a variety of ways (**Section 5.3**), as per Condition 18(d) (**Table 1-2**) and consistent with a recent request by the IEPMC.

As with the modelling completed in HydroSimulations (2018, 2019a, 2019b), the predictive period includes variation in rainfall recharge, based on the calculated historical patterns. Generally, stress periods are set at two per year for the predictive period, with a recharge rate for typical wet and typical dry periods used alternately, with some occasional variation to cater for more extreme conditions (although not including multi-year droughts). It is for this reason that peaks and troughs in inflow are modelled in subsequent sections.

During the calibration process and revision of the model, and during previous modelling assessments, a variety of methods, permeability parameter sets and fracture zone heights have been used. The configuration of the model used in the impact assessments is considered to be conservative with respect to the height of connected fracturing, the method used to represent fracturing and the off-goaf permeability enhancement.

## 5.1 Predicted Mine Inflow

**Figure 25A** presents the predicted Dendrobium Mine inflow from 2005 until 2025, capturing the complete period for all longwalls including Longwall 19. This shows that the current representation of vertically-connected fracturing and off-goaf permeability enhancement results in inflows that closely match observations during the extraction of Longwalls 1 to 13. The modelled inflows are approximately 3-6 ML/d higher during the simulated extraction of Longwalls 14 and 15 compared to observed data. The highest average annual inflow to the mine is predicted to be approximately 20 ML/d. These modelled inflows show a better correlation to observed data than results previously presented in HydroSimulations 2019a and 2019b due largely to the revised conductances applied to the drains used to simulate the height of complete drainage above the mine, as well as the revised aquifer properties applied to various geologic units. The data used and verification of these changes to model properties compared to observations is presented in **Sections 4.7** and **4.6** respectively.

**Figure 25B** shows the inflow to Area 3A under earlier longwalls as well as Longwall 19. The model simulates peaks associated with the extraction of Longwalls 6 to 8, with a peak of 5.6 ML/d simulated as entering the workings in January 2013. Following this, inflow is predicted to steadily decrease with predicted inflows prior to the simulated extraction of proposed Longwall 19 (i.e. 2022) being around 1.5 ML/d. Under simulated extraction of Longwall 19 inflows to Area 3A are predicted to peak at approximately 3 ML/d. Inflows to Area 3A from Longwall 19 alone are in the range of 0.6 to 1.5 ML/d. Inflows of this magnitude are consistent with observed inflows during the extraction of Longwalls 6 to 8 which were on average 2 ML/d with a peak of 6 ML/d.

## 5.2 Surface Water

### 5.2.1 Simulated Leakage from Lake Avon

The scenario v7TR032 (**Table 4-5**) includes enhanced permeability in the off-goaf areas, considered to simulate broad scale valley closure (valley bulging) mechanisms. This has been used to provide estimates of leakage from the reservoir.

As an update to previous SMP assessments, deterministic scenarios considering the range in observed post-mining Kh have been run (**Section 4.9.2**). This is an approach that is more consistent with the local-scale modelling approach of SCT and HGEO (e.g. the most recent of which is reported in HGEO, 2019b). The local scale approaches are based on an uncalibrated site-scale numerical model to simulate a number of hydraulic conductivity (Kh) cases based on pre- and post-mining Hawkesbury Sandstone permeability in Avon Dam (AD) bores. That local model focusses on horizontal flow between the reservoir and the fractured zone within the Hawkesbury Sandstone, as well as considering the scenario of a permeable zone along the Elouera Fault. The estimates produced by HGEO are included in sections below alongside the other estimates.

#### 5.2.1.1 Whole of Mine Effects

The maximum leakage from Lake Avon, as a result of mining at Dendrobium, has been estimated from the deterministic scenarios, and is predicted to be between 0.15 and 0.47 ML/d, with an average of the scenarios being 0.21 ML/d. The upper end of the range (0.47 ML/d) is predicted to occur for a very short period (a single model stress period), while the lower end results are predicted to be maxima for the lower Kh scenarios but also similar to the longer-term and more consistent loss rates from the higher Kh scenarios.

These are less than Dams Safety NSW's prescribed tolerable limit for Lake Avon (1 ML/d), and similar to estimates from previous regional models in Coffey, 2012, HydroSimulations, 2014, HydroSimulations, 2016a, of which the highest was in HydroSimulations, 2016a. These estimates are lower than the estimated loss of 0.71 ML/d from HGEO (2019b). For context, 0.2 ML/d is 5% of current total groundwater inflow to Area 3B (4 ML/d), while 0.7 ML/d is approximately 18%.

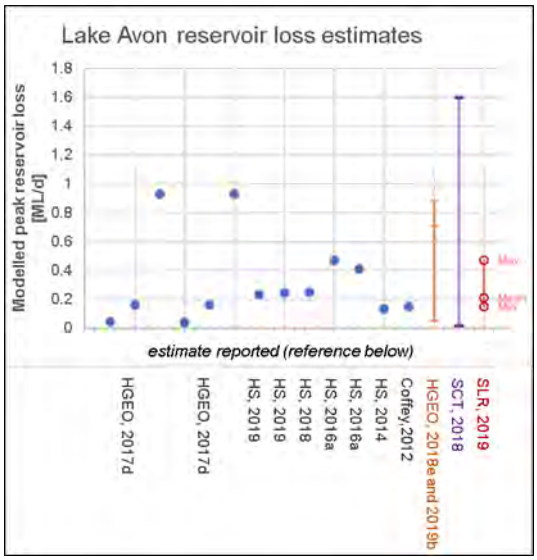



**Figure 26 Estimated losses from Lake Avon**

#### 5.2.1.2 Incremental Effects

The incremental leakage due to the extraction of Longwall 19 is estimated to be <0.001 ML/d. This small incremental leakage, effectively nil, is due to the distance from the proposed longwall to Lake Avon and the presence of the Area 3B panels between Longwall 19 and the lake (**Section 1.2.1**).

### 5.2.2 Simulated Leakage from Lake Cordeaux

#### 5.2.2.1 Whole of Mine Effects

Based on the deterministic scenarios described in **Section 4.9.2**, the range in simulated maximum leakage from Lake Cordeaux due to Dendrobium operations is 0.04-0.1 ML/d. This is similar to the previously reported estimates of 0.14 ML/d (HydroSimulations, 2019a) and 0.08 ML/d (HydroSimulations, 2019b). These estimates are lower than Dams Safety NSW's prescribed tolerable limit for Lake Cordeaux (1 ML/d).

#### 5.2.2.2 Incremental Effects

The incremental leakage due to Longwall 19 is <0.001 ML/d, effectively nil. This is due to a combination of distance and the presence of previously extracted panels between Longwall 19 and the lake (**Section 1.2.1**).

### 5.2.3 Simulated 'Incidental Take' from Watercourses

#### 5.2.3.1 Whole of Mine Effects

Condition 18(c) (**Table 1-3**) required estimates of baseflow capture to be provided in 5-yearly intervals out to 30-years after the completion of proposed mining in these areas. HydroSimulations has adopted the same approach for this assessment of Longwalls 19.

The results from the MODFLOW budget files have been extracted from the predictive scenarios, and net difference, the 'take' from surface water, calculated based on a number of zones as defined by the WSP for the Greater Metropolitan Region Unregulated River Water Sources 2011 (Section 1.4). These are summarised in **Table 5-1** in ML/year.

Because of the assumption of seam-to-surface connection and the use of 'stacked Drains' to simulate the connected fracture zone, it is considered that the estimates of surface water losses from watercourses are conservative. This is in agreement with IEPMC (2019b) [Section 3.8 of that document], which states that predictions of water losses should be conservatively high to allow for uncertainty.

These predicted surface water losses include 'take' due to the effects of groundwater drawdown and depressurisation, which may be transient in nature, as well as more long-lasting effects (even permanent effects) caused by changes to strata, namely surface cracking along stream beds, as noted in Section 3.1.

As a result of Longwall 19, the longer-lasting surface cracking effects are highly likely to occur to the undermined portion of WC14 and a small section in the middle of SC10 (**Figure 2**), and may occur at distances of up to several hundred metres from the panel edge.

The results in **Table 5-1** indicate that the Wongawilli Creek catchment would experience the greatest reduction in surface water flow, which is logical given its location between Areas 3A and 3B, and with some tributaries (e.g. WC15, but also WC21 among others) directly overlying panels.

**Table 5-1 Predicted Reduction in Surface Water Quantity (ML/yr)**

| 5 Year Interval | Upper Nepean River Tributaries Headwaters MZ) | | | | | | | | Wollongong Coastal MZ |
|---|---|---|---|---|---|---|---|---|---|
| | LA2 | LA3 | Native Dog Ck | WC15 | Wongawilli Creek | Donalds Castle Creek | Lake Avon | Lake Cordeaux | |
| Comment | | | | | (inc WC15) | | Incl. LA2, LA3, ND Ck. | | |
| 2011-15 | 0 | 0 | 2 | 2 | 109 | 99 | 18 | 312 | 47 |
| 2016-20 | 1 | 12 | 4 | 4 | 271 | 31 | 47 | 269 | 33 |
| 2021-25 | 82 | 32 | 65 | 65 | 463 | 27 | 483 | 420 | 37 |
| 2026-30 | 96 | 21 | 65 | 65 | 359 | 29 | 502 | 219 | 24 |
| 2031-35 | 59 | 17 | 33 | 33 | 133 | 80 | 281 | 118 | 18 |
| 2036-40 | 43 | 9 | 22 | 22 | 19 | 60 | 163 | 71 | 14 |
| 2041-45 | 36 | 7 | 16 | 16 | 18 | 73 | 114 | 55 | 11 |
| 2046-50 | 27 | 5 | 12 | 12 | 32 | 45 | 82 | 42 | 11 |

#### 5.2.3.2 Incremental Effects

Longwall 19 is predicted to result in some 'take' from watercourses, as summarised in **Table 5-2**. Only the zones affected are included in **Table 5-2**.

**Table 5-2 Incremental Surface Water Take – Longwall 19 (ML/yr)**

| 5 Year Interval | Lake Avon zone | Sandy Creek and tribs | Wongawilli Creek* | Total |
|---|---|---|---|---|
| 2016-20 | 0 | 0 | 0 | 0 |
| 2021-25 | 5 | 22 | 62 | 89 |
| 2026-30 | 1 | 14 | 60 | 75 |
| 2031-35 | 3 | 11 | 35 | 50 |
| 2036-40 | 3 | 7 | 23 | 33 |
| 2041-45 | 3 | 3 | 14 | 21 |
| 2046-50 | 3 | 2 | 10 | 15 |
| 2051-55 | 3 | 1 | 5 | 9 |

*within the upper Nepean River Tributaries Headwaters MZ.

**Table 5-2** indicates a very minor effects on Wongawilli Creek and within the Lake Cordeaux zone due to the western part of the Sandy Creek catchment overlying Longwall 19 (see **Figure 23**).

### 5.2.4 Simulated Take from Water Supply Catchments

In response to a recommendation by IEPMC (2018 or 2019a) [Table 1-4], the groundwater model has been used to provide estimates of the total surface water losses from the catchments to the dam wall (outlet) from Lake Avon and Lake Cordeaux. The surface water catchment to Lake Cordeaux is completely within the active domain of the groundwater model, while approximately 85% of the catchment of Lake Avon is within the active domain.

The results are summarized in **Table 5-7**, noting that these are for Dendrobium Mine Longwalls 1-21, including Longwall 19.

**Table 5-3 Surface Water Take from Water Supply Catchments [ML/yr]**

| 5 Year Interval | Lake Avon Zone | Lake Cordeaux Zone |
|---|---|---|
| 2011-15 | 18 | 312 |
| 2016-20 | 47 | 269 |
| 2021-25 | 483 | 420 |
| 2026-30 | 502 | 219 |
| 2031-35 | 281 | 118 |
| 2036-40 | 163 | 71 |
| 2041-45 | 114 | 55 |
| 2046-50 | 82 | 42 |
| 2051-55 | 36 | 38 |

The current model suggests that Dendrobium Mine could take up to 1,400 ML/yr of surface water (800-900 ML/yr from the water supply catchments and 400-500 ML/yr from Wongawilli and Donalds Castle Creeks during the period 2020-2030 and declining thereafter. Note that there is uncertainty in these estimates, based on the inability to predict actual weather conditions in the future, so they could range up and down depending on the occurrence of dry and wet years.

## 5.3 Simulated Groundwater Levels

As required by Condition 18(d) (**Table 1-3**), a variety of methods of presenting modelled groundwater levels are provided in the following sections. These have been updated from previous groundwater assessments consistent with a recent request by the IEPMC (2019a).

### 5.3.1 Contour Maps – Groundwater Levels

**Figure 27** to **Figure 38**, present modelled water levels for four 'layers' in the geological sequence at different times in the model simulation. These have been updated from previous groundwater assessments (HydroSimulations, 2019a and 2019b) consistent with requests from IEPMC. These figures now include more detailed contours over a greater geographical area alongside depth to water for each modelled layer/geological unit. These layers are:

- water table (calculated as the water level in the uppermost saturated model layer, i.e. uppermost saturated stratigraphic unit);
- lower Hawkesbury Sandstone (model layer 4);
- lower Bulgo Sandstone (model layer 7); and
- Wongawilli Coal seam (model layer 14).

**Figure 27** to **Figure 30** shows the modelled pre-mining conditions, **Figure 31** to **Figure 34** shows the conditions as simulated at the end of Longwall 20, and **Figure 35** to **Figure 38** shows the simulated groundwater levels in approximately 2200 (i.e. over 150 years after the end of mining in Area 3C).

Comparison of pre-mining conditions and to conditions at the end of mining in Areas 3A, 3B and 3C allows visual assessment of the effects of Dendrobium Mine, including Longwall 19, on water levels in those units. Significant drawdown occurs within the Wongawilli Seam (up to 290 m within the footprint of Longwall 19), lower Bulgo (approx. 125 m) and lower Hawkesbury Sandstone (10-20 m). The water table, as described above, is also disturbed by about 5 to 10 m in some locations around Longwall 19 and Area 3C.

Drawdown or depressurisation is predicted to occur at some distance outside the footprint of the longwalls. e.g. predicted heads in the lower Hawkesbury Sandstone (Layer 4) are about 345 mAHD at a point approximately 3 km west of Area 3B on **Figure 28**, and have declined to 335 mAHD on **Figure 32**. At a similar location, the depressurisation in the Bulgo Sandstone (Layer 7) is also simulated to show a 10 m decline in groundwater levels, dropping from 335 mAHD (**Figure 29**) down to 325 mAHD in **Figure 33**. The drawdown in the Wongawilli Seam is about 20 m at the same point.

Comparison of groundwater levels in the recovery period with pre-mining conditions suggests the water table and lower Hawkesbury will have recovered to close to pre-mining levels. The water levels in the Bulgo Sandstone and Wongawilli Seam are predicted to remain depressed compared to pre-mining conditions (see **Section 5.3.3**).

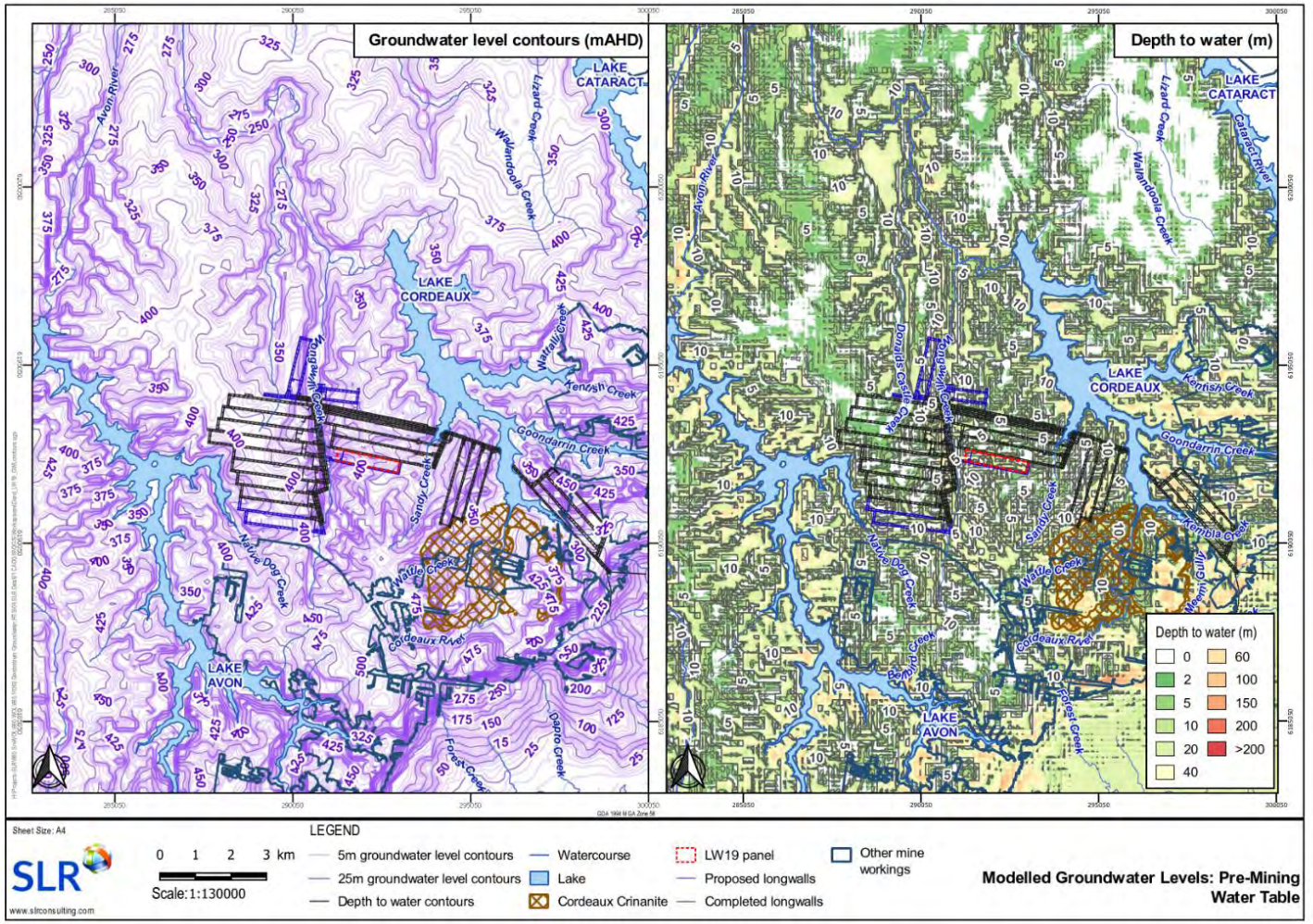



**Figure 27 Modelled Groundwater Levels and Depth to Water Table: Pre-Mining**

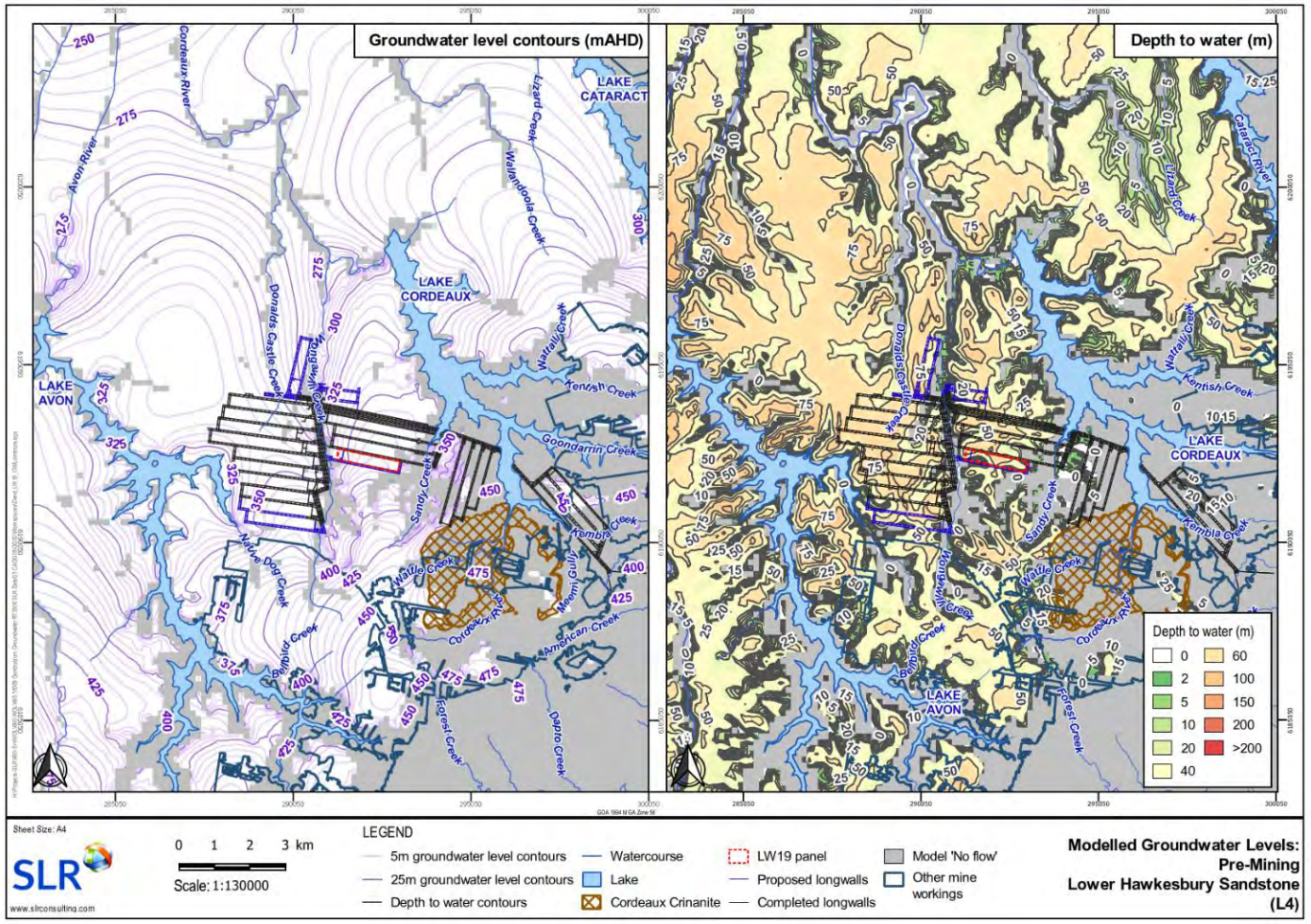



**Figure 28 Modelled Groundwater Levels and Depth to Water - Lower Hawkesbury Sandstone (L4): Pre-Mining**

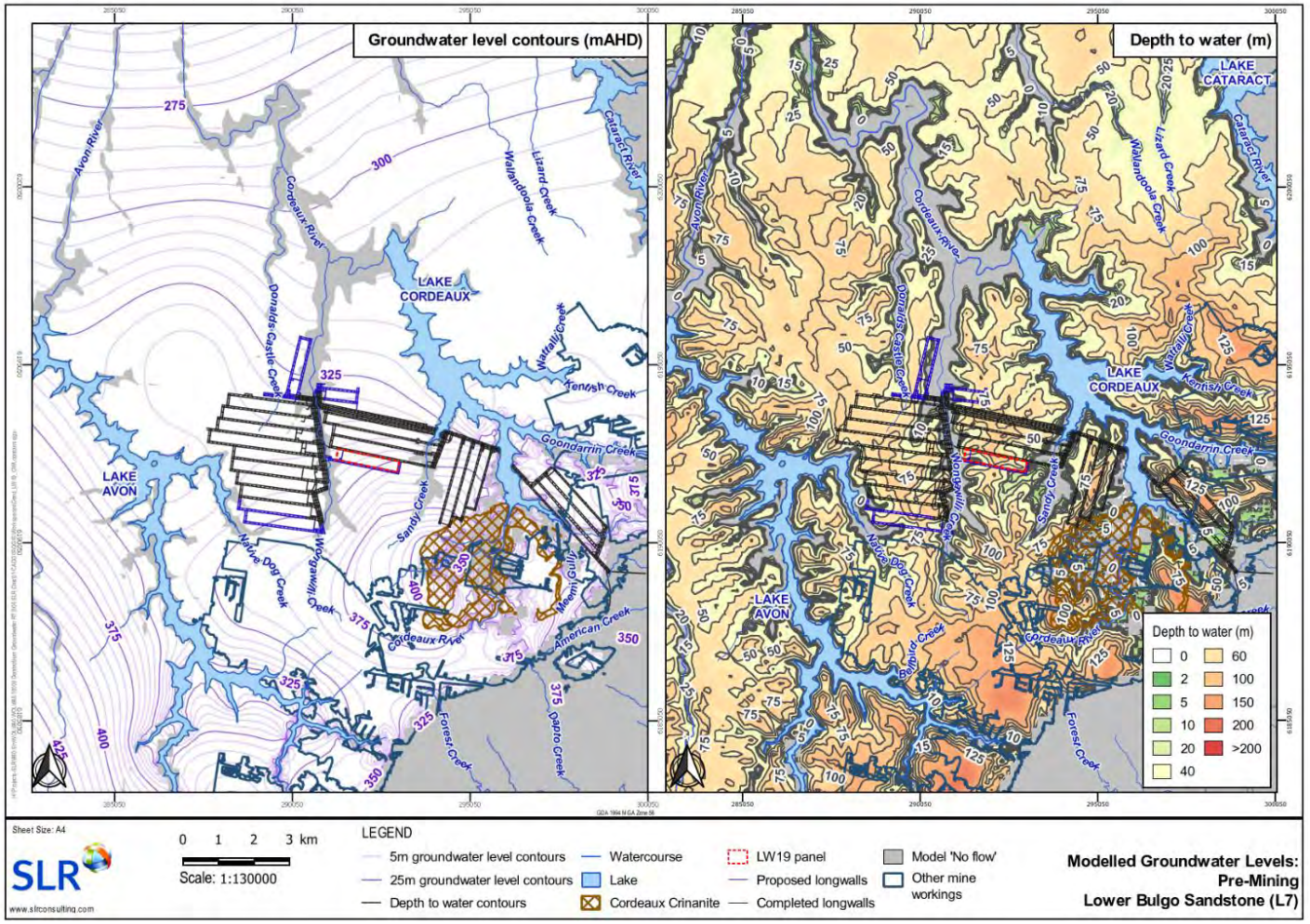



**Figure 29 Modelled Groundwater Levels and Depth to Water - Lower Bulgo Sandstone (L7): Pre-Mining**

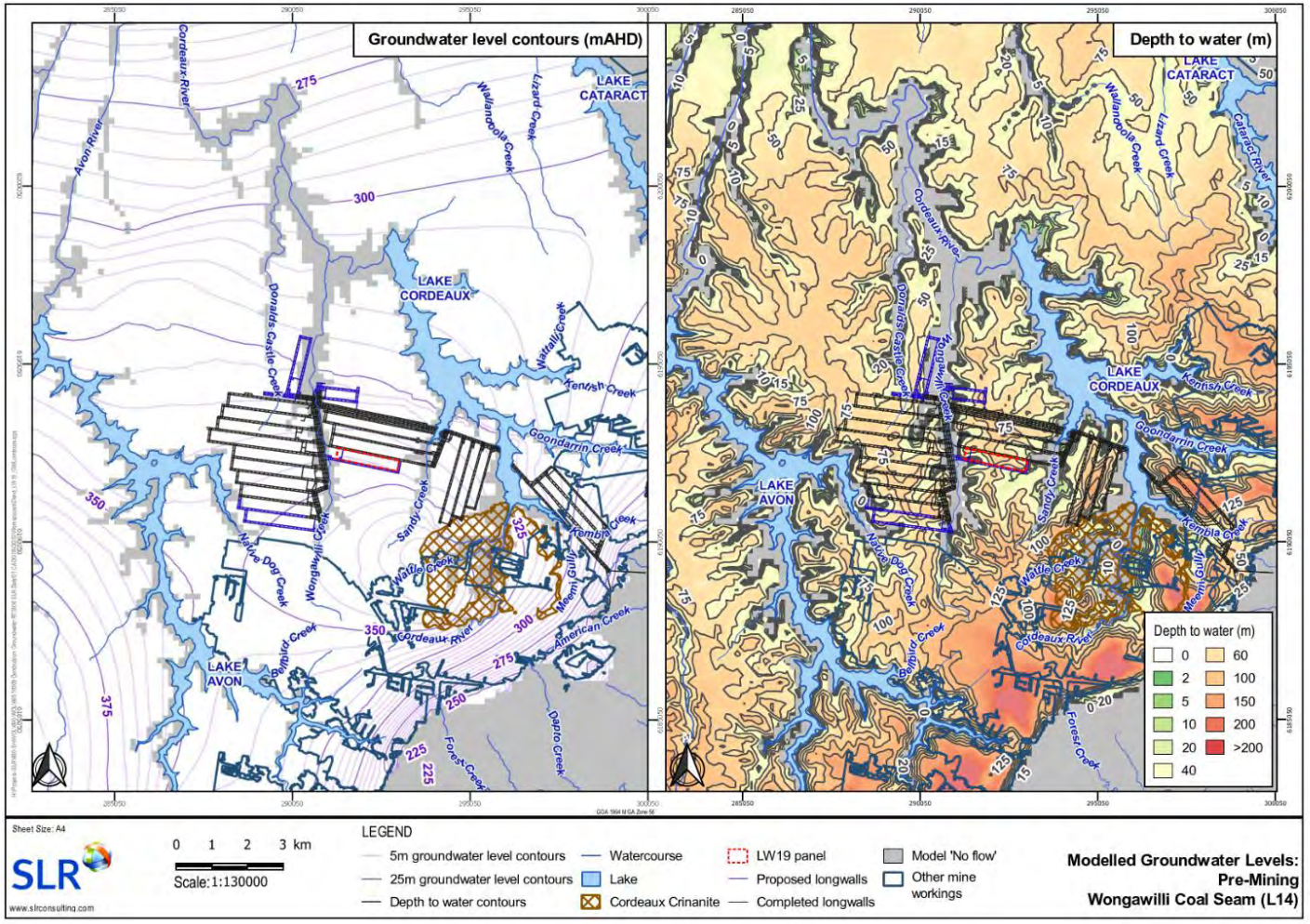



**Figure 30 Modelled Groundwater Levels and Depth to Water Wongawilli Coal Seam (L14): Pre-Mining**

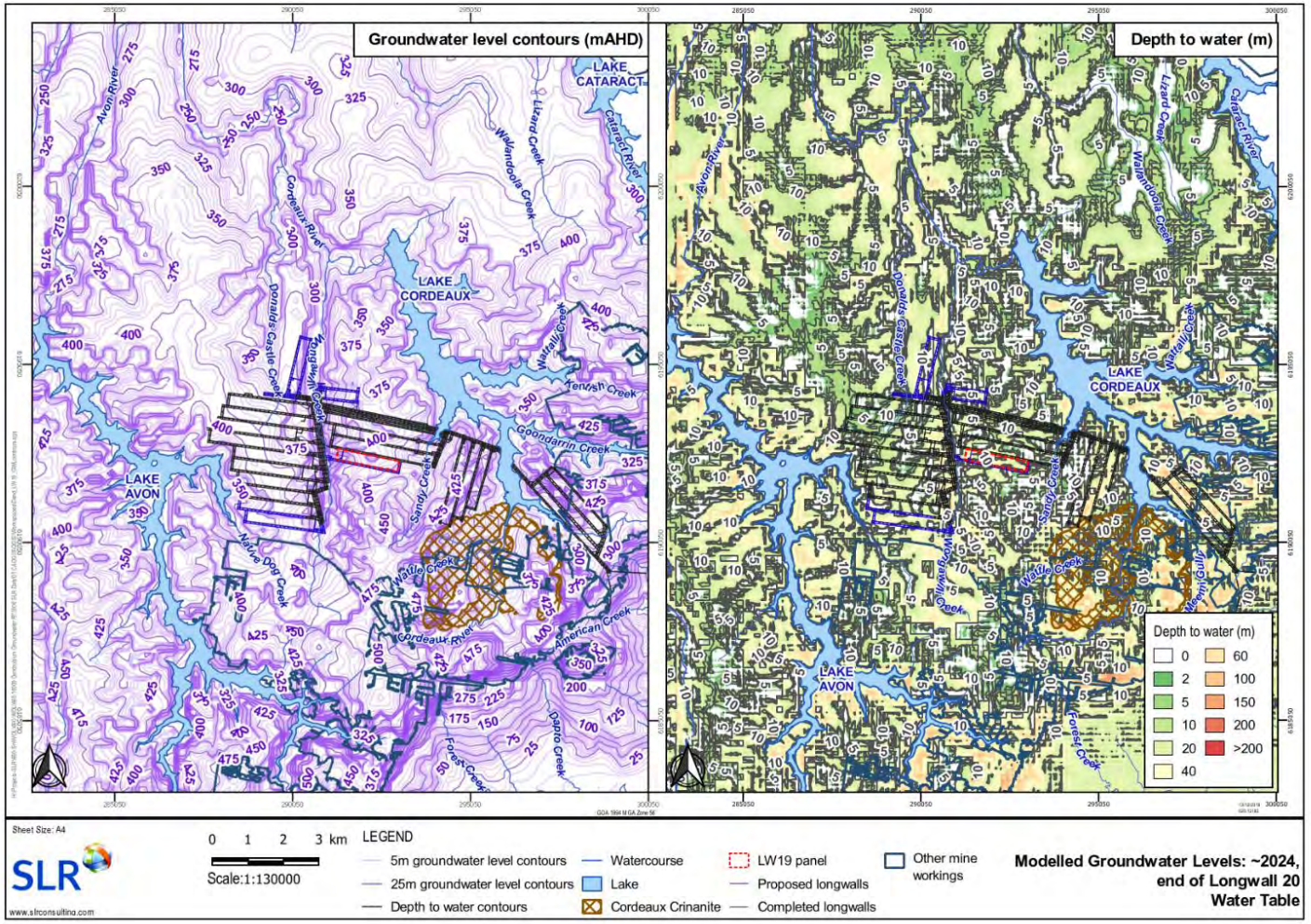



**Figure 31 Modelled Groundwater Levels and Depth to Water Table: ~2024 End of Longwall 20**

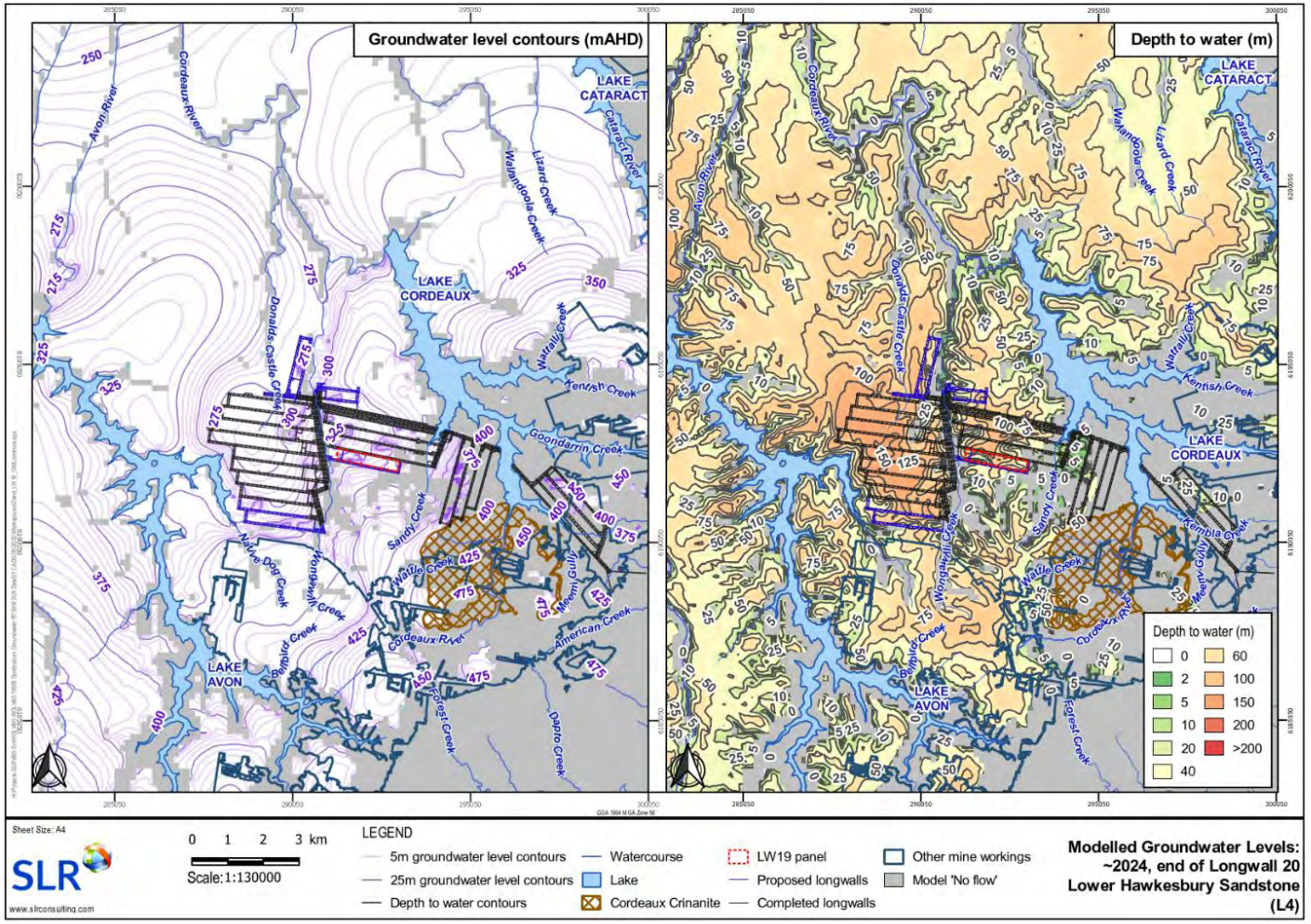



**Figure 32 Modelled Groundwater Levels and Depth to Water - Lower Hawkesbury Sandstone (L4): ~2024 End of Longwall 20**

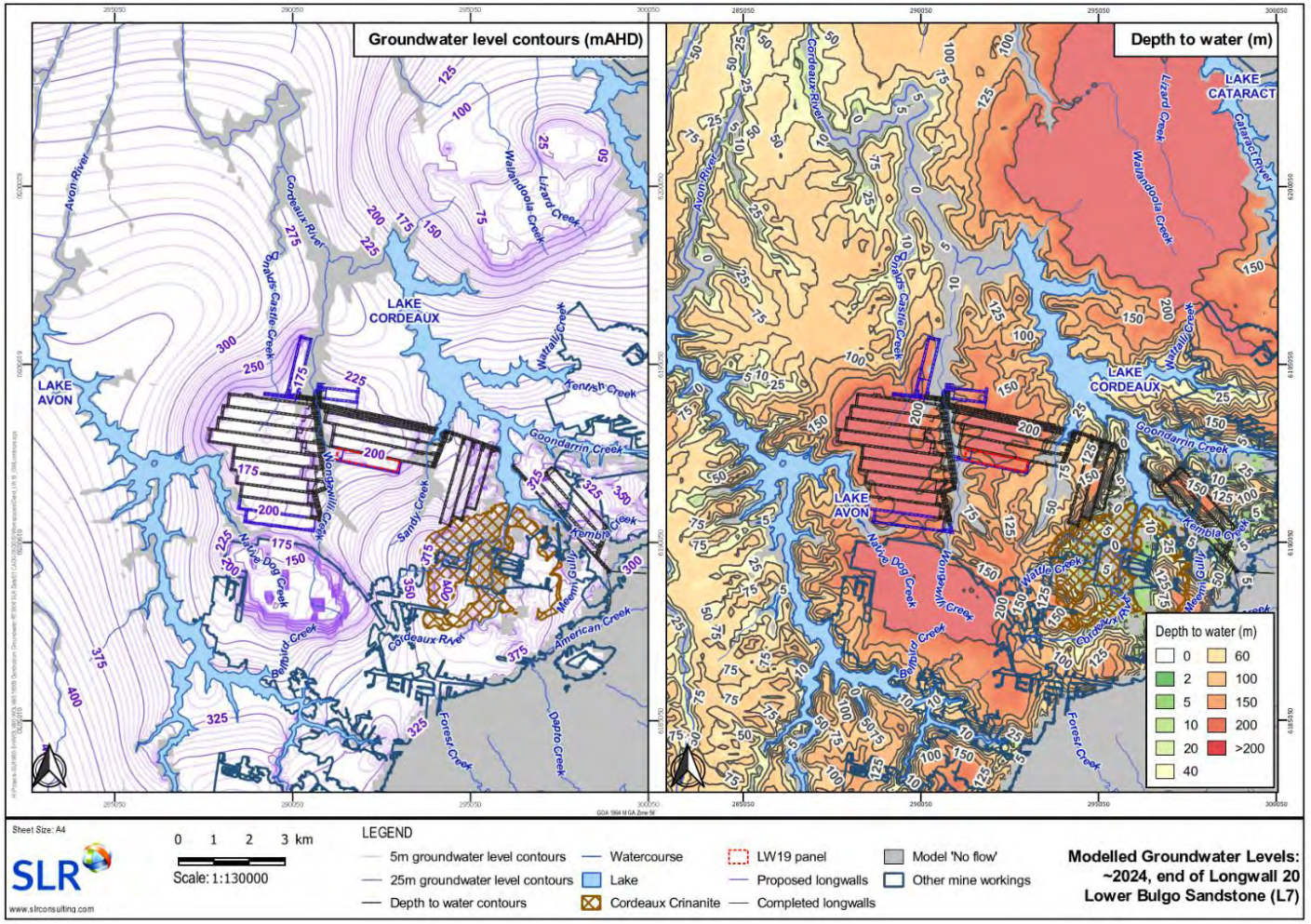



**Figure 33 Modelled Groundwater Levels and Depth to Water - Lower Bulgo Sandstone (L7): ~2024 End of Longwall 20**

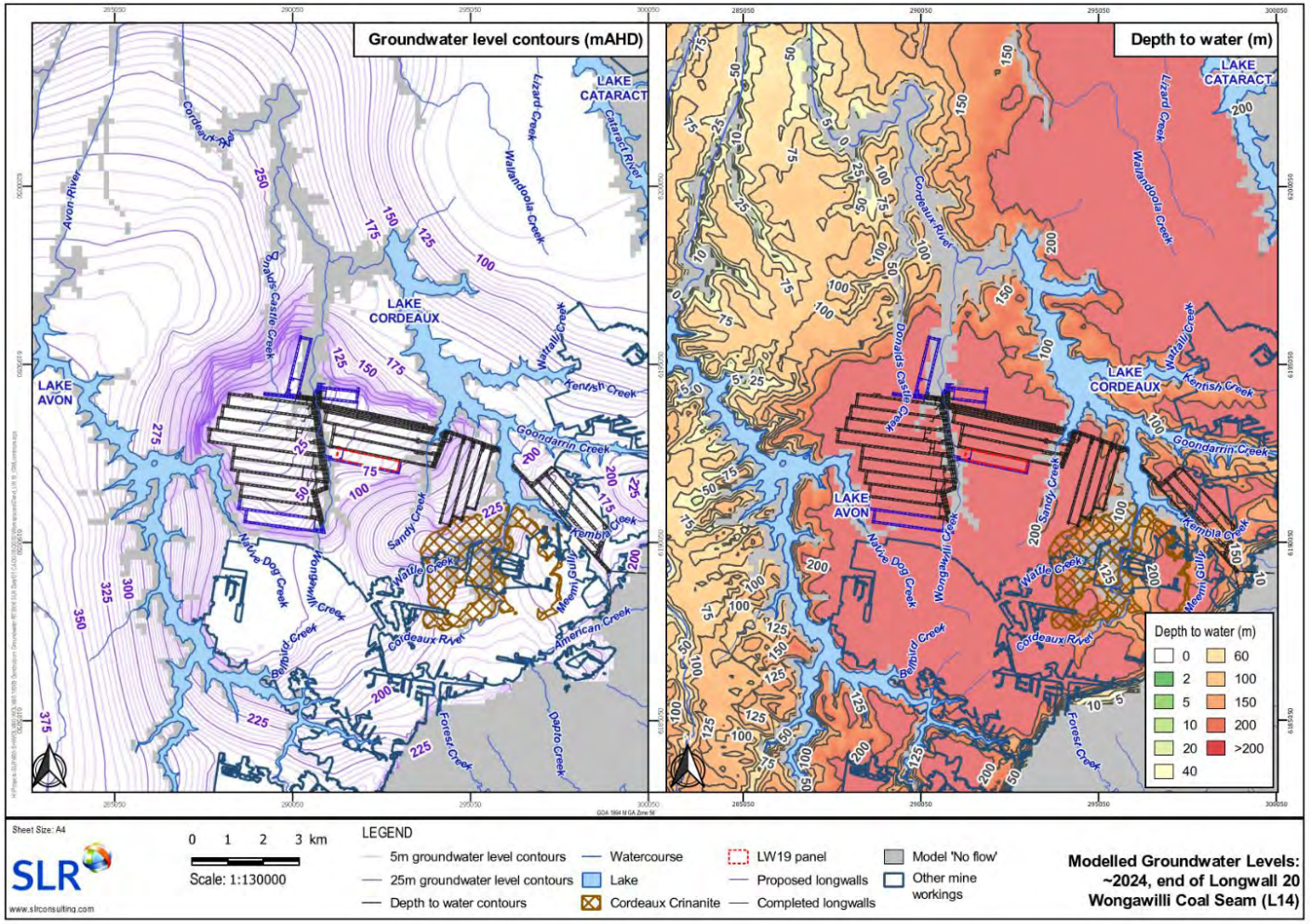



**Figure 34 Modelled Groundwater Levels and Depth to Water Wongawilli Coal Seam (L14): ~2024 End of Longwall 20**

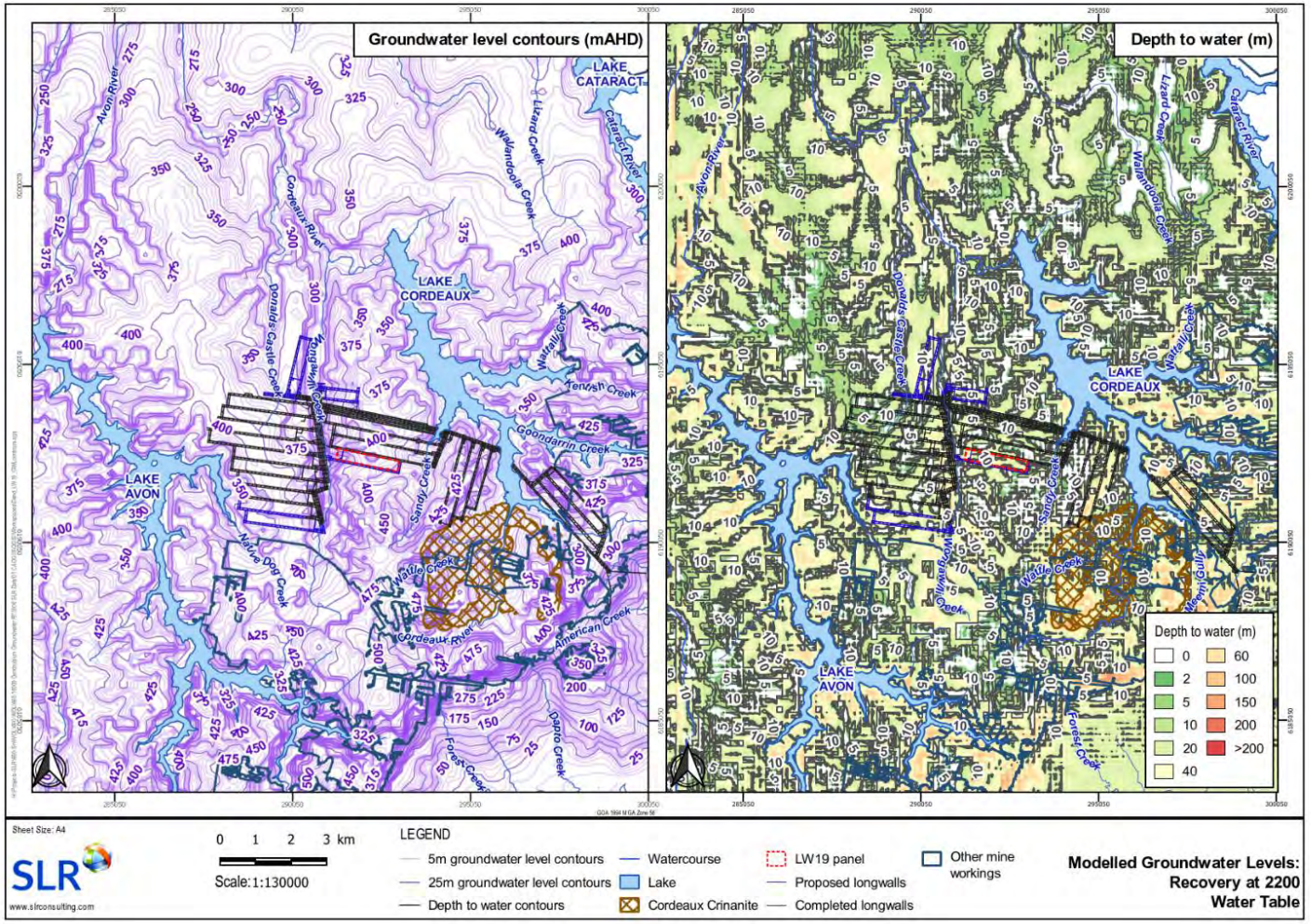



**Figure 35 Modelled Groundwater Levels and Depth to Water Table: Recovery at 2200**

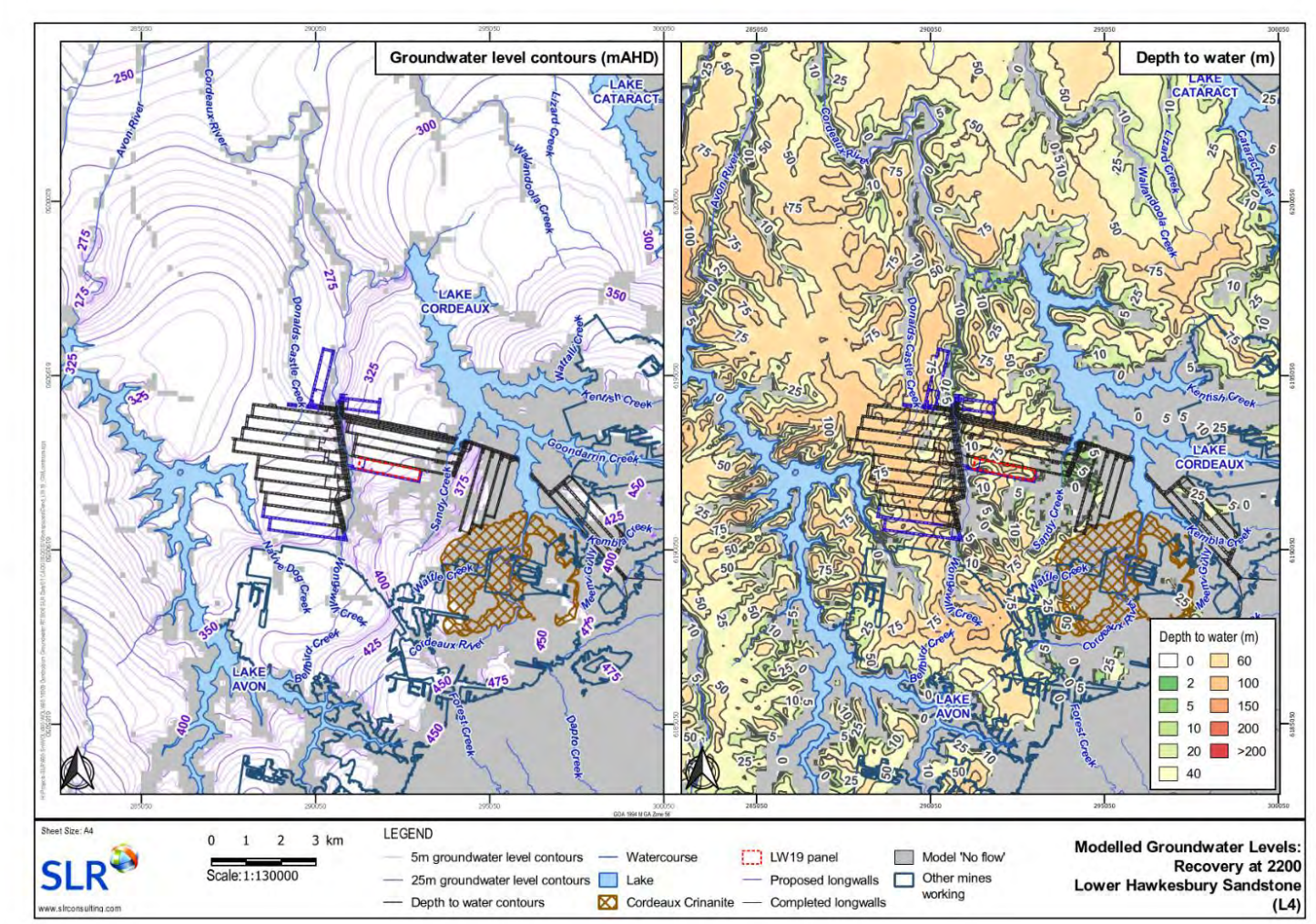



**Figure 36 Modelled Groundwater Levels and Depth to Water - Lower Hawkesbury Sandstone (L4): Recovery at 2200**

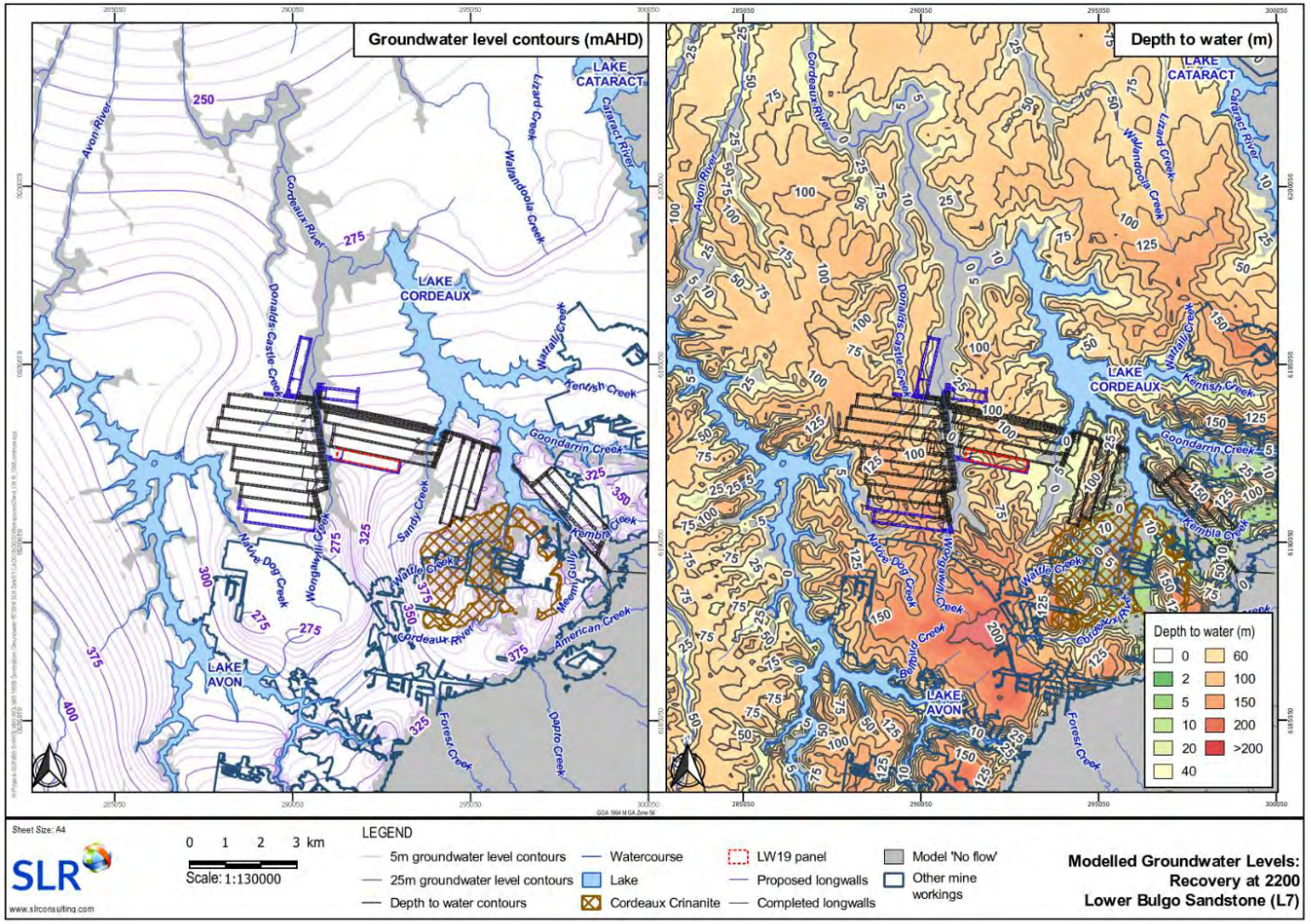



**Figure 37 Modelled Groundwater Levels and Depth to Water - Lower Bulgo Sandstone (L7): Recovery at 2200**

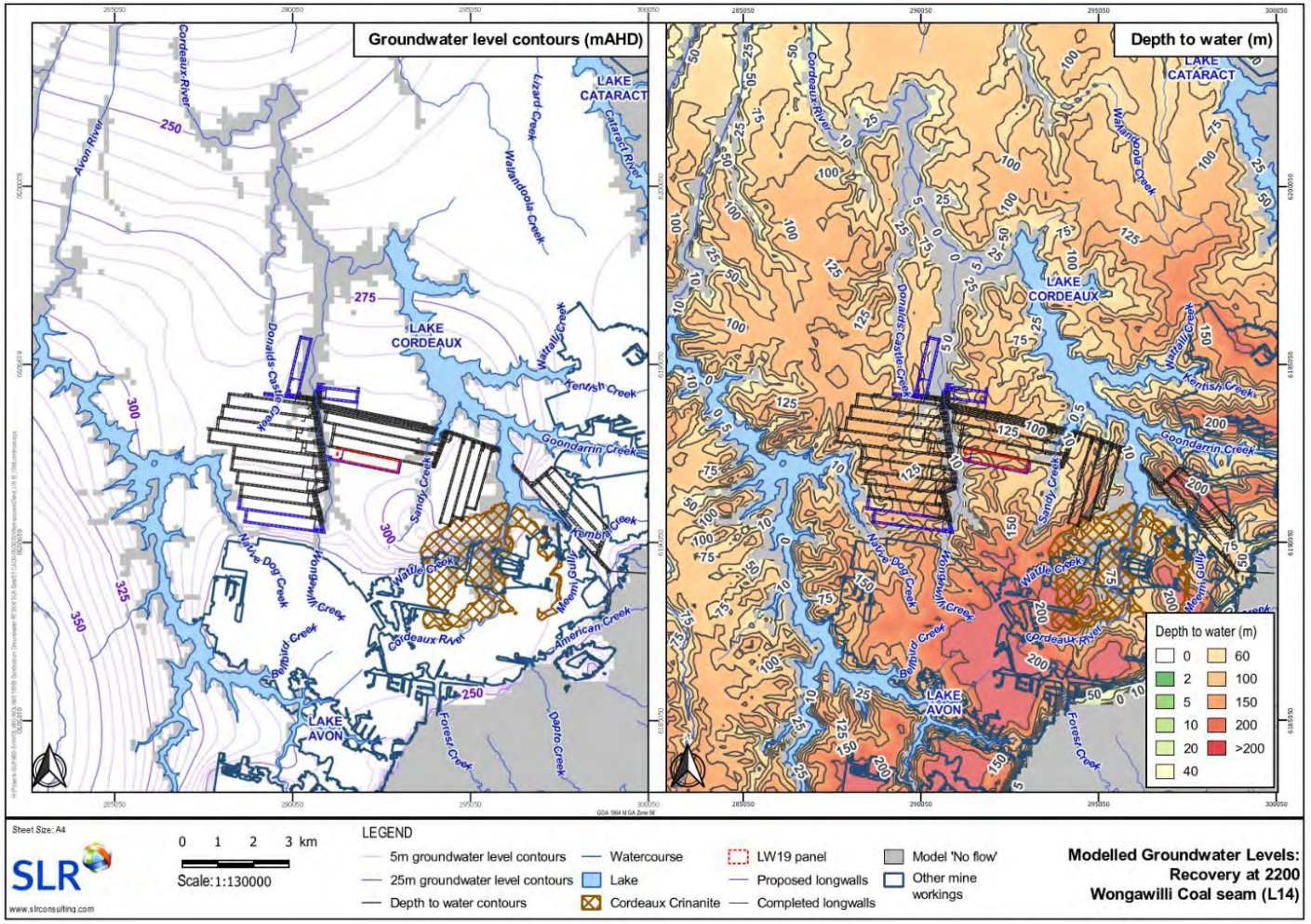



**Figure 38 Modelled Groundwater Levels and Depth to Water - Wongawilli Coal Seam (L14): Recovery at 2200**

### 5.3.2 Cross-Section – Pressure Head

A cross-section of modelled groundwater pressures, in metres ($mH_2O$) is presented in **Figure 39** for model row 130. The cross-section passes through Longwall 19 as shown on the thumbnail map within the figure. This section shows the development of pressures from pre-mining (steady state) model conditions, through the operation of Dendrobium to Longwalls 21, 19 and 20, and then through to a post-mining recovery phase.

This figure shows the relatively conservative nature of the stacked Drains method for representing groundwater drainage in the connected fracture zone, despite revised drain conductances being used in this model (see **Section 4.5.1.1**). The cross-section representing the end of mining at Areas 3A, 3B and 3C shows that the model simulates zero pressure at the surface overlying each mined area due to the imposition of the drain boundary conditions. In reality, delayed and incomplete drainage is expected due to the variable connection and somewhat random or tortuous nature of the fracture network.

The following can be observed through a comparison of the different time periods presented on each cross-section on **Figure 39**:

- Approximately 20 m of depressurisation below Lake Cordeaux from pre-mining conditions to the end of mining in Areas 3A to 3C. A return to pre-mining conditions is observed at the end of the mining recovery phase (i.e. ~175 years post-mining).
- Groundwater levels remain moderately depressed in the lower Hawkesbury Sandstone and Bald Hill Claystone above Area 3A, with pre-mining pressures being approximately 20-40 $mH_2O$ prior to mining and 5-20 $mH_2O$ at the end of the simulated recovery period.
- During mining, 5 to 10 m of depressurisation occurs in the mid Hawkesbury, 1 km from longwalls, including beneath Lake Avon.
- Depressurisation of 250 m at the Wongawilli Seam, recovering to within 40 m of pre-mining pressures.

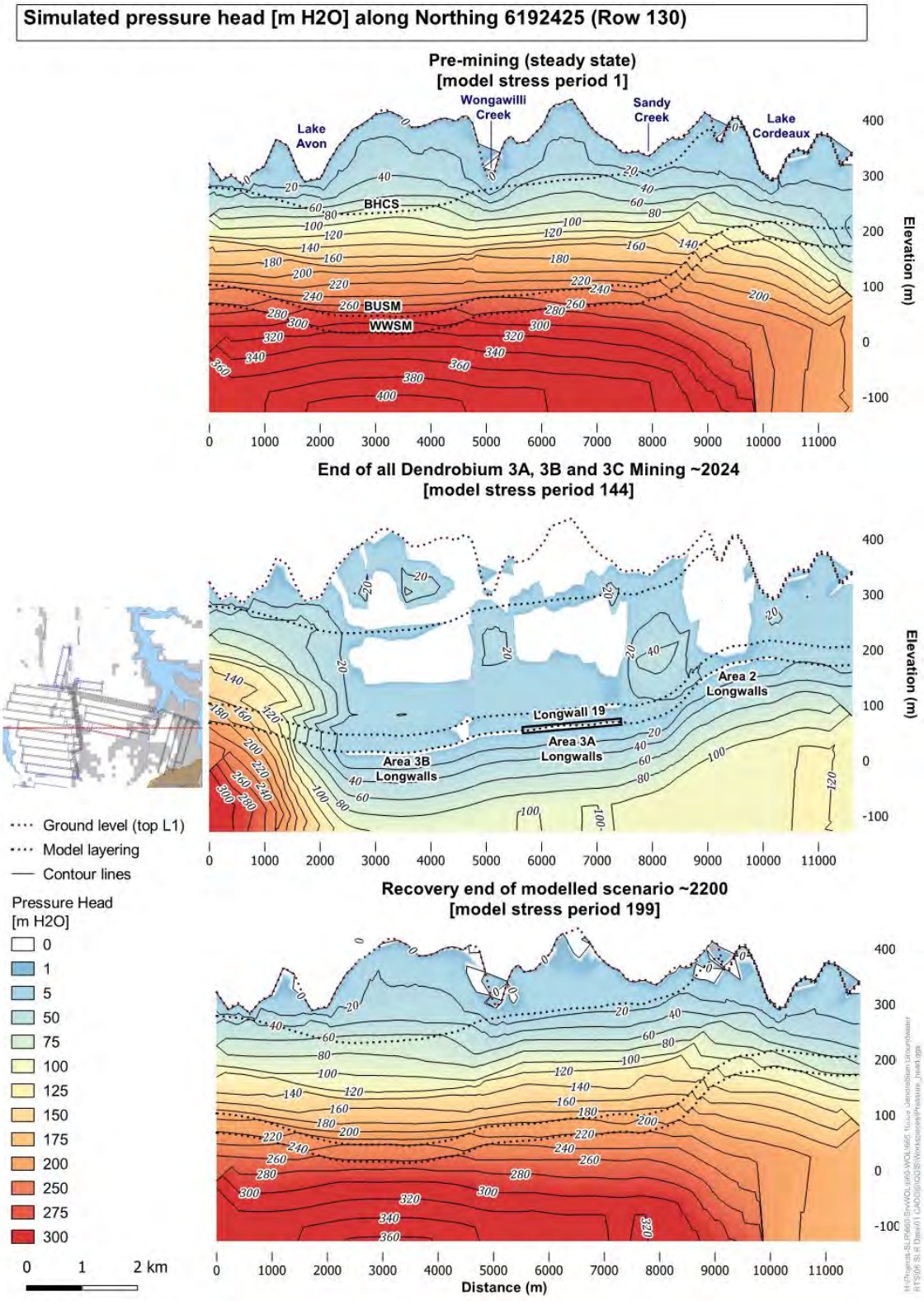



**Figure 39 Simulated Water Pressure Head (model row 130)**

### 5.3.3 Hydrographs – Groundwater Levels

Hydrographs of modelled groundwater levels through the geological sequence are provided in **Figure 40** and **Figure 41**. These show groundwater levels through time at several nominal locations surrounding Longwall 19 (these are referred to as 'monitoring wells' but are simply dummy locations used to inspect model results).

These figures show the degree of drawdown due to mining and illustrates the recovery of water levels is predicted to be partial (in many cases), recovery being relatively quick in the upper layers but occurring more slowly in the lower units (e.g. typically in all the layers below the Bald Hill Claystone).

The key points from each hydrograph are as follows:

- At a location 65 m from the thalweg of Wongawilli Creek and 230 m from the panel of Longwall 19 (**Figure 40**):
  - Water levels in the Bulli and Wongawilli Seams are predicted to experience around ~250 m of drawdown as a result of mining. This drawdown is achieved by the start of Longwall 5 in the Wongawilli Seam and the start of Longwall 14 in the Bulli Seam;
  - Above the seams, the Bulgo Sandstone (BUSS) and Stanwell Park Claystone (SPCS) (model layers 6 to 8) are predicted to experience gradual drawdown due to both mining prior to the extraction of Longwall 19, with no additional drawdown predicted after the start of Longwall 15;
  - Groundwater levels are predicted to have recovered largely to pre-mining conditions by approximately 2150;
  - Drawdown in the Bald Hill Claystone (BHCS) and Hawkesbury Sandstone (HBSS) is not apparent at this location. The BHCS continues to respond to rainfall recharge.
- At a location coincident with the location of bore S1870 (**Figure 41**):
  - Approximately 250-270 m of drawdown has been predicted for the Wongawilli and Bulli Seams as a result of mining activity, all of which has occurred prior to the simulated extraction of Longwall 19. By the end of the simulation, groundwater levels in these seams are still around 40 m below pre-mining groundwater levels;
  - Approximately 20 m of drawdown occurs in the BHCS during the extraction of Longwalls 6 and 7 (S1870 is located in the development headings separating Longwall 7 and 8);
  - Drawdown of 55 m, 90 m, and 150 m is predicted to occur in model layers 6 (Bulgo Sandstone - BUSS), 7 (lower BUSS) and 9 (Scarborough Sandstone – SBSS) respectively by the time extraction is simulated to occur at planned Longwall 16. The decline is gradual with drawdown first occurring prior to Longwall 5. Groundwater level recovery in the Bulgo Sandstone to above Lake Cordeaux levels is predicted to occur by 2150;
  - Despite predicted drawdown, groundwater levels in the Bald Hill Claystone and above remain higher than the full storage level (FSL) at Lake Cordeaux. This suggests that a reversal in the regional flow gradient of groundwater in the Hawkesbury Sandstone towards Lake Cordeaux is unlikely and mining in Areas 3A, 3B and 3C is unlikely to have a substantial impact on the lake;
  - Approximately 10 m of drawdown is modelled within the lower HBSS at this location after the extraction of Longwall 8. This layer recovers approximately 3 to 5 years after mining ends in Areas 3A, 3B and 3C;

- Spikes in simulated groundwater levels are apparent in the coal seams during historic mining. As discussed in **Section 4.6.3**, these groundwater levels are not true predictions and are likely an artefact of the changes in hydraulic conductivity and specific yield throughout the simulated progression of mining.

- At a location coincident with the location of bore S1907 (**Figure 42**):
  - Drawdown is predicted to occur below the BHCS as a result of mining. Initial declines are predicted to first occur in the BUSS and below after the extraction of Longwall 7 (~865 m north of this bore), however, largest declines are predicted to occur following the extraction of Longwalls 18 and 21. Drawdown in the coal seams ranges between 290-300 m, and is approximately 45 m in the BHCS;
  - Longwall 19 is predicted to impose an additional drawdown of approximately 15 m in the coal seams;
  - Groundwater levels at this location do not recover for affected layers for the period of simulated recovery period. The BHCS remains ~10 m below pre-mining groundwater levels, while the Wongawilli Seam remains approximately 245 m lower than pre-mining water levels;
  - Drawdown is not predicted to occur in the lower HBSS and it remains responsive to rainfall recharge.

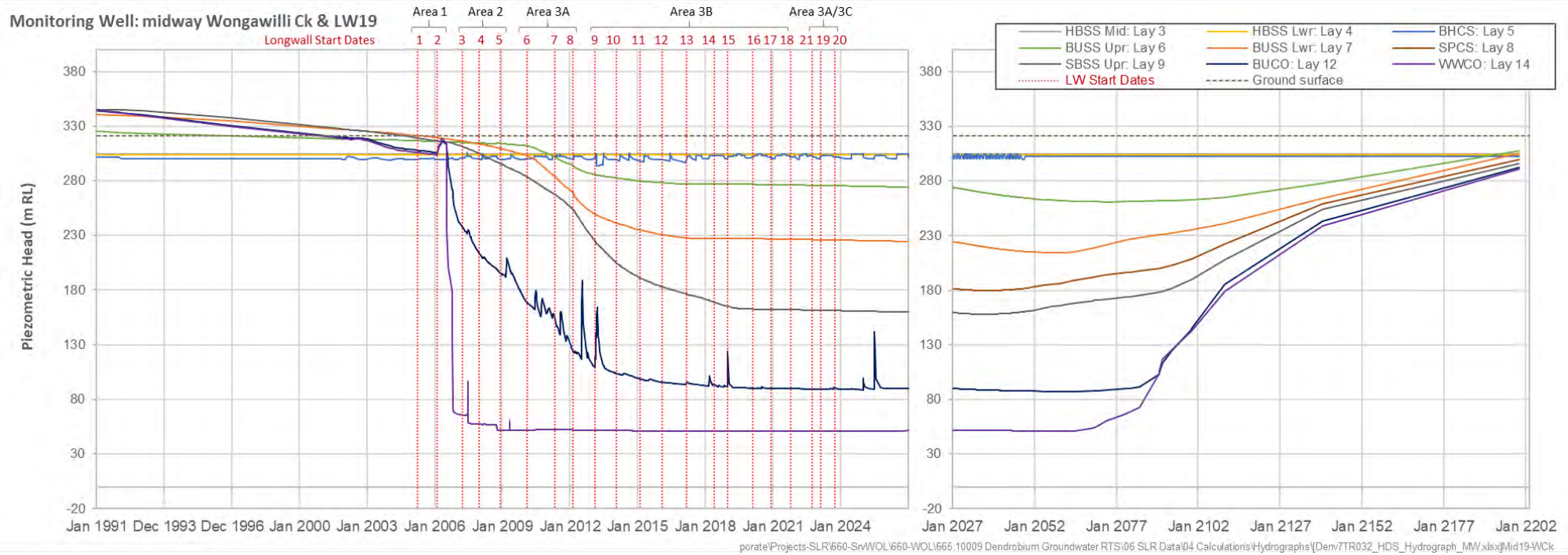



**Figure 40 Modelled Groundwater Level Hydrographs for Monitoring Bore Between Longwall 19 and Wongawilli Creek**

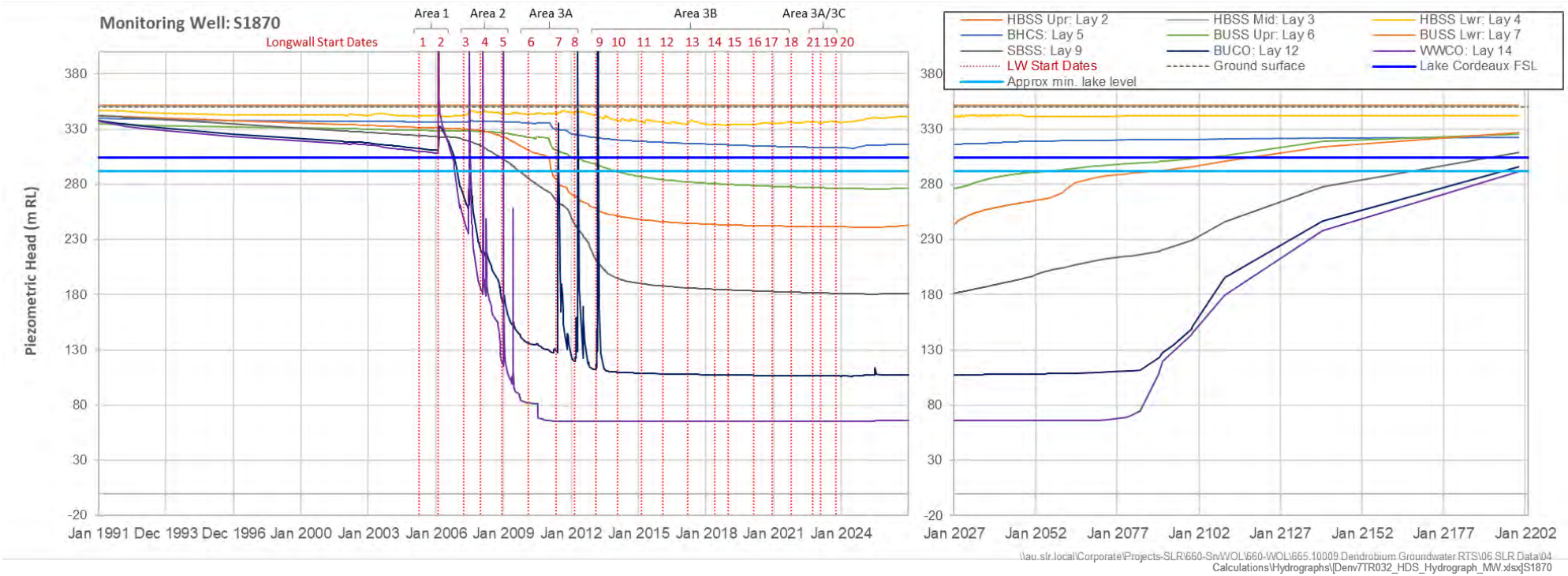



**Figure 41 Modelled Groundwater Level Hydrographs for Monitoring Bore at S1870**

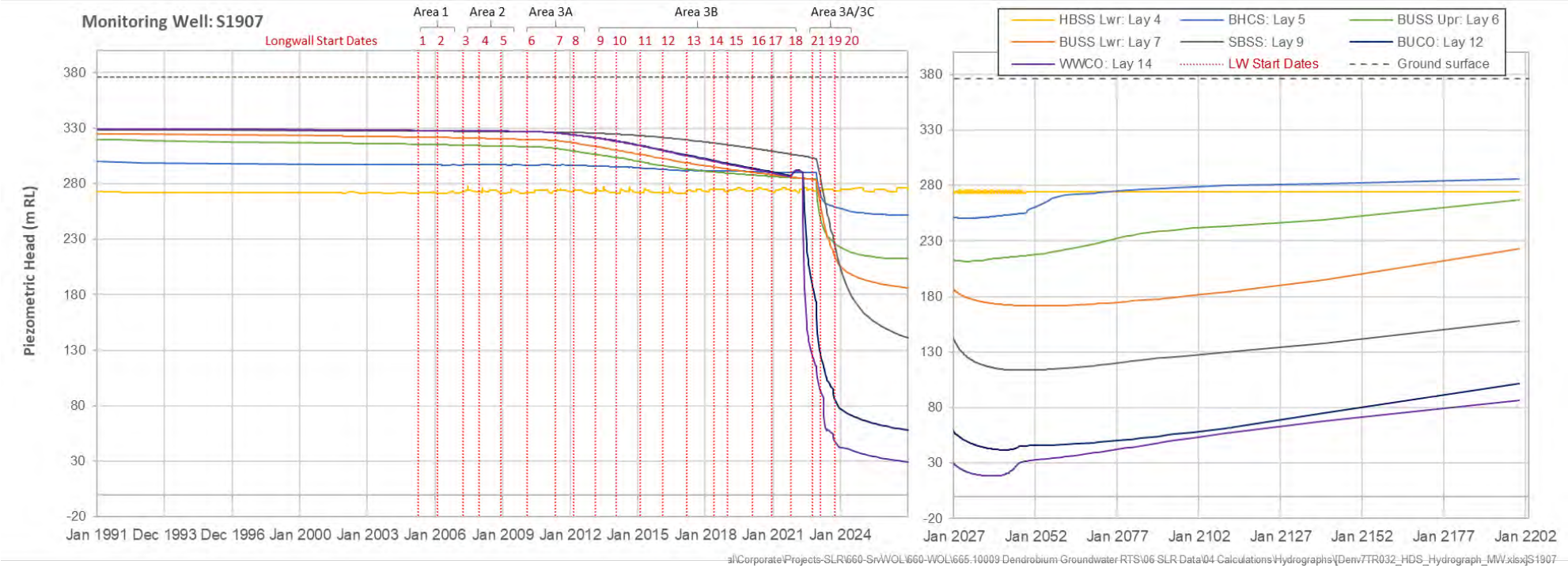



**Figure 42 Modelled Groundwater Level Hydrographs for Monitoring Bore at S1907**

### 5.3.4 Groundwater Drawdown at Groundwater Bores

The nearest Groundwater Works (bores) from the NSW government bore database are described in **Section 2.4**. The maximum predicted drawdown at each of these sites has been determined and is listed in **Table 5-4**. For reference, the Aquifer Interference Policy (2012) deems the threshold for 'minimal harm' to be 2 m. The model suggests that none of the nearest bores would be adversely affected by the extraction of Longwall 19 or Dendrobium as a whole, which is consistent with the significant distance between the bores and mine (Section 2.4).

**Table 5-4 Maximum Predicted Drawdown at Groundwater Works**

| GW Works # | Depth | Stratigraphy | Layer | Predicted Max Drawdown (m) Due to: | |
|---|---|---|---|---|---|
| | | | | Dendrobium | Longwall 19 |
| GW112386 | 6-24 m | Hawkesbury Sandstone | 4 | 0.1 | 0.0 |
| GW0490945 | 110-170 m | Hawkesbury Sandstone | 4 | 0.0 | 0.0 |
| GW068119 | 9-19 m | Shoalhaven Group | 17 | 0.0 | 0.0 |
| GW102528 | 17-169 m | Hawkesbury Sandstone | 3, 4 | 0.0 | 0.0 |

The cumulative drawdown to all mining within the model domain has been simulated, however given the low magnitude of drawdown at Groundwater Works (bores) due to the historical and proposed operation of Dendrobium (i.e. <0.1 m, as in **Table 5-4)**, the cumulative drawdowns have not been reported as they are not related to the Dendrobium Mine.

# 6 Monitoring

IMC have installed a combination of Time-Domain Reflectometry and multi-level piezometers directly above Longwalls 14 and 15 (as per the conditions in **Table 1-3**) and in other Area 3A and 3B longwalls. The analysis of this data is being finalised at the time of writing.

New groundwater monitoring sites are not currently recommended for Longwall 19, provided that existing monitoring bores around this site (e.g. S1870, s1879, s1907) remain active. SLR is currently preparing a long-term groundwater monitoring program for IMC, and this will be provided in a separate document.

Re-instatement of tritium sampling in Area 3A is desirable, however, given operational constraints regarding groundwater being pumping from Area 3B into Area 3A, as well as possible overflow from Area 2, it is considered that the effort to modify the drainage and pumping infrastructure in the underground mine may be excessive for a single longwall, especially when the results may not be representative of inflow to Area 3A (due to flow components from other areas).

# 7 Conclusions

The numerical groundwater model has been modified from previous modelling (Coffey, 2012; HydroSimulations 2013, 2014, 2016a, 2018, 2019a and 2019b). As per **Section 4.6** this was done following the acquisition of more up-to-date data that indicated that model assumptions could be revised in order to better match real-world parameters. These updates included an increase of the Kh parameters for two coal seams simulated within the model based on an analysis of drillstem test data presented in HydroSimulations (2019c). Conductances applied to the model drain cells used to represent the height of complete drainage above the mine seam were also revised to incorporate assumptions on the same parameters made in HydroSimulations (2019c). These modifications have allowed improved model calibration for mine inflows and groundwater levels.

This model is now assessed for calibration against a large dataset of groundwater levels from more than 600 target locations, as required by the Conditions of Approval. Further, HydroSimulations (2018) calibrated the model to mine inflow in each mine area as well as the total inflow and groundwater levels, as well as constraining the model to field-derived values of permeability.

The following results were obtained from the revised groundwater model:

- The model matches historical inflow to the Dendrobium Mine with reasonable accuracy for total mine inflow and the dynamic pattern of inflow to individual areas. This provides confidence in assessing associated changes in the catchment water balance.
- Dendrobium Mine inflows or groundwater make is predicted to be more than predicted previously, peaking at about 16 ML/d, although this is clearly higher than realistic (the model was a good match to total mine inflow until 2017, and for 2018-19 has been predicting about twice the recorded inflow). The extraction of Longwall 19 would cause an increase in Area 3A inflow from 1.5 ML/d to approximately 3 ML/d of the total during 2023.
- In the case of the Avon Reservoir, the simulated incremental leakage from the reservoir storage due to extraction of Longwall 19 is effectively zero, which is logical given the distance between the panel and the reservoir. Predicted losses due to Dendrobium Areas 1-3C, with and without Longwall 19, are less than Dams Safety NSW's prescribed tolerable limit.
- Leakage from Cordeaux Reservoir is also predicted to be less than the prescribed tolerable limit, and the incremental rate due to Longwall 19 is also effectively zero.
- Incidental surface water losses have been estimated using the groundwater model and tabulated as required in **Table 5-1**. The predicted take is up to 1400 ML/yr from all surface water sources and catchments, while the incremental take due to Longwall 19 is up to about 90 ML/yr (a range of estimates of surface water losses are presented through time in **Table 5-2**).
- The nearest registered groundwater work is 4.8 km north-east of Dendrobium Area 3B. Drawdown due to Dendrobium mining is predicted to be <0.1 m at this monitoring bore. No other groundwater works are predicted to be affected to any degree and none meet the 2 m threshold in the Aquifer Interference Policy.
- The nearest High Priority Groundwater Dependent Ecosystem (GDE), as defined in the relevant WSP (Section 1.4) is the Macquarie Rivulet Estuary which is over 16 km from Dendrobium Area 3C (**Figure 3**). No drawdown effects will occur at this location as a result of mining at Dendrobium.

Assessment against the Aquifer Interference (AI) Policy is summarised in **Table 7-1**.

## Table 7-1 Summary

| Aquifer | Sydney Basin Porous Rock (Nepean Sandstone Groundwater Source, Management Zone 2) | |
|---|---|---|
| Category | Highly Productive | |
| **Level 1 Minimal Impact Consideration** | | **Assessment** |
| **Water Table**<br>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:<br>- high priority groundwater dependent ecosystem; or<br>- high priority culturally significant site;<br>listed in the schedule of the relevant water sharing plan.<br>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).<br>There are no High Priority Groundwater Dependent Ecosystems (GDEs) listed in this WSP within 15 km of Dendrobium Areas 1-3C. Hence there are no known risks of mine development to such sites.<br>There are no Culturally Significant Sites in the Study Area listed in the WSP. Hence there are no known risks of mine development to such sites.<br>There is minimal risk of drawdown in excess of the water supply work drawdown criterion within the Permo-Triassic or shallow strata (based on the distance to registered groundwater works).<br>**Level 1 minimal impact consideration classification.** |
| **Water pressure**<br>A cumulative pressure head decline of not more than a 2m decline, at any water supply work. | | There is the a very minor risk of depressurisation in excess of the water supply work drawdown criterion within the Permo-Triassic strata (at GW112386).<br>**Level 1 minimal impact consideration classification.** |
| **Water quality** | | Mining-induced changes to the hydraulic properties and depressurisation of the strata in the Dendrobium Mine area may result in mixing of potentially chemically different groundwater between overlying and underlying units. However, it is considered unlikely that this will result in changes to the beneficial uses of groundwater in the Permo-Triassic rock units. The risk of water quality impacts decreases with distance from the mine footprint.<br>**Level 1 minimal impact consideration classification.** |

# 8 Recommendations

Recommendations for future data analysis and modelling are as follows:

- IMC have installed a number of centre-line goaf holes above existing longwalls in Areas 3A and 3B. Review of the analysis of the permeability and water level data and analysis by HGEO and Hebblewhite (which are currently in progress) should be undertaken once that is complete. Some early findings have been considered here based on discussion with HGEO, however once that report is finalised, the conceptual and numerical models should be revised based on that assessment
- Multivariate analysis of permeability. It became apparent during the calibration process for HydroSimulations (2018) that the focus on the extent and degree of strata deformation in trying to achieve model calibration may be misplaced, with a focus on variation in 'host' permeability (e.g. variation due to lithology/facies, weathering/structure or related to depth) providing for improved calibration results. HydroSimulations has compiled much of IMC's permeability data (although the data presented in **Appendix B** is not completely up-to-date), however some older data needs to be transferred into database format, and HydroSimulations/SLR are progressing with further analysis that should assist in informing the numerical model. Reporting on this will occur in a forthcoming groundwater assessment.
- Associated with this and noting the valid comment by IEPMC (2018 and 2019a) regarding the apparent divergence in hydraulic conductivity parameters used in the modelling for Dendrobium and for Metropolitan Mine, the model values used in the current Dendrobium model are well constrained by packer test data. However, further analysis across the Southern Coalfield would be useful, i.e. including data from Appin Mine, Tahmoor Mine, Metropolitan Mine, Russell Vale Mine, and that held by WaterNSW.
- Values of specific storage used in the modelling should be reviewed, with geotechnical parameters used to derive or constrain specific storage values. This may have little bearing on the near-surface impact assessment predictions but may improve calibration to groundwater levels in some of the deeper layers.
- Consideration of the timing of fracture zone development might assist in future calibration to inflow. It may be that the overestimation of inflow during the early period of each mine area, and subsequent underestimation after the active extraction phase, is due in part to delayed deformation in the goaf as subsequent longwalls pass. FLAC2D modelling may assist with understanding this.

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# APPENDIX A

## Model Timing

| Stress Period | Days | Date From | Date To | Scheduled Mining | Comment / Rainfall-Inflow behaviour |
|---|---|---|---|---|---|
| 1 | Steady state | | | | |
| 2 | 730 | 1/01/1990 | 31/12/1991 | | |
| 3 | 3608 | 1/01/1992 | 16/11/2001 | | |
| 4 | 20 | 17/11/2001 | 6/12/2001 | | |
| 5 | 20 | 7/12/2001 | 26/12/2001 | | |
| 6 | 20 | 27/12/2001 | 15/01/2002 | | |
| 7 | 40 | 16/01/2002 | 24/02/2002 | | |
| 8 | 100 | 25/02/2002 | 4/06/2002 | | |
| 9 | 100 | 5/06/2002 | 12/09/2002 | | |
| 10 | 100 | 13/09/2002 | 21/12/2002 | | |
| 11 | 200 | 22/12/2002 | 9/07/2003 | | |
| 12 | 200 | 10/07/2003 | 25/01/2004 | | |
| 13 | 200 | 26/01/2004 | 12/08/2004 | | |
| 14 | 232 | 13/08/2004 | 1/04/2005 | Start LW1 | |
| 15 | 90 | 2/04/2005 | 30/06/2005 | | |
| 16 | 90 | 1/07/2005 | 28/09/2005 | End LW1 | |
| 17 | 74 | 29/09/2005 | 11/12/2005 | | |
| 18 | 60 | 12/12/2005 | 9/02/2006 | Start LW2 | |
| 19 | 60 | 10/02/2006 | 10/04/2006 | | |
| 20 | 95 | 11/04/2006 | 14/07/2006 | | |
| 21 | 95 | 15/07/2006 | 17/10/2006 | End LW2 | |
| 22 | 96 | 18/10/2006 | 21/01/2007 | Start LW3 | |
| 23 | 99 | 22/01/2007 | 30/04/2007 | | |
| 24 | 44 | 1/05/2007 | 13/06/2007 | | A2rain1 |
| 25 | 4 | 14/06/2007 | 17/06/2007 | | A2week1 |
| 26 | 8 | 18/06/2007 | 25/06/2007 | | A2inflow1 |
| 27 | 43 | 26/06/2007 | 7/08/2007 | End LW3 | |
| 28 | 100 | 8/08/2007 | 15/11/2007 | | |
| 29 | 33 | 16/11/2007 | 18/12/2007 | Start LW4 | |
| 30 | 47 | 19/12/2007 | 3/02/2008 | | A2 Rain2 |
| 31 | 6 | 4/02/2008 | 9/02/2008 | | A2 week2 |
| 32 | 8 | 10/02/2008 | 17/02/2008 | | A2 inflow2 |
| 33 | 36 | 18/02/2008 | 24/03/2008 | | |
| 34 | 50 | 25/03/2008 | 13/05/2008 | | |
| 35 | 32 | 14/05/2008 | 14/06/2008 | End LW4 | |
| 36 | 110 | 15/06/2008 | 2/10/2008 | | |
| 37 | 31 | 3/10/2008 | 2/11/2008 | | |
| 38 | 30 | 3/11/2008 | 2/12/2008 | Start LW5 | |
| 39 | 31 | 3/12/2008 | 2/01/2009 | | |
| 40 | 60 | 3/01/2009 | 3/03/2009 | | |
| 41 | 60 | 4/03/2009 | 2/05/2009 | | |
| 42 | 17 | 3/05/2009 | 19/05/2009 | | A2rain3 |
| 43 | 5 | 20/05/2009 | 24/05/2009 | | A2week3 |
| 44 | 8 | 25/05/2009 | 1/06/2009 | | A2inflow3 |
| 45 | 22 | 2/06/2009 | 23/06/2009 | | |
| 46 | 88 | 24/06/2009 | 19/09/2009 | End LW5 | |
| 47 | 90 | 20/09/2009 | 18/12/2009 | | |
| 48 | 53 | 19/12/2009 | 9/02/2010 | Start LW6 | |
| 49 | 105 | 10/02/2010 | 25/05/2010 | | A2rain4 |
| 50 | 10 | 26/05/2010 | 4/06/2010 | | A2week4 |
| 51 | 8 | 5/06/2010 | 12/06/2010 | | A2inflow4 |
| 52 | 22 | 13/06/2010 | 4/07/2010 | | |
| 53 | 75 | 5/07/2010 | 17/09/2010 | | |

| Stress Period | Days | Date From | Date To | Scheduled Mining | Comment / Rainfall-Inflow behaviour |
|---|---|---|---|---|---|
| 54 | 72 | 18/09/2010 | 28/11/2010 | | A2rain5 |
| 55 | 9 | 29/11/2010 | 7/12/2010 | | A2week5 |
| 56 | 8 | 8/12/2010 | 15/12/2010 | | A2inflow5 |
| 57 | 22 | 16/12/2010 | 6/01/2011 | | |
| 58 | 71 | 7/01/2011 | 18/03/2011 | | A2rain6 |
| 59 | 4 | 19/03/2011 | 22/03/2011 | End LW6 | A2week6 |
| 60 | 8 | 23/03/2011 | 30/03/2011 | StartLW7 | A2inflow6 |
| 61 | 60 | 31/03/2011 | 29/05/2011 | | A2rain7 |
| 62 | 4 | 30/05/2011 | 2/06/2011 | | A2week7 |
| 63 | 8 | 3/06/2011 | 10/06/2011 | | A2inflow7 |
| 64 | 38 | 11/06/2011 | 18/07/2011 | | A2rain8 |
| 65 | 5 | 19/07/2011 | 23/07/2011 | | A2inflow8 |
| 66 | 8 | 24/07/2011 | 31/07/2011 | | A2inflow8 |
| 67 | 22 | 1/08/2011 | 22/08/2011 | | |
| 68 | 69 | 23/08/2011 | 30/10/2011 | End LW7 | |
| 69 | 85 | 31/10/2011 | 23/01/2012 | Start LW8 | |
| 70 | 35 | 24/01/2012 | 27/02/2012 | | A2rain9 |
| 71 | 11 | 28/02/2012 | 9/03/2012 | | A2week9 |
| 72 | 8 | 10/03/2012 | 17/03/2012 | | A2inflow9 |
| 73 | 31 | 18/03/2012 | 17/04/2012 | | |
| 74 | 85 | 18/04/2012 | 11/07/2012 | | |
| 75 | 85 | 12/07/2012 | 4/10/2012 | End LW8 | |
| 76 | 86 | 5/10/2012 | 29/12/2012 | | |
| 77 | 41 | 30/12/2012 | 8/02/2013 | Start LW9 | |
| 78 | 11 | 9/02/2013 | 19/02/2013 | | A2rain10 |
| 79 | 12 | 20/02/2013 | 3/03/2013 | | A2week10 |
| 80 | 8 | 4/03/2013 | 11/03/2013 | | A2inflow10 |
| 81 | 22 | 12/03/2013 | 2/04/2013 | | |
| 82 | 80 | 3/04/2013 | 21/06/2013 | | A2rain11 |
| 83 | 9 | 22/06/2013 | 30/06/2013 | | A2week11 |
| 84 | 8 | 1/07/2013 | 8/07/2013 | | A2inflow11 |
| 85 | 22 | 9/07/2013 | 30/07/2013 | | |
| 86 | 48 | 31/07/2013 | 16/09/2013 | End LW9 | |
| 87 | 106 | 17/09/2013 | 31/12/2013 | Start LW10 | |
| 88 | 77 | 1/01/2014 | 18/03/2014 | | A2rain12 |
| 89 | 13 | 19/03/2014 | 31/03/2014 | | A2week12 |
| 90 | 8 | 1/04/2014 | 8/04/2014 | | A2inflow12 |
| 91 | 22 | 9/04/2014 | 30/04/2014 | | |
| 92 | 107 | 1/05/2014 | 15/08/2014 | | A2rain13 |
| 93 | 12 | 16/08/2014 | 27/08/2014 | | A2week13 |
| 94 | 8 | 28/08/2014 | 4/09/2014 | | A2inflow13 |
| 95 | 22 | 5/09/2014 | 26/09/2014 | End LW10 | |
| 96 | 106 | 27/09/2014 | 10/01/2015 | Start LW11 | |
| 97 | 96 | 11/01/2015 | 16/04/2015 | | A2rain14 |
| 98 | 16 | 17/04/2015 | 2/05/2015 | | A2week14 |
| 99 | 8 | 3/05/2015 | 10/05/2015 | | A2inflow14 |
| 100 | 45 | 11/05/2015 | 24/06/2015 | End LW11 | |
| 101 | 196 | 25/06/2015 | 6/01/2016 | Start LW 12 | |
| 102 | 149 | 7/01/2016 | 3/06/2016 | | rain15 |
| 103 | 7 | 4/06/2016 | 10/06/2016 | | |
| 104 | 20 | 11/06/2016 | 30/06/2016 | End LW 12 | |
| 105 | 233 | 1/07/2016 | 18/02/2017 | Start LW 13 | |
| 106 | 71 | 19/02/2017 | 30/04/2017 | | |

| Stress Period | Days | Date From | Date To | Scheduled Mining | Comment / Rainfall-Inflow behaviour |
|---|---|---|---|---|---|
| 107 | 92 | 1/05/2017 | 31/07/2017 | | |
| 108 | 92 | 1/08/2017 | 31/10/2017 | End LW 13 | |
| 109 | 120 | 1/11/2017 | 28/02/2018 | Start LW 14 | |
| 110 | 61 | 1/03/2018 | 30/04/2018 | | |
| 111 | 92 | 1/05/2018 | 31/07/2018 | | |
| 112 | 92 | 1/08/2018 | 31/10/2018 | End LW 14 | |
| 113 | 61 | 1/11/2018 | 31/12/2018 | Start LW 15 | |
| 114 | 90 | 1/01/2019 | 31/03/2019 | | |
| 115 | 61 | 1/04/2019 | 31/05/2019 | | |
| 116 | 61 | 1/06/2019 | 31/07/2019 | End LW 15 | |
| 117 | 61 | 1/08/2019 | 30/09/2019 | | |
| 118 | 92 | 1/10/2019 | 31/12/2019 | | |
| 119 | 59 | 1/01/2020 | 28/02/2020 | | |
| 120 | 62 | 29/02/2020 | 30/04/2020 | Start LW 16 | |
| 121 | 61 | 1/05/2020 | 30/06/2020 | | |
| 122 | 92 | 1/07/2020 | 30/09/2020 | | |
| 123 | 61 | 1/10/2020 | 30/11/2020 | End LW 16 | |
| 124 | 62 | 1/12/2020 | 31/01/2021 | Start LW 17 | |
| 125 | 59 | 1/02/2021 | 31/03/2021 | | |
| 126 | 61 | 1/04/2021 | 31/05/2021 | | |
| 127 | 61 | 1/06/2021 | 31/07/2021 | | |
| 128 | 61 | 1/08/2021 | 30/09/2021 | End LW 17 | |
| 129 | 61 | 1/10/2021 | 30/11/2021 | Start LW 18 | |
| 130 | 31 | 1/12/2021 | 31/12/2021 | | |
| 131 | 59 | 1/01/2022 | 28/02/2022 | | |
| 132 | 61 | 1/03/2022 | 30/04/2022 | | |
| 133 | 61 | 1/05/2022 | 30/06/2022 | | |
| 134 | 31 | 1/07/2022 | 31/07/2022 | | |
| 135 | 61 | 1/08/2022 | 30/09/2022 | End LW 18 | |
| 136 | 61 | 1/10/2022 | 30/11/2022 | Start LW 21 | |
| 137 | 62 | 1/12/2022 | 31/01/2023 | End LW 21 | |
| 138 | 59 | 1/02/2023 | 31/03/2023 | Start LW 19 | |
| 139 | 50 | 1/04/2023 | 20/05/2023 | | |
| 140 | 51 | 21/05/2023 | 10/07/2023 | | |
| 141 | 52 | 11/07/2023 | 31/08/2023 | End LW 19 | |
| 142 | 122 | 1/09/2023 | 31/12/2023 | Start LW 20 | |
| 143 | 182 | 1/01/2024 | 30/06/2024 | End LW 20 | |
| 144 | 184 | 1/07/2024 | 31/12/2024 | | |
| 145 | 181 | 1/01/2025 | 30/06/2025 | | |
| 146 | 184 | 1/07/2025 | 31/12/2025 | | |
| 147 | 181 | 1/01/2026 | 30/06/2026 | | |
| 148 | 184 | 1/07/2026 | 31/12/2026 | | |
| 149 | 181 | 1/01/2027 | 30/06/2027 | | |
| 150 | 184 | 1/07/2027 | 31/12/2027 | | |
| 151 | 182 | 1/01/2028 | 30/06/2028 | | |
| 152 | 184 | 1/07/2028 | 31/12/2028 | | |
| 153 | 181 | 1/01/2029 | 30/06/2029 | | |
| 154 | 184 | 1/07/2029 | 31/12/2029 | | |
| 155 | 181 | 1/01/2030 | 30/06/2030 | | |
| 156 | 184 | 1/07/2030 | 31/12/2030 | | |
| 157 | 181 | 1/01/2031 | 30/06/2031 | | |
| 158 | 184 | 1/07/2031 | 31/12/2031 | | |
| 159 | 182 | 1/01/2032 | 30/06/2032 | | |

| Stress Period | Days | Date From | Date To | Scheduled Mining | Comment / Rainfall-Inflow behaviour |
|---|---|---|---|---|---|
| 160 | 184 | 1/07/2032 | 31/12/2032 | | |
| 161 | 181 | 1/01/2033 | 30/06/2033 | | |
| 162 | 184 | 1/07/2033 | 31/12/2033 | | |
| 163 | 181 | 1/01/2034 | 30/06/2034 | | |
| 164 | 184 | 1/07/2034 | 31/12/2034 | | |
| 165 | 181 | 1/01/2035 | 30/06/2035 | | |
| 166 | 184 | 1/07/2035 | 31/12/2035 | | |
| 167 | 182 | 1/01/2036 | 30/06/2036 | | |
| 168 | 184 | 1/07/2036 | 31/12/2036 | | |
| 169 | 181 | 1/01/2037 | 30/06/2037 | | |
| 170 | 184 | 1/07/2037 | 31/12/2037 | | |
| 171 | 181 | 1/01/2038 | 30/06/2038 | | |
| 172 | 184 | 1/07/2038 | 31/12/2038 | | |
| 173 | 181 | 1/01/2039 | 30/06/2039 | | |
| 174 | 184 | 1/07/2039 | 31/12/2039 | | |
| 175 | 182 | 1/01/2040 | 30/06/2040 | | |
| 176 | 184 | 1/07/2040 | 31/12/2040 | | |
| 177 | 181 | 1/01/2041 | 30/06/2041 | | |
| 178 | 184 | 1/07/2041 | 31/12/2041 | | |
| 179 | 181 | 1/01/2042 | 30/06/2042 | | |
| 180 | 184 | 1/07/2042 | 31/12/2042 | | |
| 181 | 181 | 1/01/2043 | 30/06/2043 | | |
| 182 | 184 | 1/07/2043 | 31/12/2043 | | |
| 183 | 182 | 1/01/2044 | 30/06/2044 | | |
| 184 | 184 | 1/07/2044 | 31/12/2044 | | |
| 185 | 181 | 1/01/2045 | 30/06/2045 | | |
| 186 | 184 | 1/07/2045 | 31/12/2045 | | |
| 187 | 181 | 1/01/2046 | 30/06/2046 | | |
| 188 | 184 | 1/07/2046 | 31/12/2046 | | |
| 189 | 181 | 1/01/2047 | 30/06/2047 | | |
| 190 | 184 | 1/07/2047 | 31/12/2047 | | |
| 191 | 366 | 1/01/2048 | 31/12/2048 | | |
| 192 | 365 | 1/01/2049 | 31/12/2049 | | |
| 193 | 1096 | 1/01/2050 | 31/12/2052 | Approx. 30-year post A3C mining (as per Condition of Approval) | |
| 194 | 2556 | 1/01/2053 | 31/12/2059 | | |
| 195 | 3653 | 1/01/2060 | 31/12/2069 | | |
| 196 | 3652 | 1/01/2070 | 31/12/2079 | | |
| 197 | 3653 | 1/01/2080 | 31/12/2089 | | |
| 198 | 3652 | 1/01/2090 | 31/12/2099 | | |
| 199 | 36525 | 1/01/2100 | 1/01/2200 | | |

# APPENDIX B

## Aquifer Permeability Data Summary

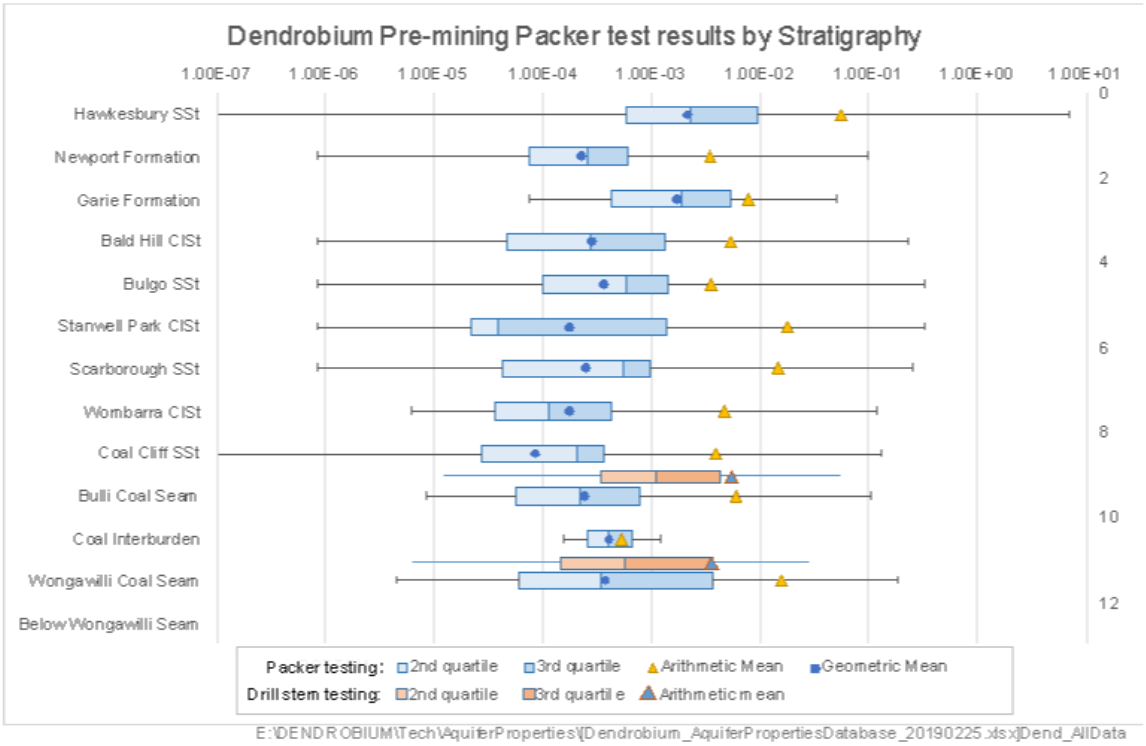
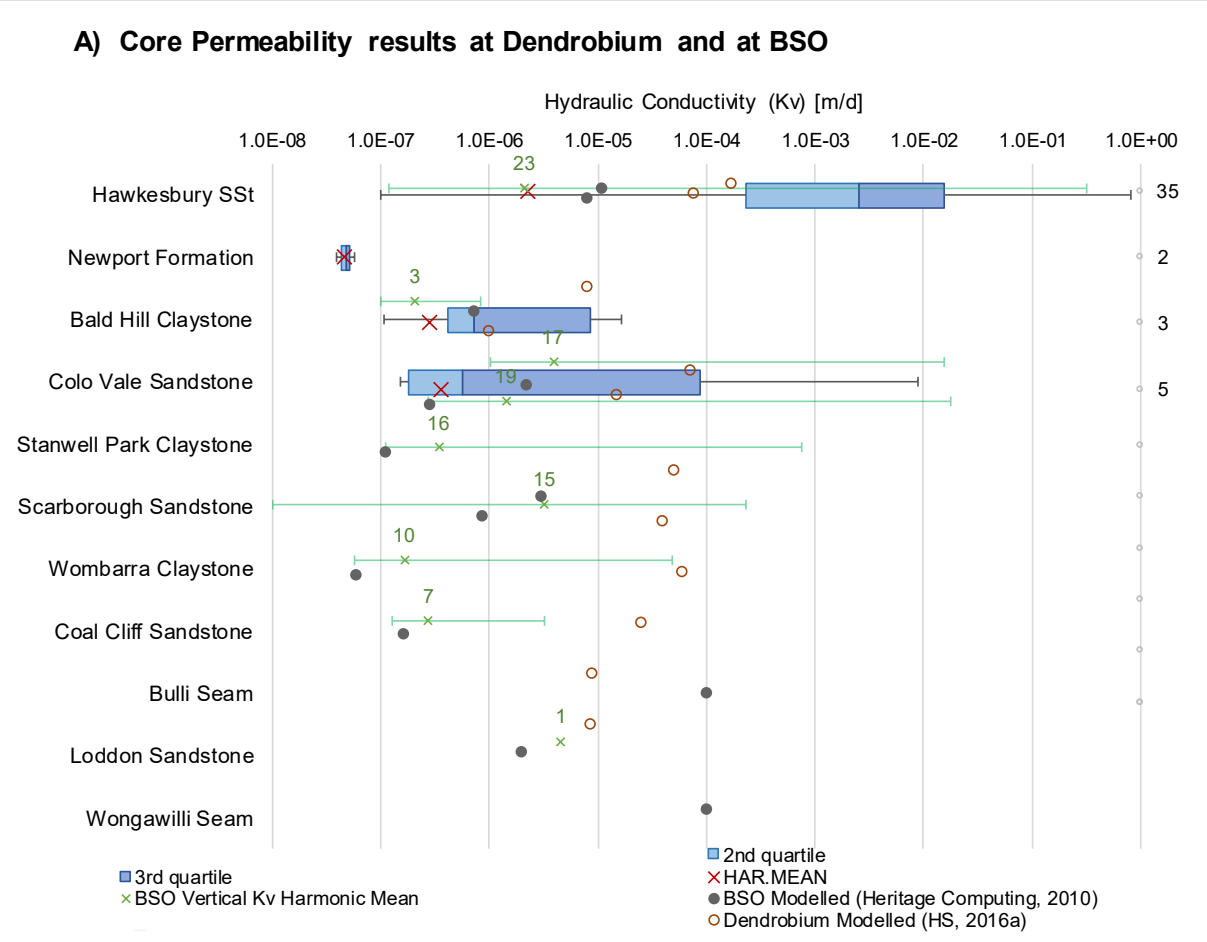
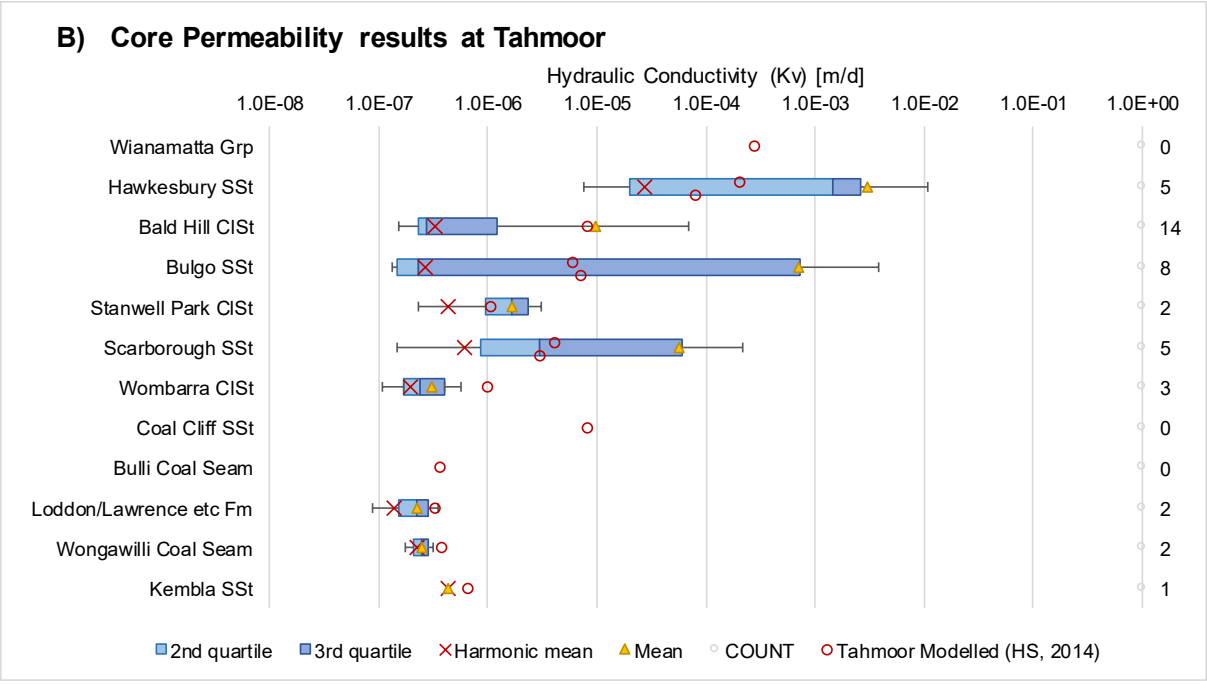



**Figure B1 Summary of Packer test (Kh) Data at Dendrobium**




X:\HYDROSIM\DENDROBIUM\Tech\AquiferProperties\Packer\Dendrobium_AquiferPropertiesDatabase_20171215.xlsx

**Figure B2 Summary of Core Test (Kv) Data at Dendrobium and Tahmoor**

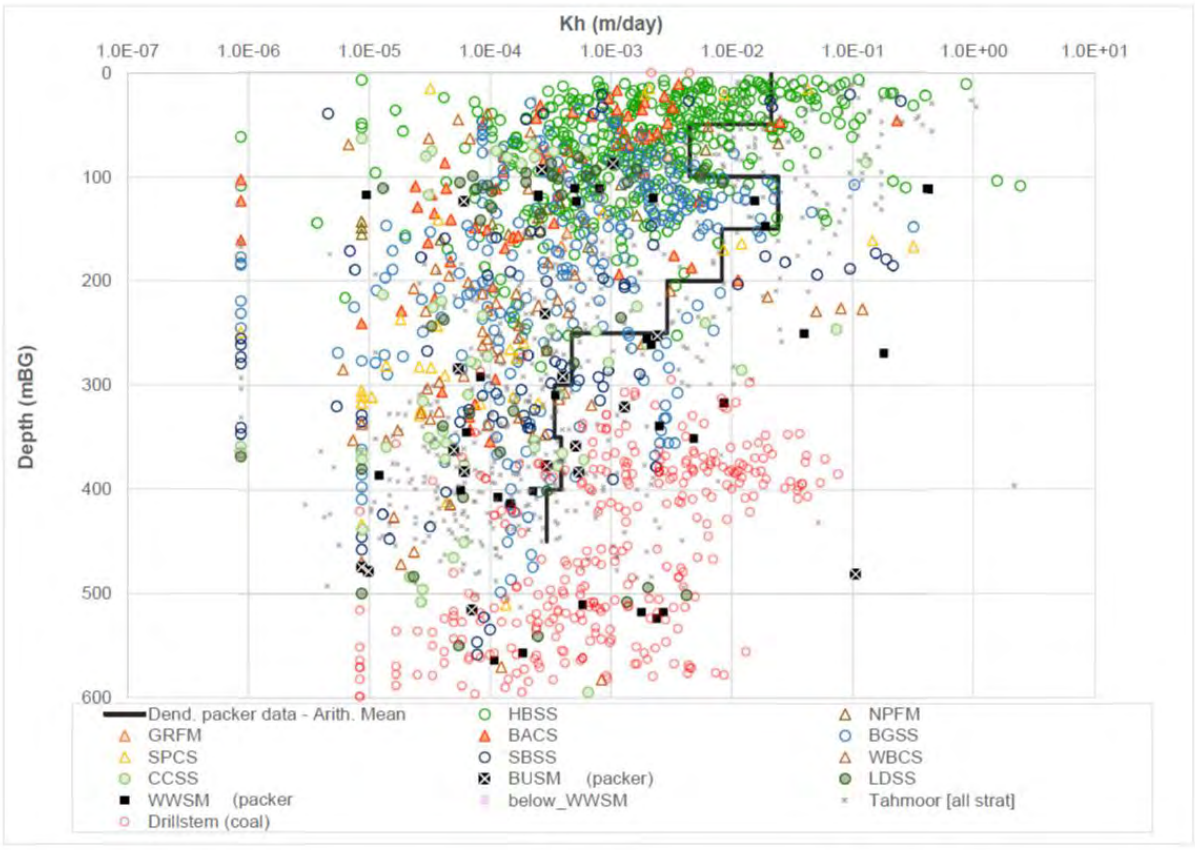



**Figure B3 Distribution of Packer Test (Kh) Data with Depth at Dendrobium for Key Geological Units**

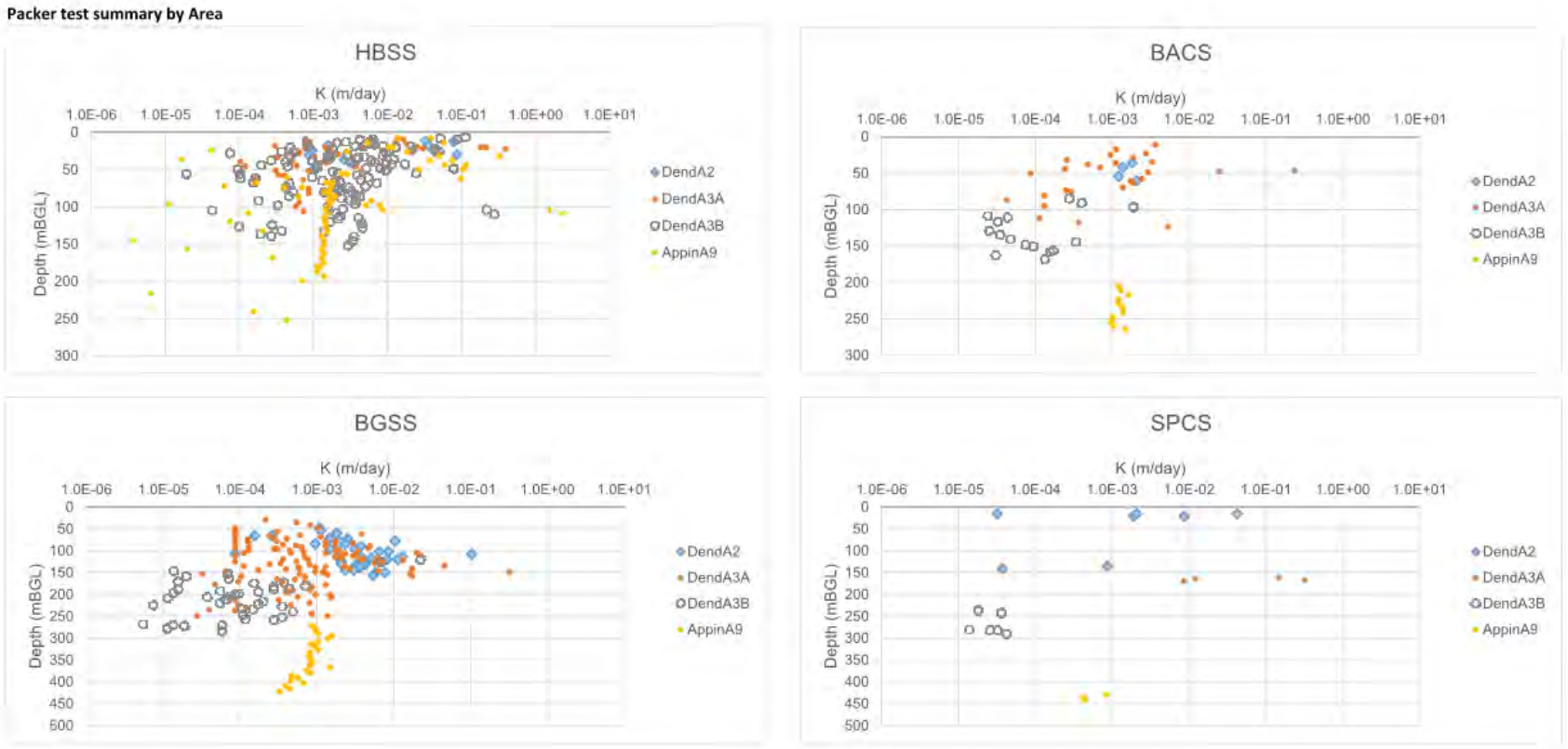



**Figure B4-1 Summary Packer (Kh) by Mine Area**

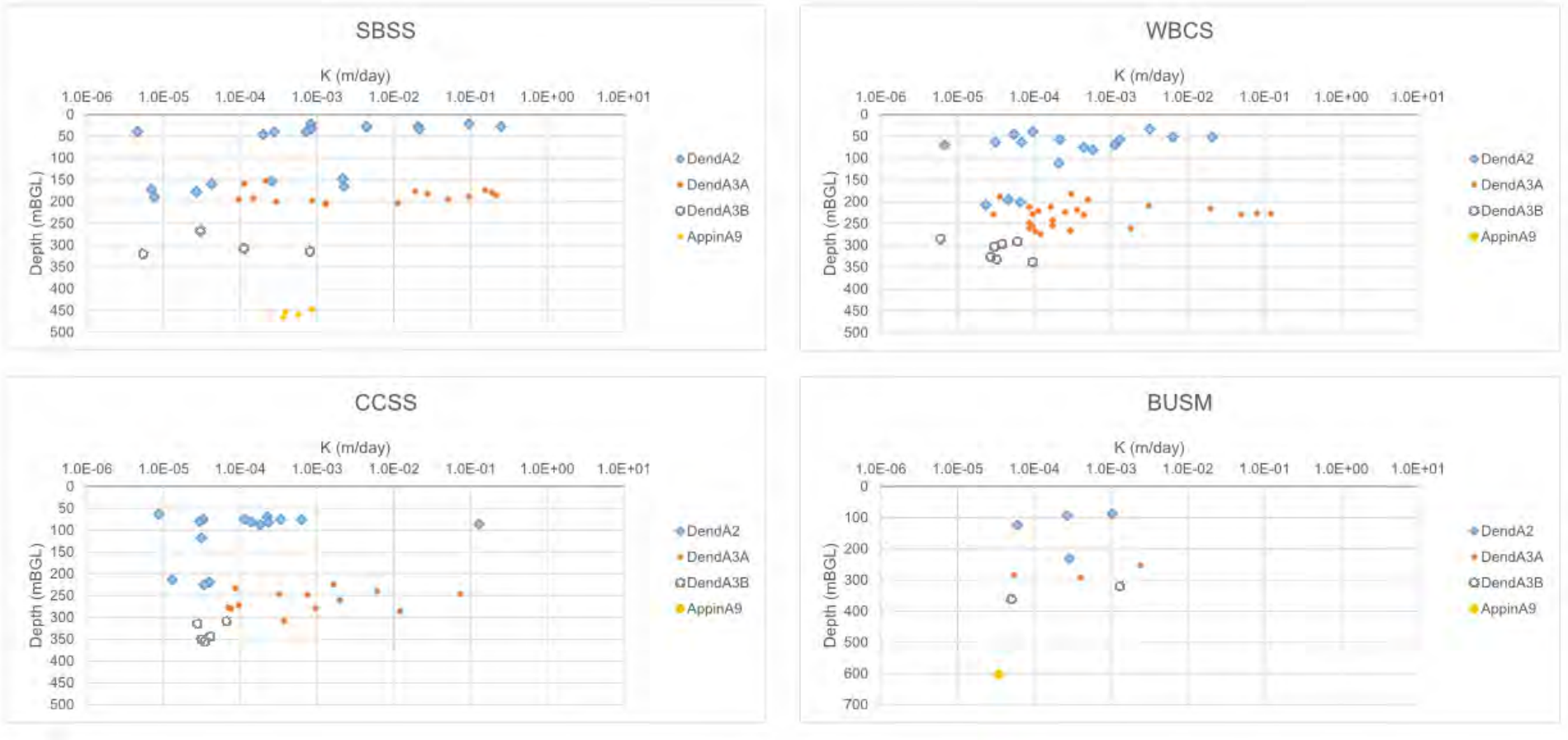



**Figure B4-2 Summary Packer (Kh) by Mine Area**

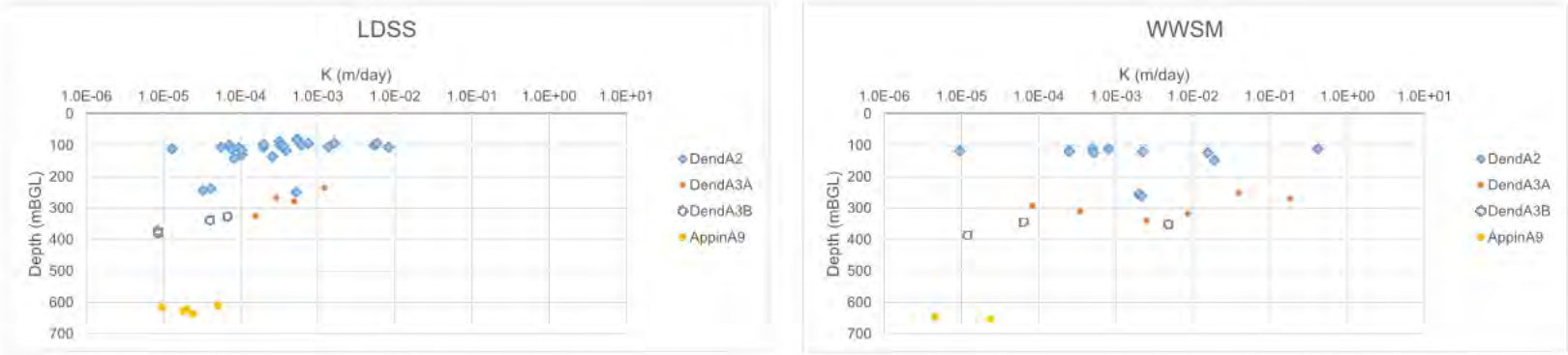



**Figure B4-3 Summary Packer (Kh) by Mine Area**

# APPENDIX C

Simulated Extent of Connected Fracturing and Surface Cracking

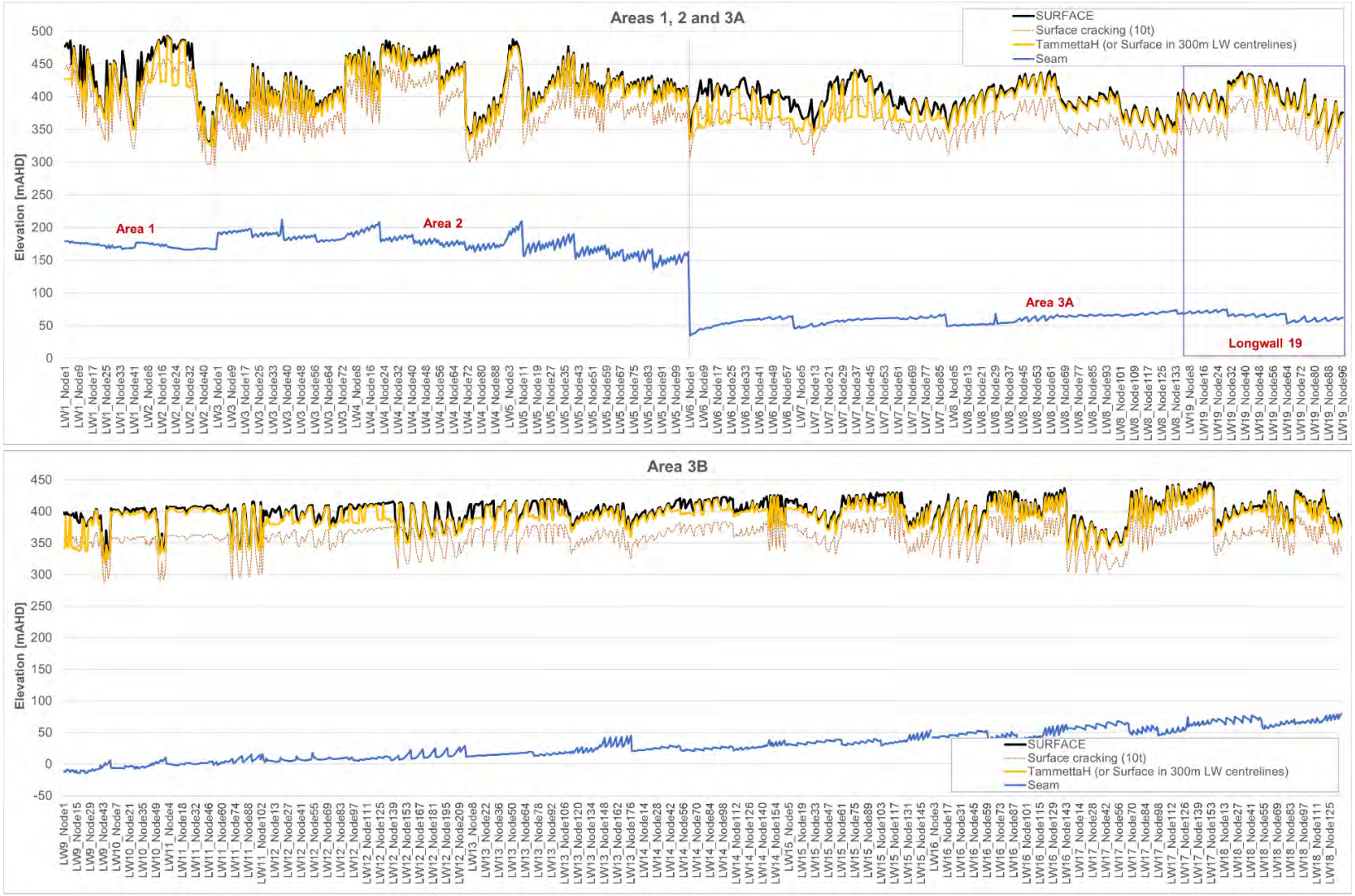



**Figure C1 Simulated Extent of Connected Fracturing and Surface Cracking Areas 1, 2 and 3A, and Area 3B**

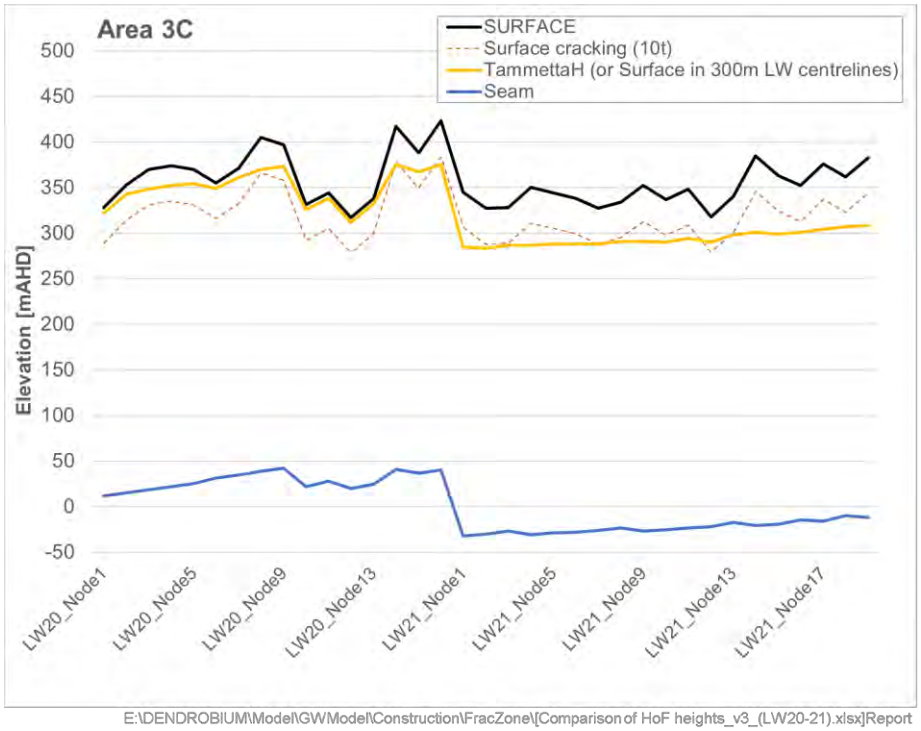



**Figure C2 Simulated Extent of Connected Fracturing and Surface Cracking Area 3C**

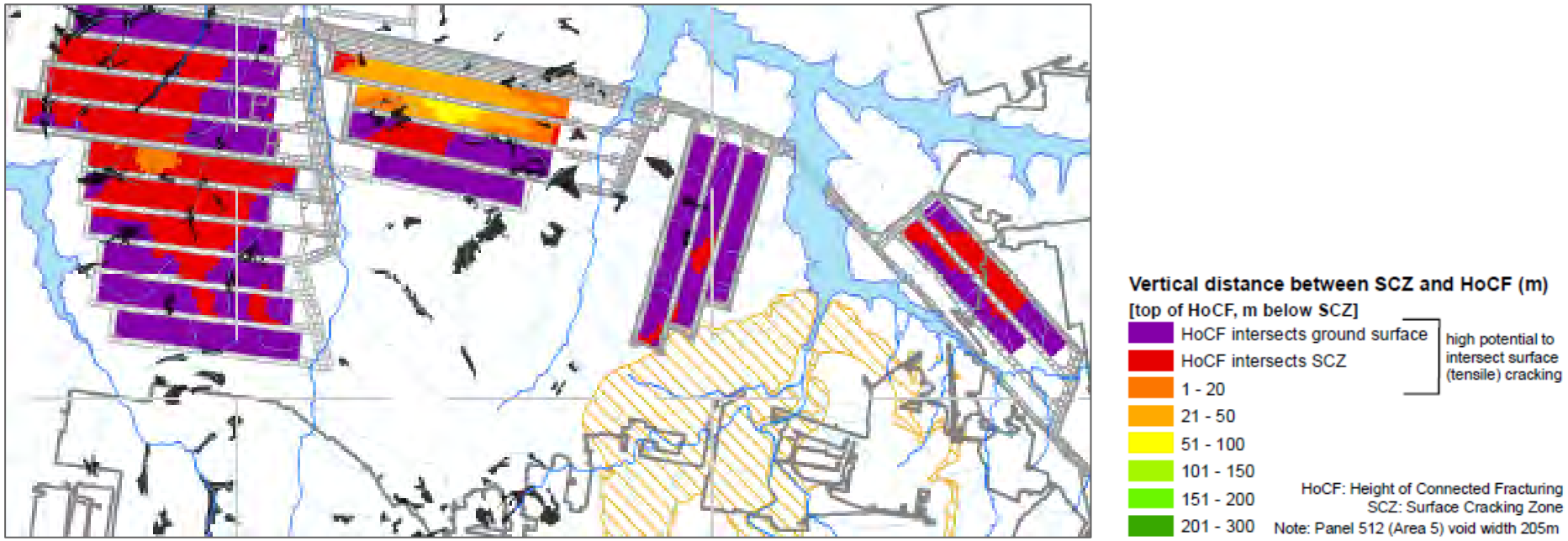



**Figure C3** **Depth to Top of Inferred Connected Fracture Zone [m] (Adapted from HydroSimulations 2019c)**

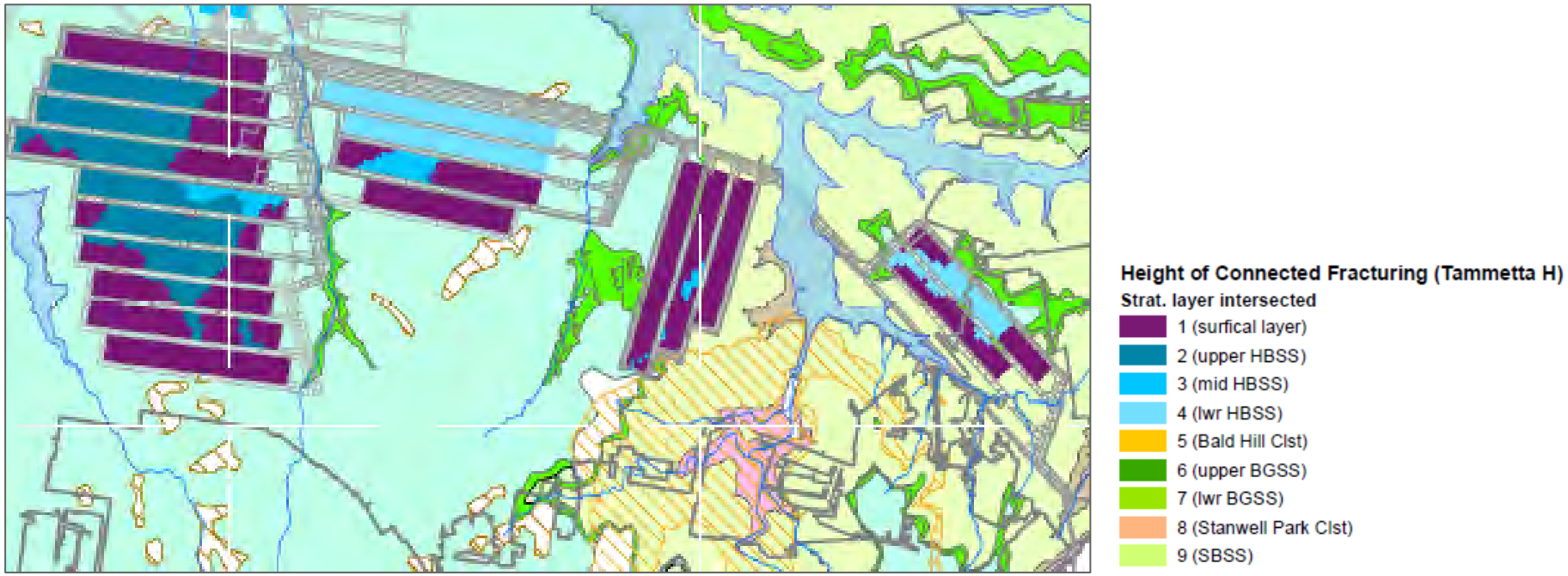
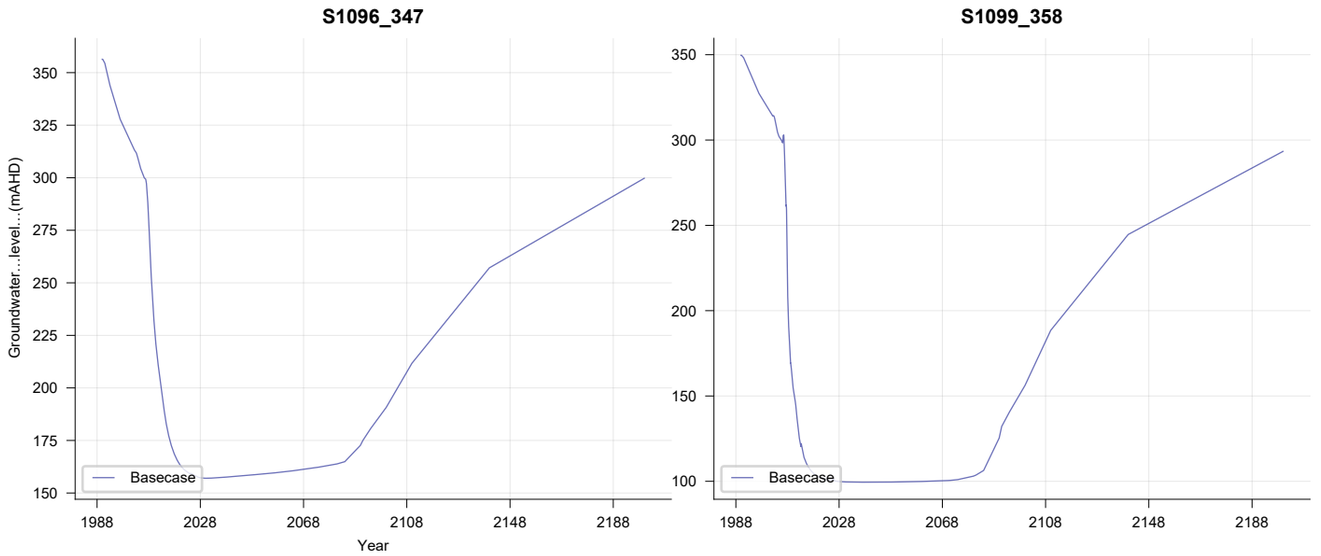


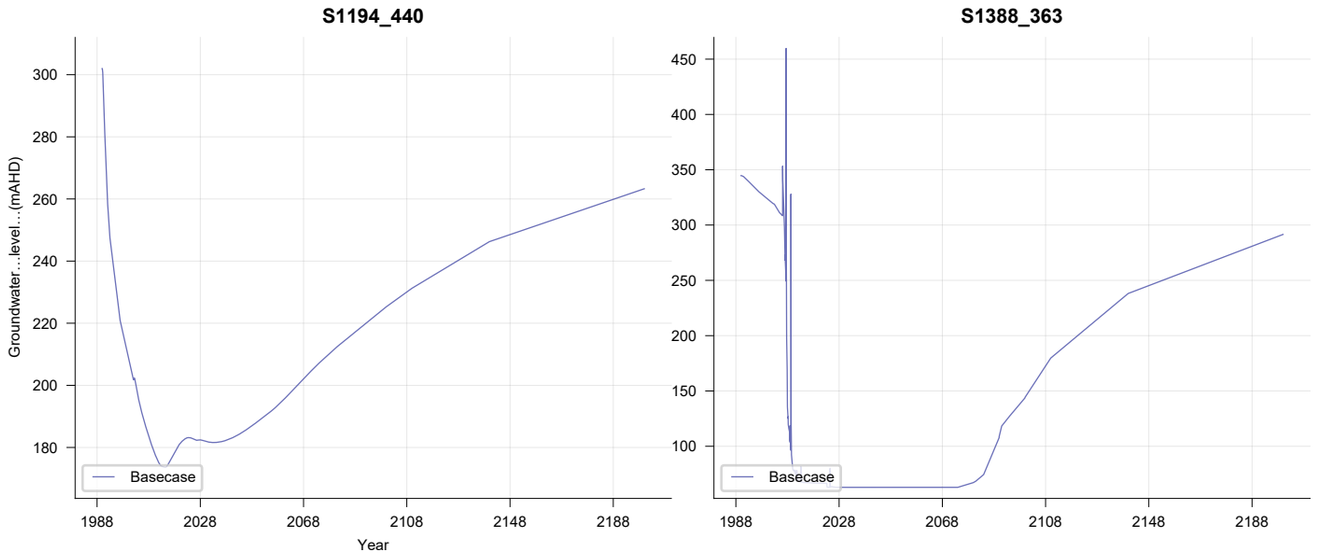

**Figure C4 Inferred layer to which top of connected fracturing extends (Adapted from HydroSimulations 2019c)**

# APPENDIX D

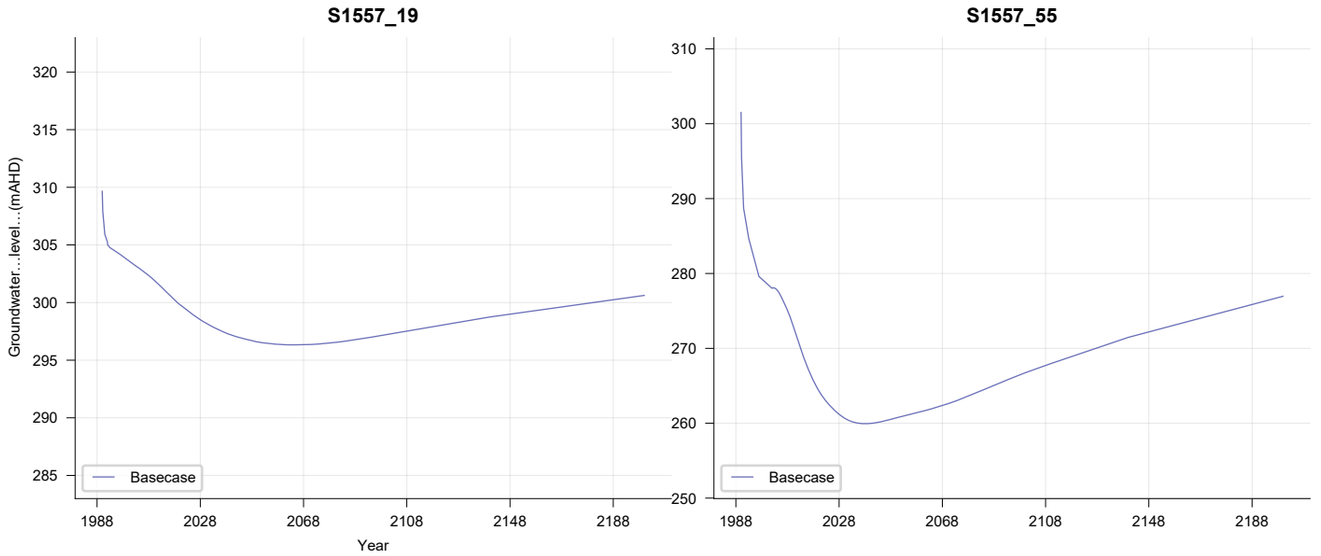
Comparison of Modelled and Observed Groundwater Levels


S1096_347
Groundwater...level...(mAHD)
Year
Basecase

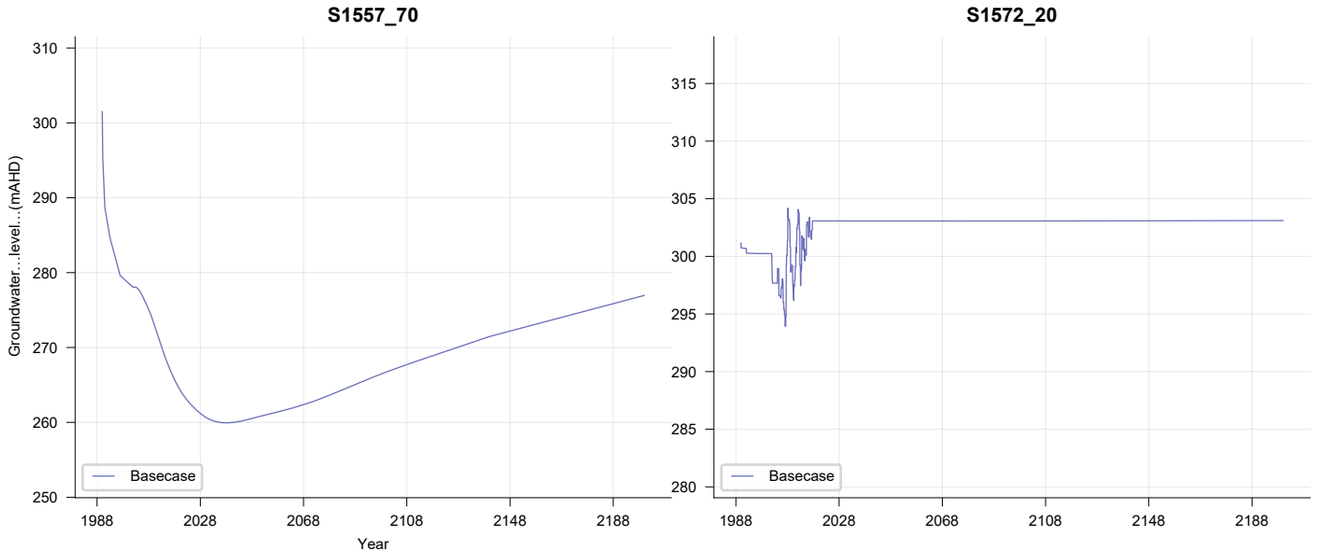

S1099_358
Basecase


S1194_440
Groundwater...level...(mAHD)
Year
Basecase


S1388_363
Basecase

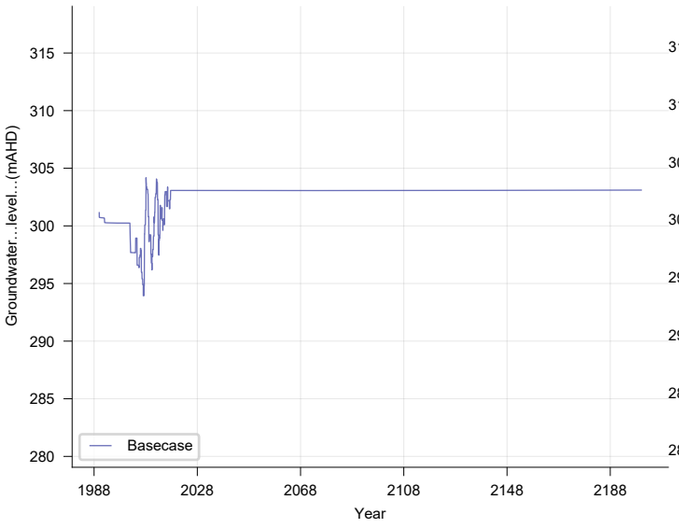

S1557_19
Groundwater...level...(mAHD)
Year
Basecase


S1557_55
Basecase

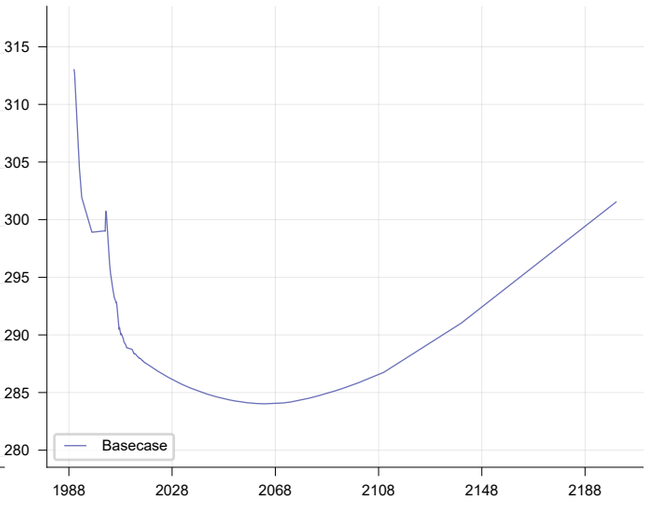

S1557_70
Groundwater...level...(mAHD)
Year
Basecase


S1572_20
Basecase

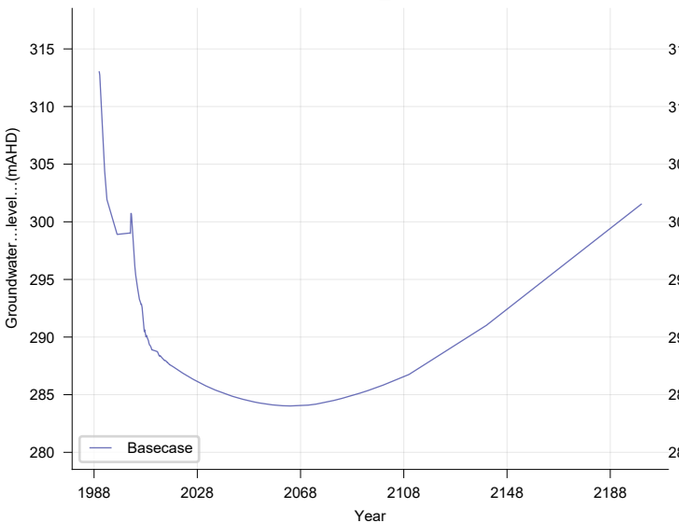
S1572_28.



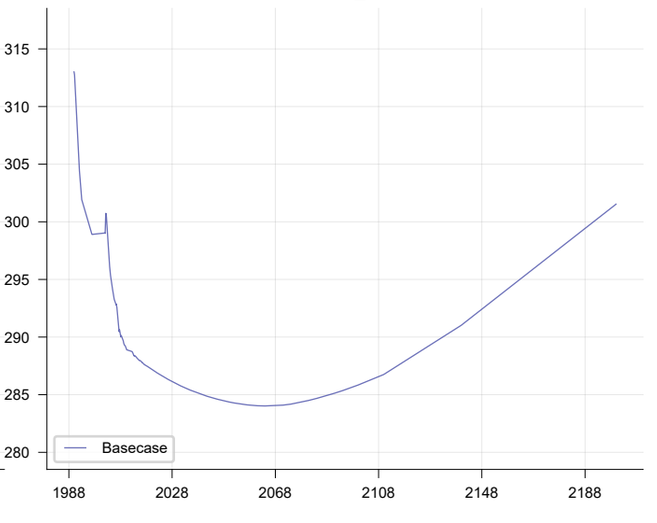

S1572_30.



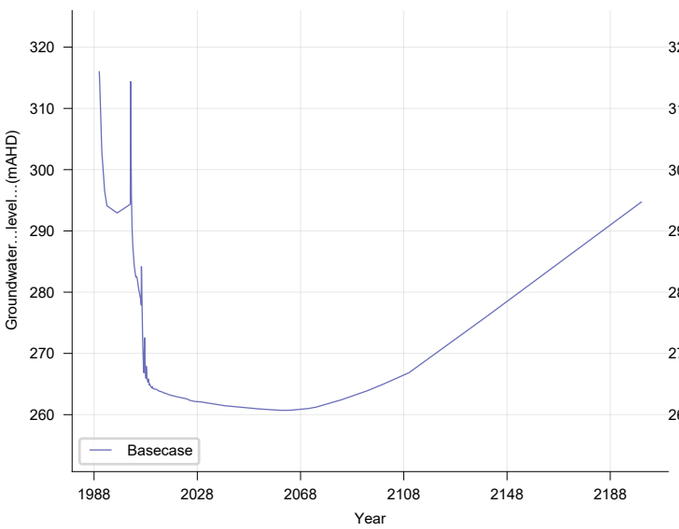

S1572_39.



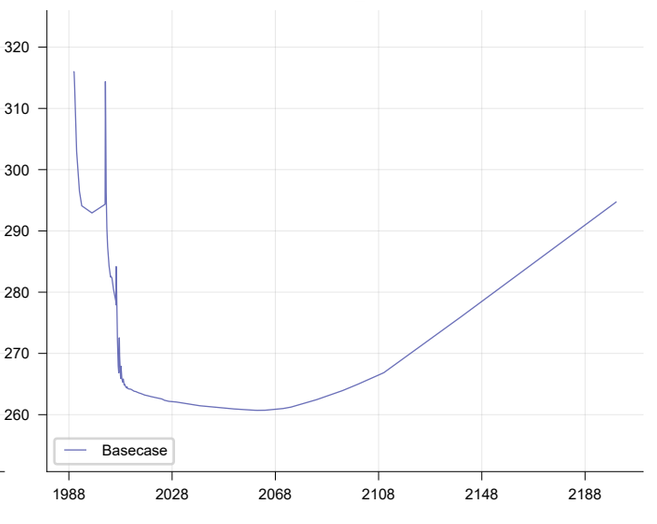

S1572_42.



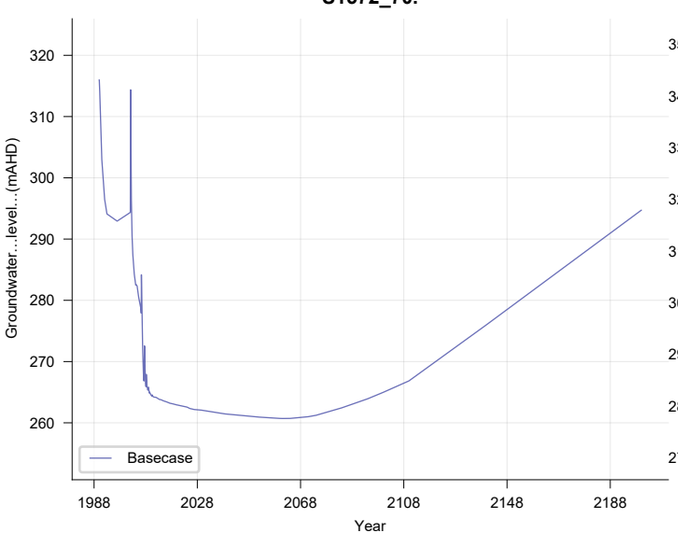

S1572_50.



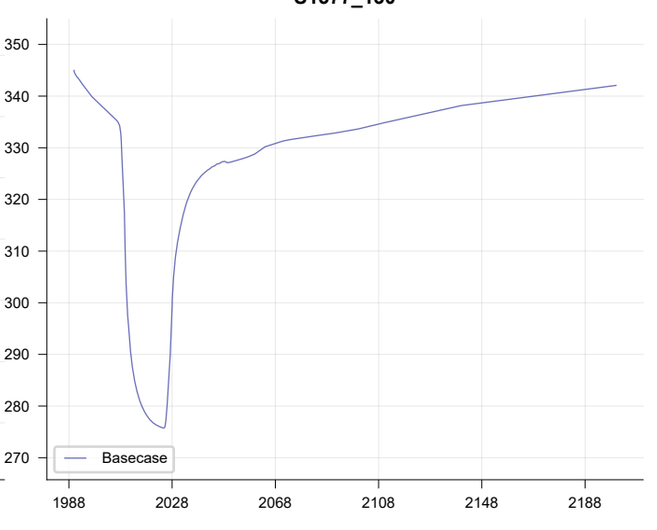

S1572_59.

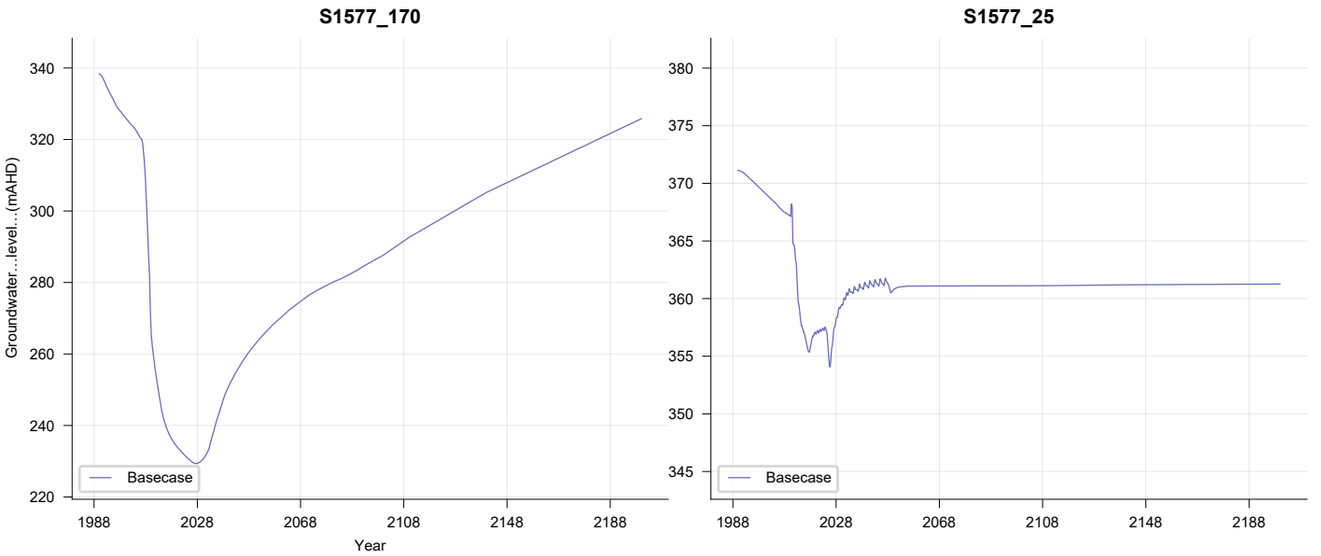



S1572_70.

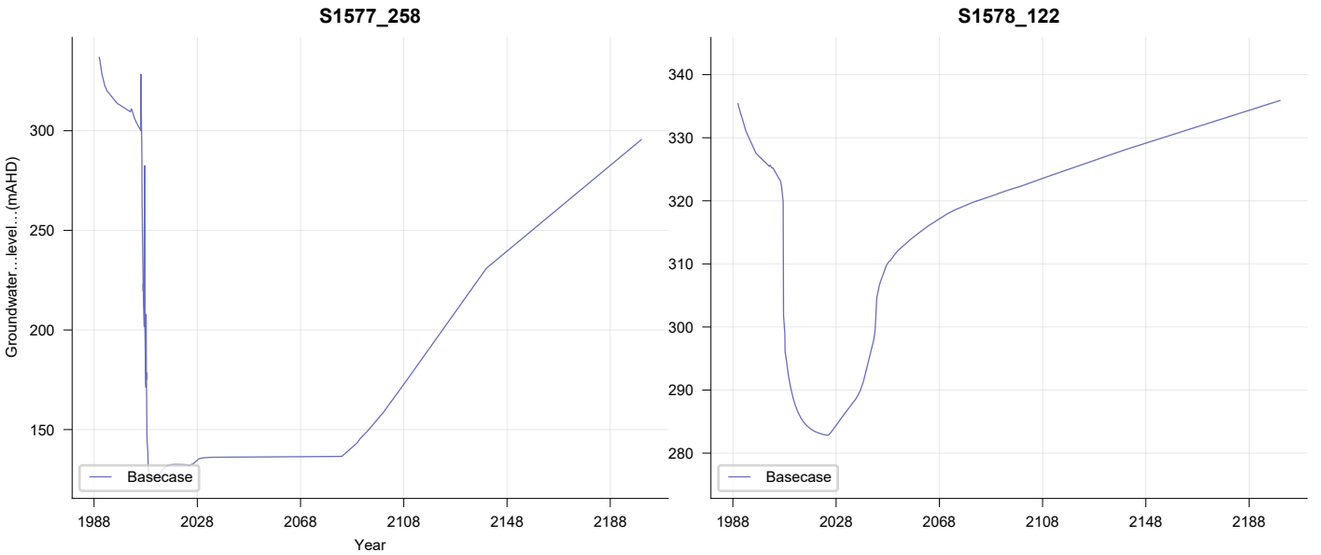



S1577_130

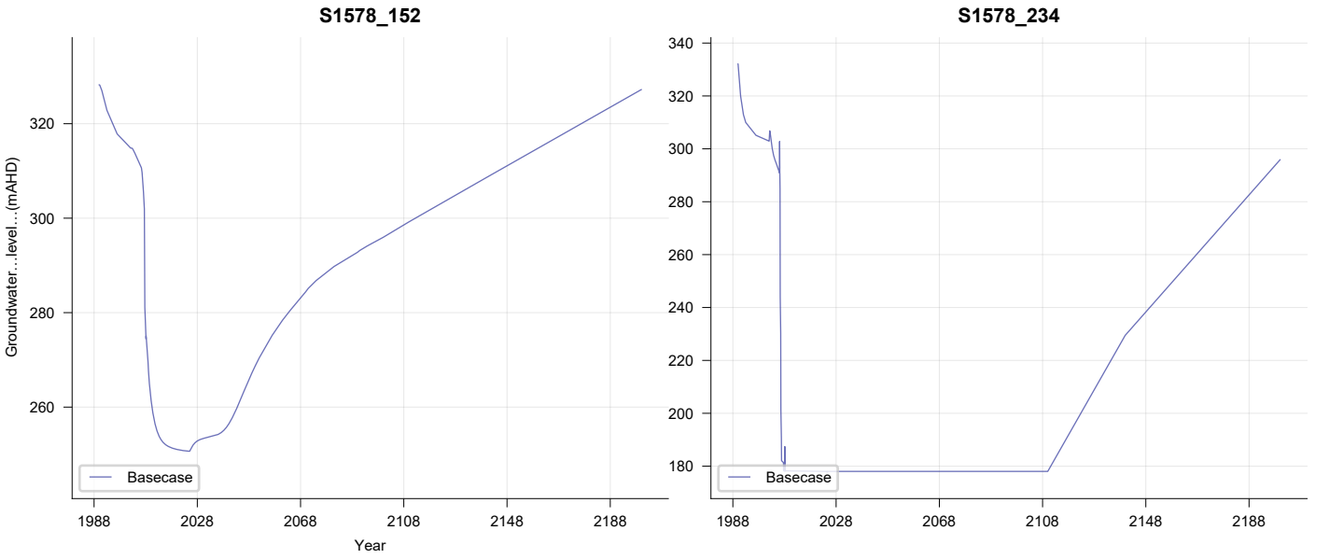



S1577_170
Groundwater...level...(mAHD)
340
320
300
280
260
240
220
Basecase
1988
2028
2068
2108
2148
2188
Year

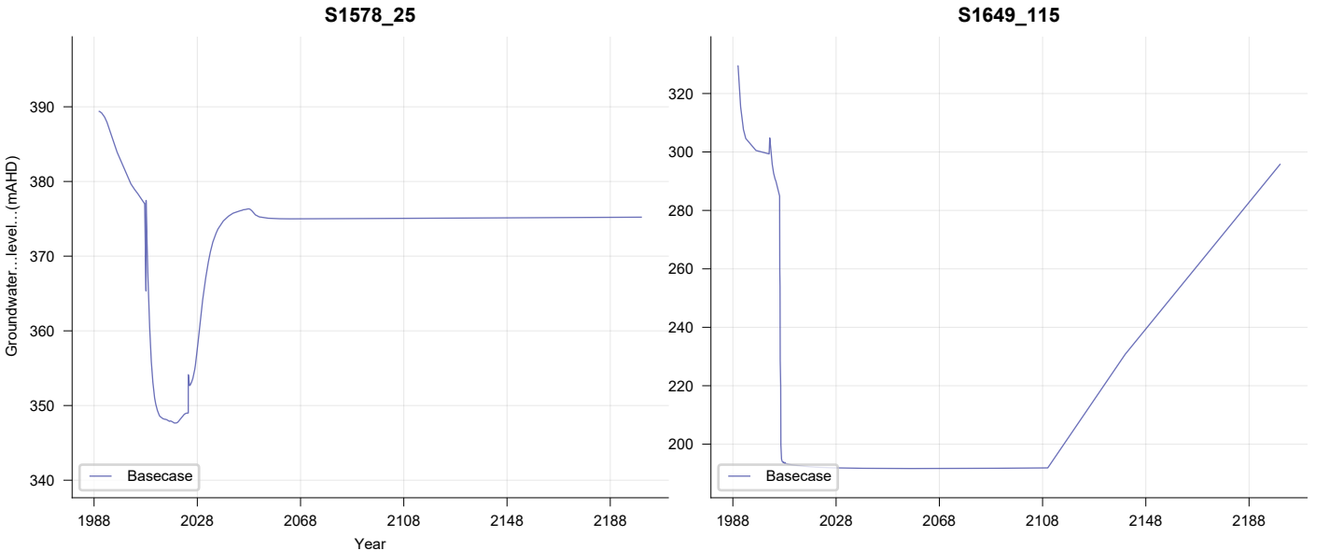

S1577_25
380
375
370
365
360
355
350
345
Basecase
1988
2028
2068
2108
2148
2188


S1577_258
Groundwater...level...(mAHD)
300
250
200
150
Basecase
1988
2028
2068
2108
2148
2188
Year

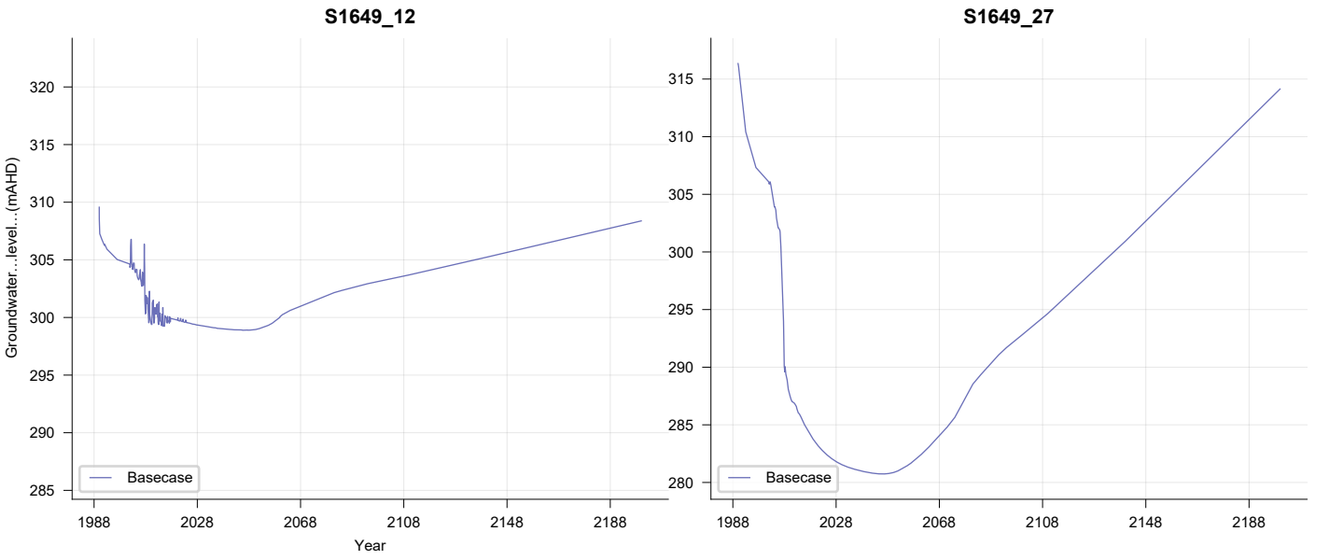

S1578_122
340
330
320
310
300
290
280
Basecase
1988
2028
2068
2108
2148
2188


S1578_152
Groundwater...level...(mAHD)
320
300
280
260
Basecase
1988
2028
2068
2108
2148
2188
Year

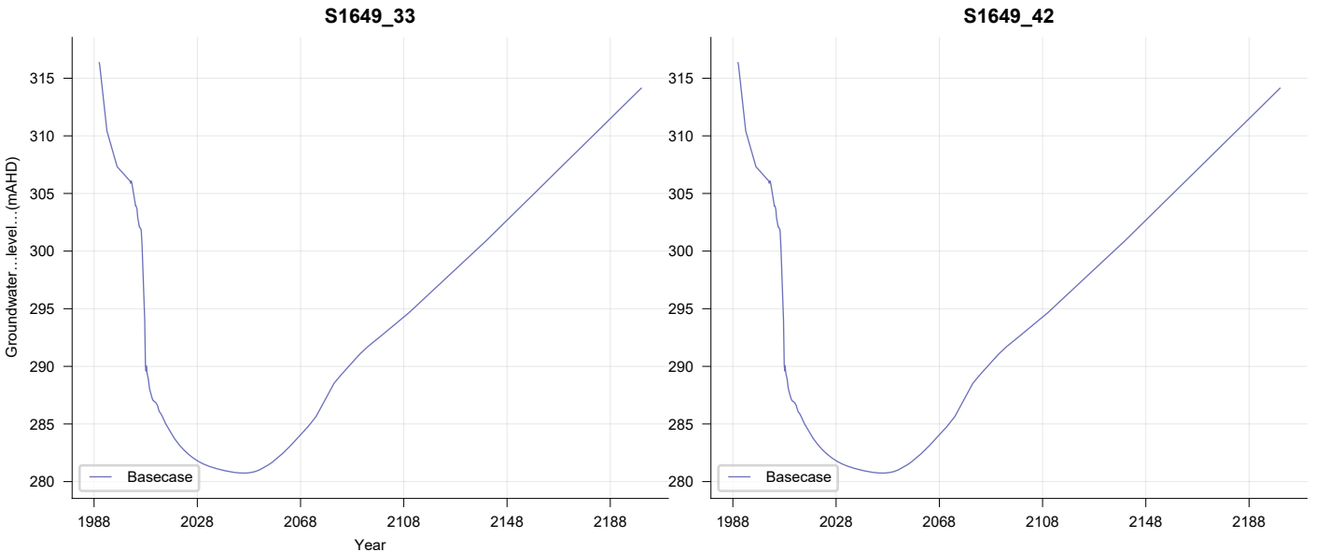

S1578_234
340
320
300
280
260
240
220
200
180
Basecase
1988
2028
2068
2108
2148
2188


S1578_25
Groundwater...level...(mAHD)
390
380
370
360
350
340
Basecase
1988
2028
2068
2108
2148
2188
Year

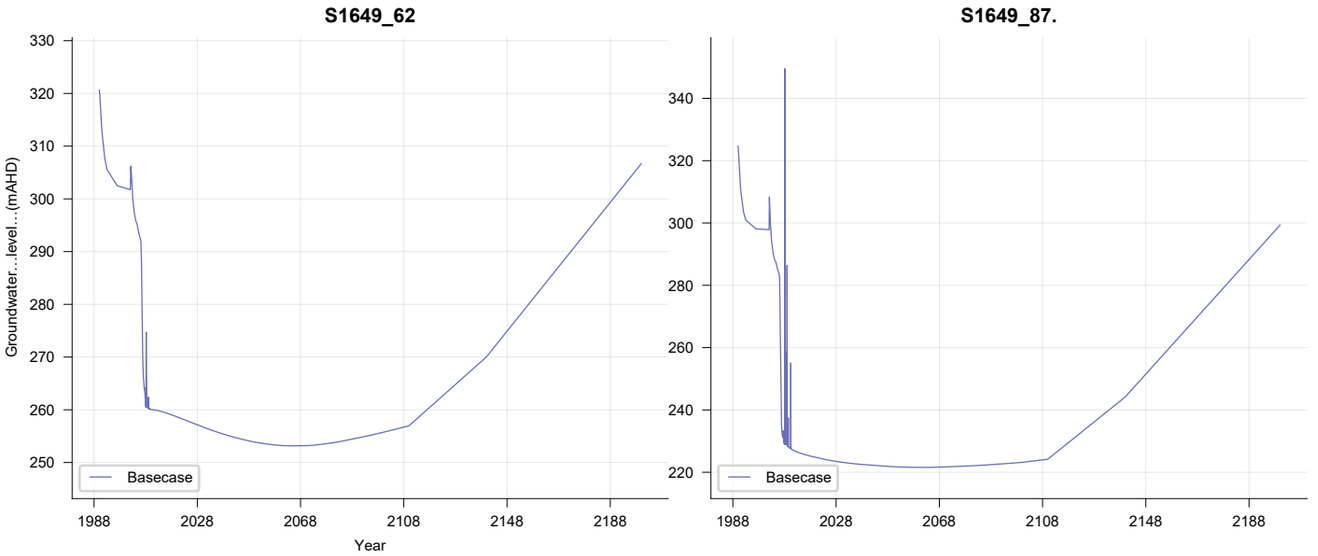

S1649_115
320
300
280
260
240
220
200
Basecase
1988
2028
2068
2108
2148
2188


S1649_12
Groundwater...level...(mAHD)
320
315
310
305
300
295
290
285
Basecase
1988
2028
2068
2108
2148
2188
Year

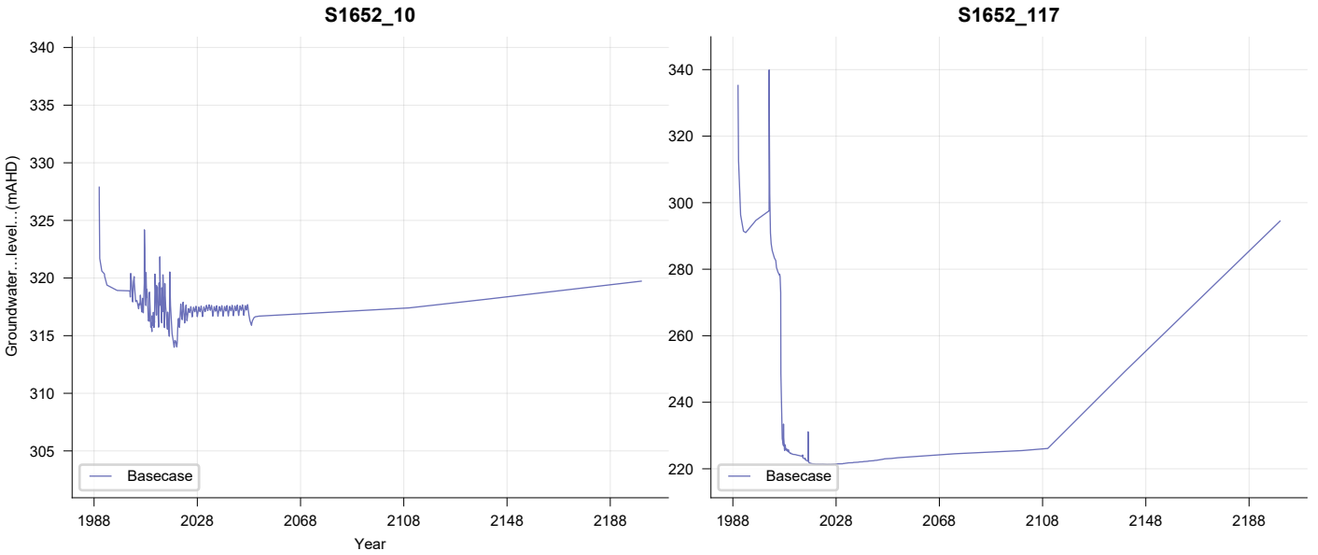

S1649_27
315
310
305
300
295
290
285
280
Basecase
1988
2028
2068
2108
2148
2188


S1649_33
Groundwater...level...(mAHD)
315
310
305
300
295
290
285
280
Basecase
1988
2028
2068
2108
2148
2188
Year

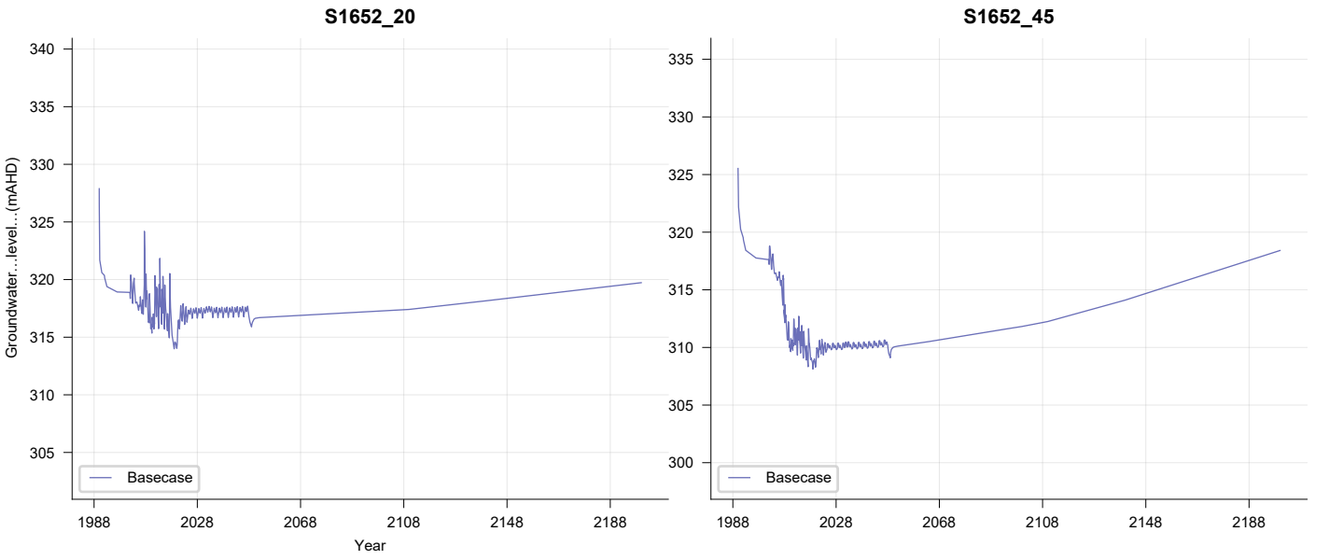

S1649_42
315
310
305
300
295
290
285
280
Basecase
1988
2028
2068
2108
2148
2188


S1649_62
Groundwater...level...(mAHD)
330
320
310
300
290
280
270
260
250
Basecase
1988
2028
2068
2108
2148
2188
Year

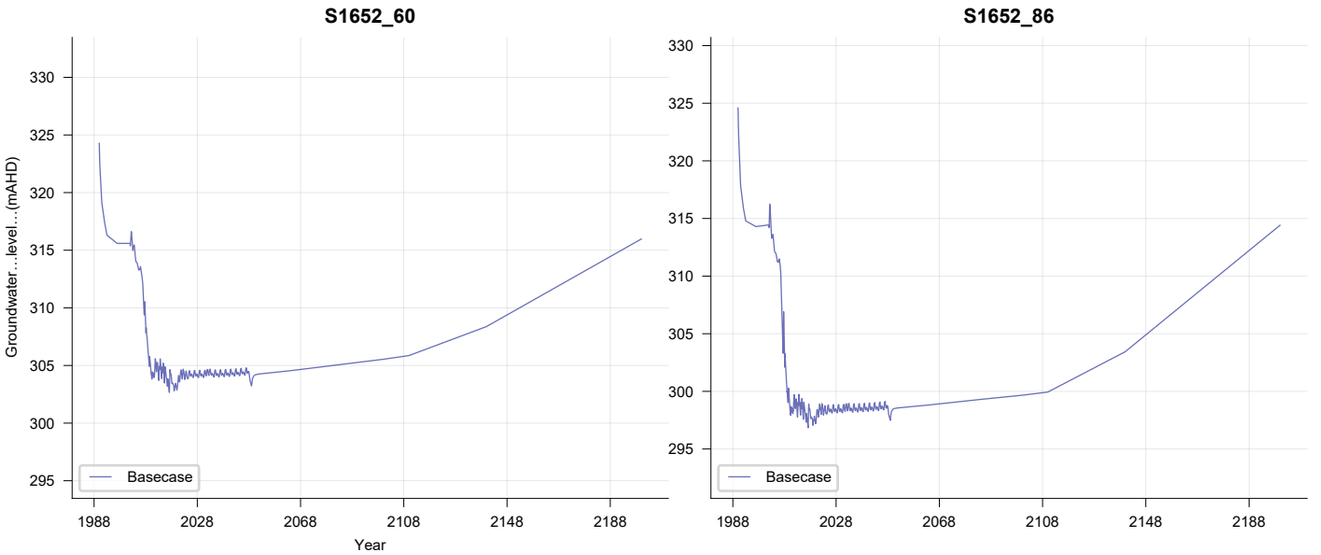

S1649_87.
340
320
300
280
260
240
220
Basecase
1988
2028
2068
2108
2148
2188


S1652_10
Groundwater...level...(mAHD)
340
335
330
325
320
315
310
305
Basecase
1988
2028
2068
2108
2148
2188
Year

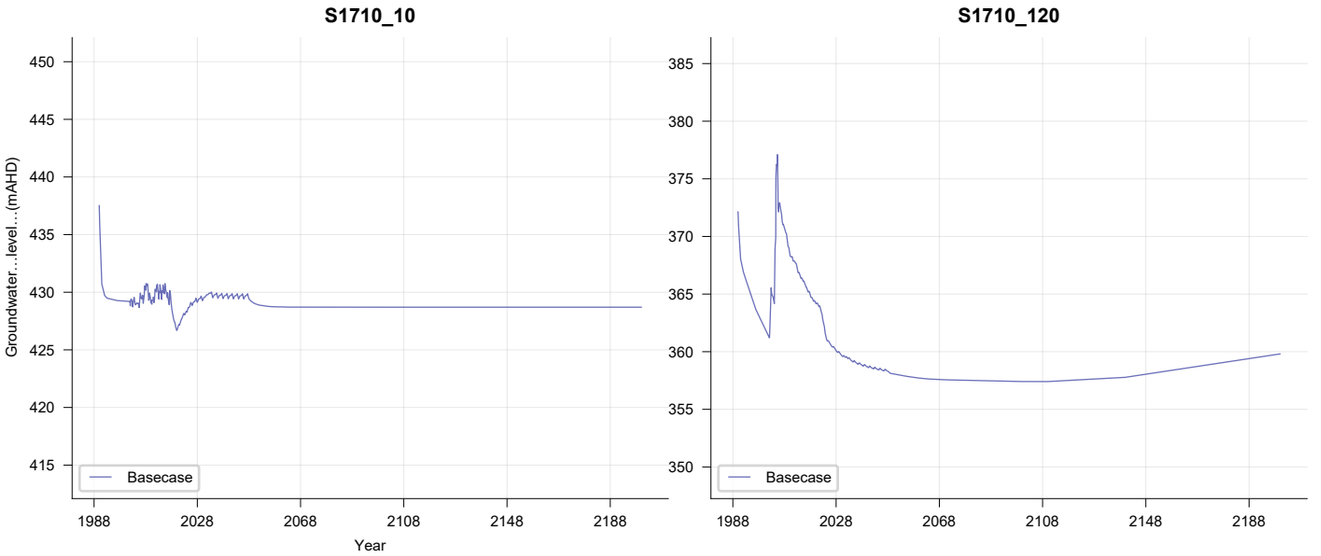

S1652_117
340
320
300
280
260
240
220
Basecase
1988
2028
2068
2108
2148
2188


S1652_20
Groundwater...level...(mAHD)
340
335
330
325
320
315
310
305
Basecase
1988
2028
2068
2108
2148
2188
Year

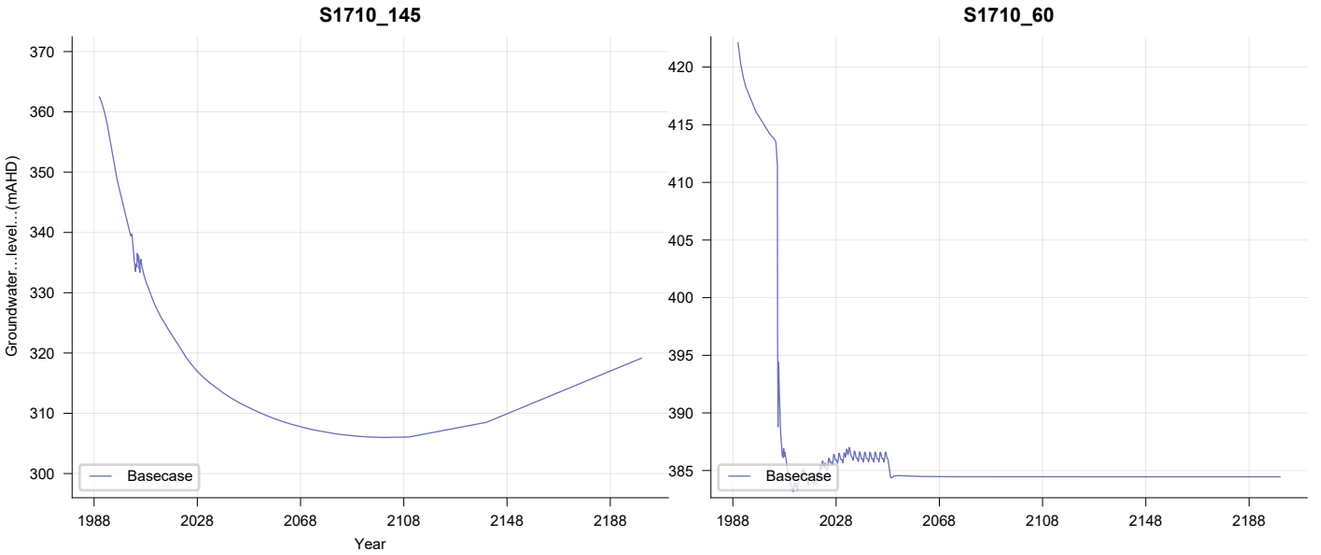

S1652_45
335
330
325
320
315
310
305
300
Basecase
1988
2028
2068
2108
2148
2188


S1652_60
Groundwater...level...(mAHD)
330
325
320
315
310
305
300
295
Basecase
1988
2028
2068
2108
2148
2188
Year

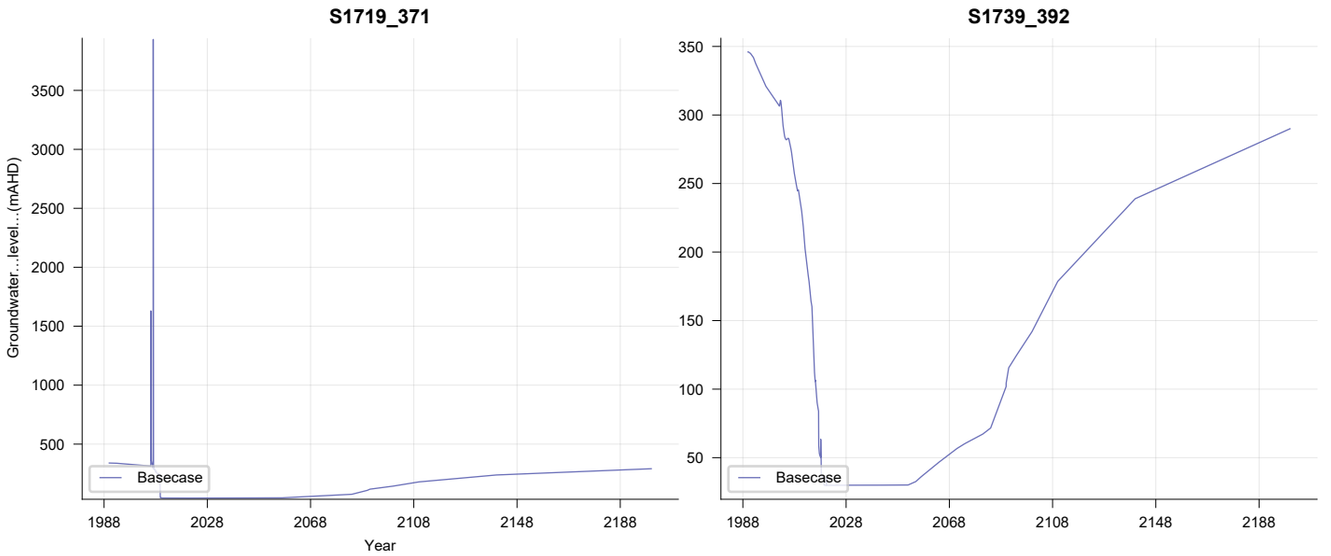

S1652_86
330
325
320
315
310
305
300
295
Basecase
1988
2028
2068
2108
2148
2188


S1710_10
Groundwater...level...(mAHD)
450
445
440
435
430
425
420
415
Basecase
1988
2028
2068
2108
2148
2188
Year

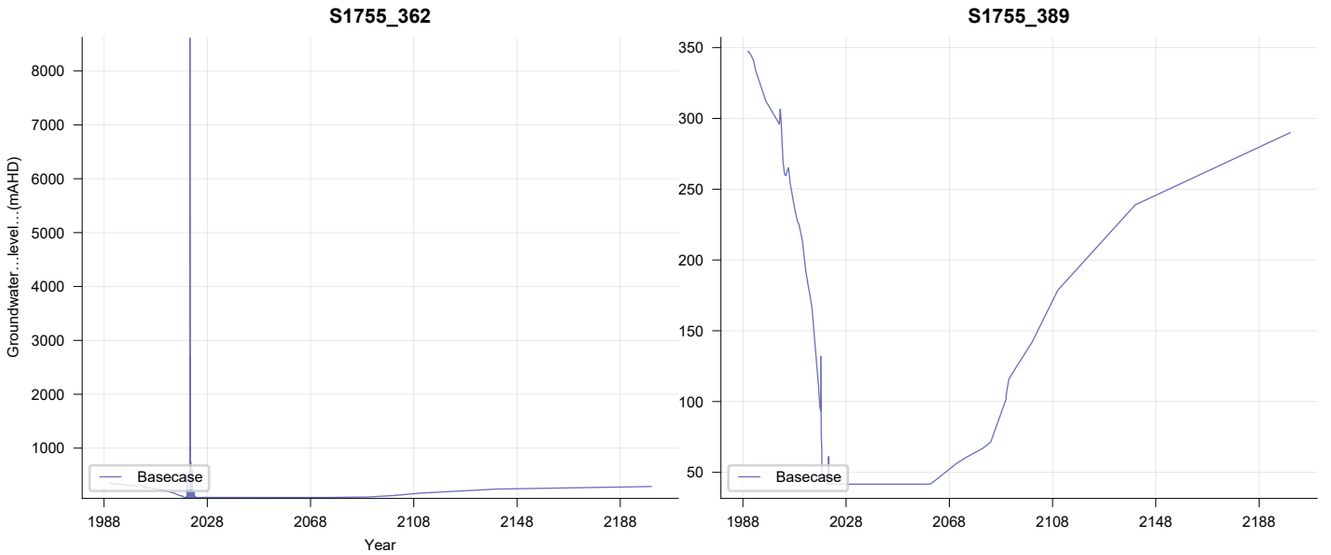

S1710_120
385
380
375
370
365
360
355
350
Basecase
1988
2028
2068
2108
2148
2188


S1710_145
Groundwater...level...(mAHD)
370
360
350
340
330
320
310
300
Basecase
1988
2028
2068
2108
2148
2188
Year

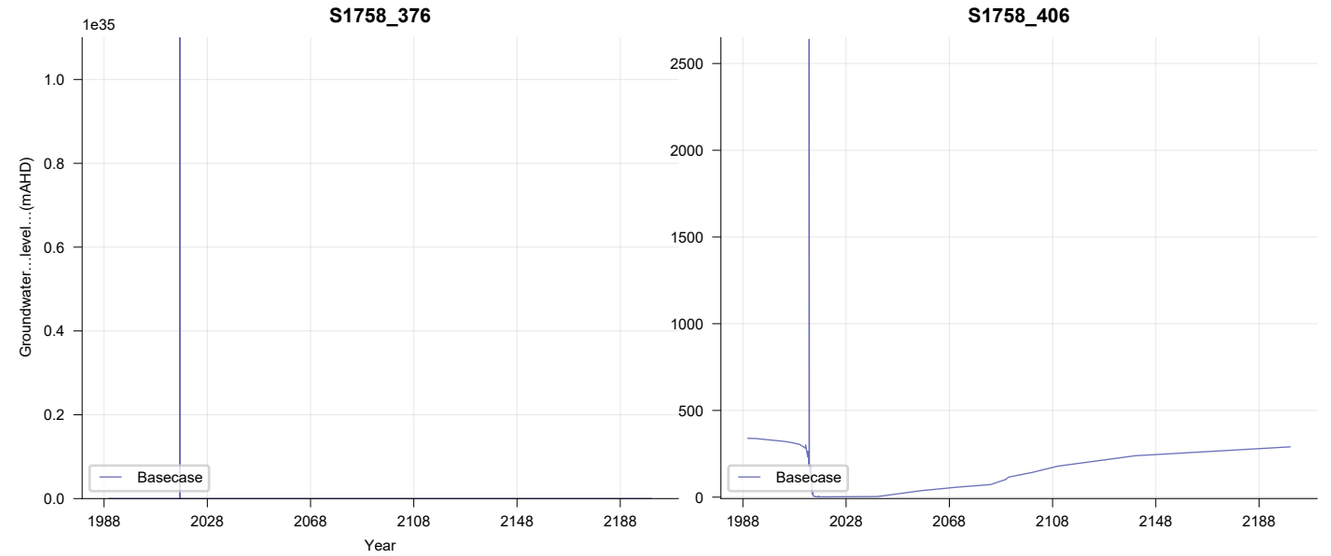

S1710_60
420
415
410
405
400
395
390
385
Basecase
1988
2028
2068
2108
2148
2188


S1719_371
Groundwater...level...(mAHD)
Basecase
Year

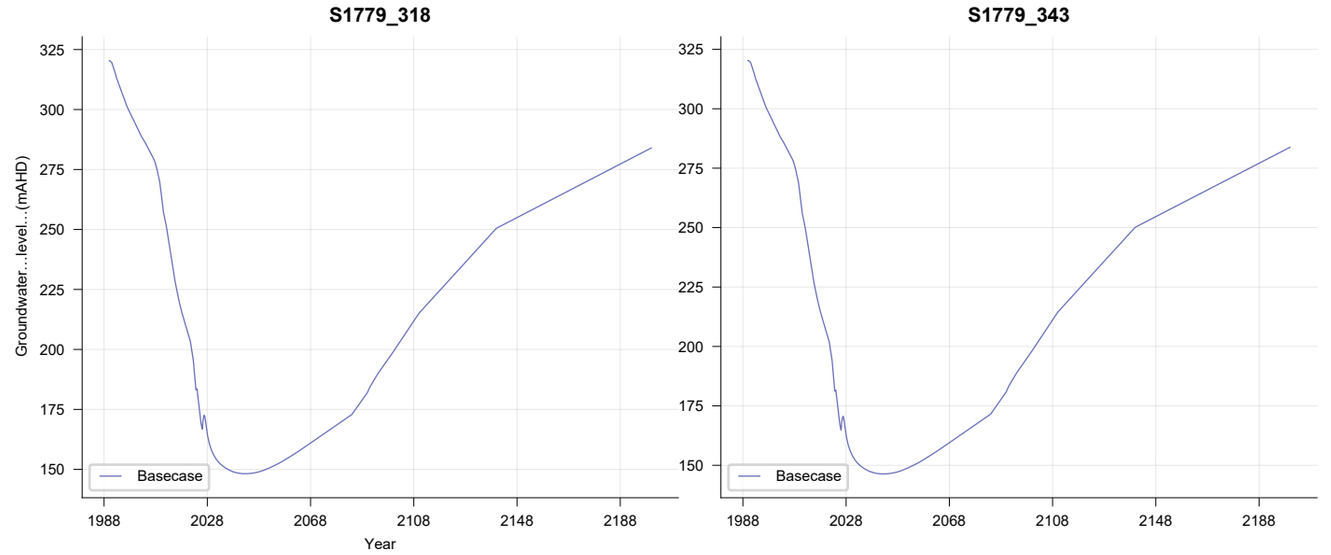

S1739_392
Basecase


S1755_362
Groundwater...level...(mAHD)
Basecase
Year

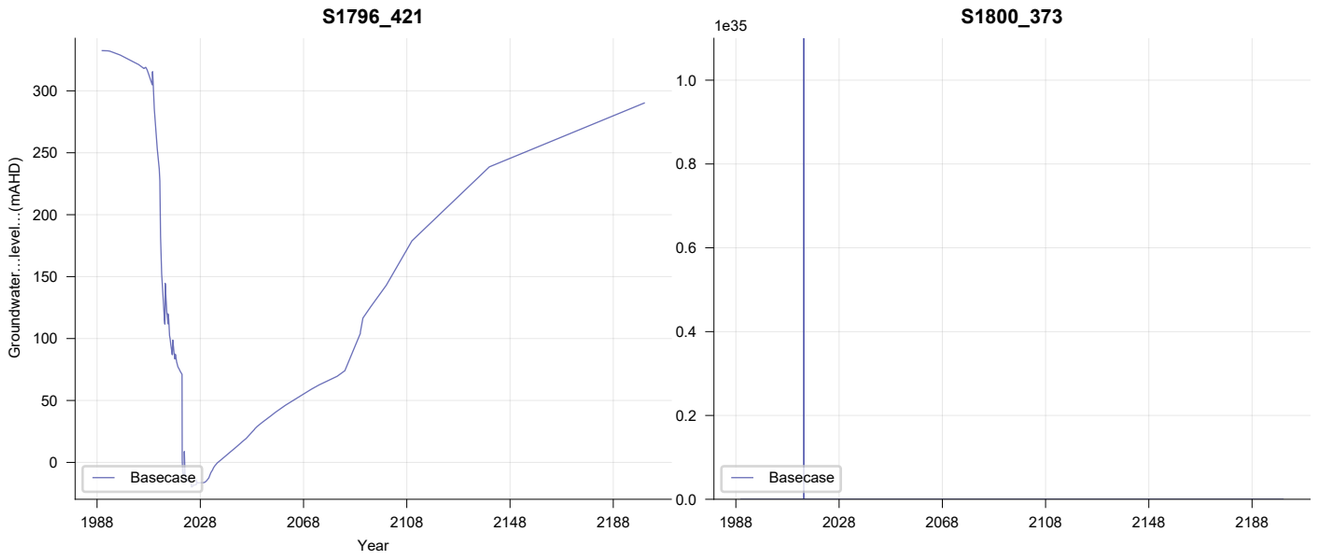

S1755_389
Basecase


S1758_376
1e35
Groundwater...level...(mAHD)
Basecase
Year

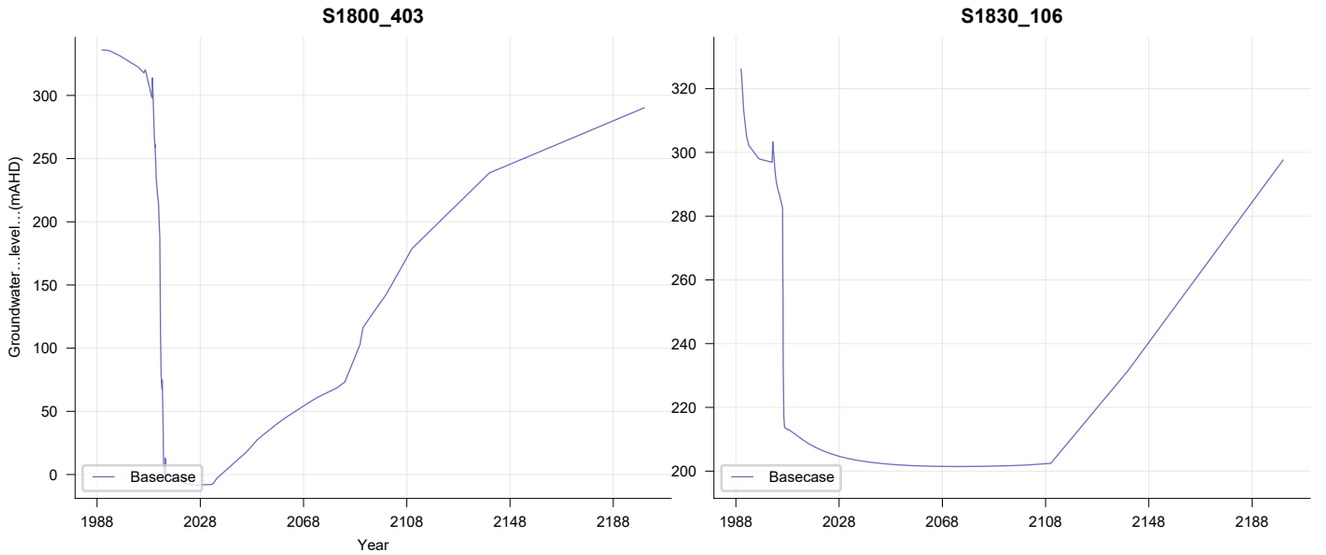

S1758_406
Basecase


S1779_318
Groundwater...level...(mAHD)
Basecase
Year

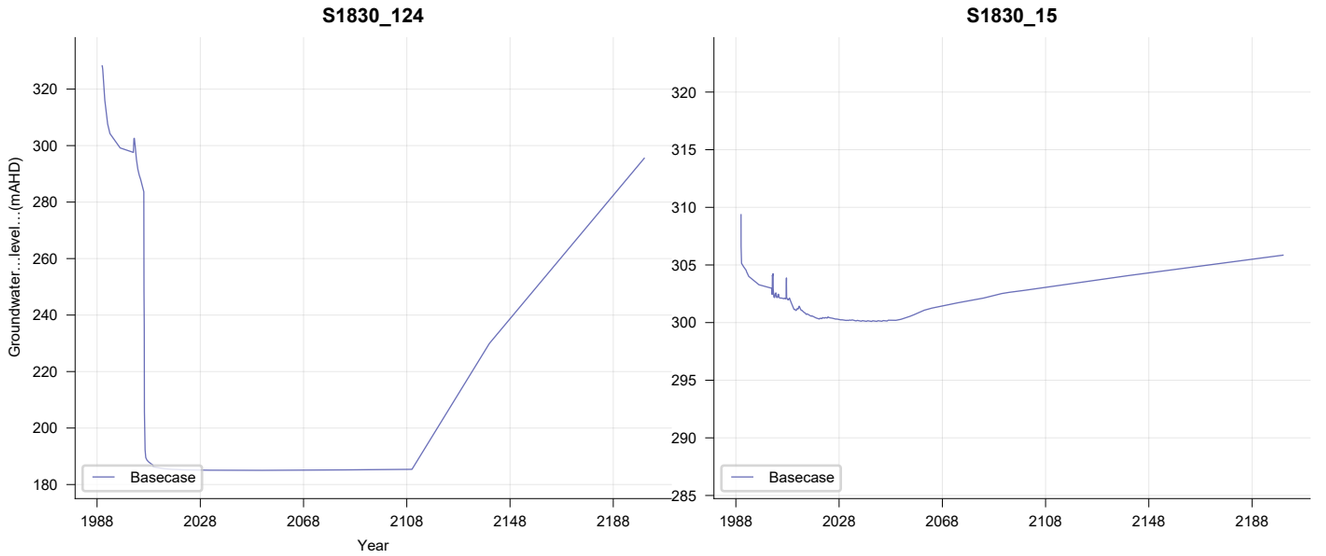

S1779_343
Basecase


S1796_421
Groundwater...level...(mAHD)
Year
Basecase
1988
2028
2068
2108
2148
2188

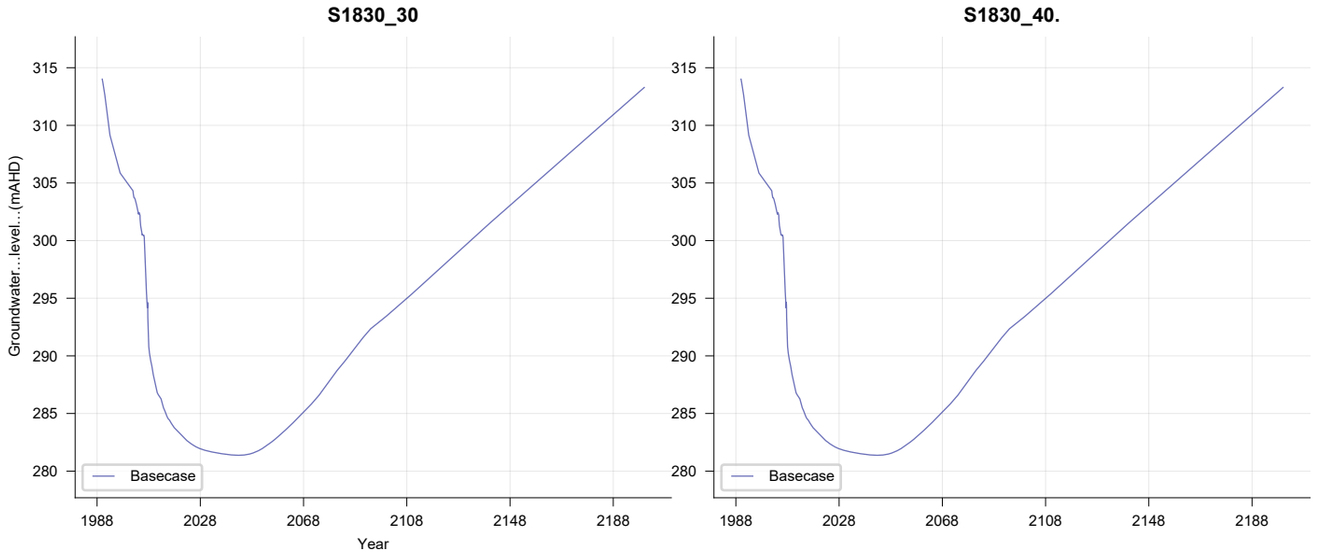

S1800_373
1e35
Basecase


S1800_403
Groundwater...level...(mAHD)
Year
Basecase

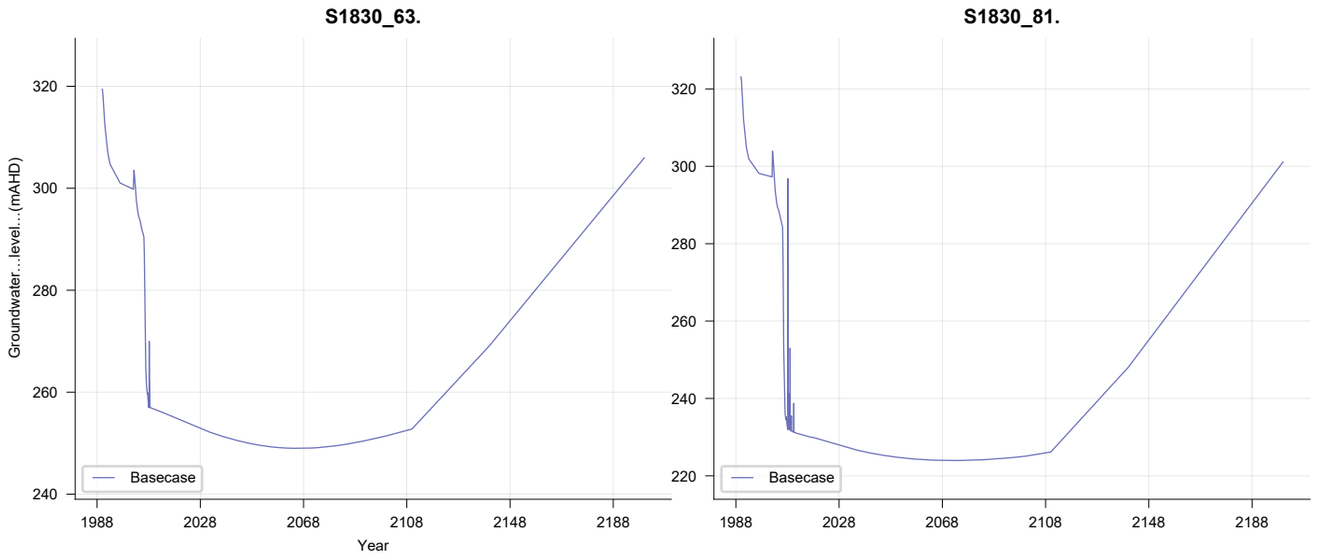

S1830_106
Basecase


S1830_124
Groundwater...level...(mAHD)
Year
Basecase

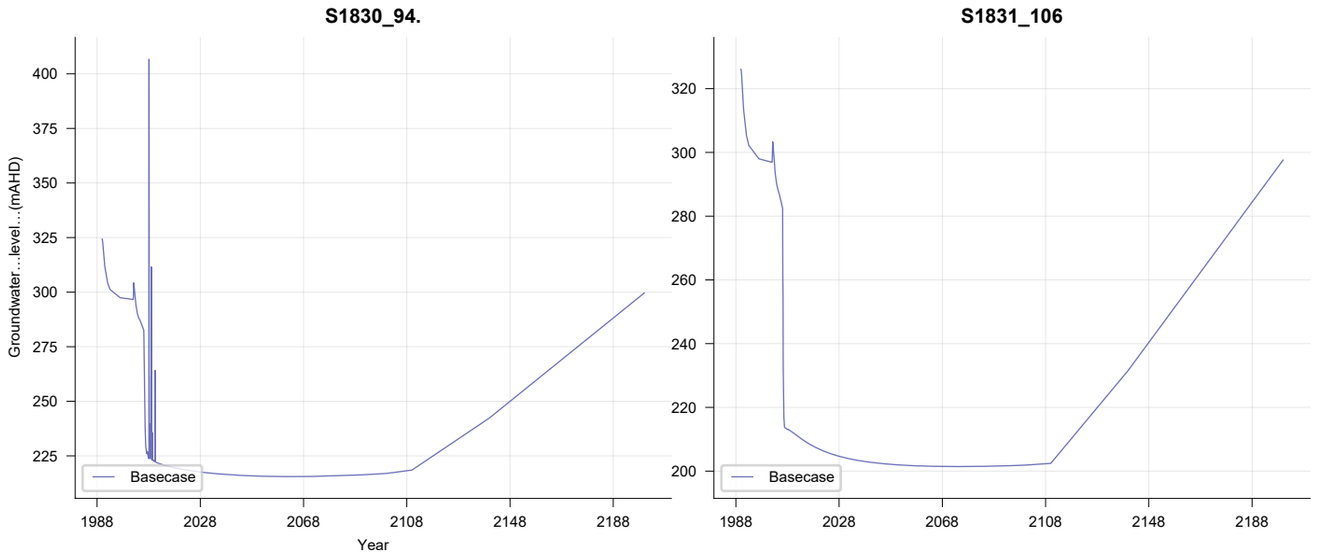

S1830_15
Basecase


S1830_30
Groundwater...level...(mAHD)
Year
Basecase

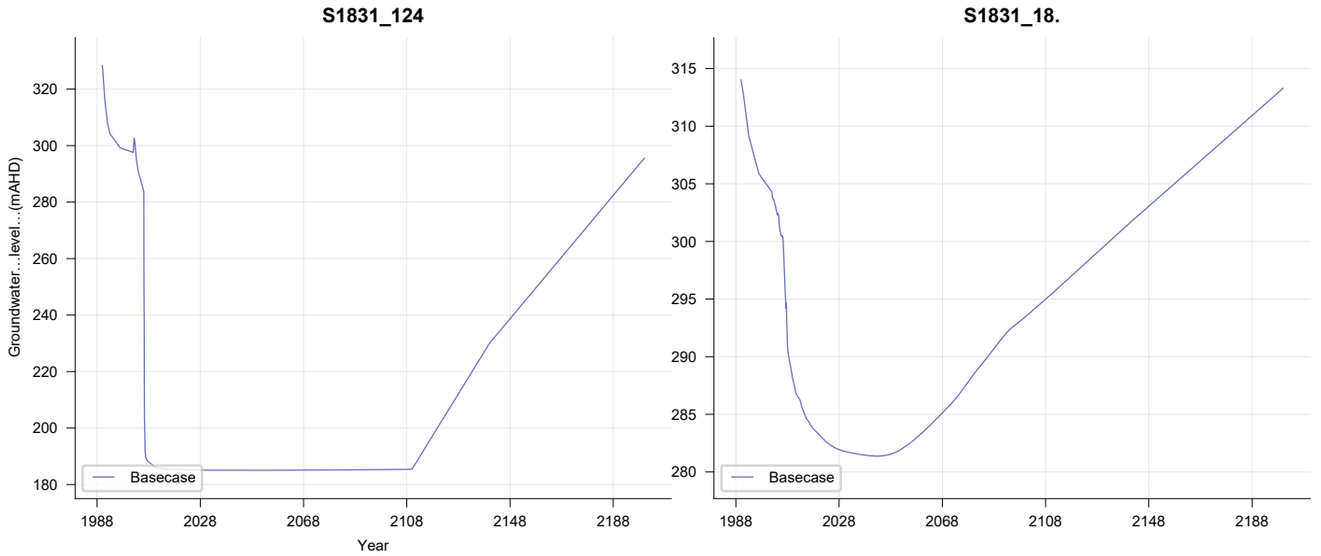

S1830_40.
Basecase


S1830_63.
Groundwater...level...(mAHD)
320
300
280
260
240
Basecase
1988
2028
2068
2108
2148
2188
Year

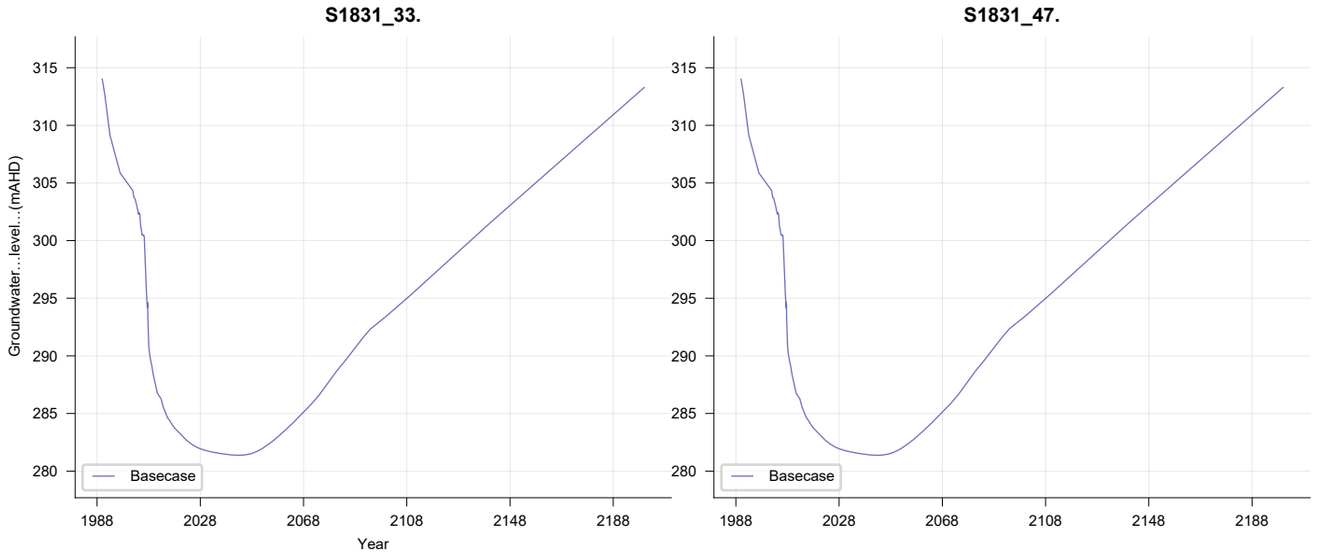

S1830_81.
320
300
280
260
240
220
Basecase
1988
2028
2068
2108
2148
2188


S1830_94.
Groundwater...level...(mAHD)
400
375
350
325
300
275
250
225
Basecase
1988
2028
2068
2108
2148
2188
Year

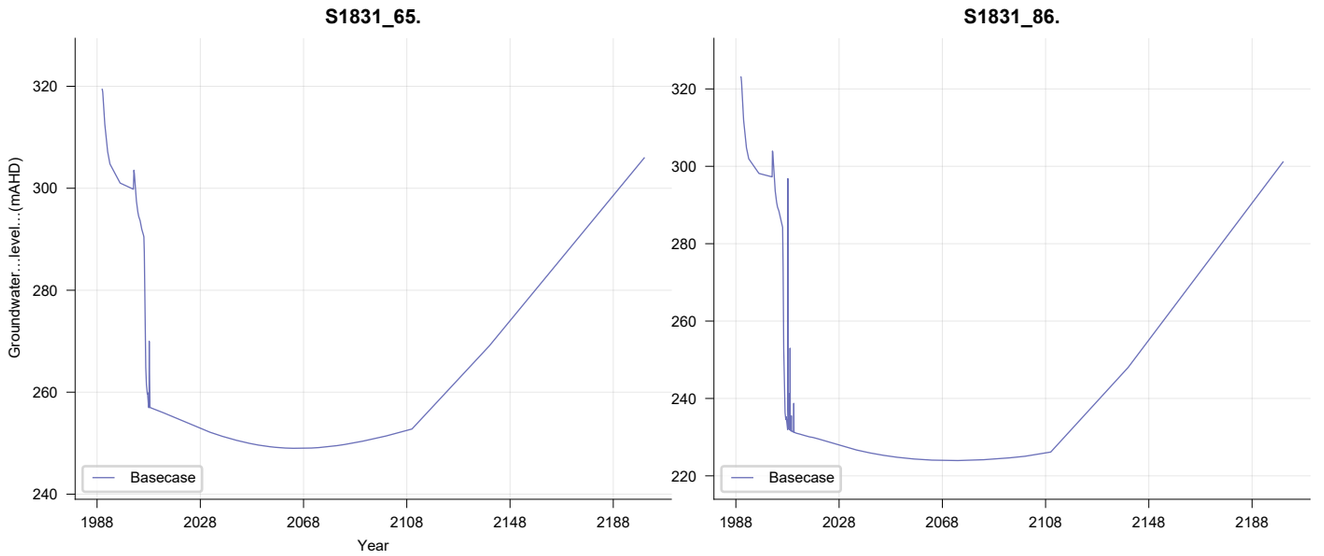

S1831_106
320
300
280
260
240
220
200
Basecase
1988
2028
2068
2108
2148
2188


S1831_124
Groundwater...level...(mAHD)
320
300
280
260
240
220
200
180
Basecase
1988
2028
2068
2108
2148
2188
Year

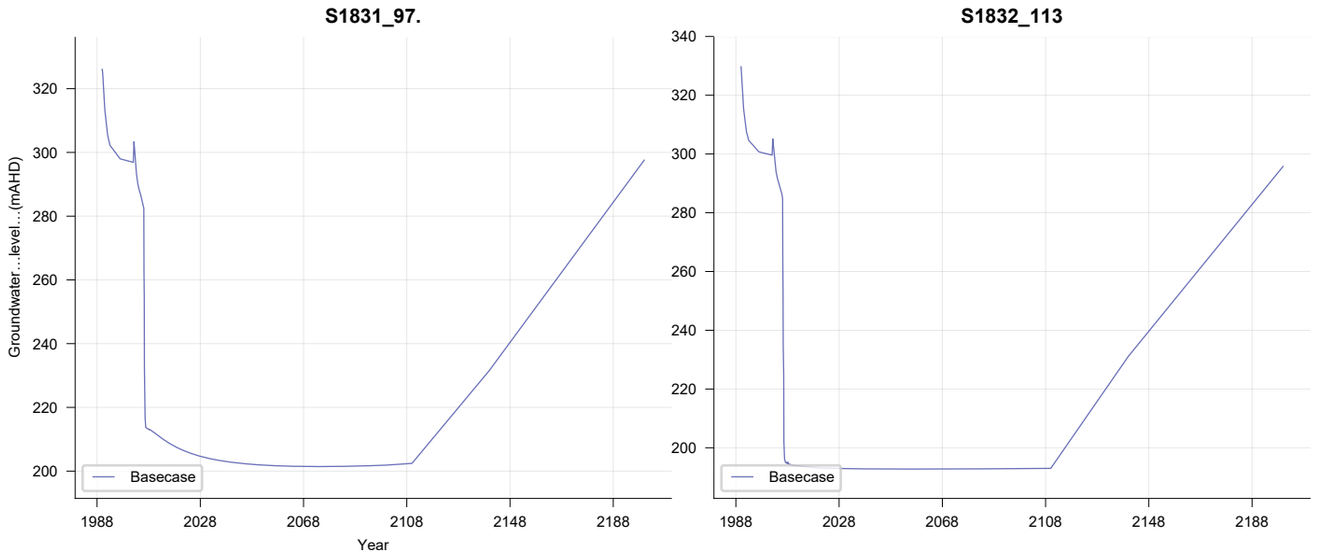

S1831_18.
315
310
305
300
295
290
285
280
Basecase
1988
2028
2068
2108
2148
2188


S1831_33.
Groundwater...level...(mAHD)
315
310
305
300
295
290
285
280
Basecase
1988
2028
2068
2108
2148
2188
Year

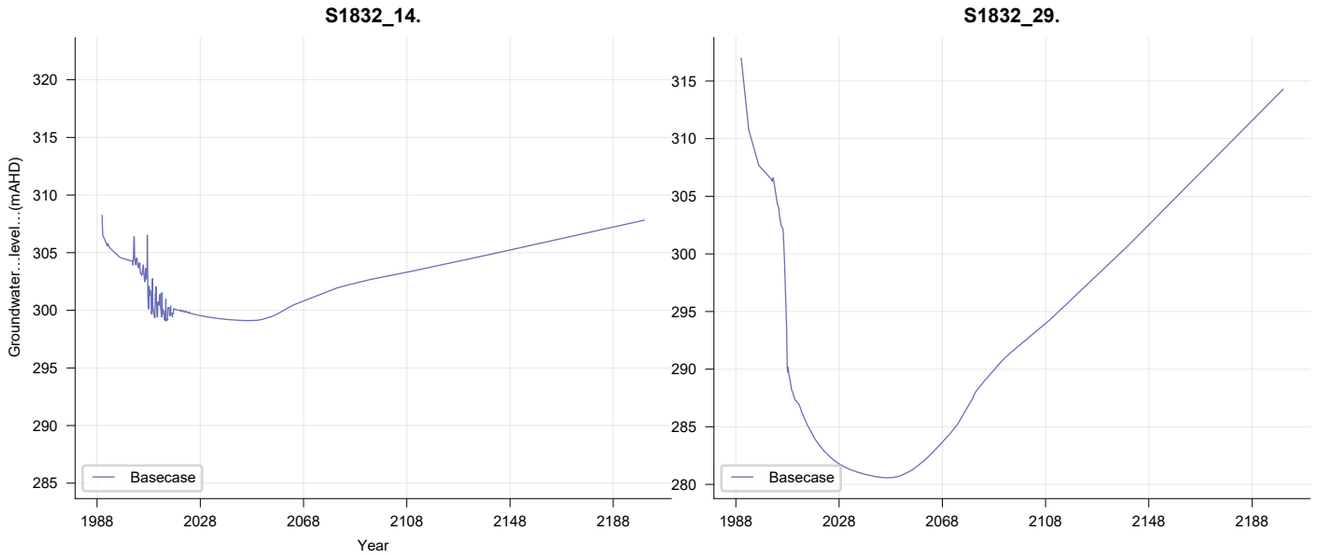

S1831_47.
315
310
305
300
295
290
285
280
Basecase
1988
2028
2068
2108
2148
2188


S1831_65.
Groundwater...level...(mAHD)
320
300
280
260
240
Basecase
1988
2028
2068
2108
2148
2188
Year

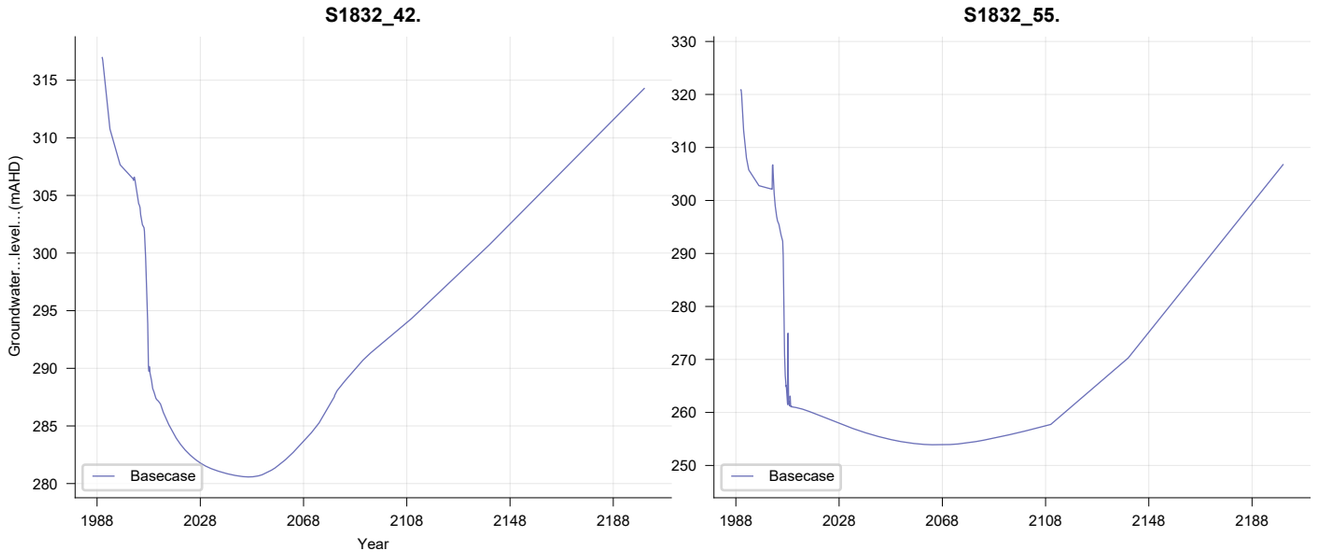

S1831_86.
320
300
280
260
240
220
Basecase
1988
2028
2068
2108
2148
2188


S1831_97.
Groundwater...level...(mAHD)
320
300
280
260
240
220
200
Basecase
1988
2028
2068
2108
2148
2188
Year

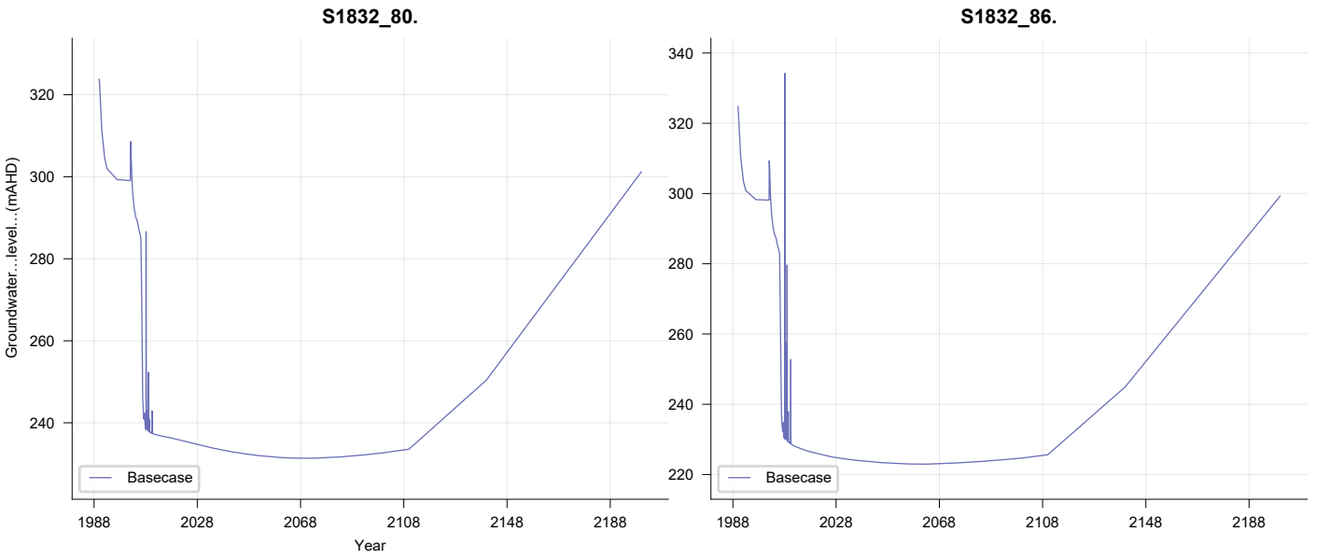

S1832_113
340
320
300
280
260
240
220
200
Basecase
1988
2028
2068
2108
2148
2188


S1832_14.
Groundwater...level...(mAHD)
320
315
310
305
300
295
290
285
Basecase
1988
2028
2068
2108
2148
2188
Year

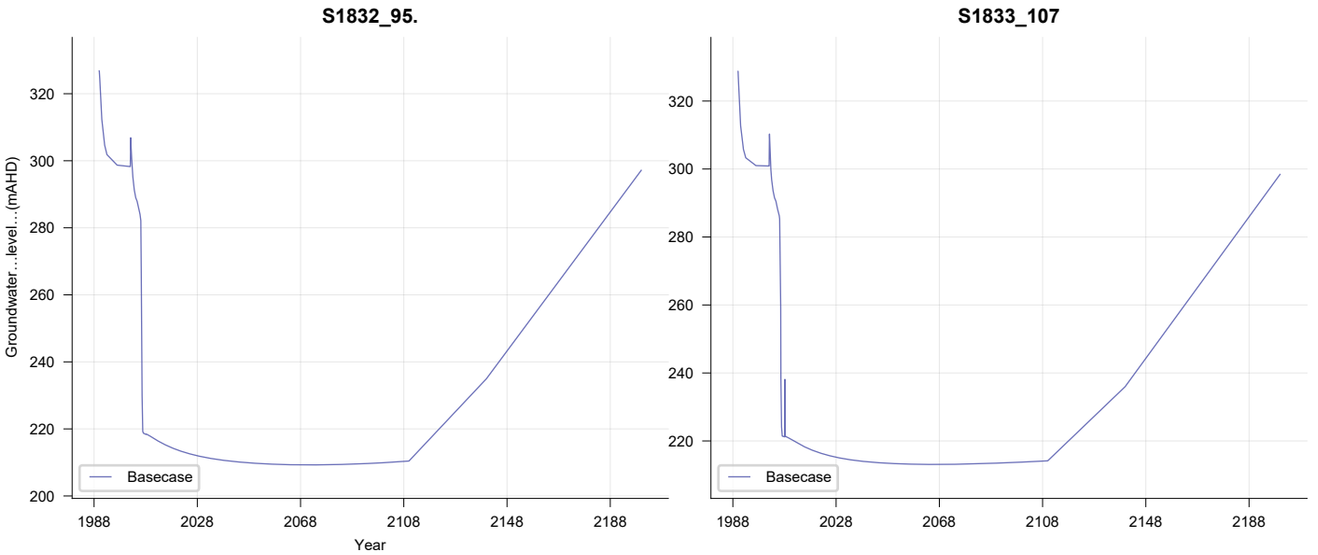

S1832_29.
315
310
305
300
295
290
285
280
Basecase
1988
2028
2068
2108
2148
2188


S1832_42.
Groundwater...level...(mAHD)
315
310
305
300
295
290
285
280
Basecase
1988
2028
2068
2108
2148
2188
Year

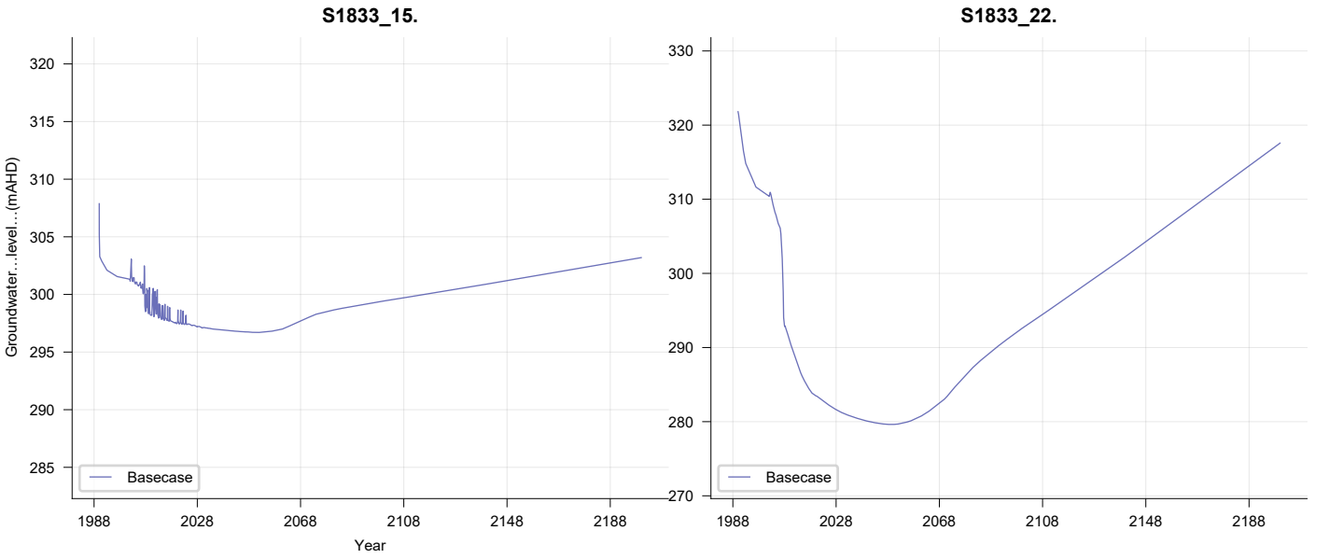

S1832_55.
330
320
310
300
290
280
270
260
250
Basecase
1988
2028
2068
2108
2148
2188


S1832_80.
Groundwater...level...(mAHD)
320
300
280
260
240
Basecase
1988
2028
2068
2108
2148
2188
Year

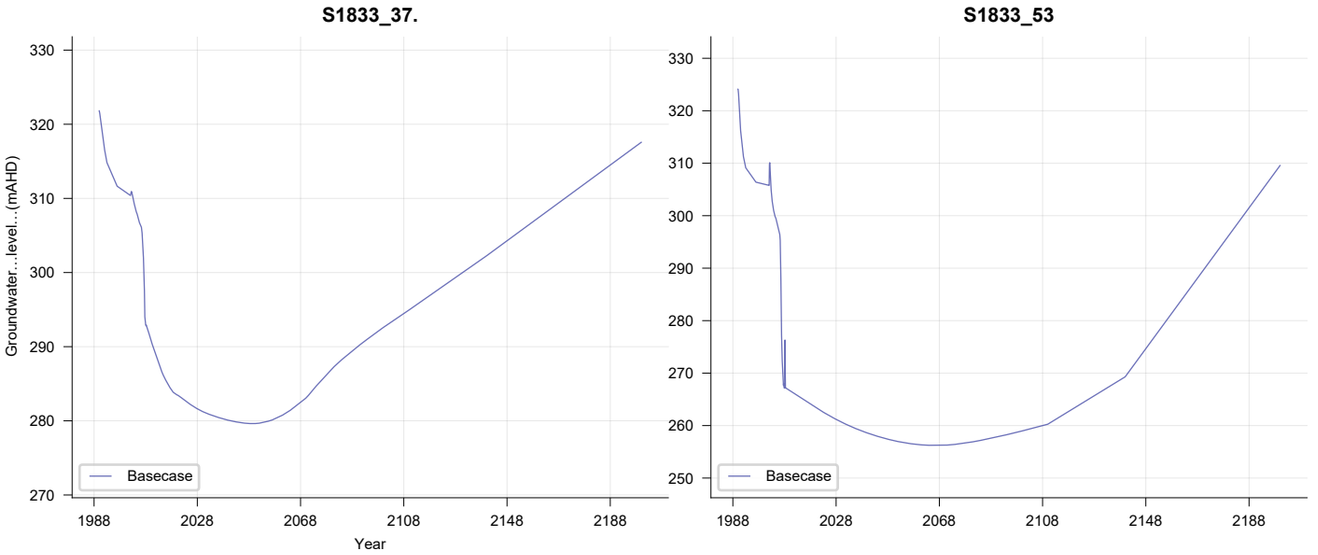

S1832_86.
340
320
300
280
260
240
220
Basecase
1988
2028
2068
2108
2148
2188


S1832_95.
Groundwater...level...(mAHD)
320
300
280
260
240
220
200
Basecase
1988
2028
2068
2108
2148
2188
Year

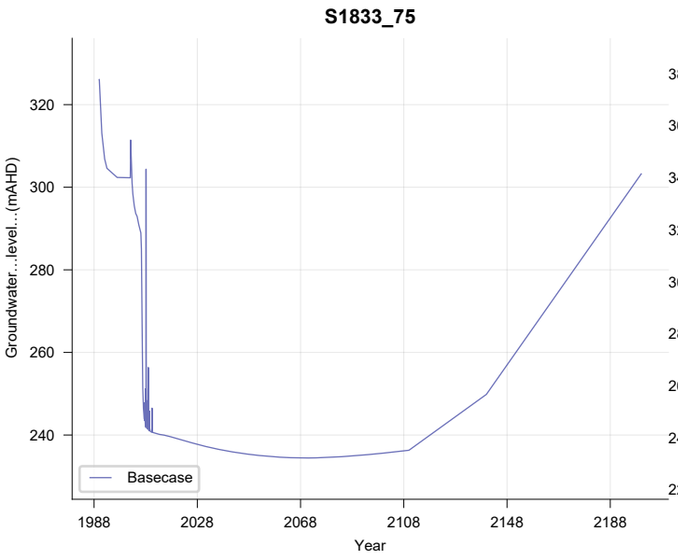

S1833_107
320
300
280
260
240
220
Basecase
1988
2028
2068
2108
2148
2188

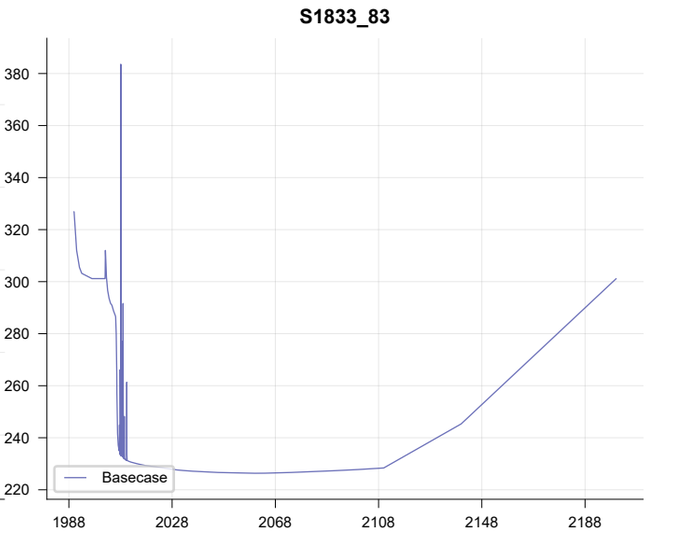

S1833_15.
Groundwater...level...(mAHD)
320
315
310
305
300
295
290
285
Basecase
1988
2028
2068
2108
2148
2188
Year

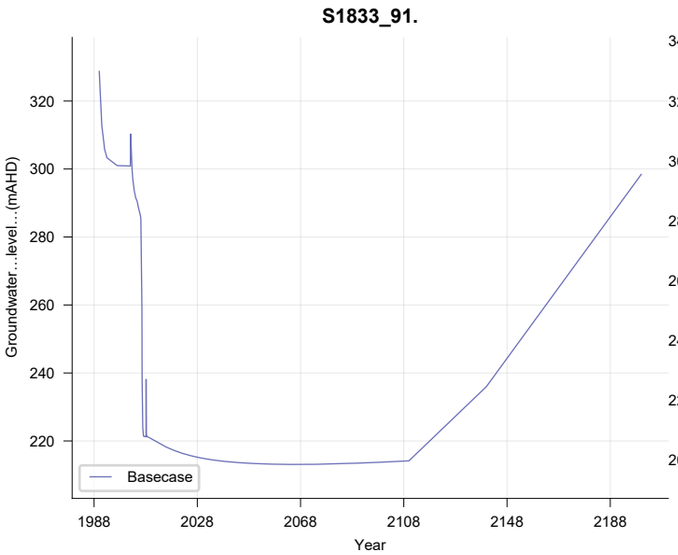

S1833_22.
330
320
310
300
290
280
270
Basecase
1988
2028
2068
2108
2148
2188

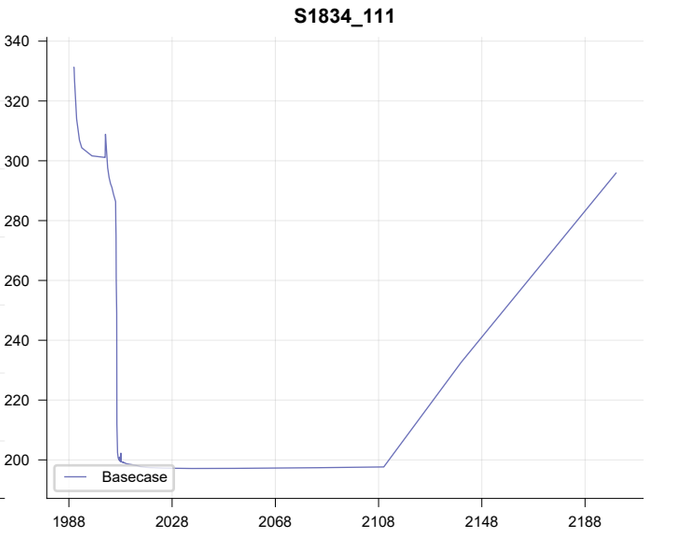

S1833_37.
Groundwater...level...(mAHD)
330
320
310
300
290
280
270
Basecase
1988
2028
2068
2108
2148
2188
Year

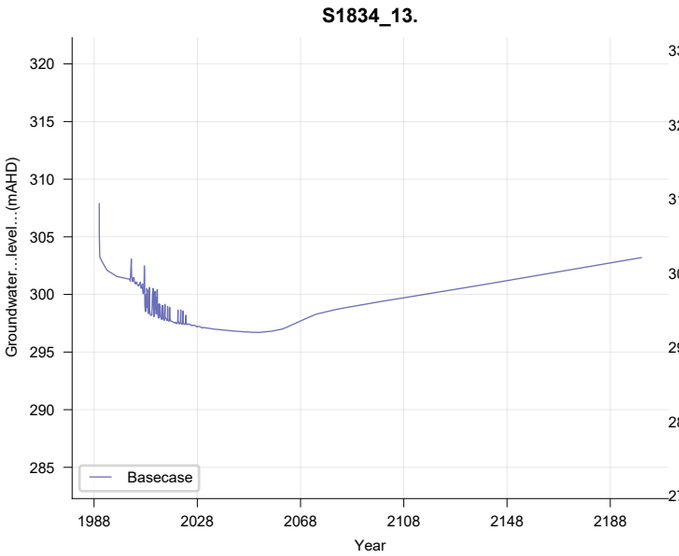

S1833_53
330
320
310
300
290
280
270
260
250
Basecase
1988
2028
2068
2108
2148
2188

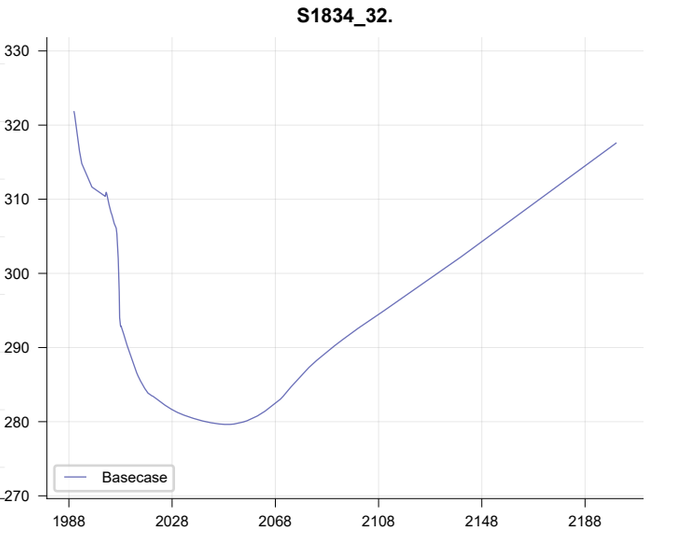

S1833_75
Groundwater...level...(mAHD)
320
300
280
260
240
Basecase
1988
2028
2068
2108
2148
2188
Year

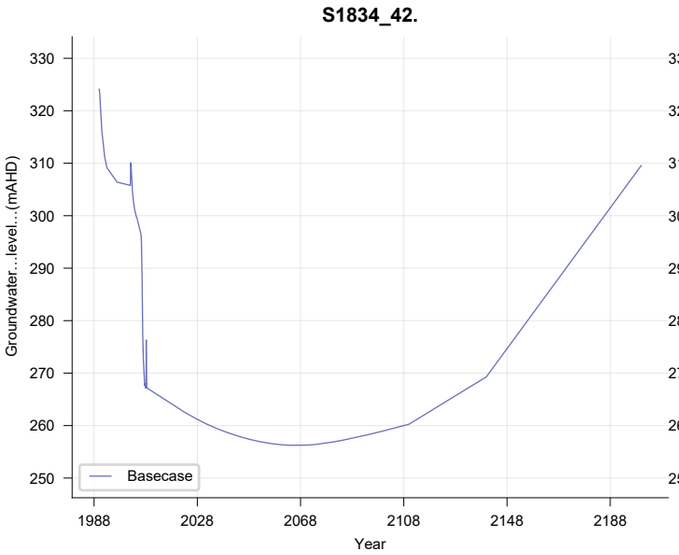

S1833_83
380
360
340
320
300
280
260
240
220
Basecase
1988
2028
2068
2108
2148
2188

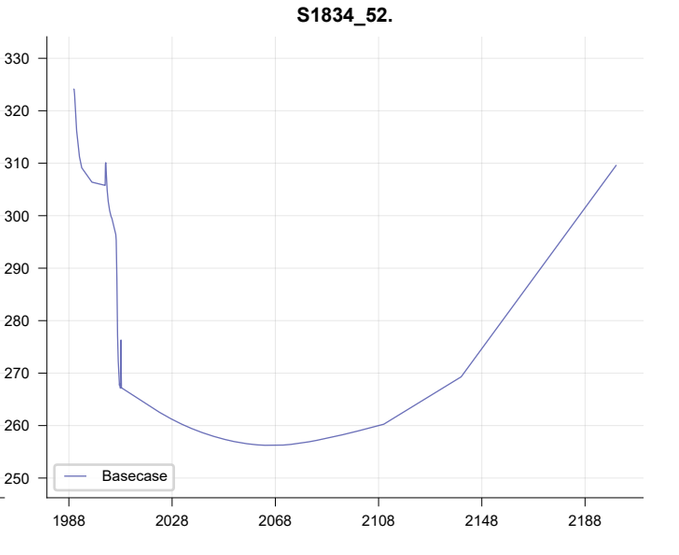

S1833_91.
Groundwater...level...(mAHD)
320
300
280
260
240
220
Basecase
1988
2028
2068
2108
2148
2188
Year

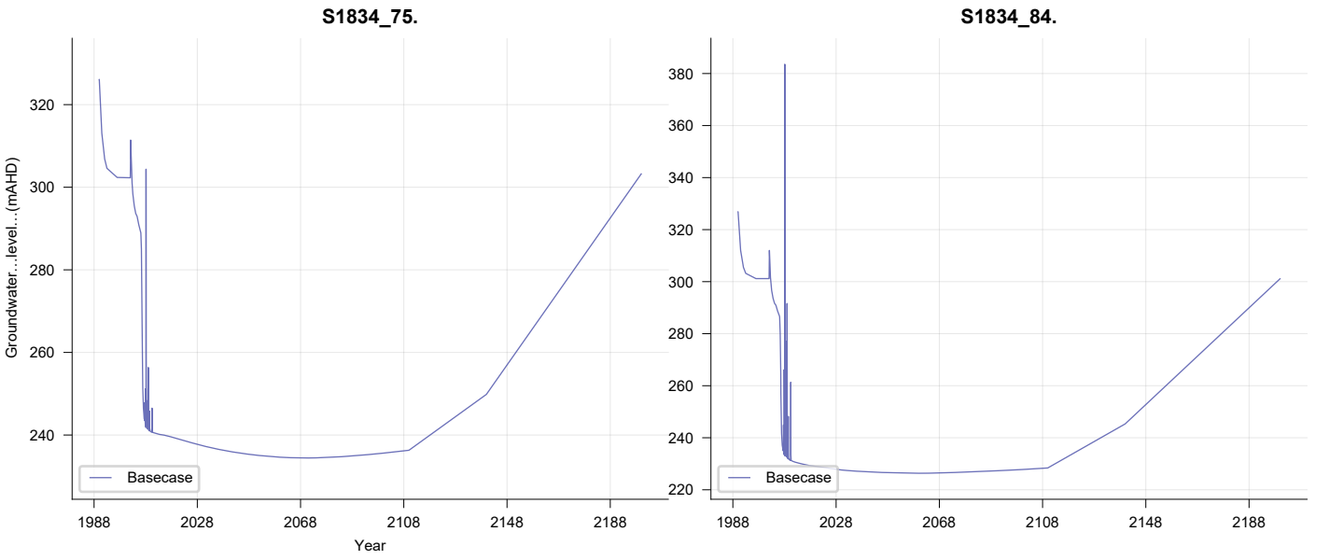

S1834_111
340
320
300
280
260
240
220
200
Basecase
1988
2028
2068
2108
2148
2188


S1834_13.
Groundwater...level...(mAHD)
320
315
310
305
300
295
290
285
Basecase
1988
2028
2068
2108
2148
2188
Year

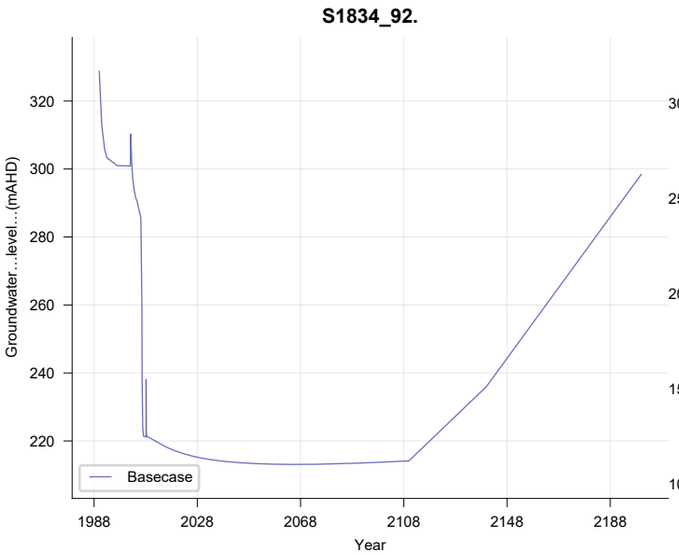

S1834_32.
330
320
310
300
290
280
270
Basecase
1988
2028
2068
2108
2148
2188

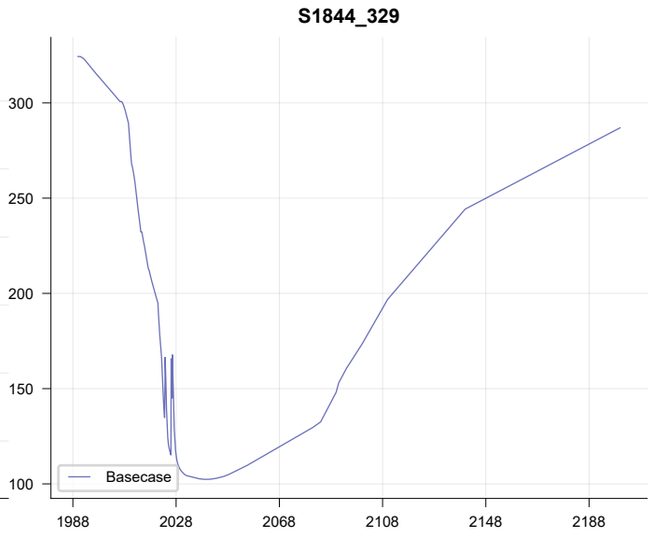

S1834_42.
Groundwater...level...(mAHD)
330
320
310
300
290
280
270
260
250
Basecase
1988
2028
2068
2108
2148
2188
Year

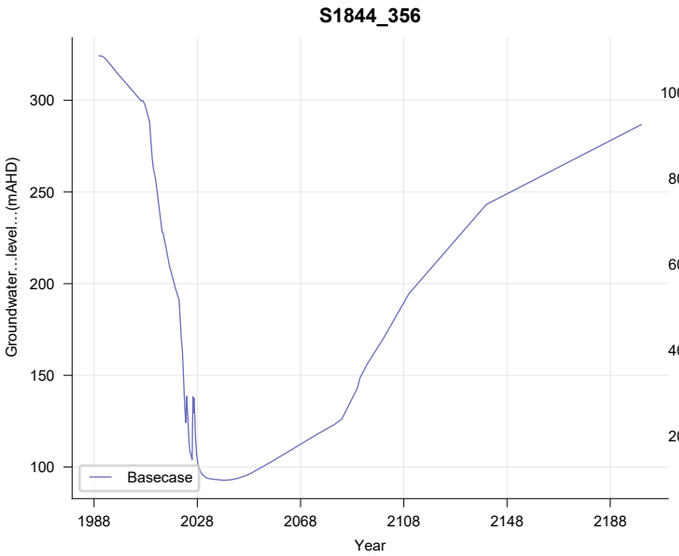

S1834_52.
330
320
310
300
290
280
270
260
250
Basecase
1988
2028
2068
2108
2148
2188

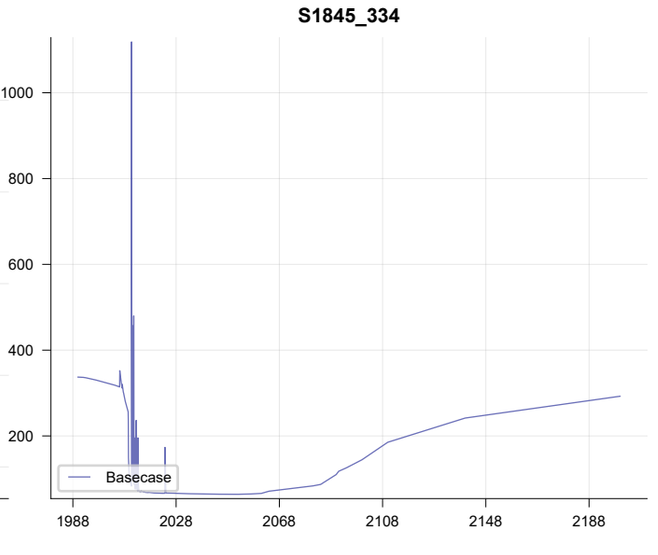

S1834_75.
Groundwater...level...(mAHD)
320
300
280
260
240
Basecase
1988
2028
2068
2108
2148
2188
Year

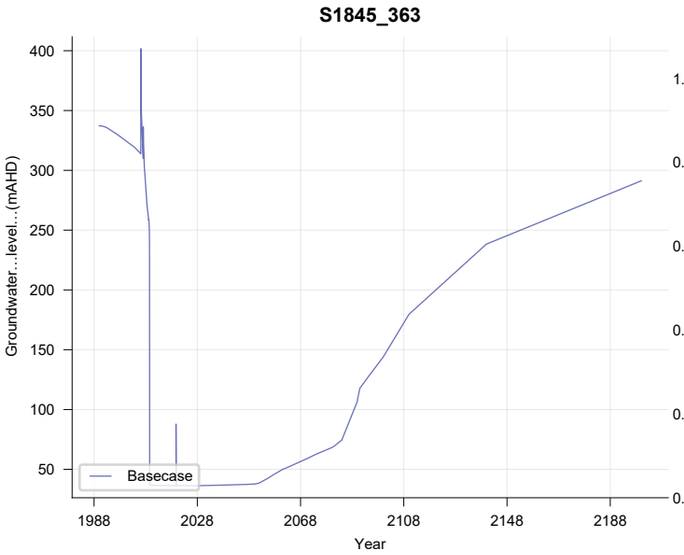

S1834_84.
380
360
340
320
300
280
260
240
220
Basecase
1988
2028
2068
2108
2148
2188

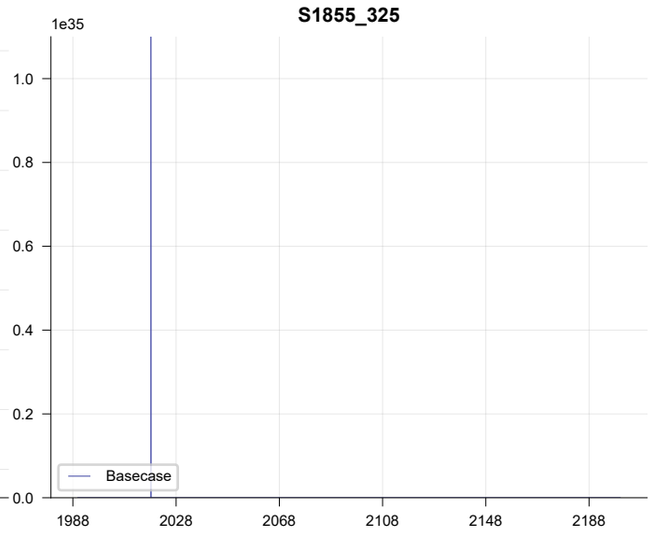

S1834_92.
Groundwater...level...(mAHD)
320
300
280
260
240
220
Basecase
1988
2028
2068
2108
2148
2188
Year

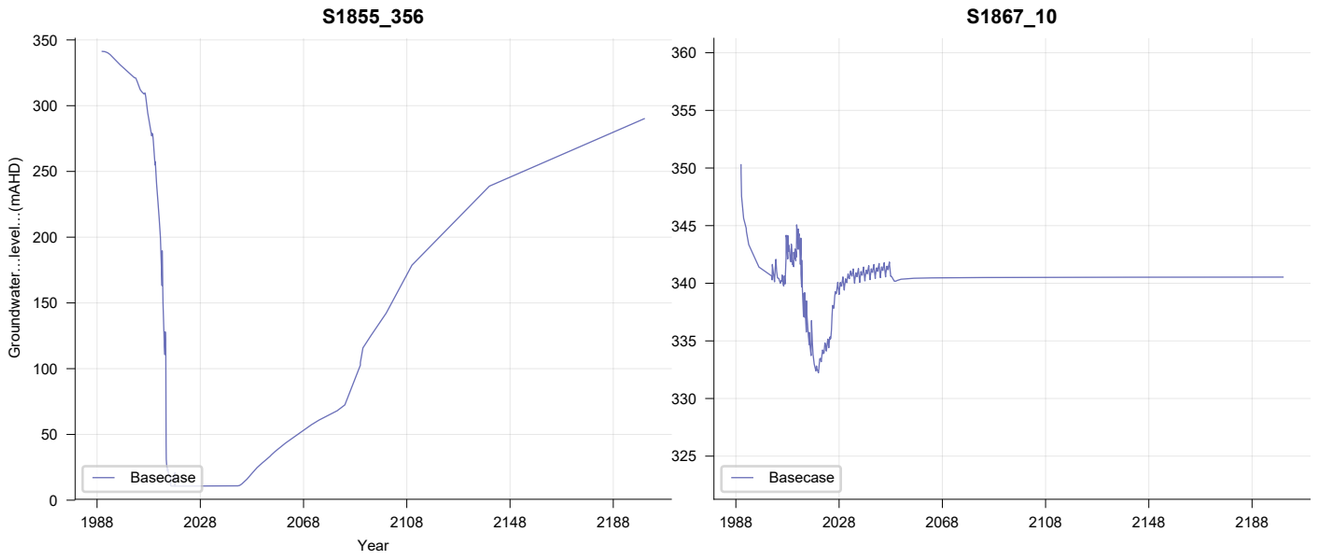

S1844_329
300
250
200
150
100
Basecase
1988
2028
2068
2108
2148
2188


S1844_356
Groundwater...level...(mAHD)
300
250
200
150
100
Basecase
1988
2028
2068
2108
2148
2188
Year

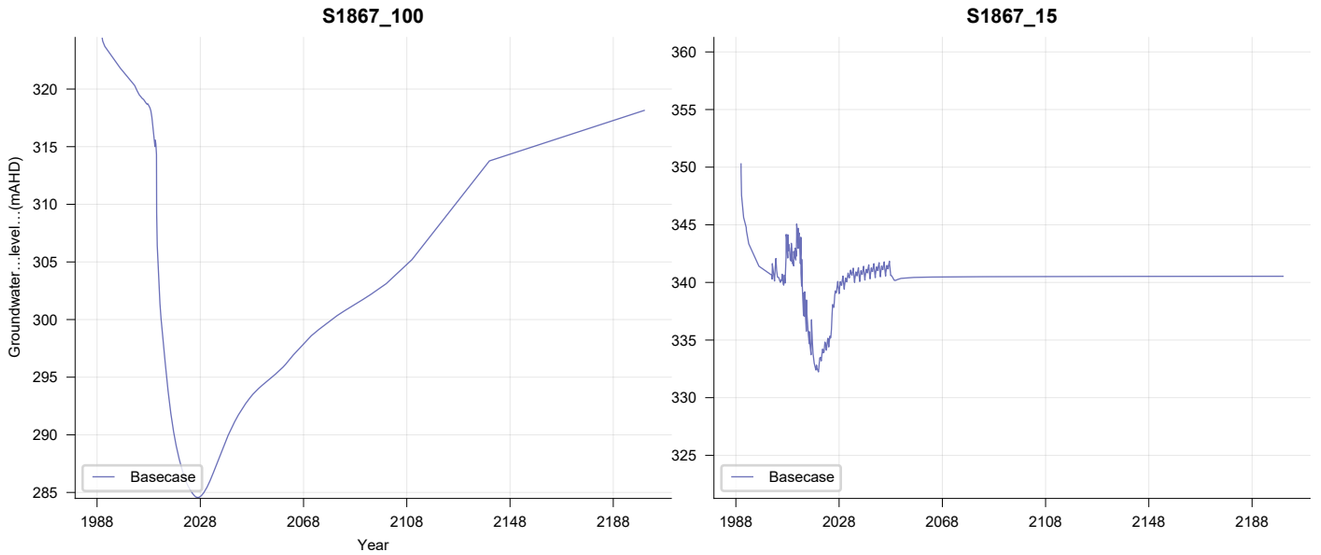

S1845_334
1000
800
600
400
200
Basecase
1988
2028
2068
2108
2148
2188


S1845_363
Groundwater...level...(mAHD)
400
350
300
250
200
150
100
50
Basecase
1988
2028
2068
2108
2148
2188
Year

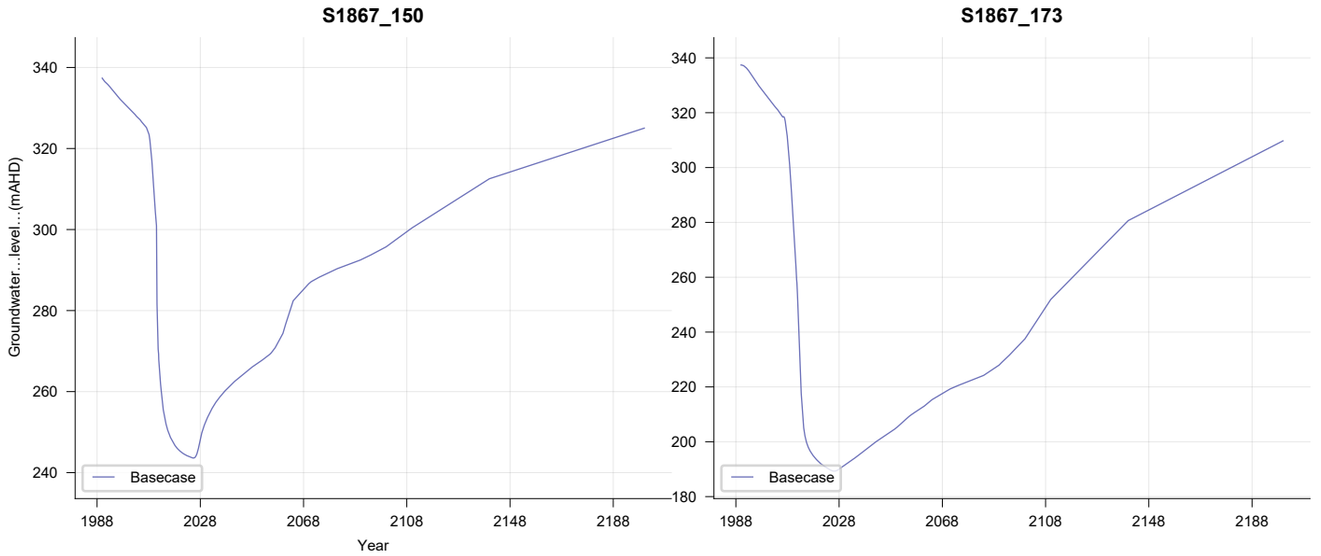

S1855_325
1e35
1.0
0.8
0.6
0.4
0.2
0.0
Basecase
1988
2028
2068
2108
2148
2188


S1855_356
Groundwater...level...(mAHD)
Year
Basecase

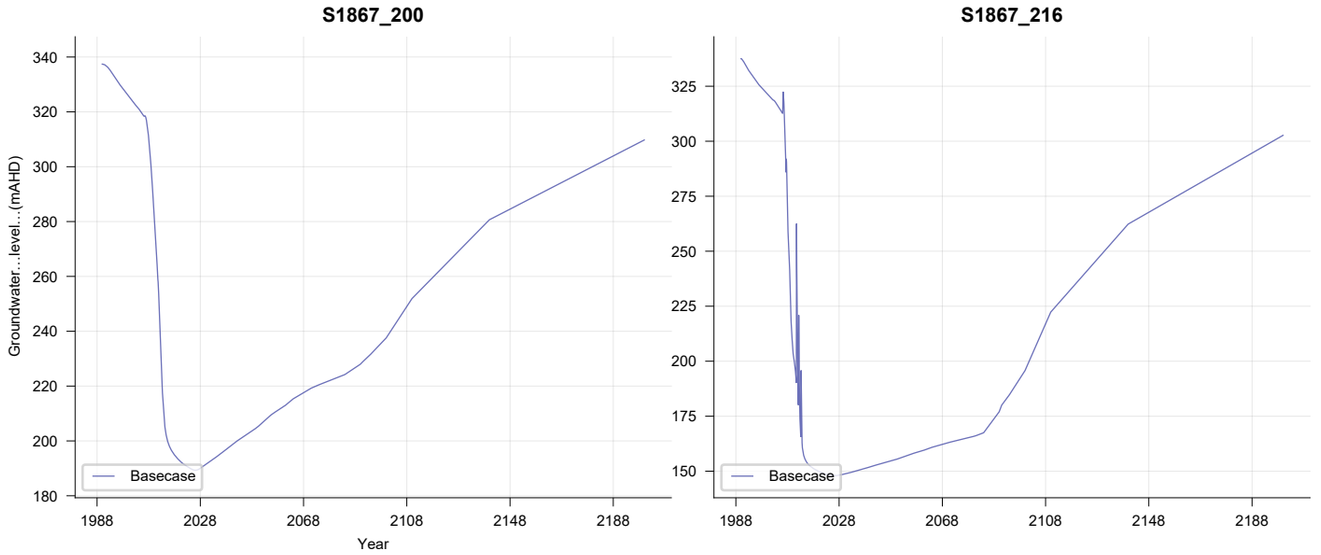

S1867_10
Basecase


S1867_100
Groundwater...level...(mAHD)
Year
Basecase

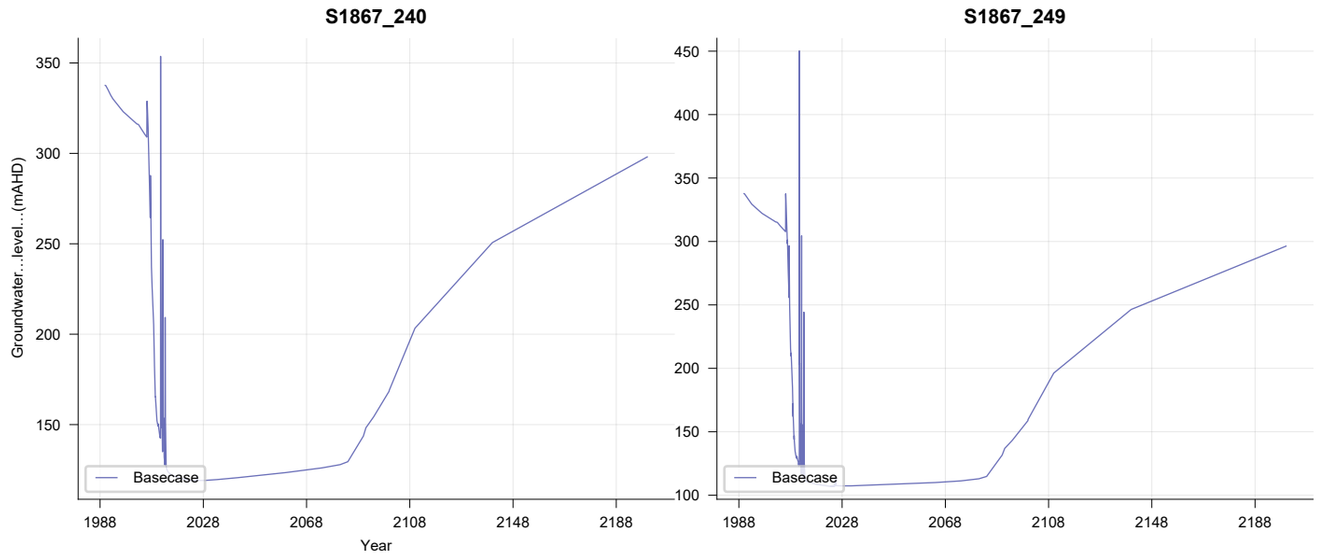

S1867_15
Basecase


S1867_150
Groundwater...level...(mAHD)
Year
Basecase

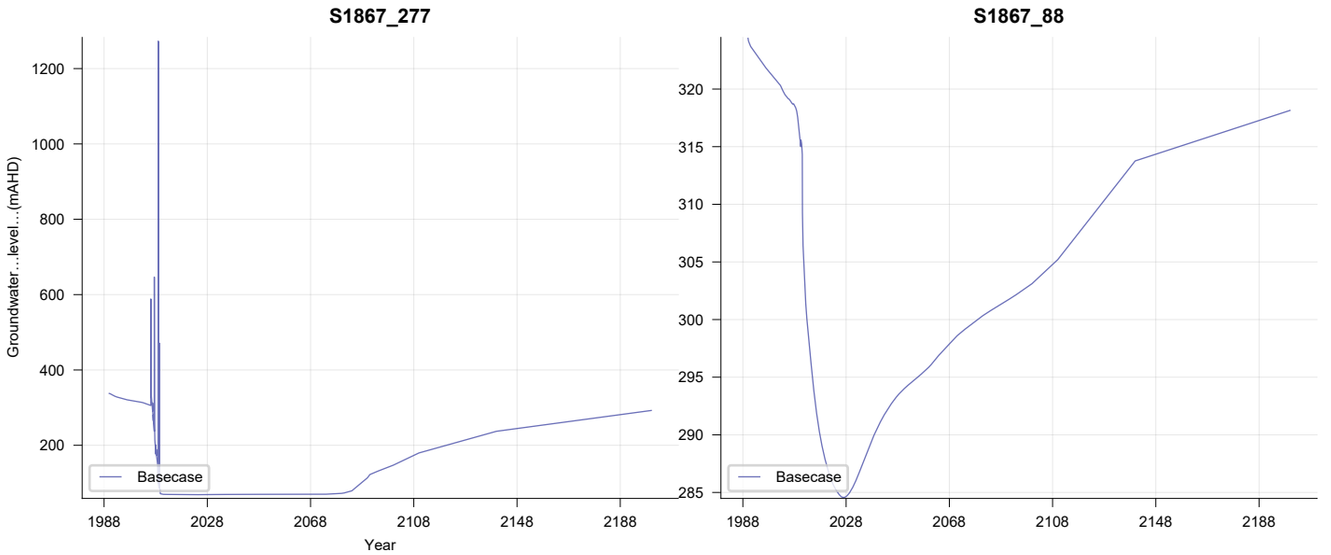

S1867_173
Basecase


S1867_200
Groundwater...level...(mAHD)
Year
Basecase

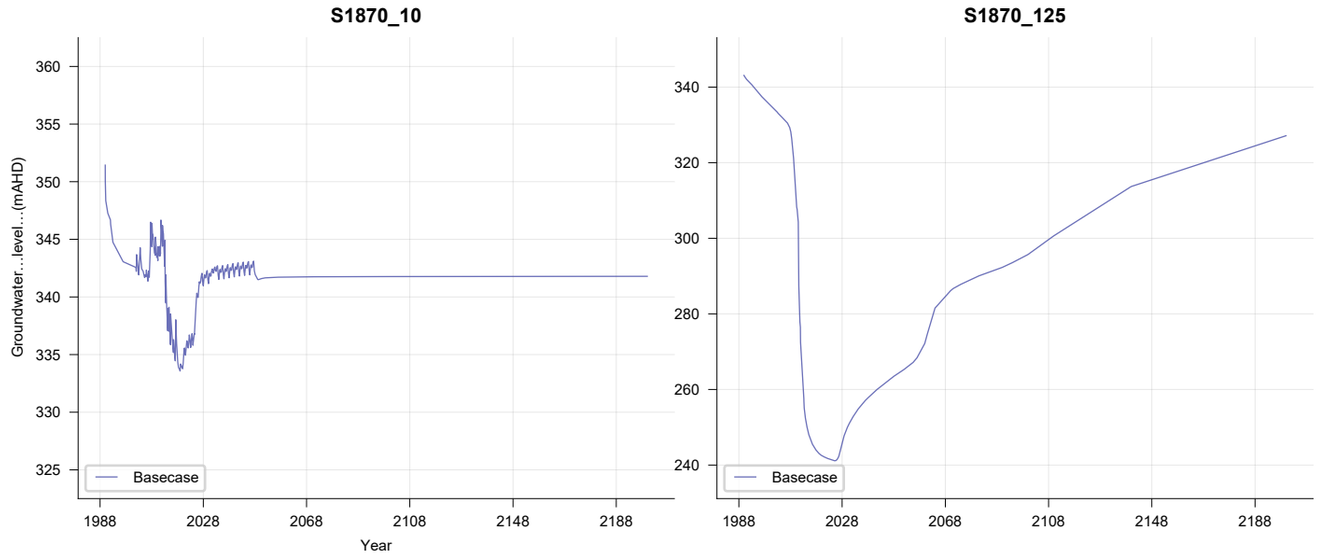

S1867_216
Basecase


S1867_240
Groundwater...level...(mAHD)
Year
Basecase

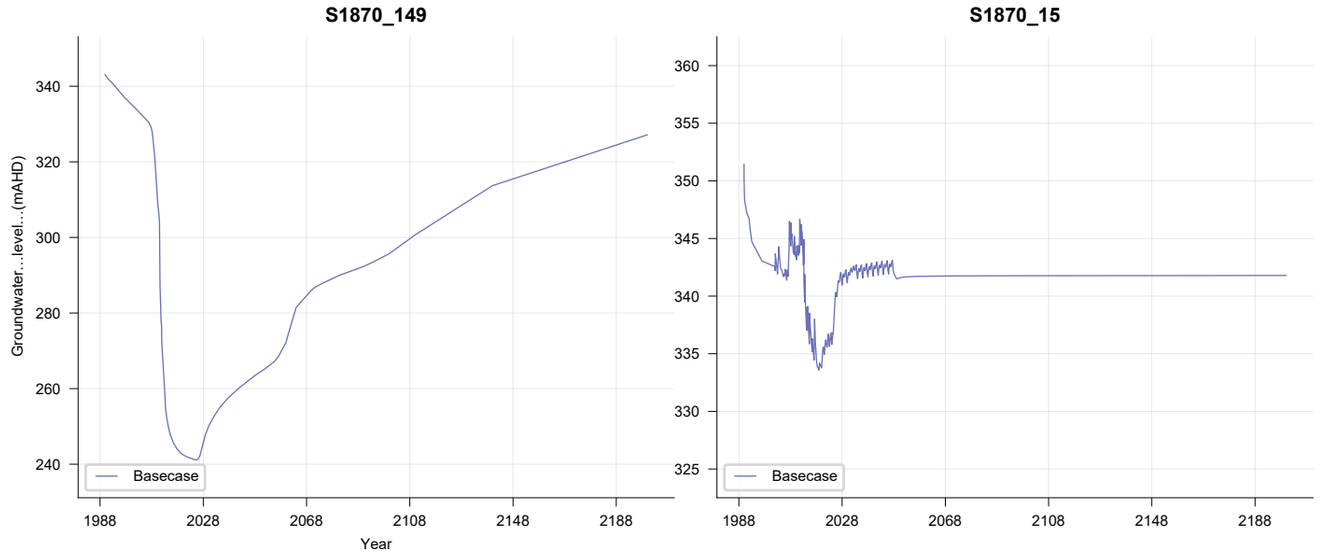

S1867_249
Basecase


S1867_277
Groundwater...level...(mAHD)
Year
Basecase

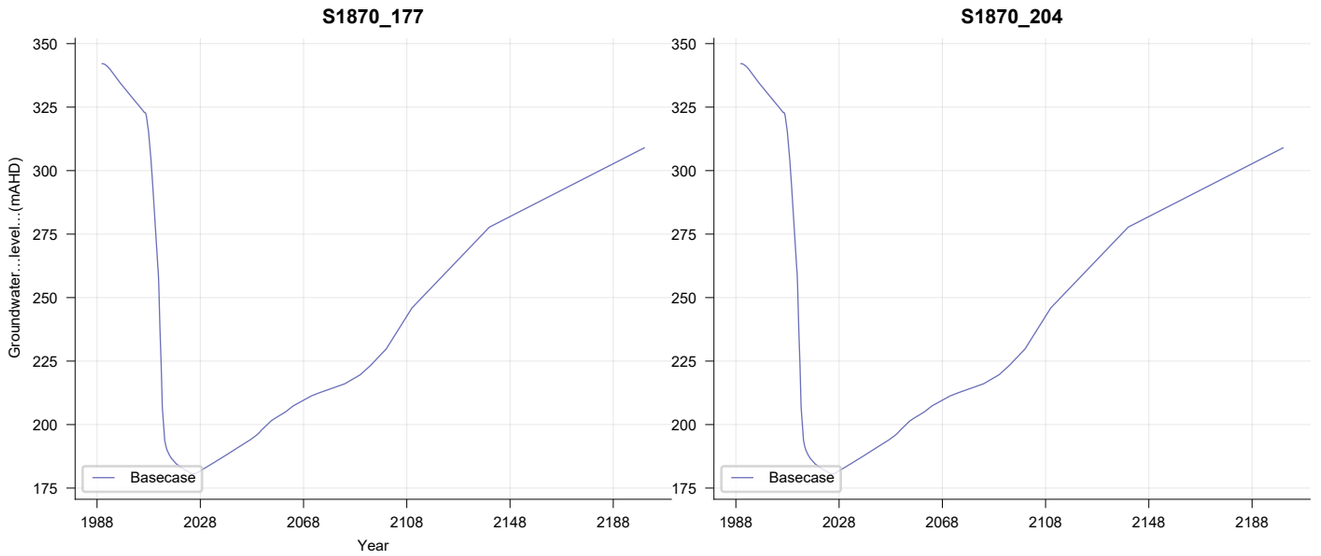

S1867_88
Basecase


S1870_10
Groundwater...level...(mAHD)
Year
Basecase

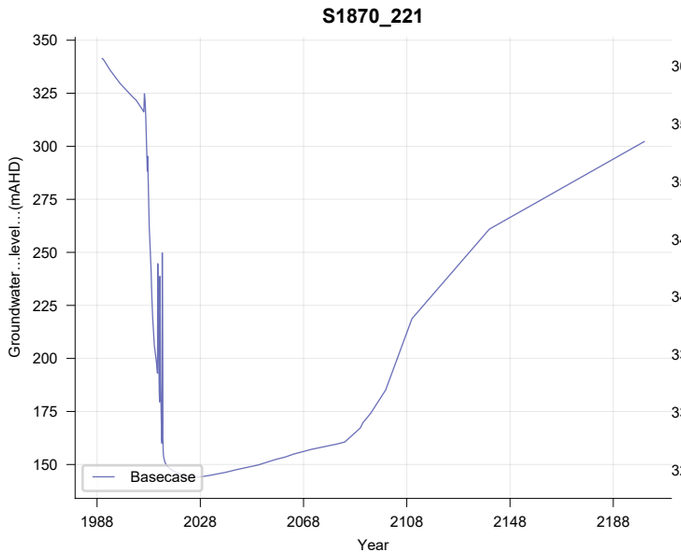

S1870_125
Basecase

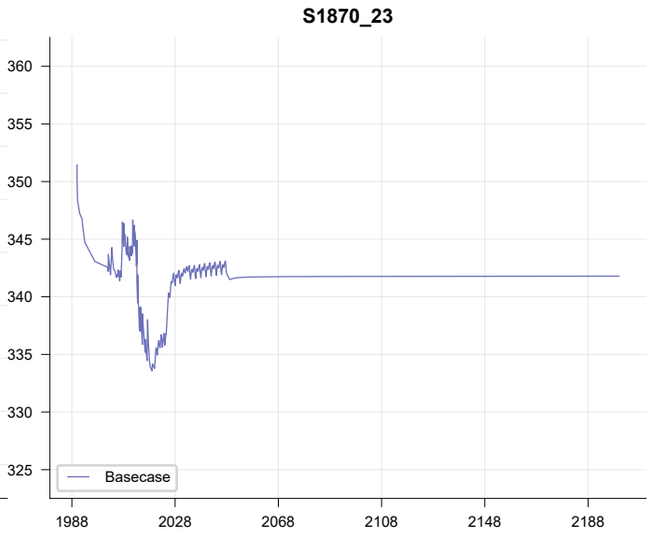

S1870_149
Groundwater...level...(mAHD)
Year
Basecase

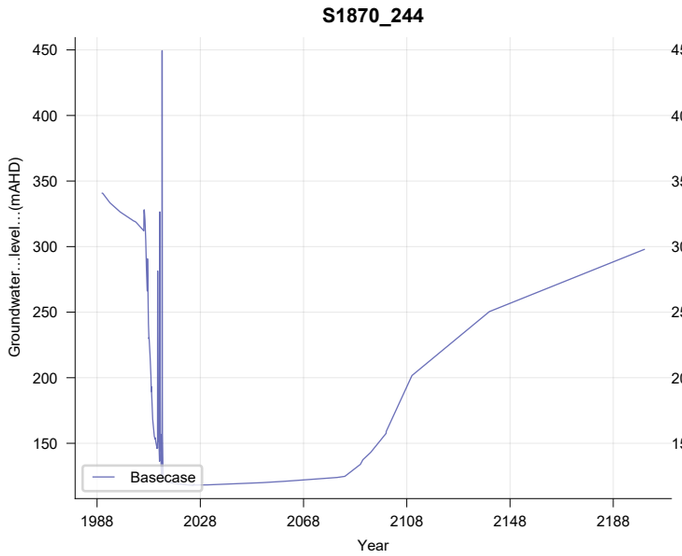

S1870_15
Basecase

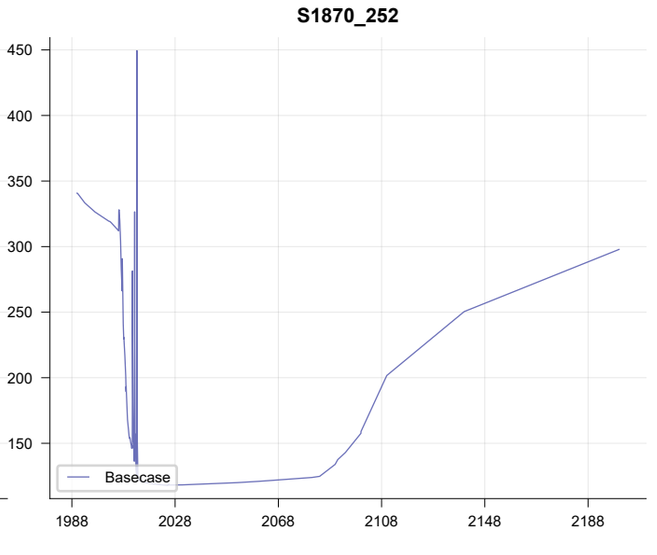

S1870_177
Groundwater...level...(mAHD)
Year
Basecase

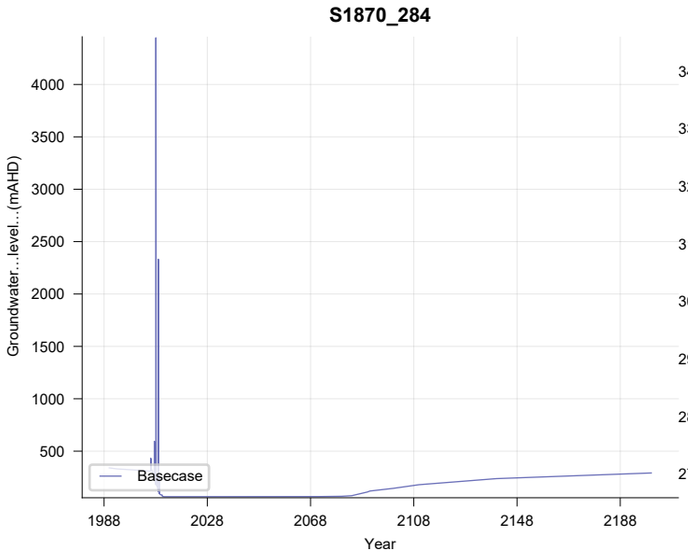

S1870_204
Basecase

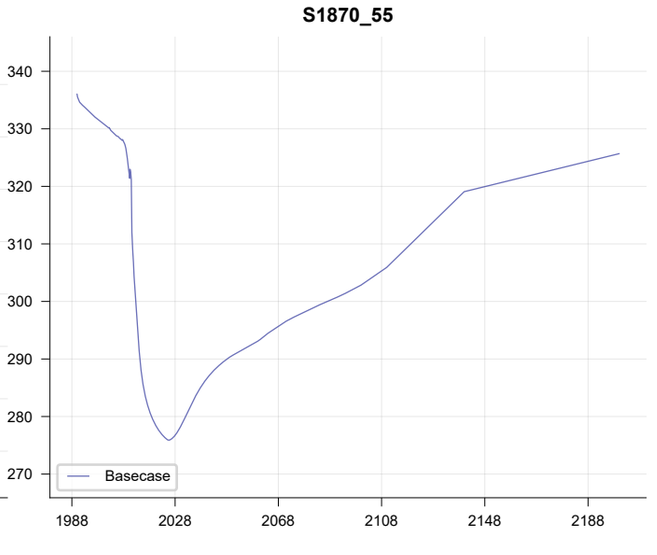

S1870_221
Groundwater...level...(mAHD)
Year
Basecase

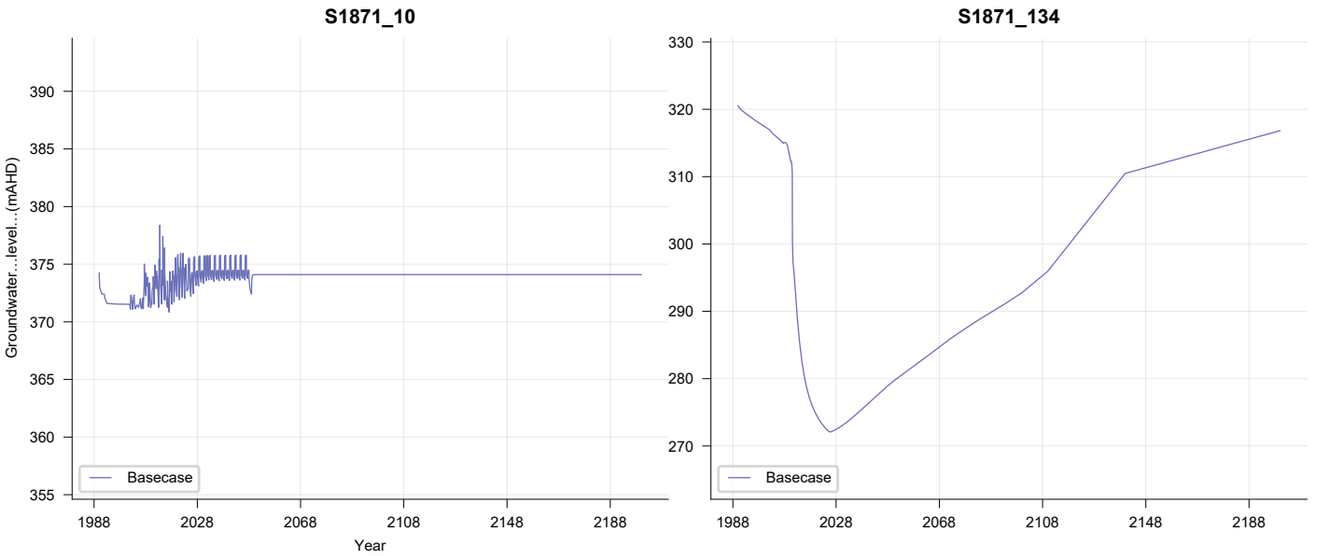

S1870_23
Basecase


S1870_244
Groundwater...level...(mAHD)
Year
Basecase

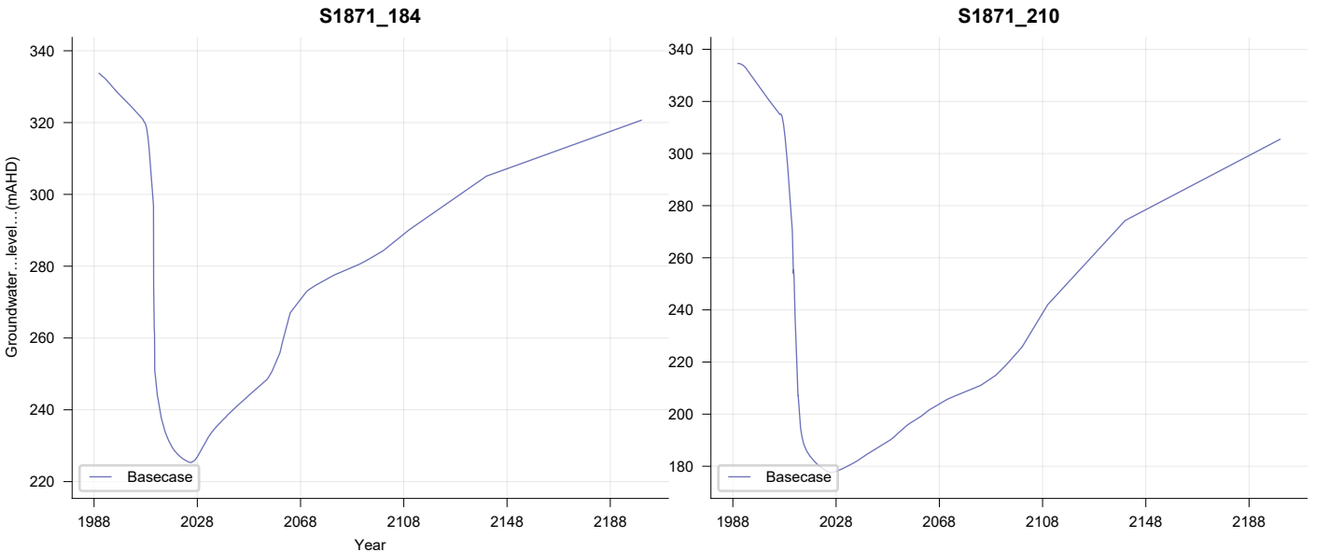

S1870_252
Basecase


S1870_284
Groundwater...level...(mAHD)
Year
Basecase

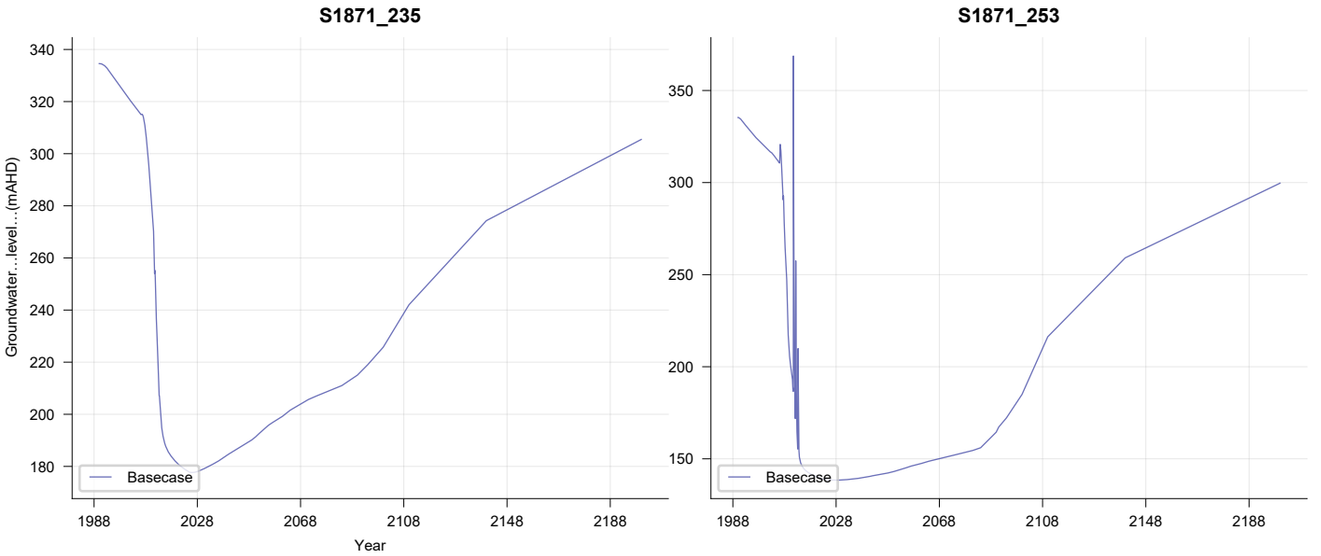

S1870_55
Basecase


S1871_10
Groundwater...level...(mAHD)
390
385
380
375
370
365
360
355
Basecase
1988
2028
2068
2108
2148
2188
Year

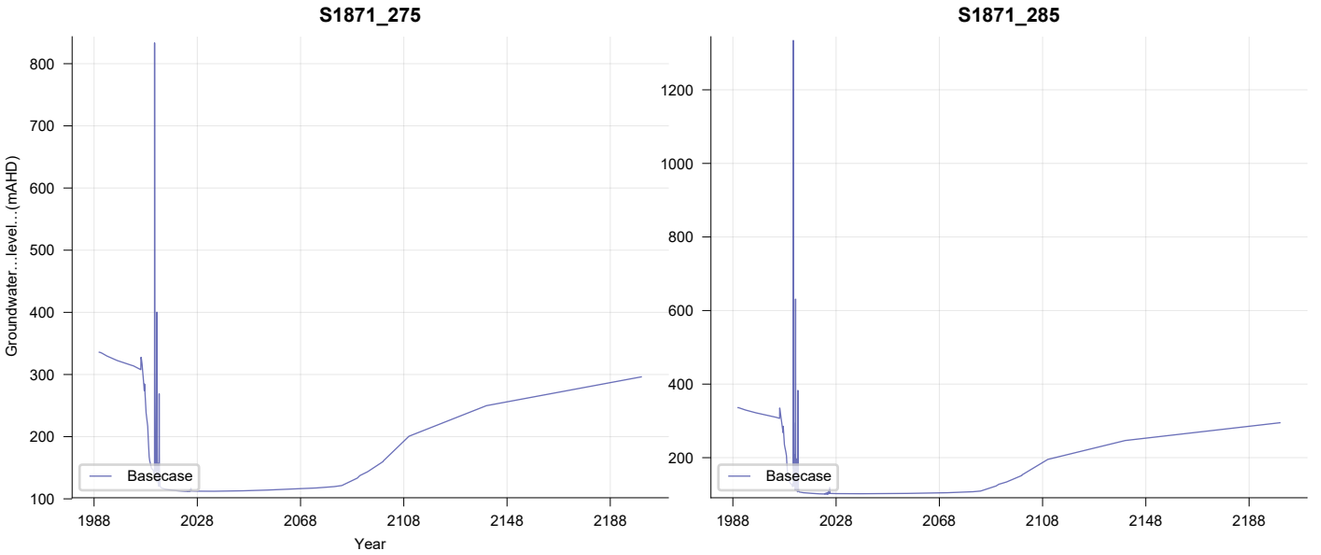

S1871_134
330
320
310
300
290
280
270
Basecase
1988
2028
2068
2108
2148
2188


S1871_184
Groundwater...level...(mAHD)
340
320
300
280
260
240
220
Basecase
1988
2028
2068
2108
2148
2188
Year

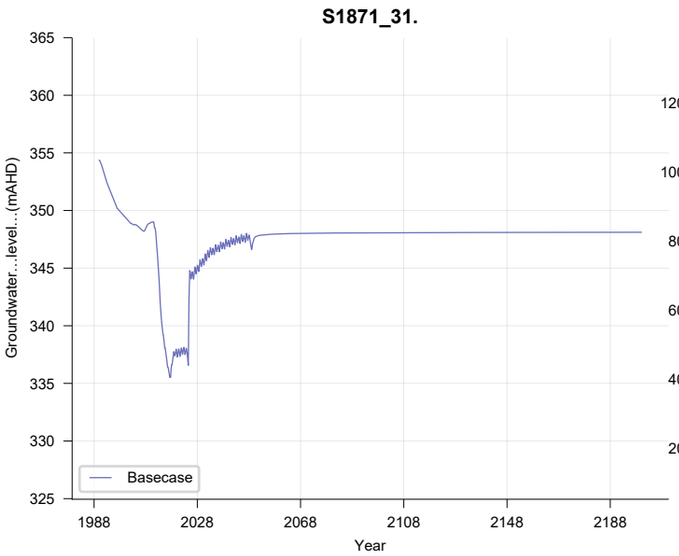

S1871_210
340
320
300
280
260
240
220
200
180
Basecase
1988
2028
2068
2108
2148
2188

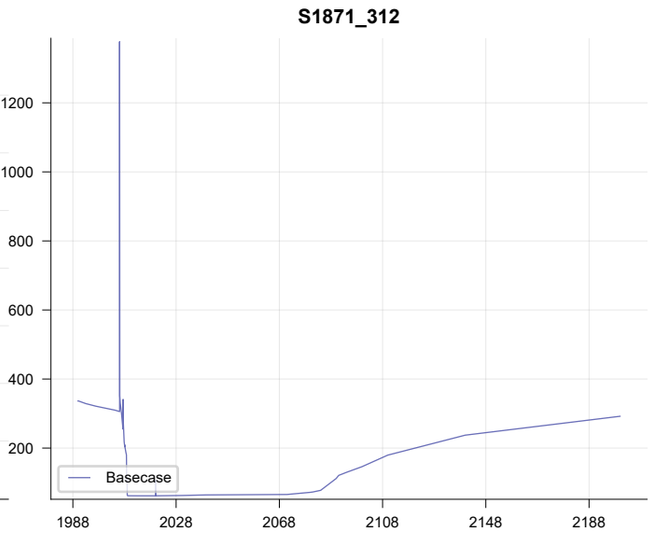

S1871_235
Groundwater...level...(mAHD)
340
320
300
280
260
240
220
200
180
Basecase
1988
2028
2068
2108
2148
2188
Year

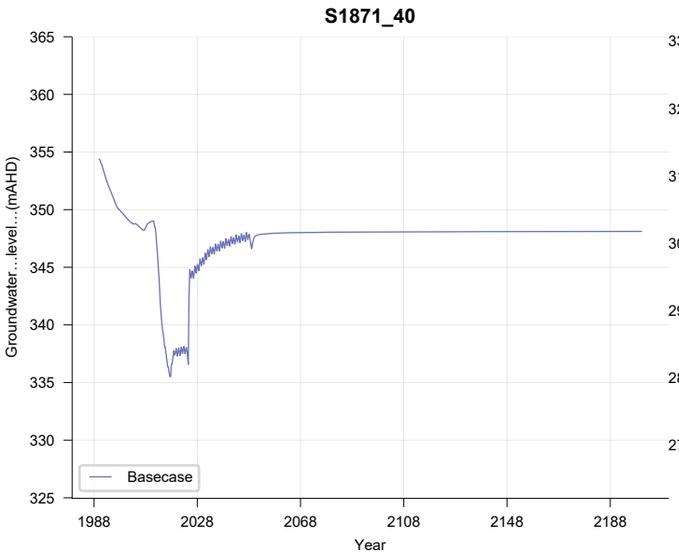

S1871_253
350
300
250
200
150
Basecase
1988
2028
2068
2108
2148
2188

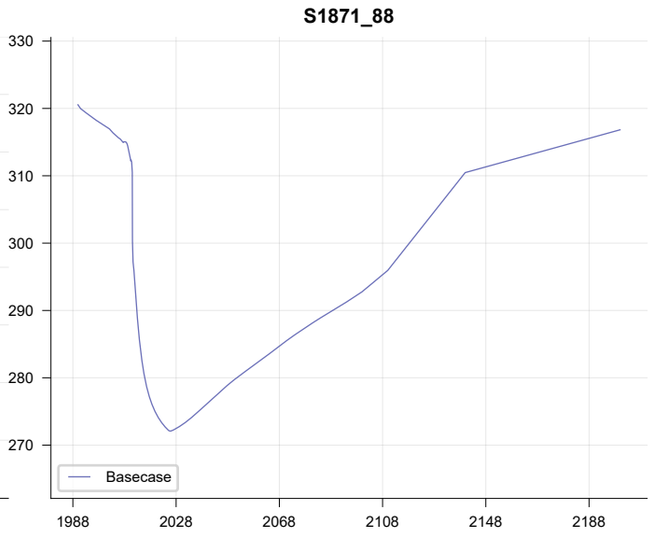

S1871_275
Groundwater...level...(mAHD)
800
700
600
500
400
300
200
100
Basecase
1988
2028
2068
2108
2148
2188
Year

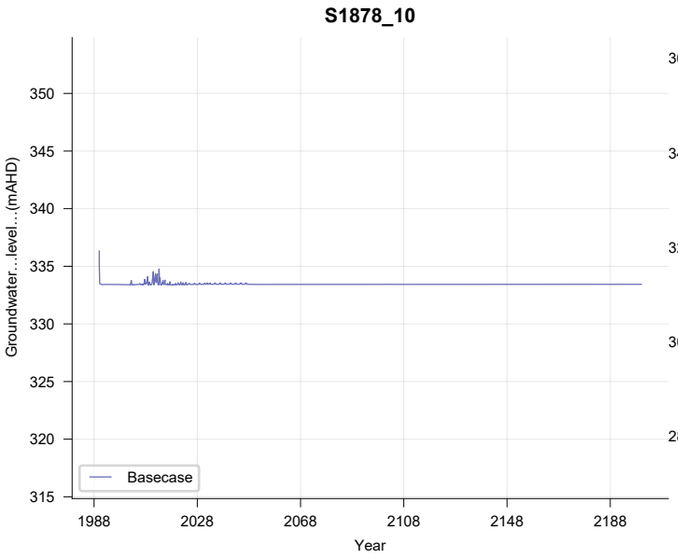

S1871_285
1200
1000
800
600
400
200
Basecase
1988
2028
2068
2108
2148
2188

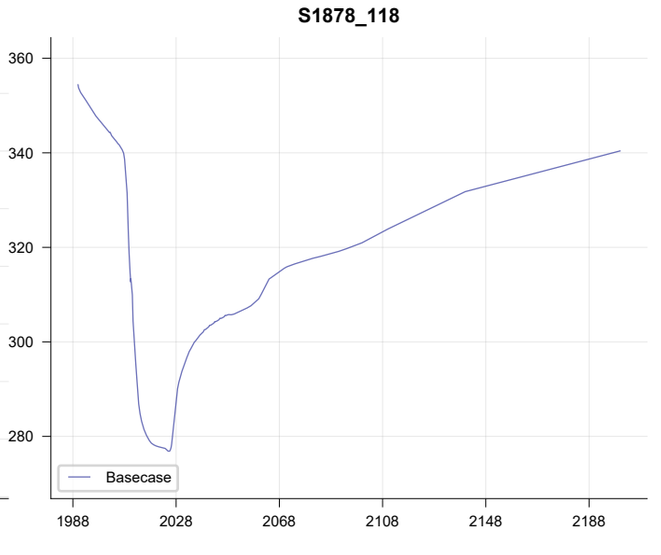

S1871_31.
Groundwater...level...(mAHD)
Year
Basecase

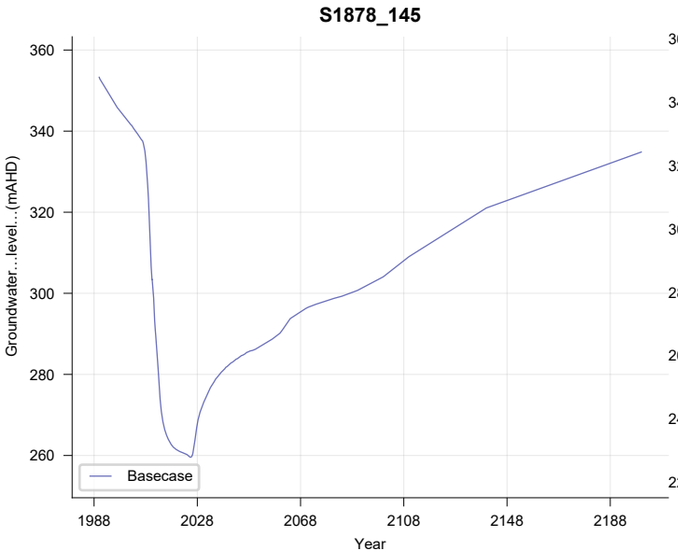

S1871_312
Basecase

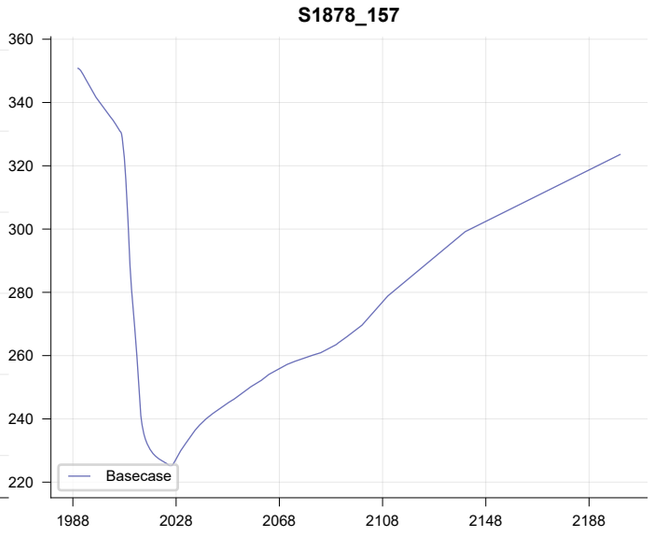

S1871_40
Groundwater...level...(mAHD)
Year
Basecase

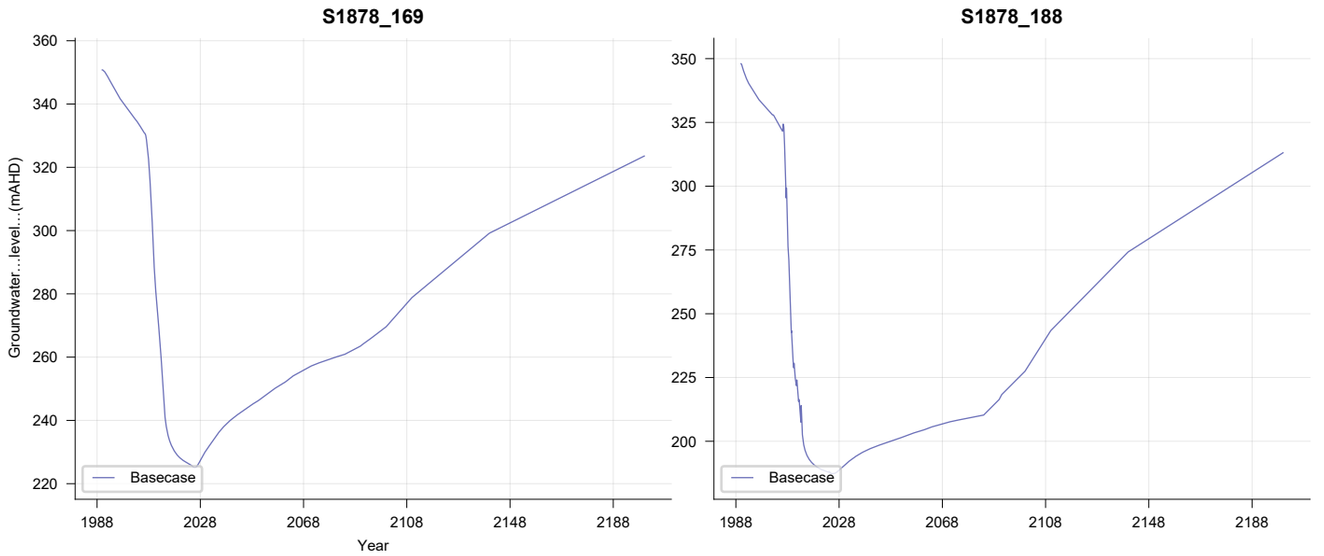

S1871_88
Basecase


S1878_10
Groundwater...level...(mAHD)
Year
Basecase

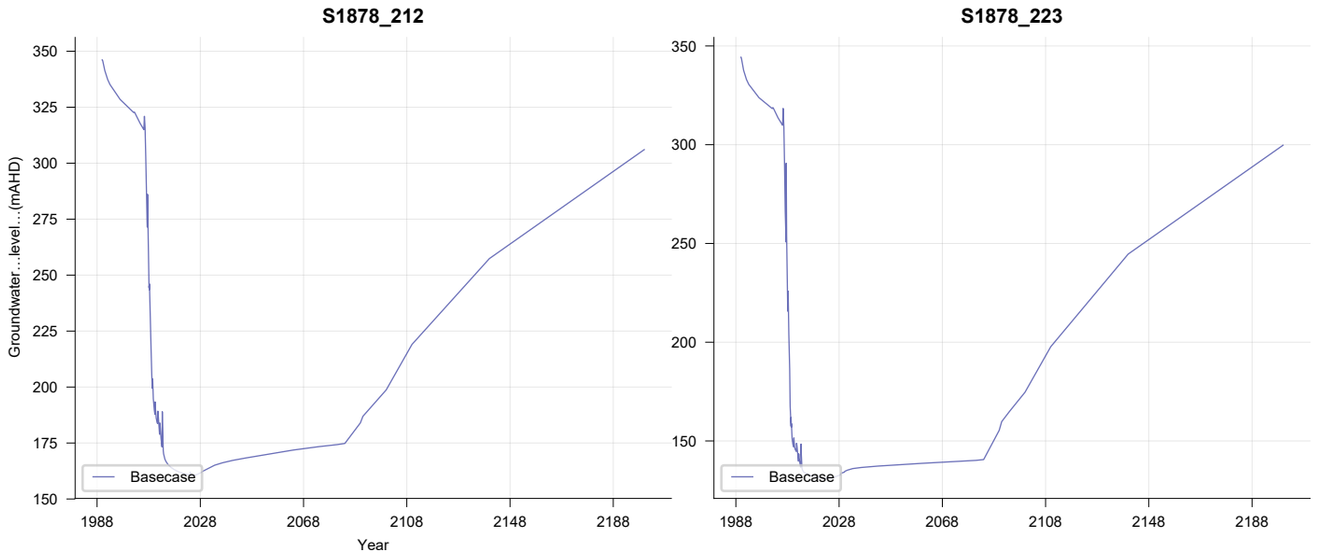

S1878_118
Basecase


S1878_145
Groundwater...level...(mAHD)
Year
Basecase

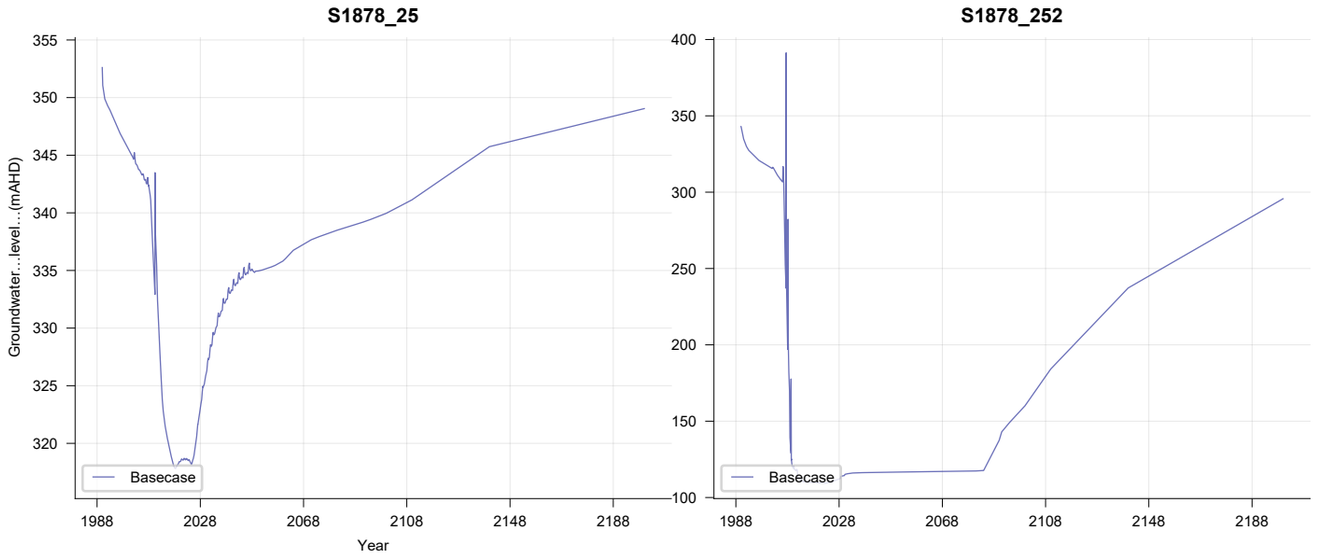

S1878_157
Basecase


S1878_169
Groundwater...level...(mAHD)
Year
Basecase

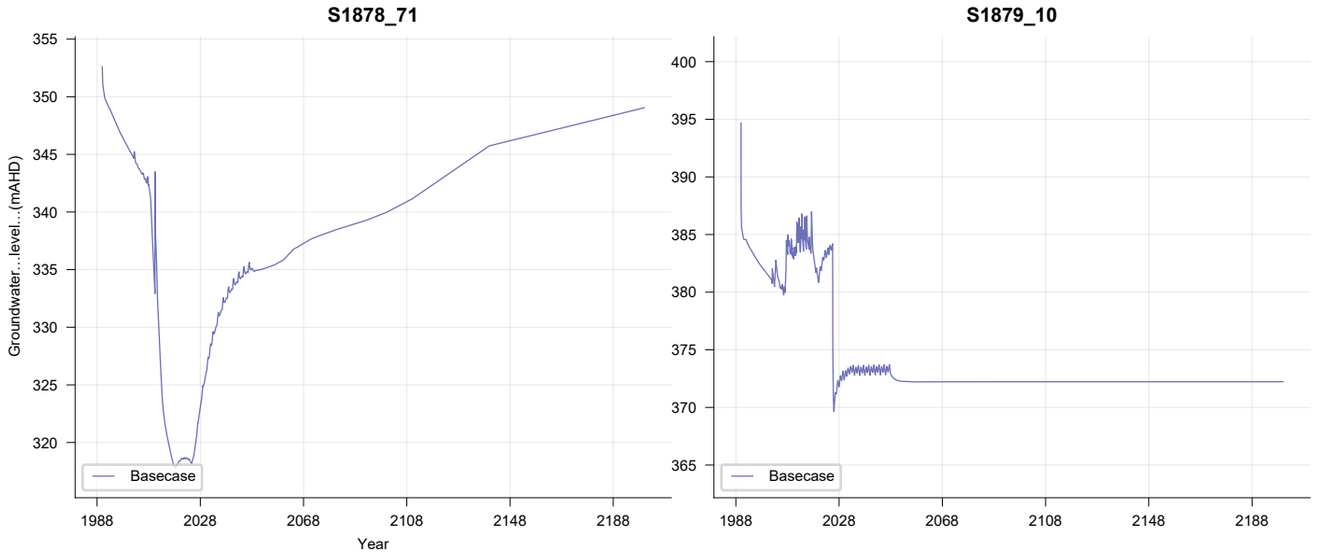

S1878_188
Basecase


S1878_212
Groundwater...level...(mAHD)
Year
Basecase

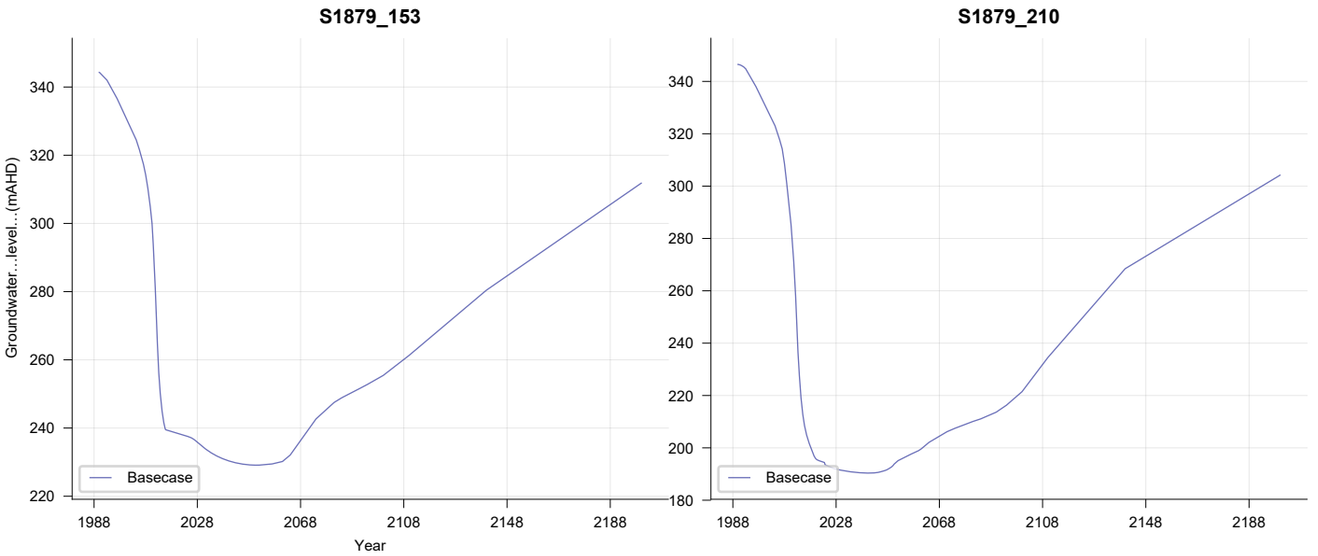

S1878_223
Basecase


S1878_25
Groundwater...level...(mAHD)
Year
Basecase

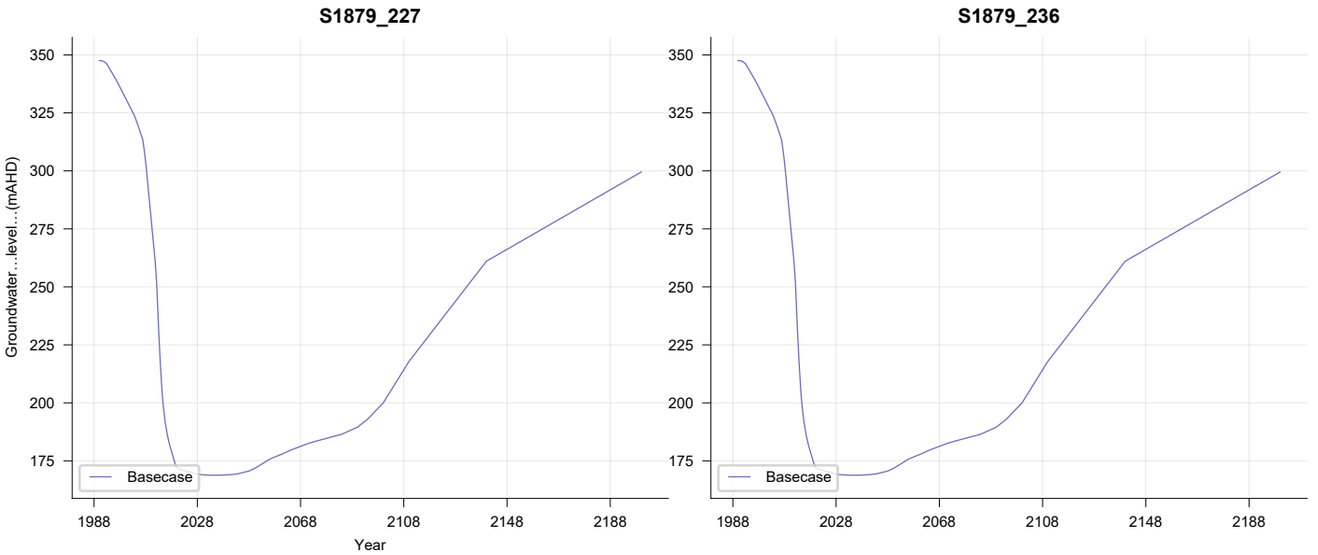

S1878_252
Basecase


S1878_71
Groundwater...level...(mAHD)
Year
Basecase

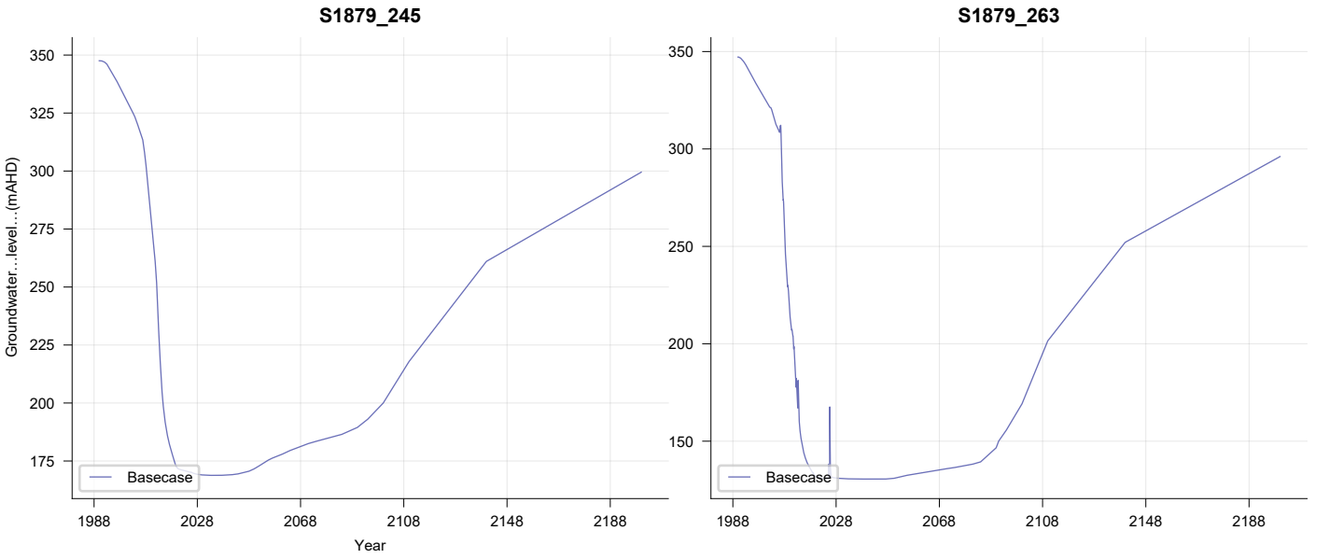

S1879_10
Basecase


S1879_153
Groundwater...level...(mAHD)
Year
Basecase

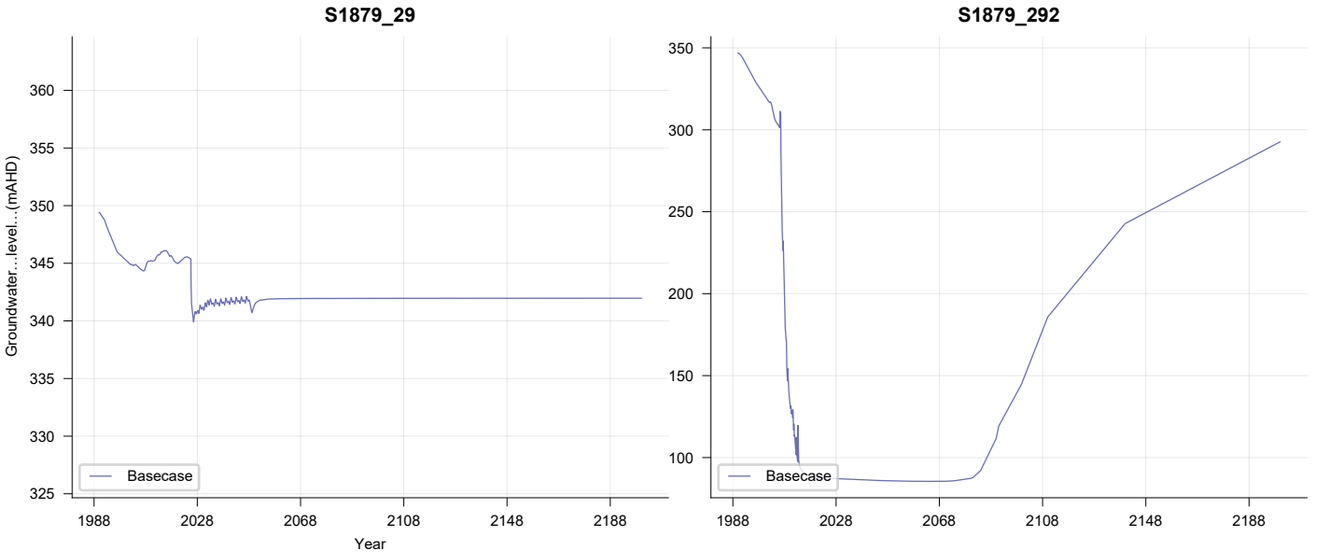

S1879_210
Basecase


S1879_227
Groundwater...level...(mAHD)
Year
Basecase

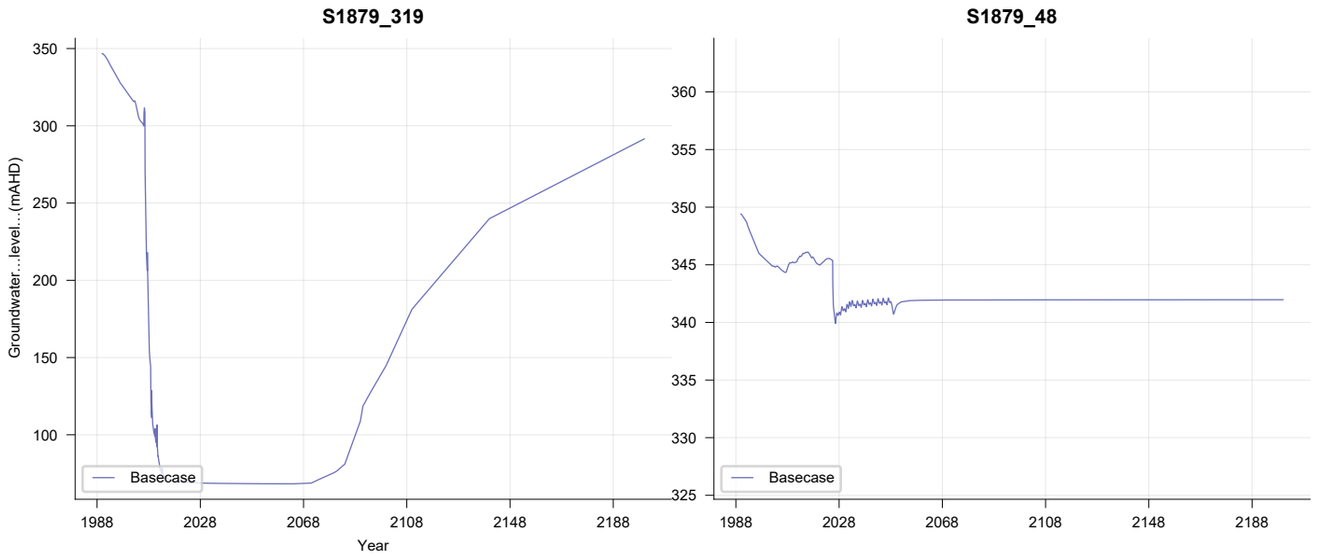

S1879_236
Basecase


S1879_245
Groundwater...level...(mAHD)
Year
Basecase

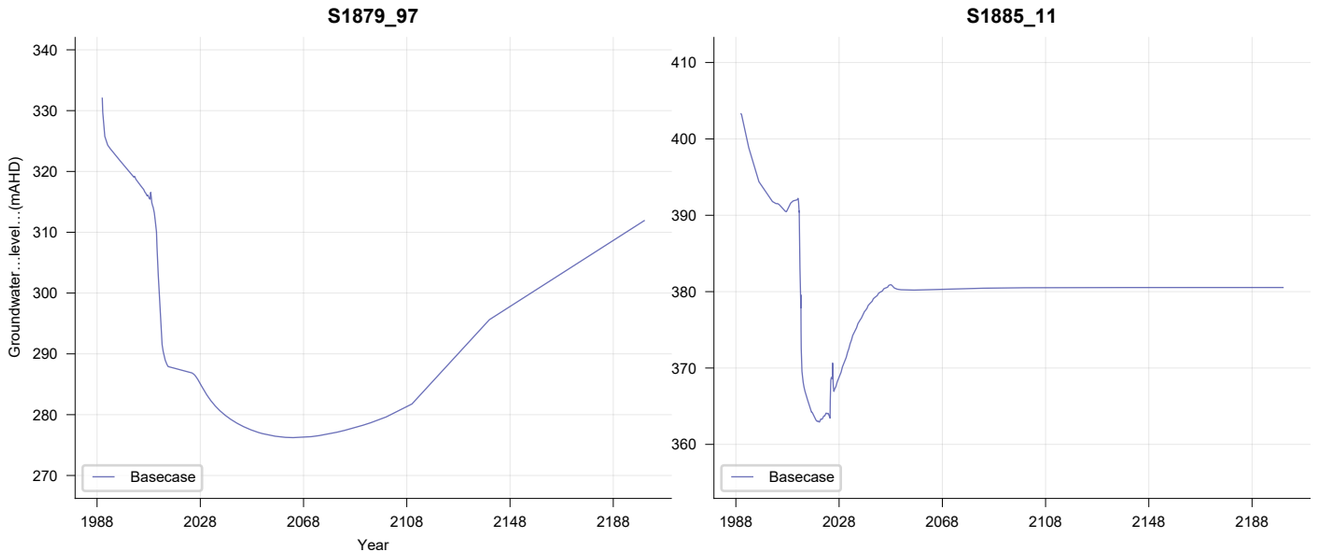

S1879_263
Basecase


S1879_29
Groundwater...level...(mAHD)
Year
Basecase

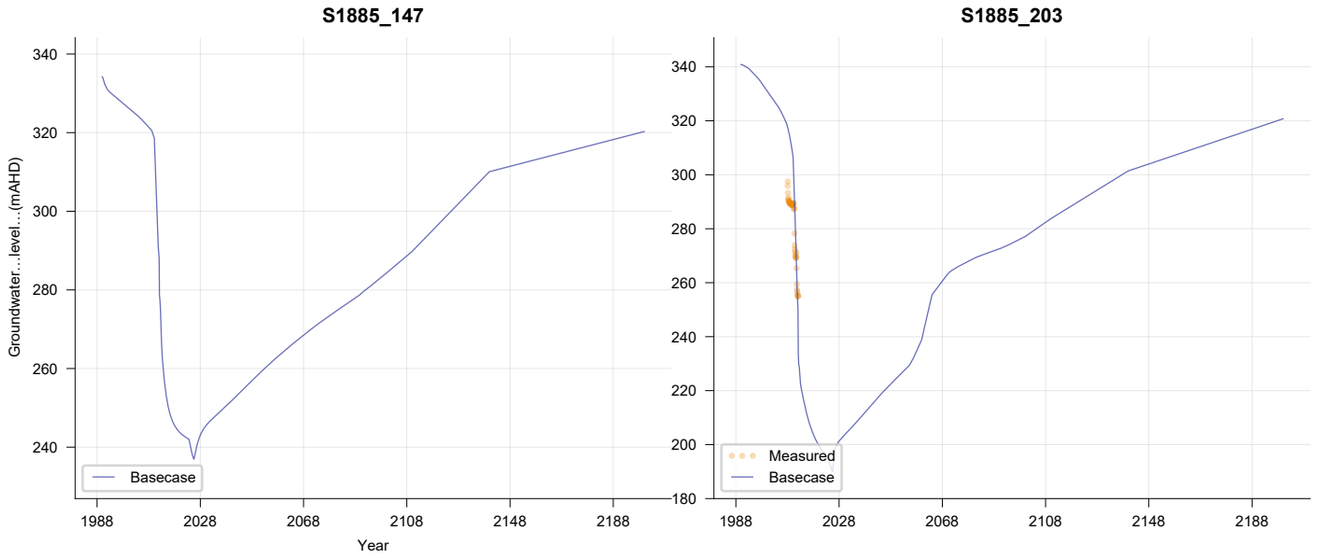

S1879_292
Basecase


S1879_319
Groundwater...level...(mAHD)
Year
Basecase

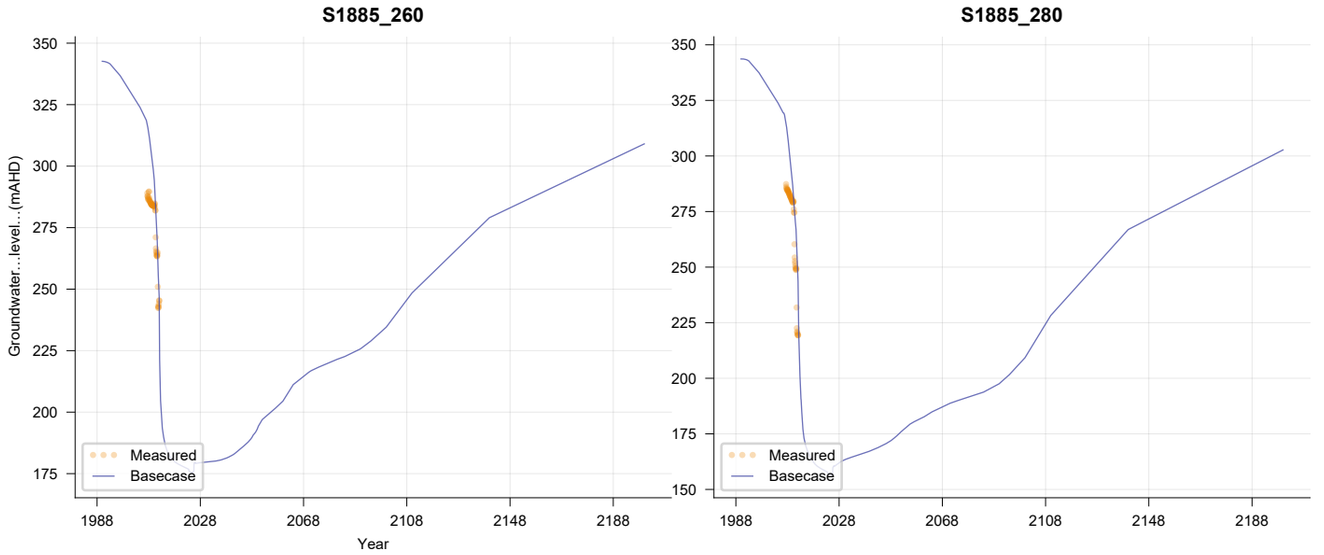

S1879_48
Basecase


S1879_97
Groundwater...level...(mAHD)
Year
Basecase

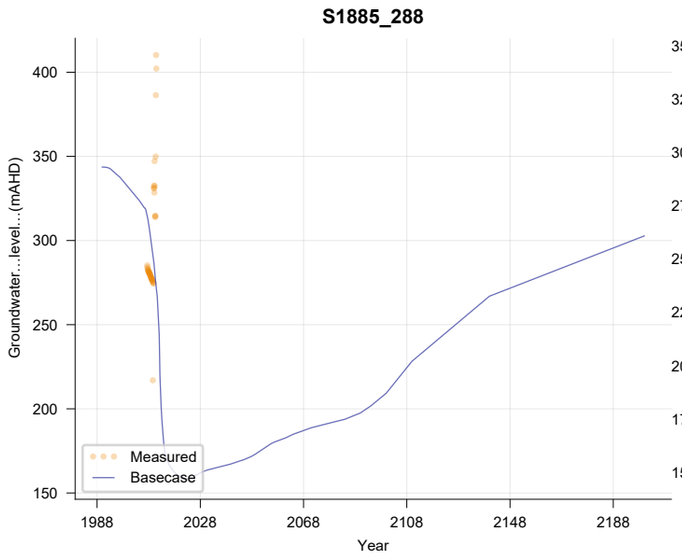

S1885_11
Basecase

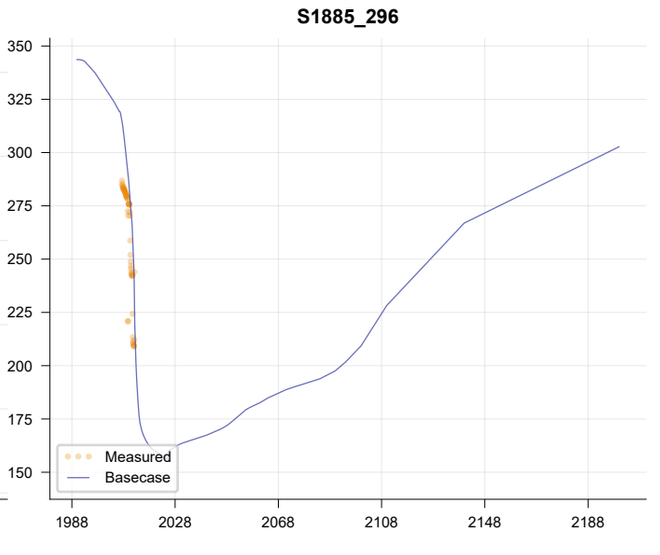

S1885_147
Groundwater...level...(mAHD)
Year
Basecase

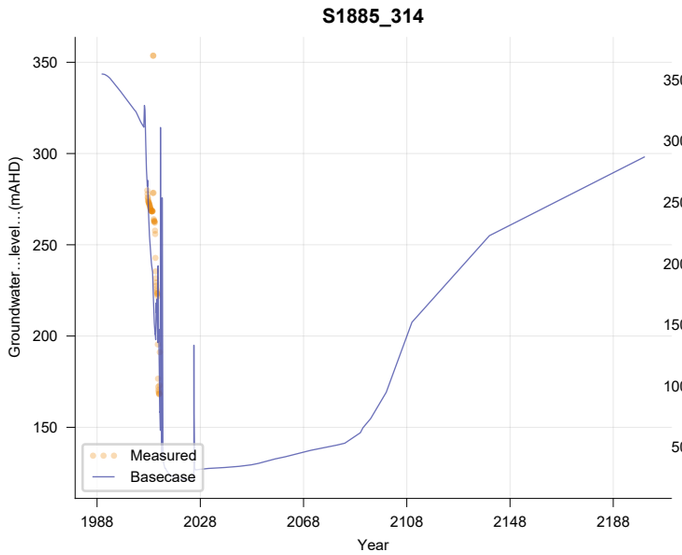

S1885_203
Measured
Basecase

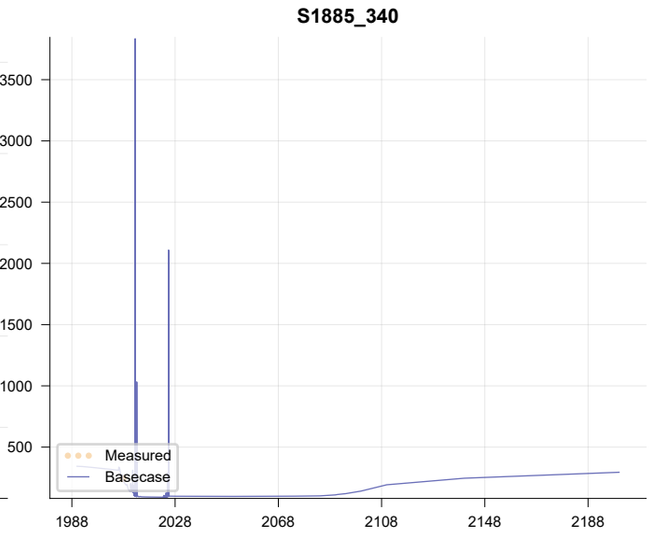

S1885_260
Groundwater...level...(mAHD)
Year
Measured
Basecase

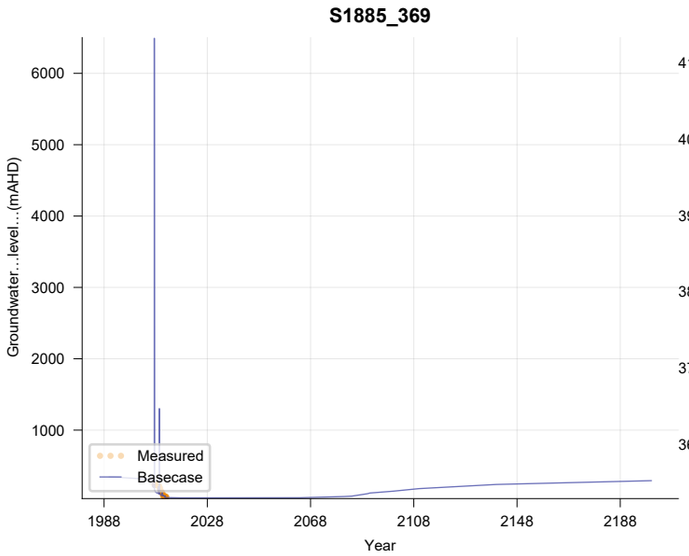

S1885_280
Measured
Basecase

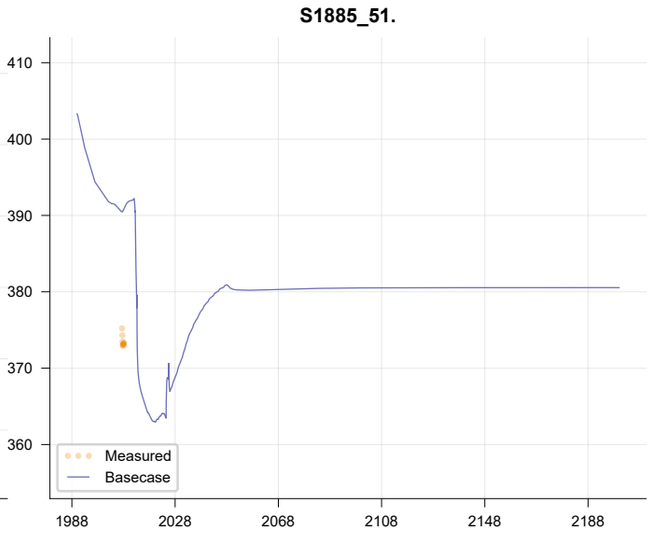

S1885_288
Groundwater...level...(mAHD)
Year
Measured
Basecase

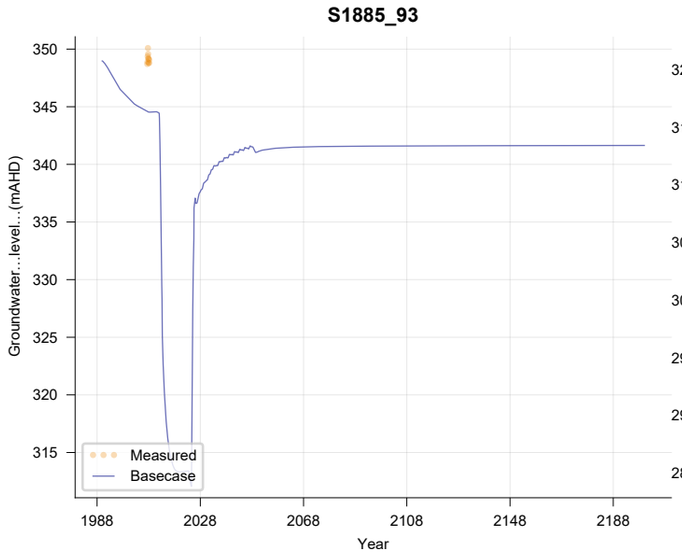

S1885_296
Measured
Basecase

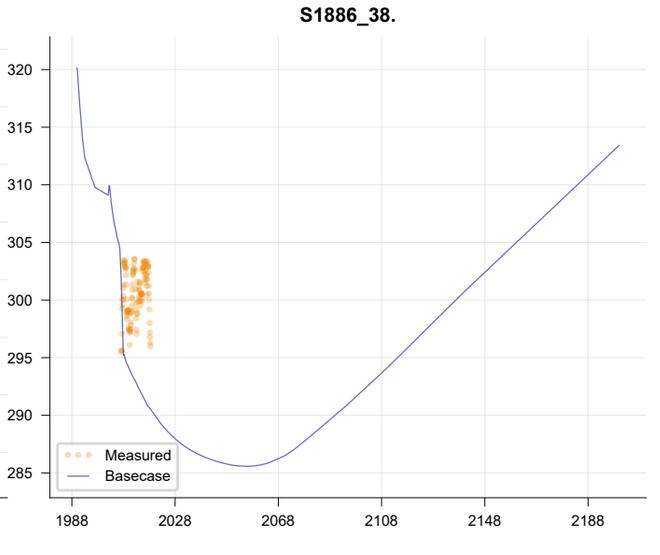

S1885_314
Groundwater...level...(mAHD)
Year
Measured
Basecase

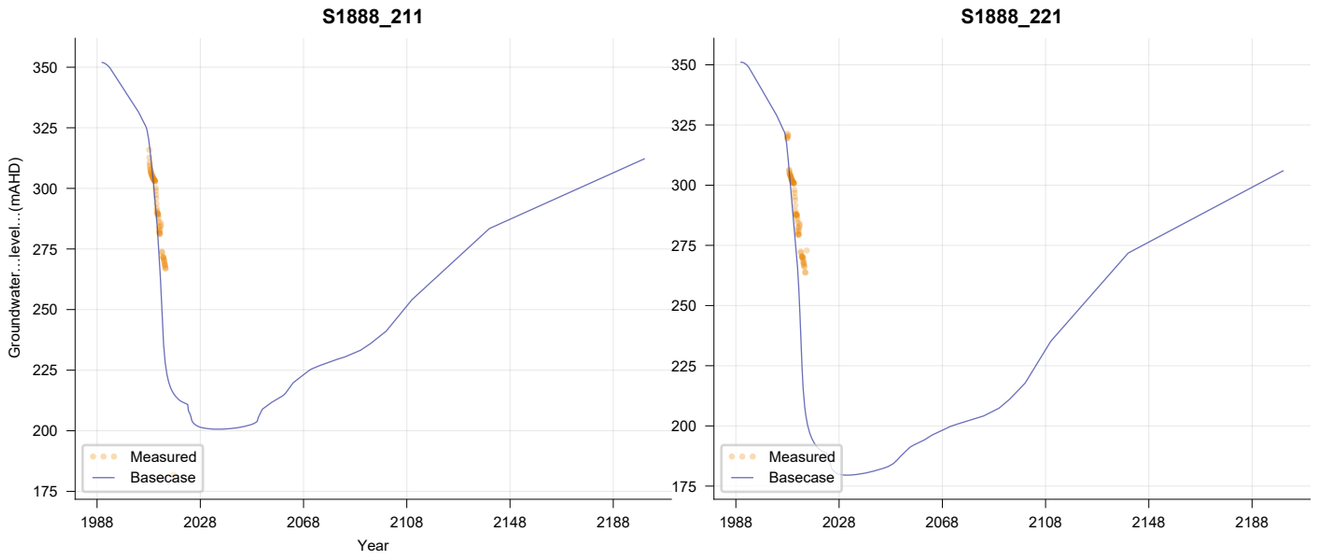

S1885_340
Measured
Basecase


S1885_369
Groundwater...level...(mAHD)
Year
Measured
Basecase

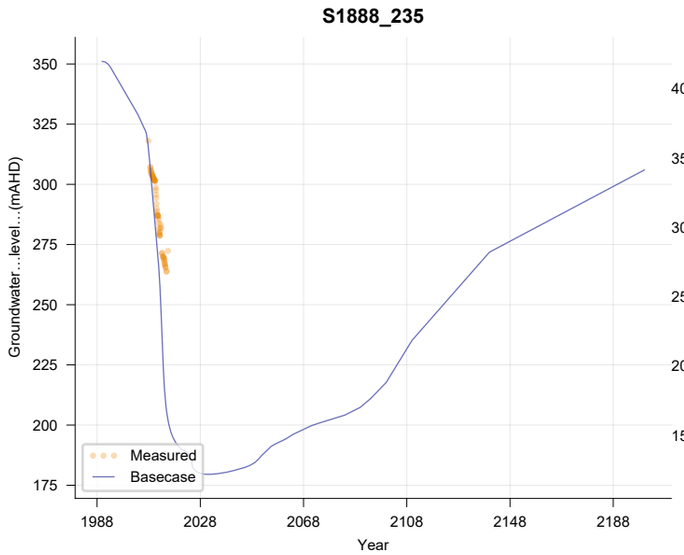

S1885_51.
Measured
Basecase

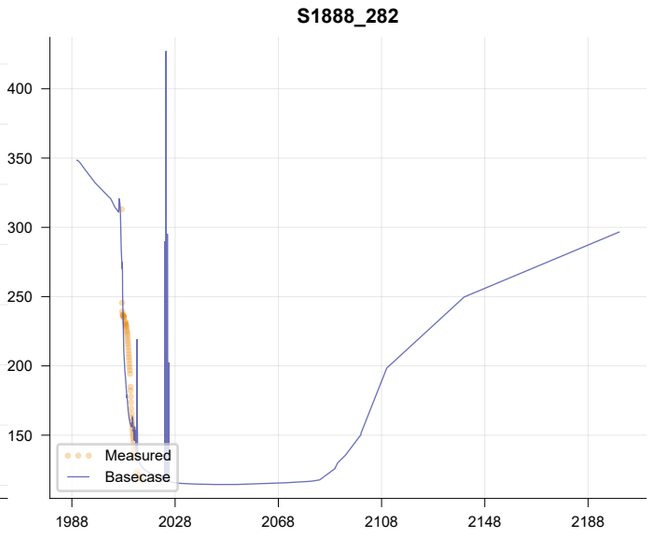

S1885_93
Groundwater...level...(mAHD)
Year
Measured
Basecase

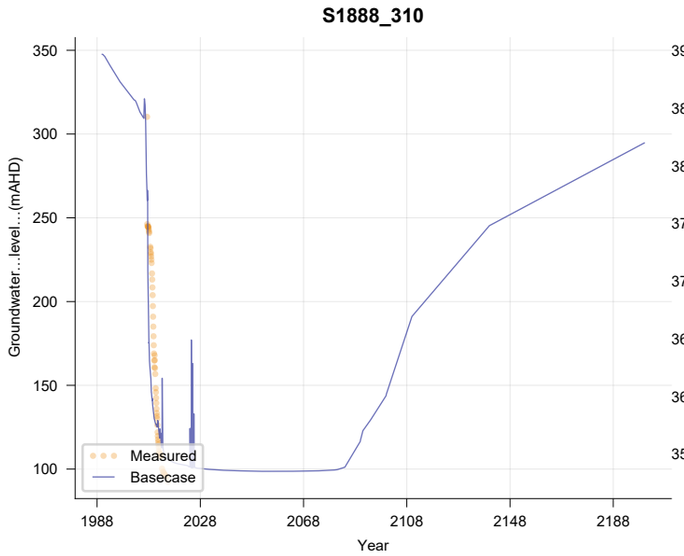

S1886_38.
Measured
Basecase

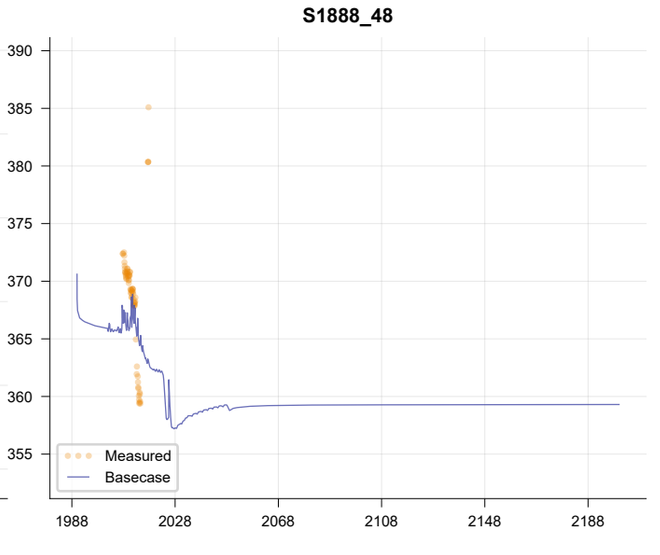

S1888_211
Groundwater...level...(mAHD)
Year
Measured
Basecase

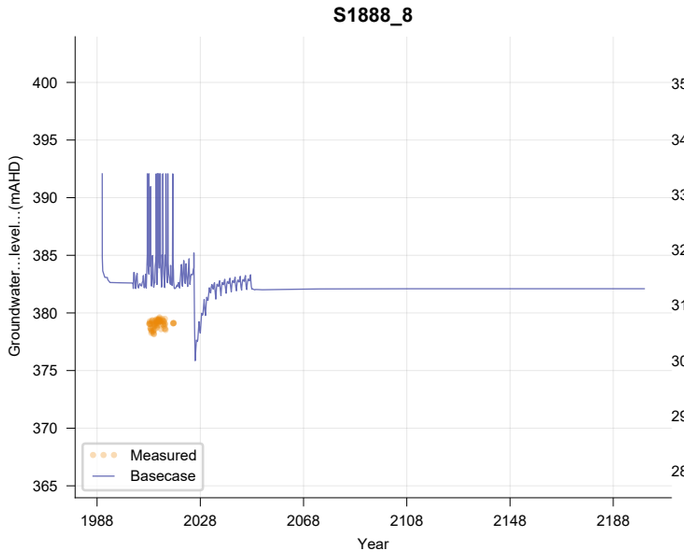

S1888_221
Measured
Basecase

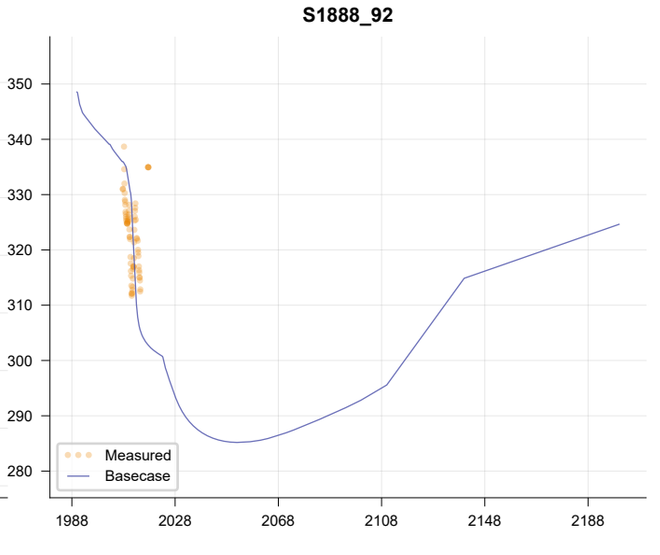

S1888_235
Groundwater...level...(mAHD)
Year
Measured
Basecase

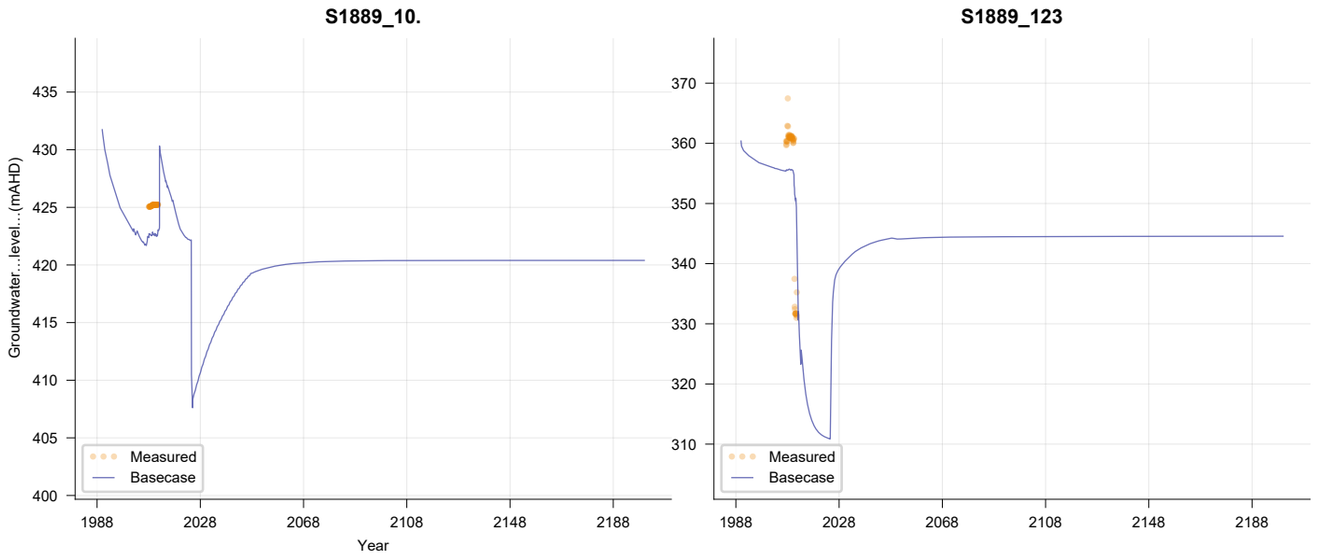

S1888_282
Measured
Basecase


S1888_310
Groundwater...level...(mAHD)
Year
Measured
Basecase

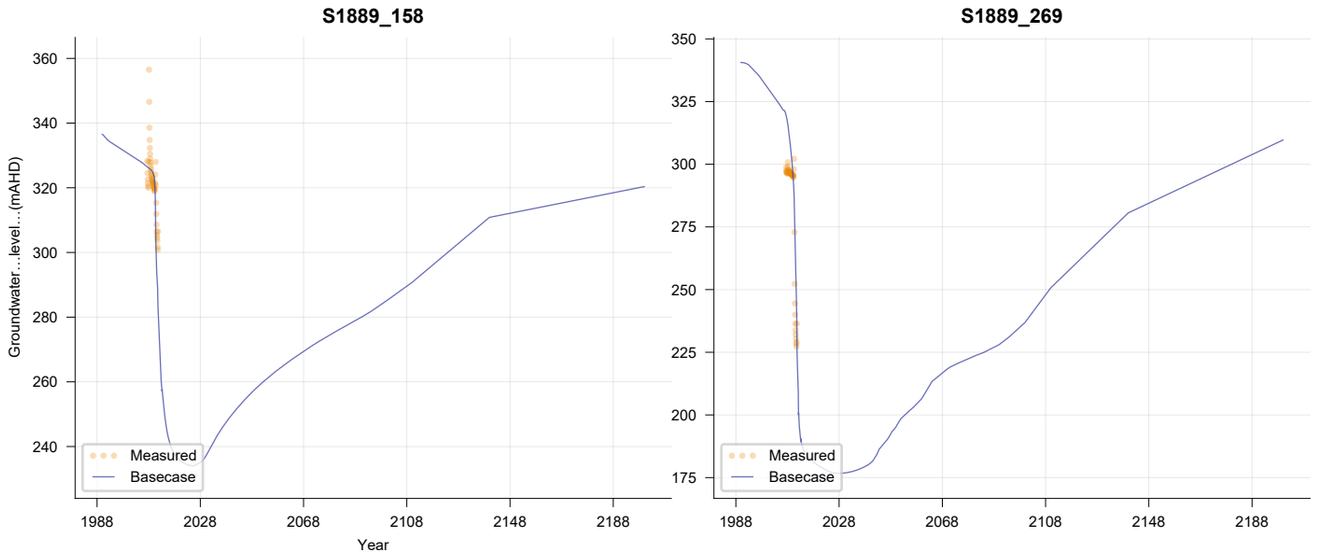

S1888_48
Measured
Basecase


S1888_8
Groundwater...level...(mAHD)
Year
Measured
Basecase

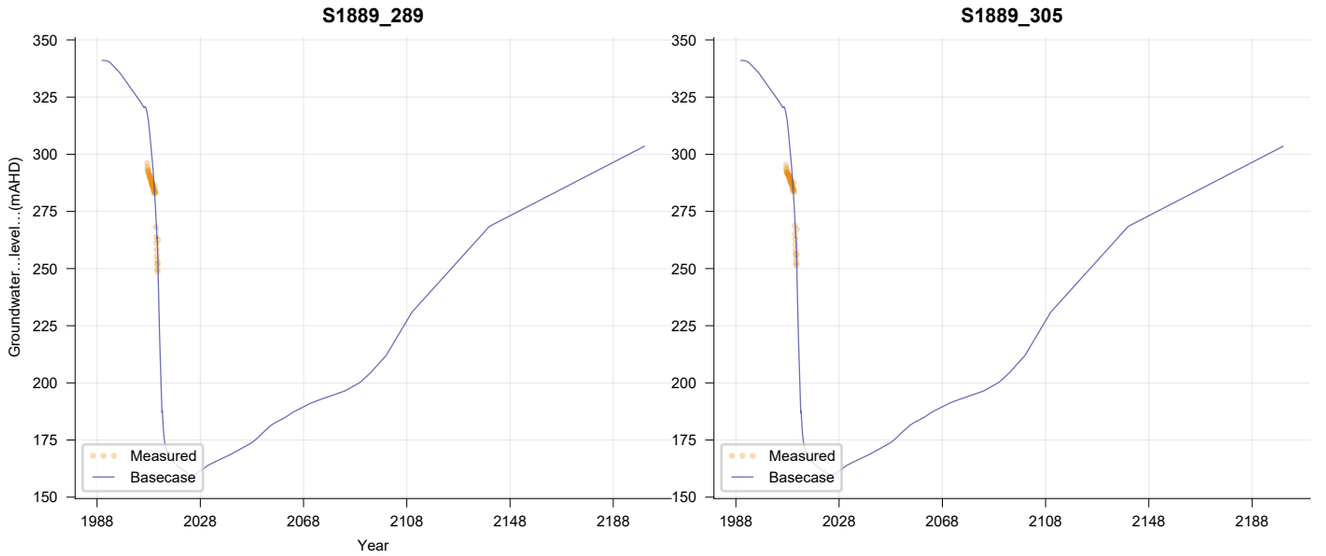

S1888_92
Measured
Basecase


S1889_10.
Groundwater...level...(mAHD)
435
430
425
420
415
410
405
400
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

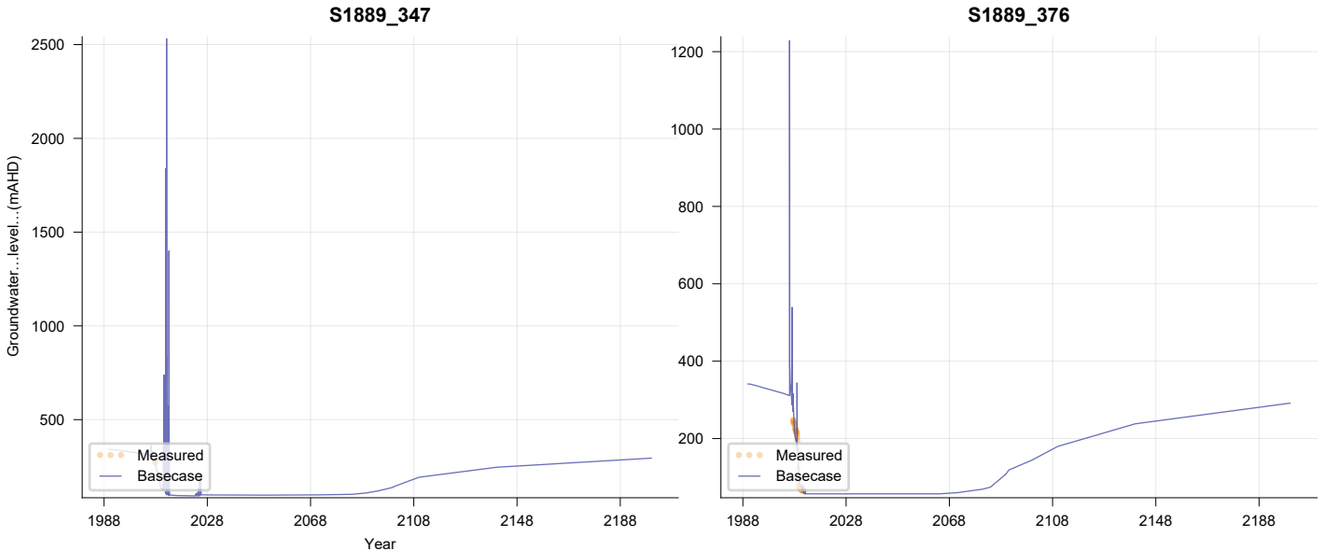

S1889_123
370
360
350
340
330
320
310
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1889_158
Groundwater...level...(mAHD)
360
340
320
300
280
260
240
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

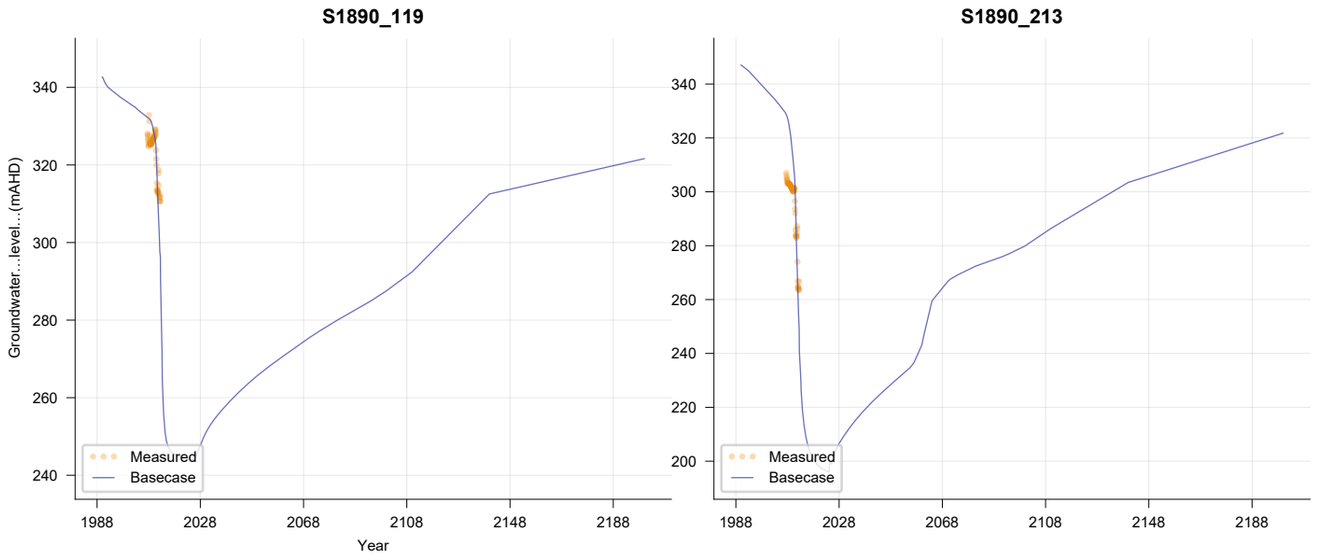

S1889_269
350
325
300
275
250
225
200
175
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1889_289
Groundwater...level...(mAHD)
350
325
300
275
250
225
200
175
150
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

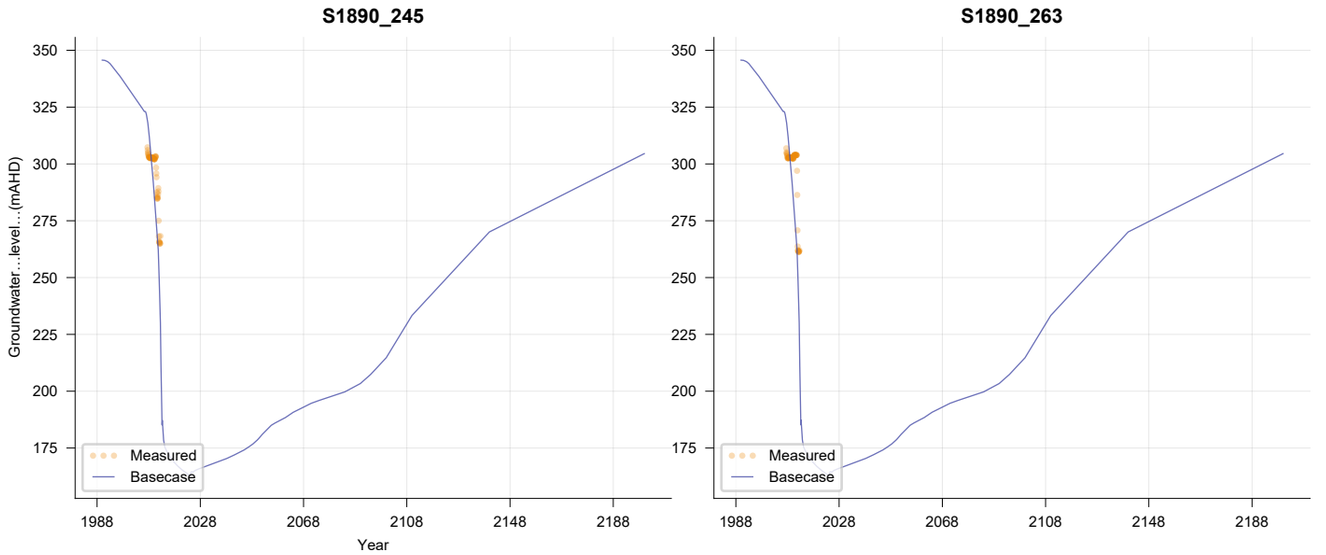

S1889_305
350
325
300
275
250
225
200
175
150
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1889_347
Groundwater...level...(mAHD)
2500
2000
1500
1000
500
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

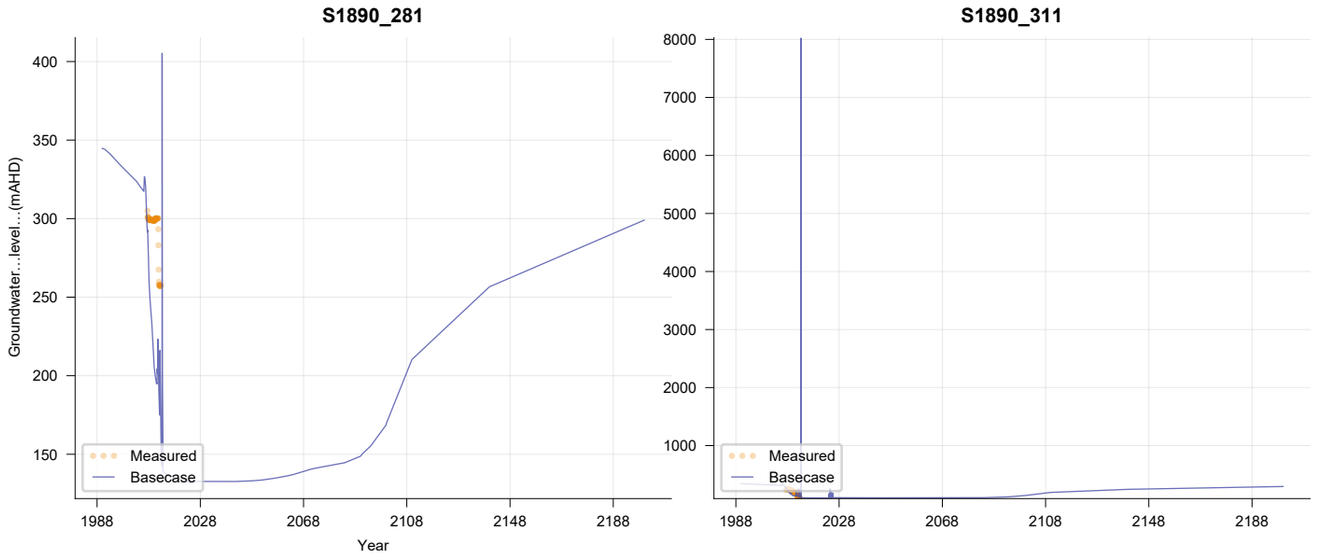

S1889_376
1200
1000
800
600
400
200
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1890_119
Groundwater...level...(mAHD)
Year
Measured
Basecase

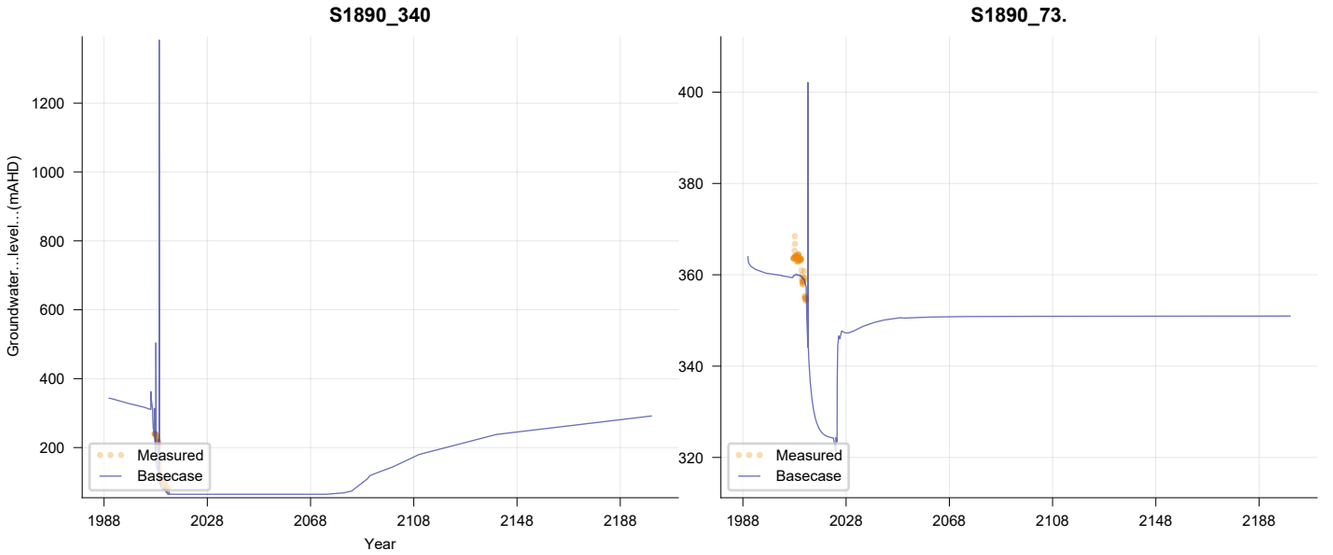

S1890_213
Measured
Basecase


S1890_245
Groundwater...level...(mAHD)
Year
Measured
Basecase

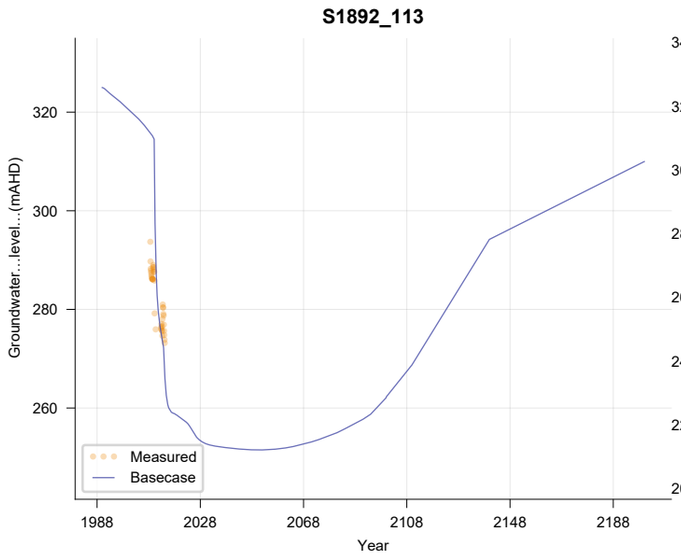

S1890_263
Measured
Basecase

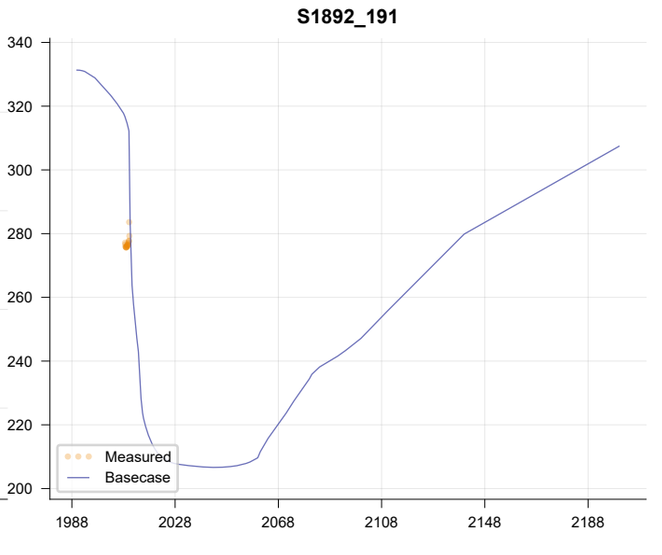

S1890_281
Groundwater...level...(mAHD)
Year
Measured
Basecase

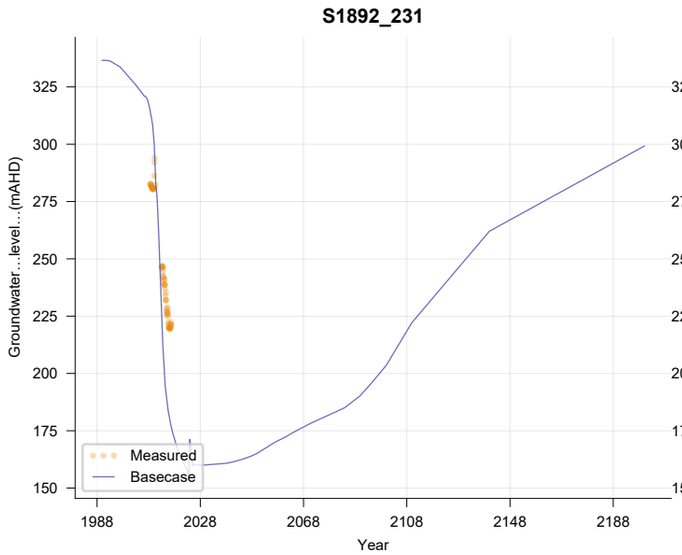

S1890_311
Measured
Basecase

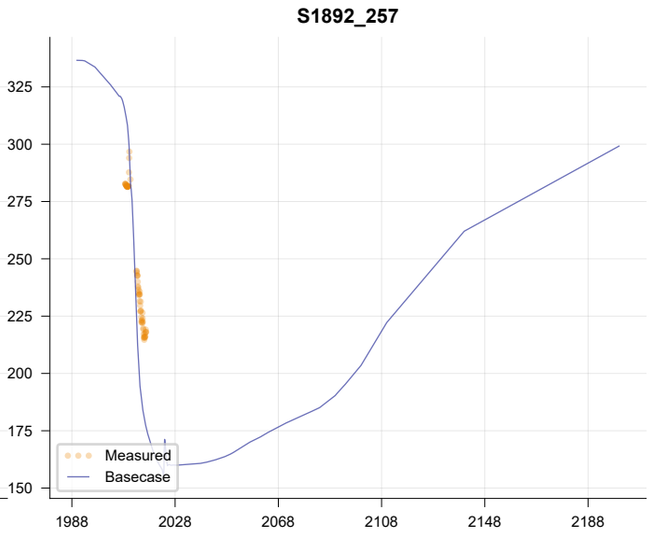

S1890_340
Groundwater...level...(mAHD)
Year
Measured
Basecase

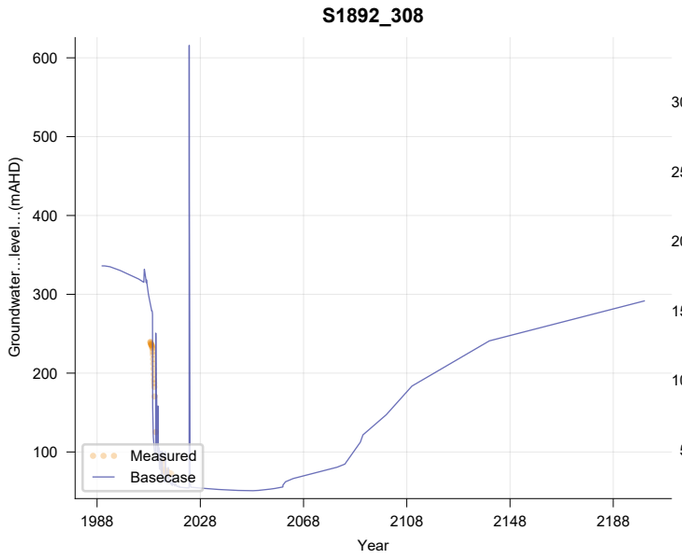

S1890_73.
Measured
Basecase

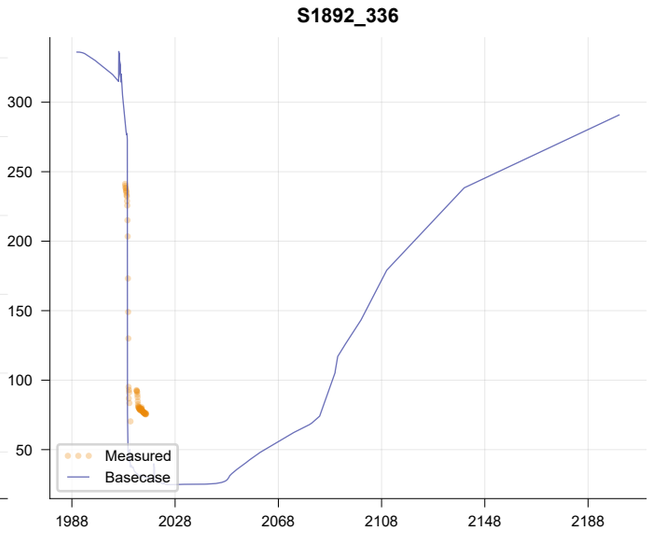

S1892_113
Groundwater...level...(mAHD)
320
300
280
260
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

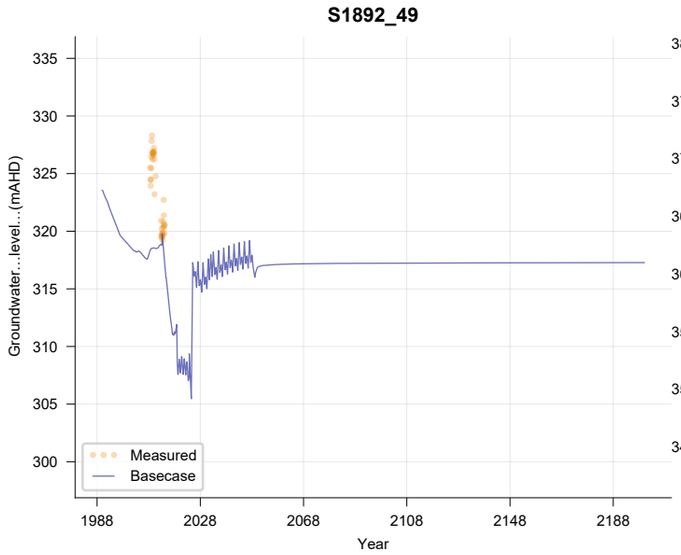

S1892_191
340
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188

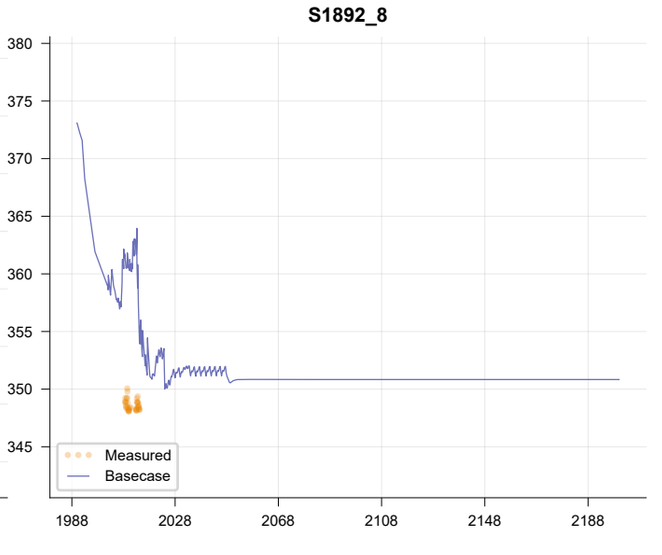

S1892_231
Groundwater...level...(mAHD)
325
300
275
250
225
200
175
150
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

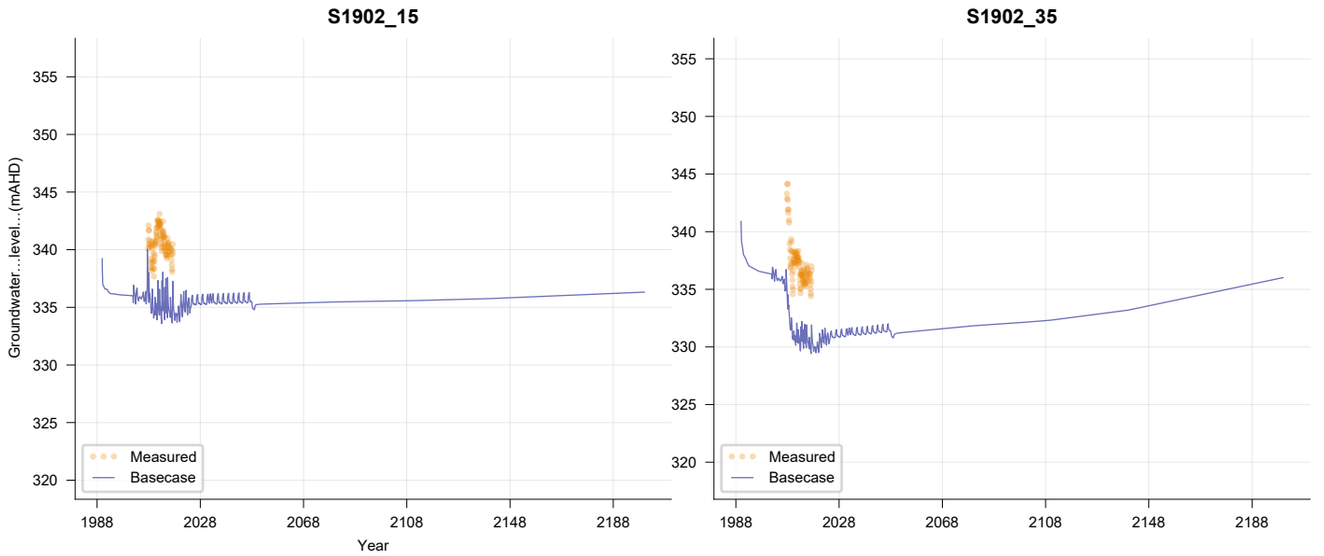

S1892_257
325
300
275
250
225
200
175
150
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1892_308
Groundwater...level...(mAHD)
600
500
400
300
200
100
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

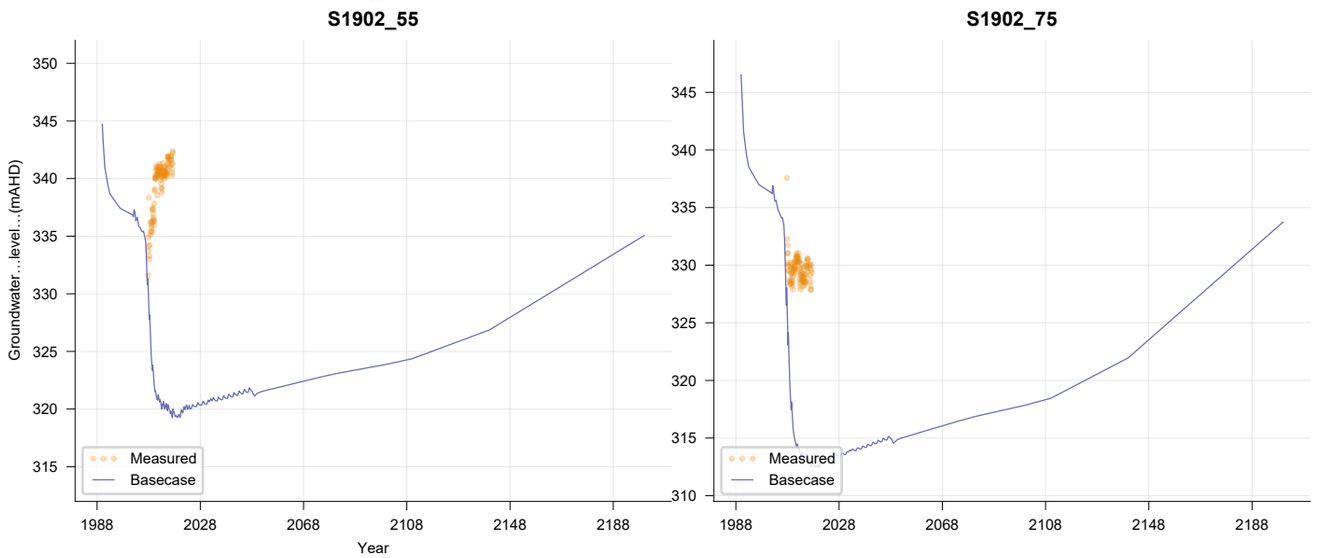

S1892_336
300
250
200
150
100
50
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1892_49
Groundwater...level...(mAHD)
335
330
325
320
315
310
305
300
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

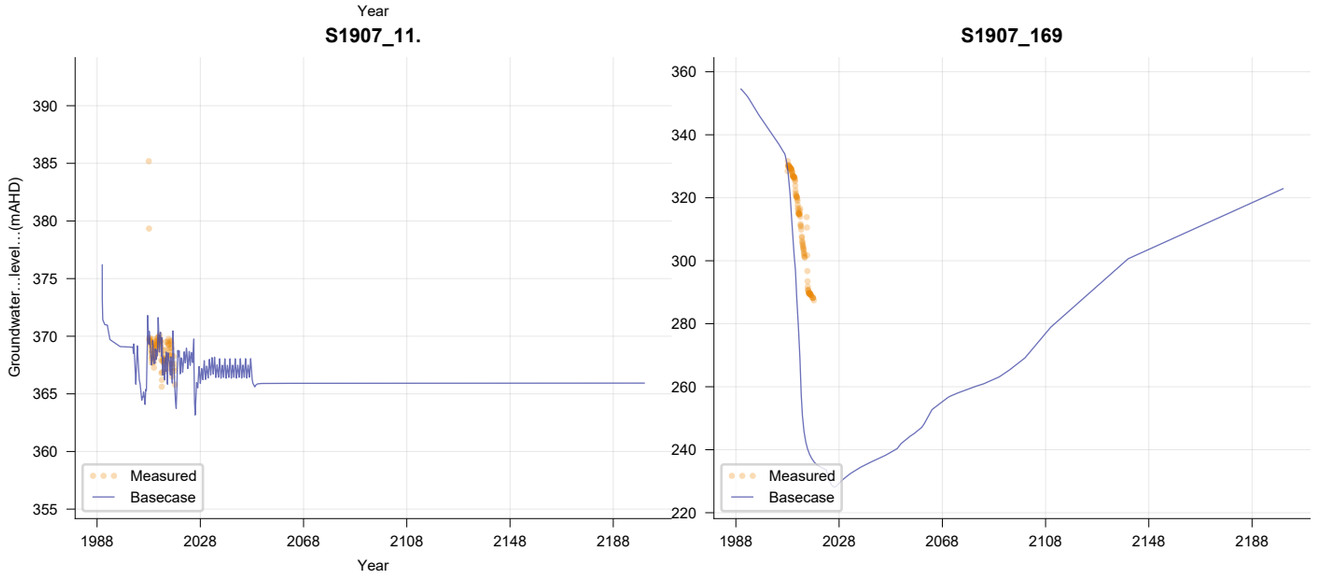

S1892_8
380
375
370
365
360
355
350
345
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1902_15
Groundwater...level...(mAHD)
355
350
345
340
335
330
325
320
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

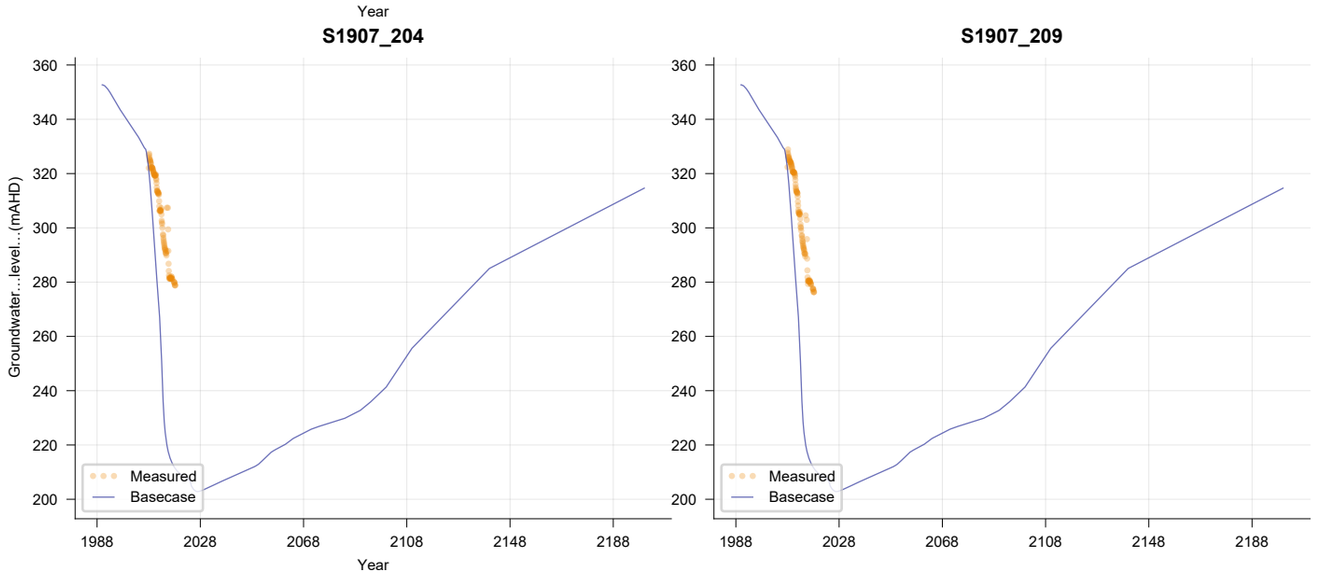

S1902_35
355
350
345
340
335
330
325
320
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1902_55
Groundwater...level...(mAHD)
350
345
340
335
330
325
320
315
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

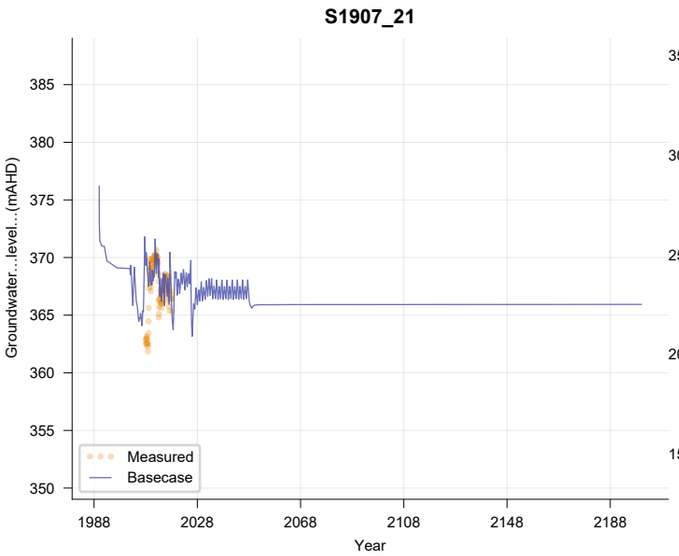

S1902_75
345
340
335
330
325
320
315
310
Measured
Basecase
1988
2028
2068
2108
2148
2188

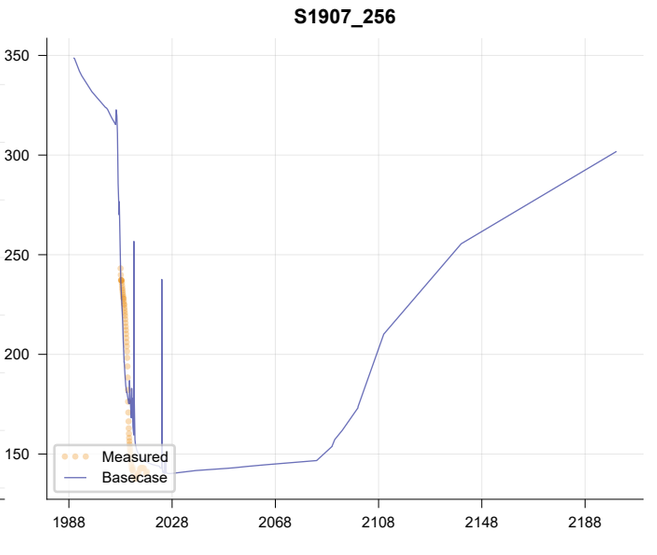

S1907_11.
Groundwater...level...(mAHD)
390
385
380
375
370
365
360
355
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

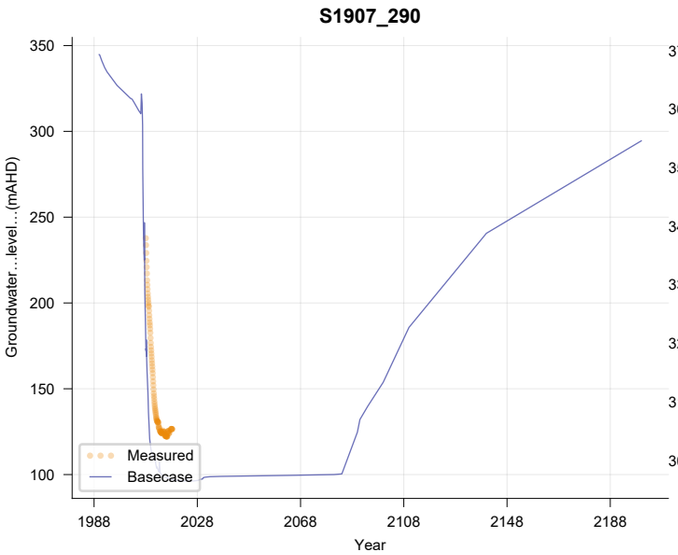

S1907_169
360
340
320
300
280
260
240
220
Measured
Basecase
1988
2028
2068
2108
2148
2188

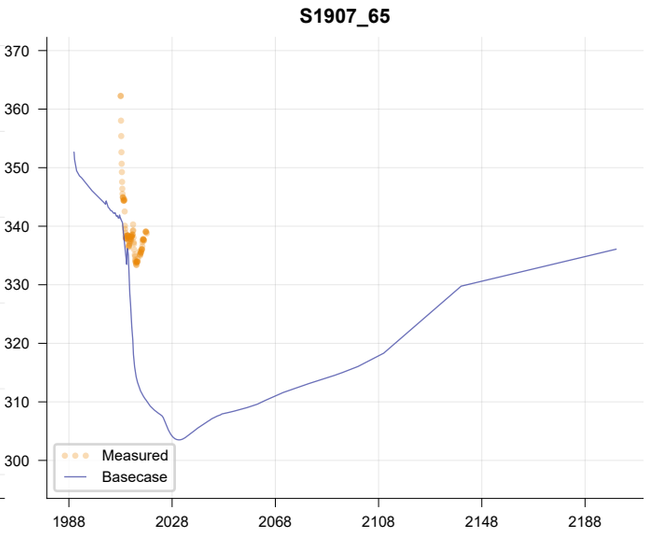

S1907_204
Groundwater...level...(mAHD)
360
340
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

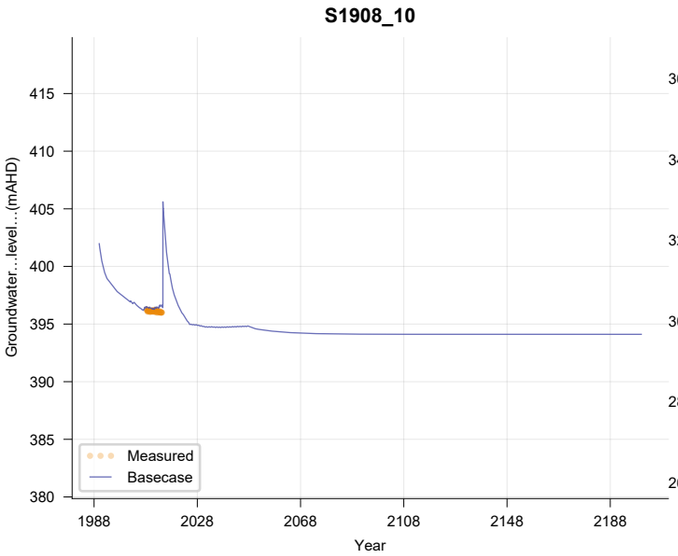

S1907_209
360
340
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188

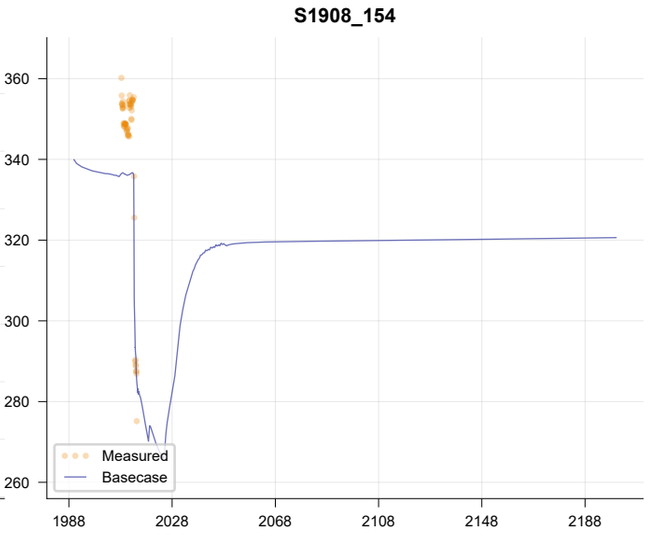

S1907_21
Groundwater...level...(mAHD)
385
380
375
370
365
360
355
350
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

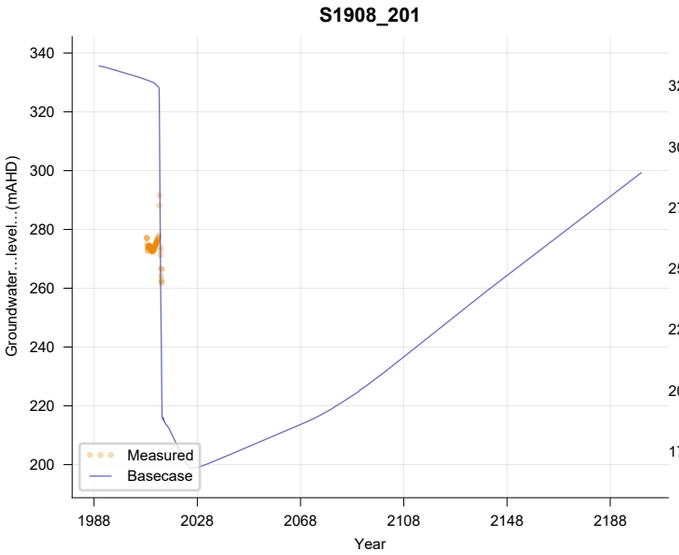

S1907_256
350
300
250
200
150
Measured
Basecase
1988
2028
2068
2108
2148
2188

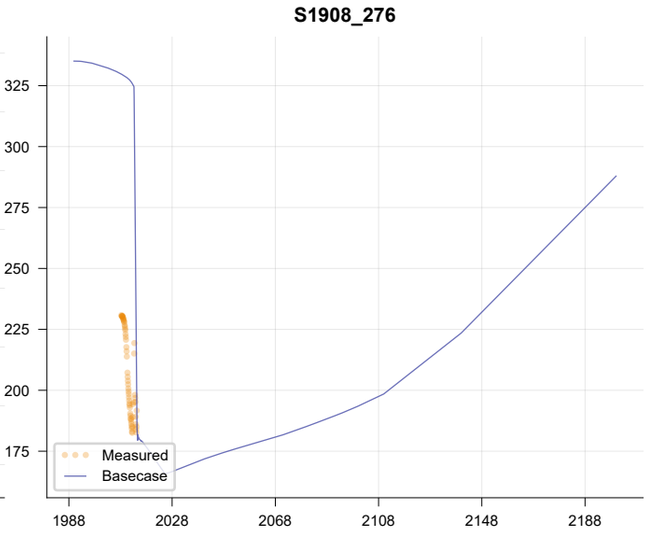

S1907_290
Groundwater...level...(mAHD)
350
300
250
200
150
100
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

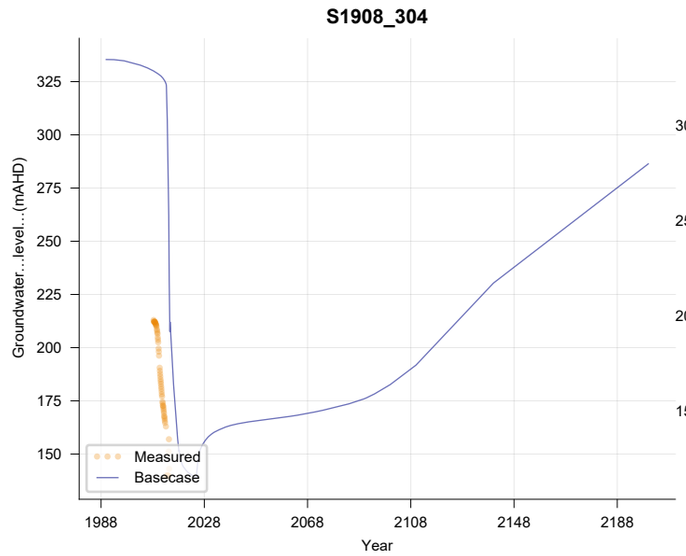

S1907_65
370
360
350
340
330
320
310
300
Measured
Basecase
1988
2028
2068
2108
2148
2188

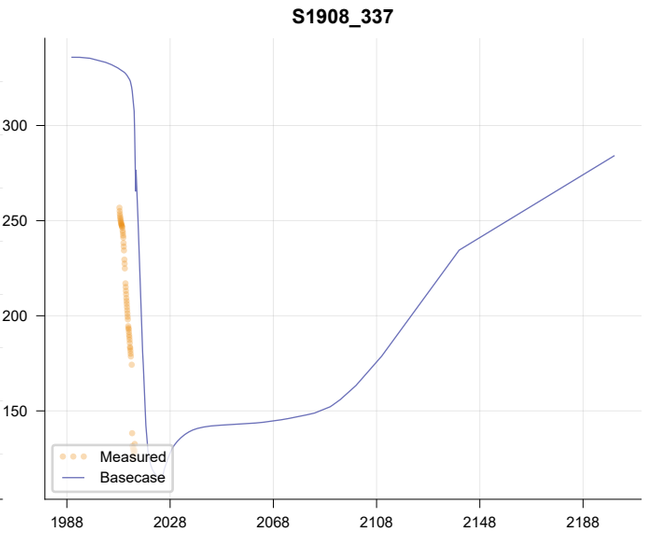

S1908_10
Groundwater...level...(mAHD)
415
410
405
400
395
390
385
380
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

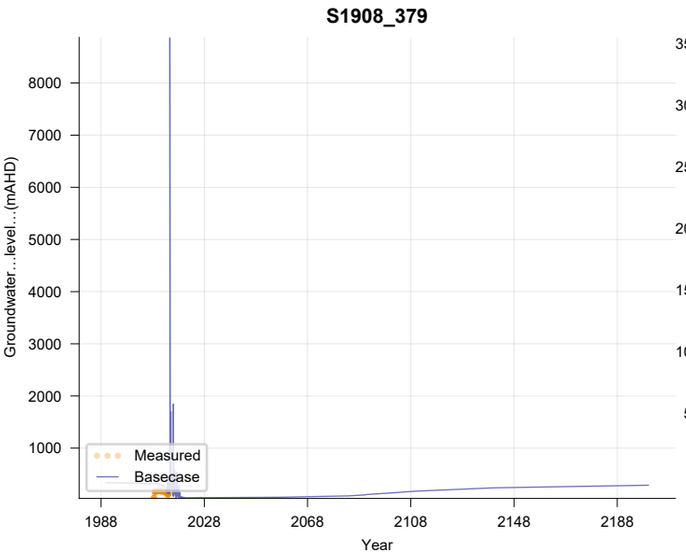

S1908_154
360
340
320
300
280
260
Measured
Basecase
1988
2028
2068
2108
2148
2188

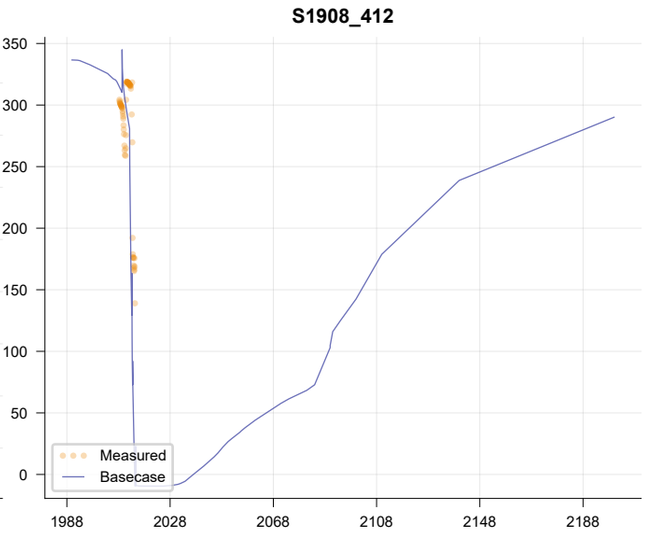

S1908_201
Groundwater...level...(mAHD)
340
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

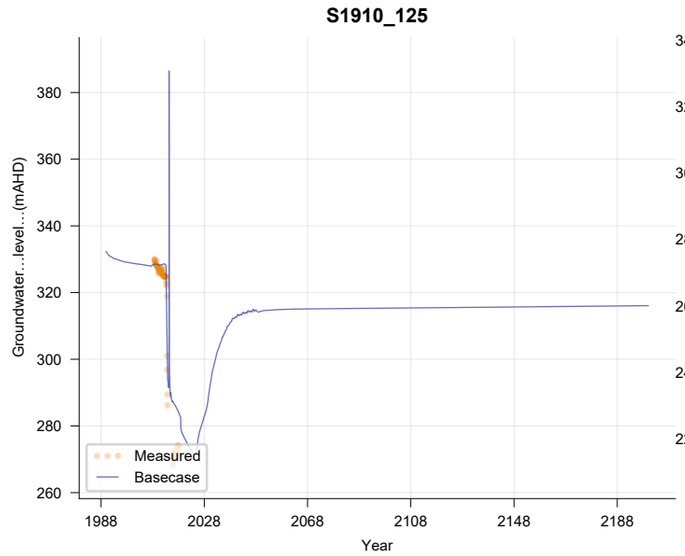

S1908_276
325
300
275
250
225
200
175
Measured
Basecase
1988
2028
2068
2108
2148
2188

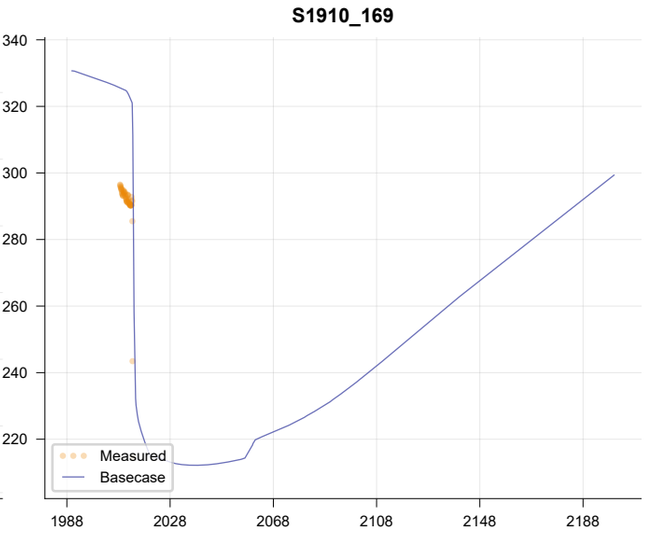

S1908_304
Groundwater...level...(mAHD)
325
300
275
250
225
200
175
150
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

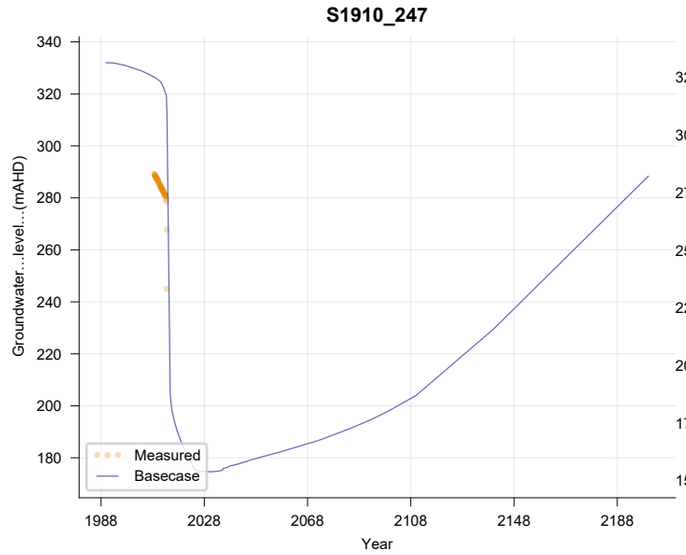

S1908_337
300
250
200
150
Measured
Basecase
1988
2028
2068
2108
2148
2188

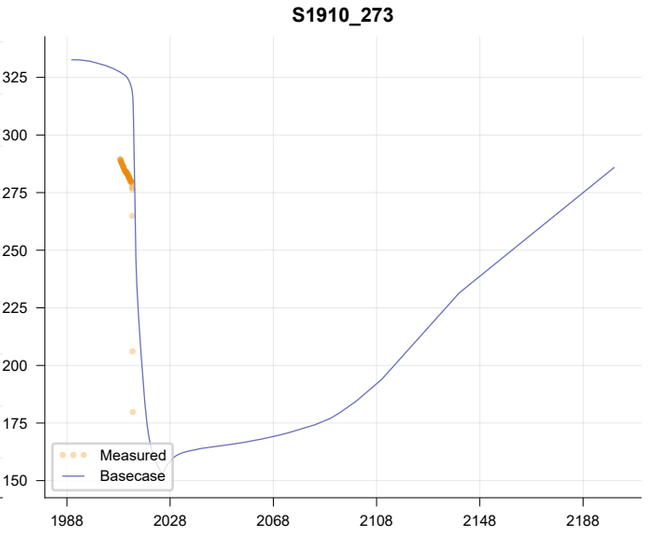

S1908_379
Groundwater...level...(mAHD)
8000
7000
6000
5000
4000
3000
2000
1000
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

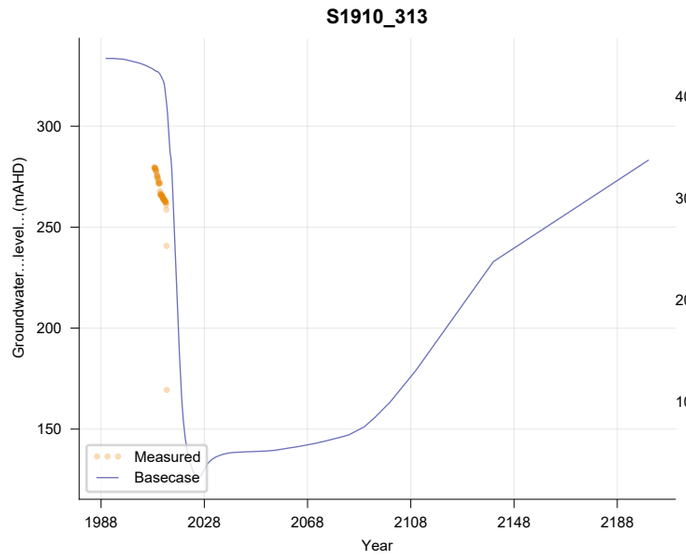

S1908_412
350
300
250
200
150
100
50
0
Measured
Basecase
1988
2028
2068
2108
2148
2188

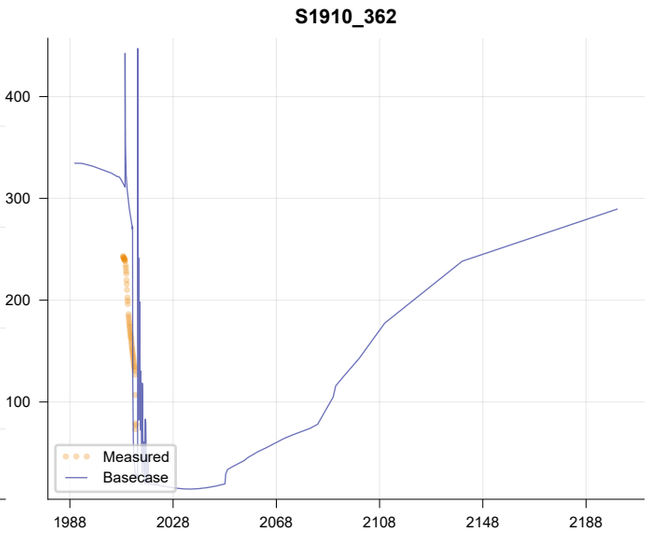

S1910_125
Groundwater...level...(mAHD)
380
360
340
320
300
280
260
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

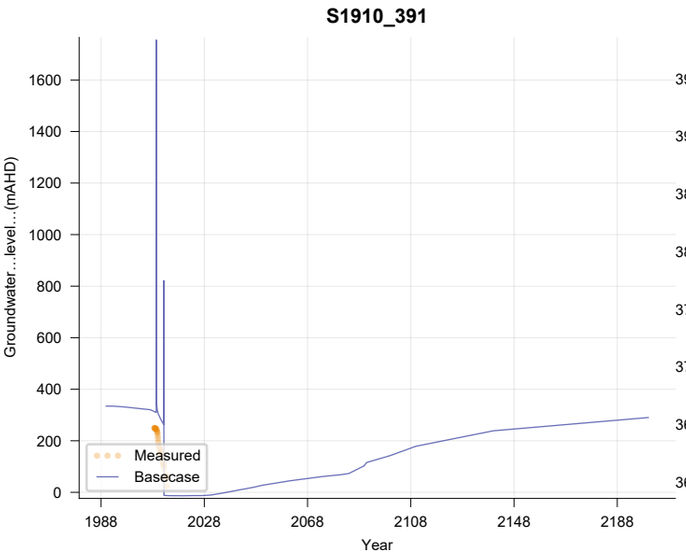

S1910_169
340
320
300
280
260
240
220
Measured
Basecase
1988
2028
2068
2108
2148
2188

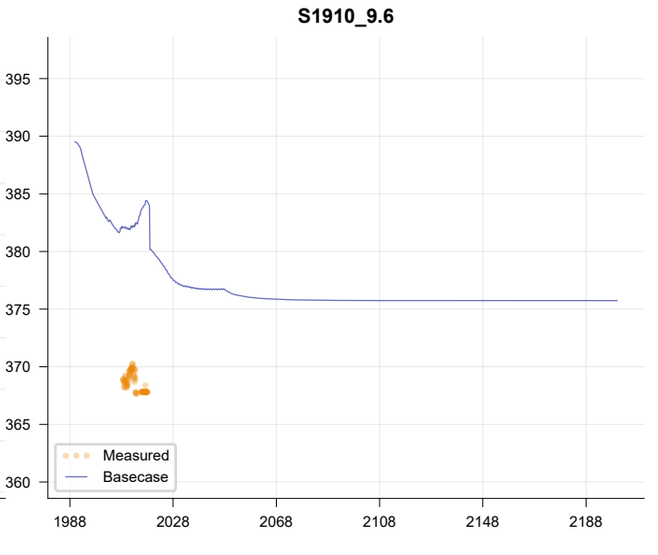

S1910_247
Groundwater...level...(mAHD)
340
320
300
280
260
240
220
200
180
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

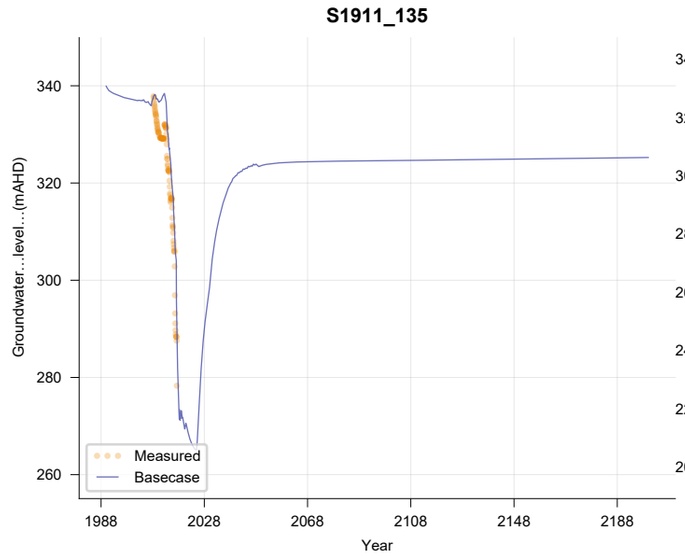

S1910_273
325
300
275
250
225
200
175
150
Measured
Basecase
1988
2028
2068
2108
2148
2188

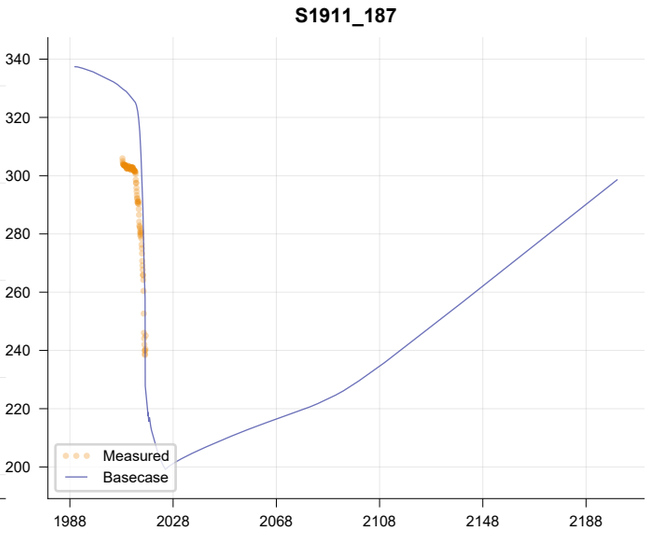

S1910_313
Groundwater...level...(mAHD)
300
250
200
150
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

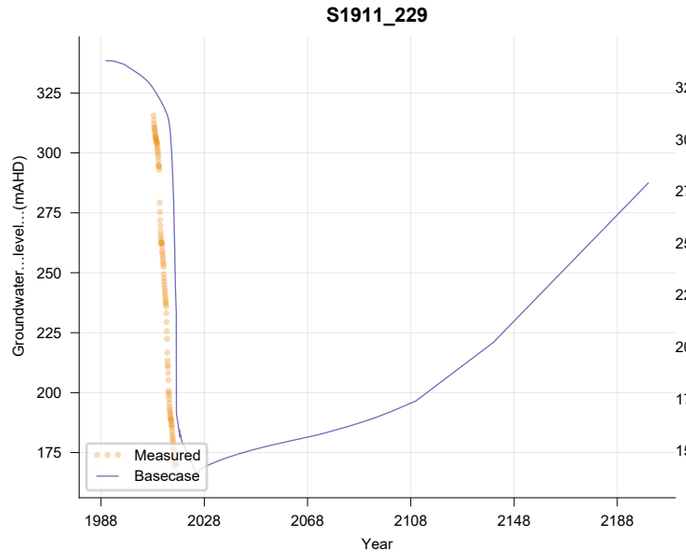

S1910_362
400
300
200
100
Measured
Basecase
1988
2028
2068
2108
2148
2188

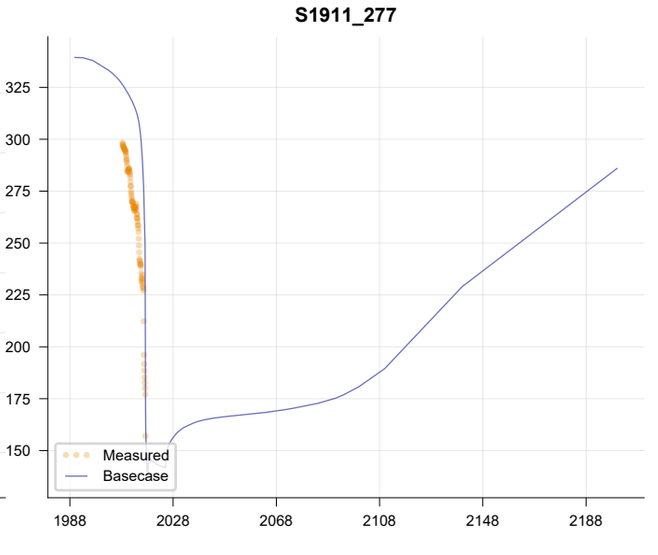

S1910_391
Groundwater...level...(mAHD)
1600
1400
1200
1000
800
600
400
200
0
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year


S1910_9.6
395
390
385
380
375
370
365
360
Measured
Basecase
1988
2028
2068
2108
2148
2188

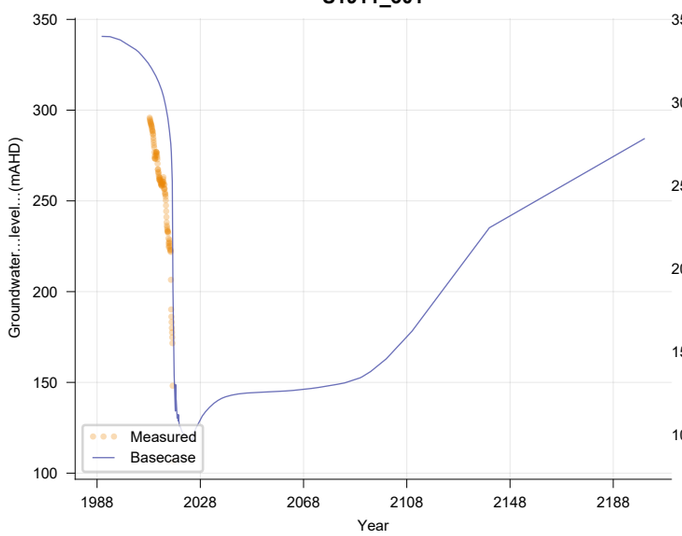

S1911_135
Groundwater...level...(mAHD)
340
320
300
280
260
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year


S1911_187
340
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188

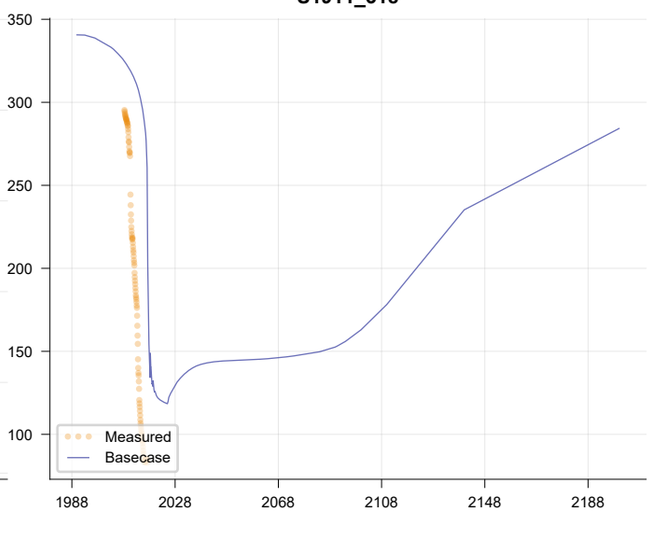

S1911_229
Groundwater...level...(mAHD)
325
300
275
250
225
200
175
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year


S1911_277
325
300
275
250
225
200
175
150
Measured
Basecase
1988
2028
2068
2108
2148
2188

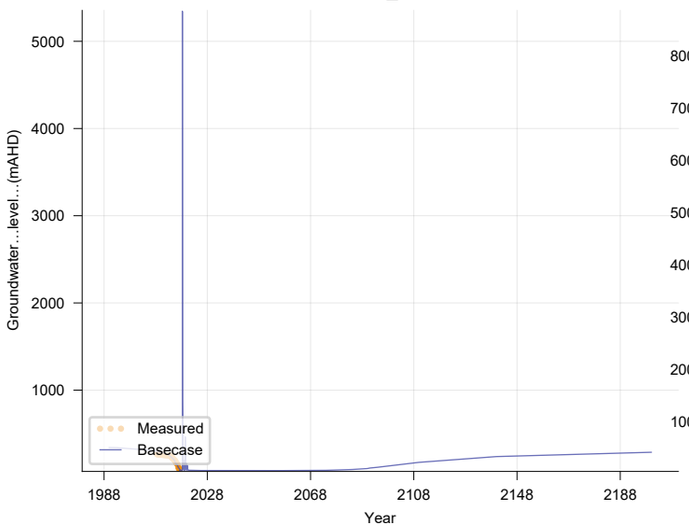
## S1911_301



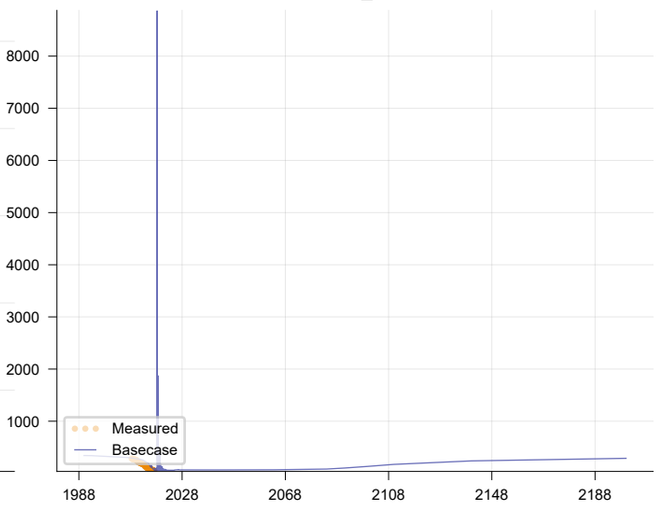

## S1911_318



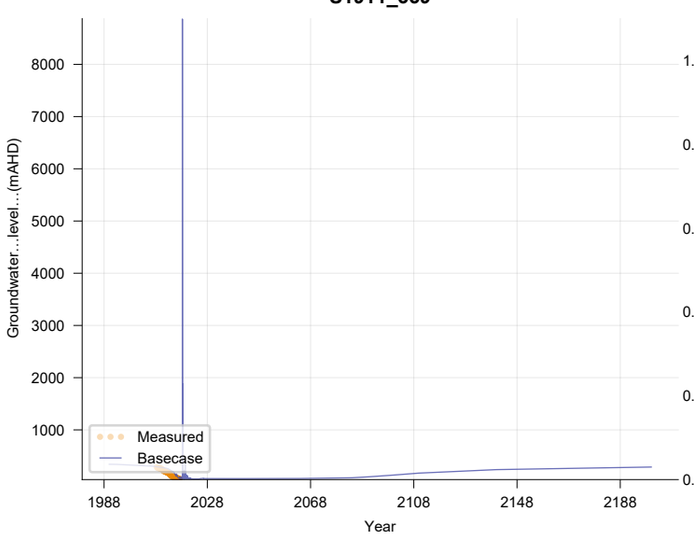

## S1911_331



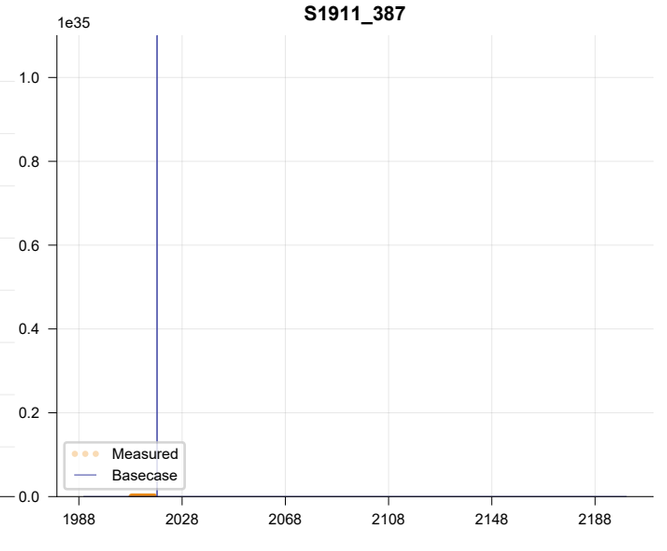

## S1911_349



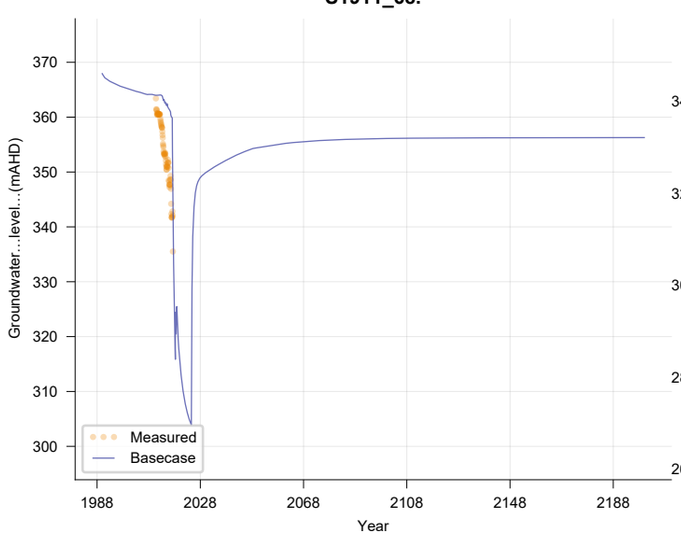

## S1911_359



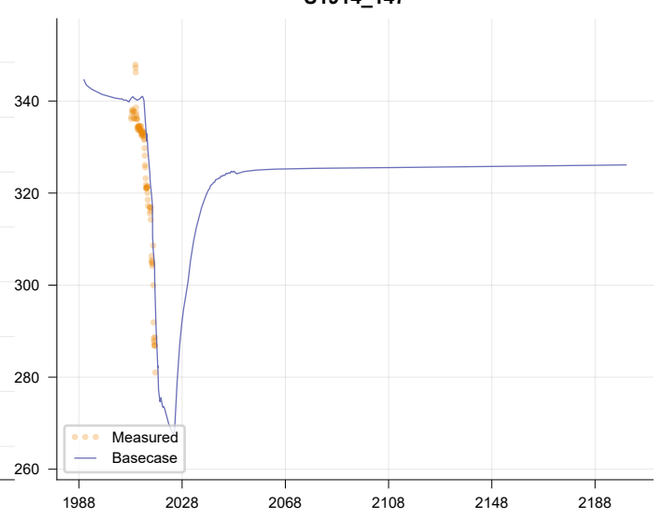

## S1911_387

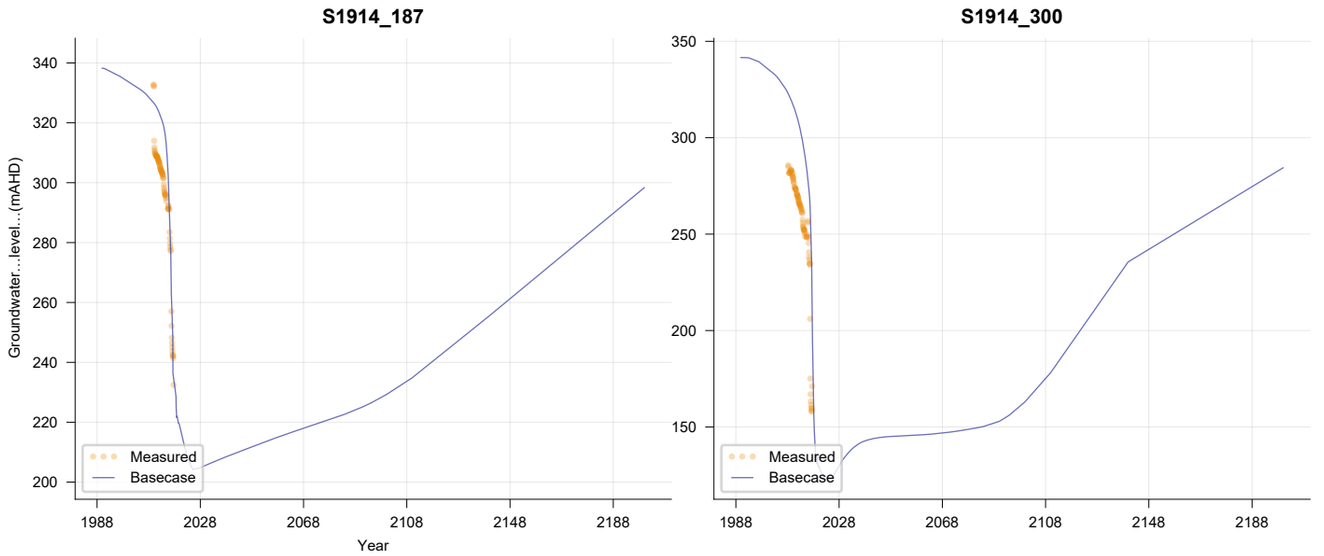



## S1911_68.

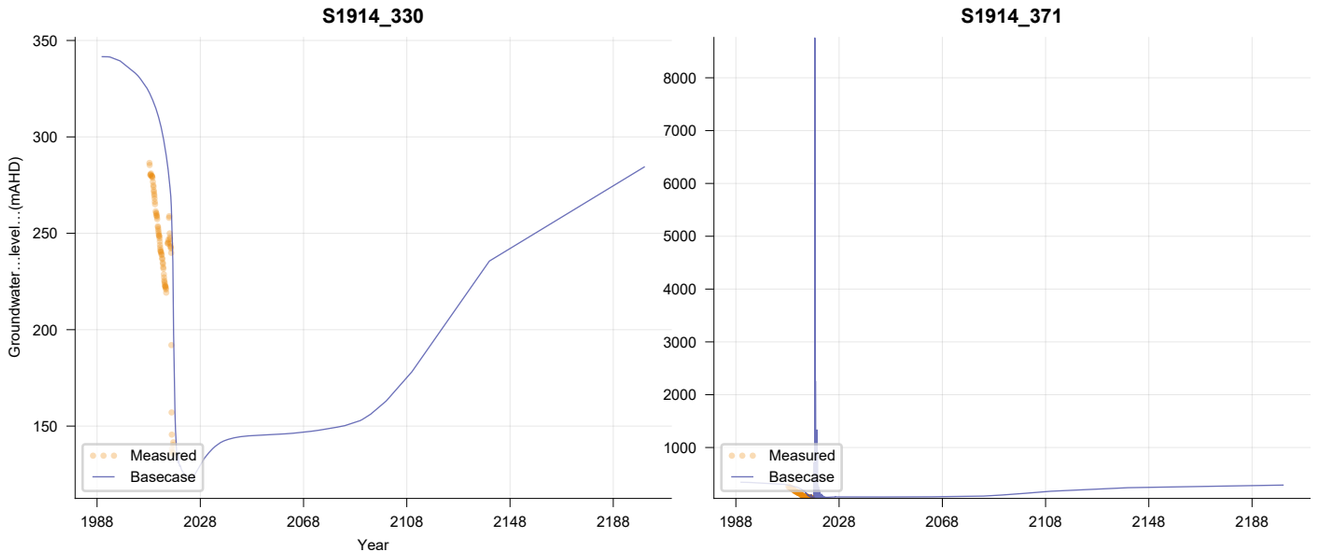



## S1914_147

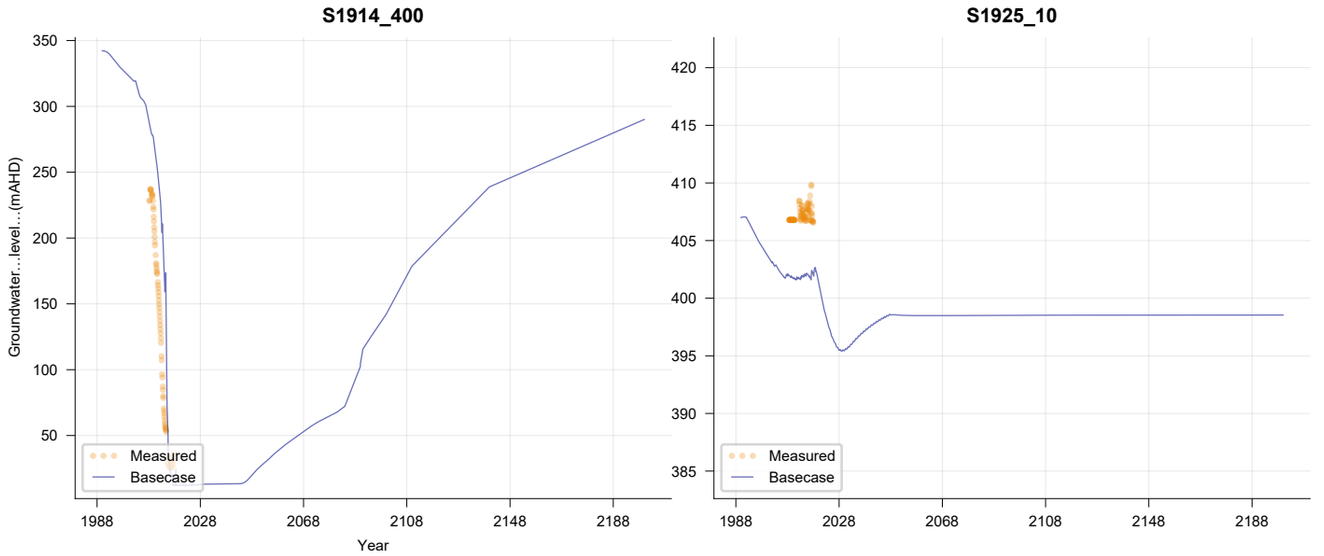



S1914_187
Groundwater...level...(mAHD)
Year
Measured
Basecase

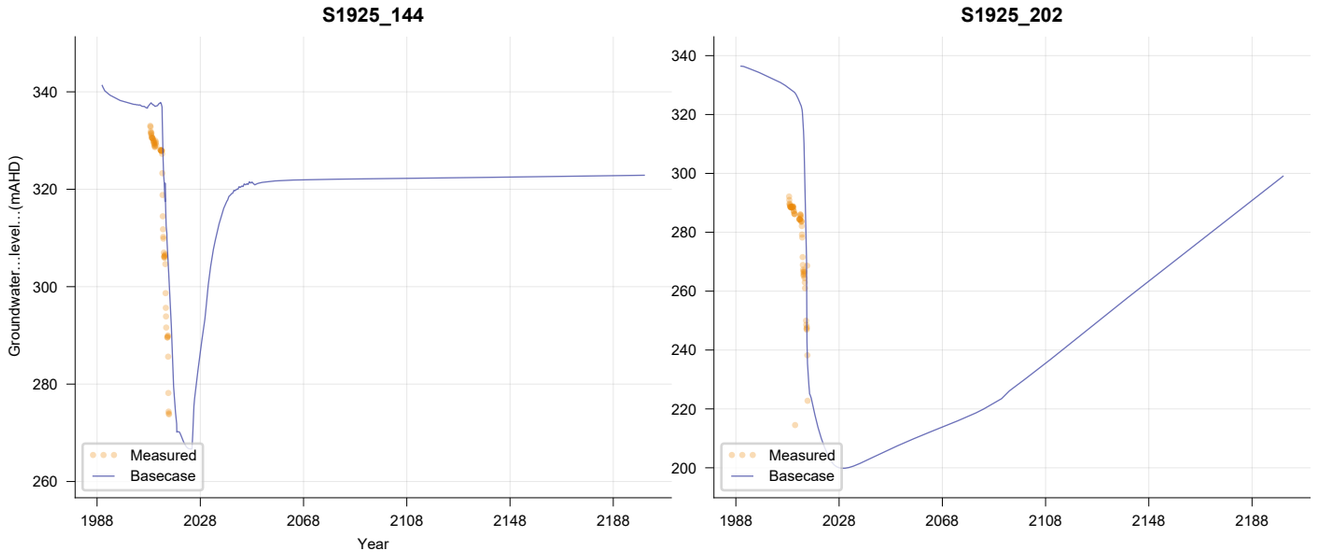

S1914_300
Measured
Basecase


S1914_330
Groundwater...level...(mAHD)
Year
Measured
Basecase

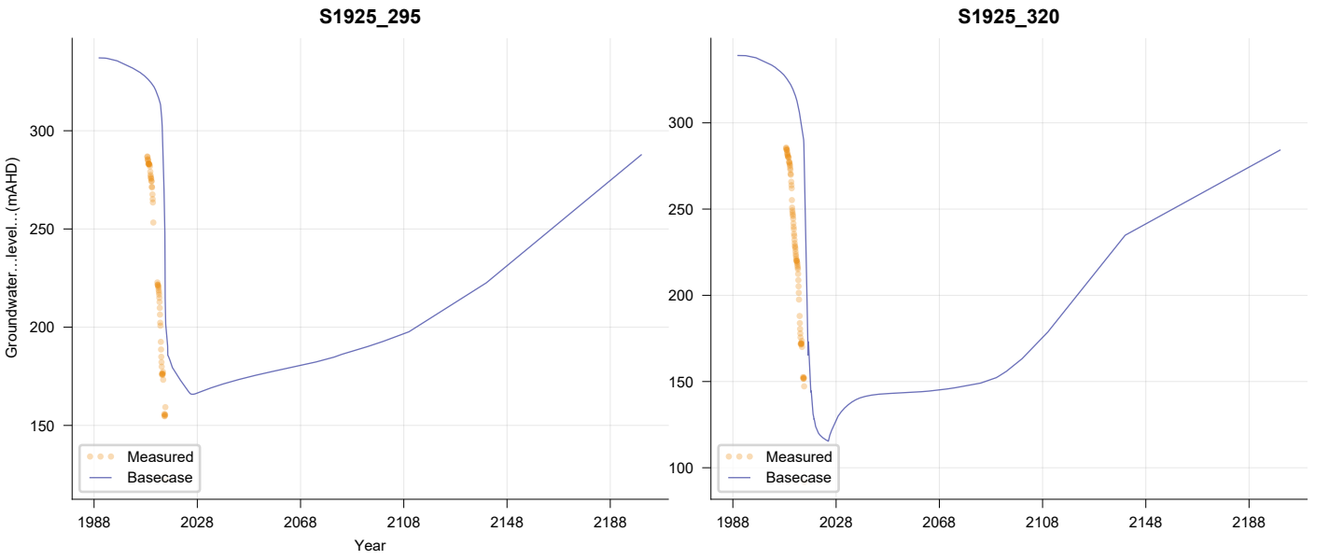

S1914_371
Measured
Basecase


S1914_400
Groundwater...level...(mAHD)
Year
Measured
Basecase

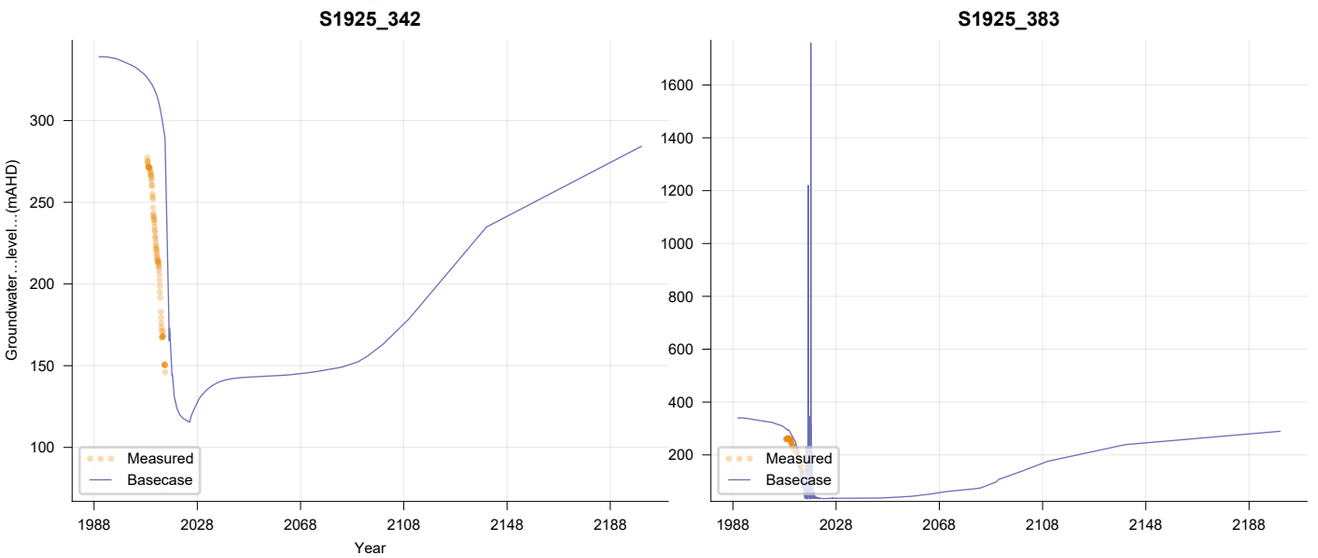

S1925_10
Measured
Basecase


S1925_144
Groundwater...level...(mAHD)
Year
Measured
Basecase

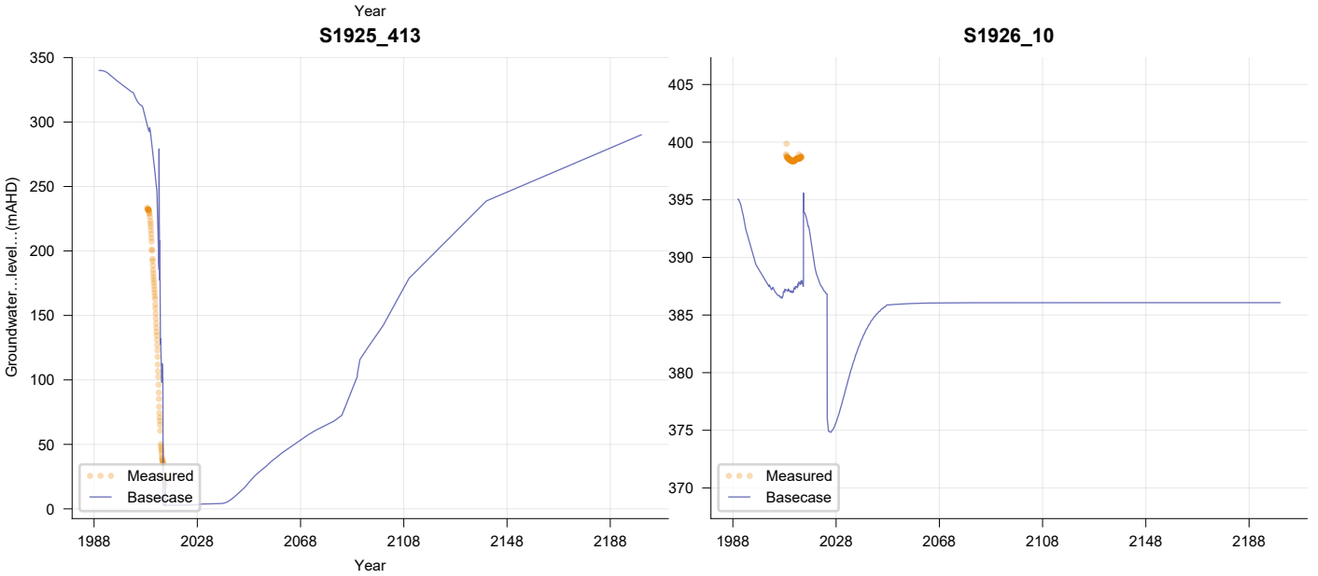

S1925_202
Measured
Basecase


S1925_295
Groundwater...level...(mAHD)
300
250
200
150
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

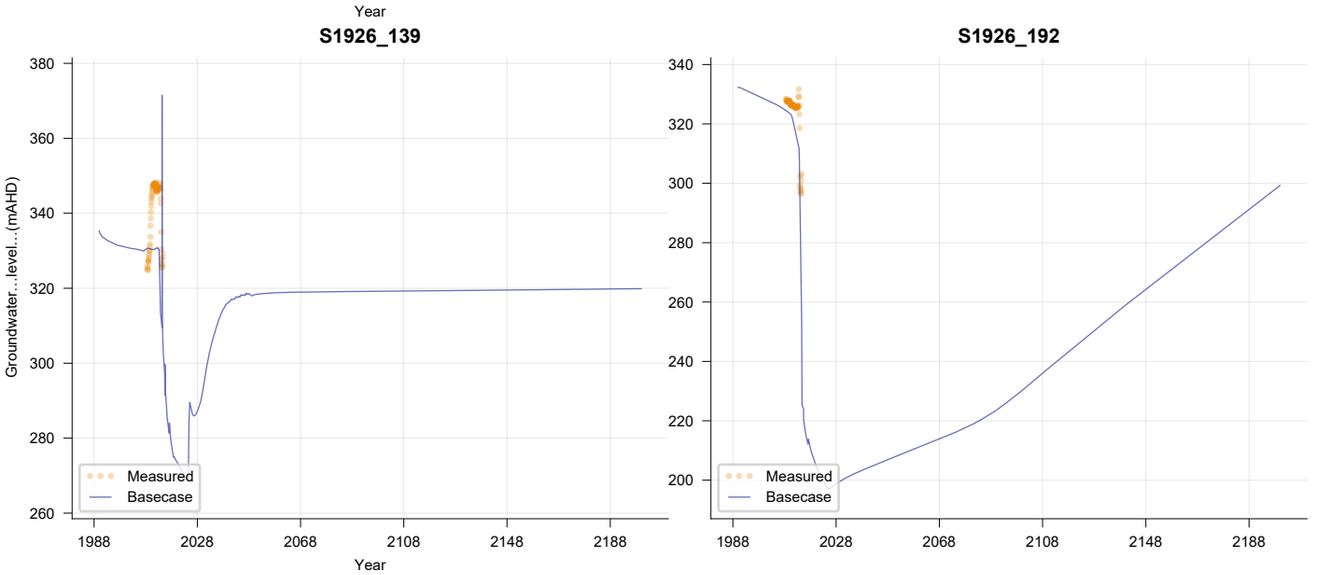

S1925_320
300
250
200
150
100
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1925_342
Groundwater...level...(mAHD)
300
250
200
150
100
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

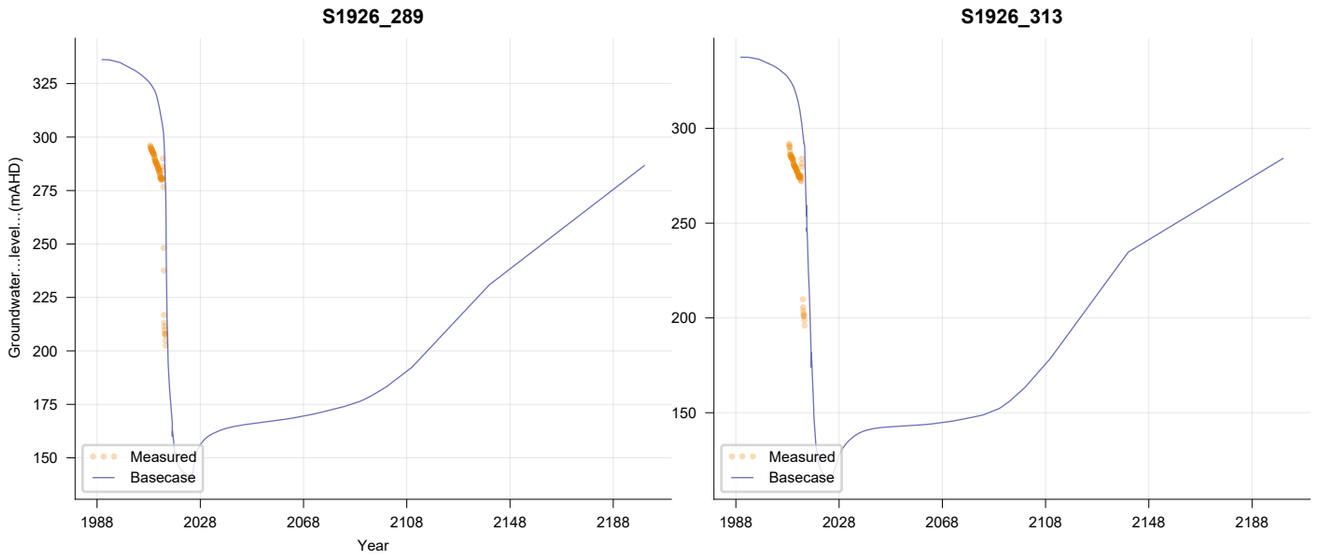

S1925_383
1600
1400
1200
1000
800
600
400
200
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1925_413
Groundwater...level...(mAHD)
350
300
250
200
150
100
50
0
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

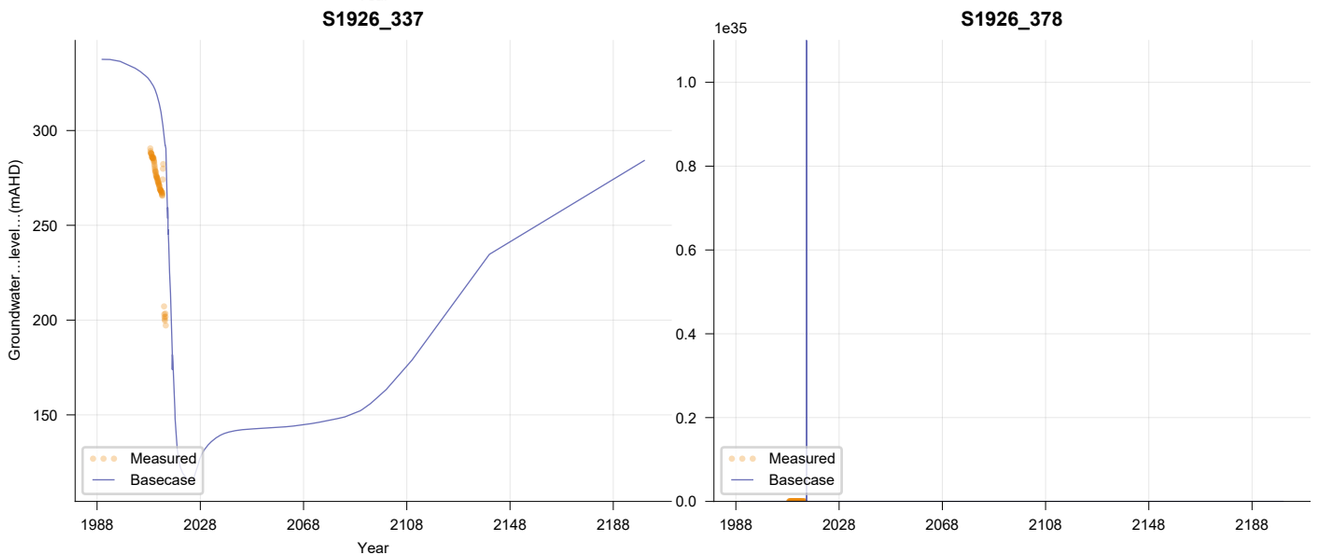

S1926_10
405
400
395
390
385
380
375
370
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1926_139
Groundwater...level...(mAHD)
380
360
340
320
300
280
260
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

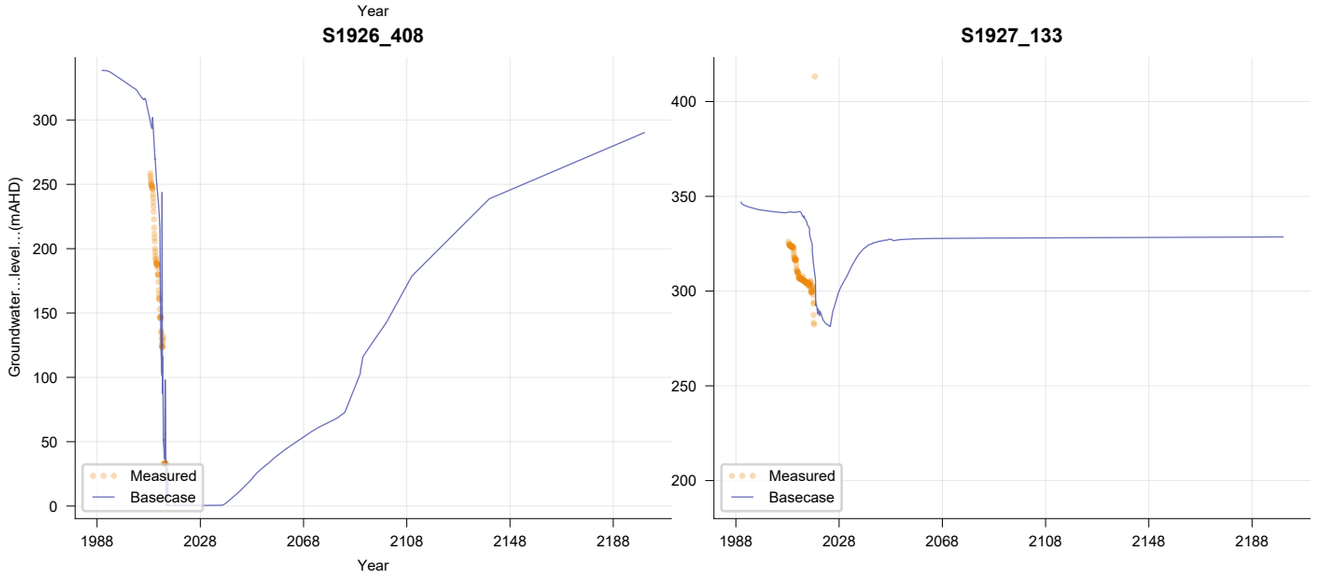

S1926_192
340
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1926_289
Groundwater...level...(mAHD)
325
300
275
250
225
200
175
150
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

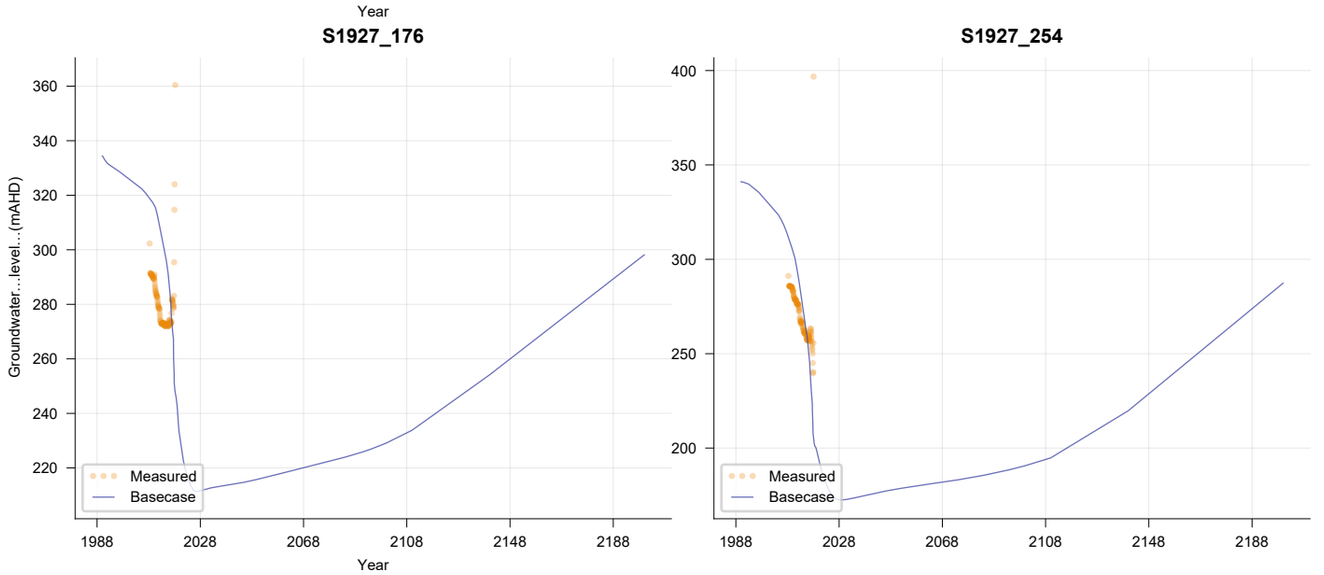

S1926_313
300
250
200
150
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1926_337
Groundwater...level...(mAHD)
300
250
200
150
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

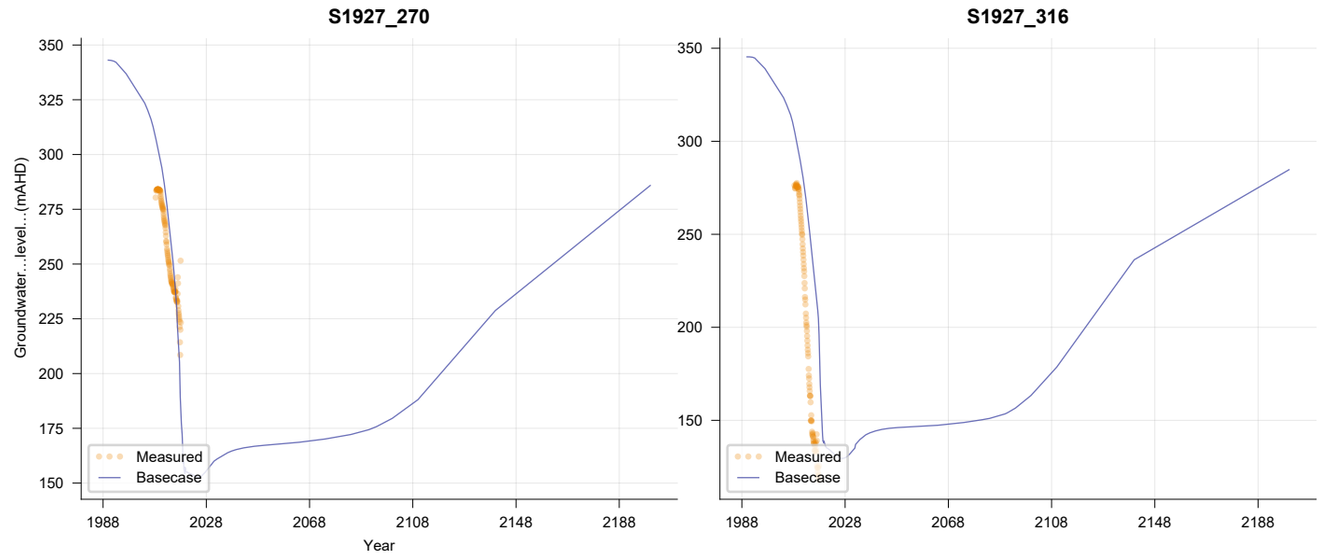

S1926_378
1e35
1.0
0.8
0.6
0.4
0.2
0.0
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1926_408
Groundwater...level...(mAHD)
300
250
200
150
100
50
0
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

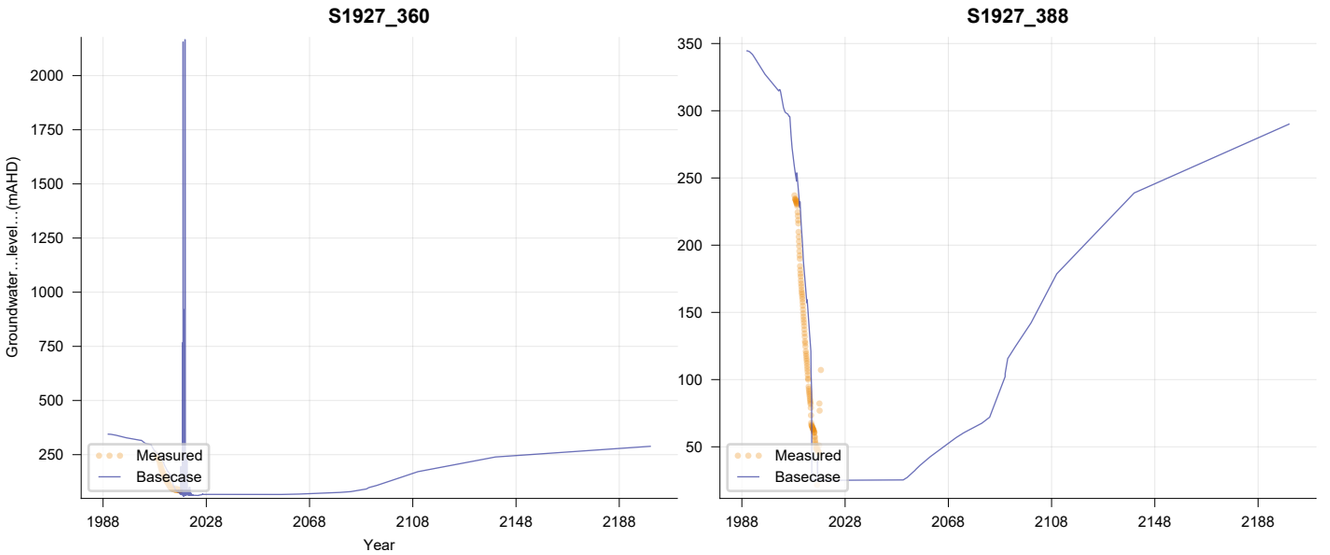

S1927_133
400
350
300
250
200
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1927_176
Groundwater...level...(mAHD)
360
340
320
300
280
260
240
220
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

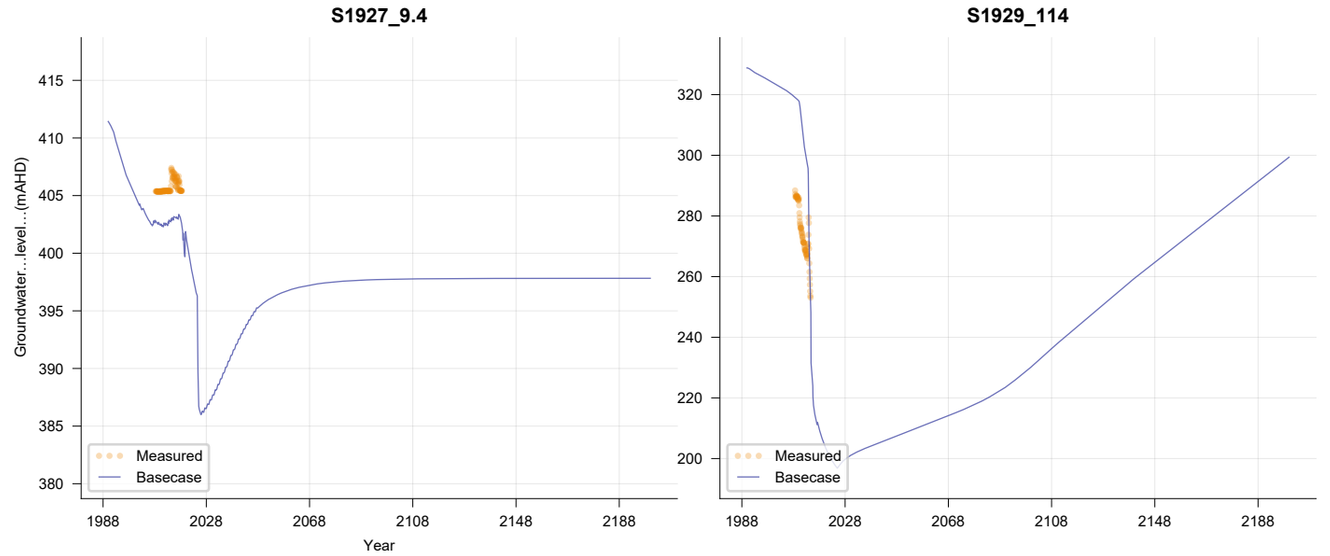

S1927_254
400
350
300
250
200
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1927_270
Groundwater...level...(mAHD)
Year
Measured
Basecase

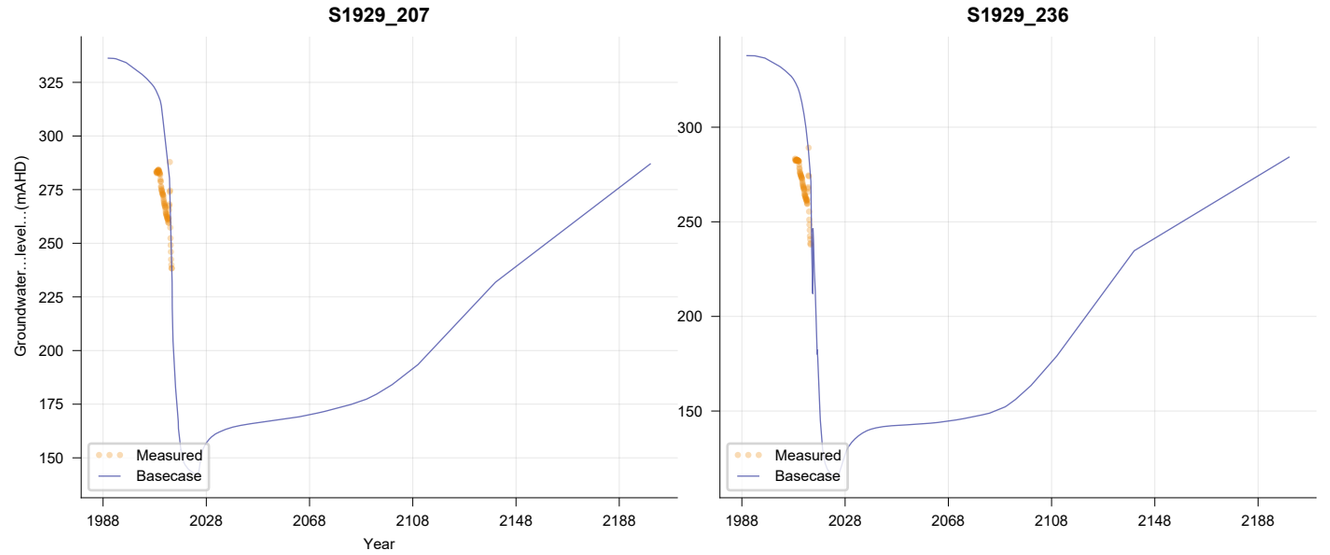

S1927_316
Measured
Basecase


S1927_360
Groundwater...level...(mAHD)
Year
Measured
Basecase

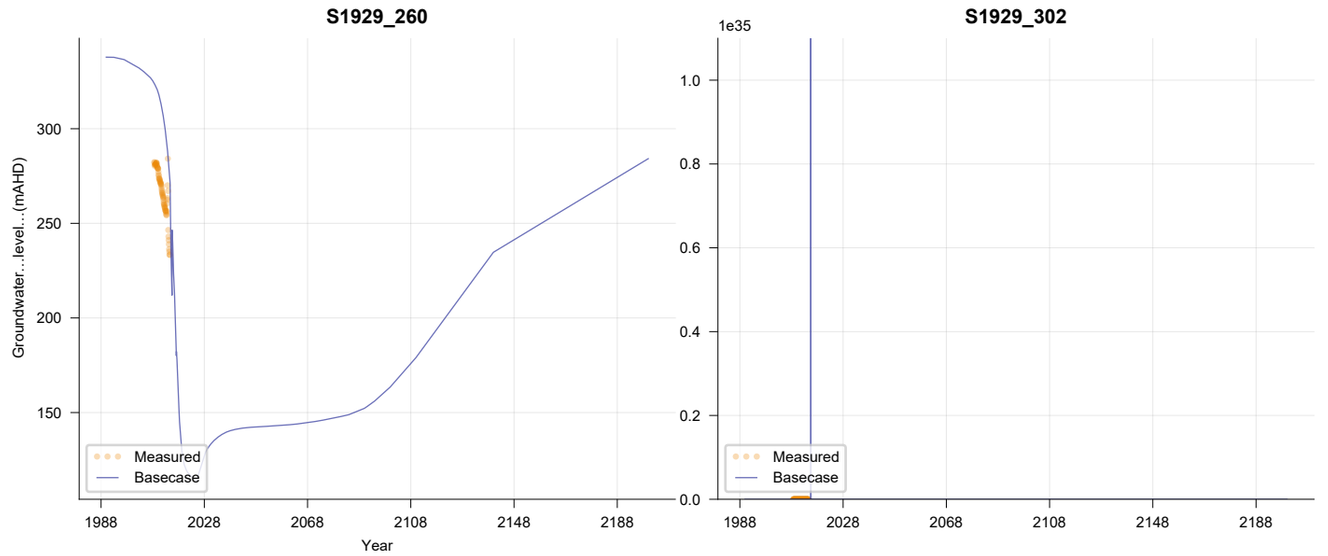

S1927_388
Measured
Basecase


S1927_9.4
Groundwater...level...(mAHD)
Year
Measured
Basecase

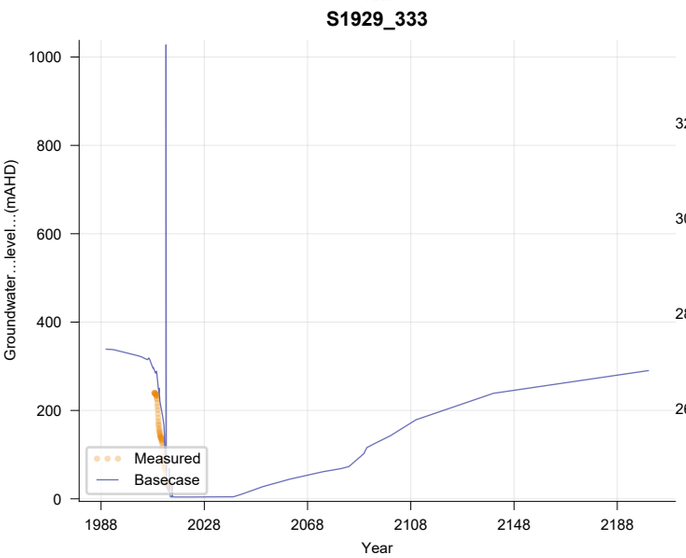

S1929_114
Measured
Basecase

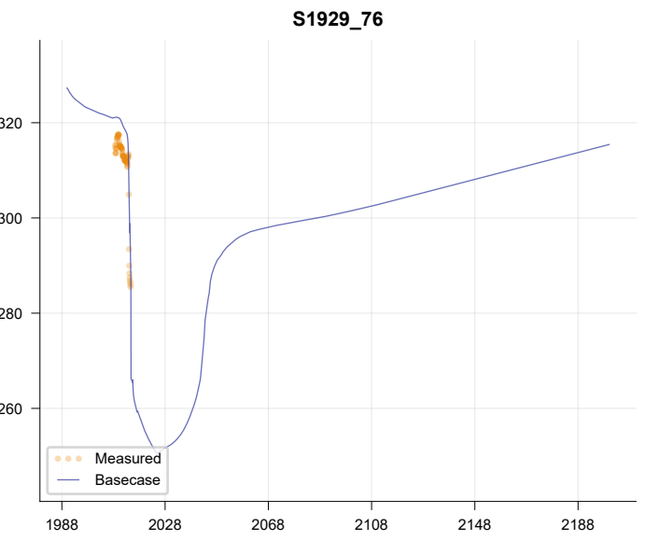

S1929_207
Groundwater...level...(mAHD)
Year
Measured
Basecase

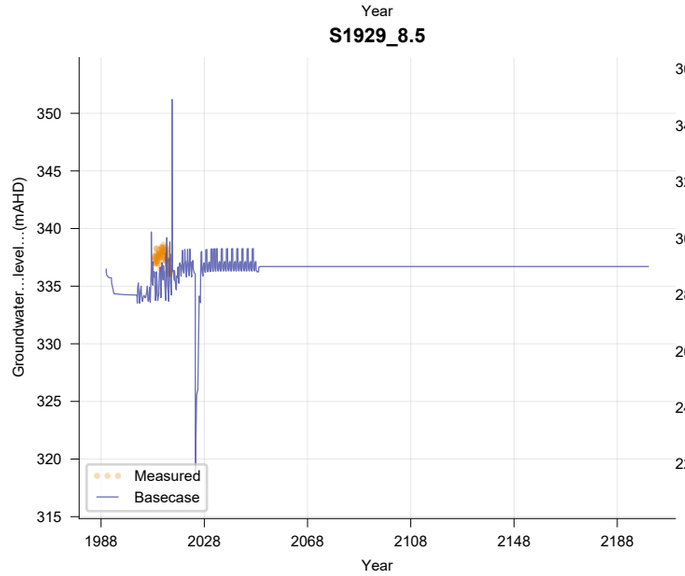

S1929_236
Measured
Basecase

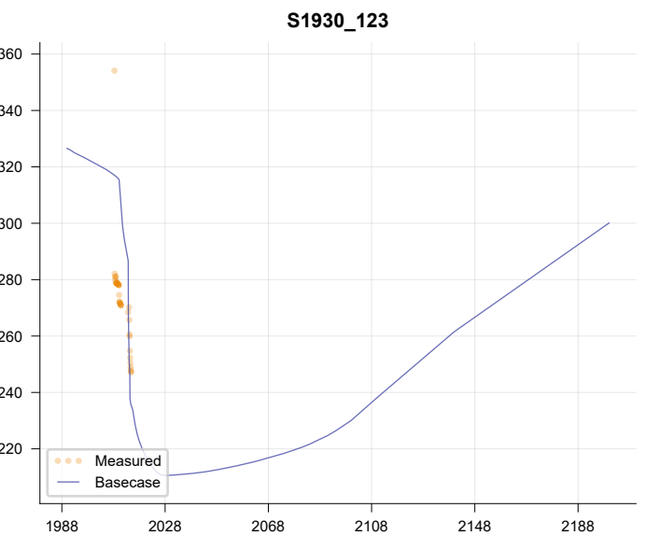

S1929_260
Groundwater...level...(mAHD)
300
250
200
150
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

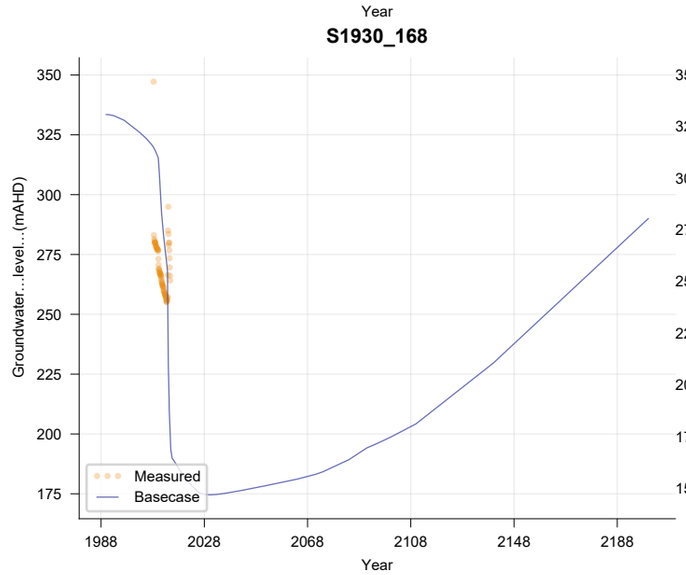

S1929_302
1e35
1.0
0.8
0.6
0.4
0.2
0.0
Measured
Basecase
1988
2028
2068
2108
2148
2188

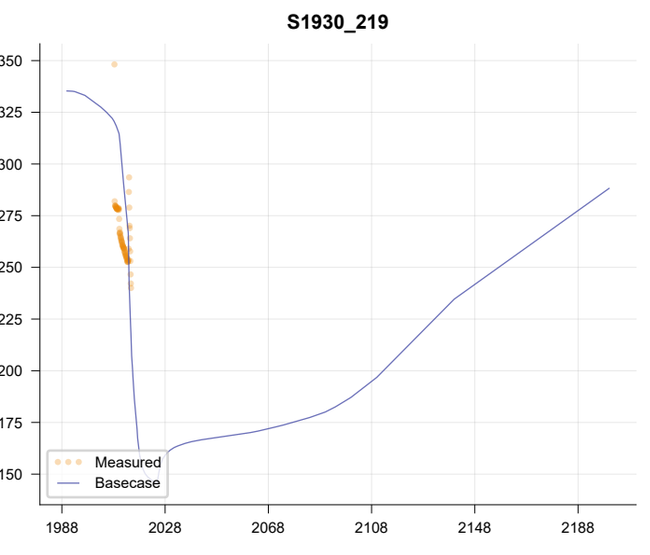

S1929_333
Groundwater...level...(mAHD)
1000
800
600
400
200
0
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

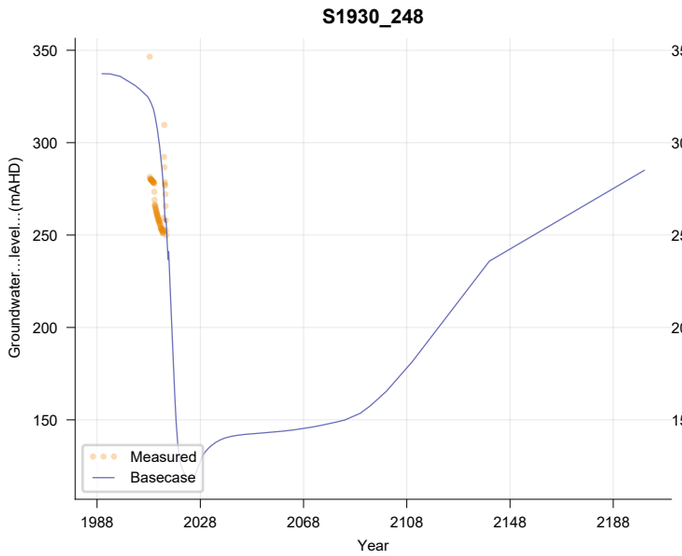

S1929_76
320
300
280
260
Measured
Basecase
1988
2028
2068
2108
2148
2188

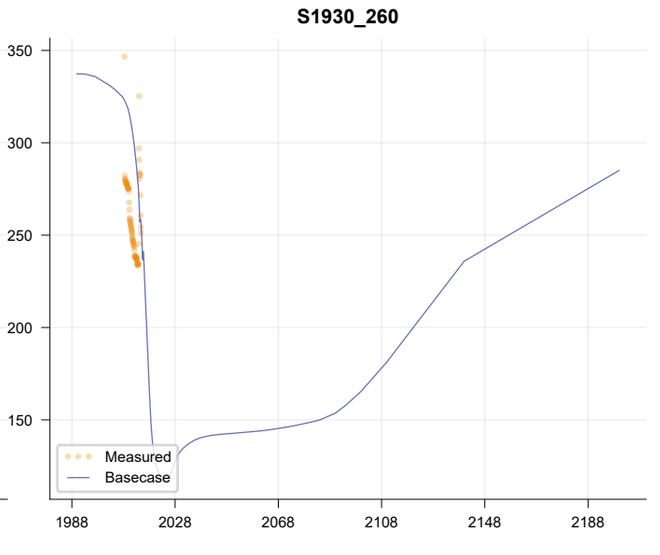

S1929_8.5
Groundwater...level...(mAHD)
350
345
340
335
330
325
320
315
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

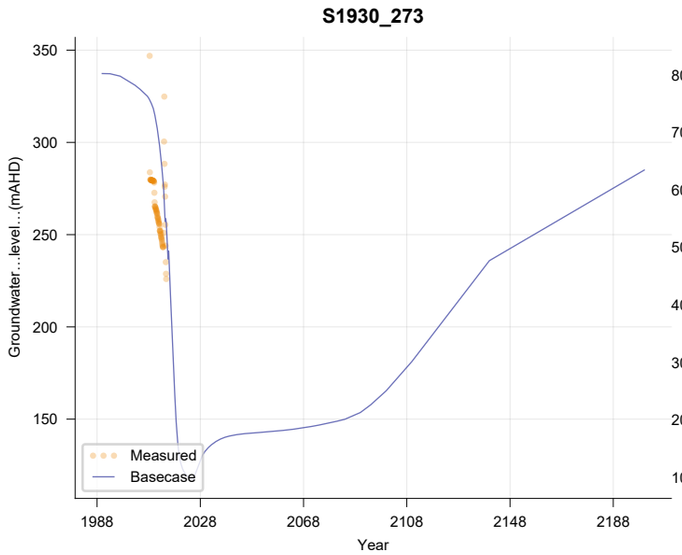

S1930_123
360
340
320
300
280
260
240
220
Measured
Basecase
1988
2028
2068
2108
2148
2188

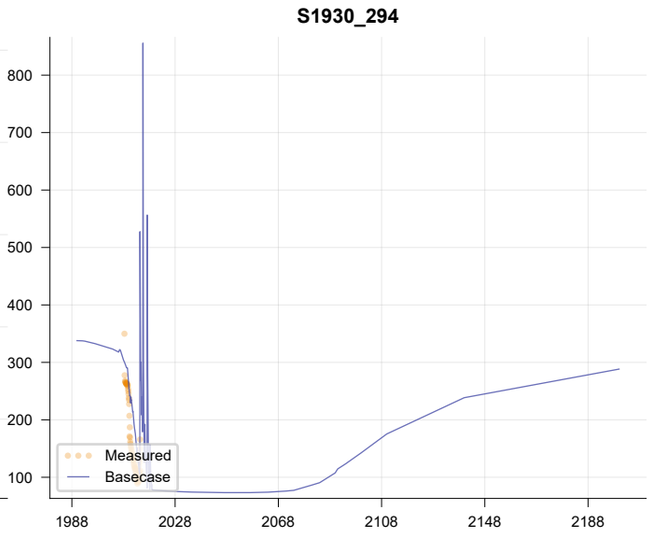

S1930_168
Groundwater...level...(mAHD)
350
325
300
275
250
225
200
175
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

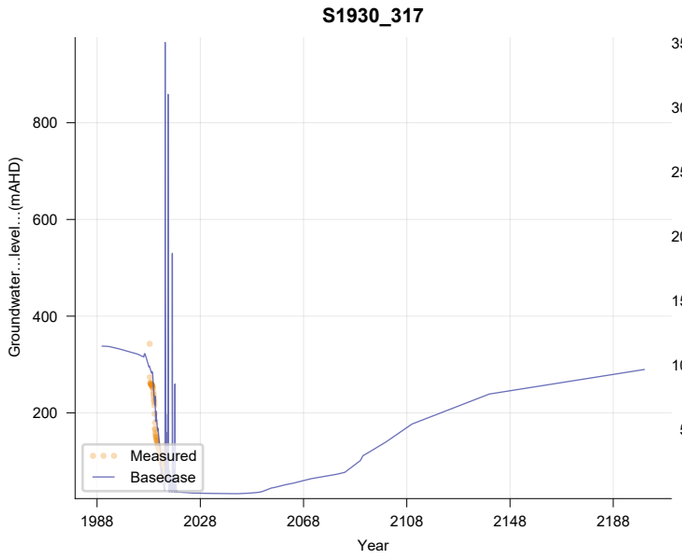

S1930_219
350
325
300
275
250
225
200
175
150
Measured
Basecase
1988
2028
2068
2108
2148
2188

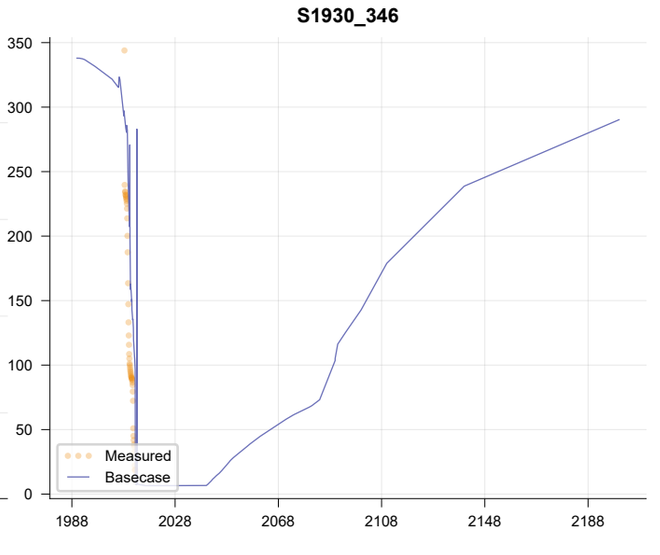

S1930_248
Groundwater...level...(mAHD)
350
300
250
200
150
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

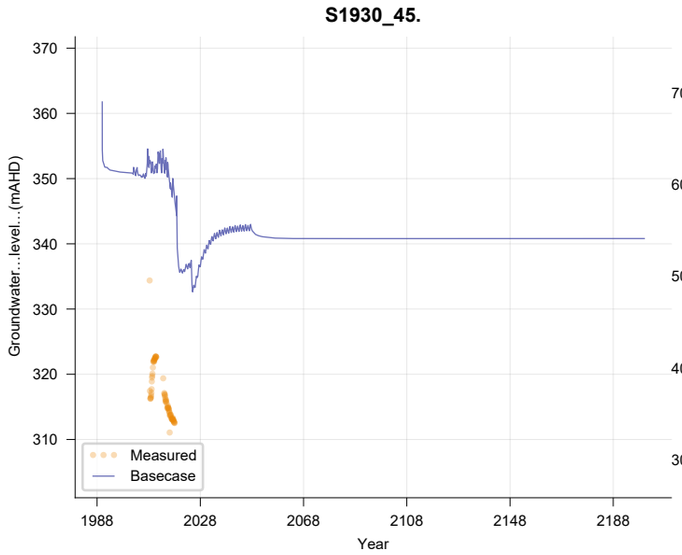

S1930_260
350
300
250
200
150
Measured
Basecase
1988
2028
2068
2108
2148
2188

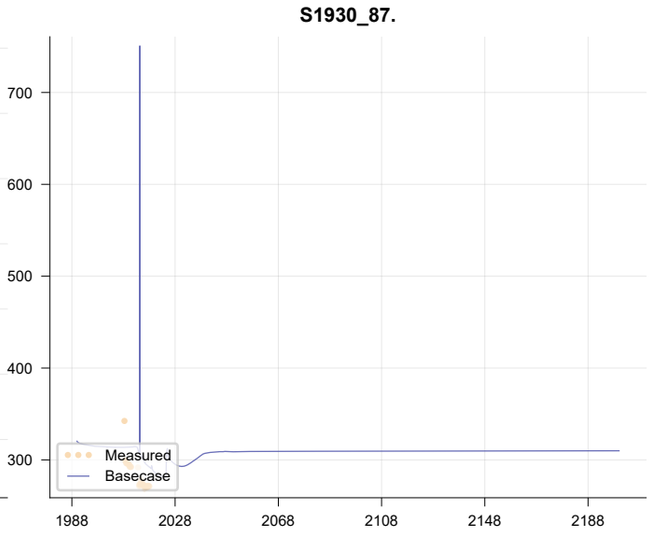

S1930_273
Groundwater...level...(mAHD)
350
300
250
200
150
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

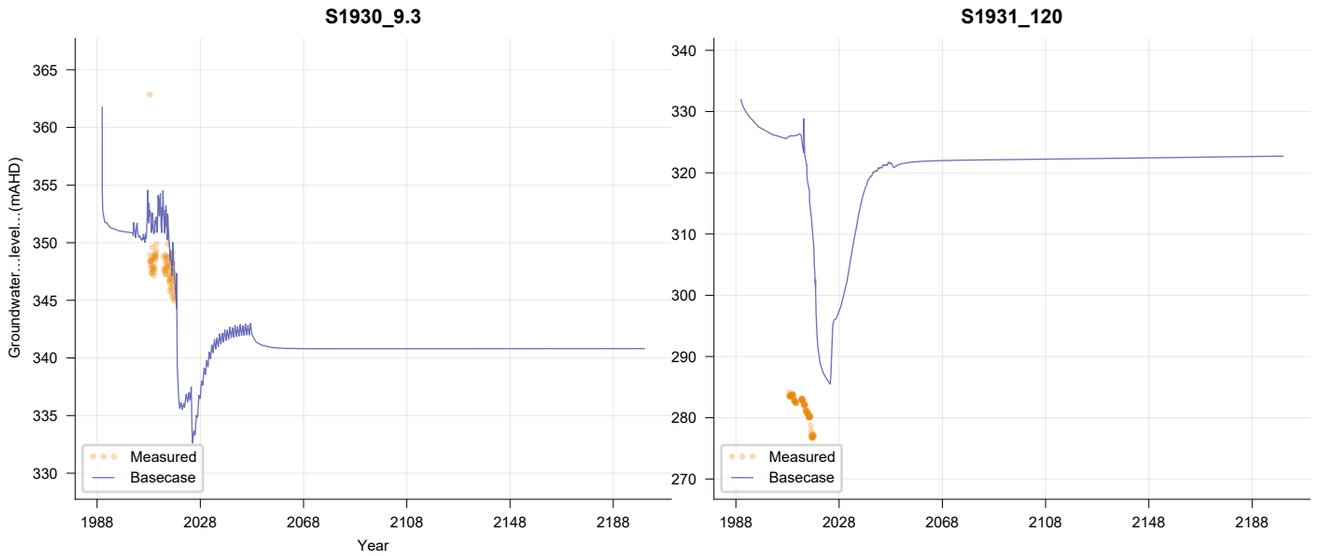

S1930_294
800
700
600
500
400
300
200
100
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1930_317
Groundwater...level...(mAHD)
800
600
400
200
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

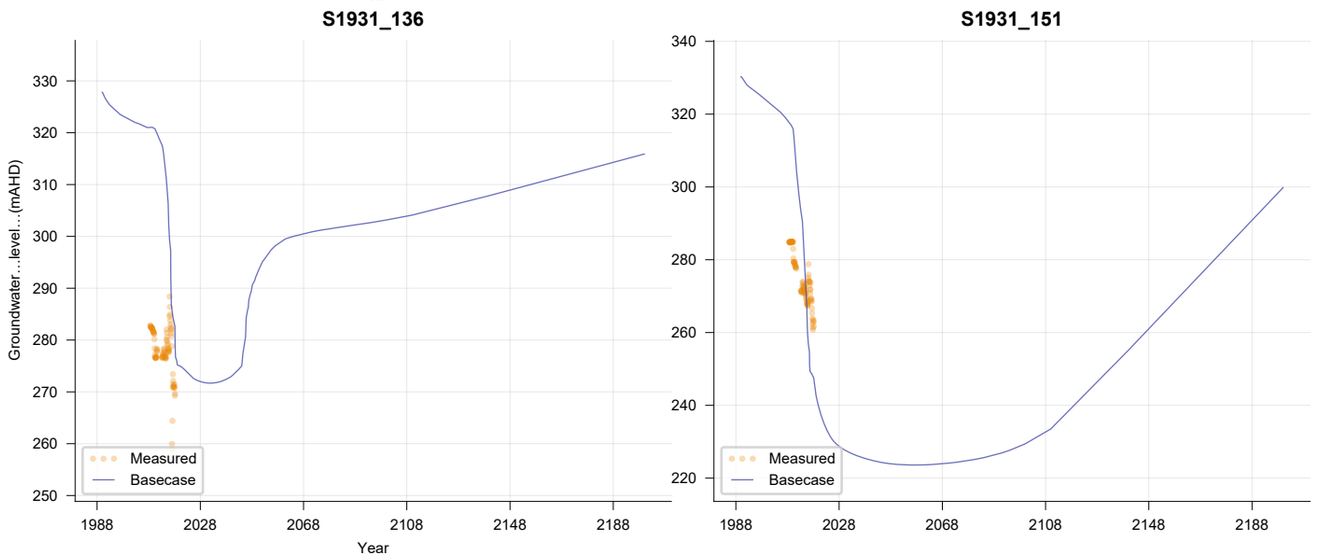

S1930_346
350
300
250
200
150
100
50
0
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1930_45.
Groundwater...level...(mAHD)
370
360
350
340
330
320
310
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

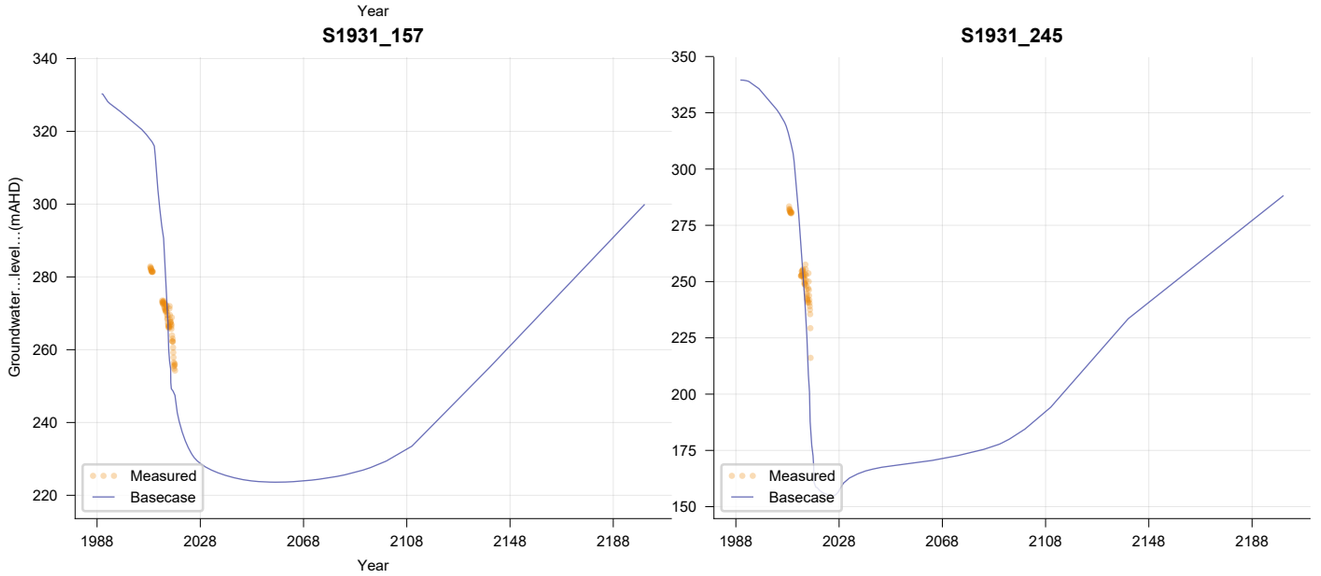

S1930_87.
700
600
500
400
300
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1930_9.3
Groundwater...level...(mAHD)
Year
Measured
Basecase

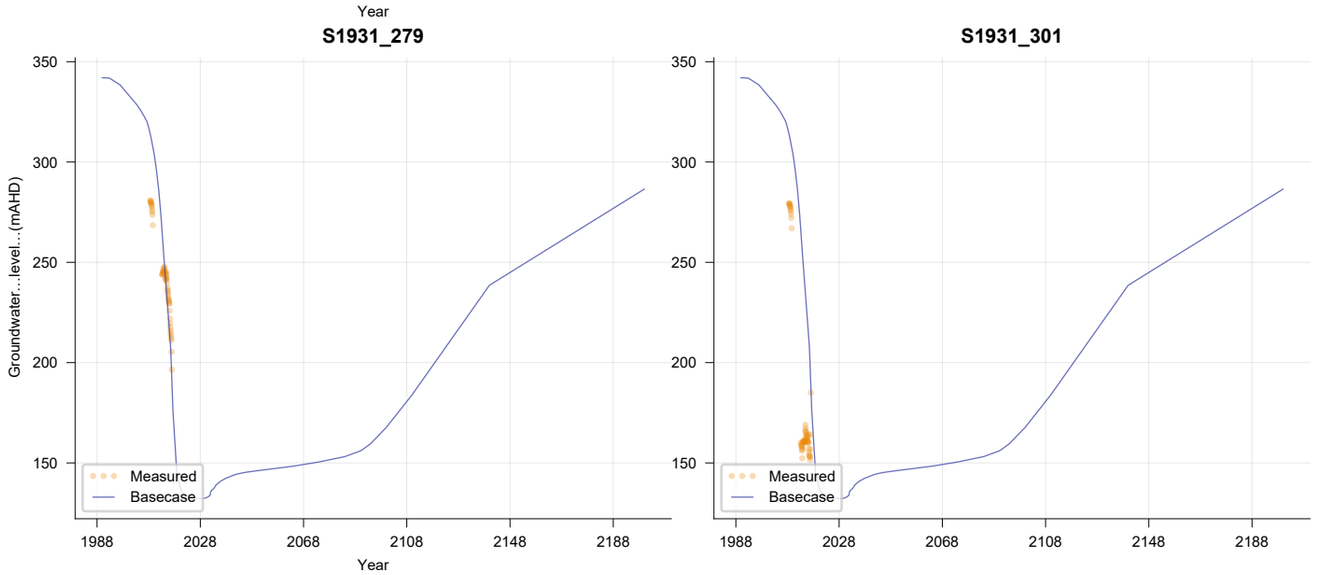

S1931_120
Groundwater...level...(mAHD)
Year
Measured
Basecase


S1931_136
Groundwater...level...(mAHD)
Year
Measured
Basecase

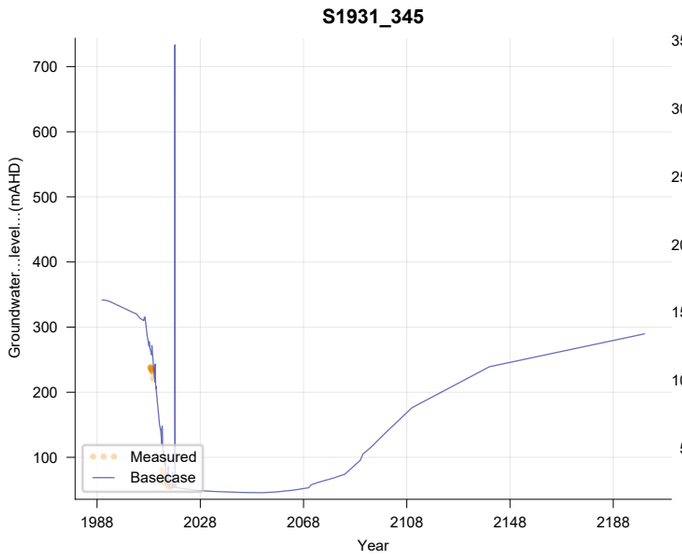

S1931_151
Groundwater...level...(mAHD)
Year
Measured
Basecase

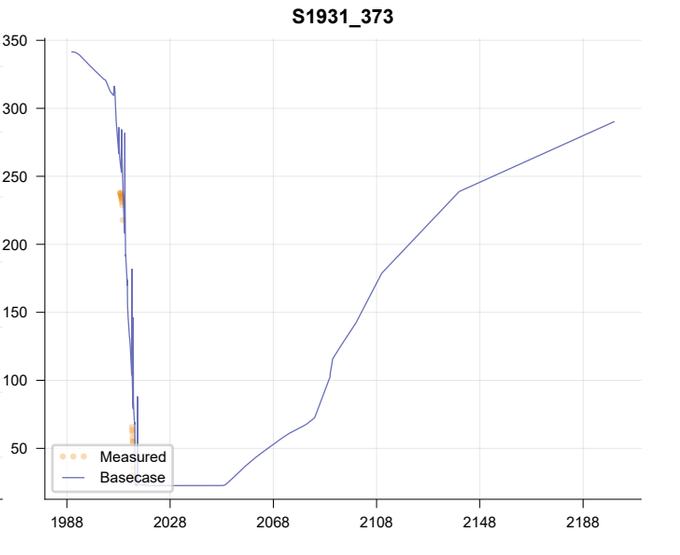

S1931_157
Groundwater...level...(mAHD)
Year
Measured
Basecase

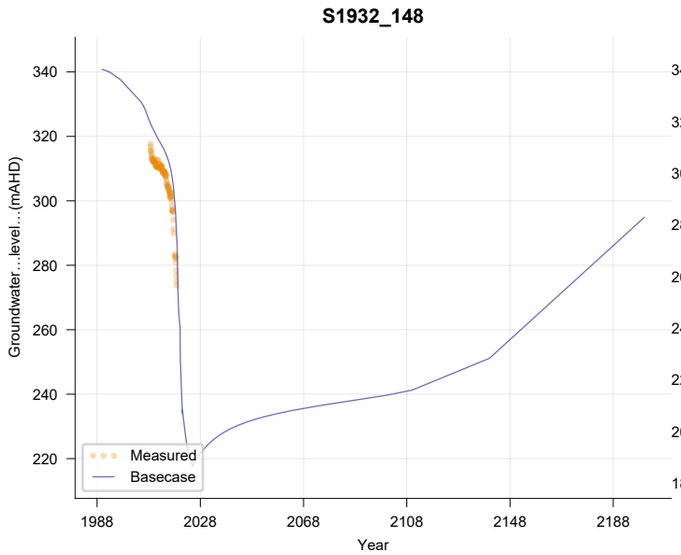

S1931_245
Groundwater...level...(mAHD)
Year
Measured
Basecase

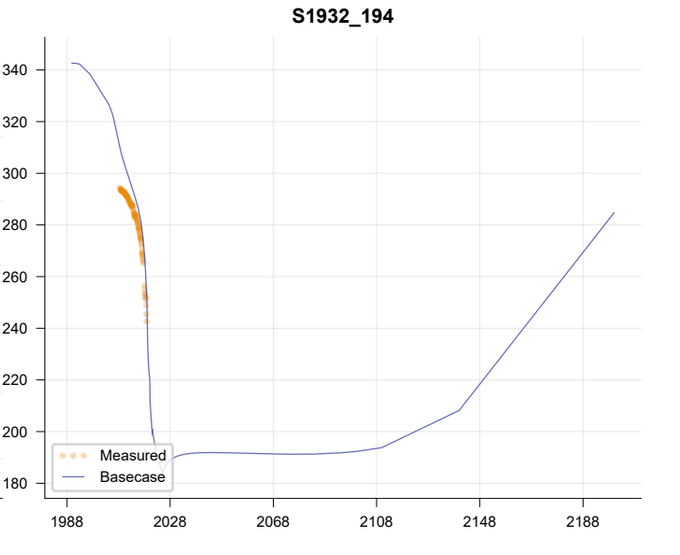

S1931_279
Groundwater...level...(mAHD)
Year
Measured
Basecase

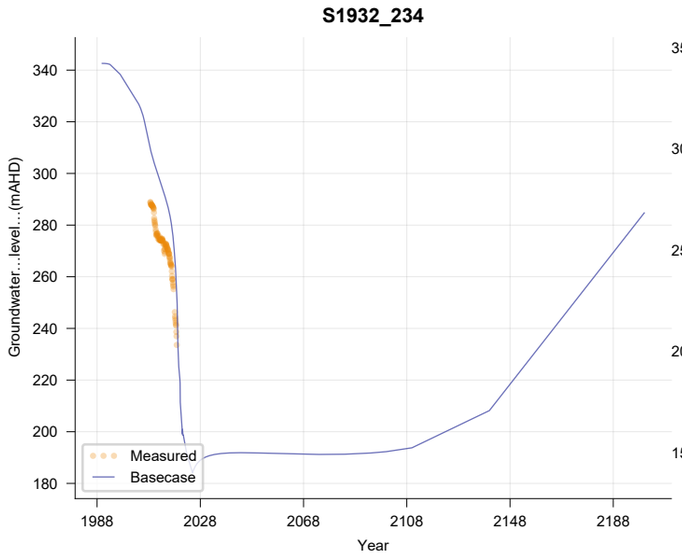

S1931_301
Groundwater...level...(mAHD)
Year
Measured
Basecase

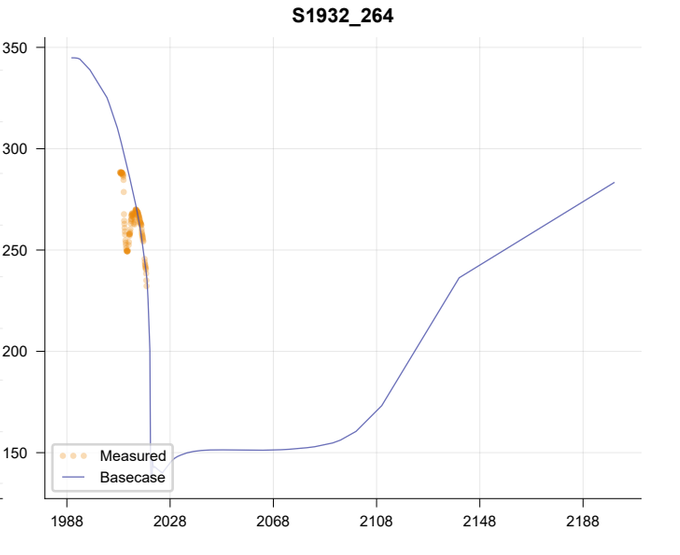

S1931_345
Groundwater...level...(mAHD)
Year
Measured
Basecase

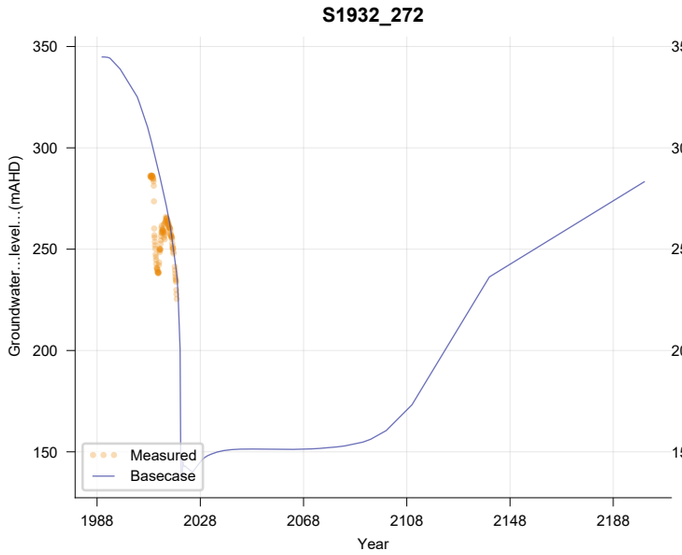

S1931_373
Measured
Basecase

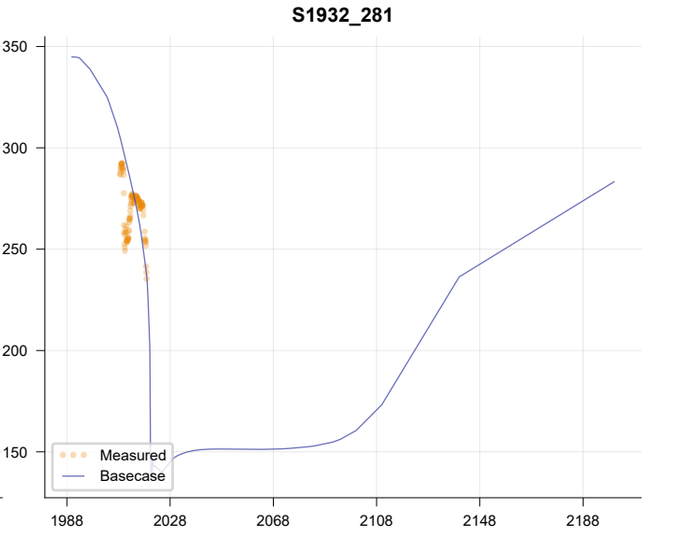

S1932_148
Groundwater...level...(mAHD)
Year
Measured
Basecase

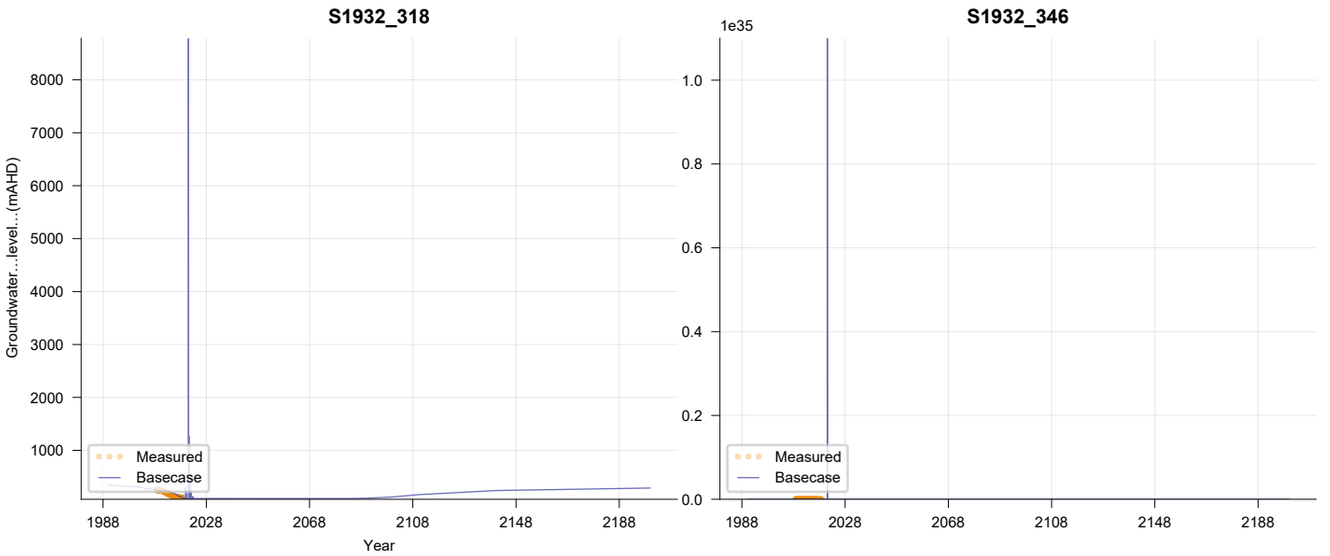

S1932_194
Measured
Basecase


S1932_234
Groundwater...level...(mAHD)
Year
Measured
Basecase

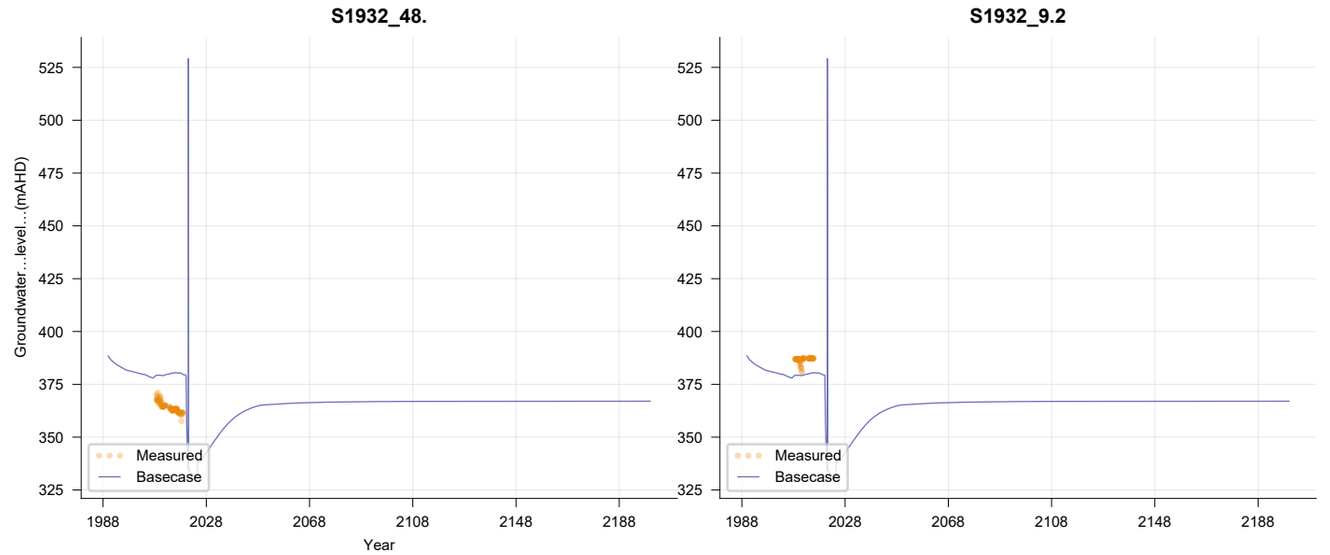

S1932_264
Measured
Basecase


S1932_272
Groundwater...level...(mAHD)
Year
Measured
Basecase

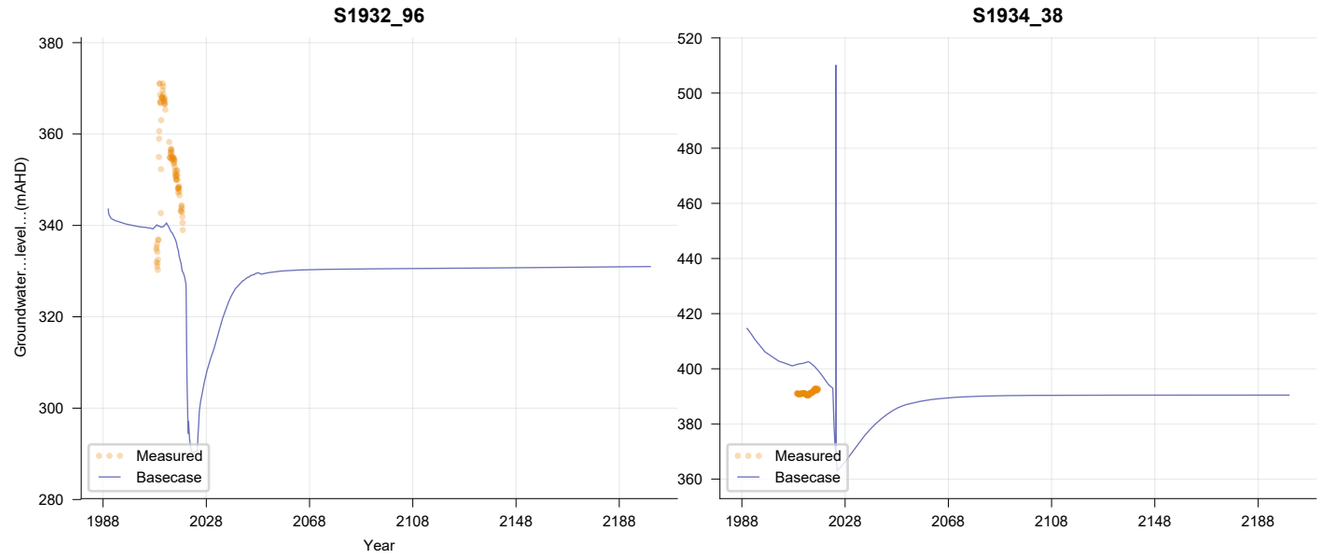

S1932_281
Measured
Basecase


S1932_318
Groundwater...level...(mAHD)
8000
7000
6000
5000
4000
3000
2000
1000
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

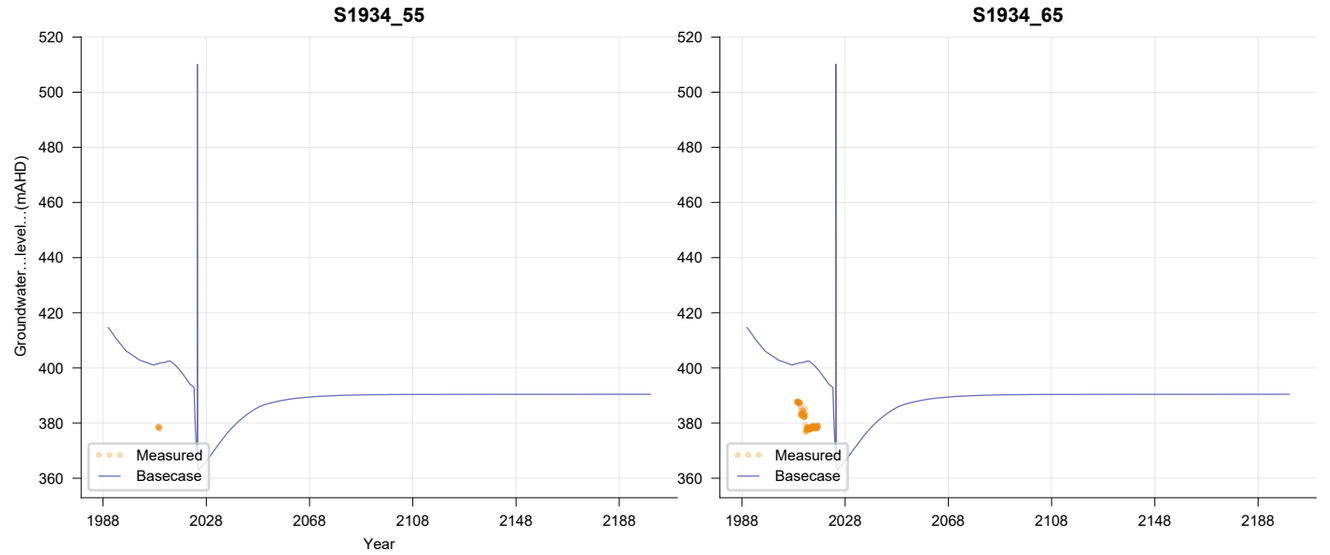

S1932_346
1e35
1.0
0.8
0.6
0.4
0.2
0.0
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1932_48.
Groundwater...level...(mAHD)
525
500
475
450
425
400
375
350
325
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

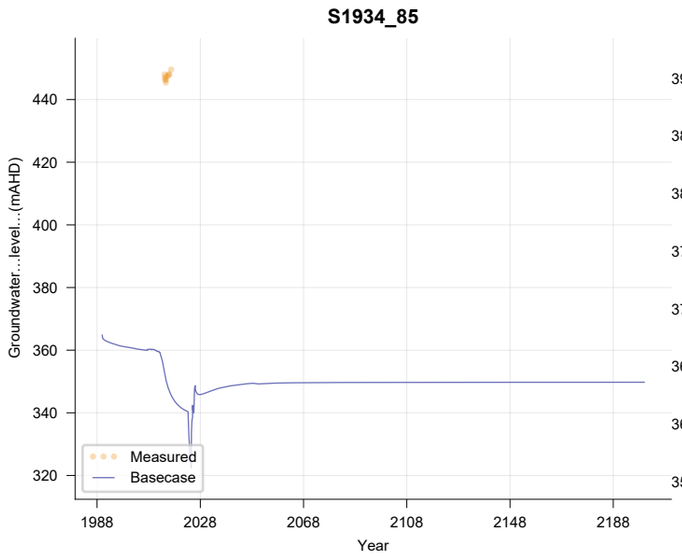

S1932_9.2
525
500
475
450
425
400
375
350
325
Measured
Basecase
1988
2028
2068
2108
2148
2188

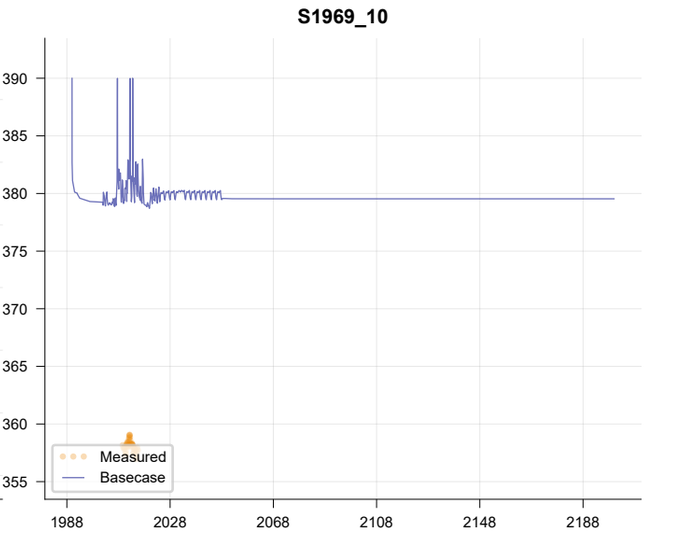

S1932_96
Groundwater...level...(mAHD)
380
360
340
320
300
280
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

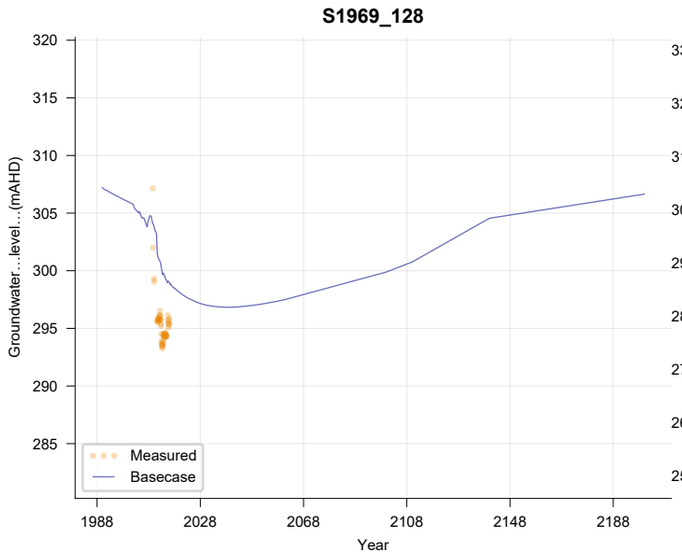

S1934_38
520
500
480
460
440
420
400
380
360
Measured
Basecase
1988
2028
2068
2108
2148
2188

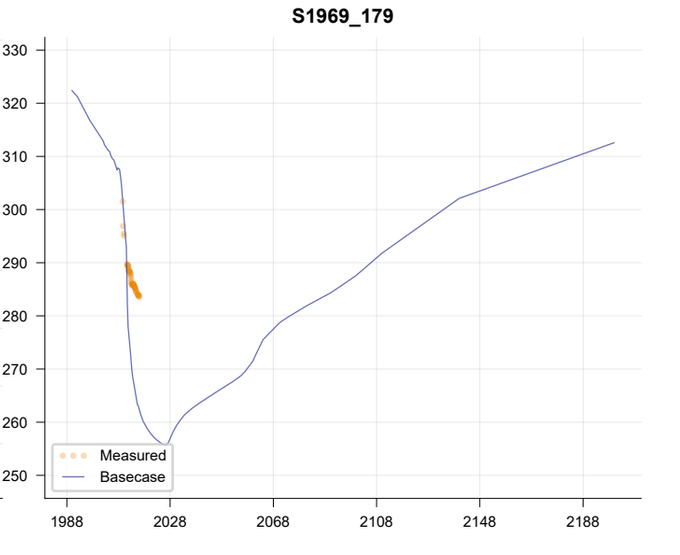

S1934_55
Groundwater...level...(mAHD)
520
500
480
460
440
420
400
380
360
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

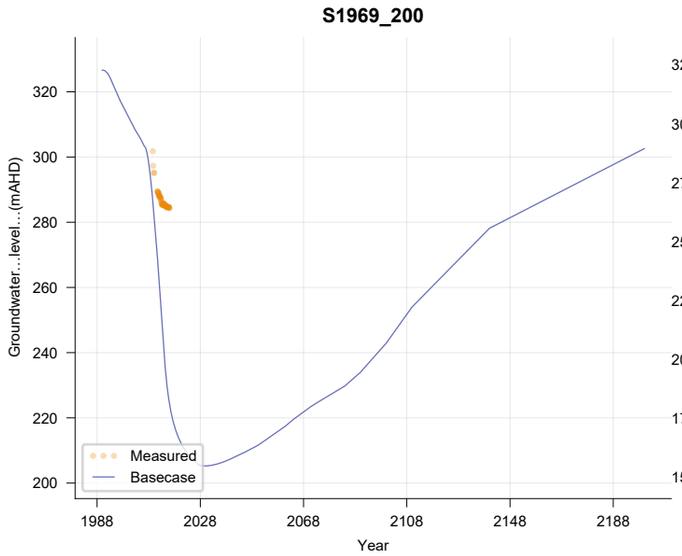

S1934_65
520
500
480
460
440
420
400
380
360
Measured
Basecase
1988
2028
2068
2108
2148
2188

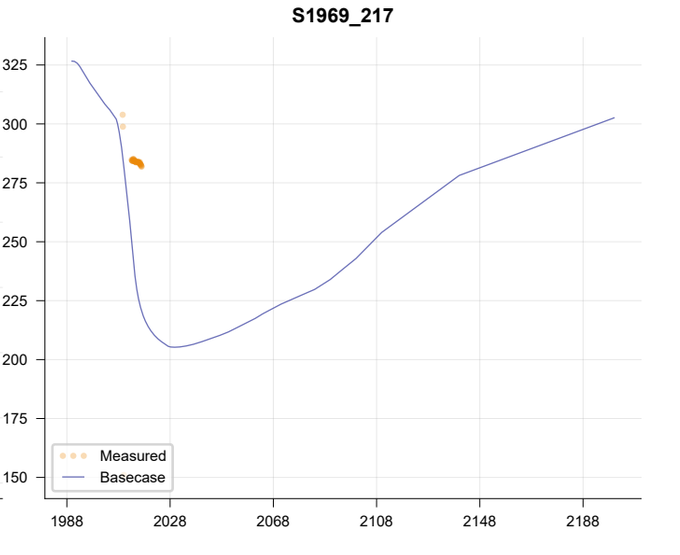

S1934_85
Groundwater...level...(mAHD)
Year
Measured
Basecase

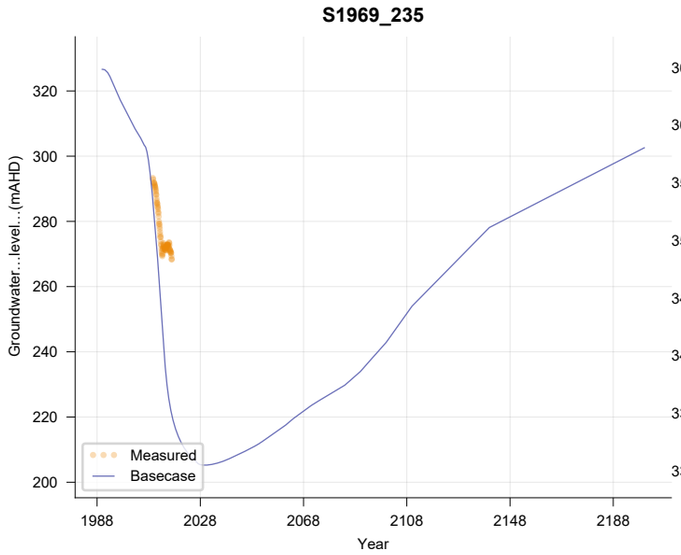

S1969_10
Measured
Basecase

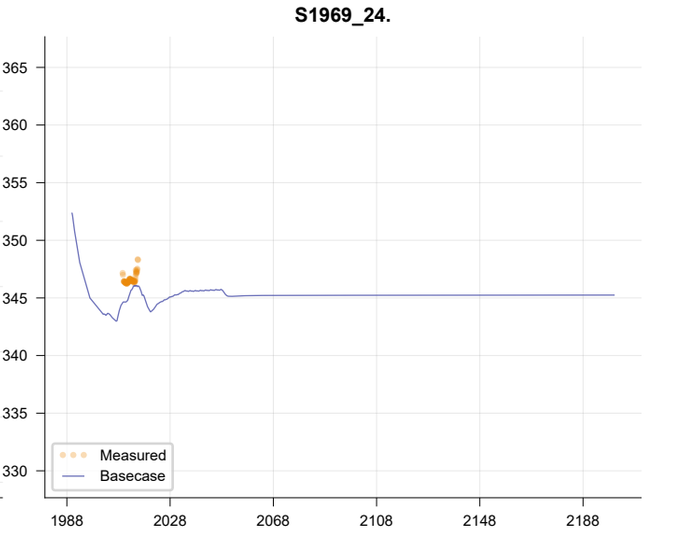

S1969_128
Groundwater...level...(mAHD)
Year
Measured
Basecase

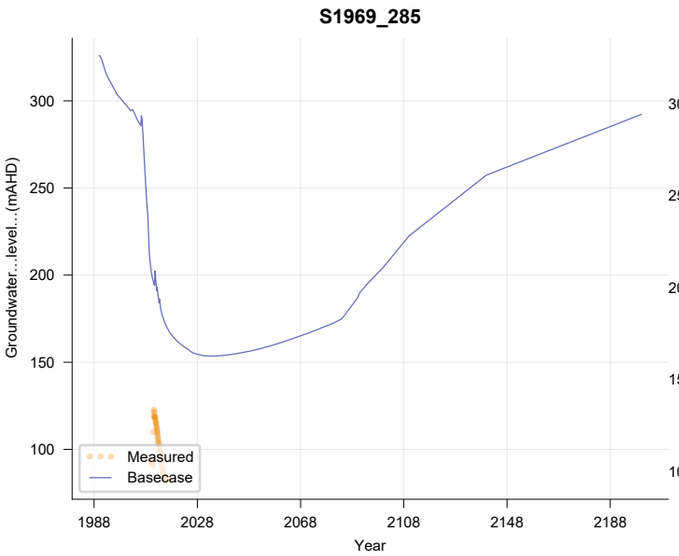

S1969_179
Measured
Basecase

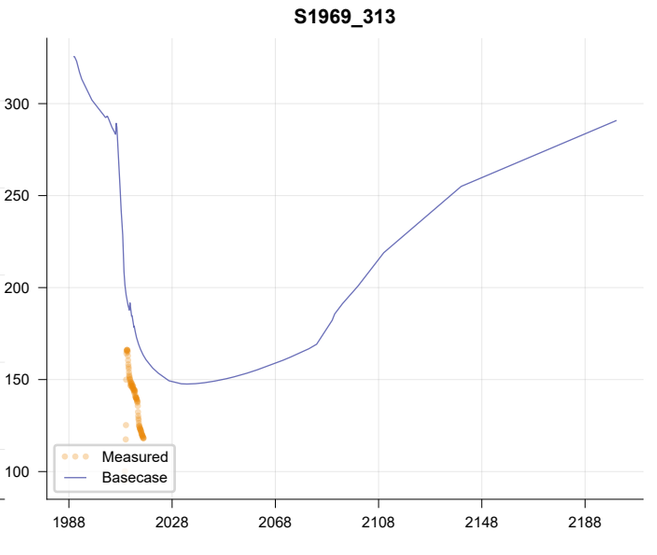

S1969_200
Groundwater...level...(mAHD)
Year
Measured
Basecase

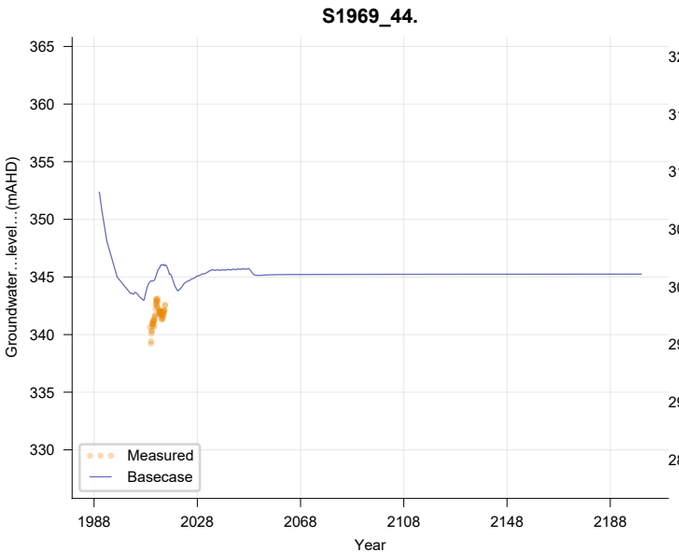

S1969_217
Measured
Basecase

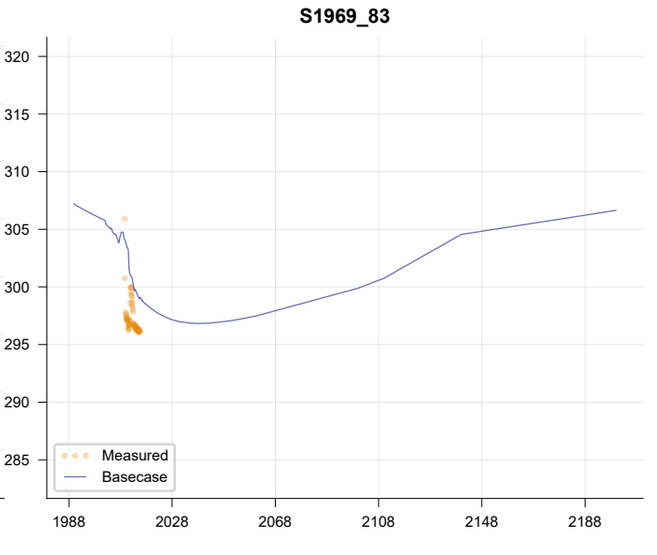

S1969_235
Groundwater...level...(mAHD)
Year
Measured
Basecase

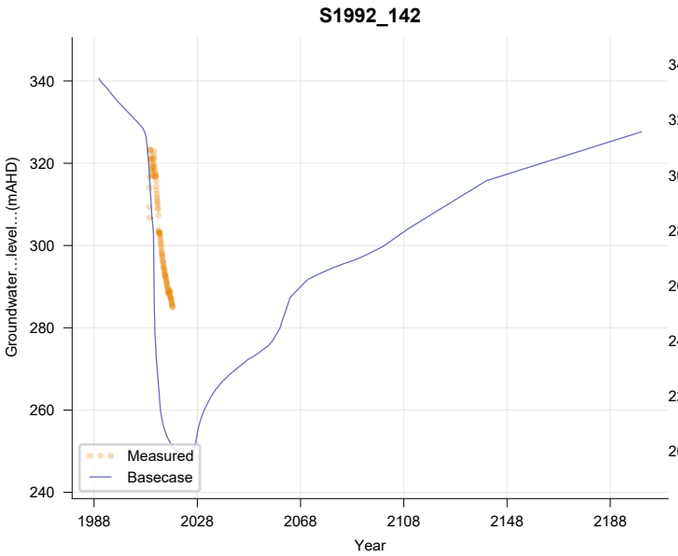

S1969_24.
Measured
Basecase

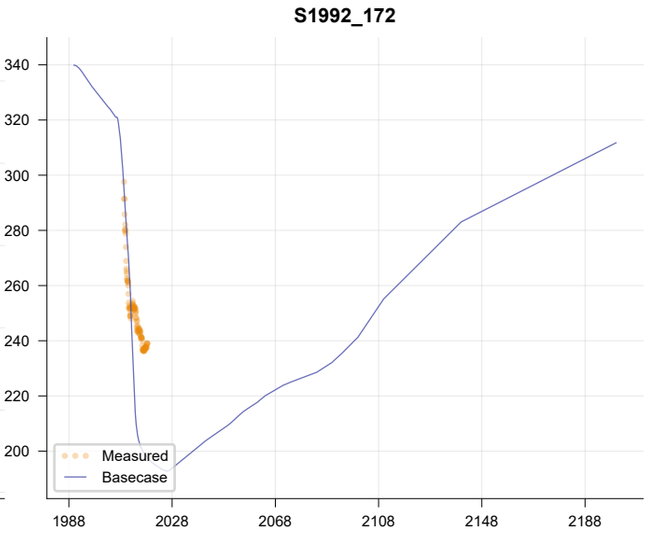

S1969_285
Groundwater...level...(mAHD)
300
250
200
150
100
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

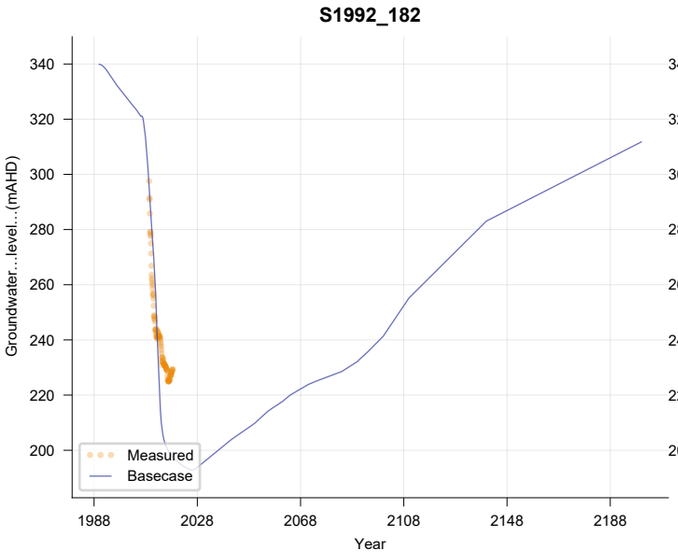

S1969_313
300
250
200
150
100
Measured
Basecase
1988
2028
2068
2108
2148
2188

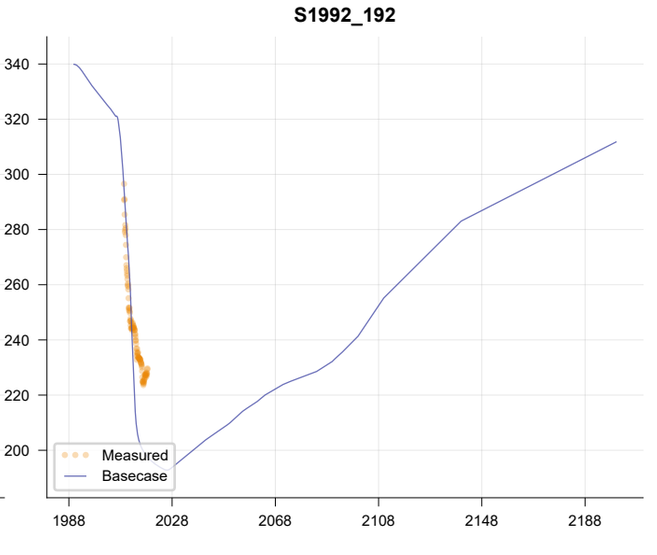

S1969_44.
Groundwater...level...(mAHD)
365
360
355
350
345
340
335
330
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

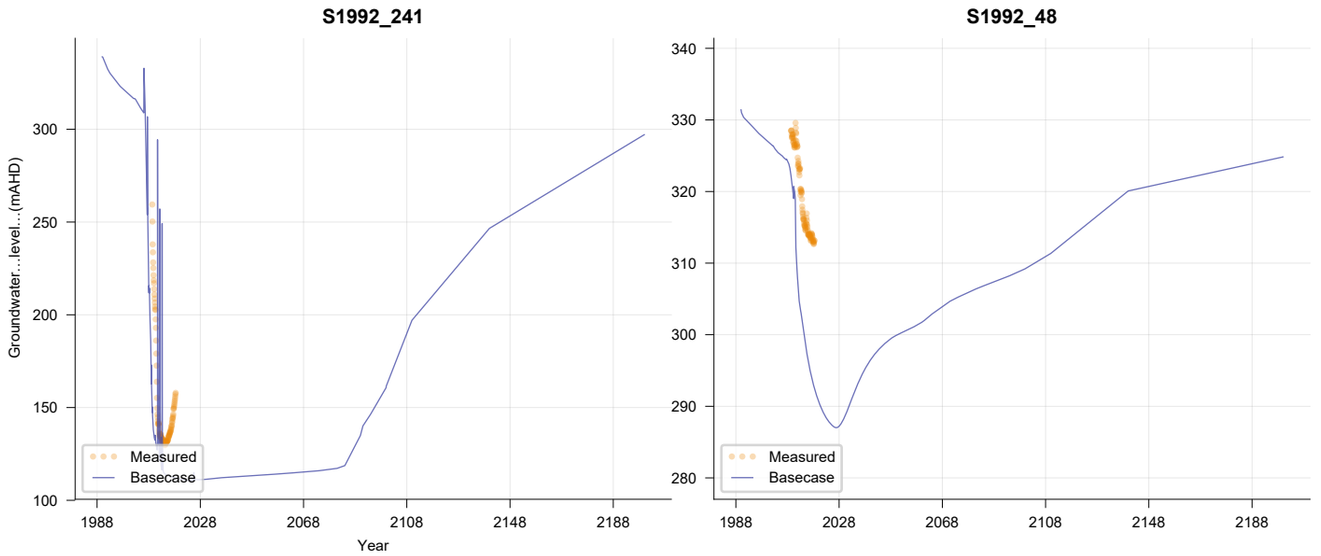

S1969_83
320
315
310
305
300
295
290
285
Measured
Basecase
1988
2028
2068
2108
2148
2188


S1992_142
Groundwater...level...(mAHD)
340
320
300
280
260
240
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

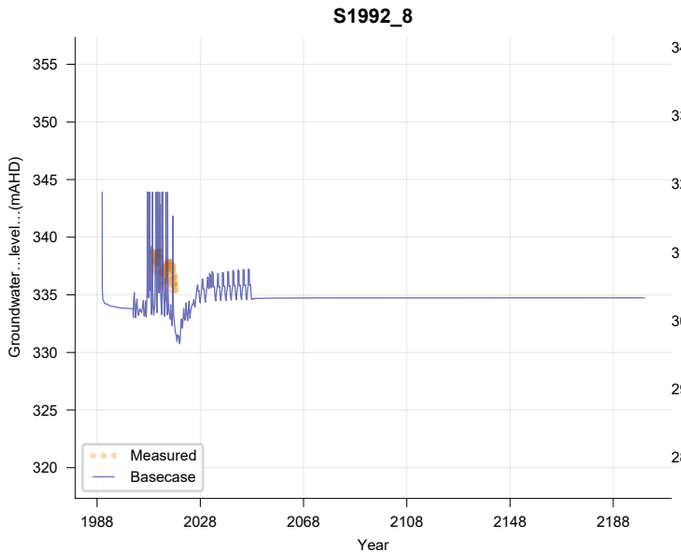

S1992_172
340
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188

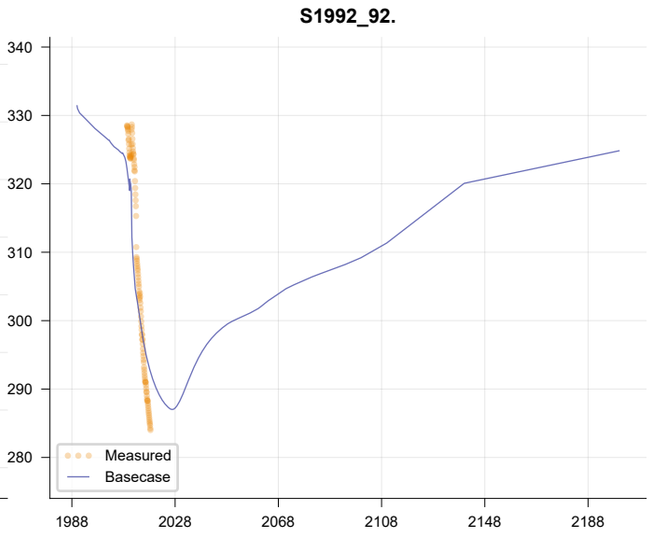

S1992_182
Groundwater...level...(mAHD)
340
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

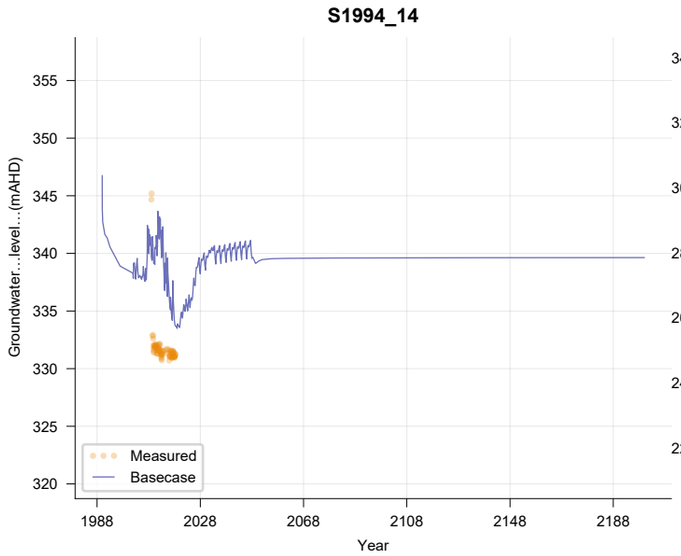

S1992_192
340
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188

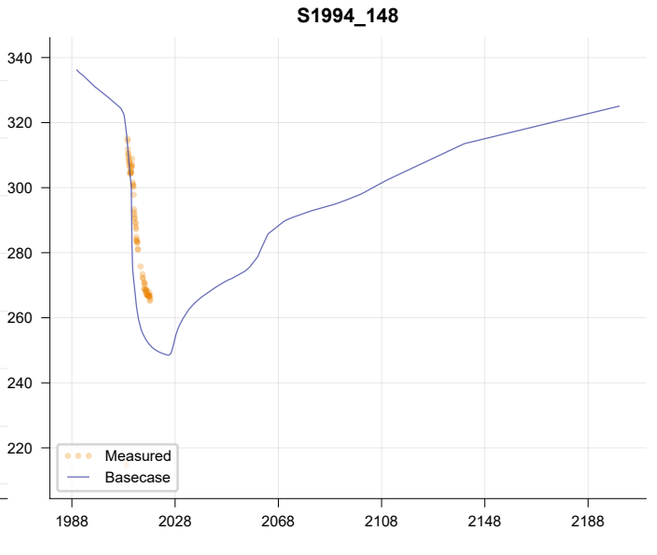

S1992_241
Groundwater...level...(mAHD)
Year
Measured
Basecase

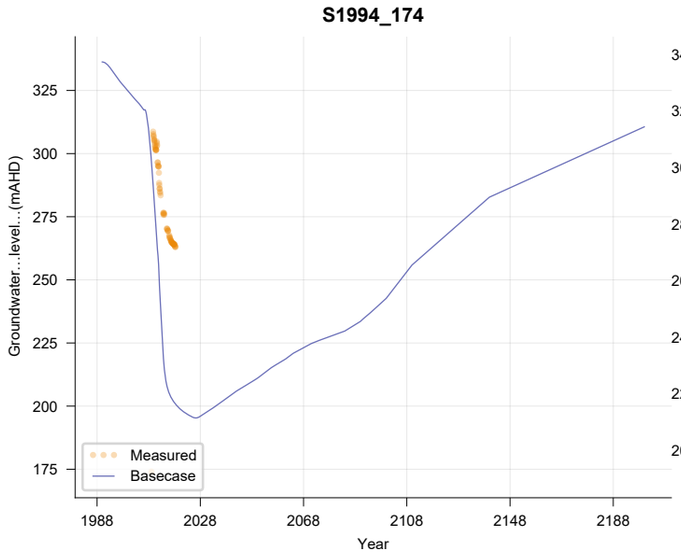

S1992_48
Measured
Basecase

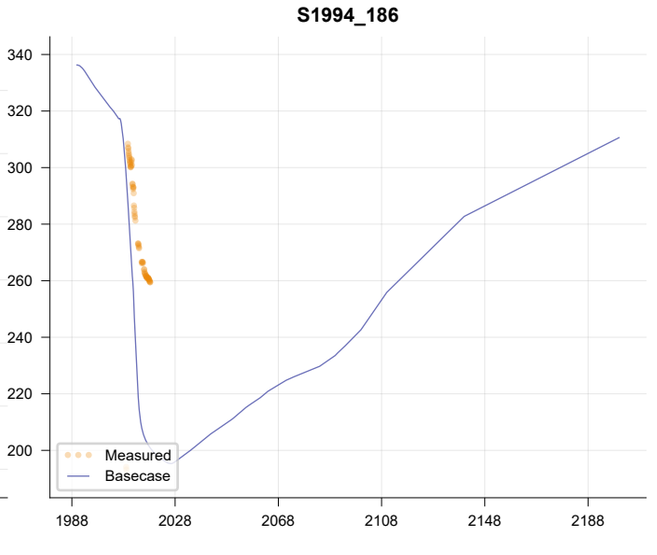

S1992_8
Groundwater...level...(mAHD)
Year
Measured
Basecase

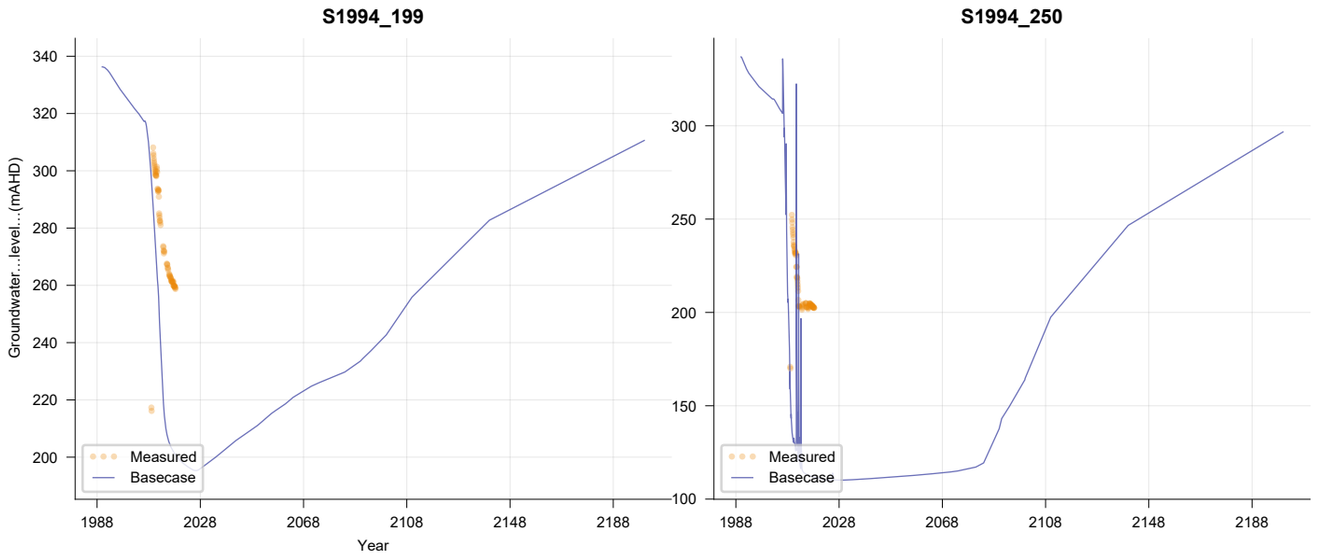

S1992_92.
Measured
Basecase


S1994_14
Groundwater...level...(mAHD)
Year
Measured
Basecase

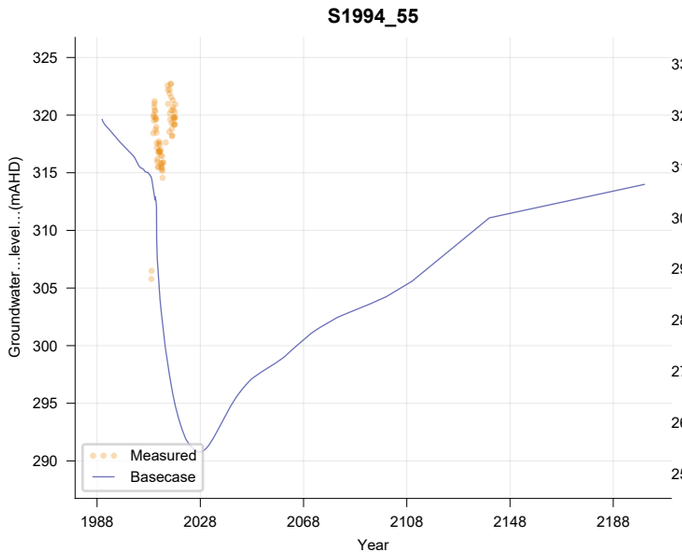

S1994_148
Measured
Basecase

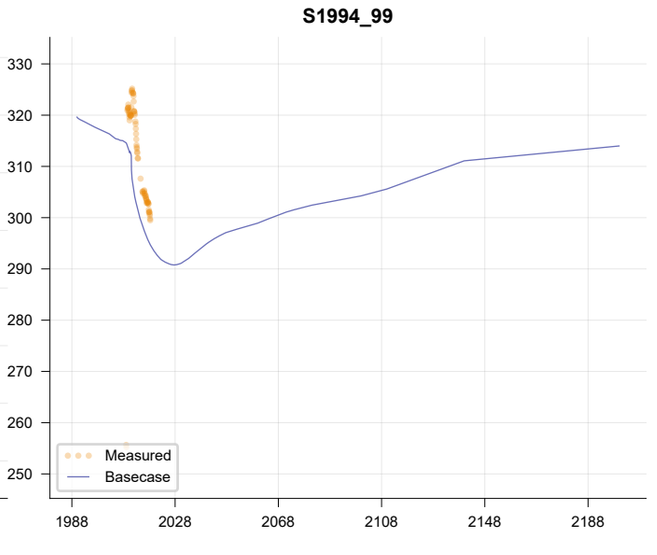

S1994_174
Groundwater...level...(mAHD)
Year
Measured
Basecase

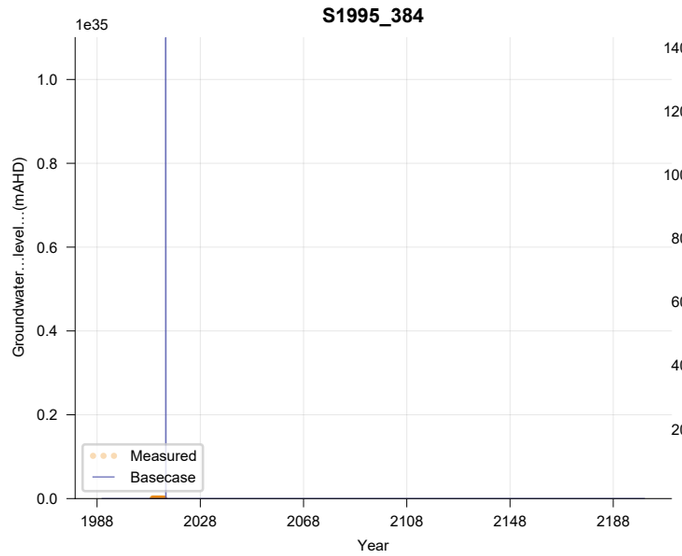

S1994_186
Measured
Basecase

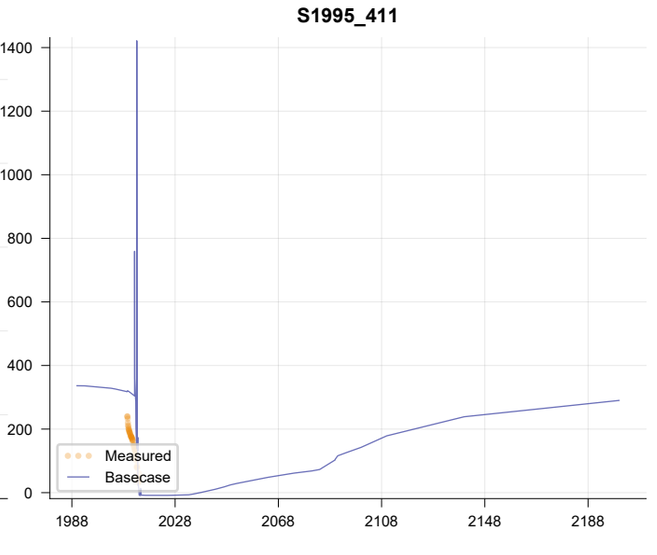

S1994_199
Groundwater...level...(mAHD)
Year
Measured
Basecase

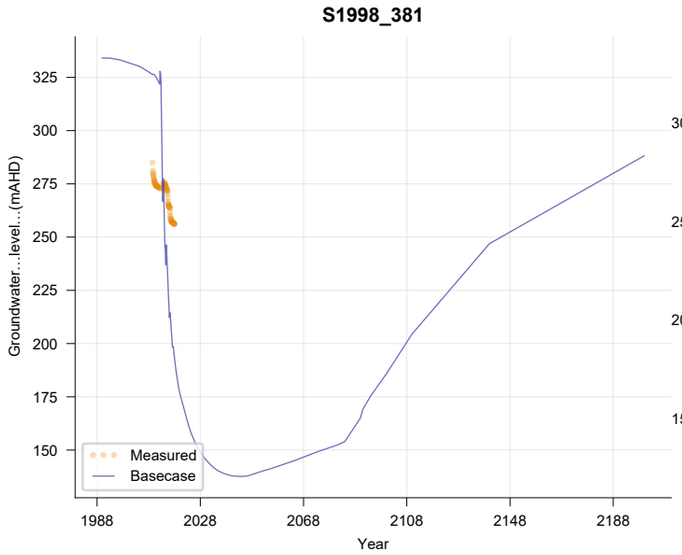

S1994_250
Measured
Basecase

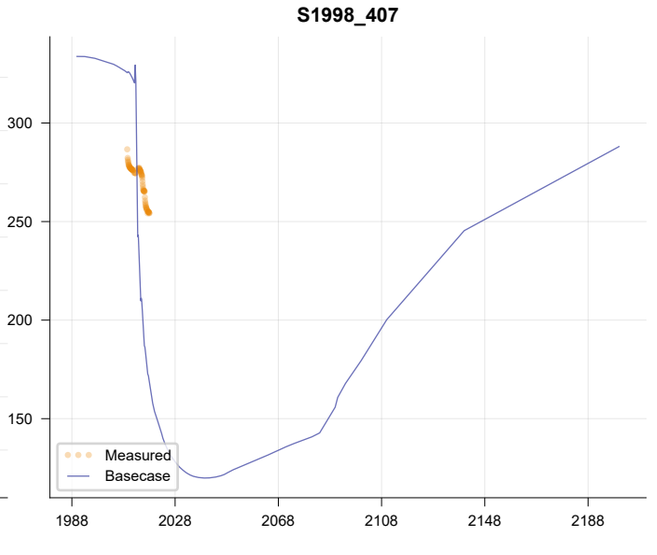

S1994_55
Groundwater...level...(mAHD)
Year
Measured
Basecase

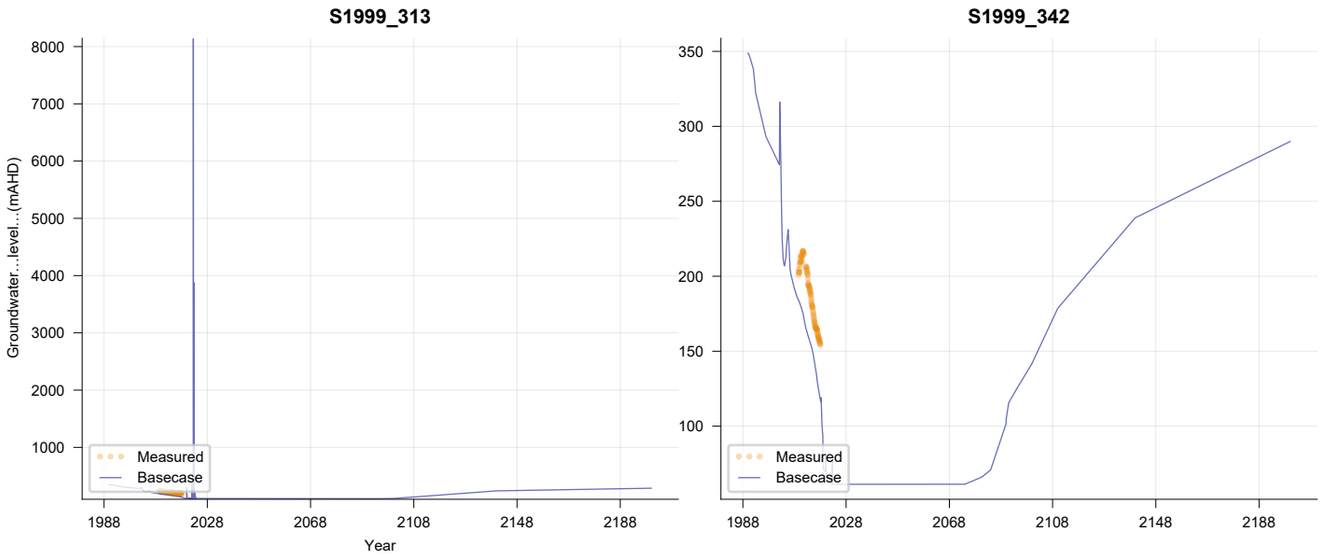

S1994_99
Measured
Basecase


S1995_384
1e35
Groundwater...level...(mAHD)
Year
Measured
Basecase

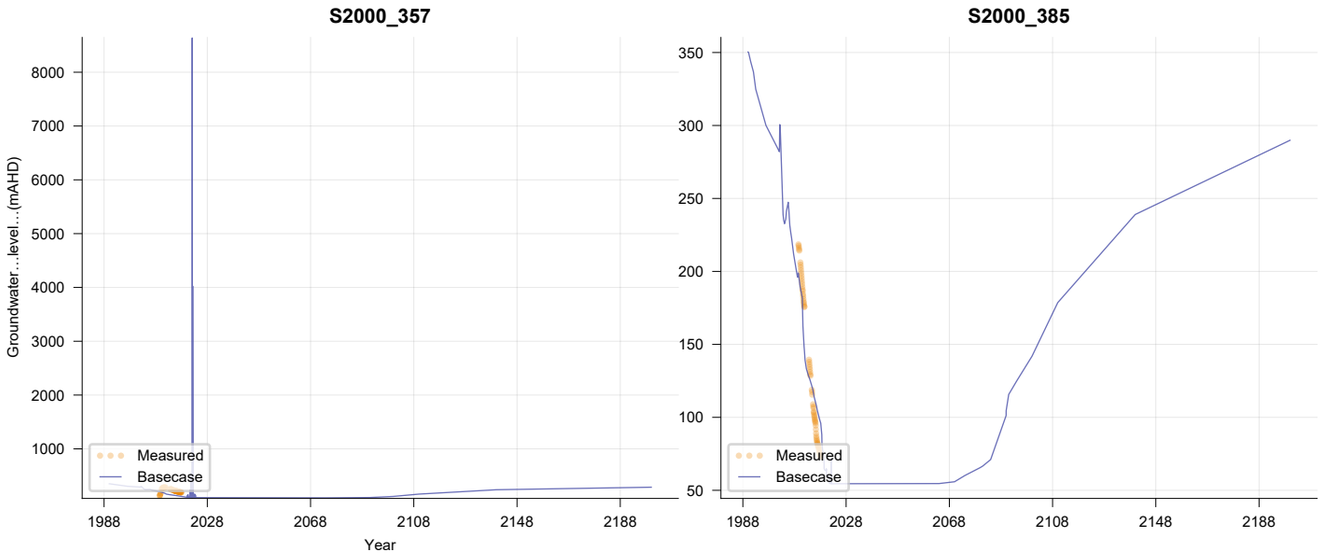

S1995_411
Measured
Basecase


S1998_381
Groundwater...level...(mAHD)
Year
Measured
Basecase

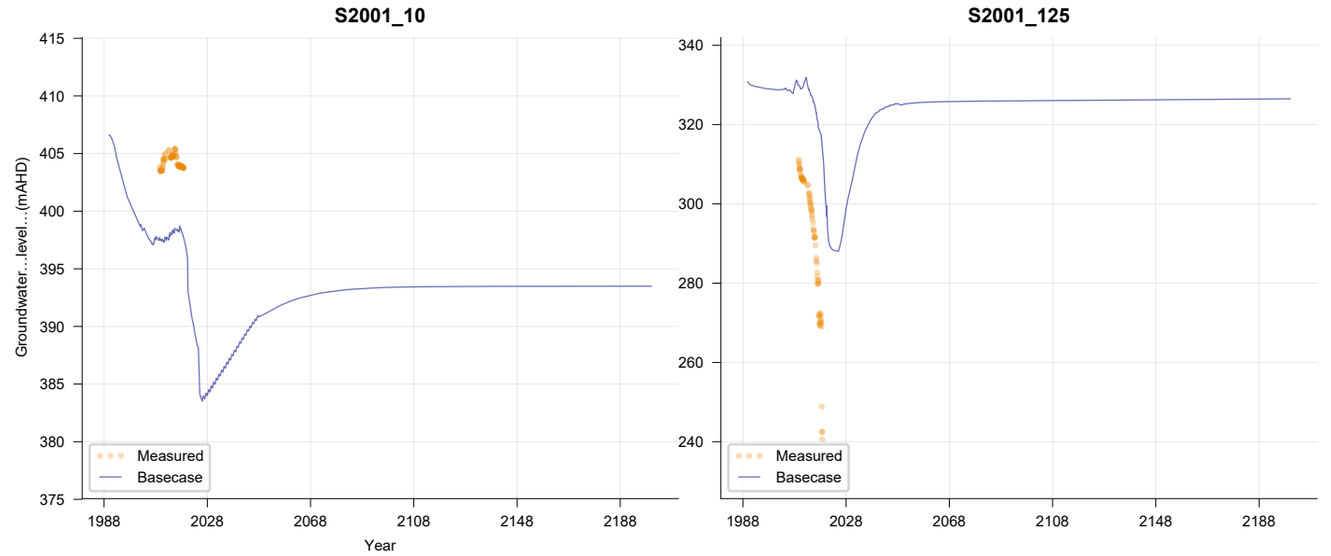

S1998_407
Measured
Basecase


S1999_313
Groundwater...level...(mAHD)
8000
7000
6000
5000
4000
3000
2000
1000
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

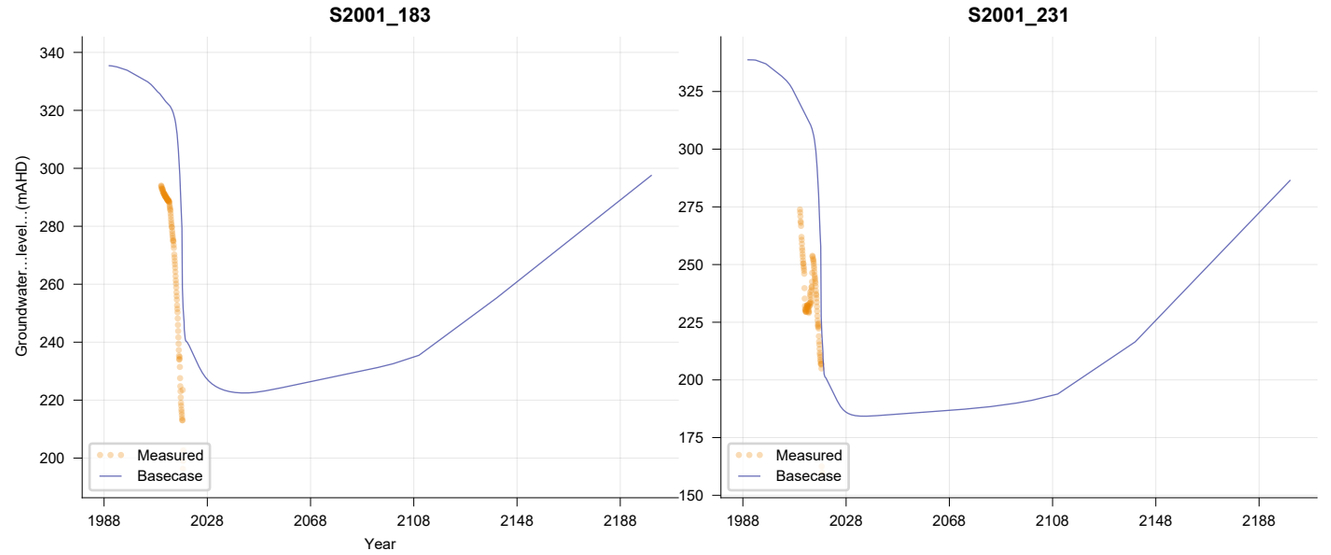

S1999_342
350
300
250
200
150
100
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2000_357
Groundwater...level...(mAHD)
8000
7000
6000
5000
4000
3000
2000
1000
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

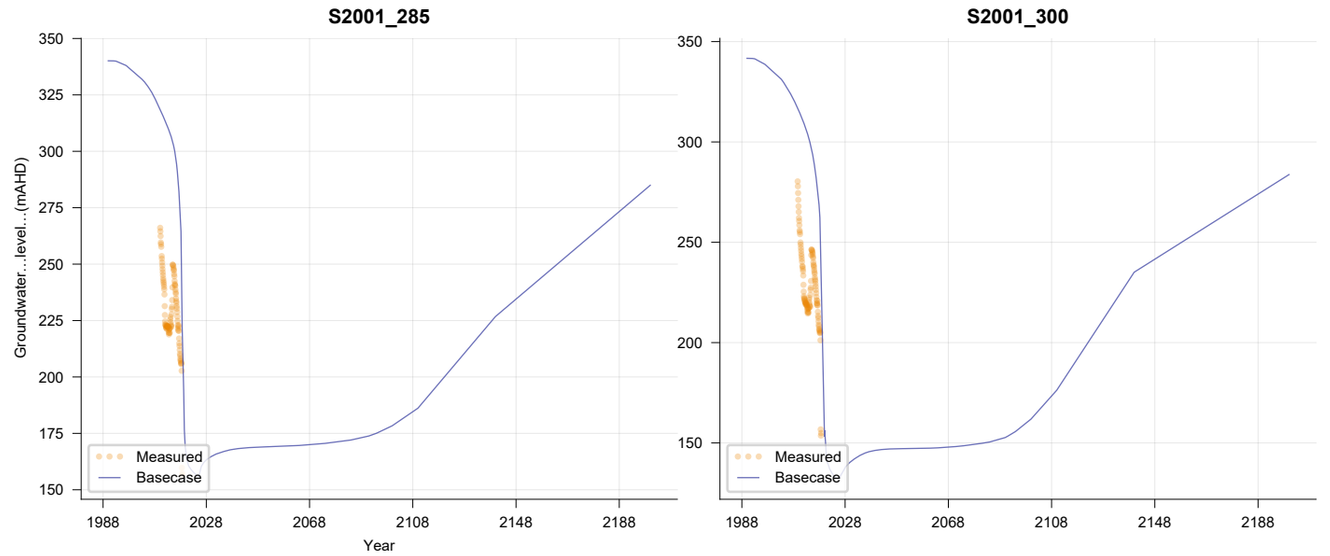

S2000_385
350
300
250
200
150
100
50
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2001_10
Groundwater...level...(mAHD)
415
410
405
400
395
390
385
380
375
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

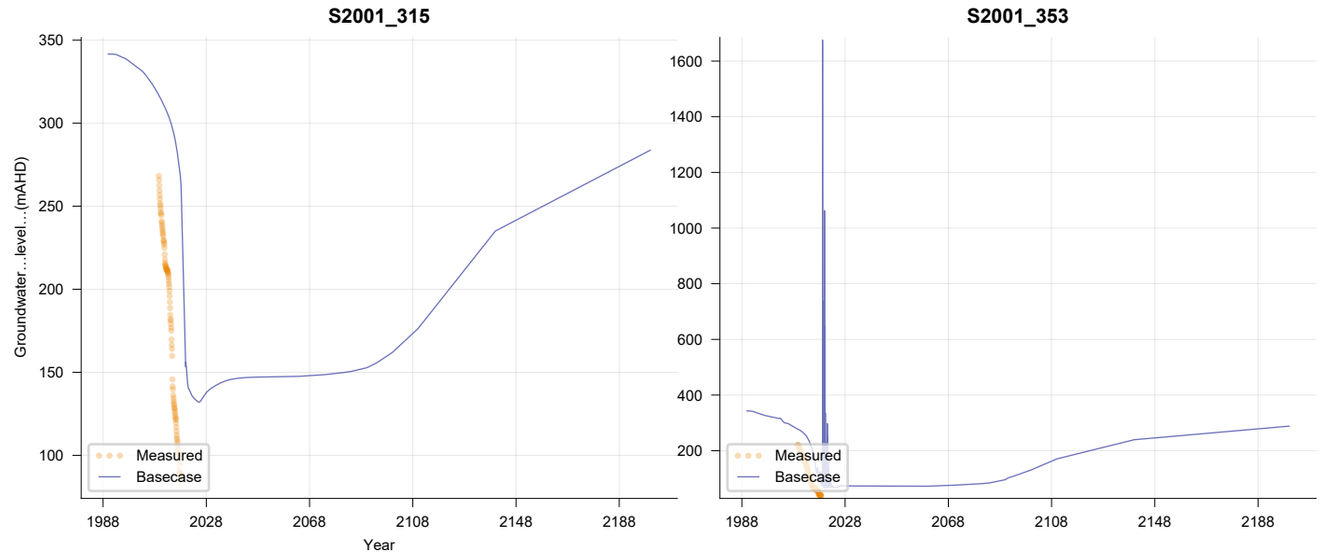

S2001_125
340
320
300
280
260
240
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2001_183
Groundwater...level...(mAHD)
340
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

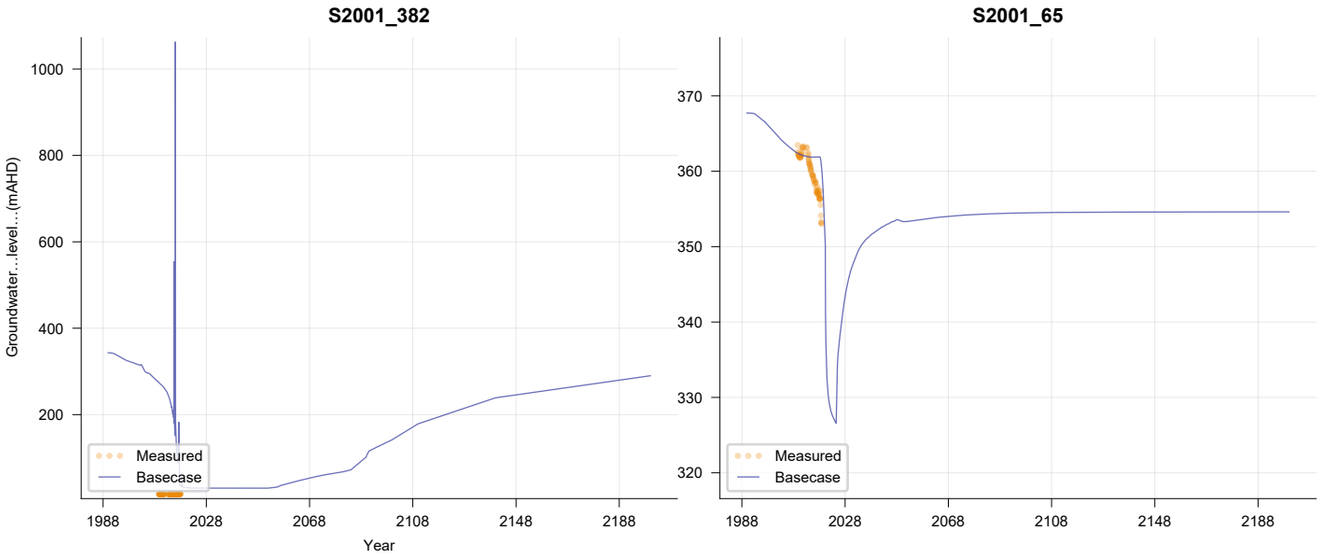

S2001_231
325
300
275
250
225
200
175
150
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2001_285
Groundwater...level...(mAHD)
Year
Measured
Basecase

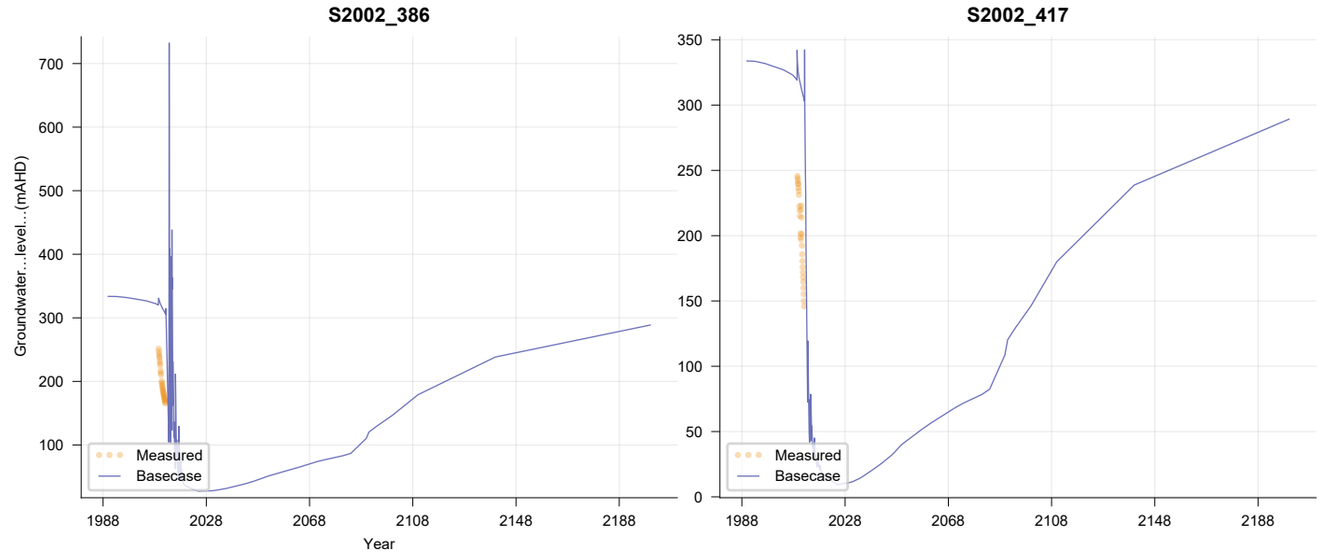

S2001_300
Measured
Basecase


S2001_315
Groundwater...level...(mAHD)
Year
Measured
Basecase


S2001_353
Measured
Basecase

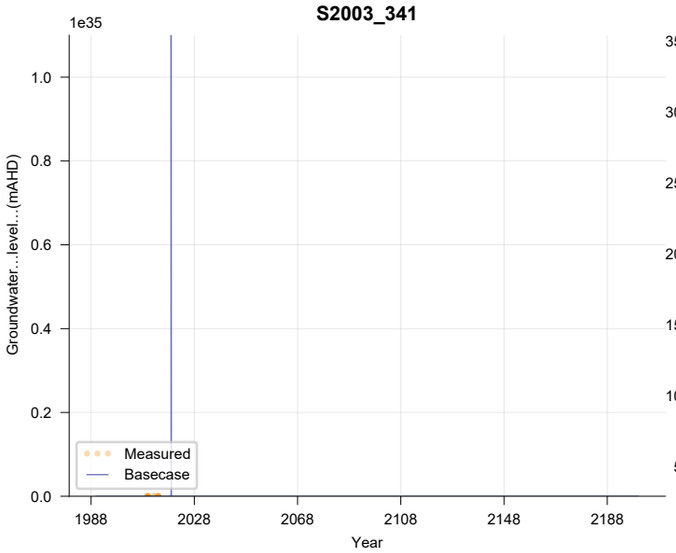

S2001_382
Groundwater...level...(mAHD)
Year
Measured
Basecase


S2001_65
Measured
Basecase

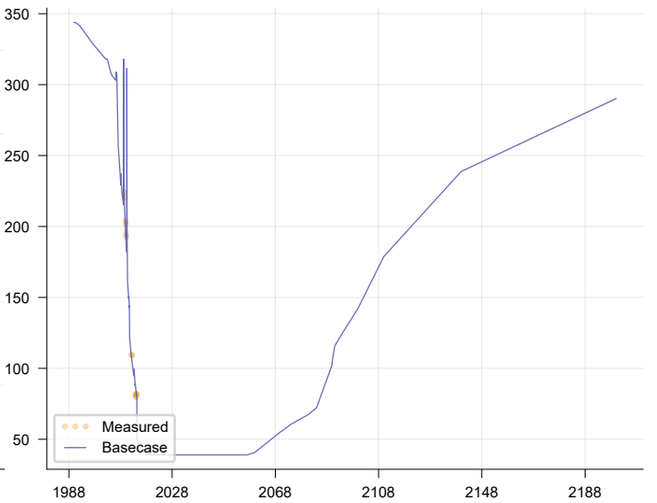

S2002_386
Groundwater...level...(mAHD)
Year
Measured
Basecase


S2002_417
Measured
Basecase

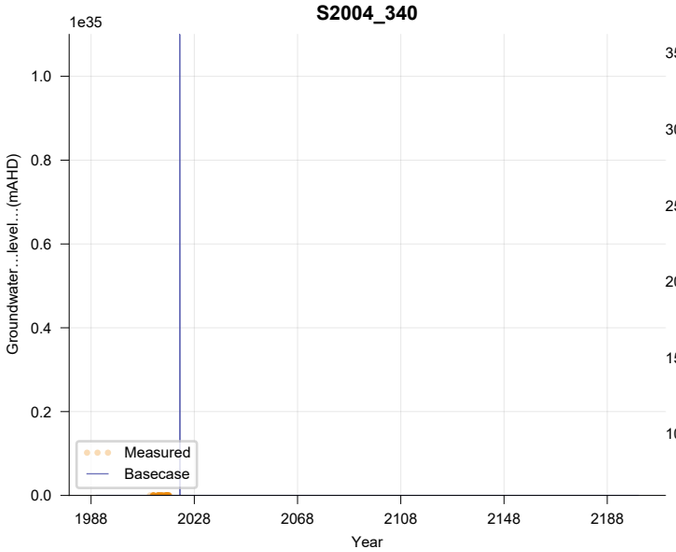
## S2003_341



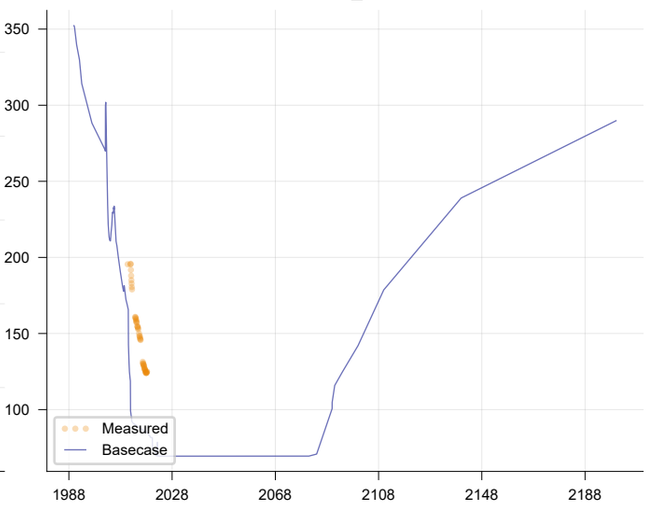

## S2003_368



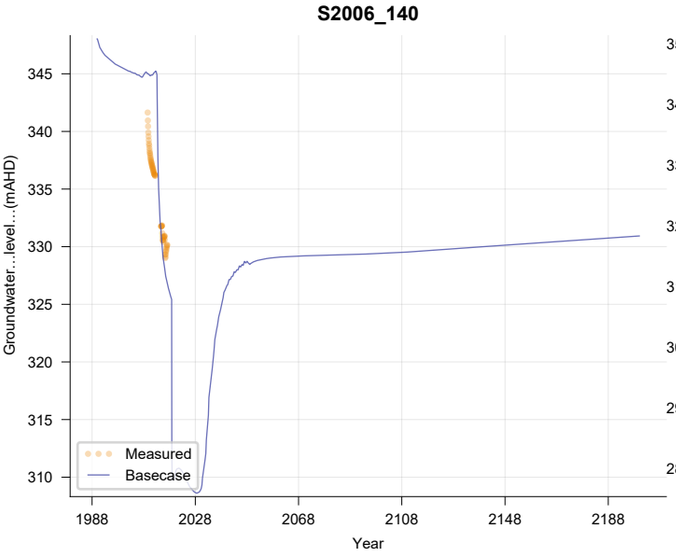

## S2004_340



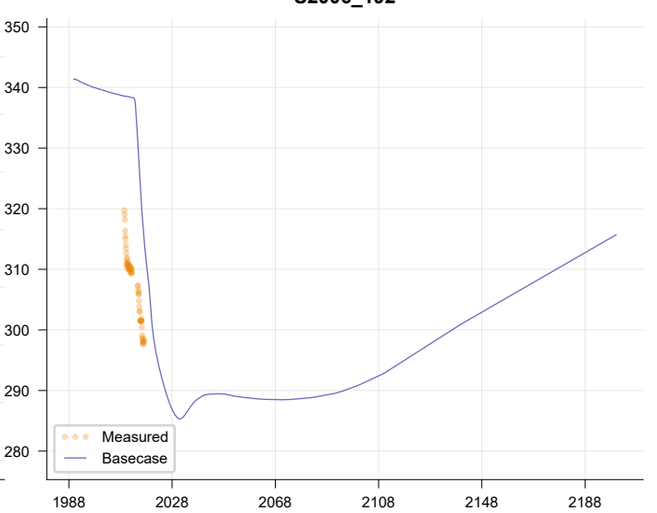

## S2004_372



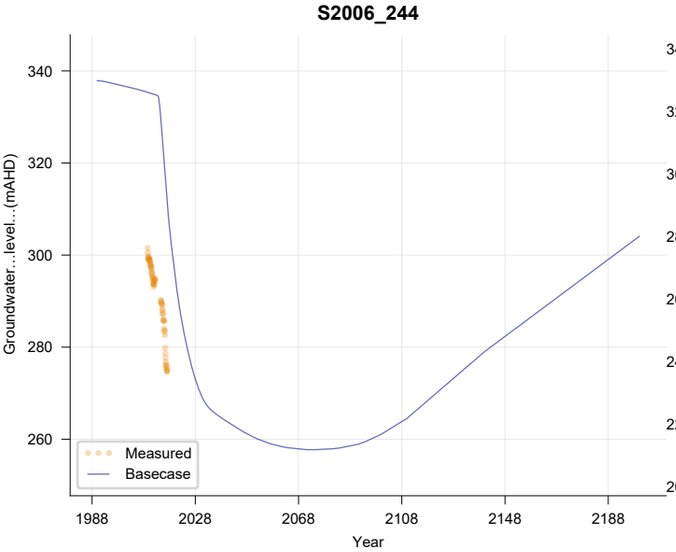

## S2006_140



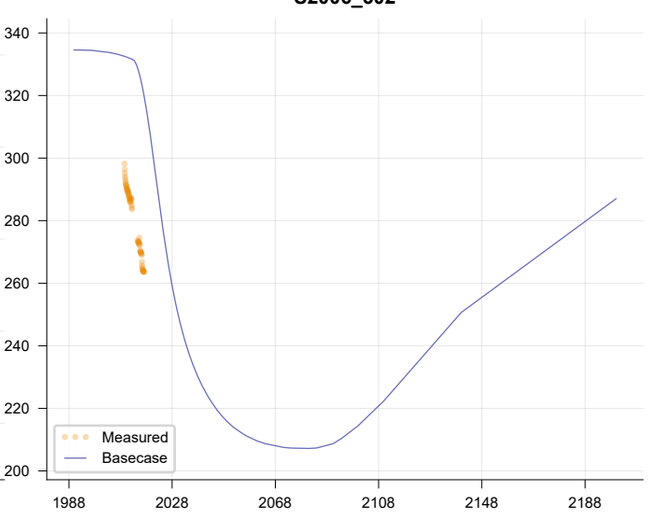

## S2006_192

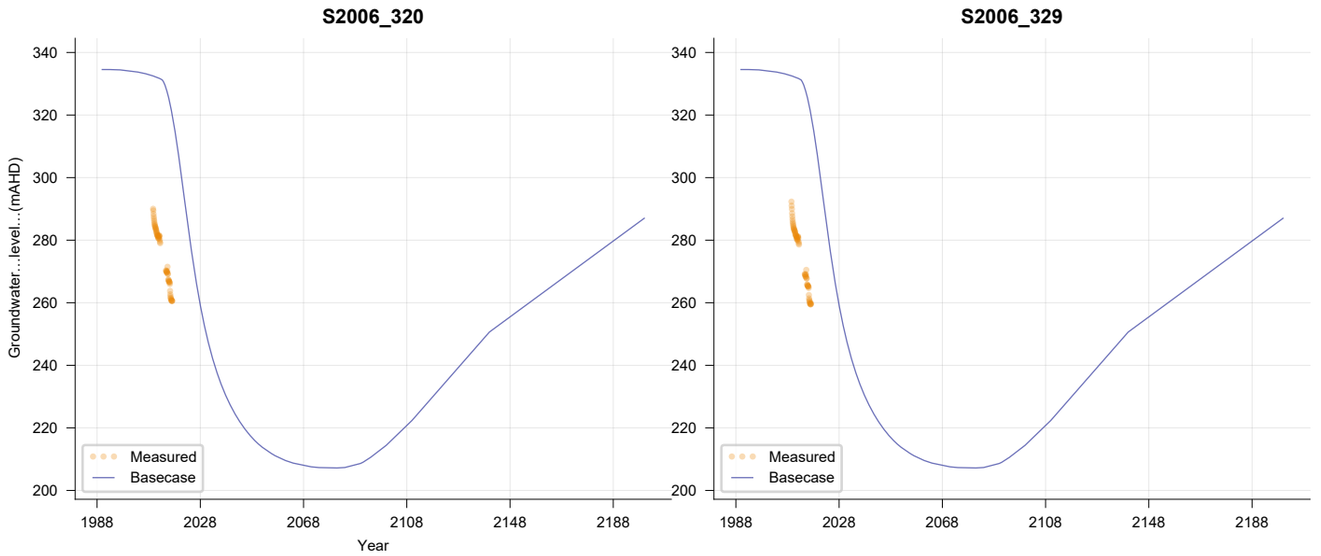



## S2006_244

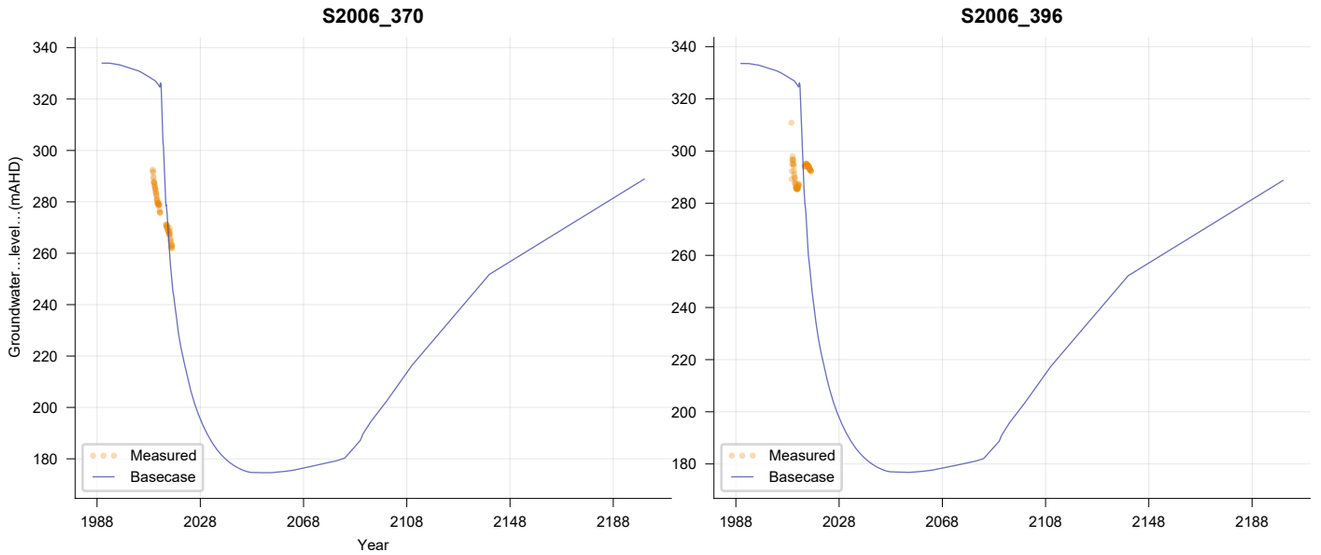



## S2006_302

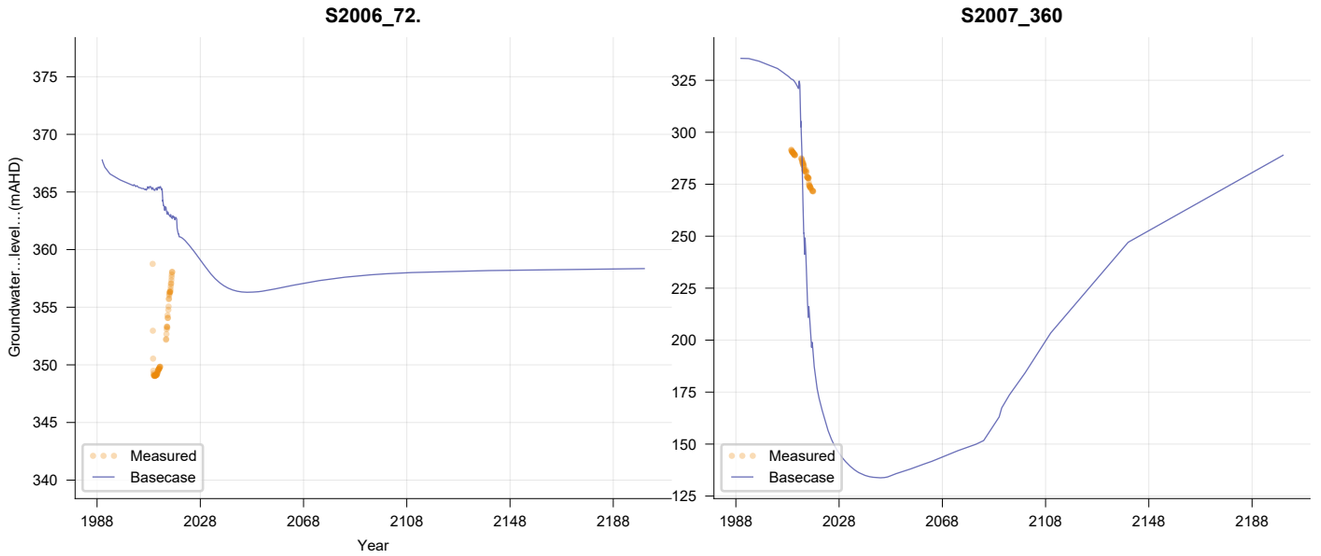



S2006_320
Groundwater...level...(mAHD)
Year
Measured
Basecase

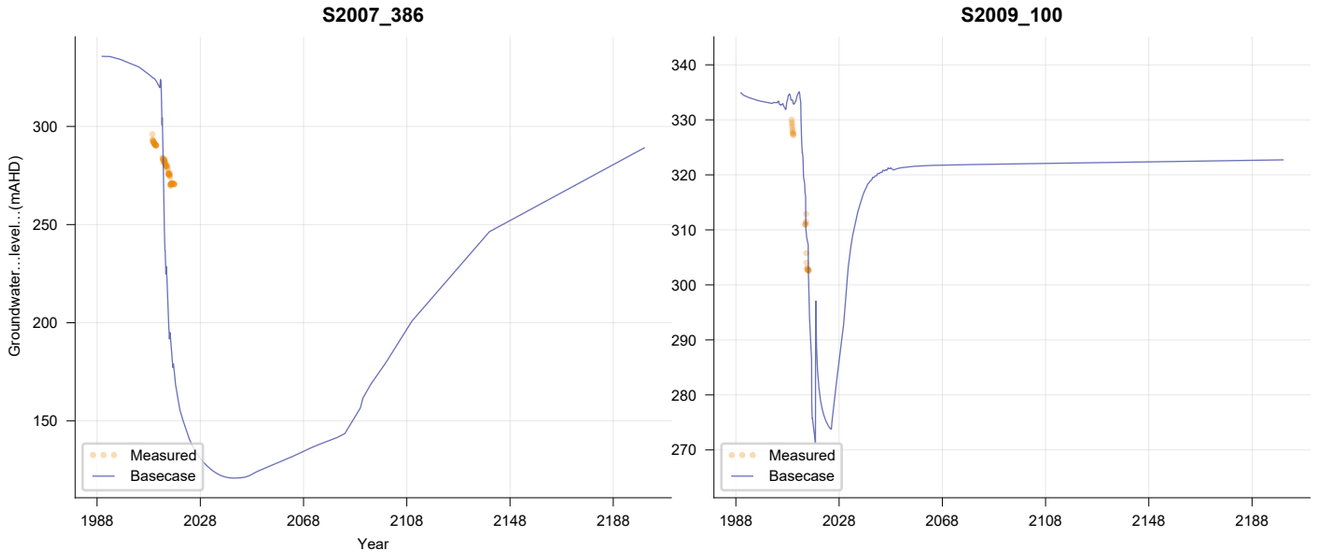

S2006_329
Measured
Basecase


S2006_370
Groundwater...level...(mAHD)
Year
Measured
Basecase

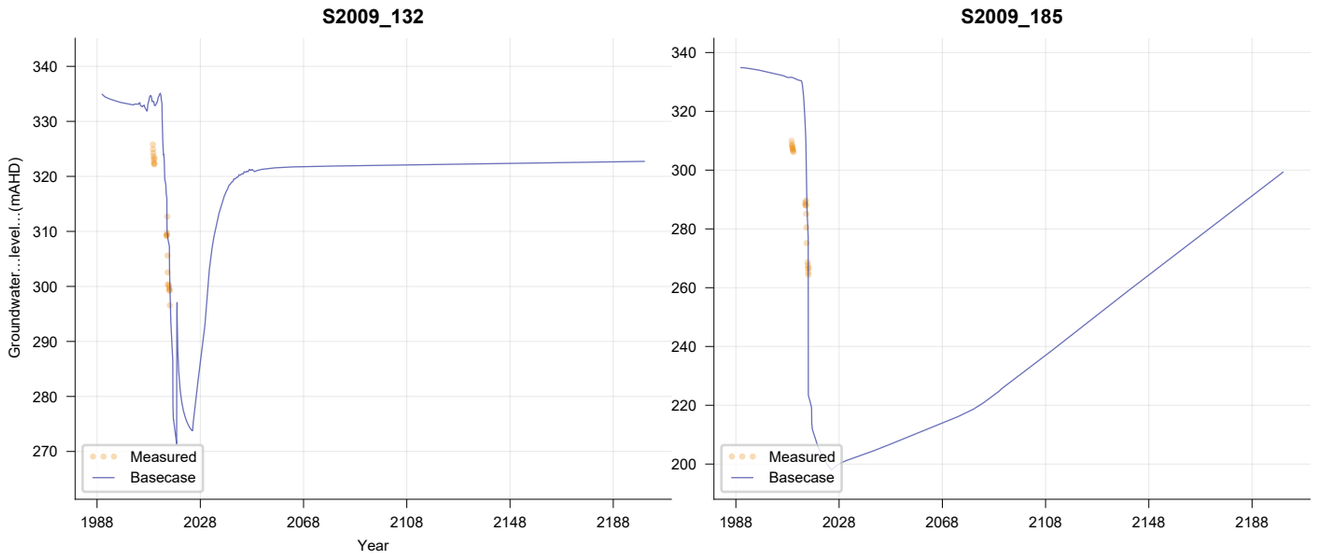

S2006_396
Measured
Basecase


S2006_72.
Groundwater...level...(mAHD)
Year
Measured
Basecase

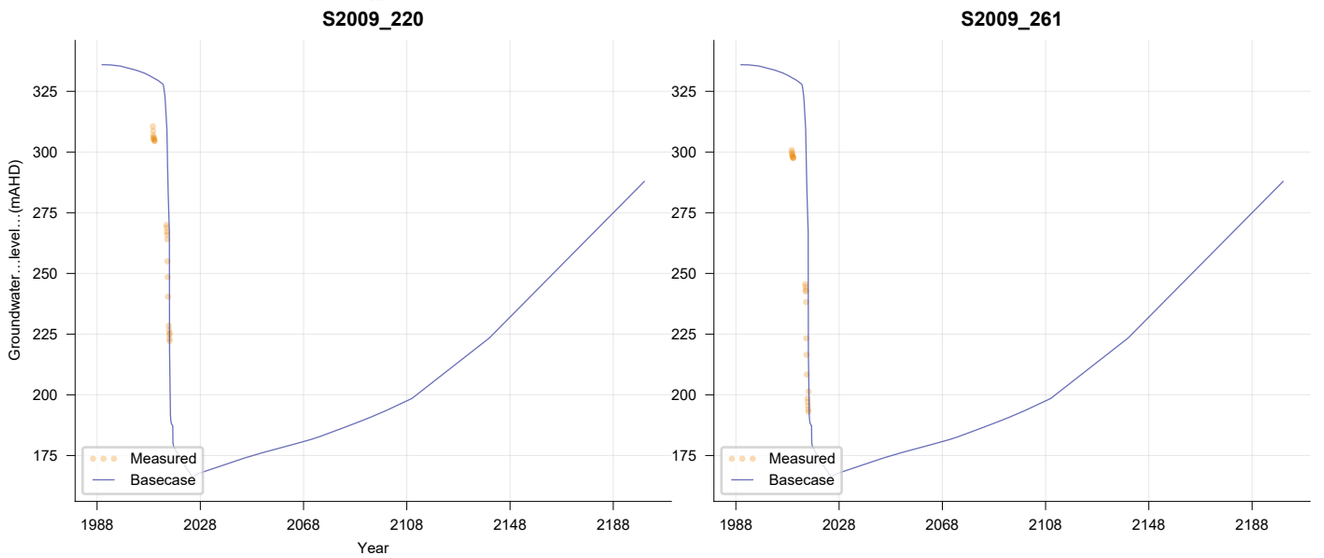

S2007_360
Measured
Basecase


S2007_386
Groundwater...level...(mAHD)
Year
Measured
Basecase

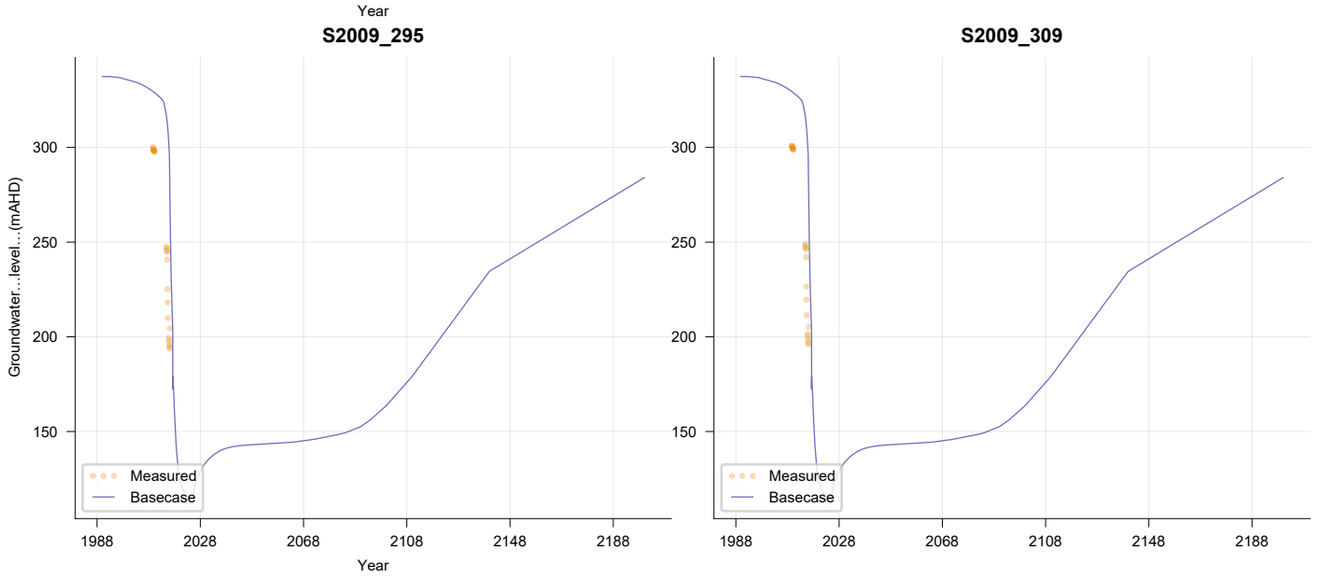

S2009_100
Measured
Basecase


S2009_132
Groundwater...level...(mAHD)
340
330
320
310
300
290
280
270
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

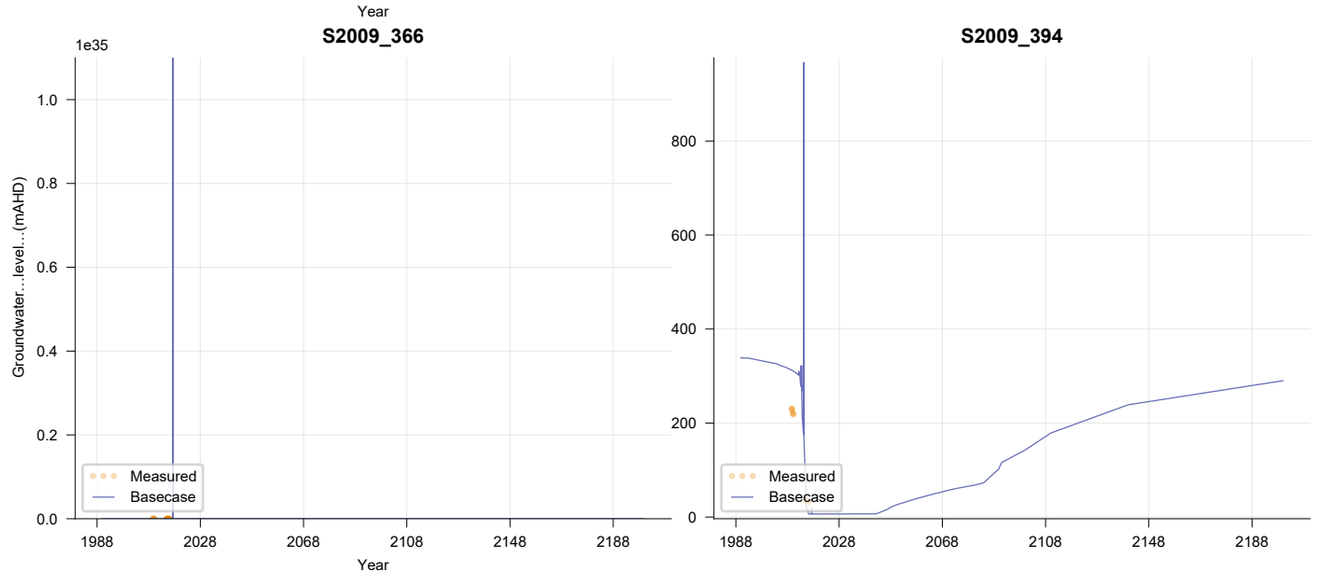

S2009_185
340
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2009_220
Groundwater...level...(mAHD)
325
300
275
250
225
200
175
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

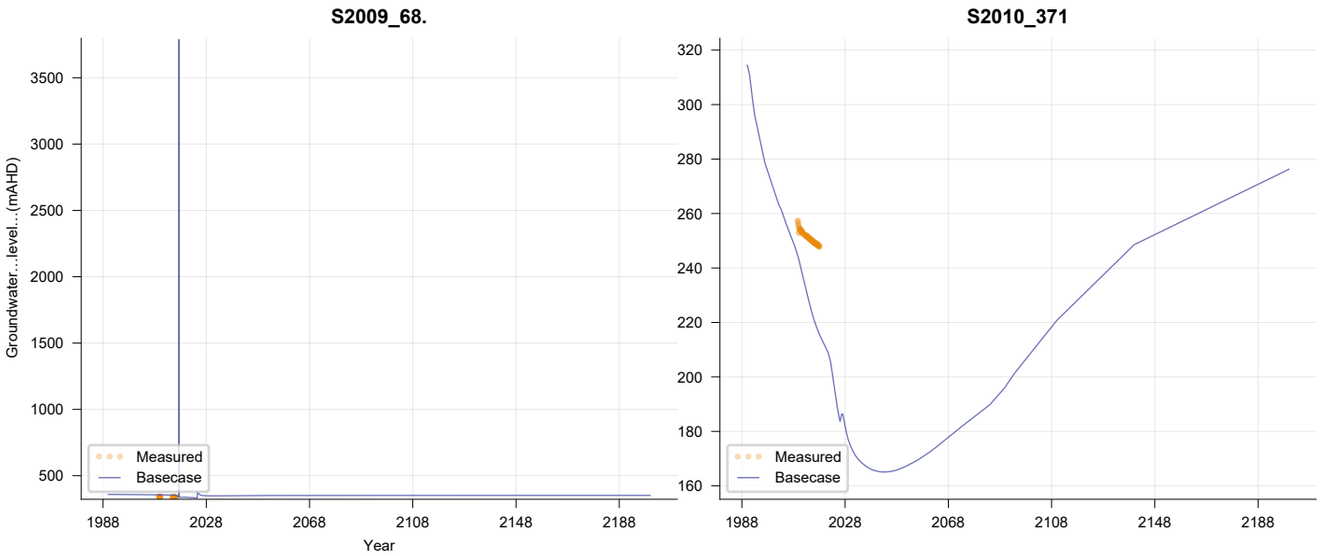

S2009_261
325
300
275
250
225
200
175
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2009_295
Groundwater...level...(mAHD)
300
250
200
150
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

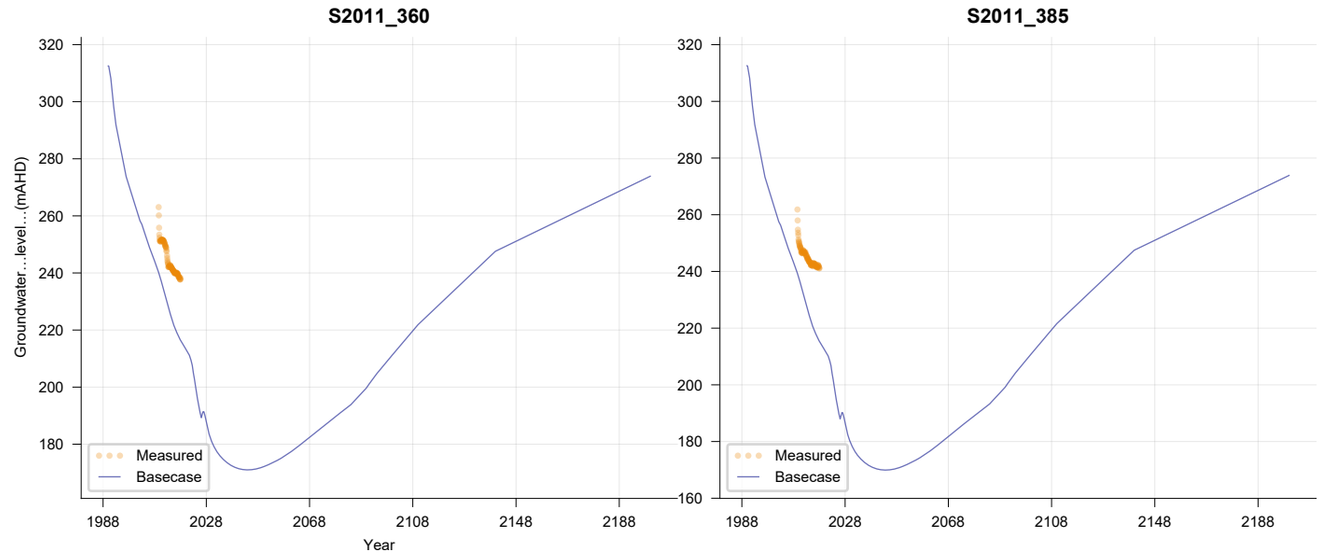

S2009_309
300
250
200
150
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2009_366
1e35
Groundwater...level...(mAHD)
1.0
0.8
0.6
0.4
0.2
0.0
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

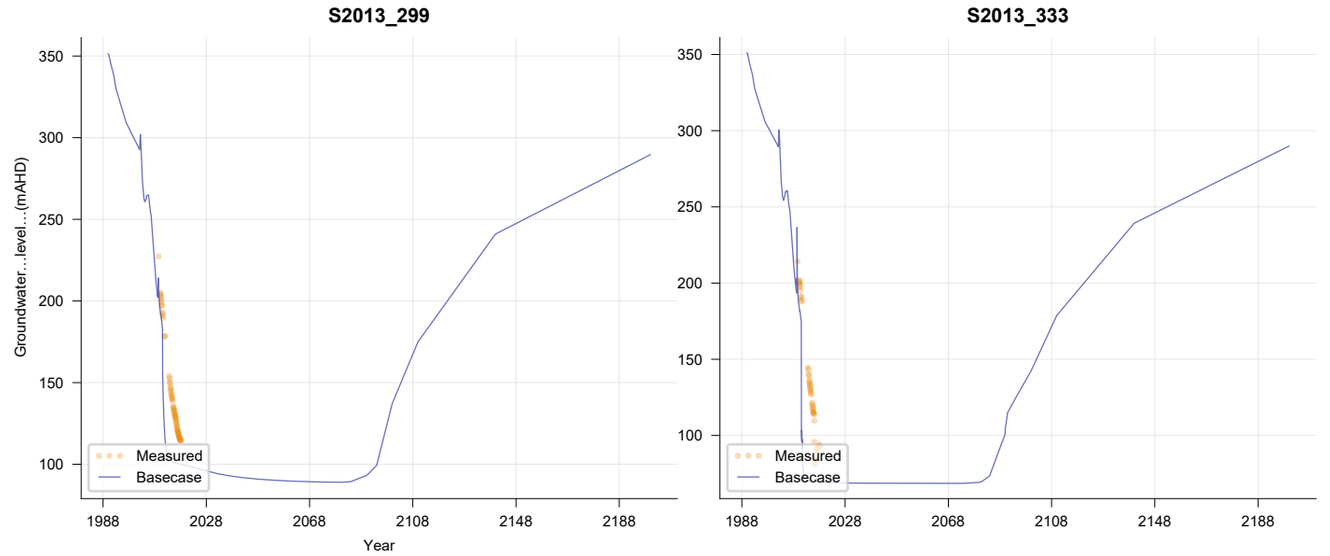

S2009_394
800
600
400
200
0
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2009_68.
Groundwater...level...(mAHD)
Year
Measured
Basecase

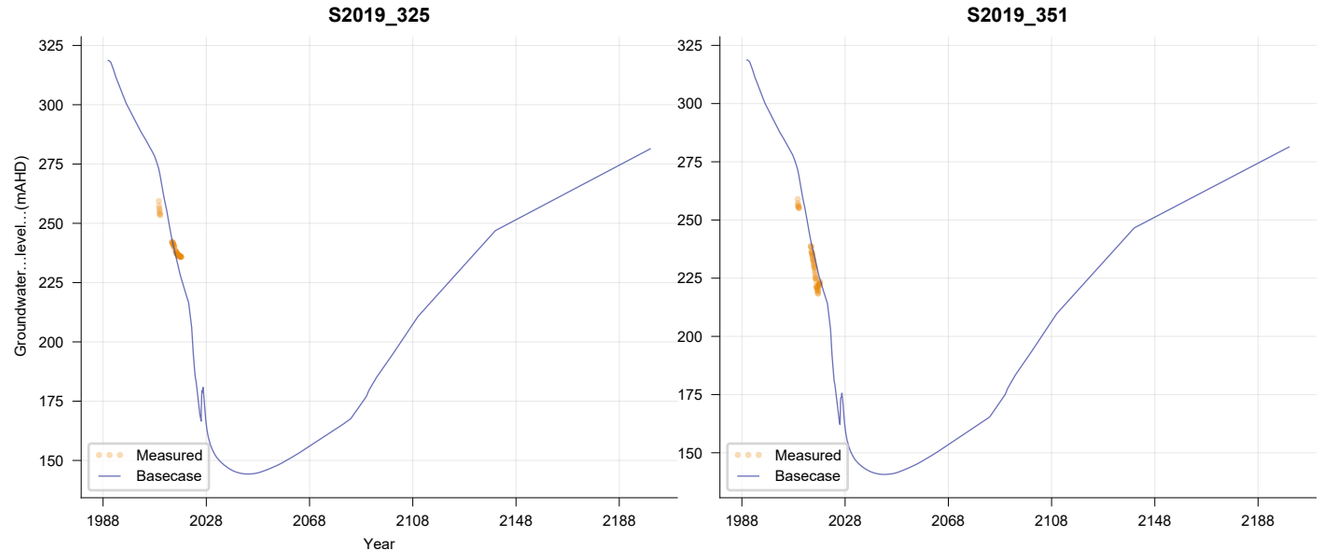

S2010_371
Measured
Basecase


S2011_360
Groundwater...level...(mAHD)
Year
Measured
Basecase

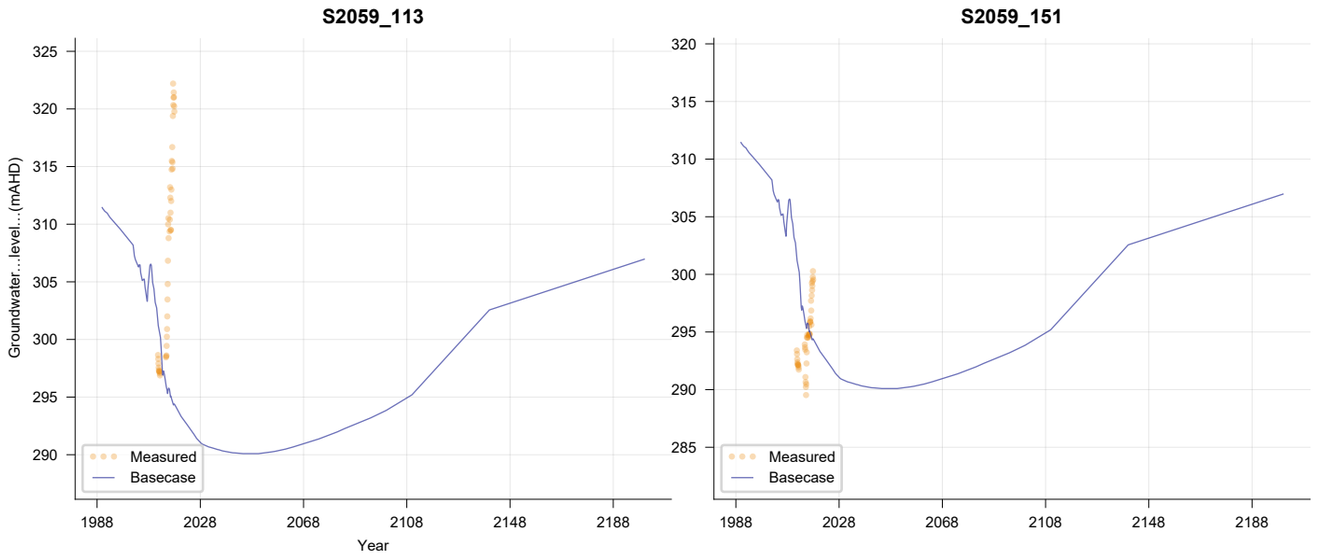

S2011_385
Measured
Basecase


S2013_299
Groundwater...level...(mAHD)
Year
Measured
Basecase

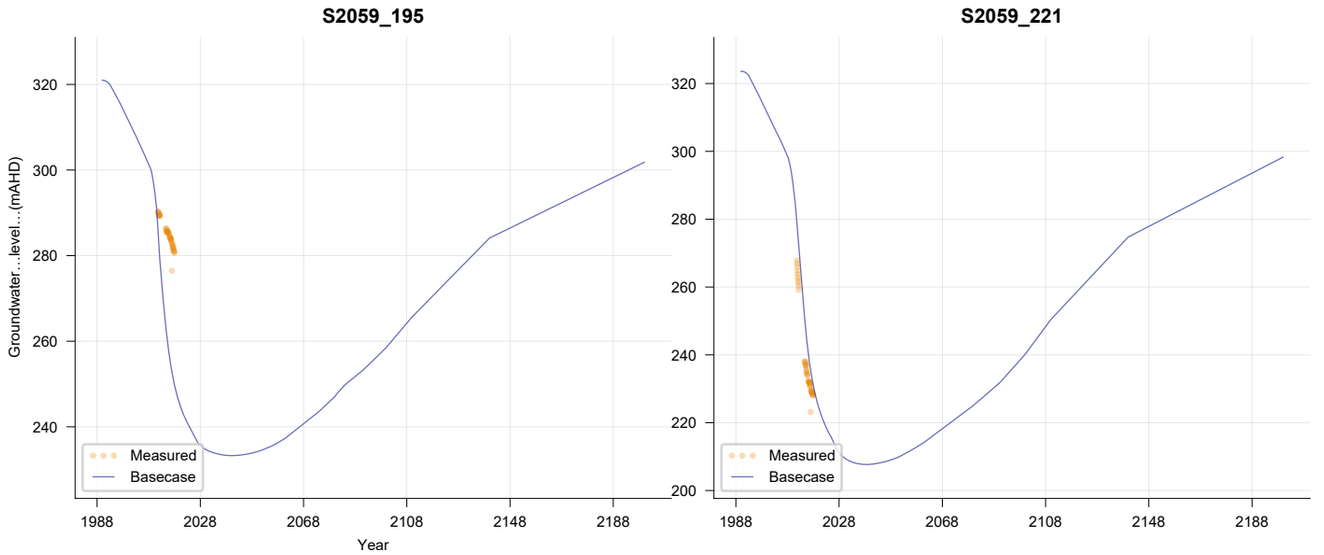

S2013_333
Measured
Basecase


S2019_325
Groundwater...level...(mAHD)
Year
Measured
Basecase

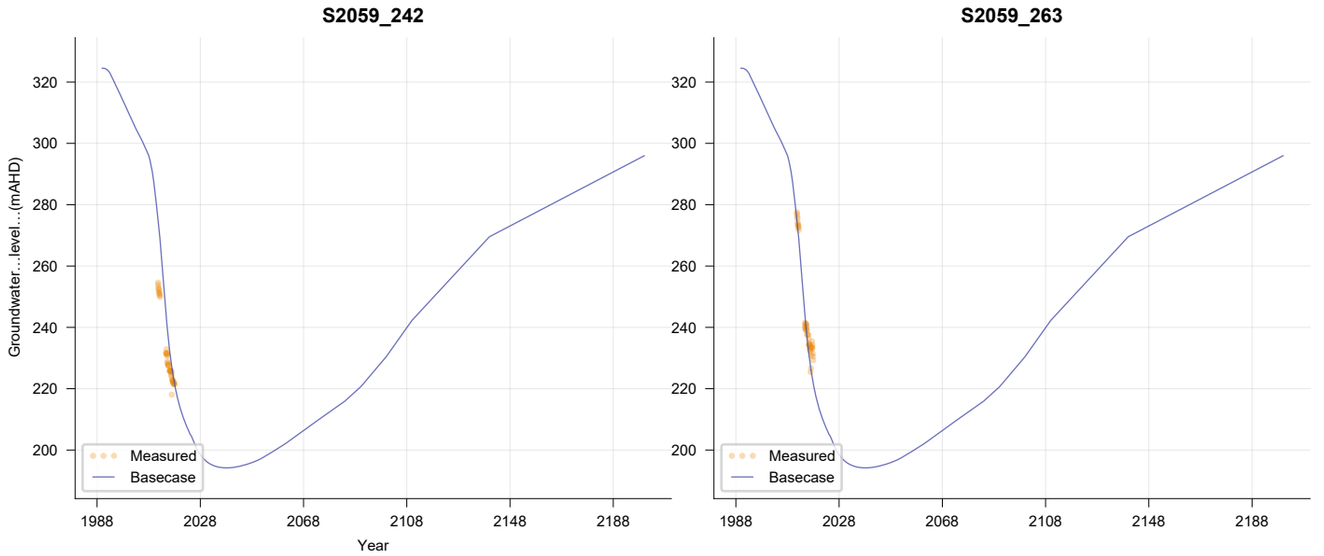

S2019_351
Measured
Basecase


S2059_113
Groundwater...level...(mAHD)
325
320
315
310
305
300
295
290
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

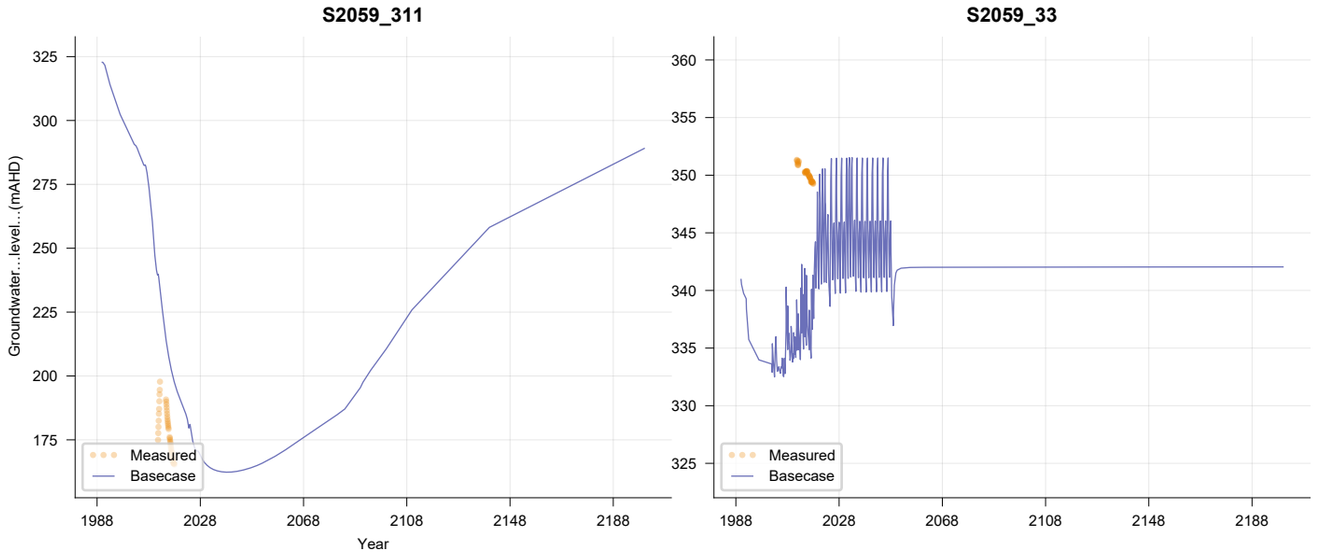

S2059_151
320
315
310
305
300
295
290
285
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2059_195
Groundwater...level...(mAHD)
320
300
280
260
240
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

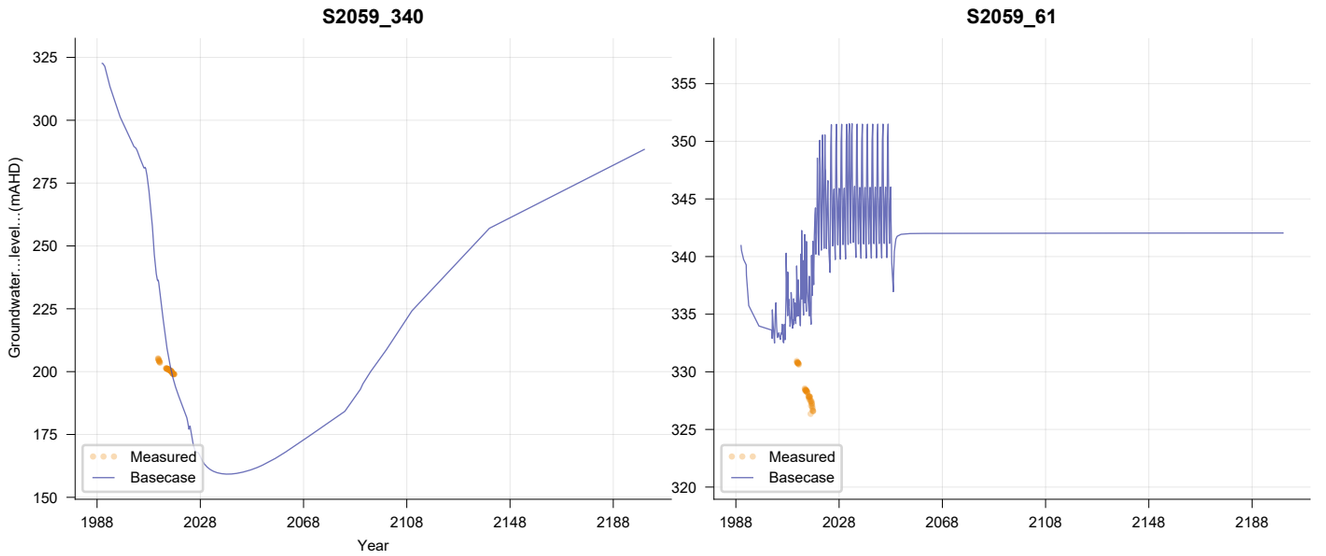

S2059_221
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2059_242
Groundwater...level...(mAHD)
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

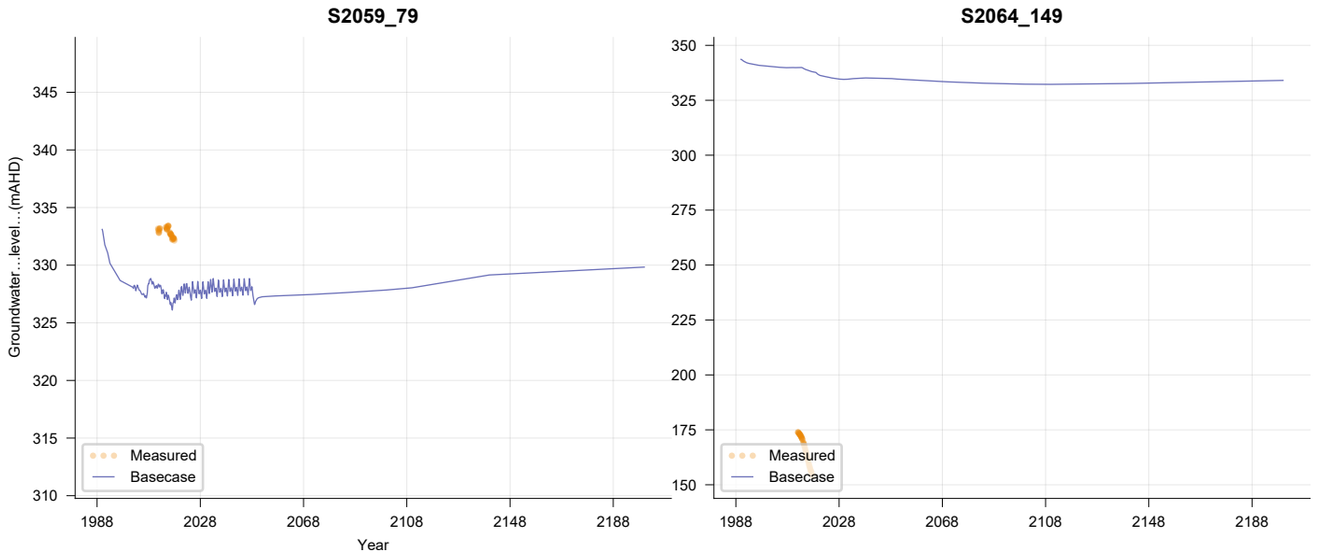

S2059_263
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2059_311
Groundwater...level...(mAHD)
325
300
275
250
225
200
175
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

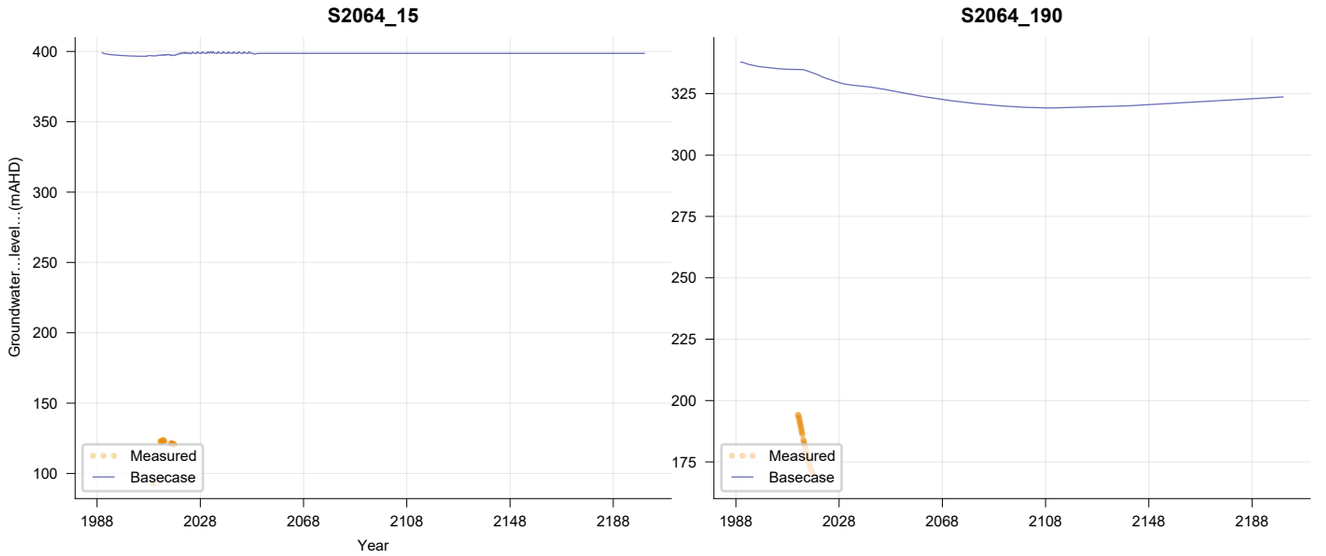

S2059_33
360
355
350
345
340
335
330
325
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2059_340
Groundwater...level...(mAHD)
325
300
275
250
225
200
175
150
1988
2028
2068
2108
2148
2188
Year
Measured
Basecase

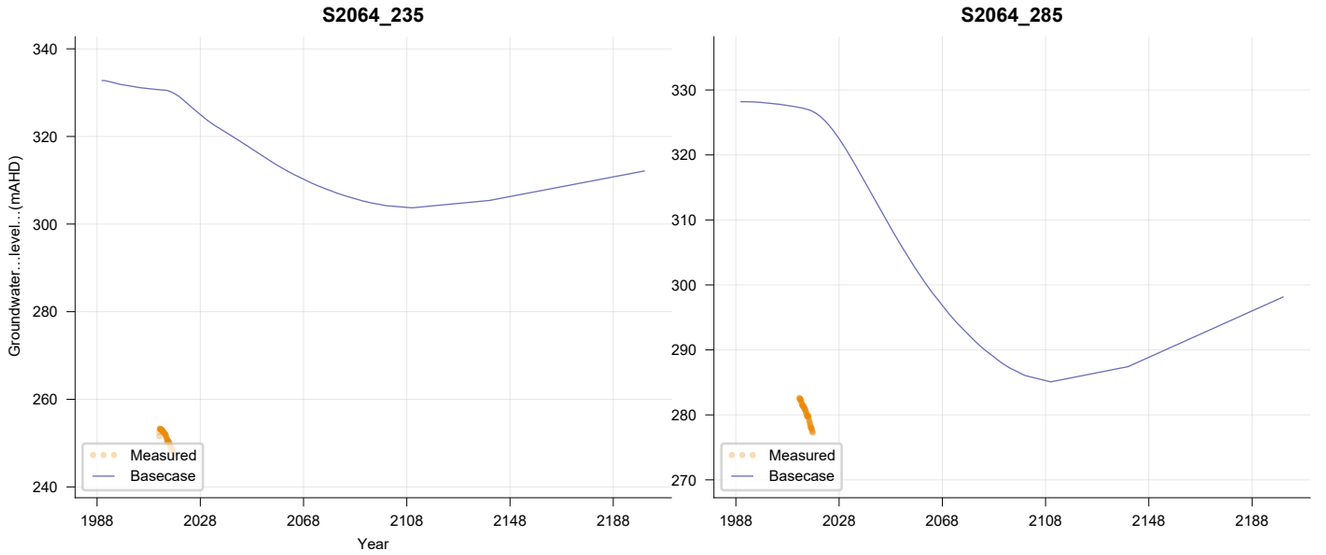

S2059_61
355
350
345
340
335
330
325
320
1988
2028
2068
2108
2148
2188
Measured
Basecase


S2059_79
Groundwater...level...(mAHD)
345
340
335
330
325
320
315
310
1988
2028
2068
2108
2148
2188
Year
Measured
Basecase

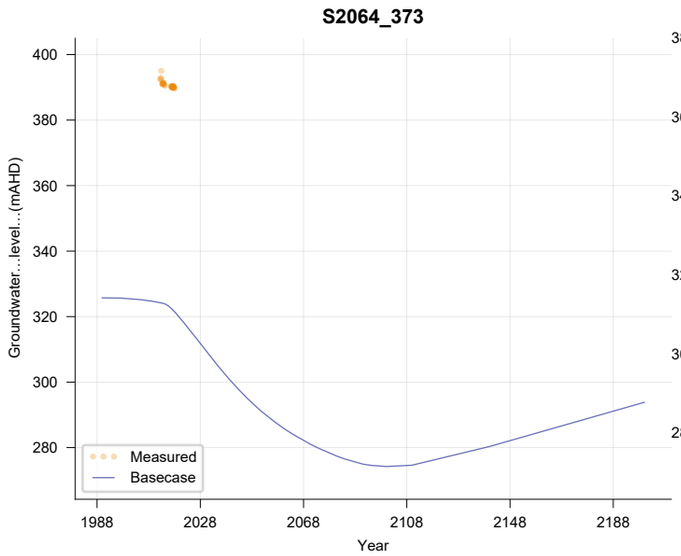

S2064_149
350
325
300
275
250
225
200
175
150
1988
2028
2068
2108
2148
2188
Measured
Basecase

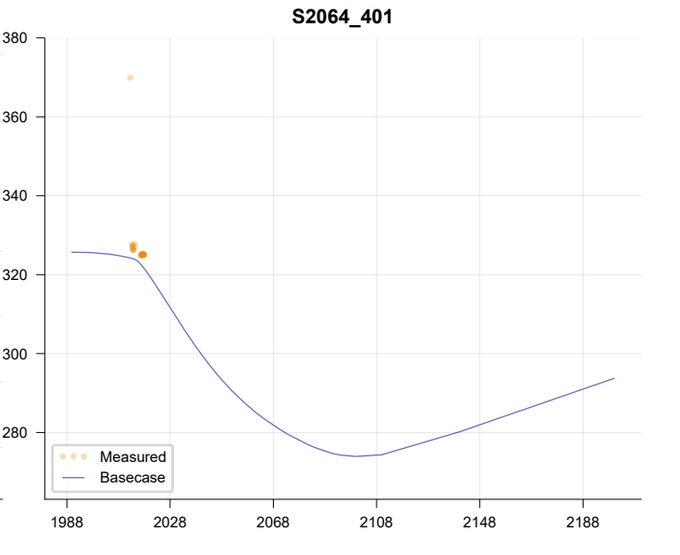

S2064_15
Groundwater...level...(mAHD)
400
350
300
250
200
150
100
1988
2028
2068
2108
2148
2188
Year
Measured
Basecase

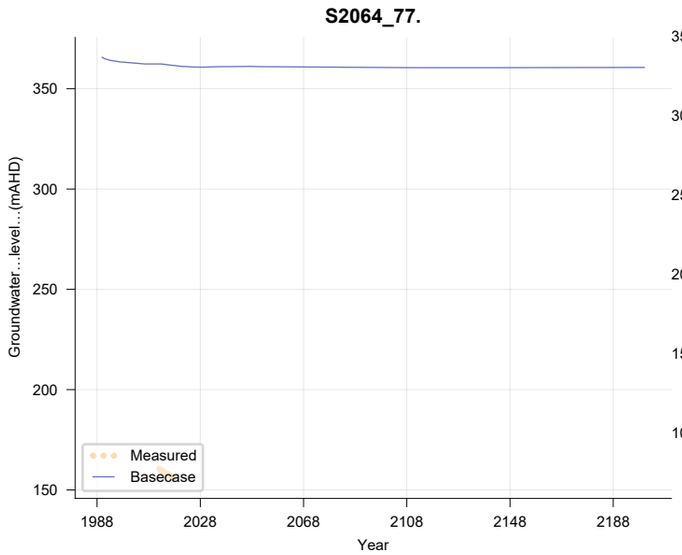

S2064_190
325
300
275
250
225
200
175
1988
2028
2068
2108
2148
2188
Measured
Basecase

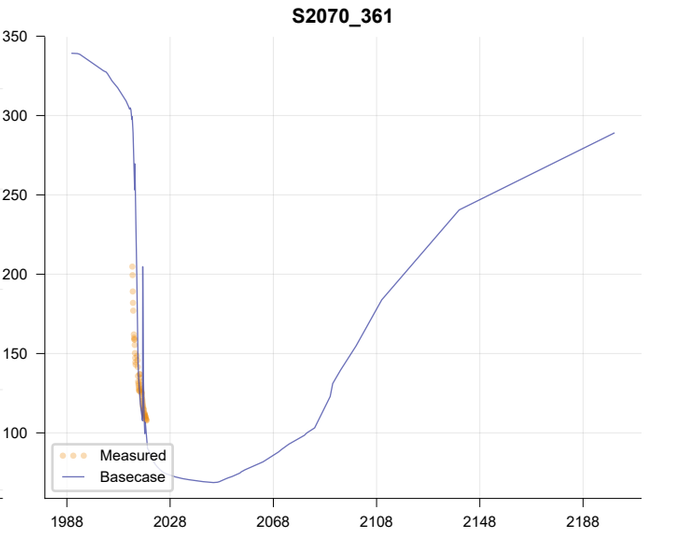

S2064_235
Groundwater...level...(mAHD)
340
320
300
280
260
240
1988
2028
2068
2108
2148
2188
Year
Measured
Basecase

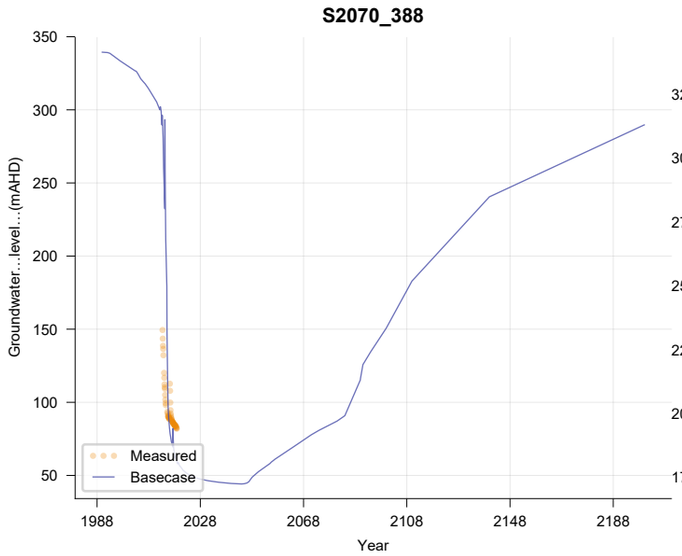

S2064_285
330
320
310
300
290
280
270
1988
2028
2068
2108
2148
2188
Measured
Basecase

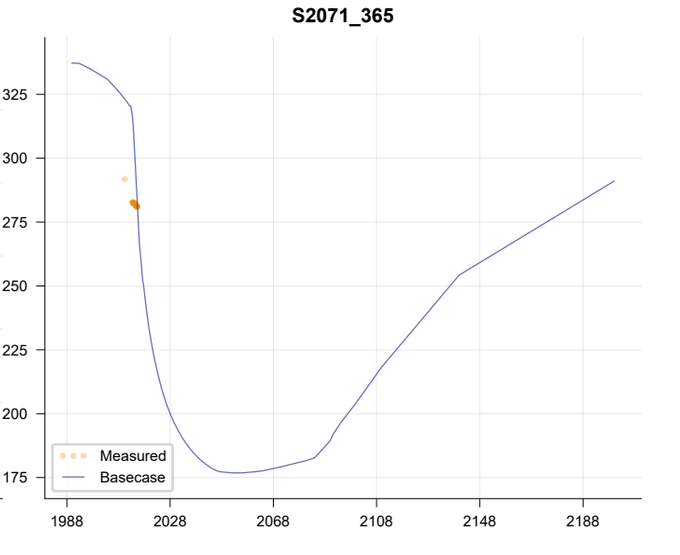

S2064_373
Groundwater...level...(mAHD)
Year
Measured
Basecase

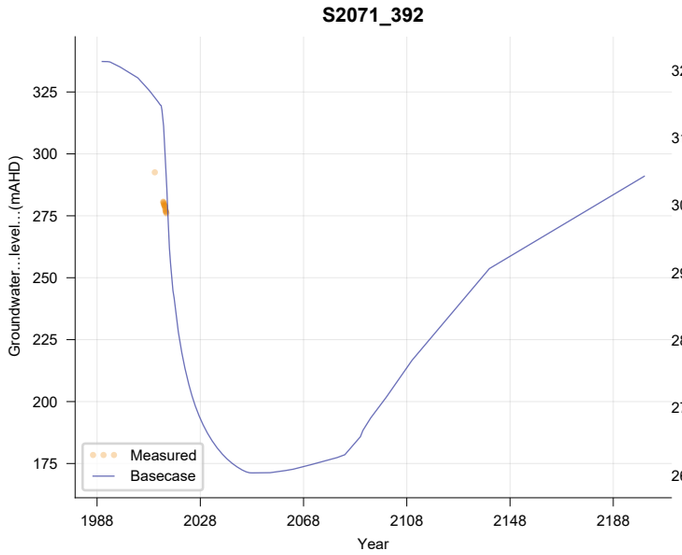

S2064_401
Measured
Basecase

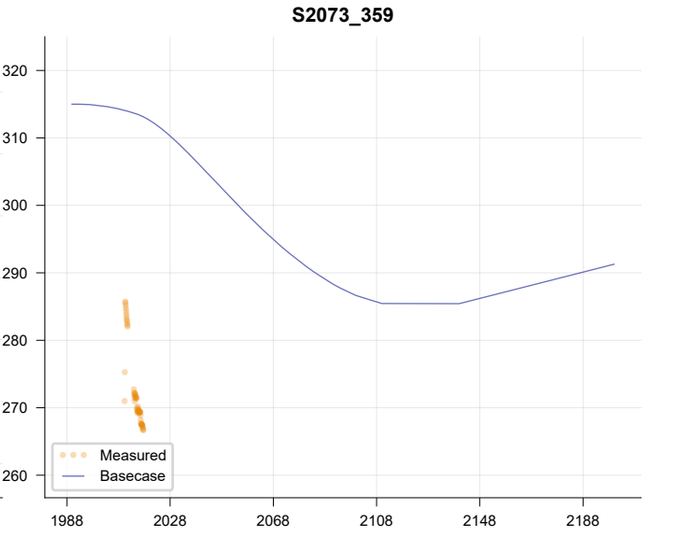

S2064_77.
Groundwater...level...(mAHD)
Year
Measured
Basecase

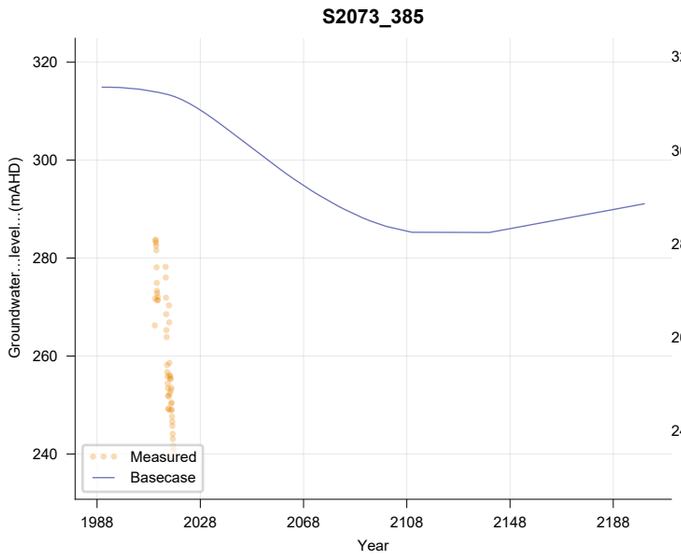

S2070_361
Measured
Basecase

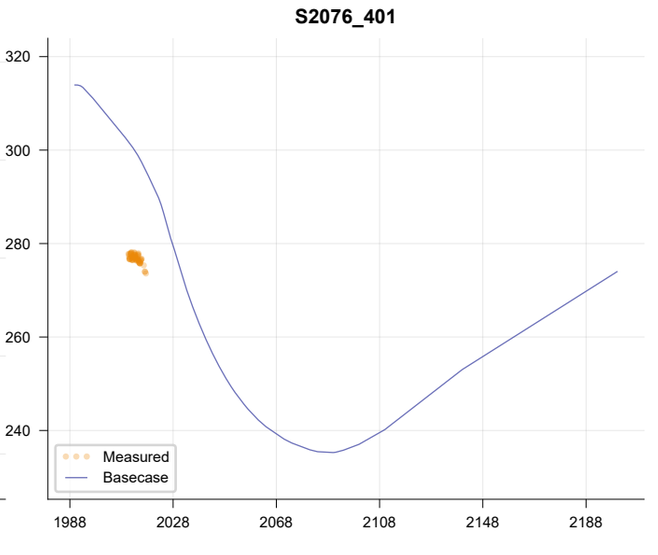

S2070_388
Groundwater...level...(mAHD)
Year
Measured
Basecase

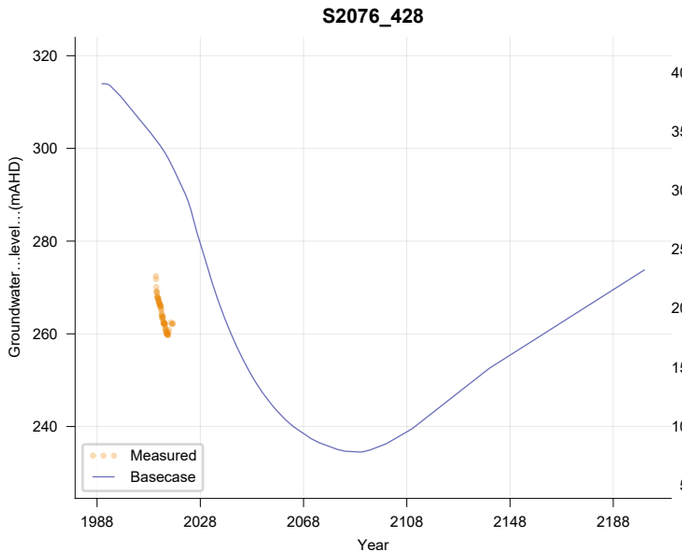

S2071_365
Measured
Basecase

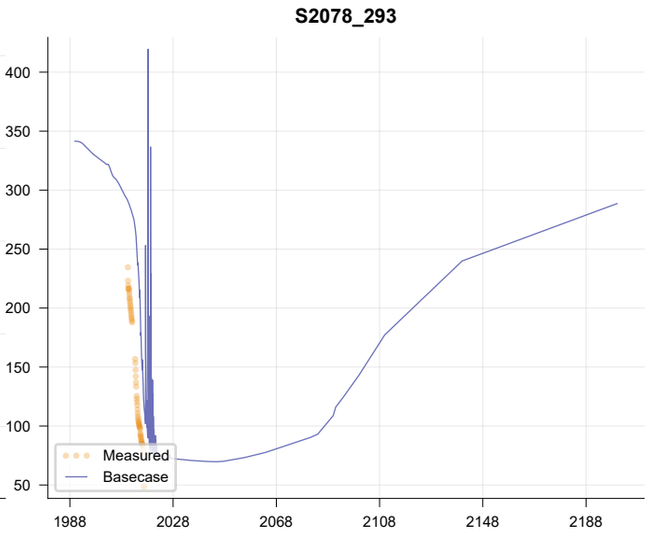

S2071_392
Groundwater...level...(mAHD)
Year
Measured
Basecase

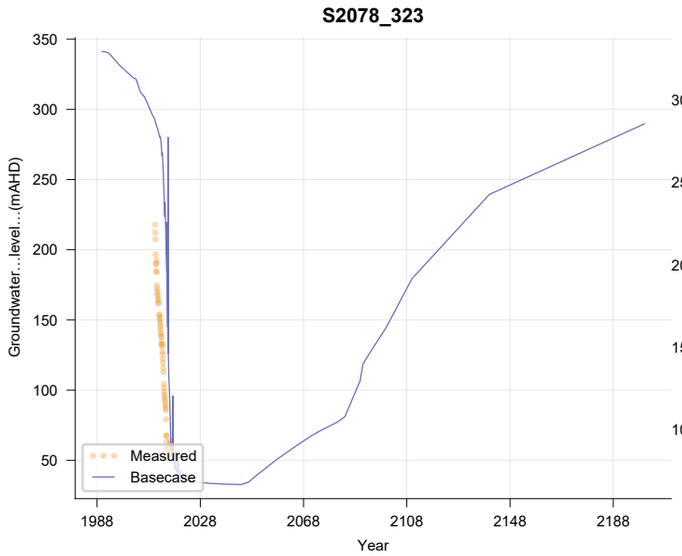

S2073_359
Measured
Basecase

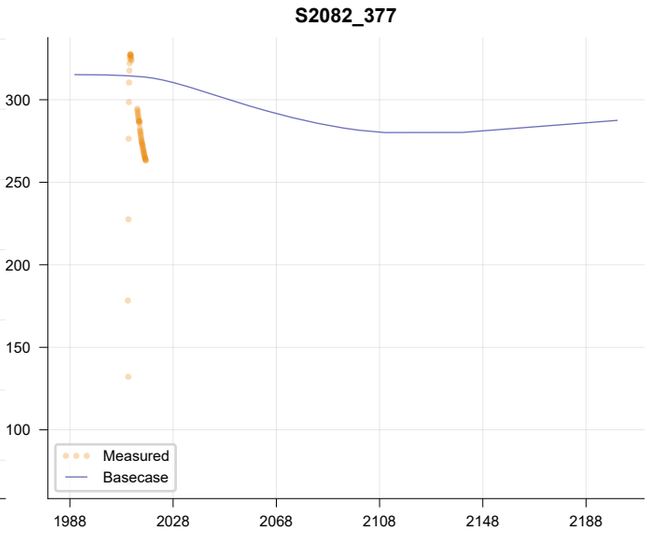

S2073_385
Groundwater...level...(mAHD)
320
300
280
260
240
1988
2028
2068
2108
2148
2188
Year
Measured
Basecase

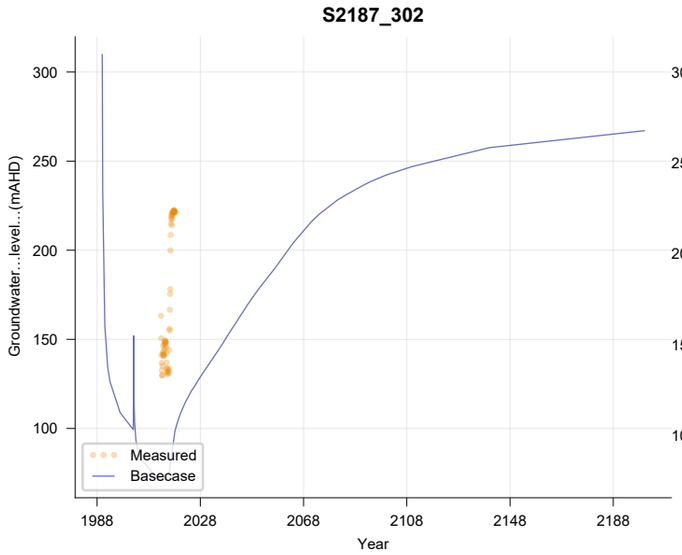

S2076_401
320
300
280
260
240
1988
2028
2068
2108
2148
2188
Measured
Basecase

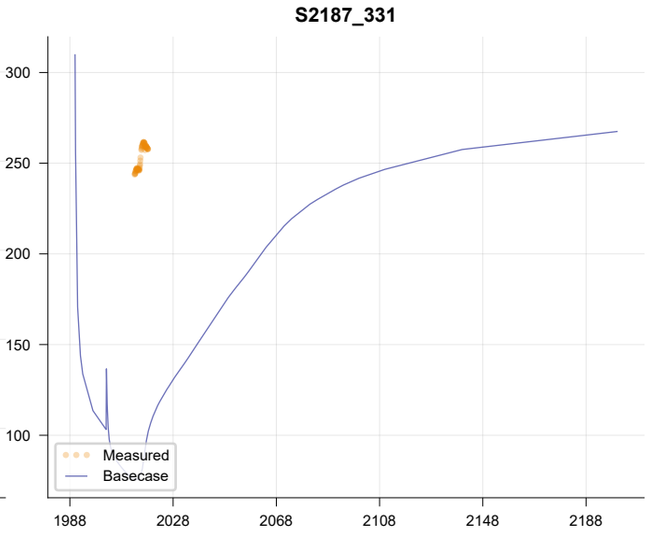

S2076_428
Groundwater...level...(mAHD)
320
300
280
260
240
1988
2028
2068
2108
2148
2188
Year
Measured
Basecase

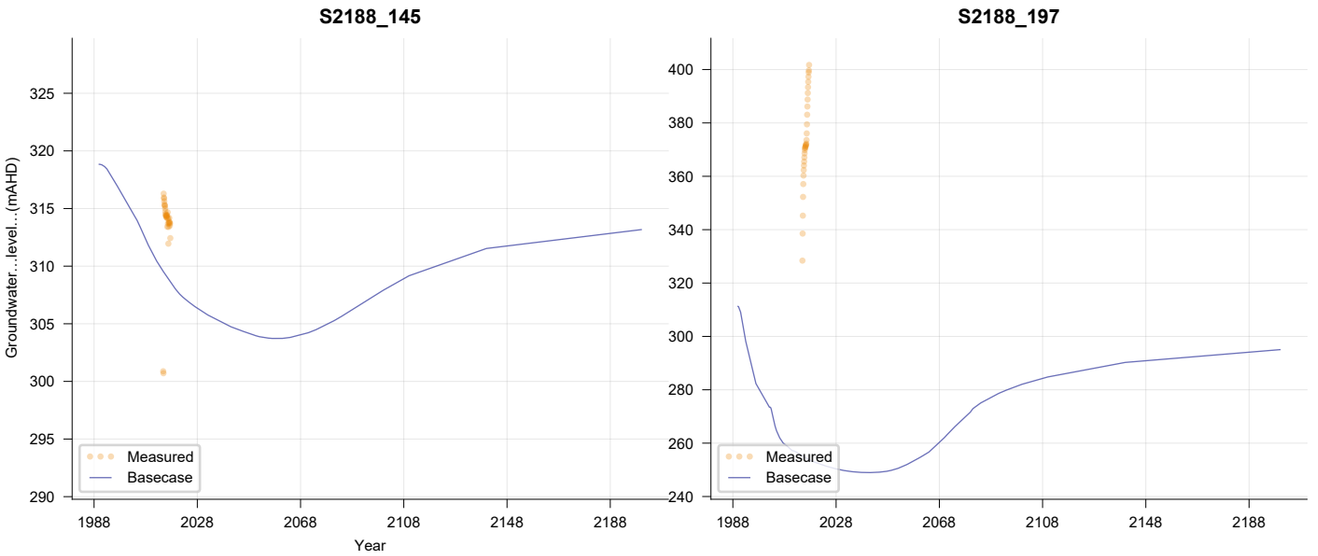

S2078_293
400
350
300
250
200
150
100
50
1988
2028
2068
2108
2148
2188
Measured
Basecase


S2078_323
Groundwater...level...(mAHD)
350
300
250
200
150
100
50
1988
2028
2068
2108
2148
2188
Year
Measured
Basecase

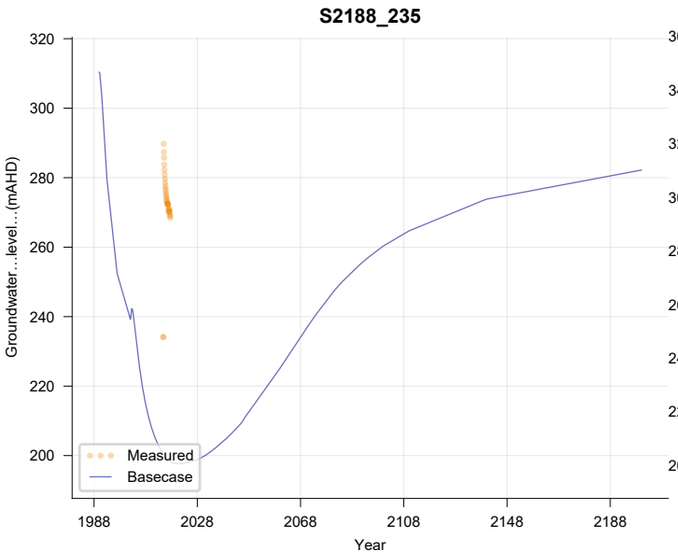

S2082_377
300
250
200
150
100
1988
2028
2068
2108
2148
2188
Measured
Basecase

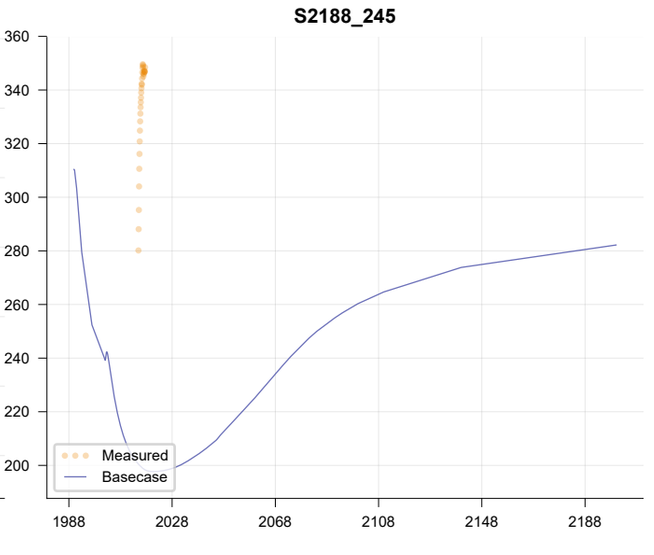

S2187_302
Groundwater...level...(mAHD)
300
250
200
150
100
1988
2028
2068
2108
2148
2188
Year
Measured
Basecase

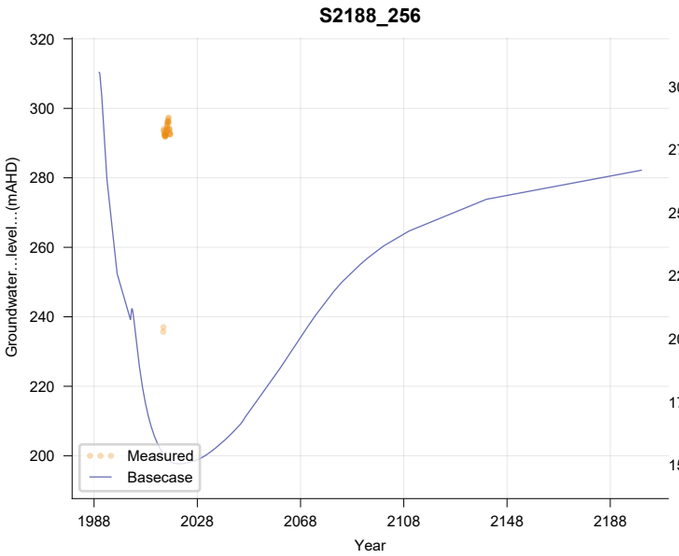

S2187_331
300
250
200
150
100
1988
2028
2068
2108
2148
2188
Measured
Basecase

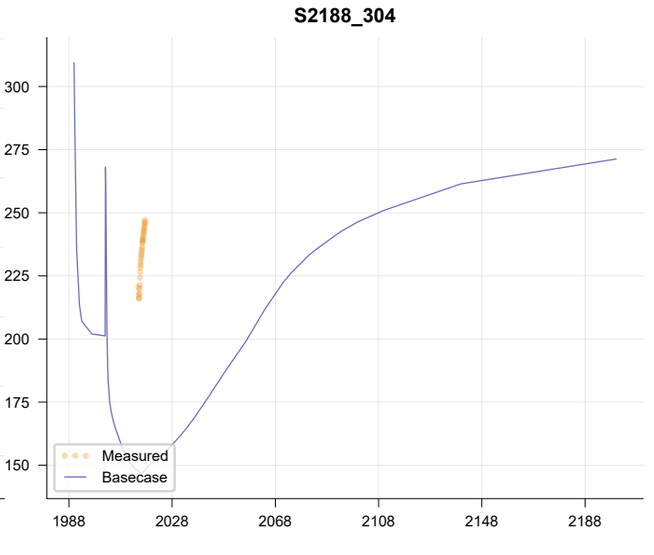

S2188_145
Groundwater...level...(mAHD)
Year
Measured
Basecase

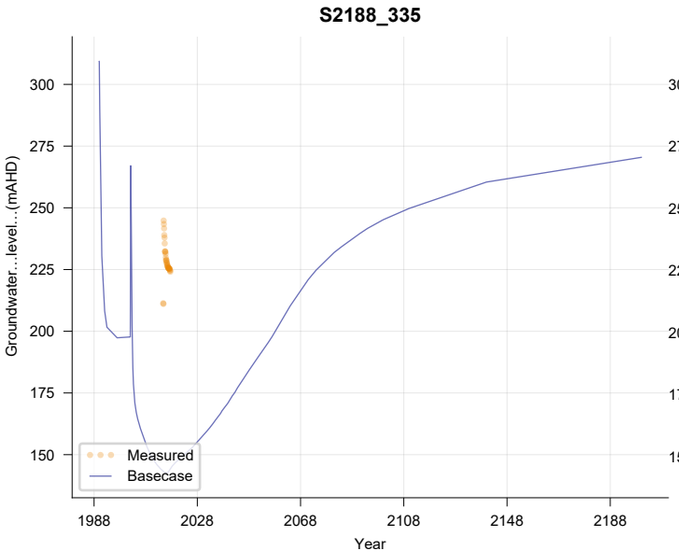

S2188_197
Measured
Basecase

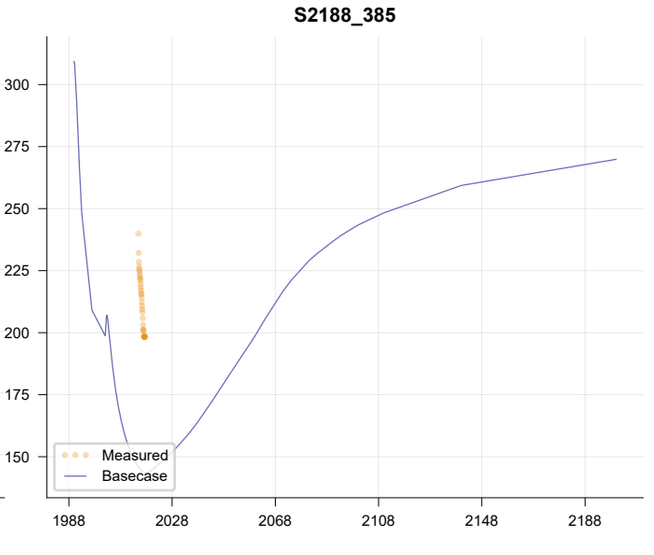

S2188_235
Groundwater...level...(mAHD)
Year
Measured
Basecase

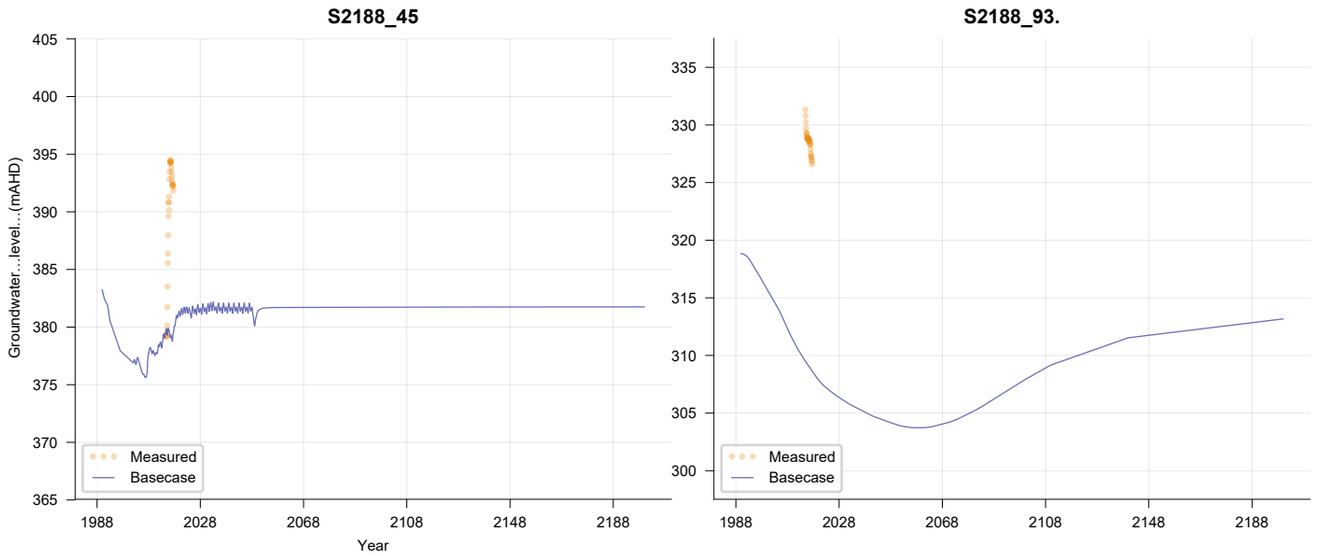

S2188_245
Measured
Basecase


S2188_256
Groundwater...level...(mAHD)
Year
Measured
Basecase

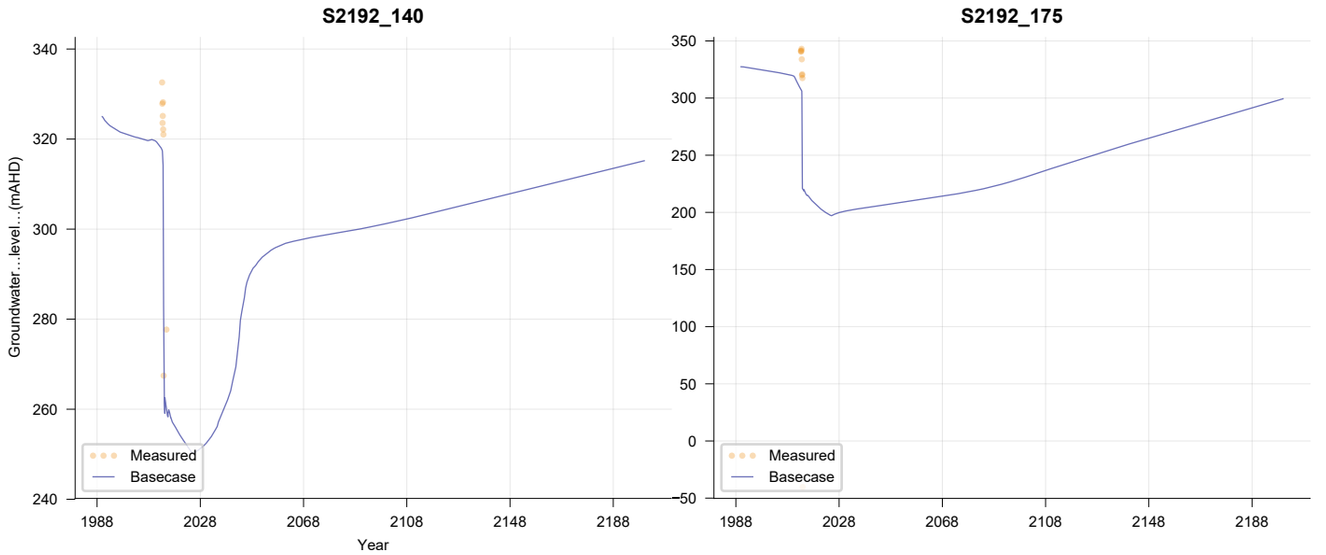

S2188_304
Measured
Basecase


S2188_335
Groundwater...level...(mAHD)
Year
Measured
Basecase

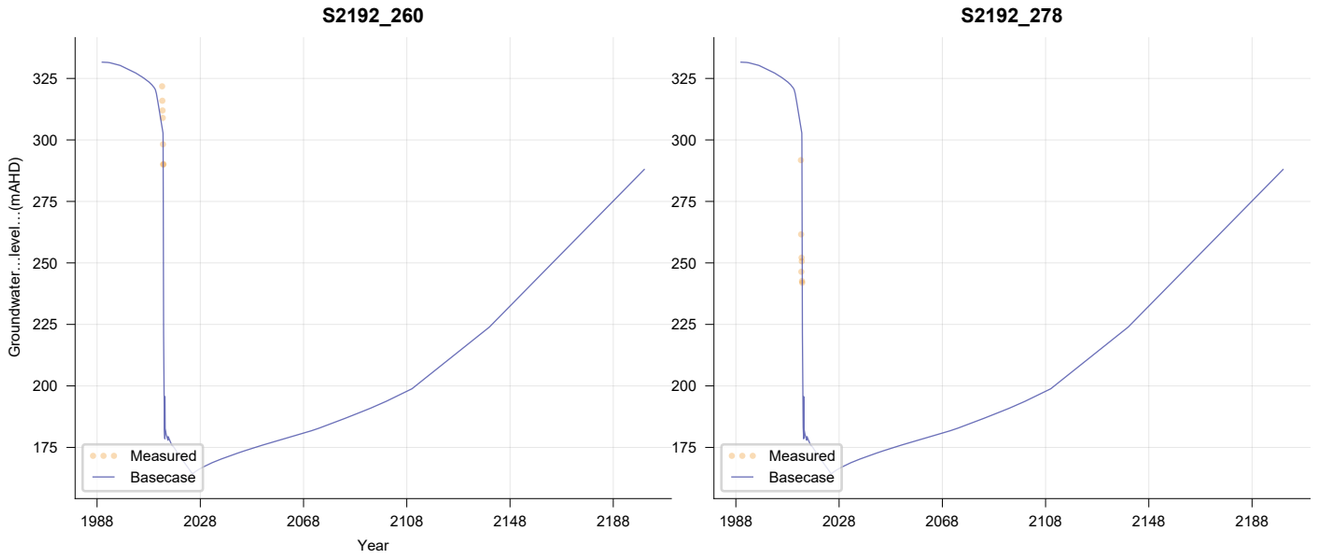

S2188_385
Measured
Basecase


S2188_45
Groundwater...level...(mAHD)
405
400
395
390
385
380
375
370
365
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

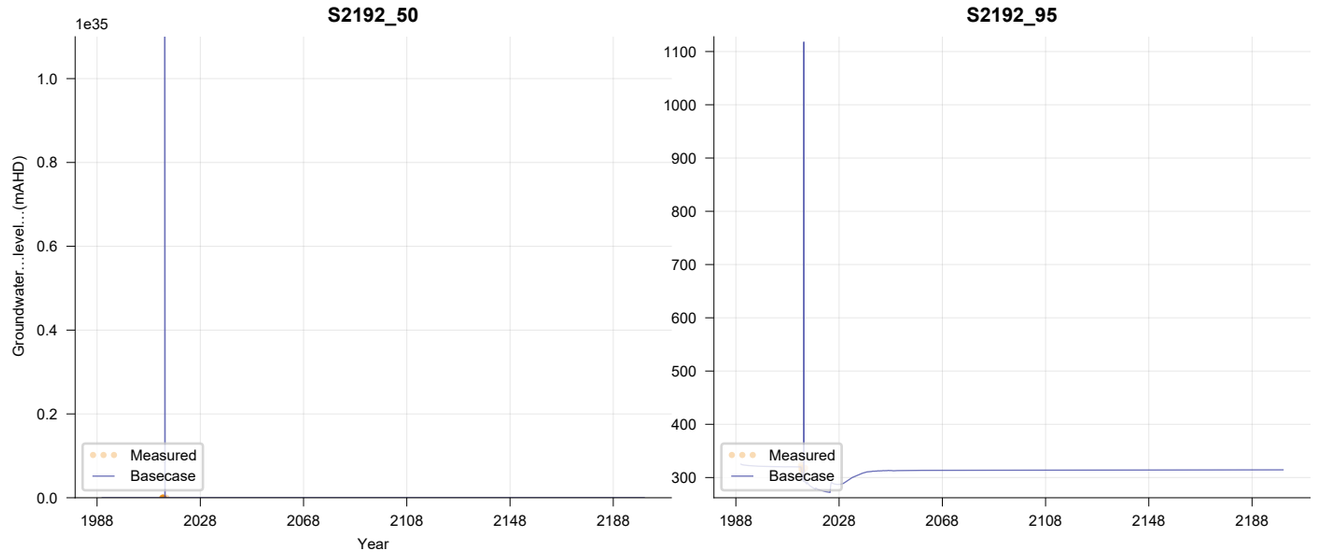

S2188_93.
335
330
325
320
315
310
305
300
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2192_140
Groundwater...level...(mAHD)
340
320
300
280
260
240
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

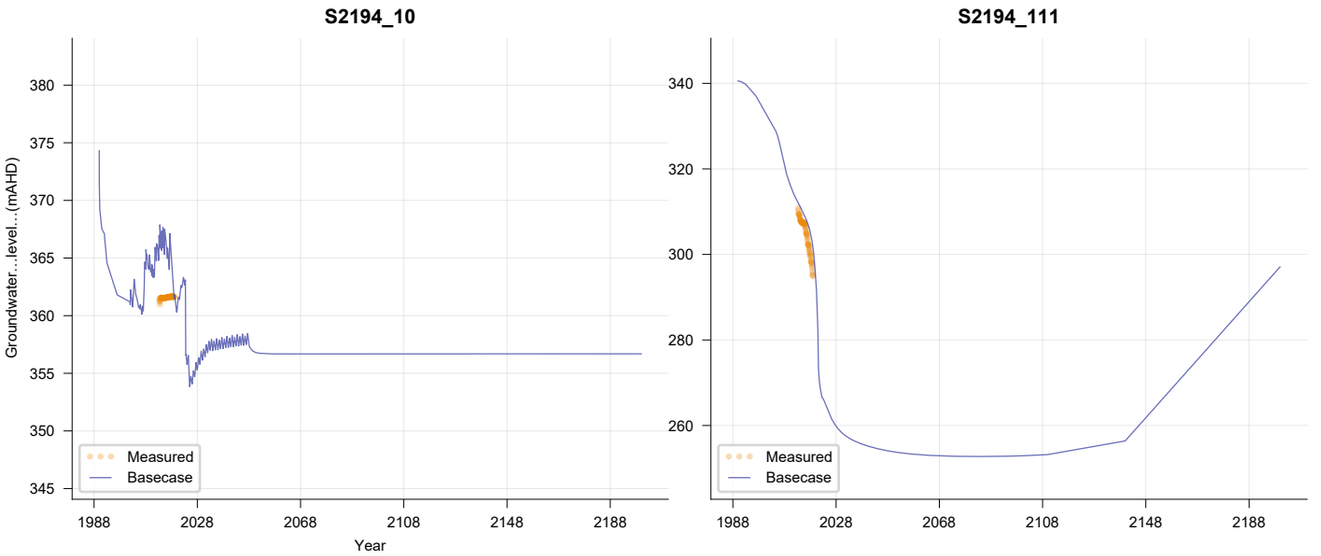

S2192_175
350
300
250
200
150
100
50
0
−50
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2192_260
Groundwater...level...(mAHD)
325
300
275
250
225
200
175
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

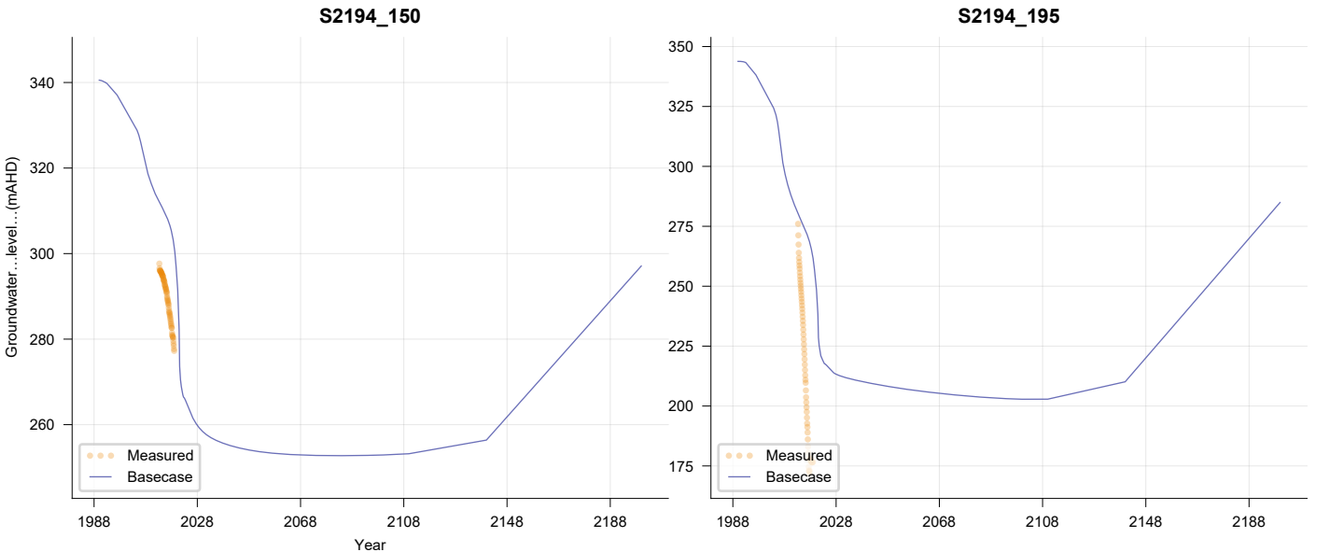

S2192_278
325
300
275
250
225
200
175
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2192_50
1e35
Groundwater...level...(mAHD)
1.0
0.8
0.6
0.4
0.2
0.0
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

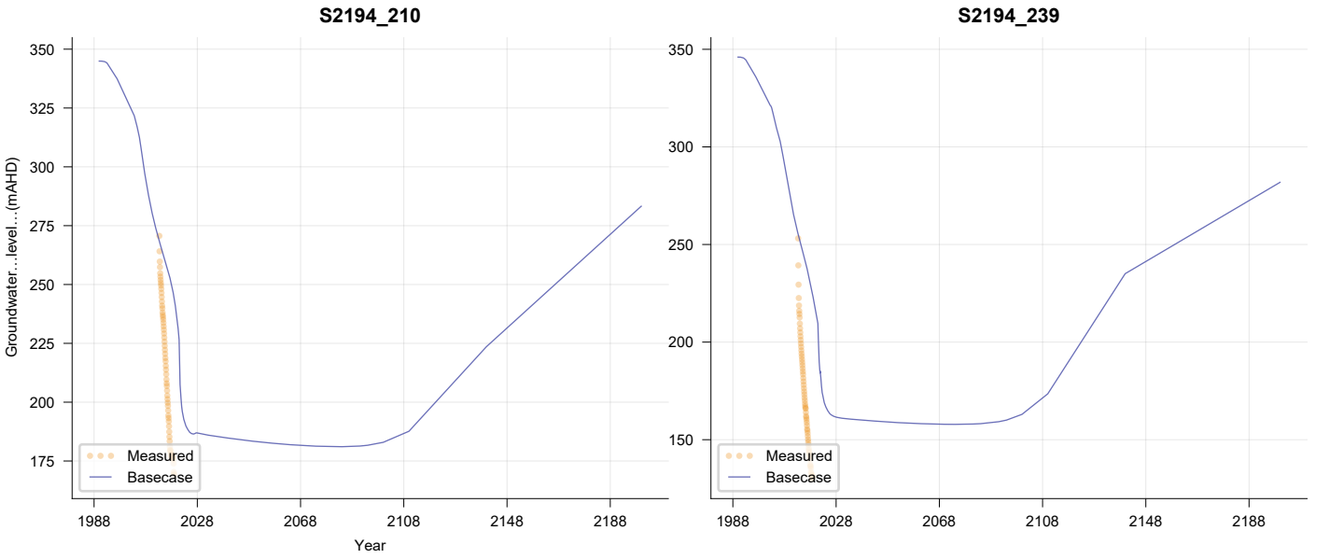

S2192_95
1100
1000
900
800
700
600
500
400
300
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2194_10
Groundwater...level...(mAHD)
380
375
370
365
360
355
350
345
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

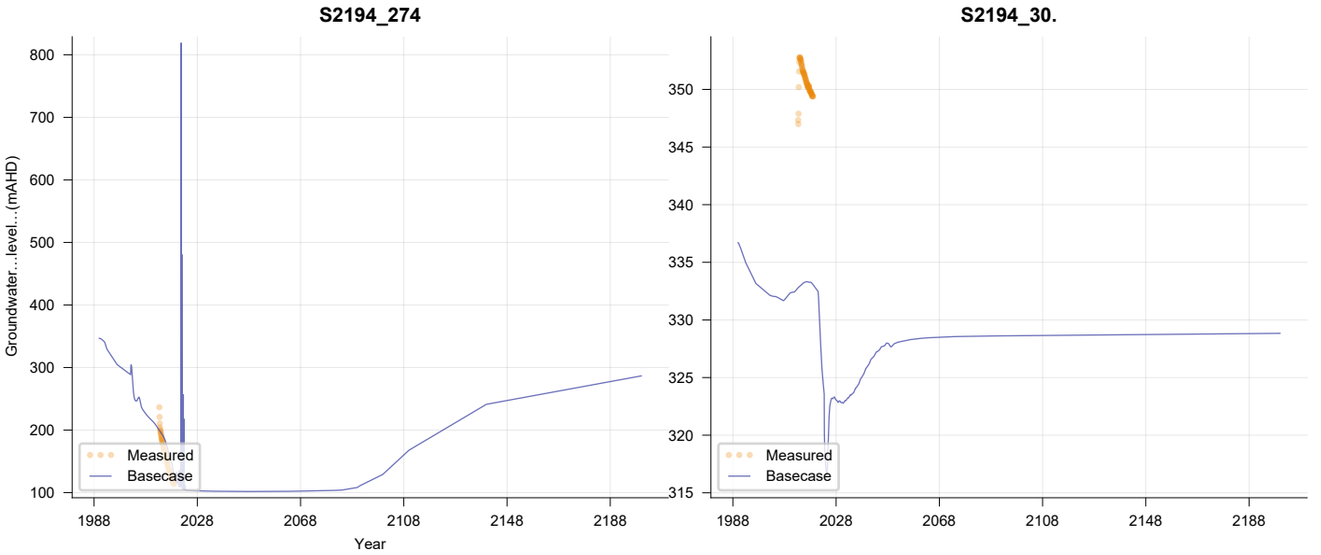

S2194_111
340
320
300
280
260
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2194_150
Groundwater...level...(mAHD)
340
320
300
280
260
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

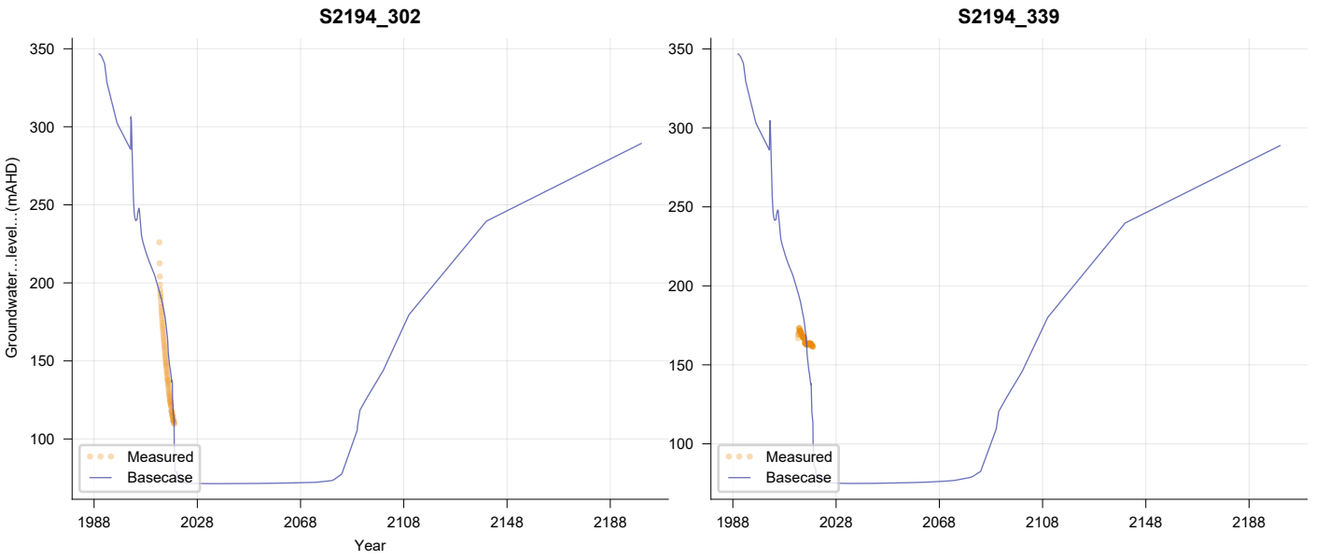

S2194_195
350
325
300
275
250
225
200
175
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2194_210
Groundwater...level...(mAHD)
350
325
300
275
250
225
200
175
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

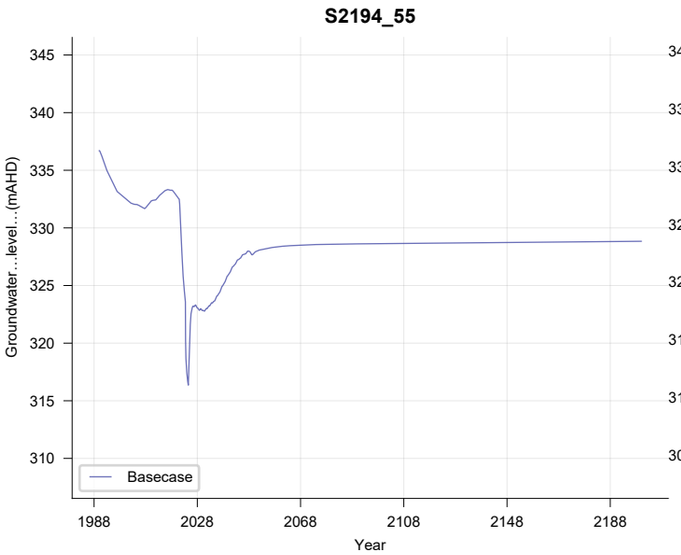

S2194_239
350
300
250
200
150
Measured
Basecase
1988
2028
2068
2108
2148
2188

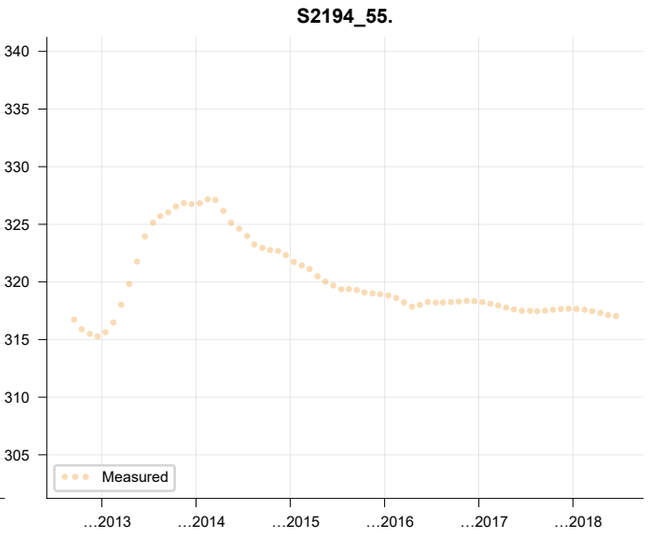

S2194_274
Groundwater...level...(mAHD)
800
700
600
500
400
300
200
100
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

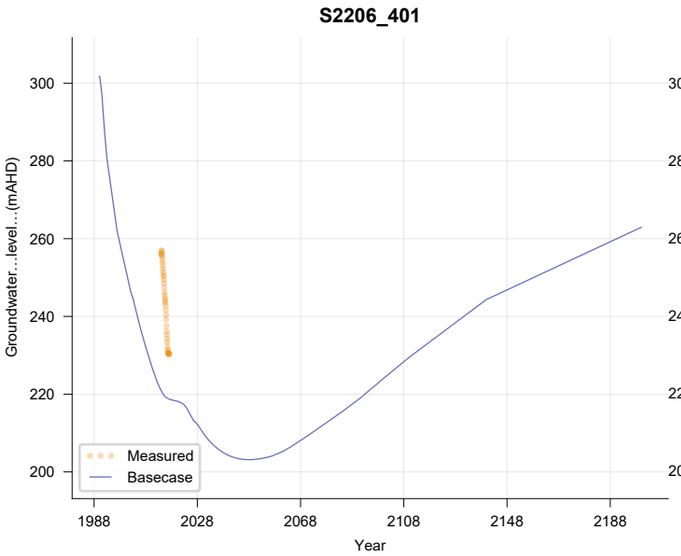

S2194_30.
350
345
340
335
330
325
320
315
Measured
Basecase
1988
2028
2068
2108
2148
2188

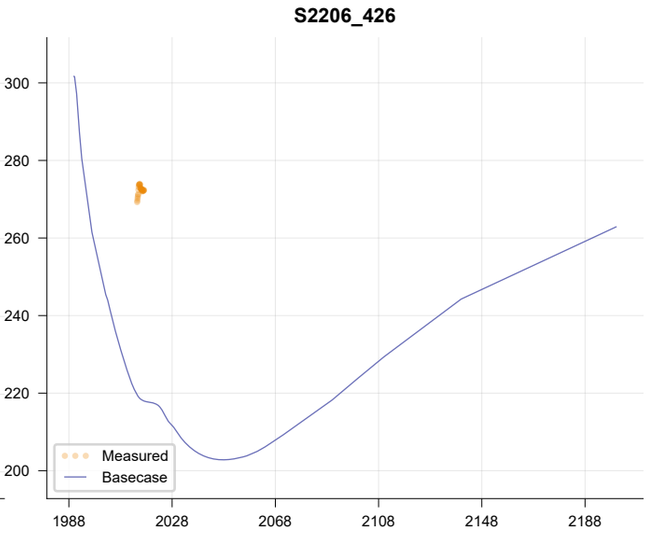

S2194_302
Groundwater…level…(mAHD)
350
300
250
200
150
100
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

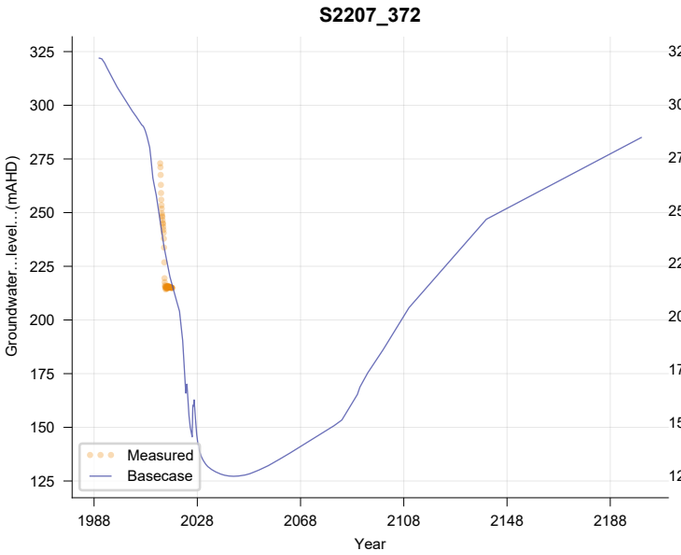

S2194_339
350
300
250
200
150
100
Measured
Basecase
1988
2028
2068
2108
2148
2188

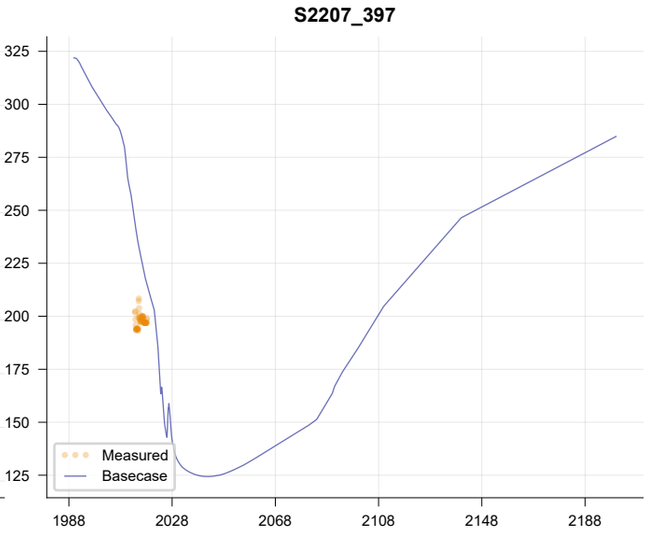

S2194_55
Groundwater…level…(mAHD)
345
340
335
330
325
320
315
310
Basecase
1988
2028
2068
2108
2148
2188
Year

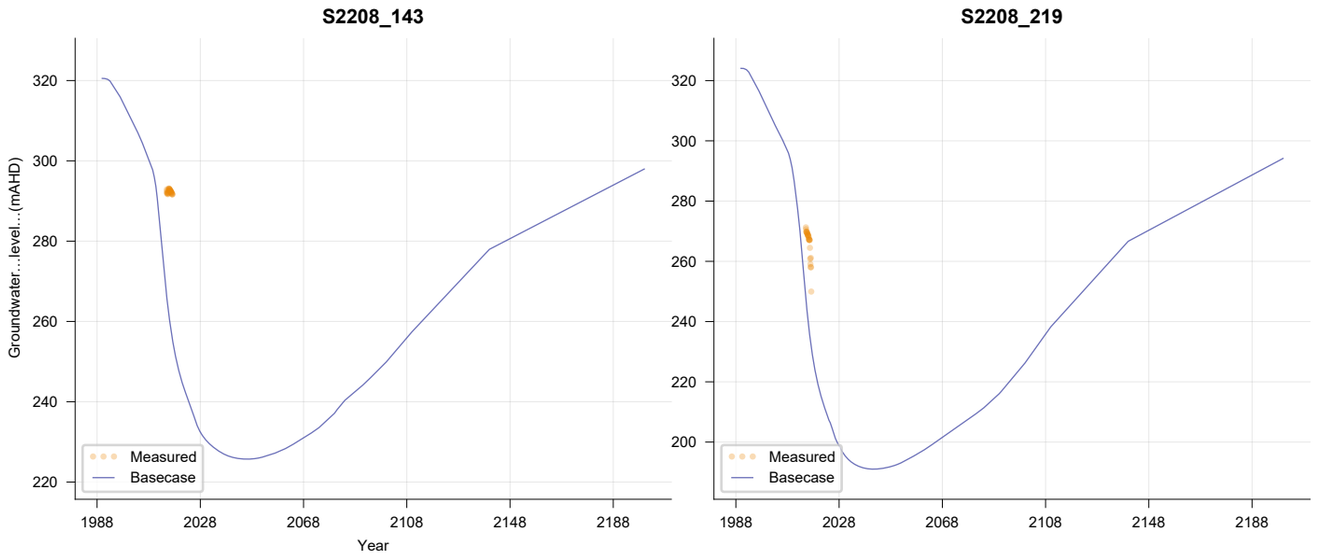

S2194_55.
340
335
330
325
320
315
310
305
Measured
…2013
…2014
…2015
…2016
…2017
…2018


S2206_401
Groundwater…level…(mAHD)
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

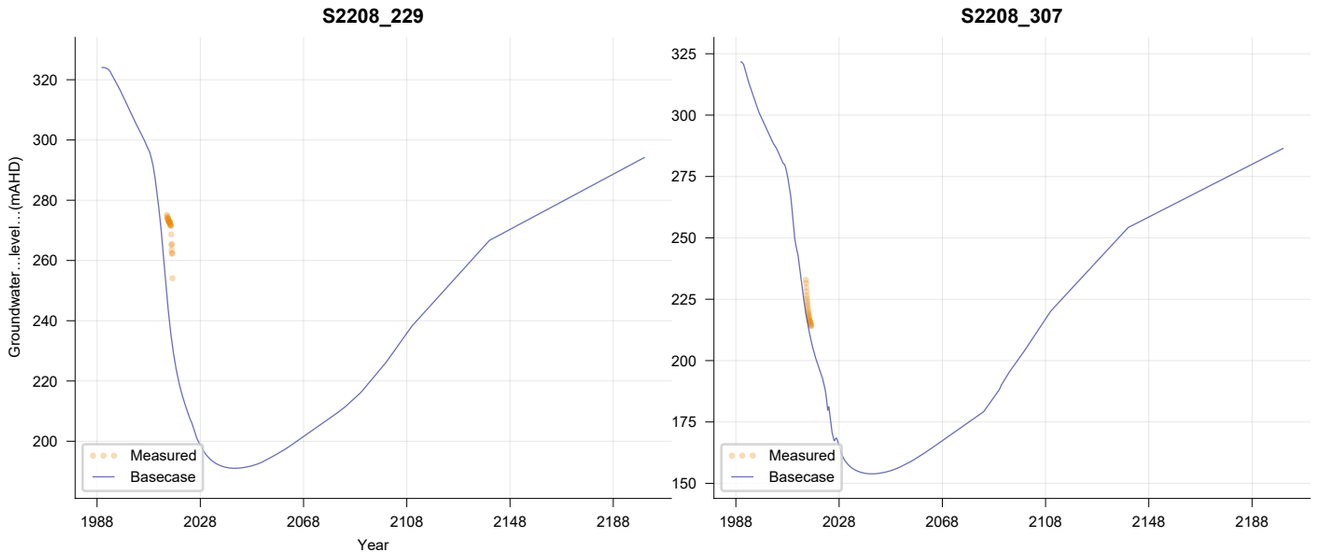

S2206_426
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2207_372
Groundwater…level…(mAHD)
325
300
275
250
225
200
175
150
125
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

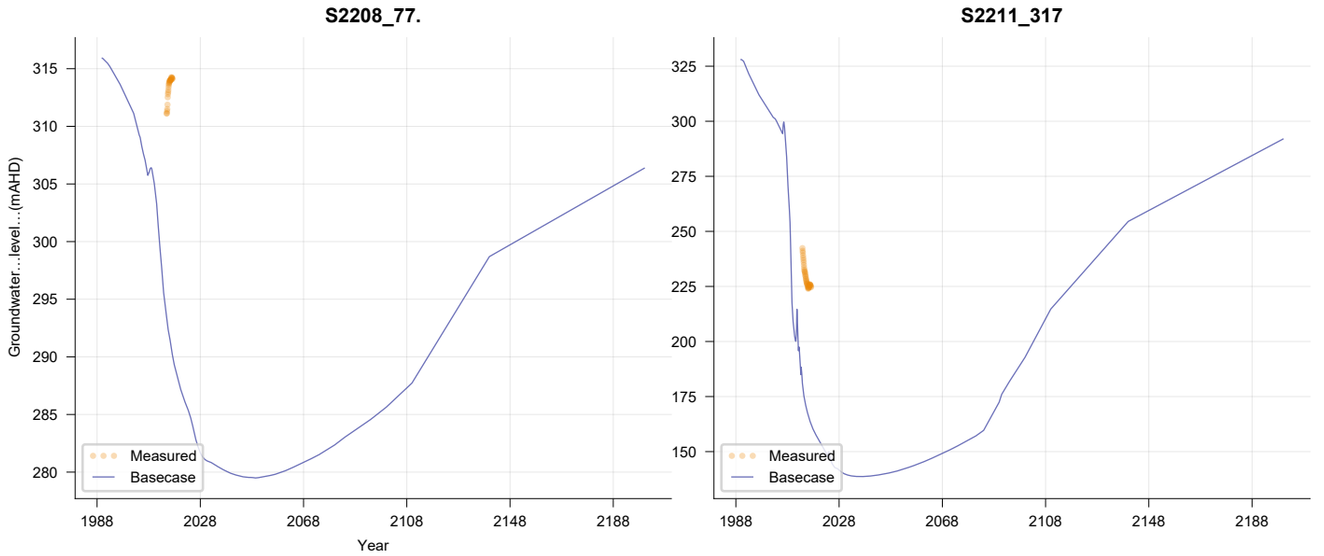

S2207_397
325
300
275
250
225
200
175
150
125
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2208_143
Groundwater...level...(mAHD)
320
300
280
260
240
220
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

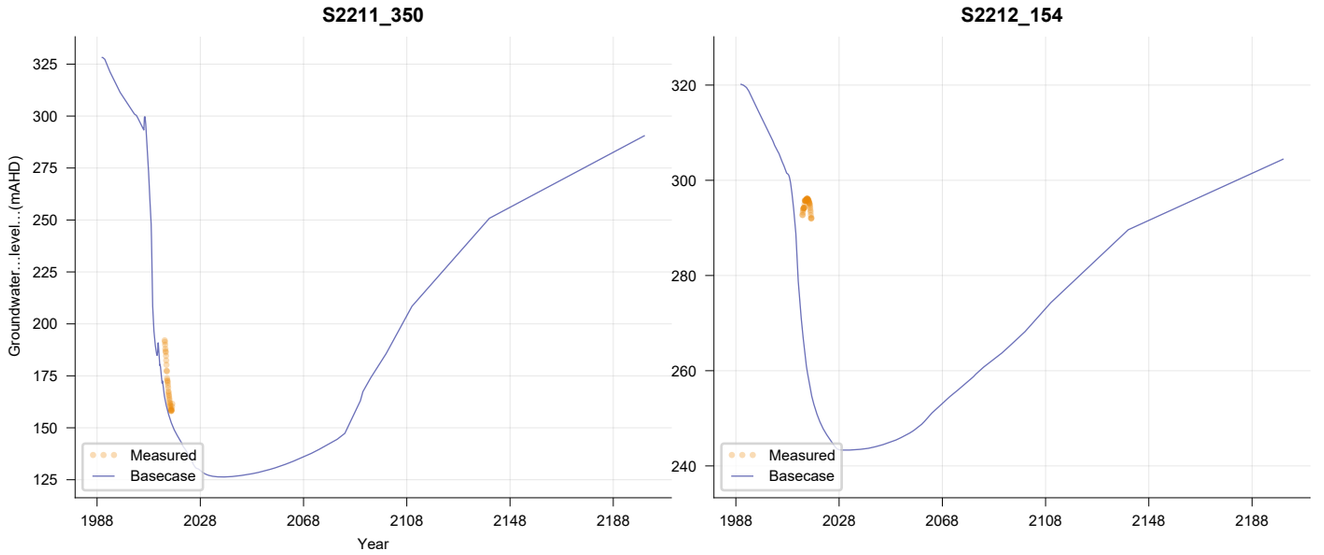

S2208_219
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2208_229
Groundwater...level...(mAHD)
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

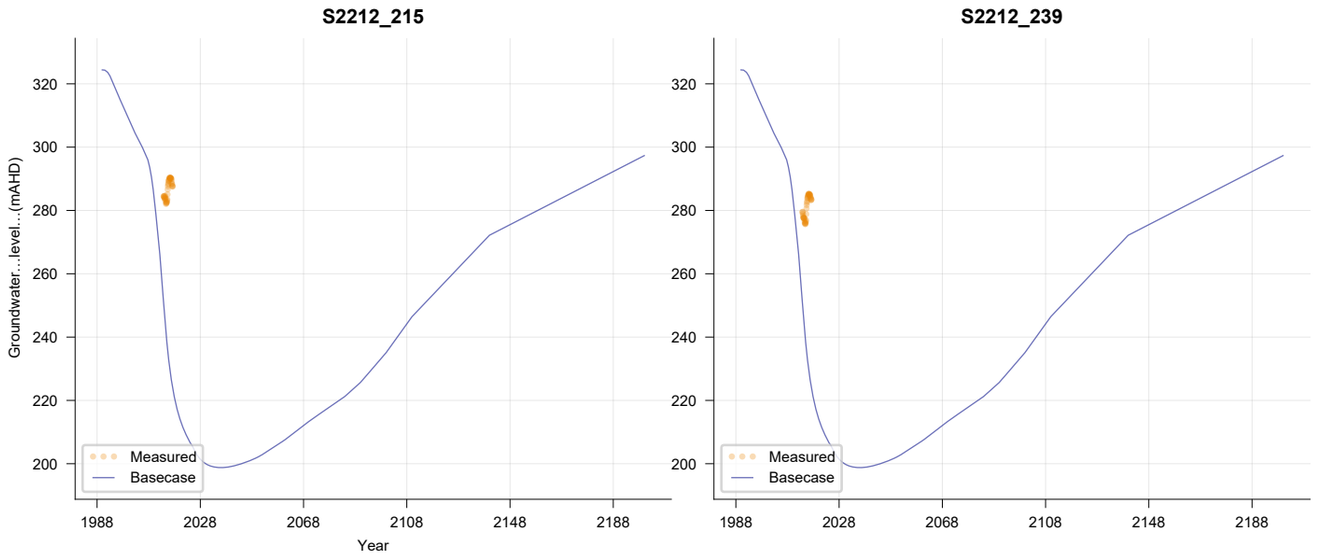

S2208_307
325
300
275
250
225
200
175
150
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2208_77.
Groundwater...level...(mAHD)
315
310
305
300
295
290
285
280
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

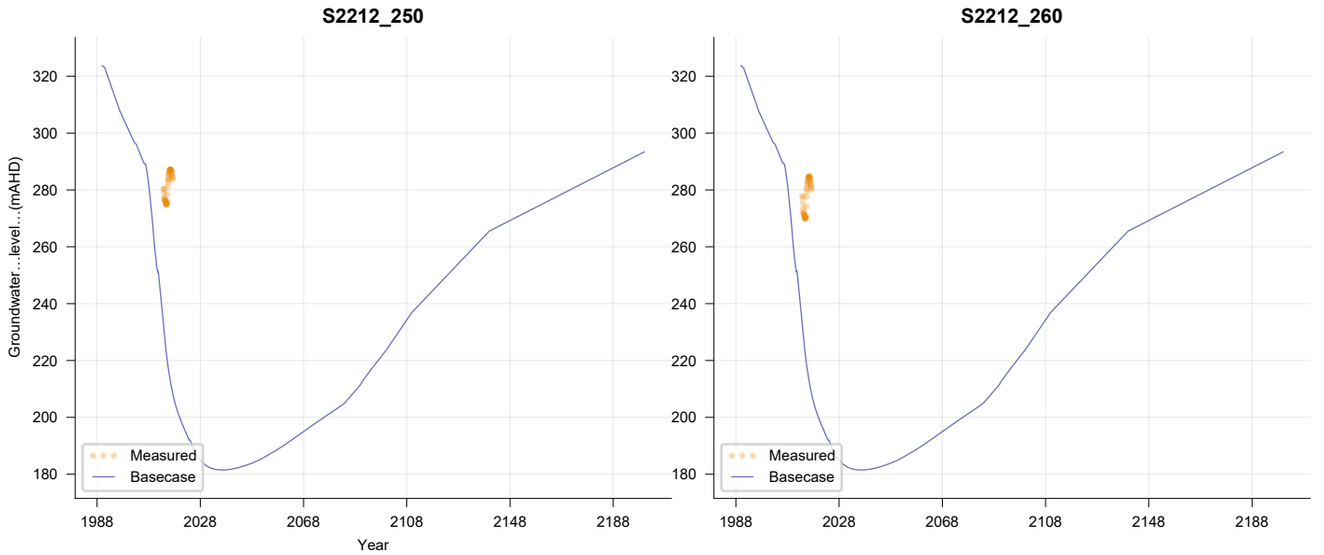

S2211_317
325
300
275
250
225
200
175
150
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2211_350
Groundwater...level...(mAHD)
325
300
275
250
225
200
175
150
125
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

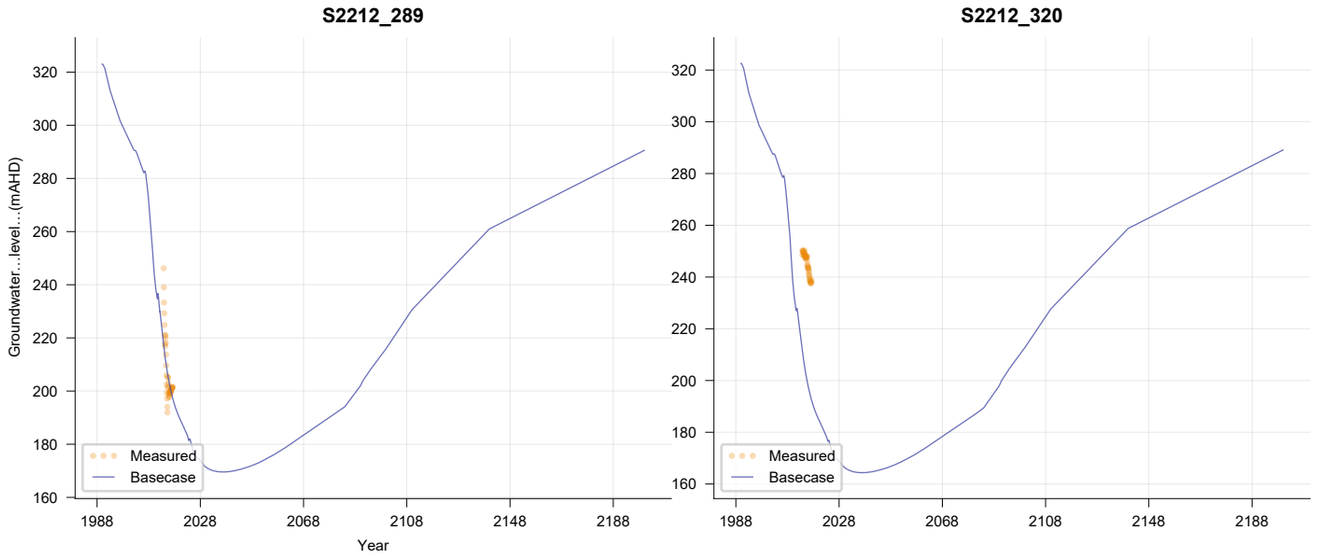

S2212_154
320
300
280
260
240
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2212_215
Groundwater...level...(mAHD)
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

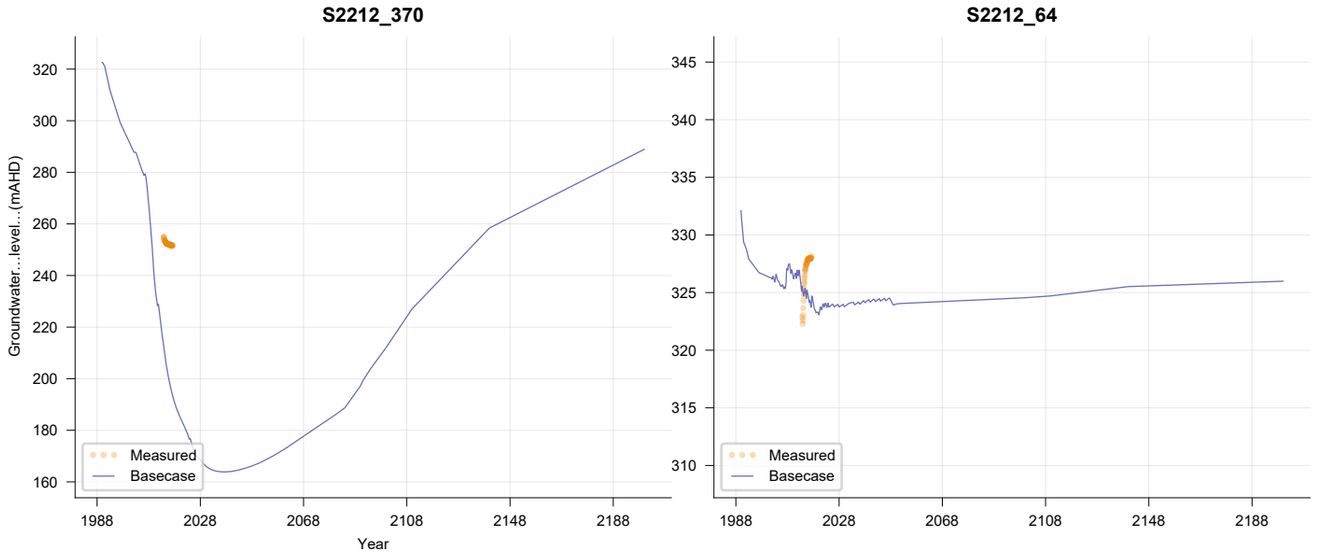

S2212_239
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2212_250
Groundwater...level...(mAHD)
320
300
280
260
240
220
200
180
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

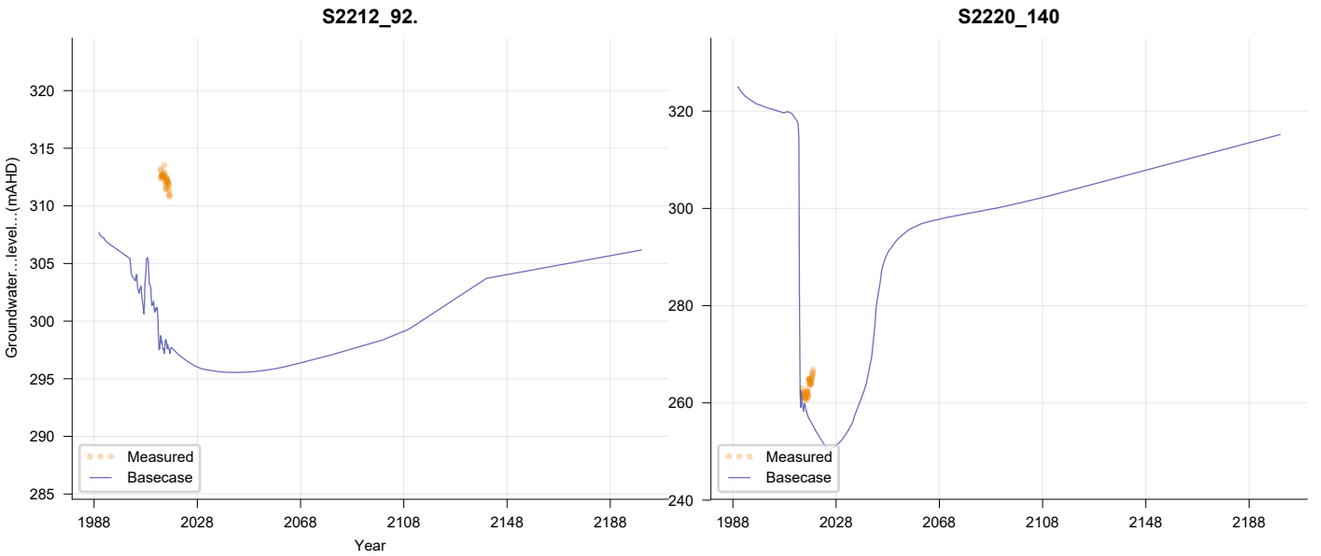

S2212_260
320
300
280
260
240
220
200
180
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2212_289
Groundwater...level...(mAHD)
320
300
280
260
240
220
200
180
160
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

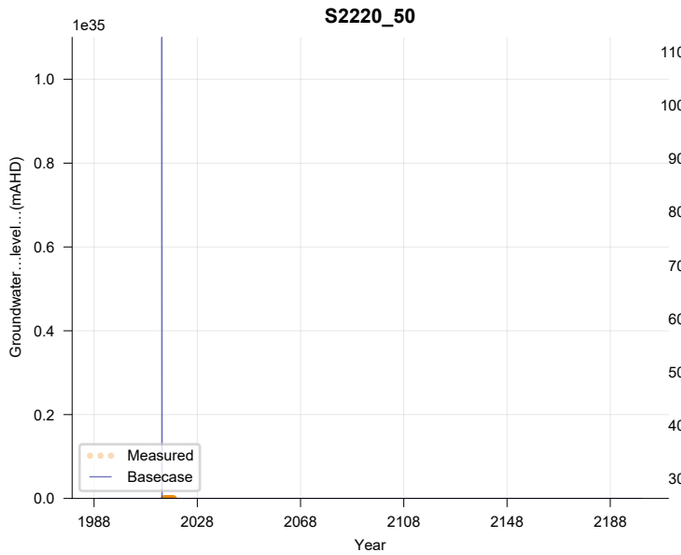

S2212_320
320
300
280
260
240
220
200
180
160
Measured
Basecase
1988
2028
2068
2108
2148
2188

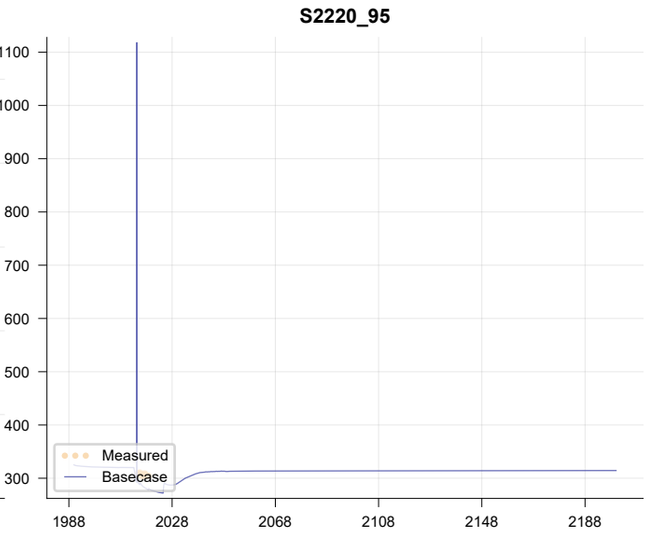

S2212_370
Groundwater...level...(mAHD)
320
300
280
260
240
220
200
180
160
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

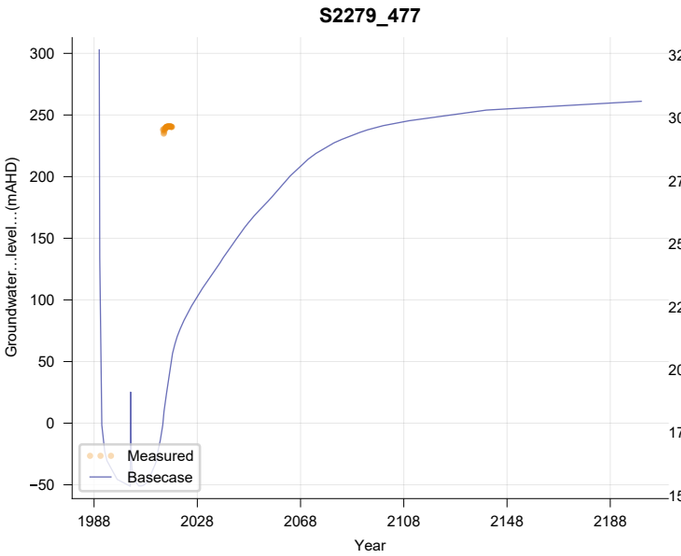

S2212_64
345
340
335
330
325
320
315
310
Measured
Basecase
1988
2028
2068
2108
2148
2188

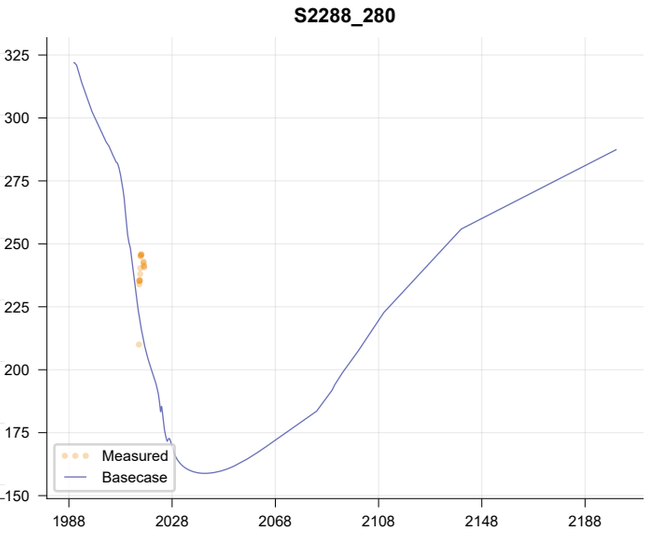

S2212_92.
Groundwater...level...(mAHD)
320
315
310
305
300
295
290
285
1988
2028
2068
2108
2148
2188
Year
Measured
Basecase

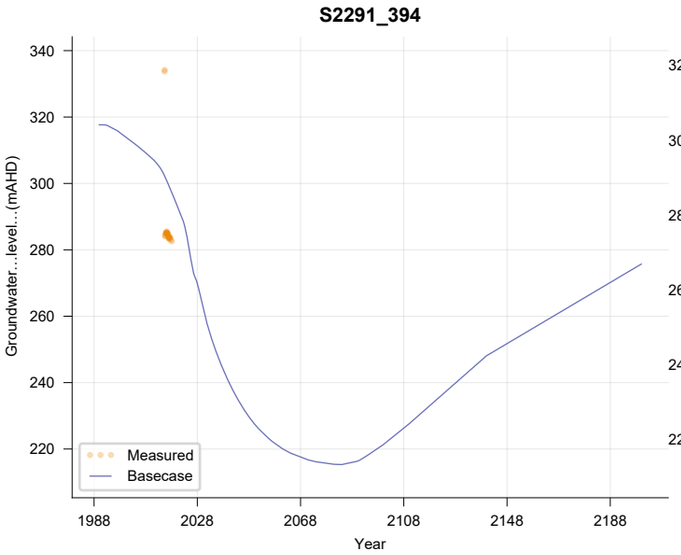

S2220_140
320
300
280
260
240
1988
2028
2068
2108
2148
2188
Measured
Basecase

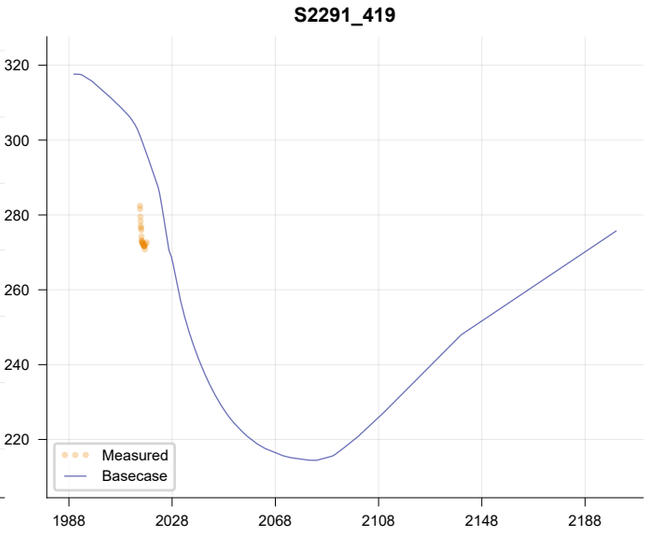

S2220_50
1e35
Groundwater...level...(mAHD)
1.0
0.8
0.6
0.4
0.2
0.0
1988
2028
2068
2108
2148
2188
Year
Measured
Basecase

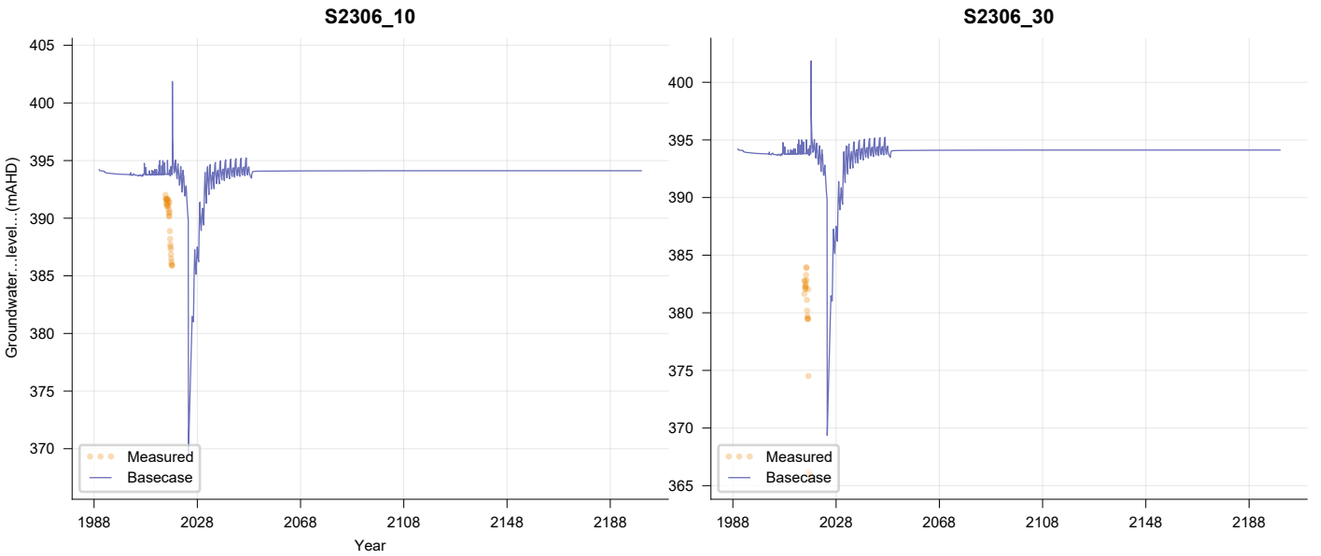

S2220_95
1100
1000
900
800
700
600
500
400
300
1988
2028
2068
2108
2148
2188
Measured
Basecase


S2279_477
Groundwater...level...(mAHD)
300
250
200
150
100
50
0
−50
1988
2028
2068
2108
2148
2188
Year
Measured
Basecase

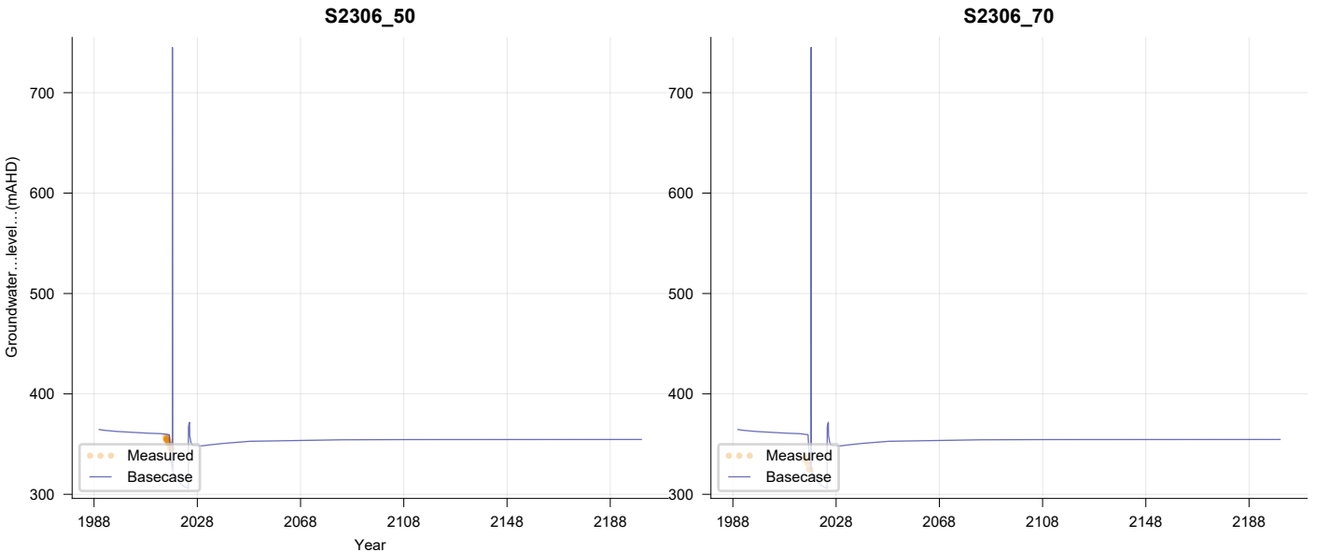

S2288_280
325
300
275
250
225
200
175
150
1988
2028
2068
2108
2148
2188
Measured
Basecase


S2291_394
Groundwater...level...(mAHD)
340
320
300
280
260
240
220
1988
2028
2068
2108
2148
2188
Year
Measured
Basecase

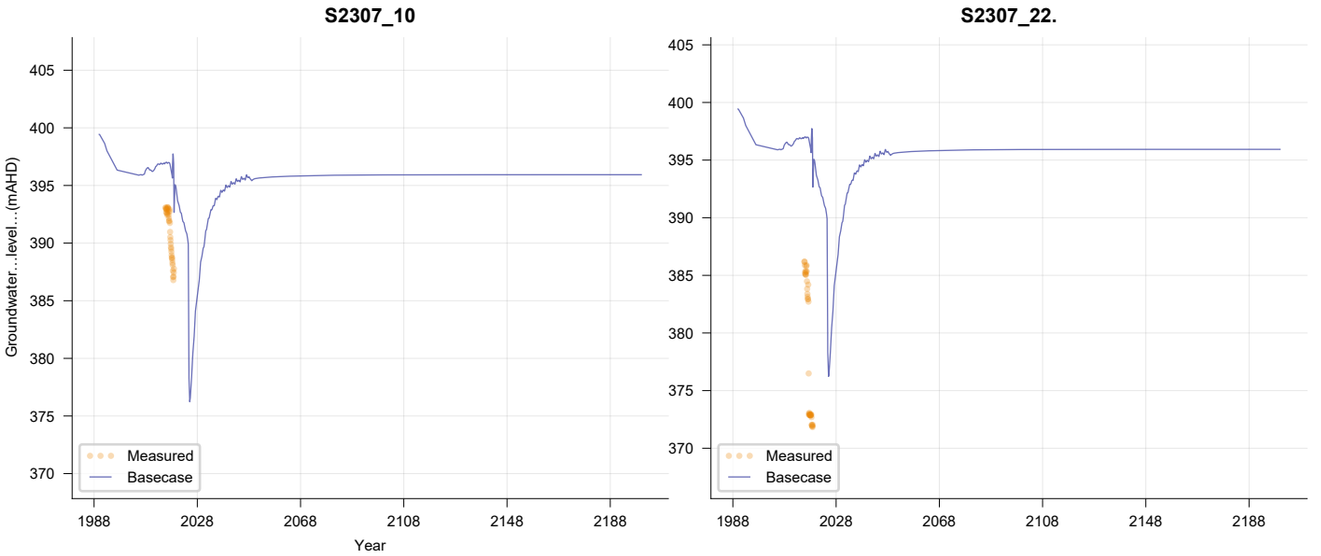

S2291_419
320
300
280
260
240
220
1988
2028
2068
2108
2148
2188
Measured
Basecase


S2306_10
Groundwater…level…(mAHD)
405
400
395
390
385
380
375
370
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

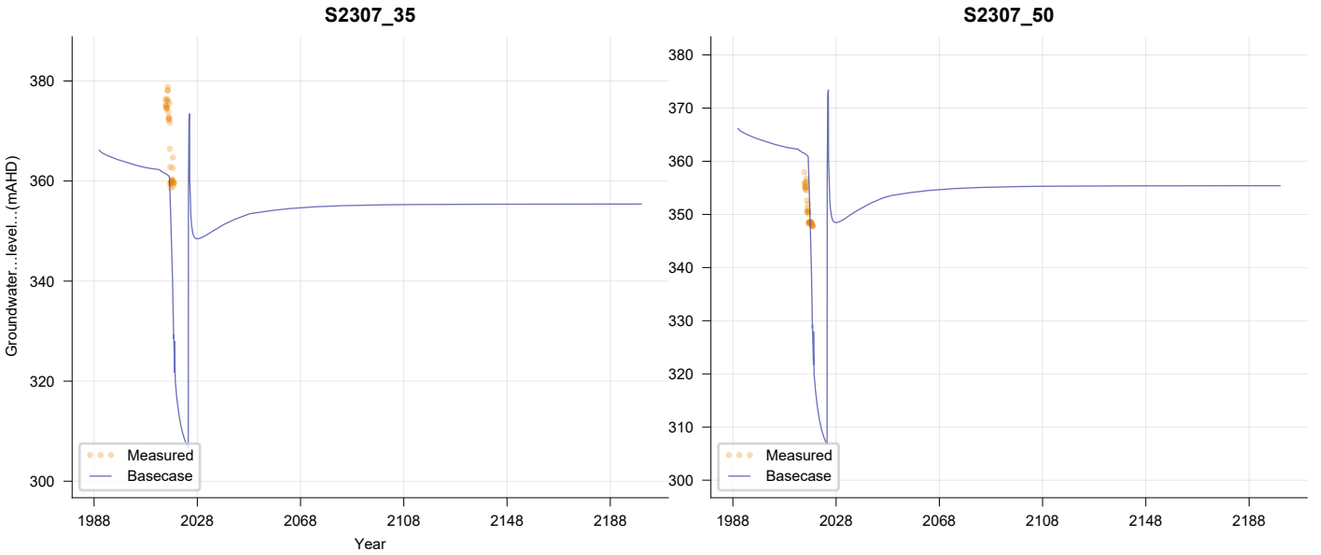

S2306_30
400
395
390
385
380
375
370
365
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2306_50
Groundwater…level…(mAHD)
700
600
500
400
300
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

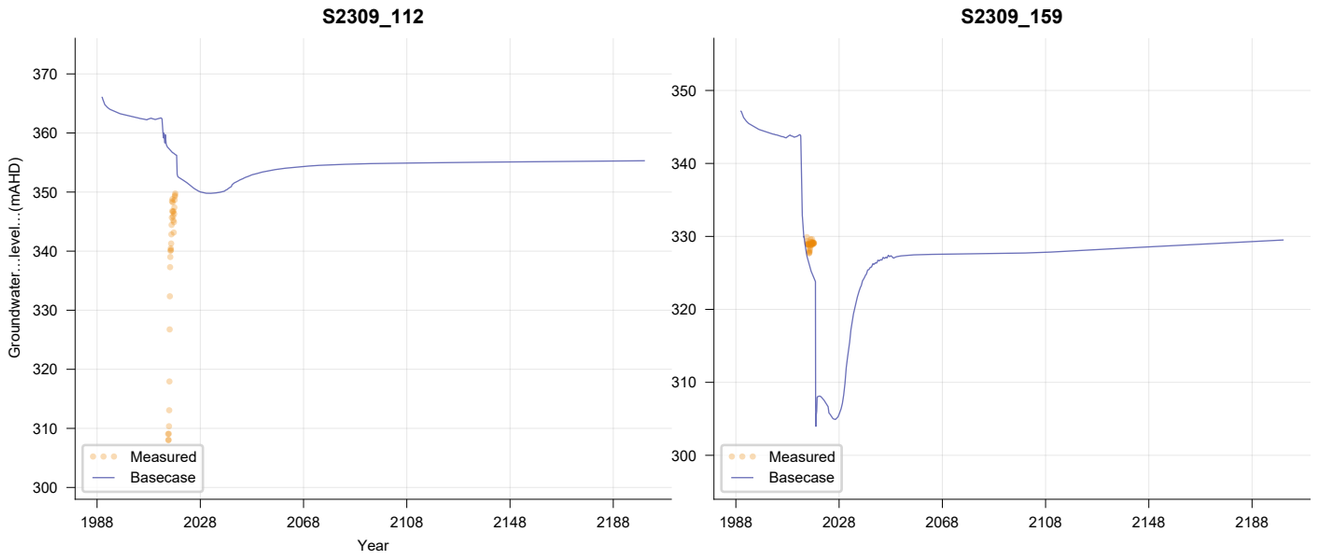

S2306_70
700
600
500
400
300
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2307_10
Groundwater…level…(mAHD)
405
400
395
390
385
380
375
370
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

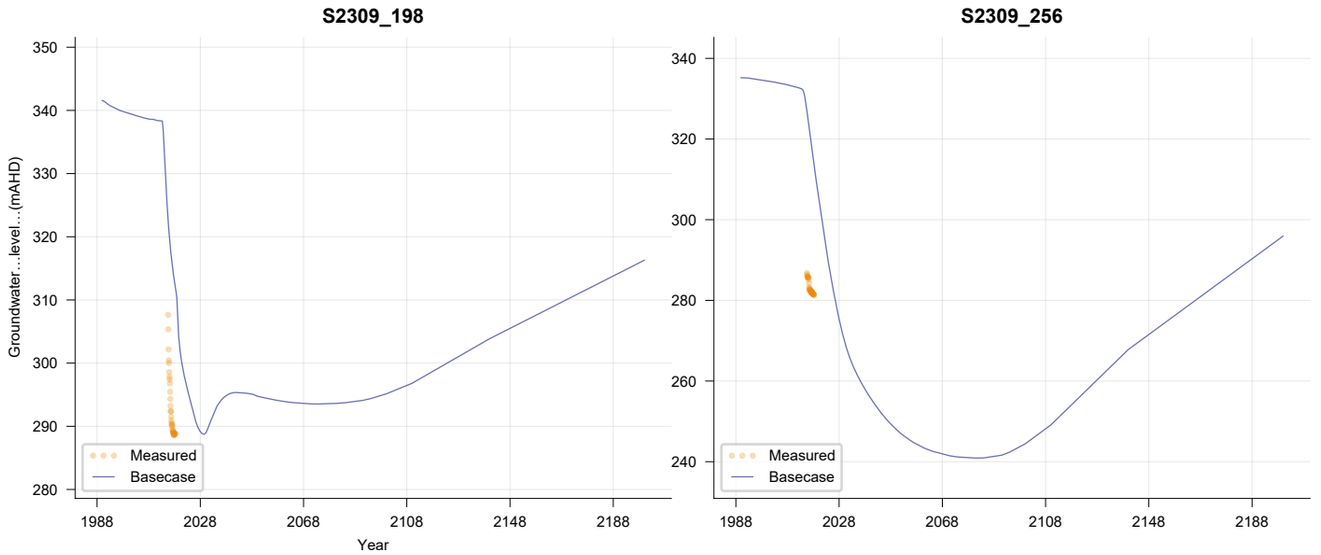

S2307_22.
405
400
395
390
385
380
375
370
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2307_35
Groundwater…level…(mAHD)
380
360
340
320
300
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

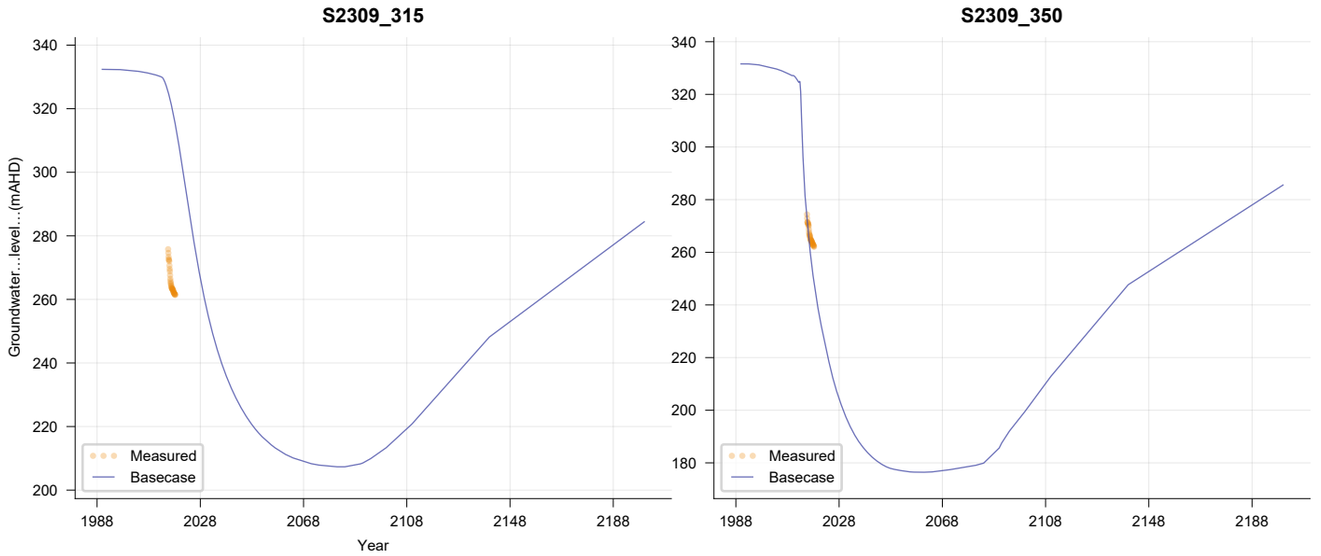

S2307_50
380
370
360
350
340
330
320
310
300
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2309_112
Groundwater...level...(mAHD)
370
360
350
340
330
320
310
300
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

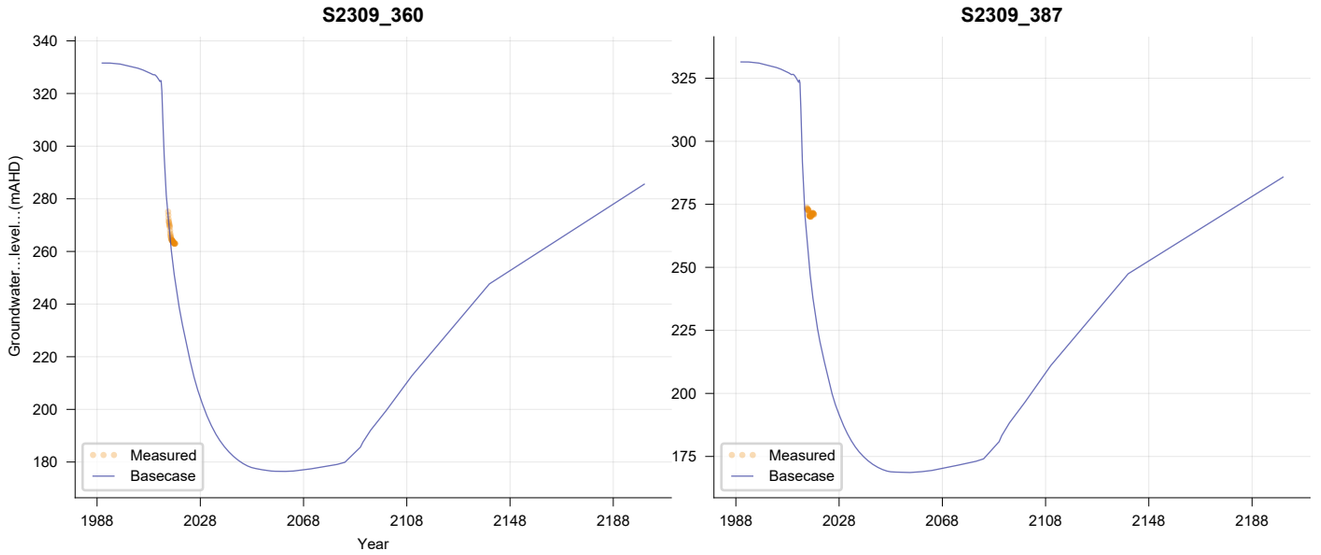

S2309_159
350
340
330
320
310
300
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2309_198
Groundwater...level...(mAHD)
350
340
330
320
310
300
290
280
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

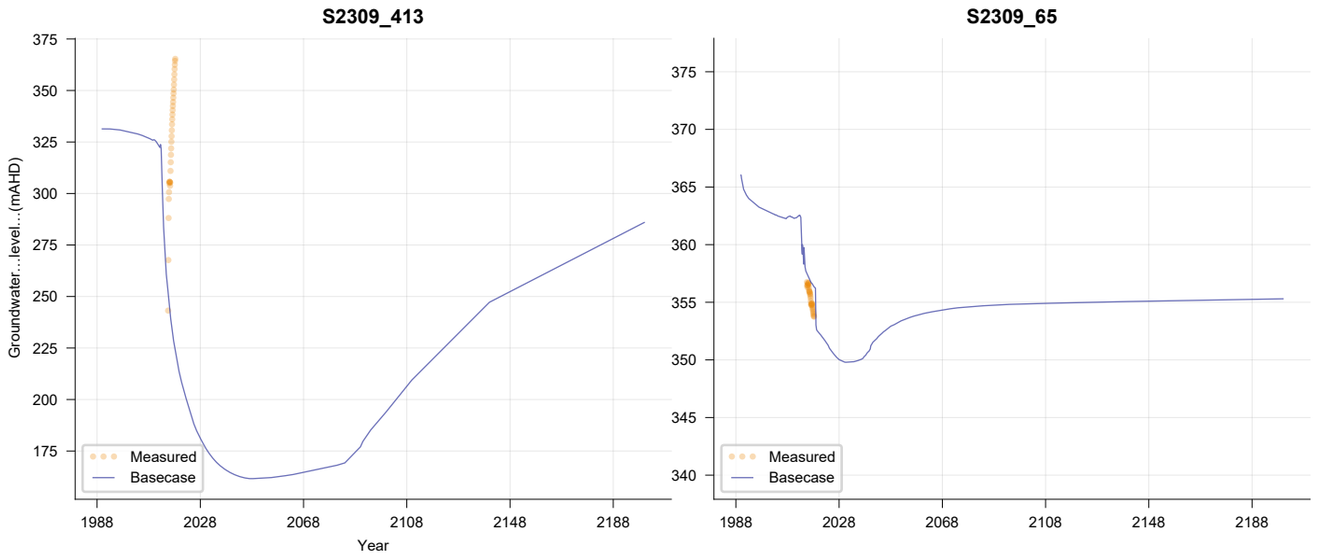

S2309_256
340
320
300
280
260
240
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2309_315
Groundwater...level...(mAHD)
340
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

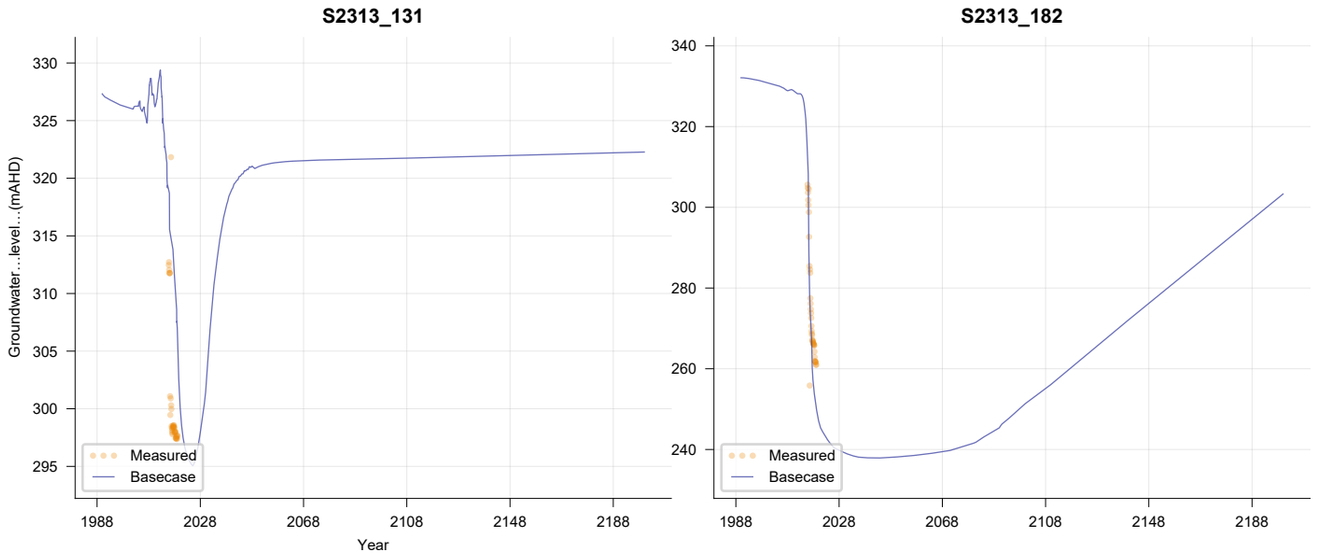

S2309_350
340
320
300
280
260
240
220
200
180
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2309_360
Groundwater...level...(mAHD)
340
320
300
280
260
240
220
200
180
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

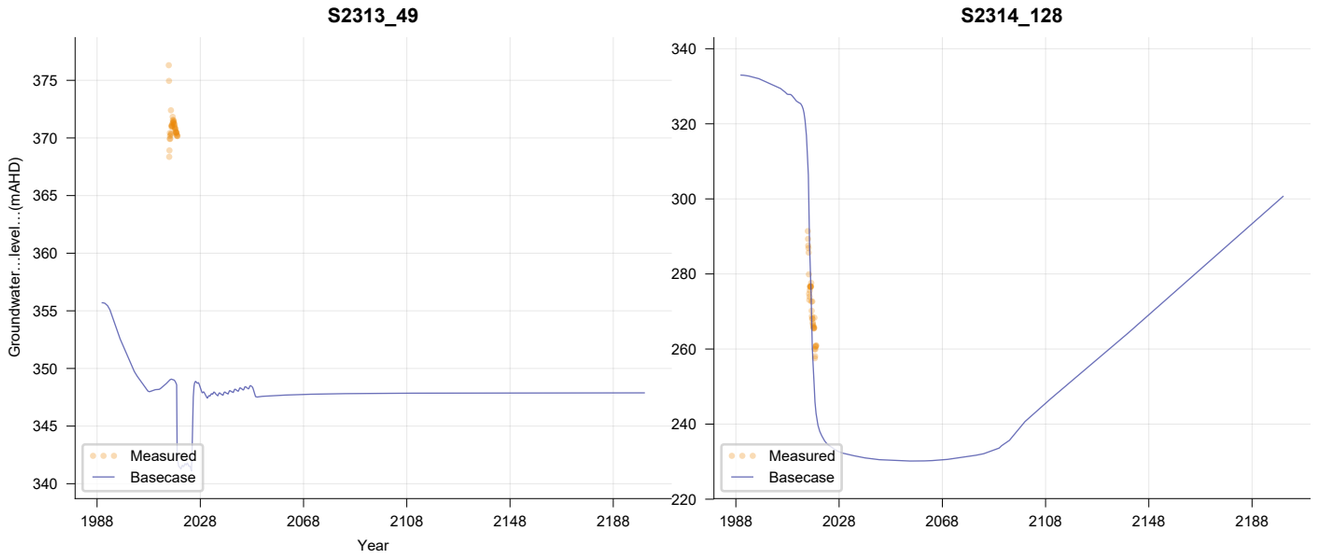

S2309_387
325
300
275
250
225
200
175
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2309_413
Groundwater...level...(mAHD)
Year
Measured
Basecase

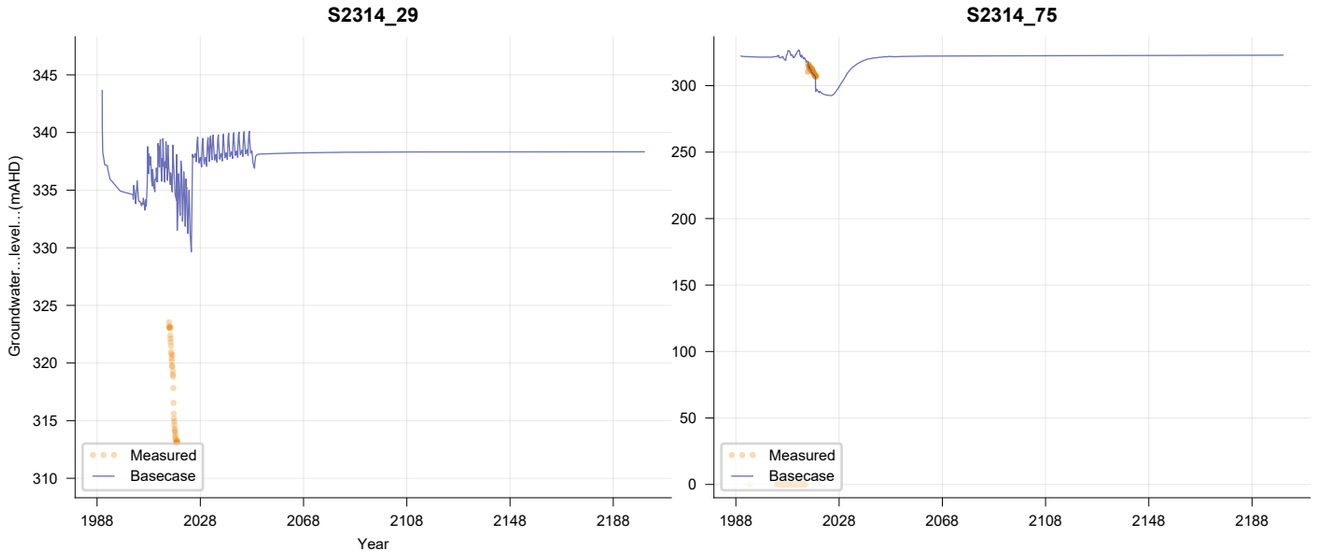

S2309_65
Measured
Basecase


S2313_131
Groundwater...level...(mAHD)
Year
Measured
Basecase

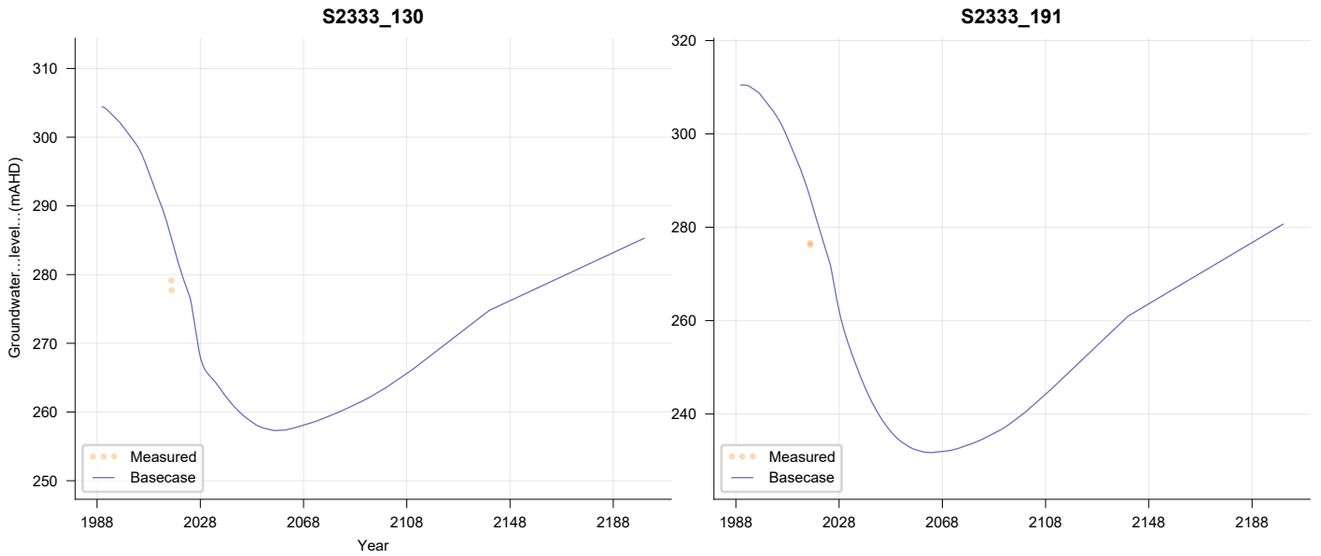

S2313_182
Measured
Basecase


S2313_49
Groundwater...level...(mAHD)
Year
Measured
Basecase

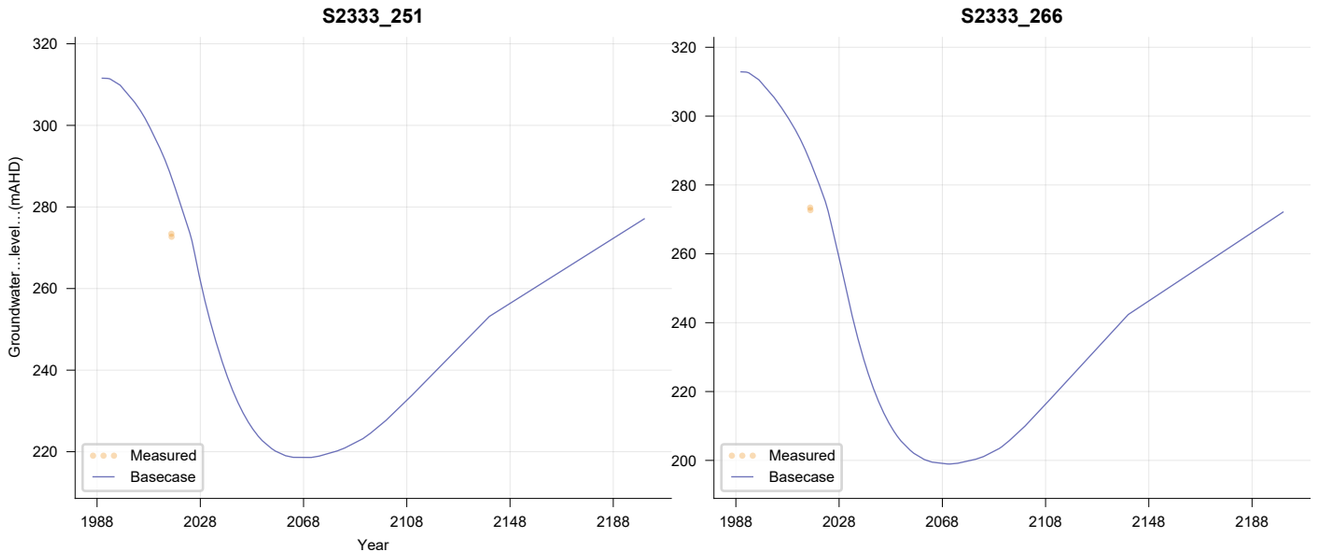

S2314_128
Measured
Basecase


S2314_29
Groundwater...level...(mAHD)
Year
Measured
Basecase

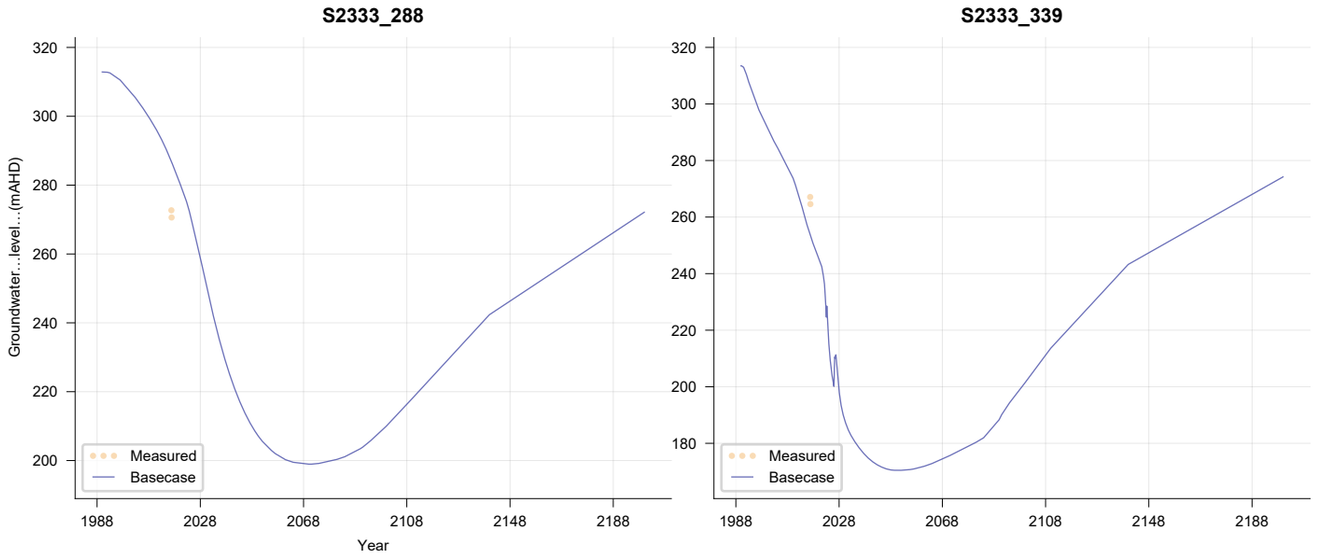

S2314_75
Measured
Basecase


S2333_130
Groundwater...level...(mAHD)
Year
Measured
Basecase

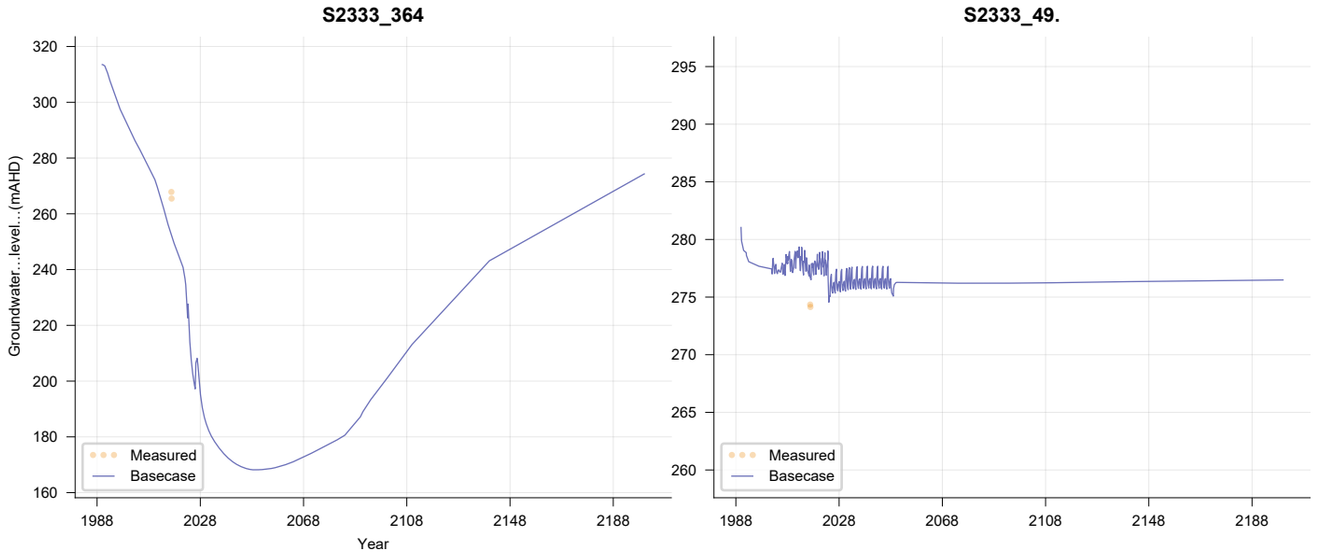

S2333_191
Measured
Basecase


S2333_251
Groundwater...level...(mAHD)
Year
Measured
Basecase

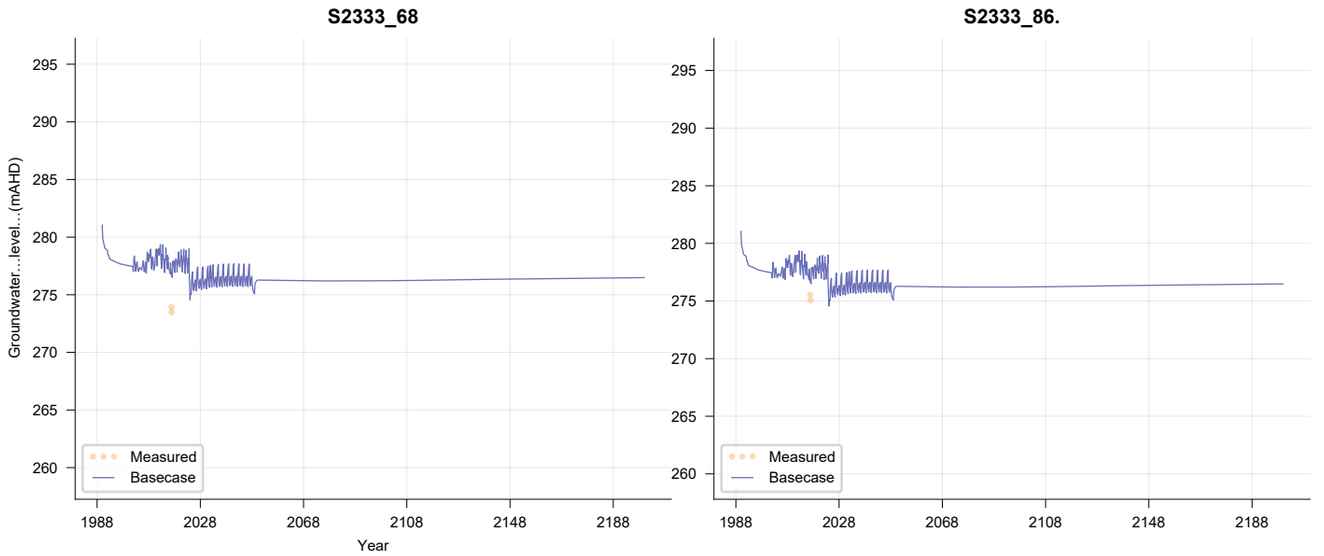

S2333_266
Measured
Basecase


S2333_288
Groundwater...level...(mAHD)
Year
Measured
Basecase

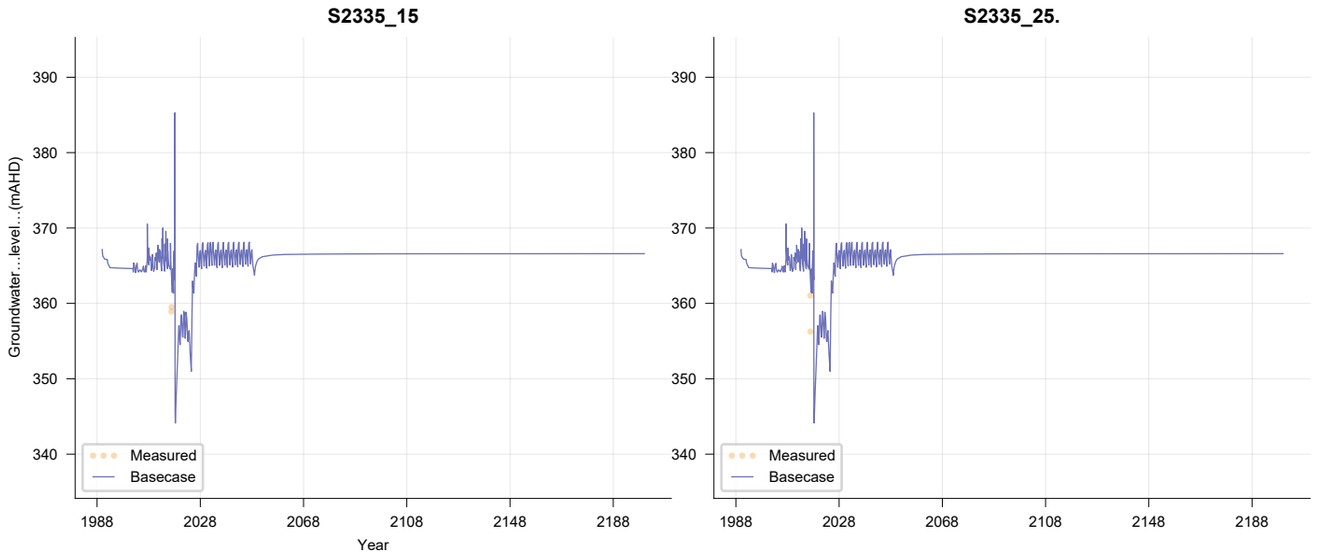

S2333_339
Measured
Basecase


S2333_364
Groundwater...level...(mAHD)
Year
Measured
Basecase

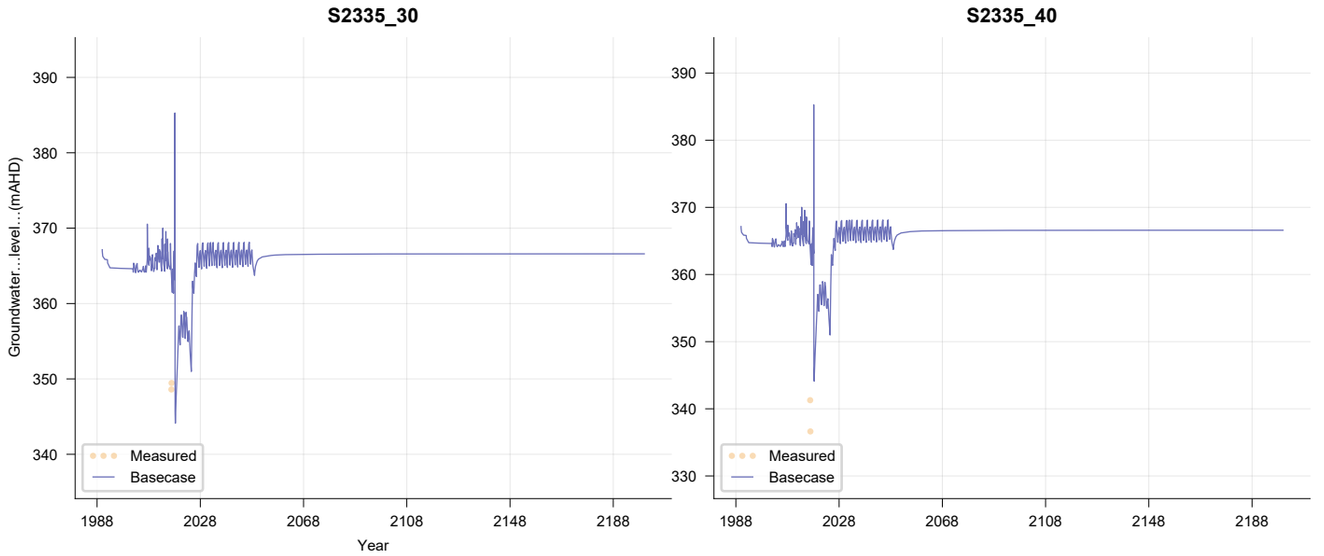

S2333_49.
Measured
Basecase


S2333_68
Groundwater...level...(mAHD)
295
290
285
280
275
270
265
260
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

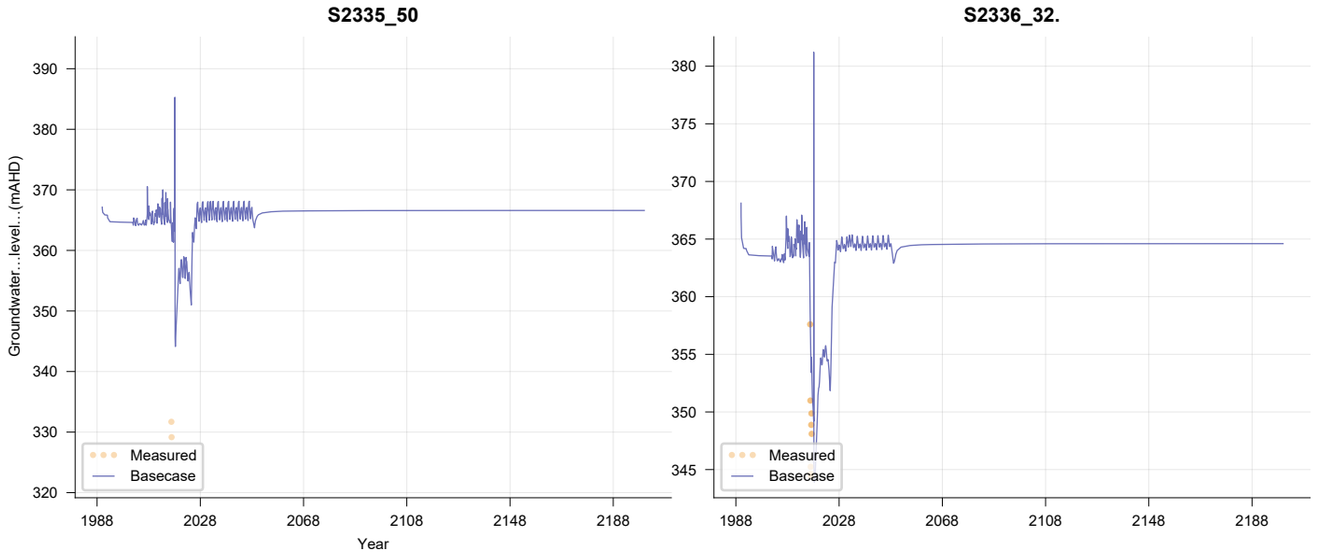

S2333_86.
295
290
285
280
275
270
265
260
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2335_15
Groundwater...level...(mAHD)
390
380
370
360
350
340
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

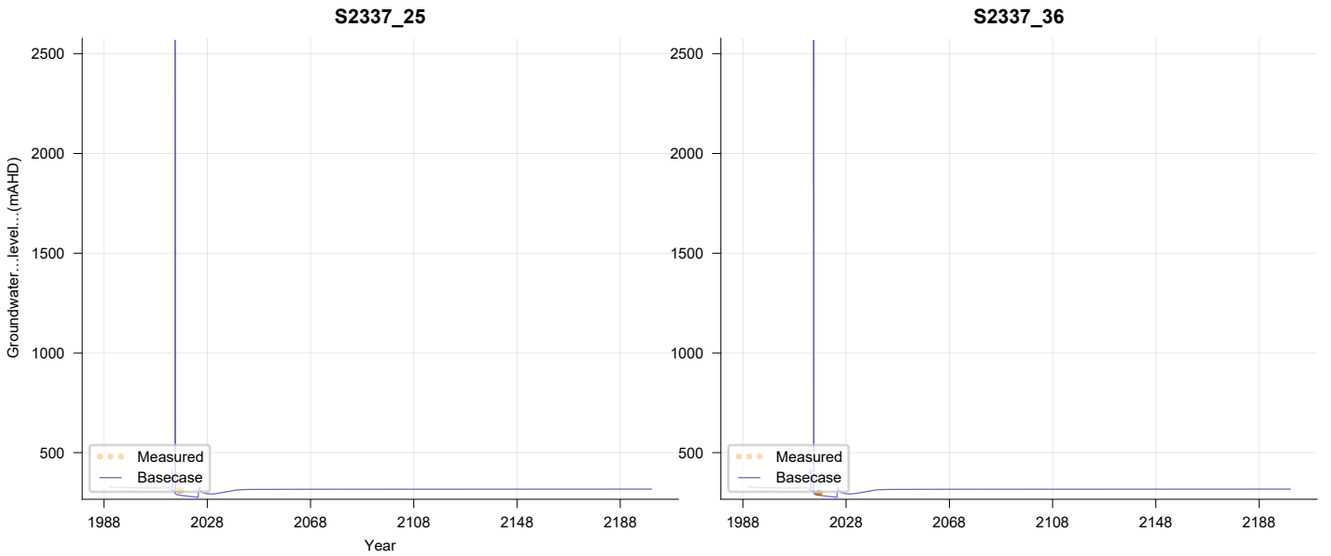

S2335_25.
390
380
370
360
350
340
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2335_30
Groundwater...level...(mAHD)
390
380
370
360
350
340
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

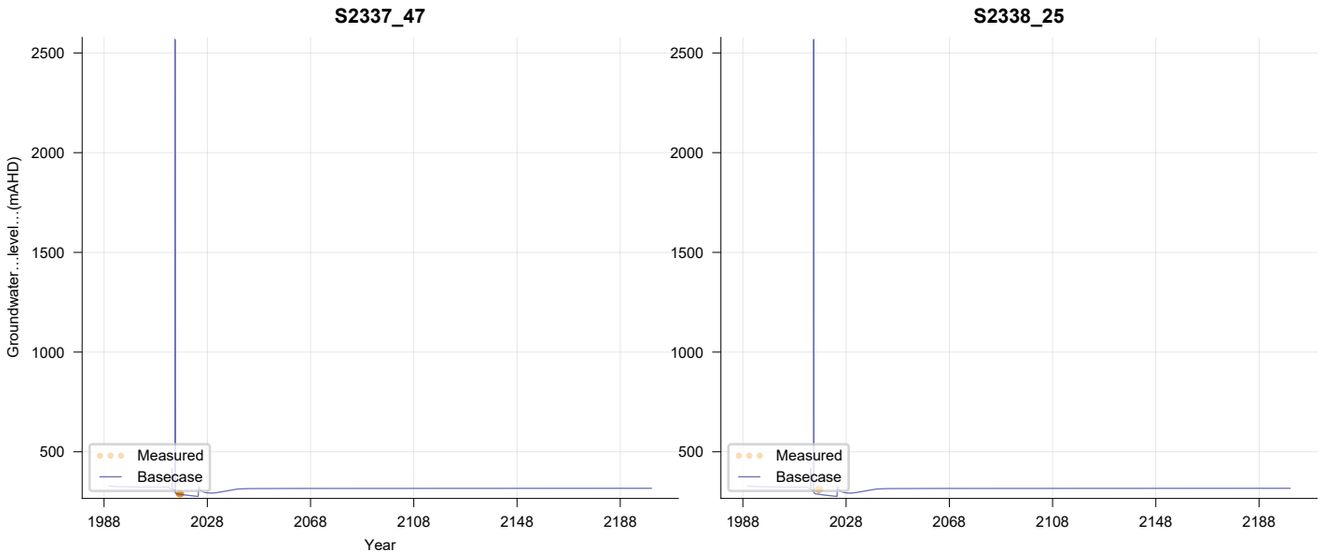

S2335_40
390
380
370
360
350
340
330
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2335_50
Groundwater...level...(mAHD)
390
380
370
360
350
340
330
320
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

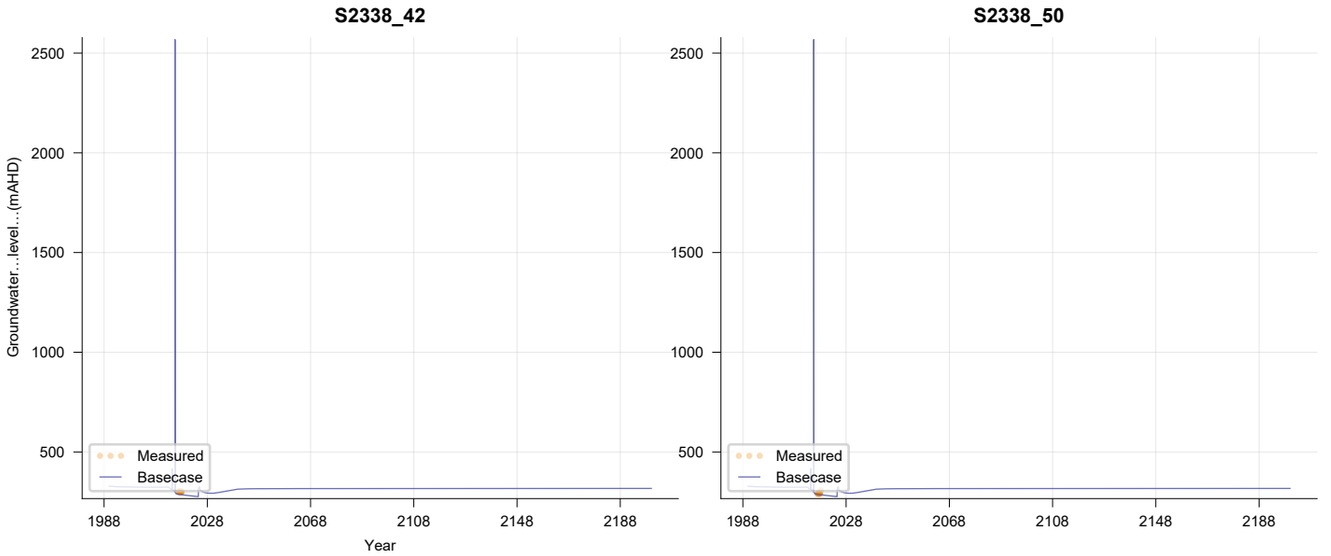

S2336_32.
380
375
370
365
360
355
350
345
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2337_25
Groundwater...level...(mAHD)
2500
2000
1500
1000
500
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

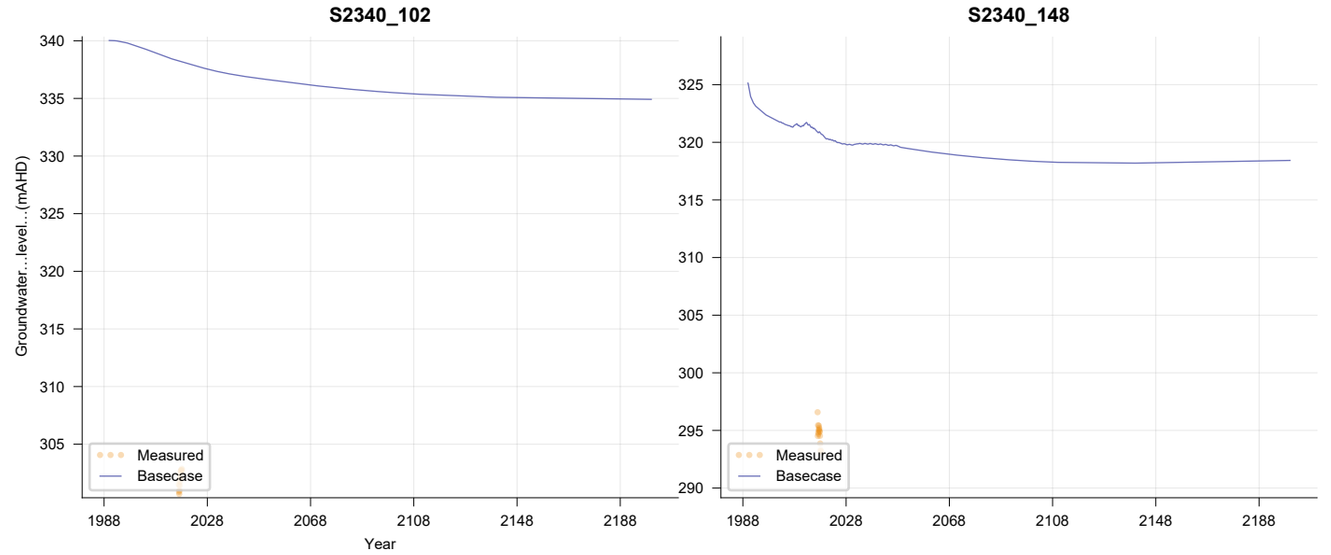

S2337_36
2500
2000
1500
1000
500
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2337_47
Groundwater...level...(mAHD)
2500
2000
1500
1000
500
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

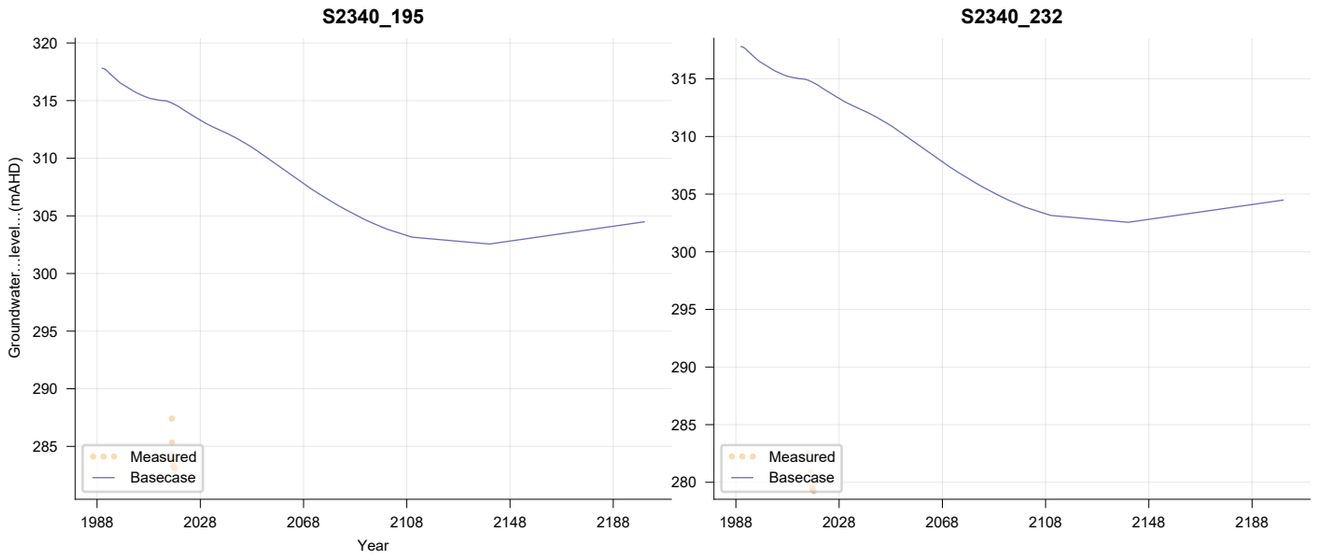

S2338_25
2500
2000
1500
1000
500
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2338_42
Groundwater...level...(mAHD)
2500
2000
1500
1000
500
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

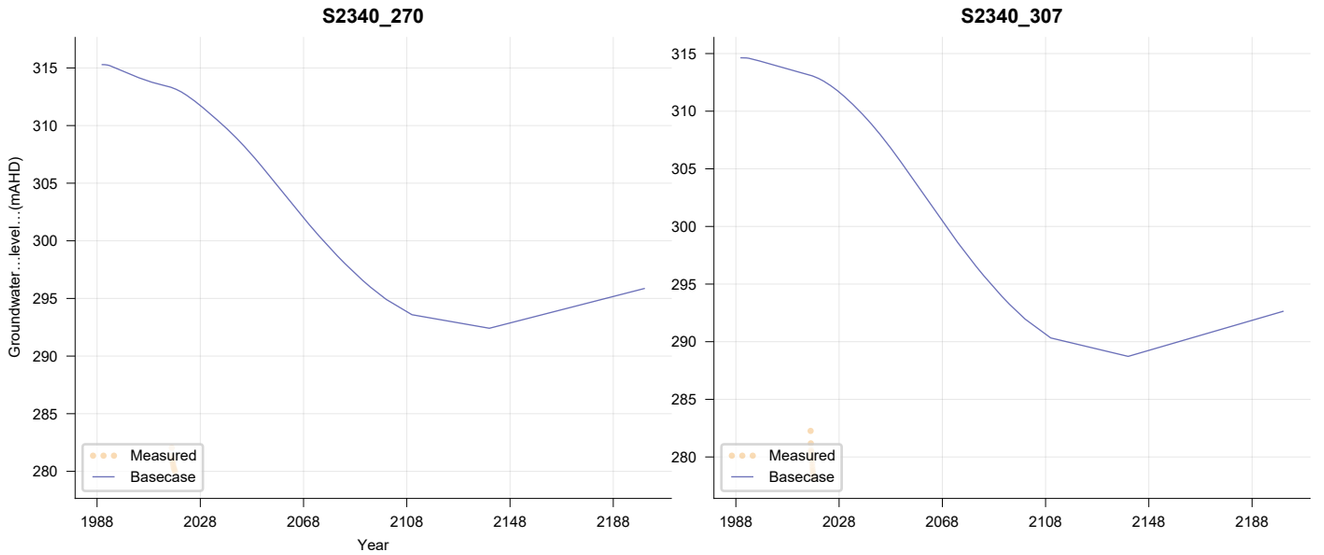

S2338_50
2500
2000
1500
1000
500
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2340_102
Groundwater...level...(mAHD)
340
335
330
325
320
315
310
305
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

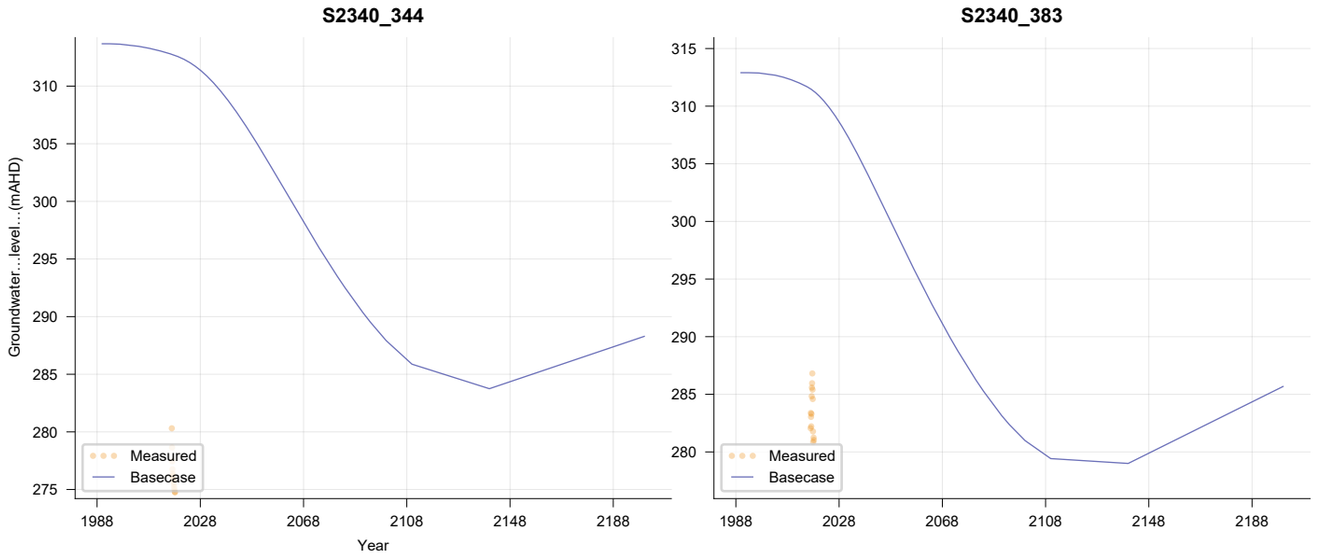

S2340_148
325
320
315
310
305
300
295
290
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2340_195
Groundwater...level...(mAHD)
320
315
310
305
300
295
290
285
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

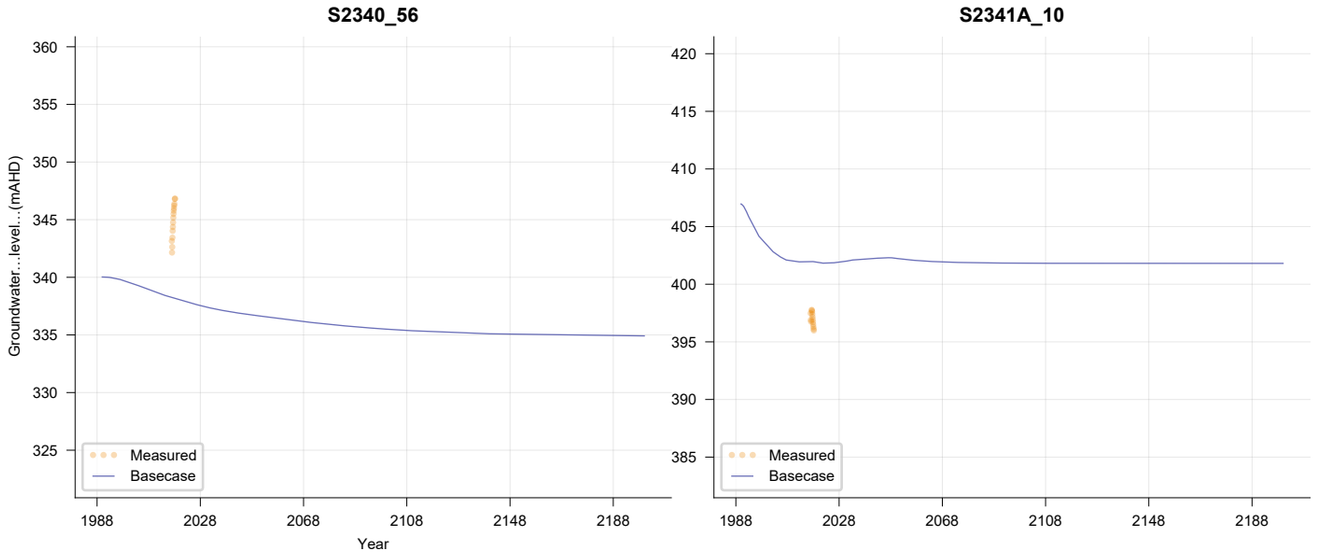

S2340_232
315
310
305
300
295
290
285
280
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2340_270
Groundwater...level...(mAHD)
315
310
305
300
295
290
285
280
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

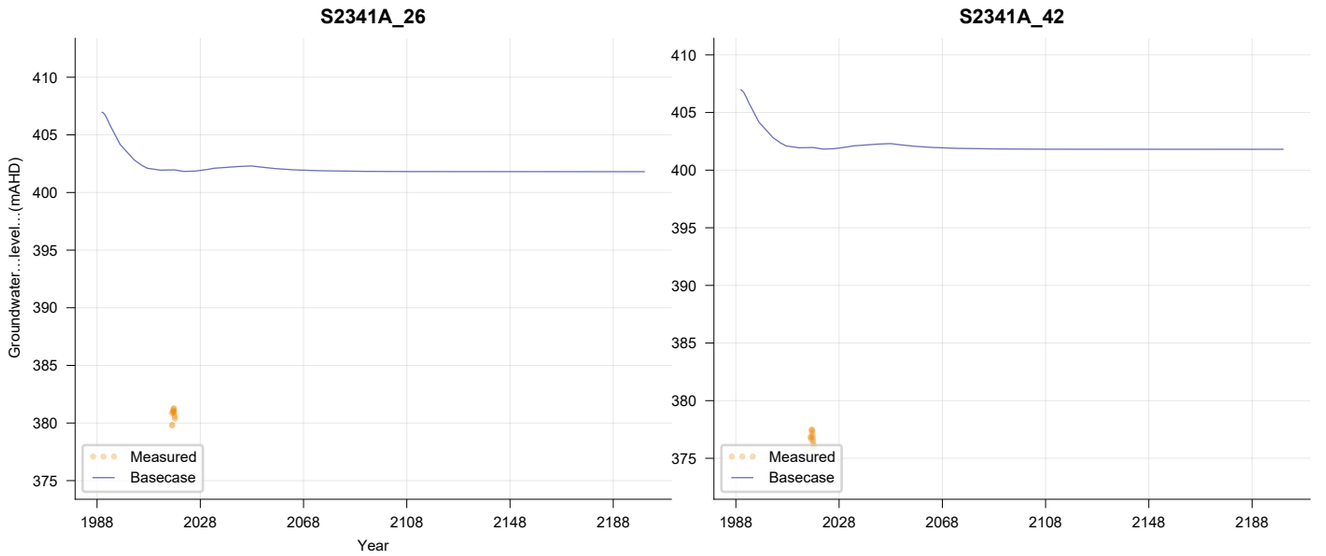

S2340_307
315
310
305
300
295
290
285
280
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2340_344
Groundwater...level...(mAHD)
310
305
300
295
290
285
280
275
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

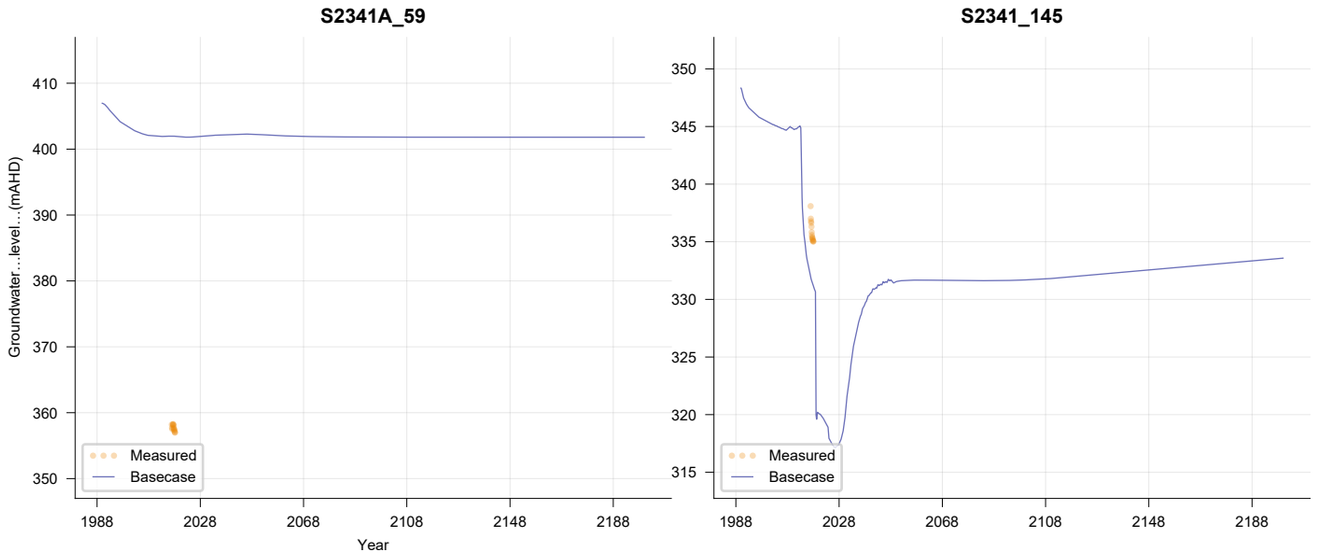

S2340_383
315
310
305
300
295
290
285
280
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2340_56
Groundwater...level...(mAHD)
360
355
350
345
340
335
330
325
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

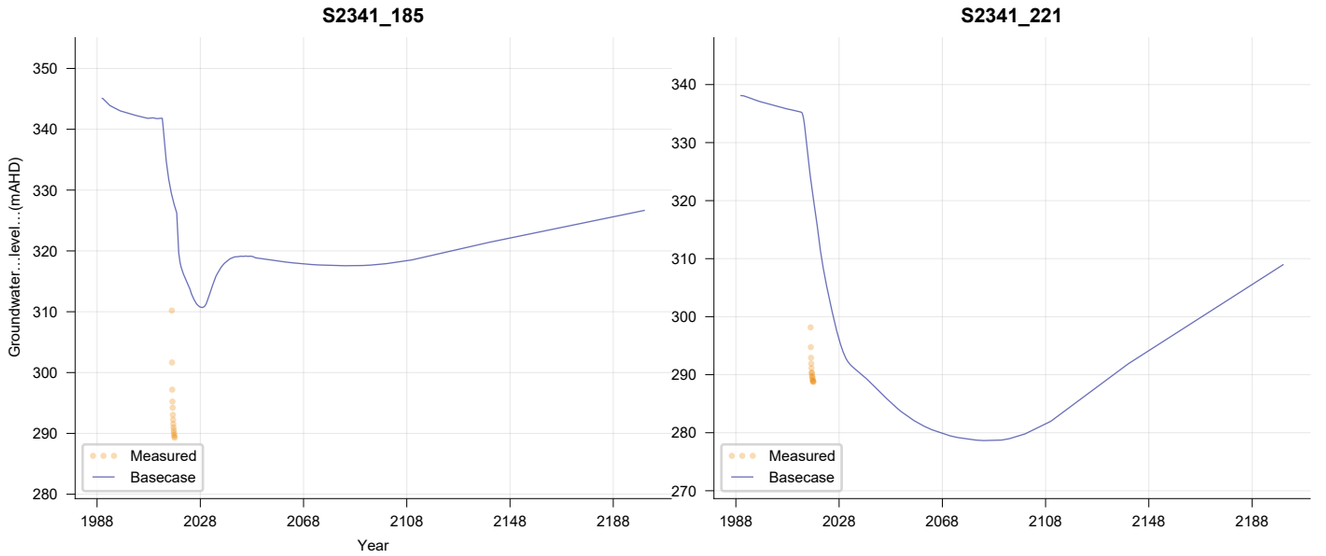

S2341A_10
420
415
410
405
400
395
390
385
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2341A_26
Groundwater...level...(mAHD)
Year
Measured
Basecase

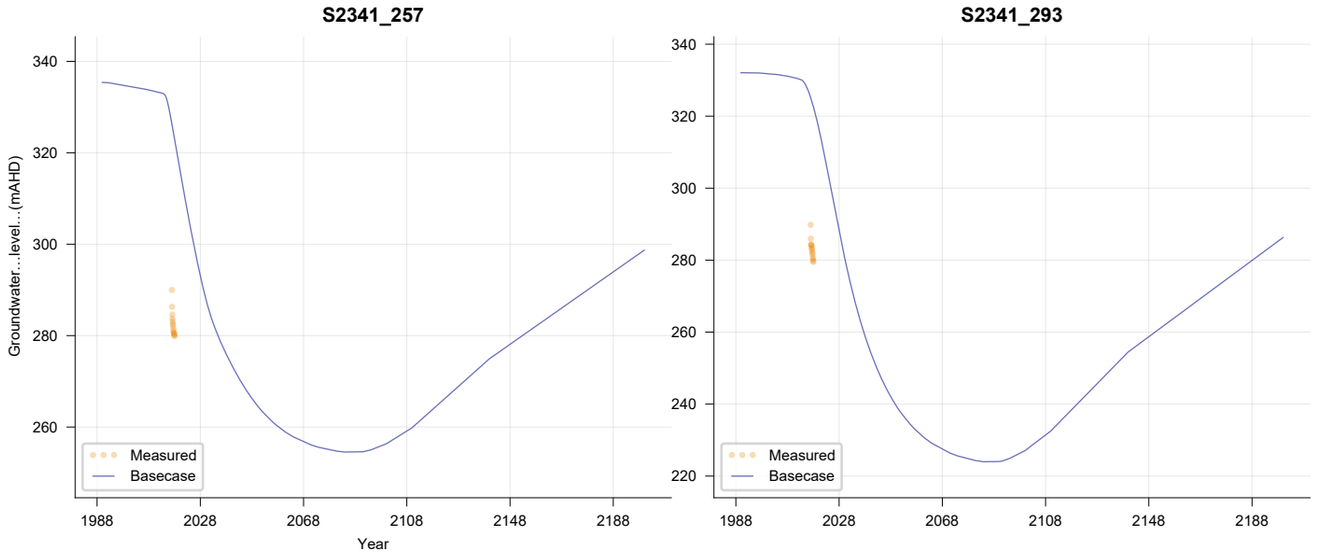

S2341A_42
Measured
Basecase


S2341A_59
Groundwater...level...(mAHD)
Year
Measured
Basecase

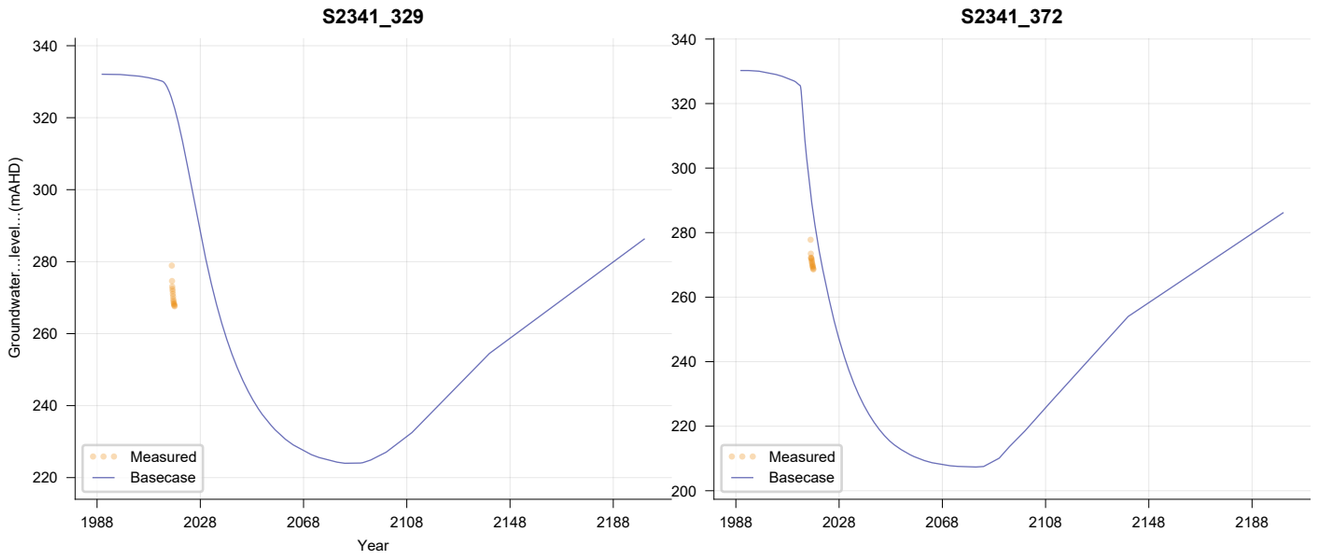

S2341_145
Measured
Basecase


S2341_185
Groundwater...level...(mAHD)
Year
Measured
Basecase

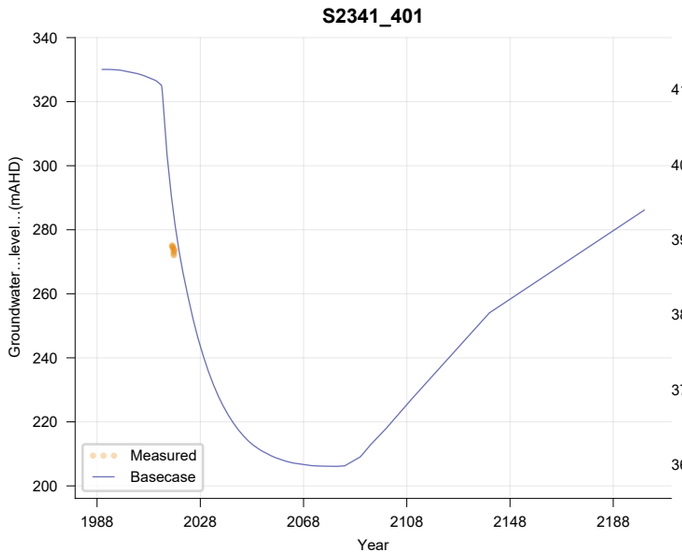

S2341_221
Measured
Basecase

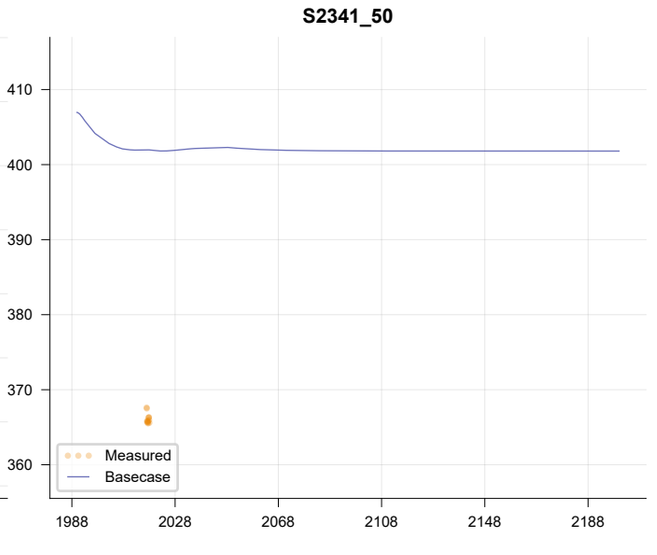

S2341_257
Groundwater...level...(mAHD)
Year
Measured
Basecase

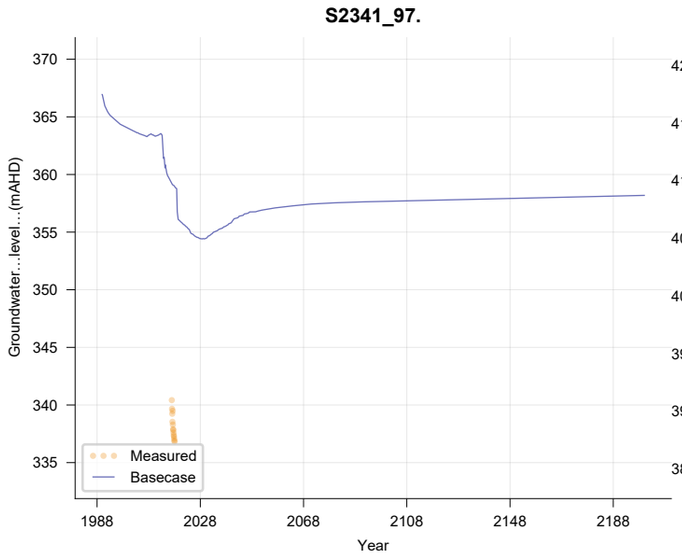

S2341_293
Measured
Basecase

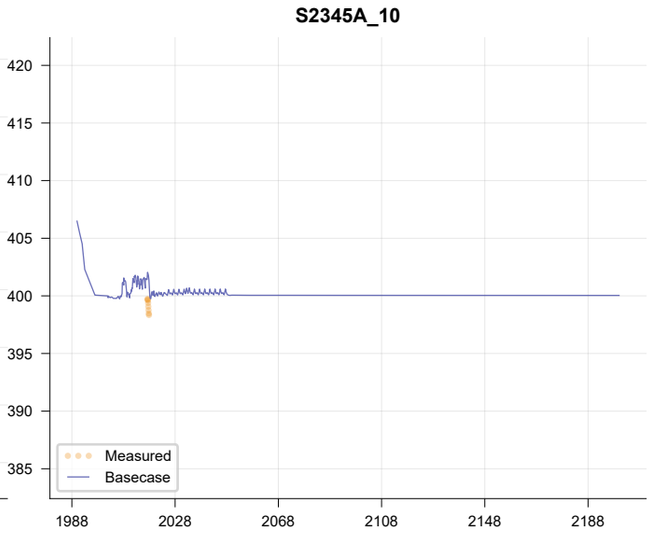

S2341_329
Groundwater...level...(mAHD)
Year
Measured
Basecase

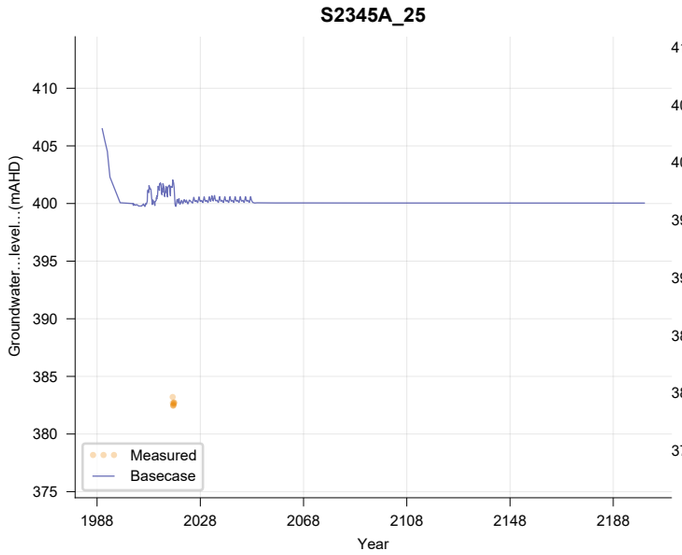

S2341_372
Measured
Basecase

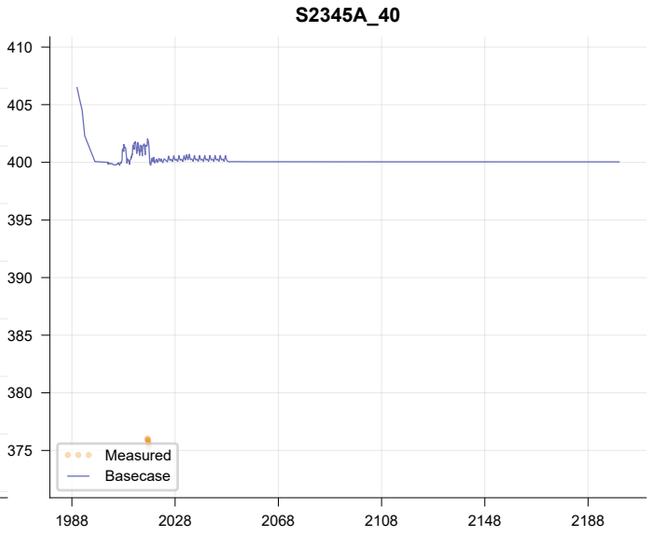

S2341_401
Groundwater...level...(mAHD)
Year
Measured
Basecase

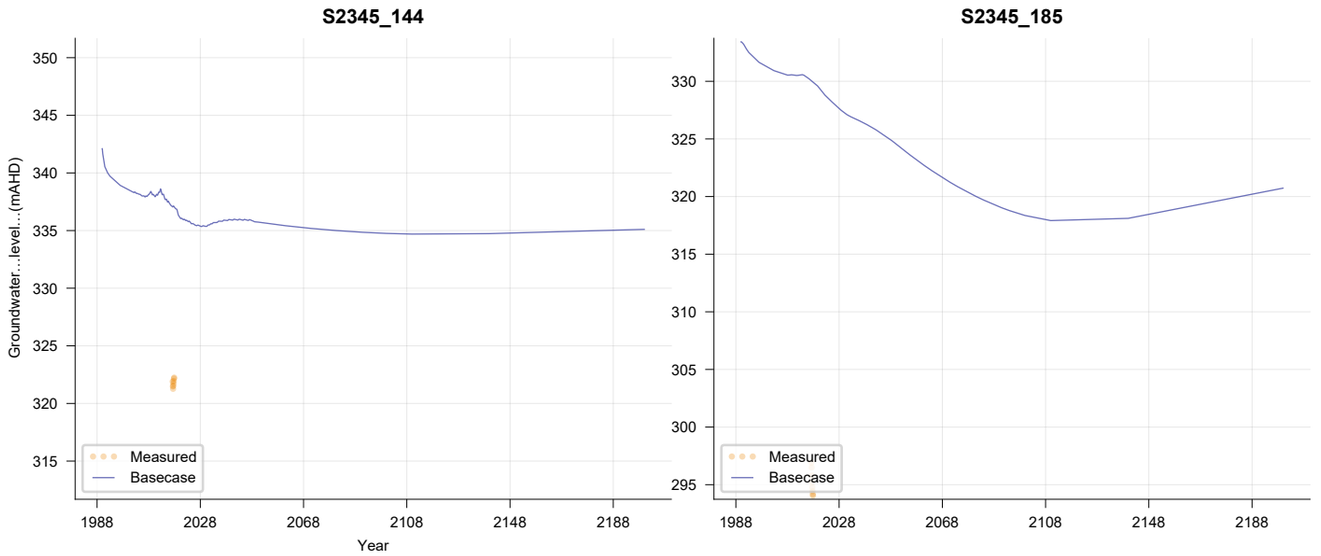

S2341_50
Measured
Basecase


S2341_97.
Groundwater...level...(mAHD)
Year
Measured
Basecase

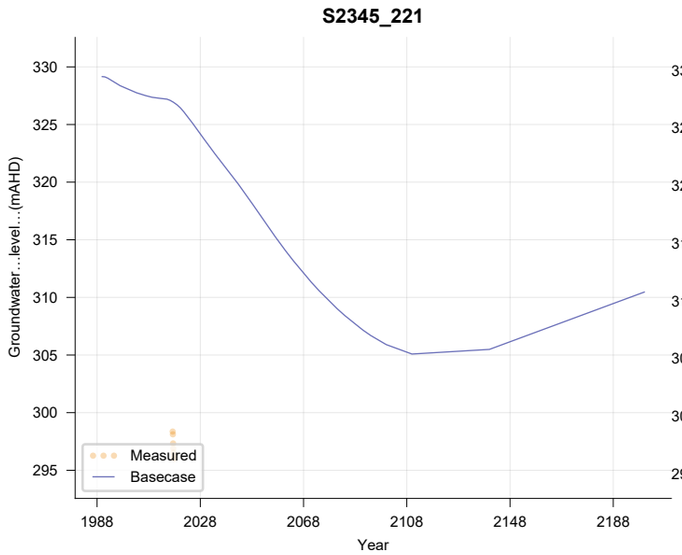

S2345A_10
Measured
Basecase

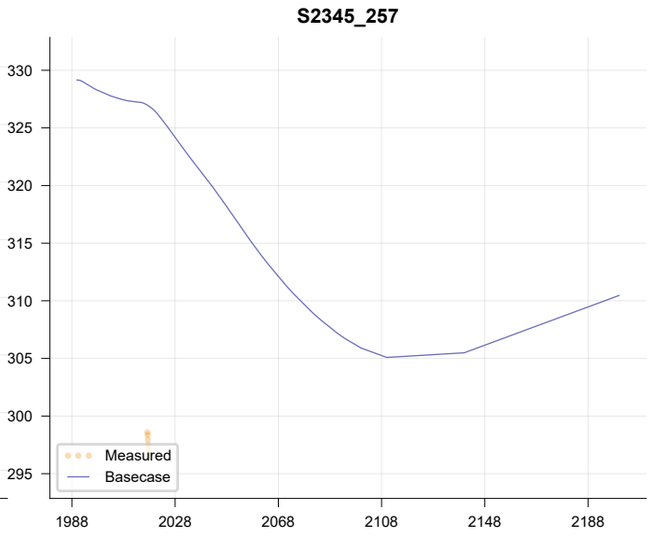

S2345A_25
Groundwater...level...(mAHD)
Year
Measured
Basecase

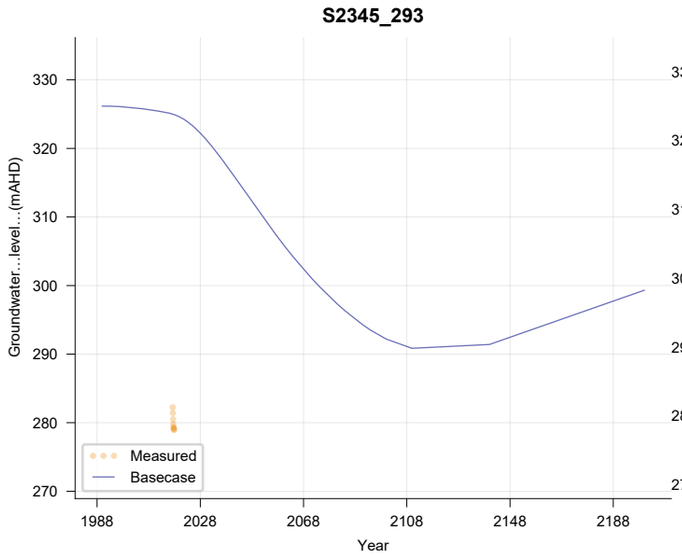

S2345A_40
Measured
Basecase

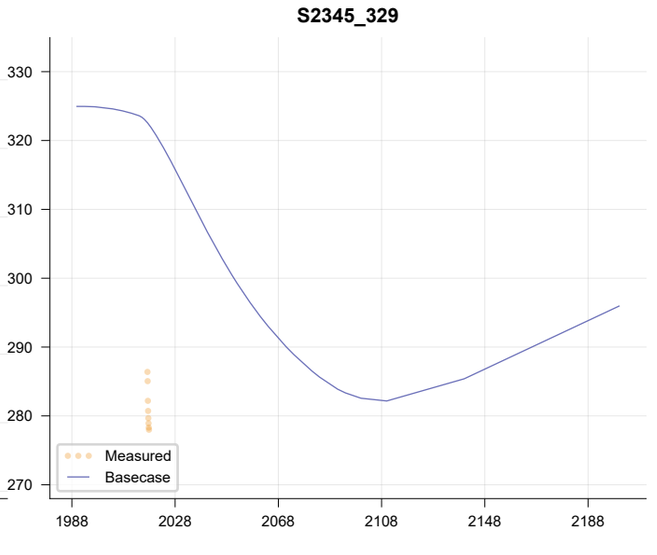

S2345_144
Groundwater...level...(mAHD)
Year
Measured
Basecase

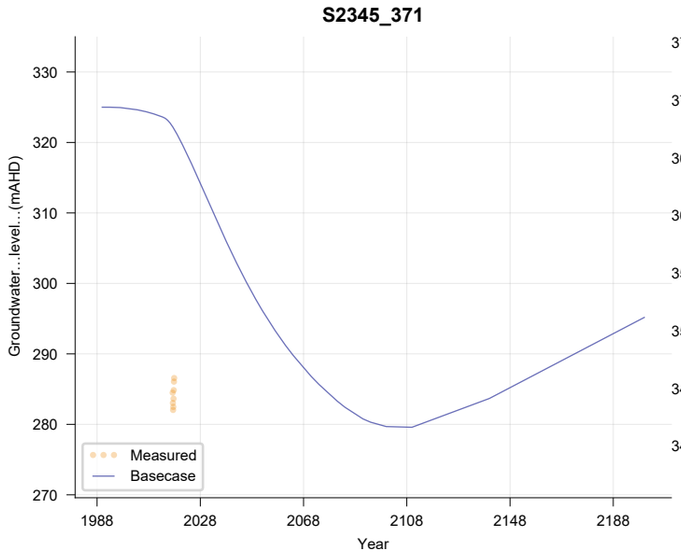

S2345_185
Measured
Basecase

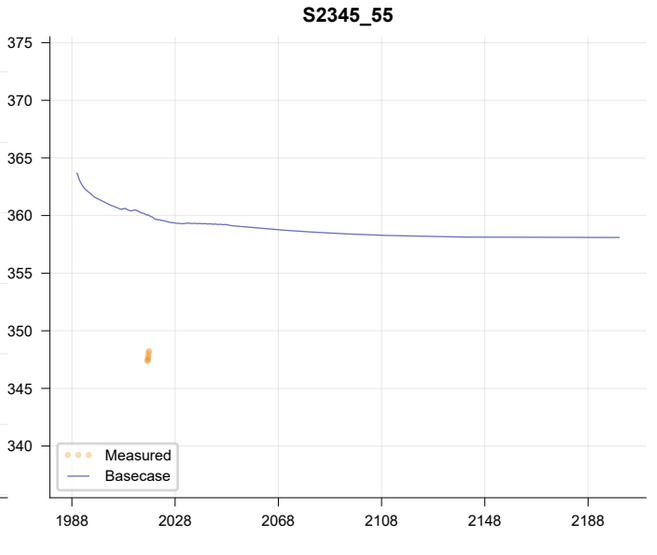

S2345_221
Groundwater...level...(mAHD)
Year
Measured
Basecase

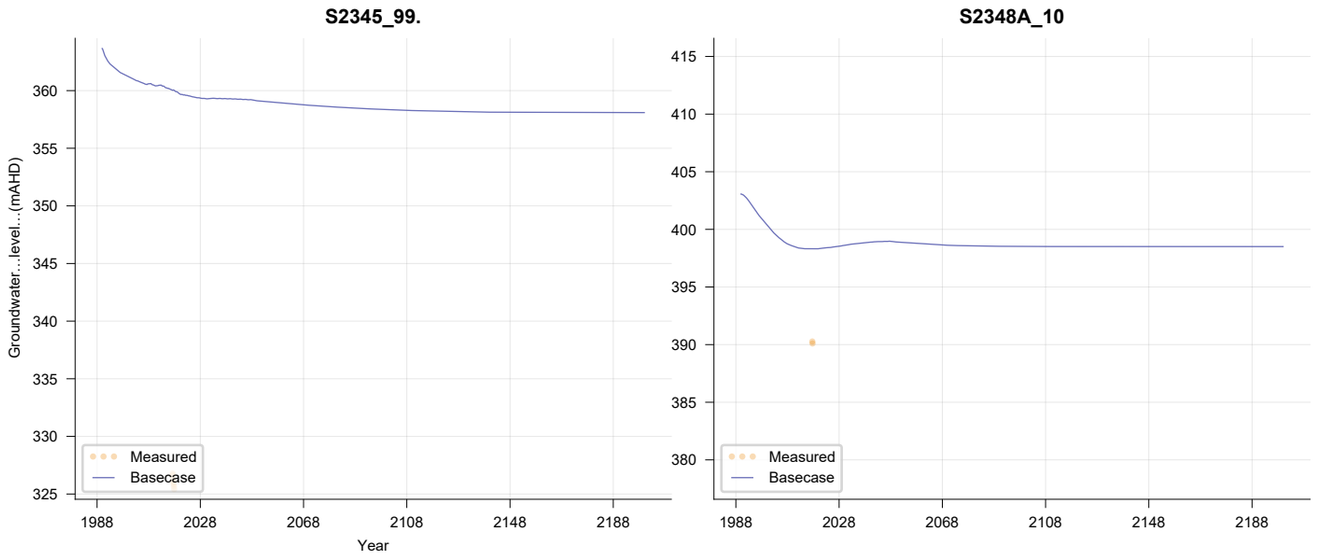

S2345_257
Measured
Basecase


S2345_293
Groundwater...level...(mAHD)
Year
Measured
Basecase

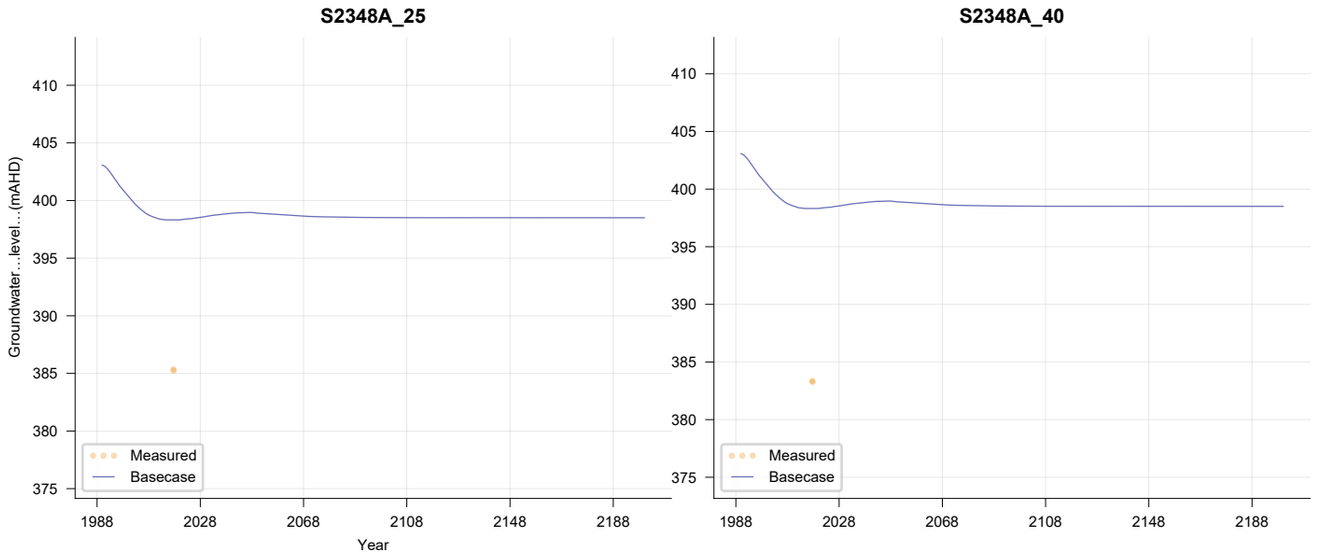

S2345_329
Measured
Basecase


S2345_371
Groundwater...level...(mAHD)
Year
Measured
Basecase

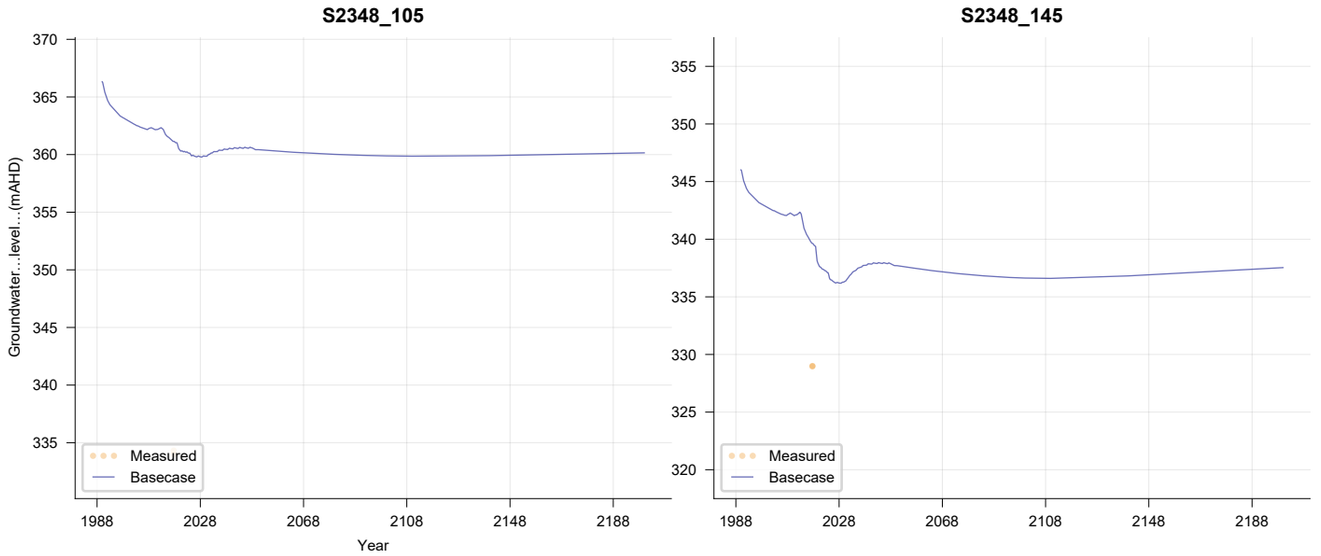

S2345_55
Measured
Basecase


S2345_99.
Groundwater...level...(mAHD)
Year
Measured
Basecase

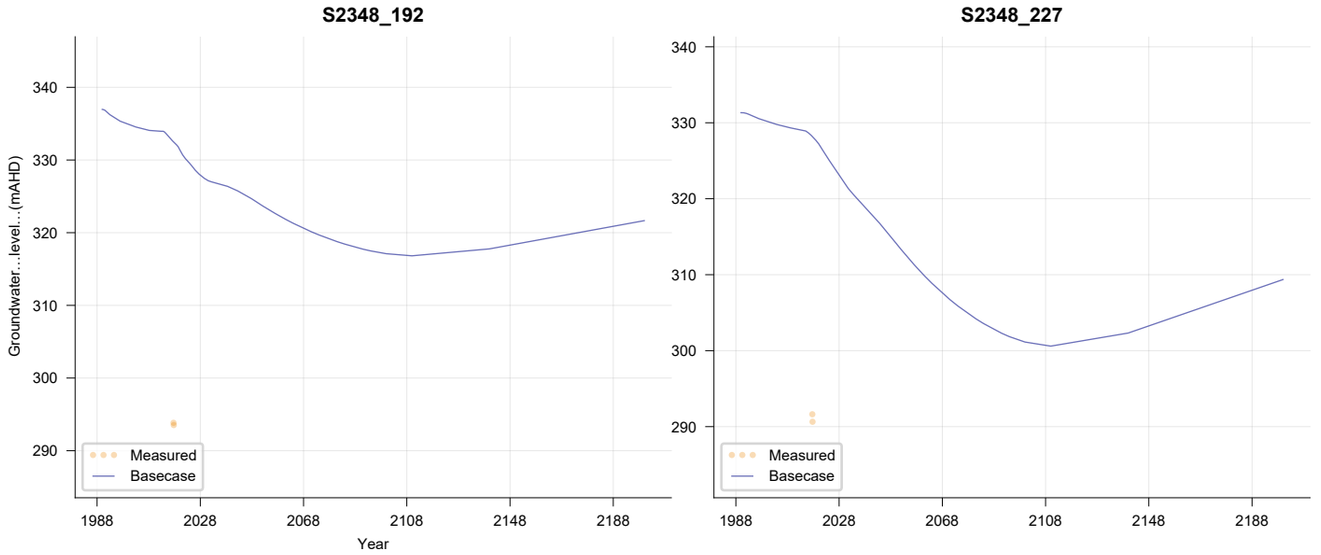

S2348A_10
Measured
Basecase


S2348A_25
Groundwater...level...(mAHD)
Year
Measured
Basecase

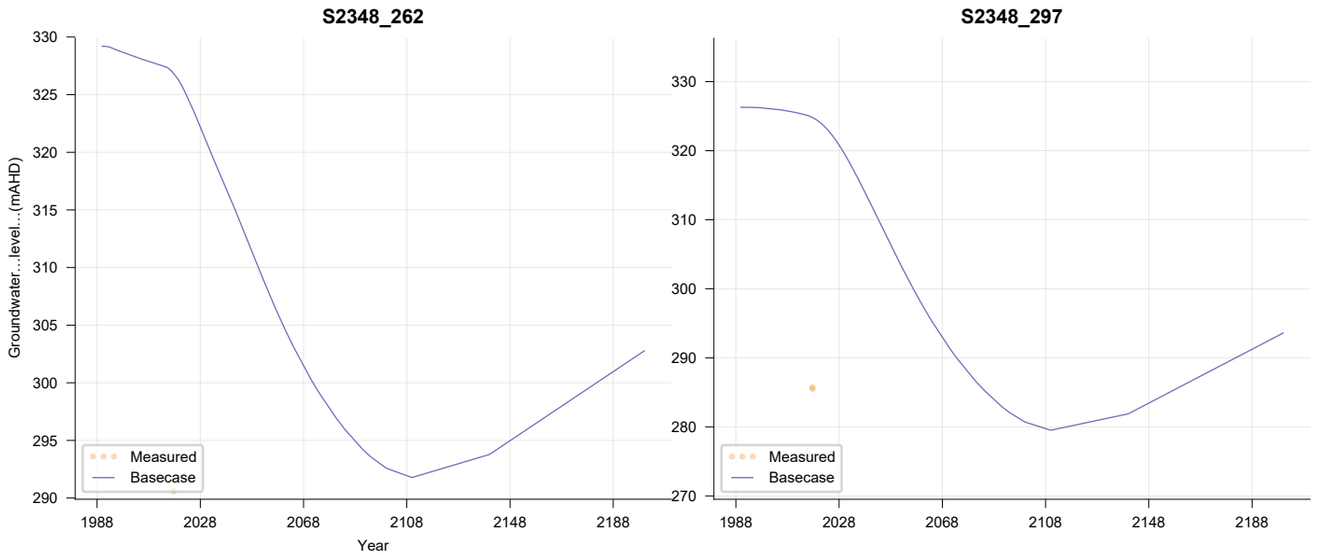

S2348A_40
Measured
Basecase


S2348_105
Groundwater...level...(mAHD)
Year
Measured
Basecase

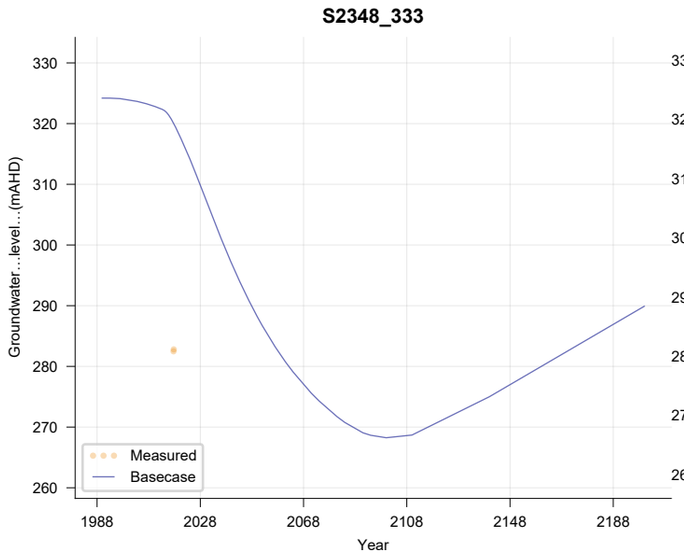

S2348_145
Measured
Basecase

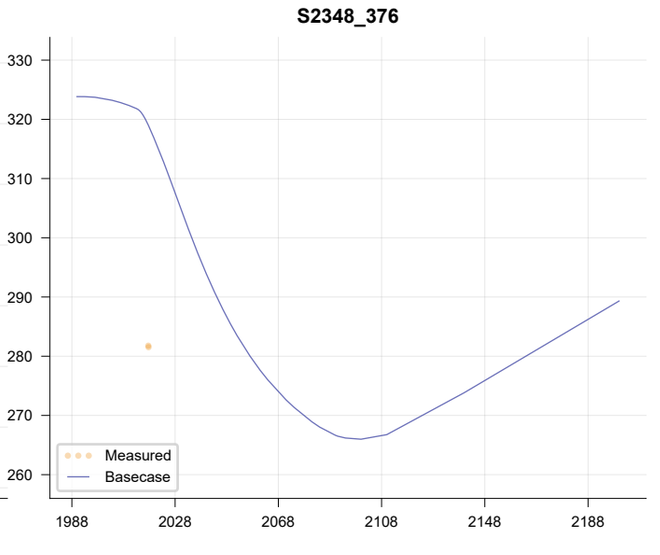

S2348_192
Groundwater...level...(mAHD)
Year
Measured
Basecase

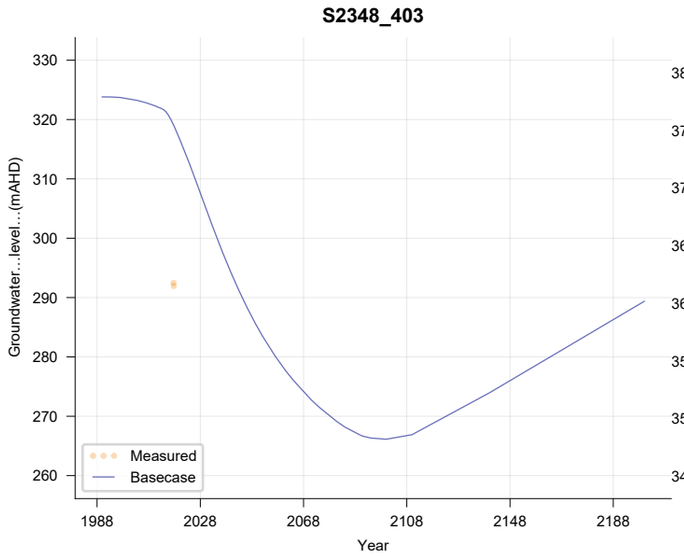

S2348_227
Measured
Basecase

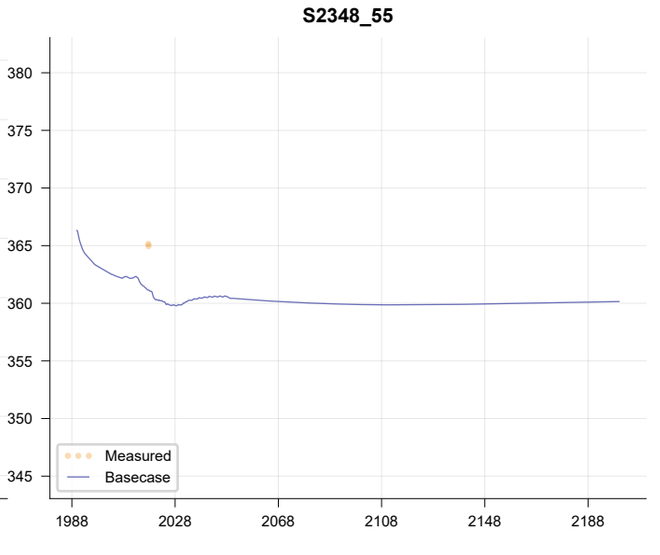

S2348_262
Groundwater…level…(mAHD)
Year
Measured
Basecase

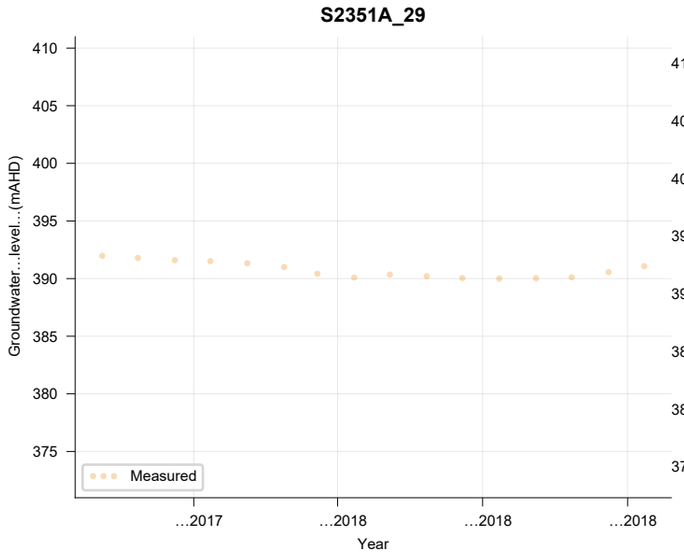

S2348_297
Measured
Basecase

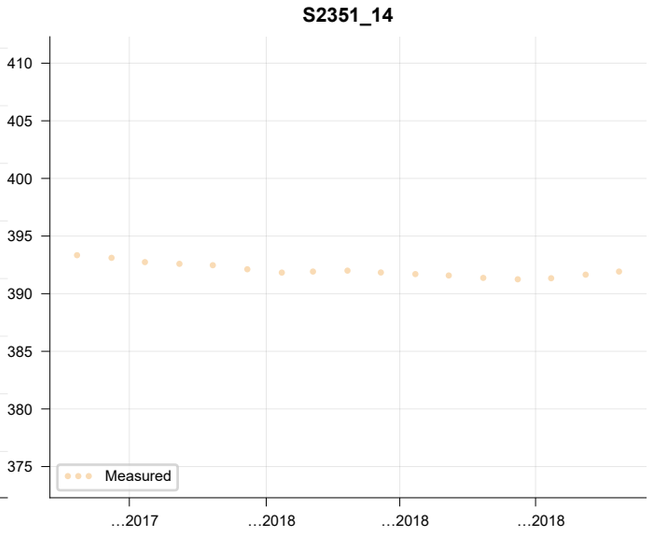

S2348_333
Groundwater…level…(mAHD)
Year
Measured
Basecase

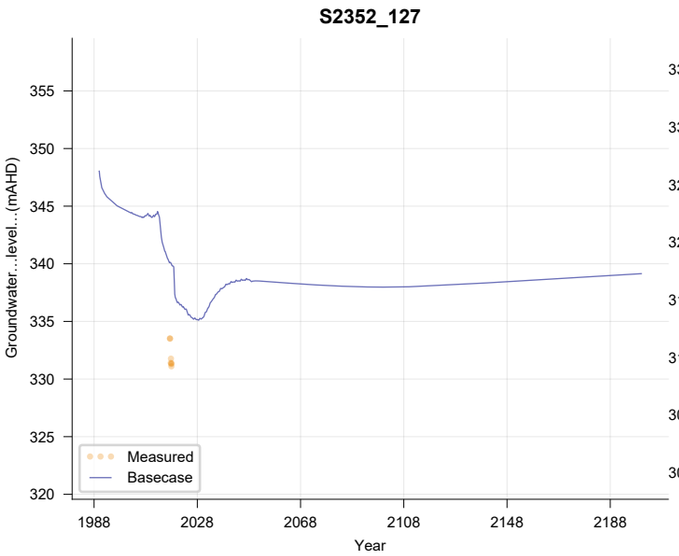

S2348_376
Measured
Basecase

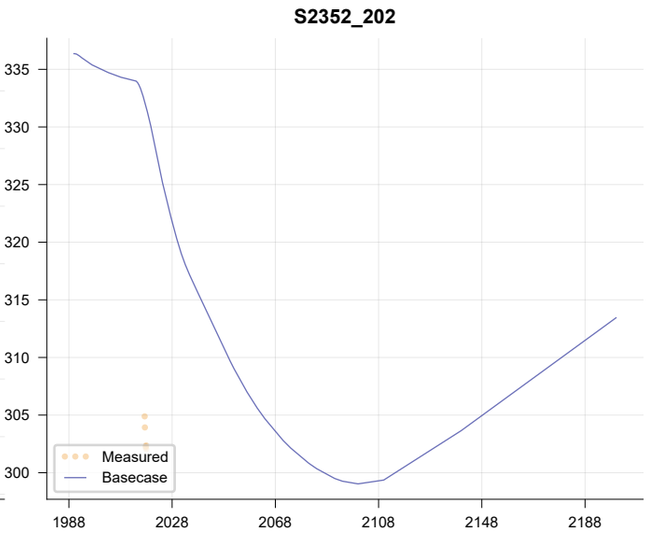

S2348_403
Groundwater…level…(mAHD)
Year
Measured
Basecase

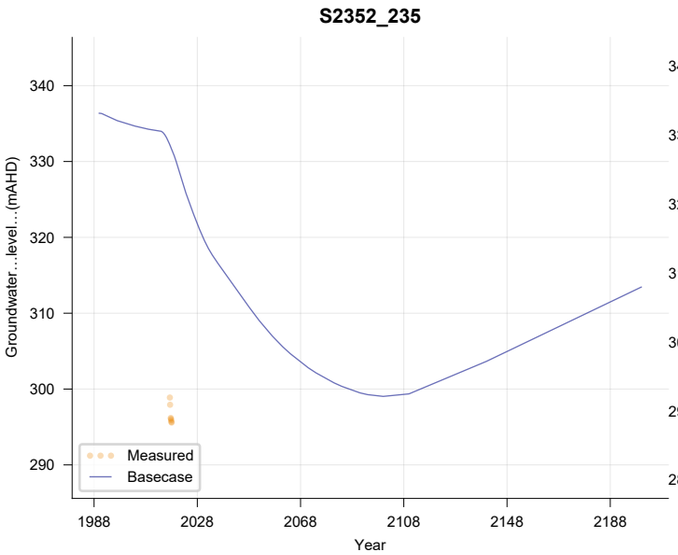

S2348_55
Measured
Basecase

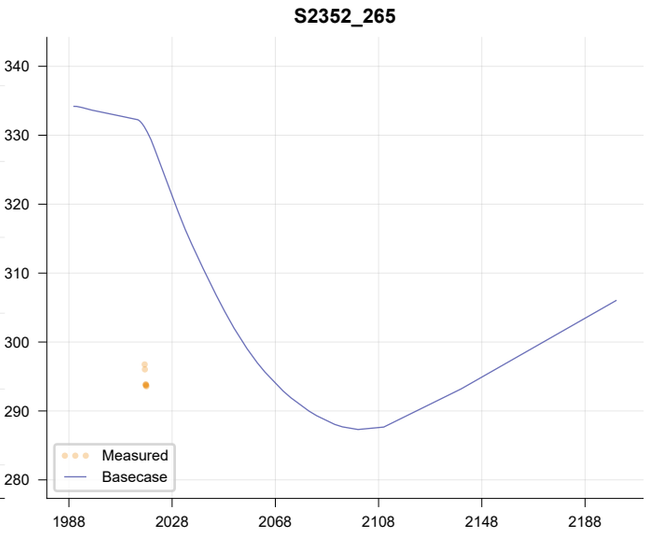

S2351A_29
Groundwater…level…(mAHD)
Year
Measured

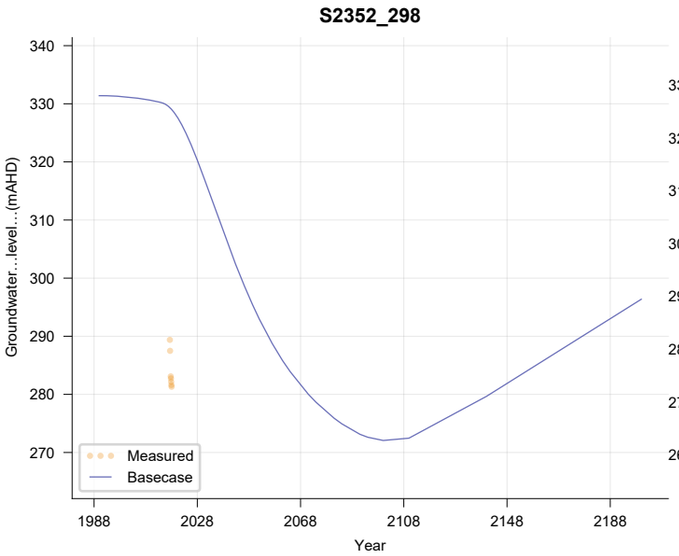

S2351_14
Measured

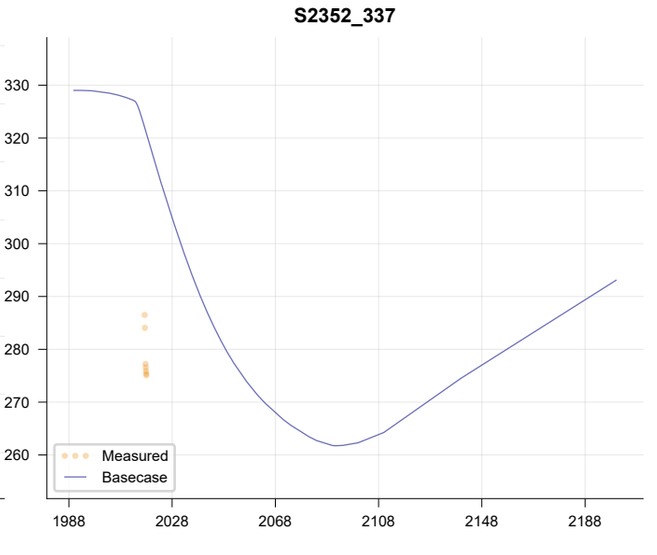

S2352_127
Groundwater...level...(mAHD)
355
350
345
340
335
330
325
320
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

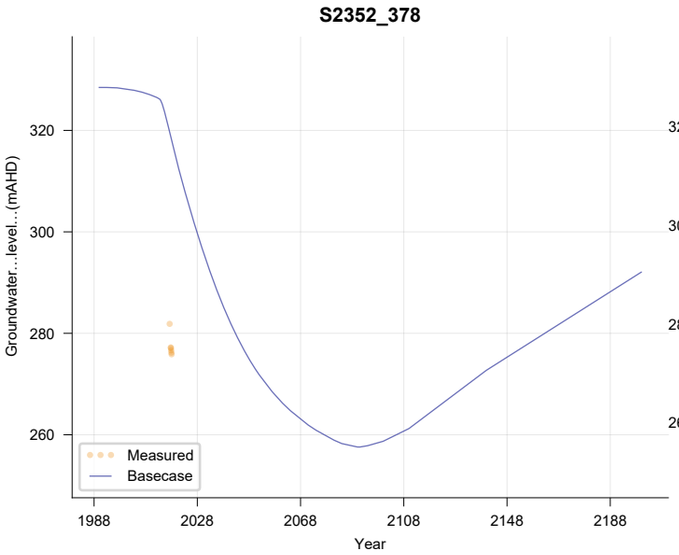

S2352_202
335
330
325
320
315
310
305
300
Measured
Basecase
1988
2028
2068
2108
2148
2188

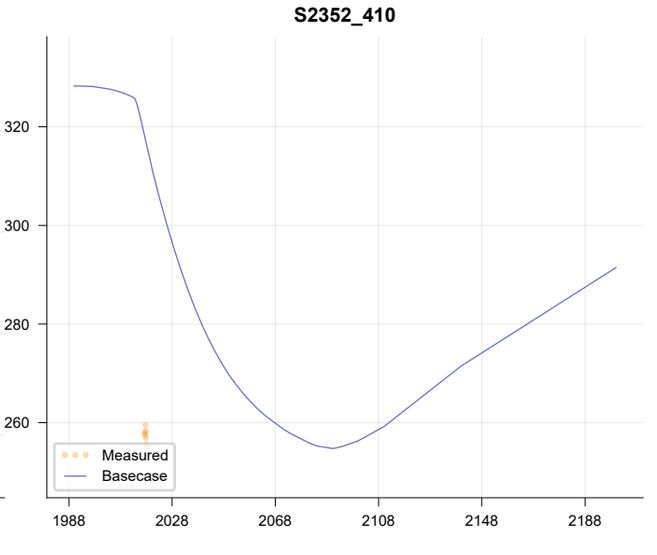

S2352_235
Groundwater...level...(mAHD)
340
330
320
310
300
290
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

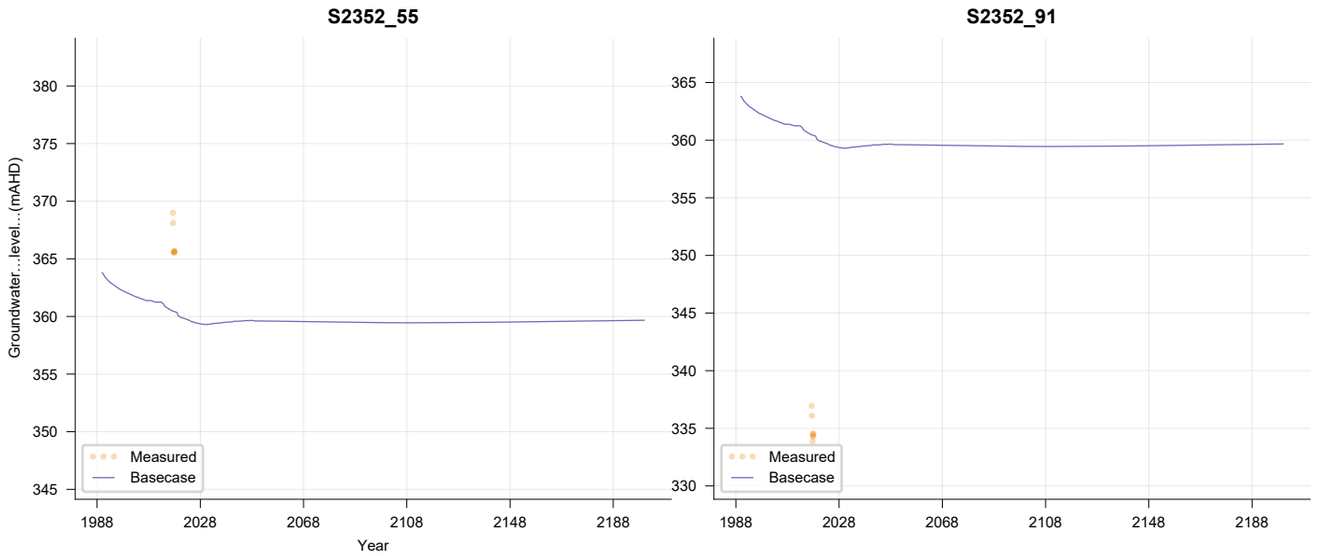

S2352_265
340
330
320
310
300
290
280
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2352_298
Groundwater...level...(mAHD)
340
330
320
310
300
290
280
270
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

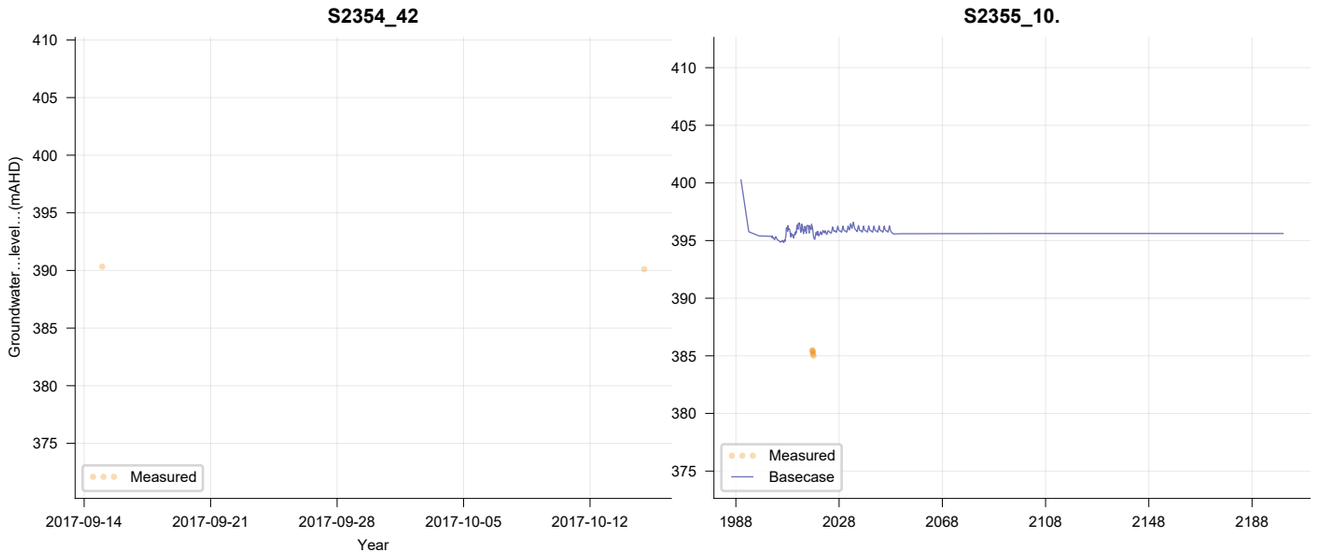

S2352_337
330
320
310
300
290
280
270
260
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2352_378
Groundwater...level...(mAHD)
320
300
280
260
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

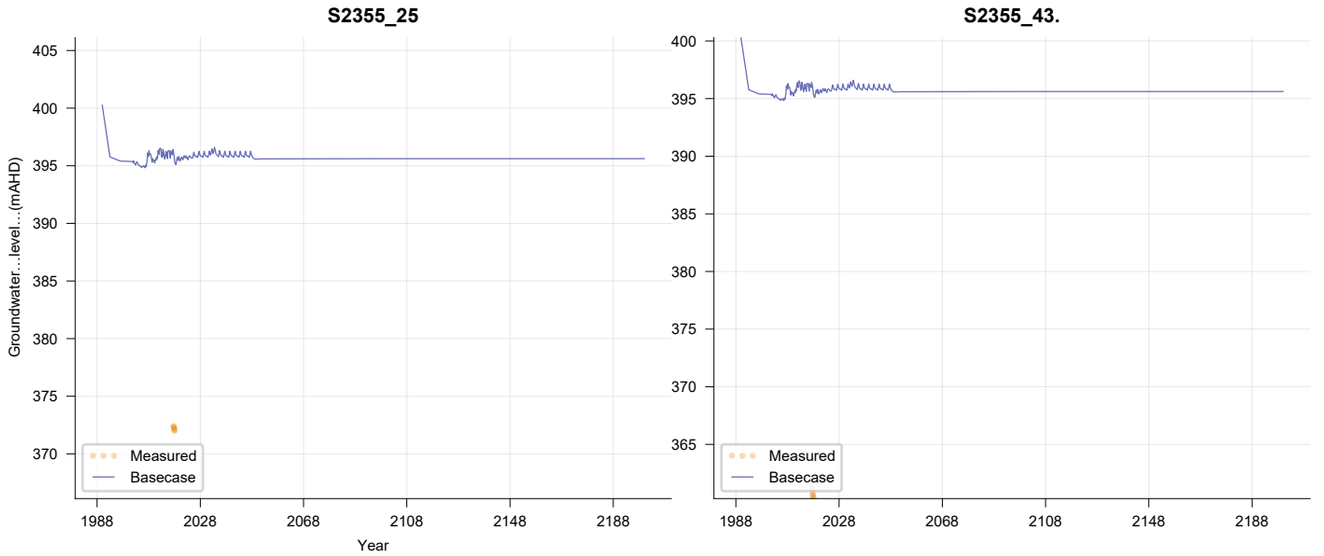

S2352_410
320
300
280
260
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2352_55
Groundwater...level...(mAHD)
380
375
370
365
360
355
350
345
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

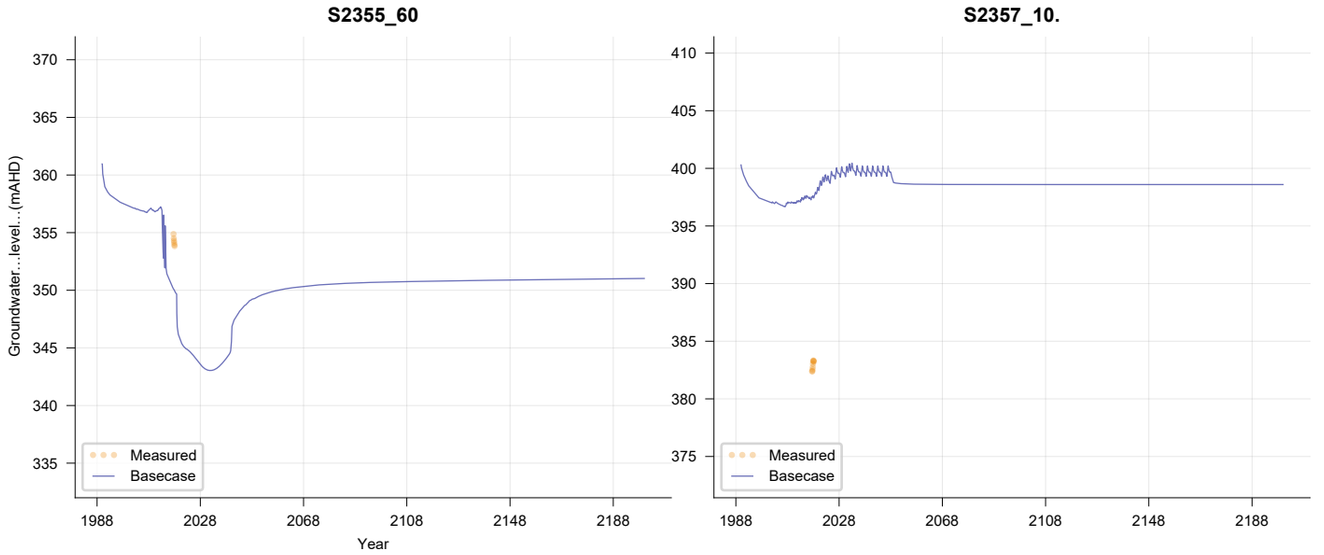

S2352_91
365
360
355
350
345
340
335
330
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2354_42
Groundwater...level...(mAHD)
410
405
400
395
390
385
380
375
Measured
2017-09-14
2017-09-21
2017-09-28
2017-10-05
2017-10-12
Year

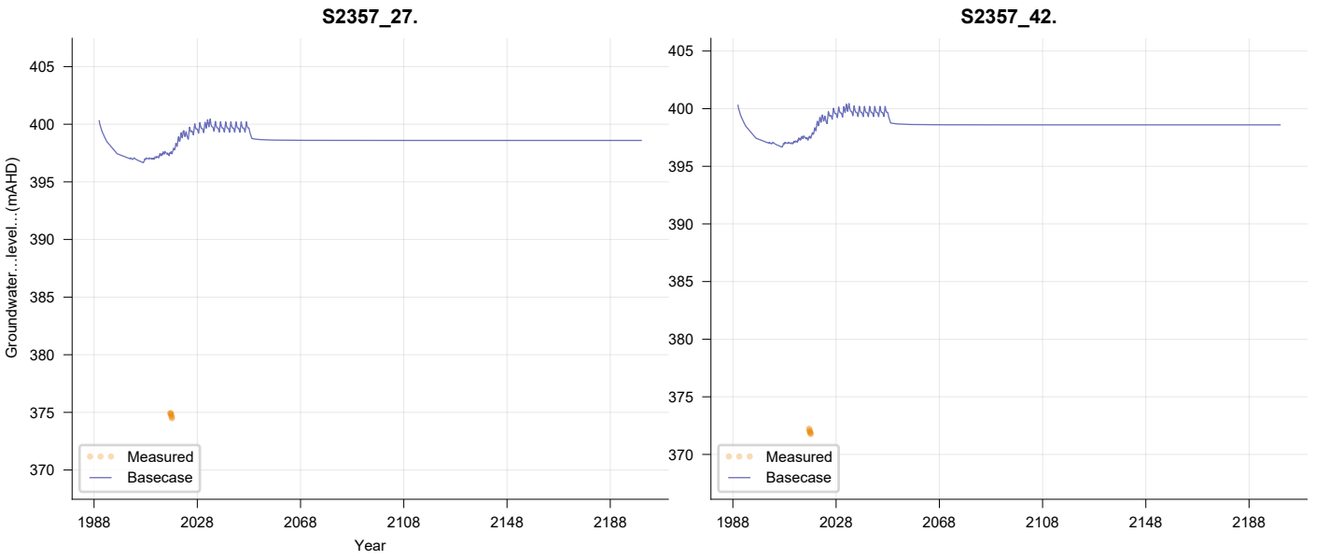

S2355_10.
410
405
400
395
390
385
380
375
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2355_25
Groundwater...level...(mAHD)
405
400
395
390
385
380
375
370
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

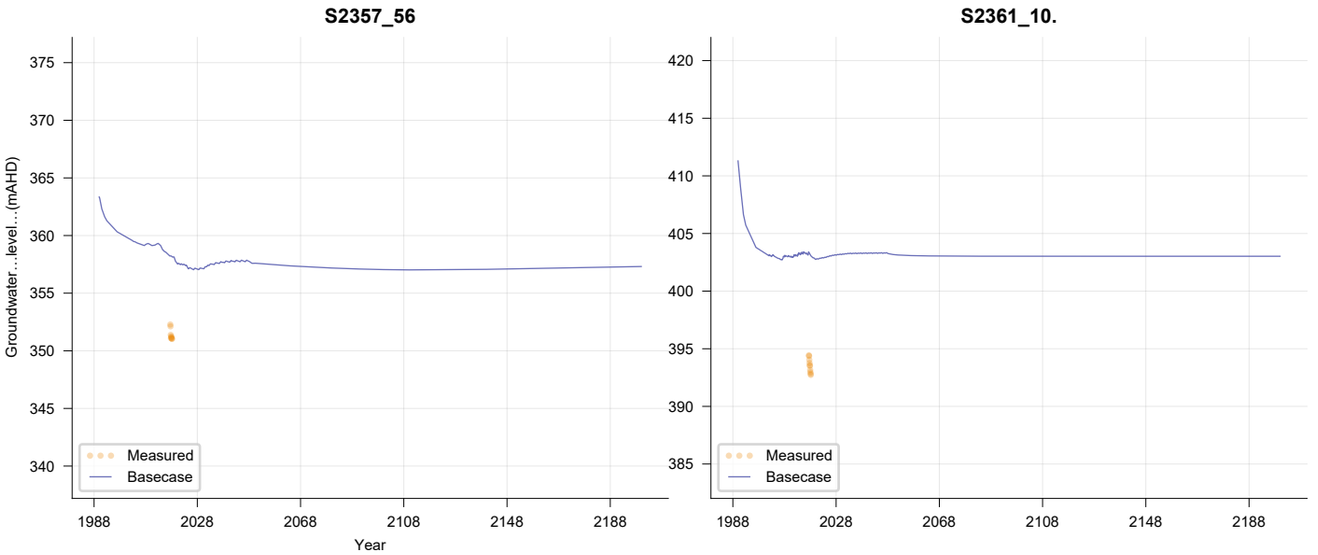

S2355_43.
400
395
390
385
380
375
370
365
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2355_60
Groundwater...level...(mAHD)
370
365
360
355
350
345
340
335
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

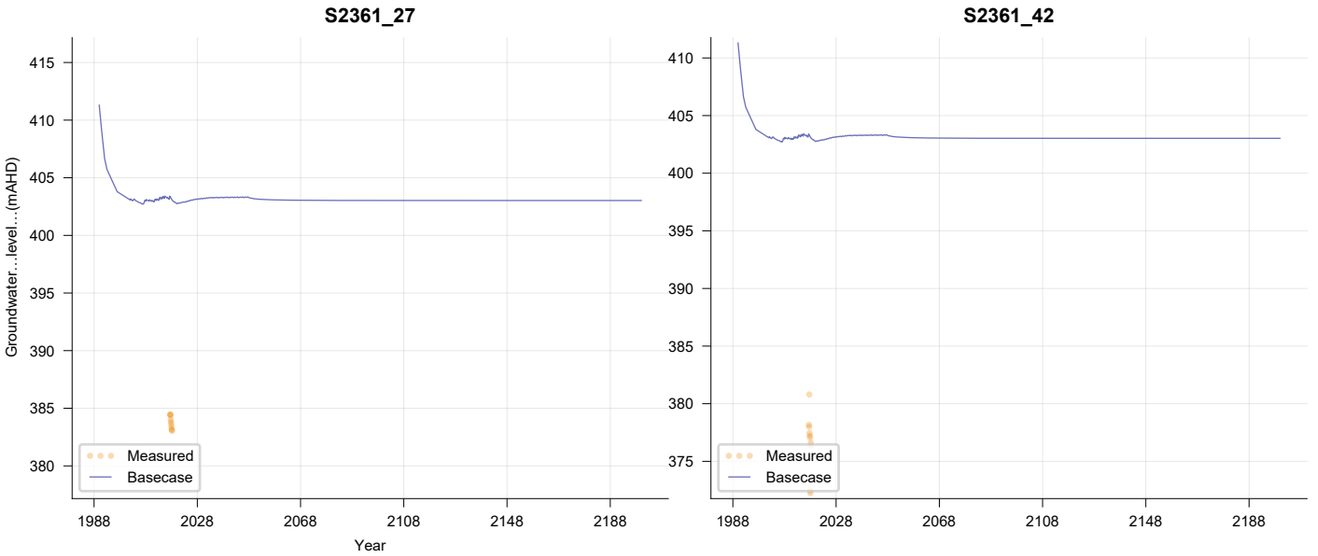

S2357_10.
410
405
400
395
390
385
380
375
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2357_27.
Groundwater...level...(mAHD)
405
400
395
390
385
380
375
370
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

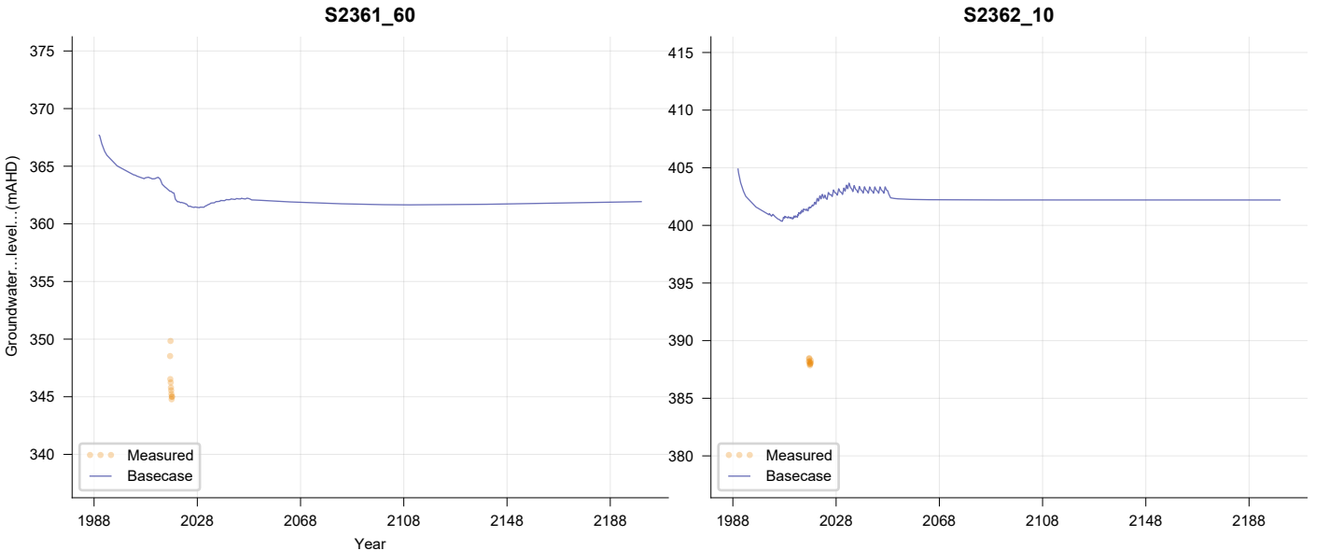

S2357_42.
405
400
395
390
385
380
375
370
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2357_56
Groundwater...level...(mAHD)
375
370
365
360
355
350
345
340
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

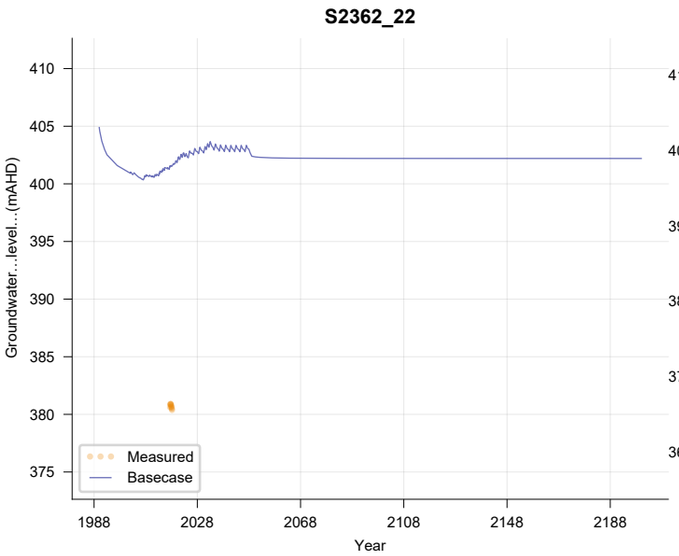

S2361_10.
420
415
410
405
400
395
390
385
Measured
Basecase
1988
2028
2068
2108
2148
2188

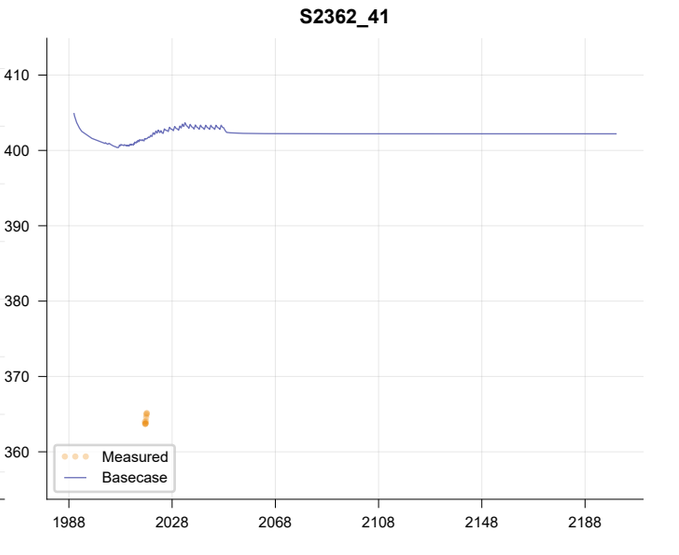

S2361_27
Groundwater...level...(mAHD)
415
410
405
400
395
390
385
380
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

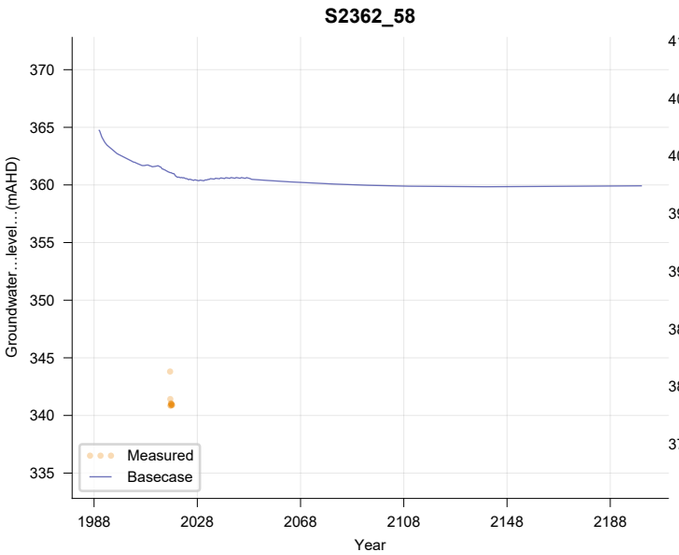

S2361_42
410
405
400
395
390
385
380
375
Measured
Basecase
1988
2028
2068
2108
2148
2188

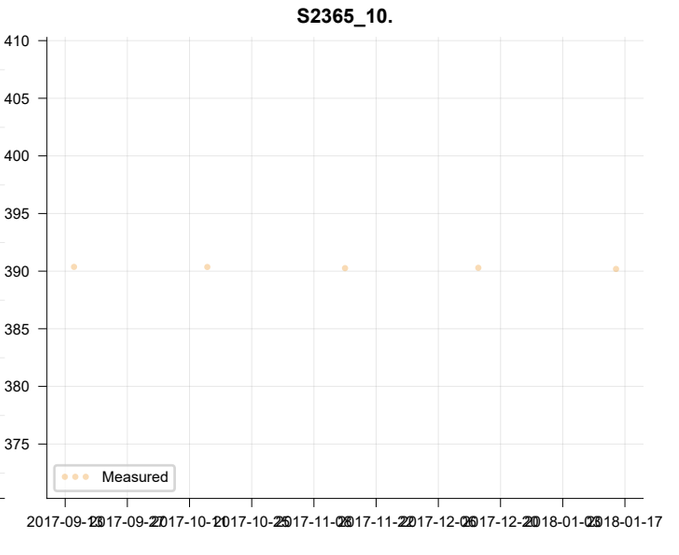

S2361_60
Groundwater...level...(mAHD)
375
370
365
360
355
350
345
340
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

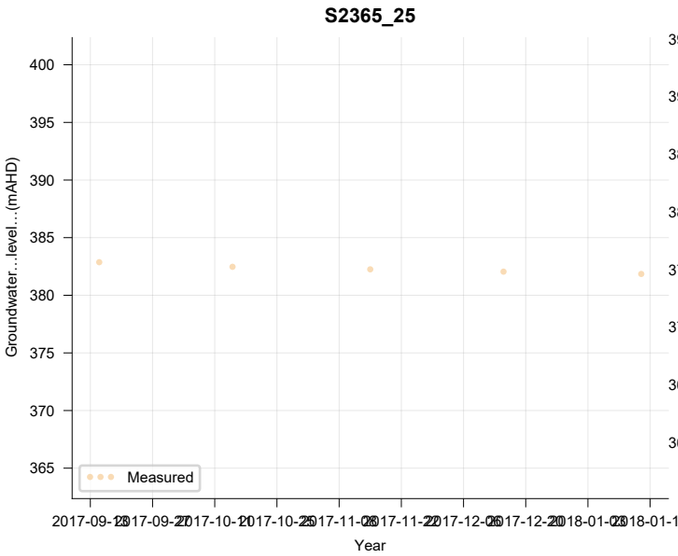

S2362_10
415
410
405
400
395
390
385
380
Measured
Basecase
1988
2028
2068
2108
2148
2188

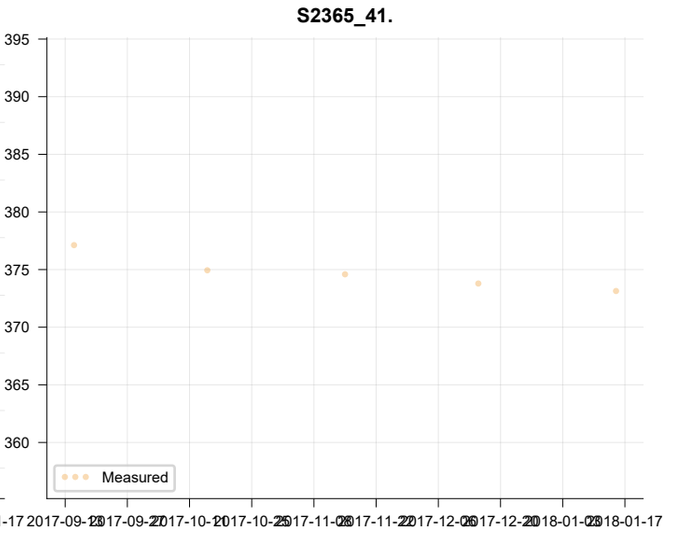

S2362_22
Groundwater...level...(mAHD)
Year
Measured
Basecase

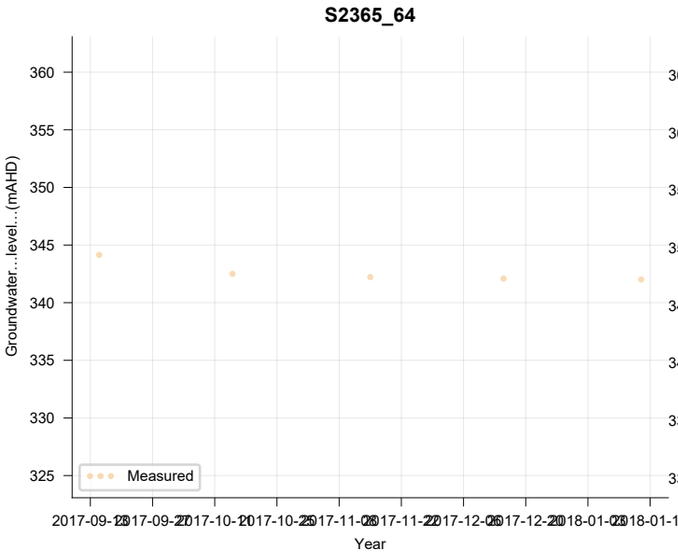

S2362_41
Measured
Basecase


S2362_58
Groundwater...level...(mAHD)
Year
Measured
Basecase

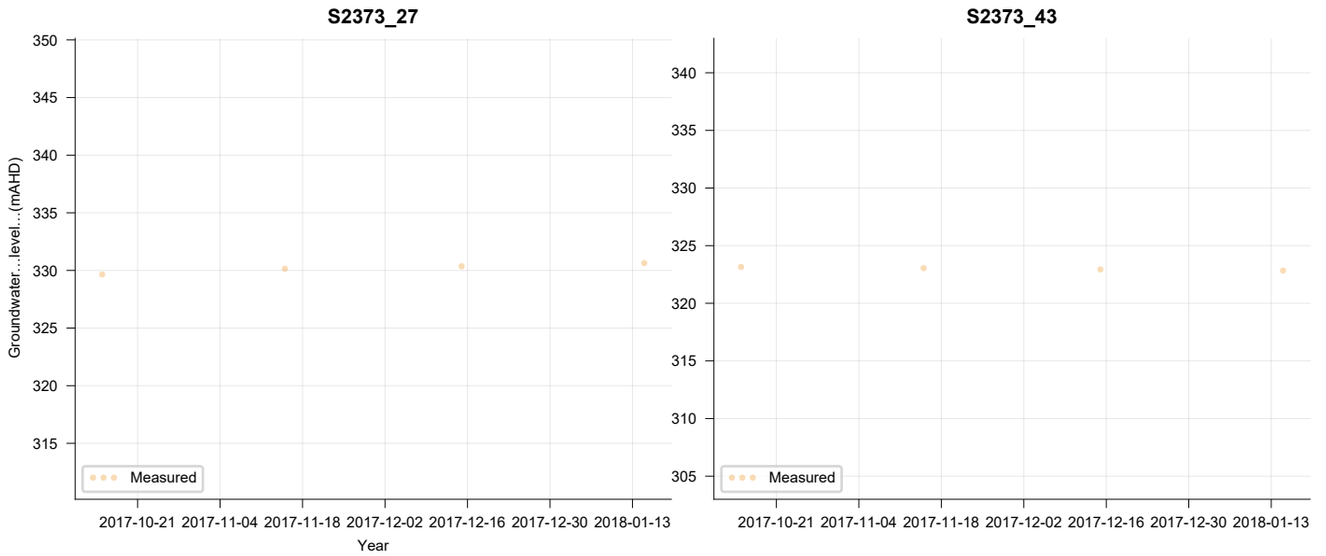

S2365_10.
Measured


S2365_25
Groundwater...level...(mAHD)
Year
Measured

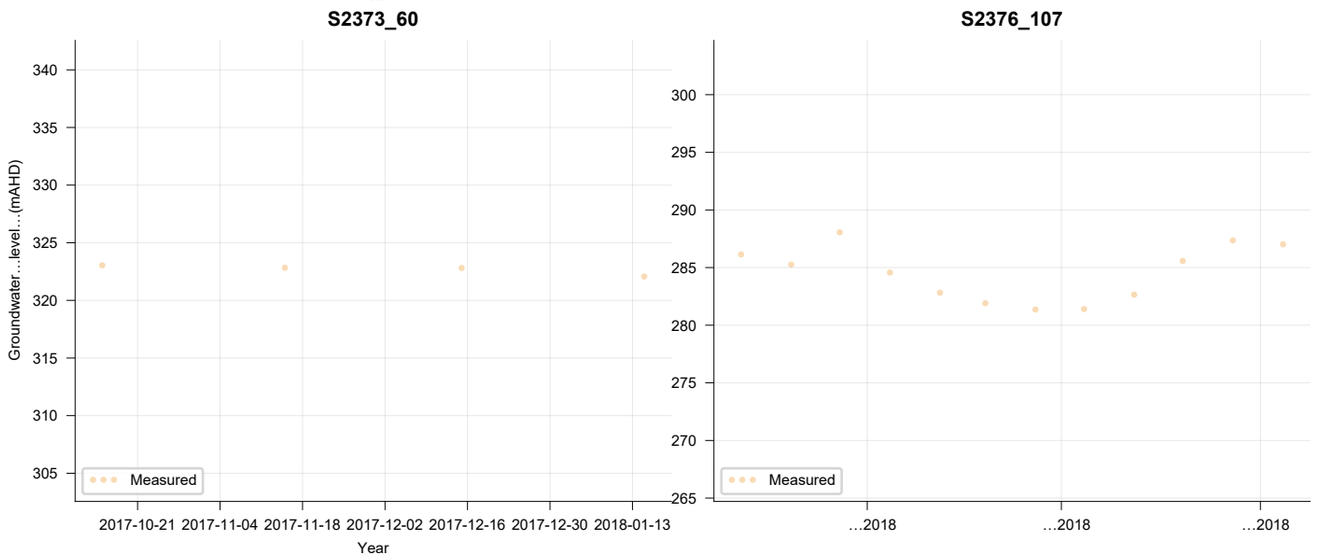

S2365_41.
Measured


S2365_64
Groundwater...level...(mAHD)
Year
Measured

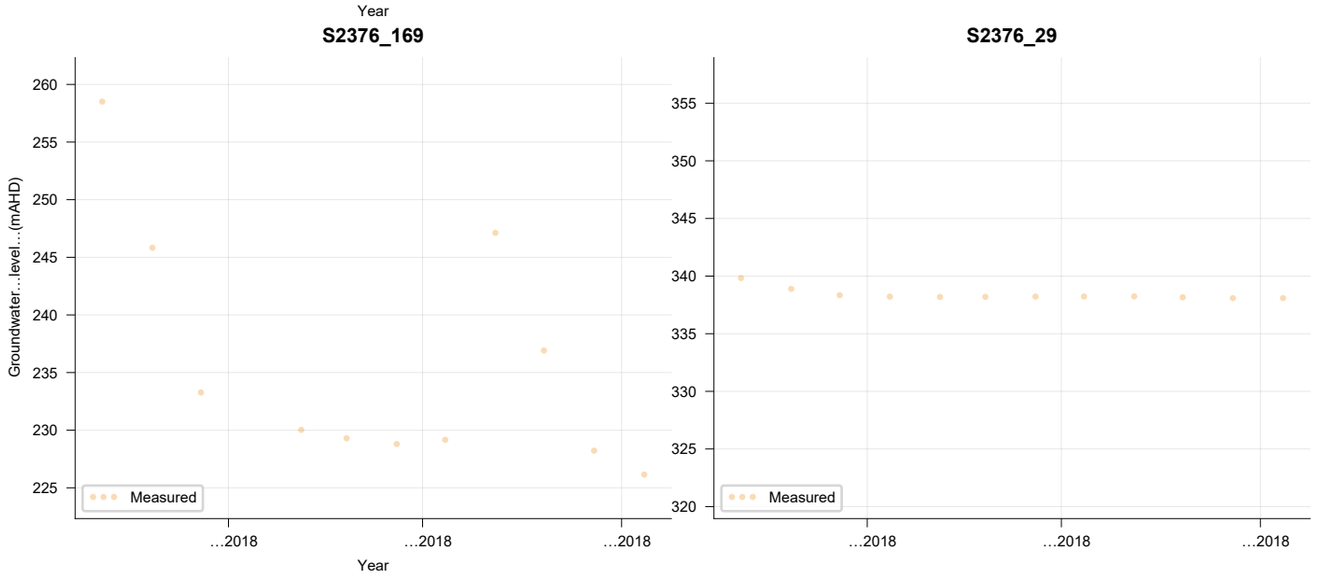

S2373_10.
Measured


S2373_27
Groundwater…level…(mAHD)
350
345
340
335
330
325
320
315
Measured
2017-10-21 2017-11-04 2017-11-18 2017-12-02 2017-12-16 2017-12-30 2018-01-13
Year

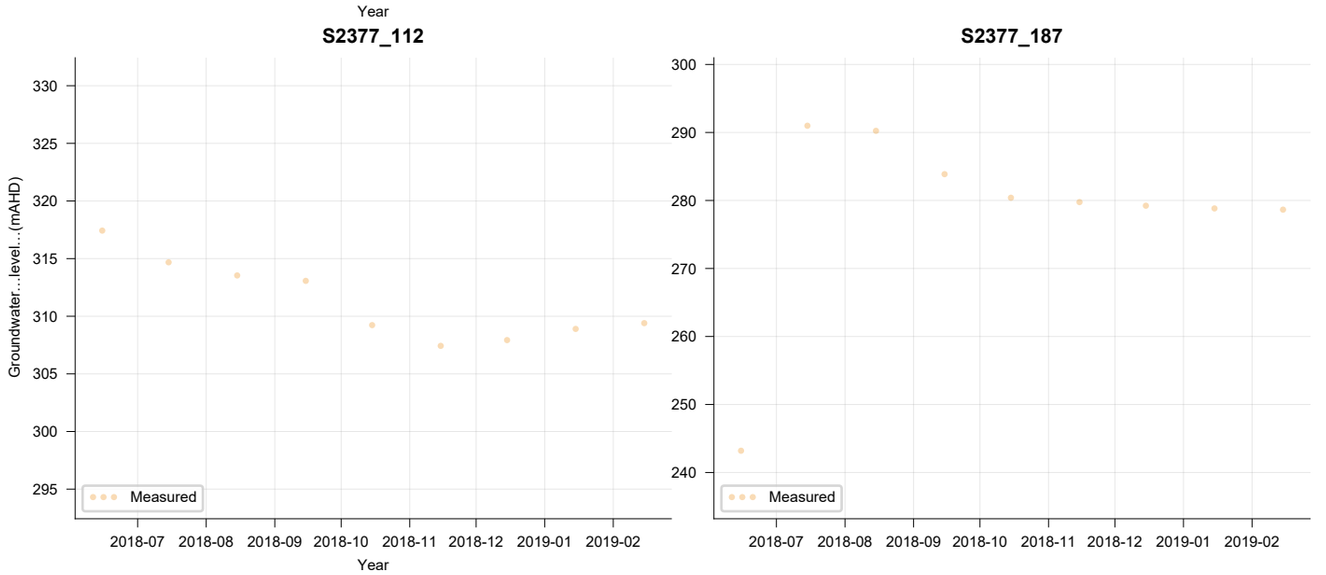

S2373_43
340
335
330
325
320
315
310
305
Measured
2017-10-21 2017-11-04 2017-11-18 2017-12-02 2017-12-16 2017-12-30 2018-01-13


S2373_60
Groundwater…level…(mAHD)
340
335
330
325
320
315
310
305
Measured
2017-10-21 2017-11-04 2017-11-18 2017-12-02 2017-12-16 2017-12-30 2018-01-13
Year

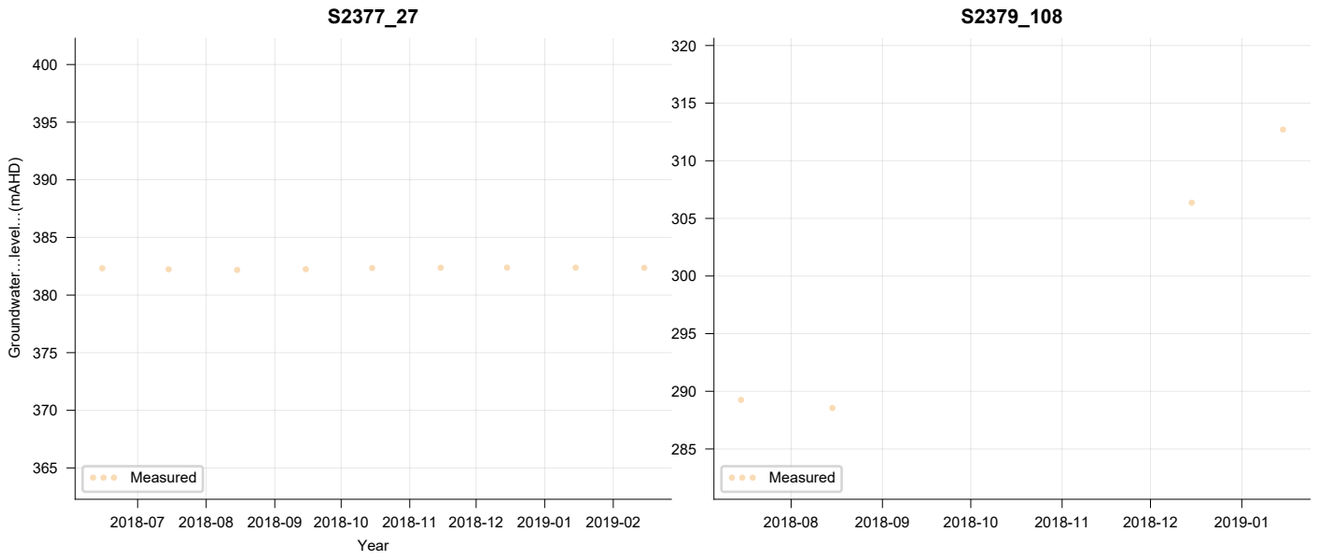

S2376_107
300
295
290
285
280
275
270
265
Measured
…2018
…2018
…2018


S2376_169
Groundwater…level…(mAHD)
260
255
250
245
240
235
230
225
Measured
…2018
…2018
…2018
Year

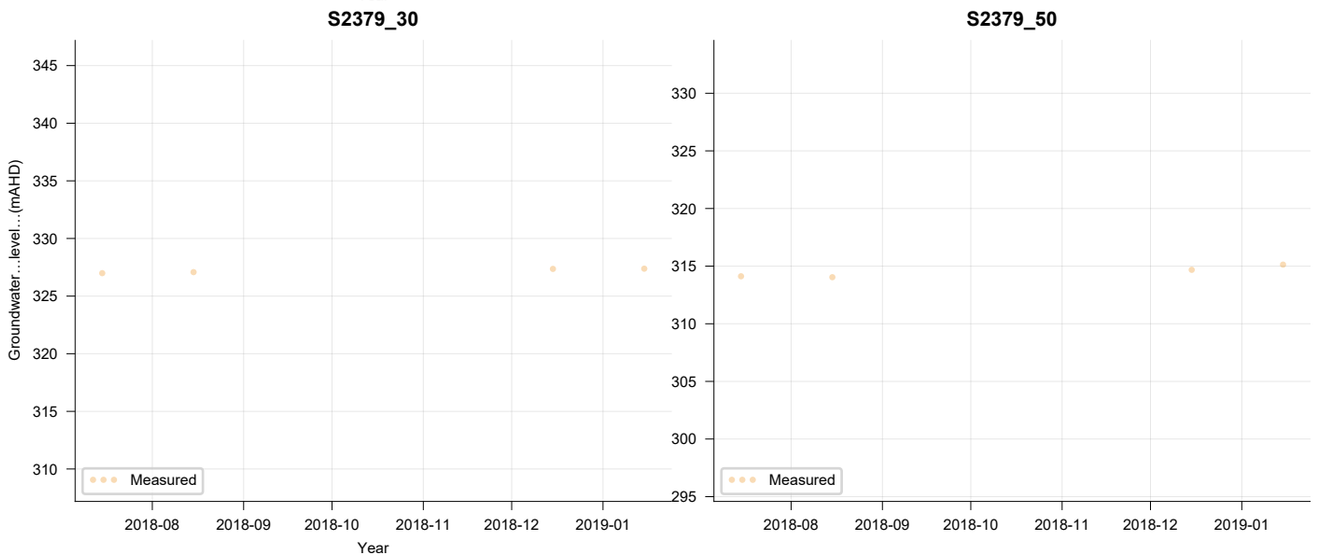

S2376_29
355
350
345
340
335
330
325
320
Measured
…2018
…2018
…2018


S2377_112
Groundwater…level…(mAHD)
330
325
320
315
310
305
300
295
Measured
2018-07 2018-08 2018-09 2018-10 2018-11 2018-12 2019-01 2019-02
Year

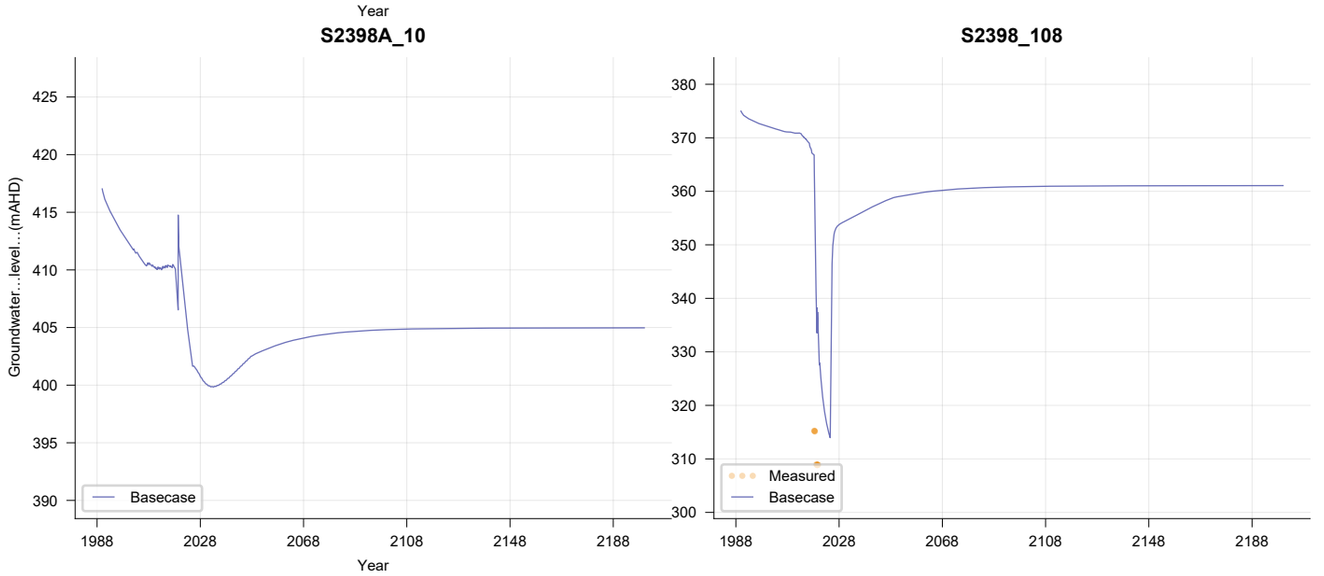

S2377_187
300
290
280
270
260
250
240
Measured
2018-07 2018-08 2018-09 2018-10 2018-11 2018-12 2019-01 2019-02


S2377_27
Groundwater...level...(mAHD)
Year
Measured
2018-07
2018-08
2018-09
2018-10
2018-11
2018-12
2019-01
2019-02

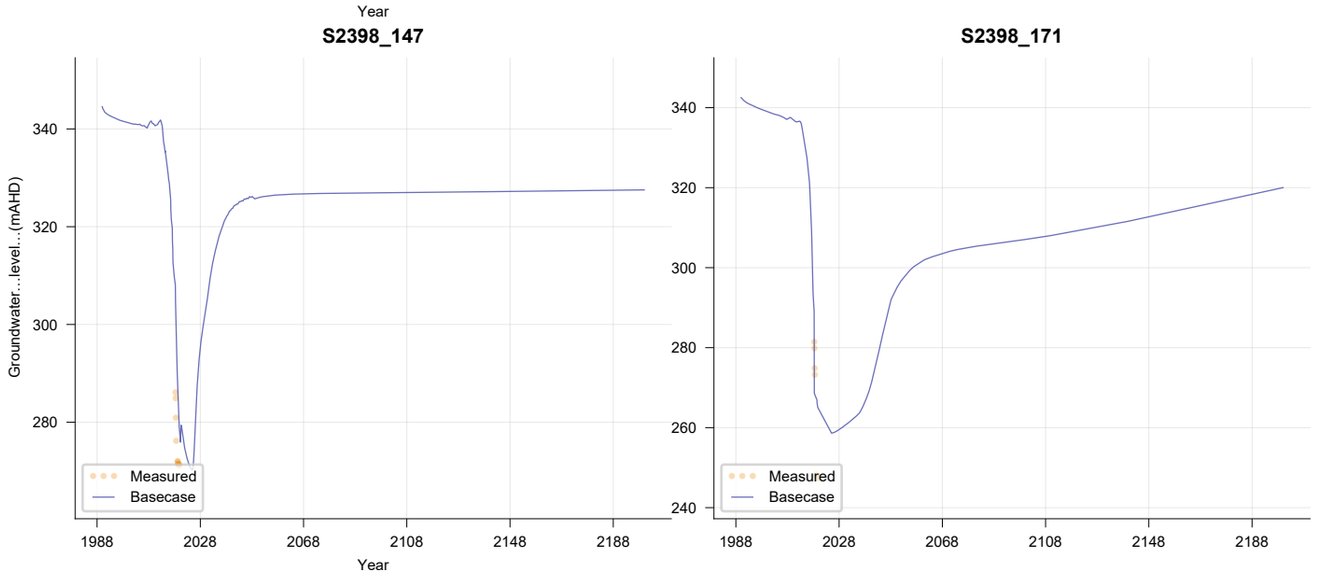

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2018-09
2018-10
2018-11
2018-12
2019-01


S2379_30
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Year
Measured
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2018-09
2018-10
2018-11
2018-12
2019-01

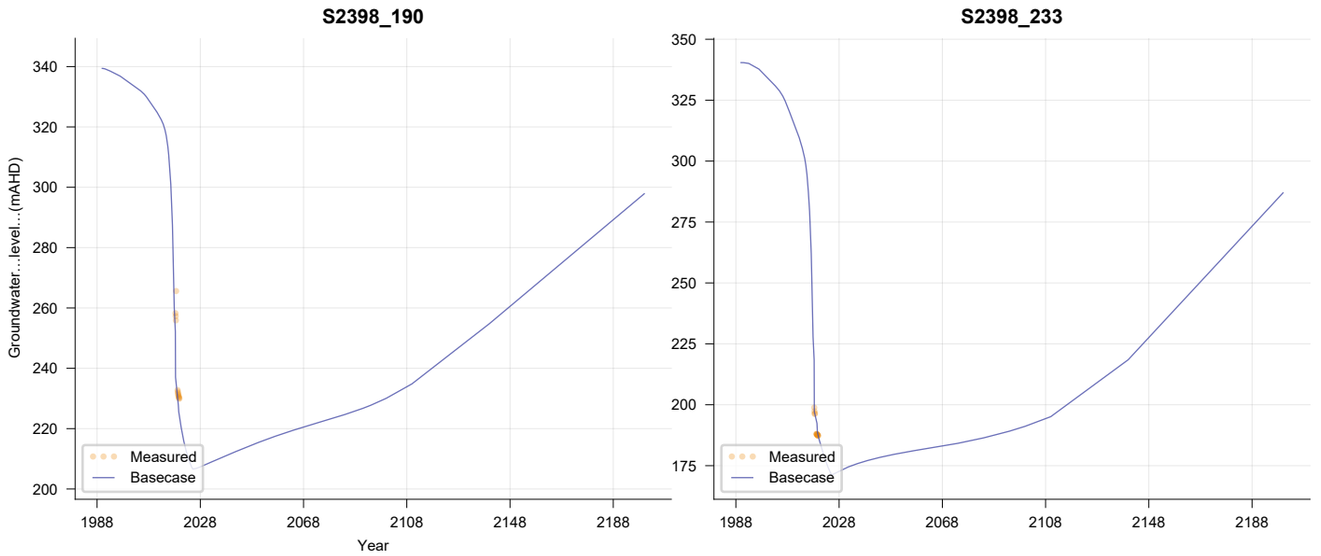

S2379_50
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2018-09
2018-10
2018-11
2018-12
2019-01


S2398A_10
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Year
Basecase
1988
2028
2068
2108
2148
2188

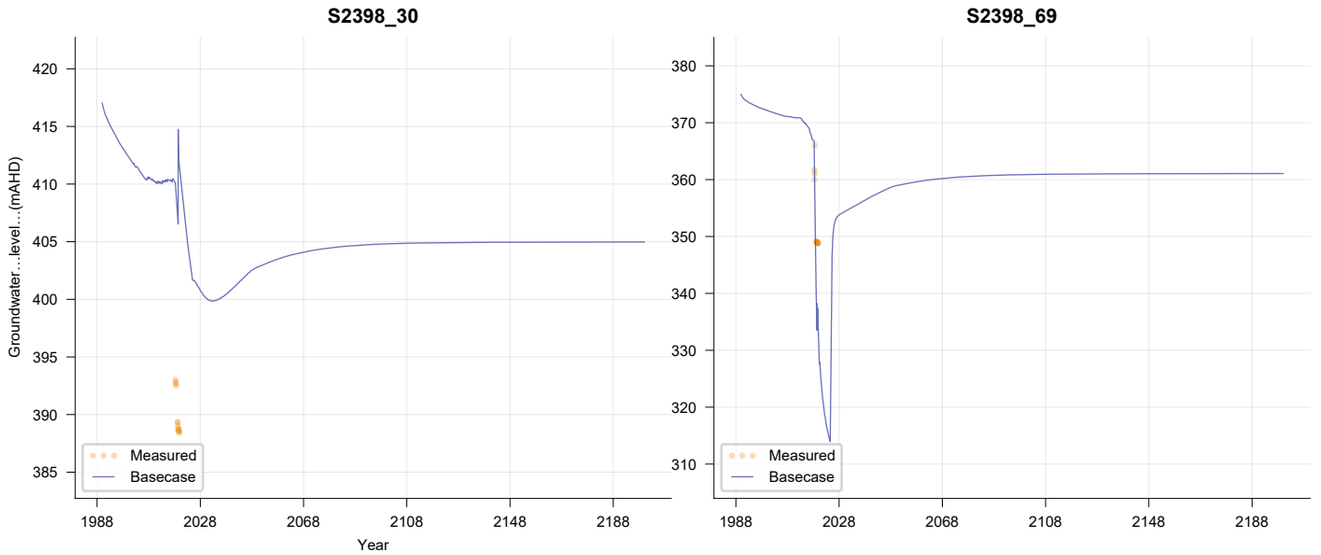

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Measured
Basecase
1988
2028
2068
2108
2148
2188


S2398_147
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Year
Measured
Basecase
1988
2028
2068
2108
2148
2188

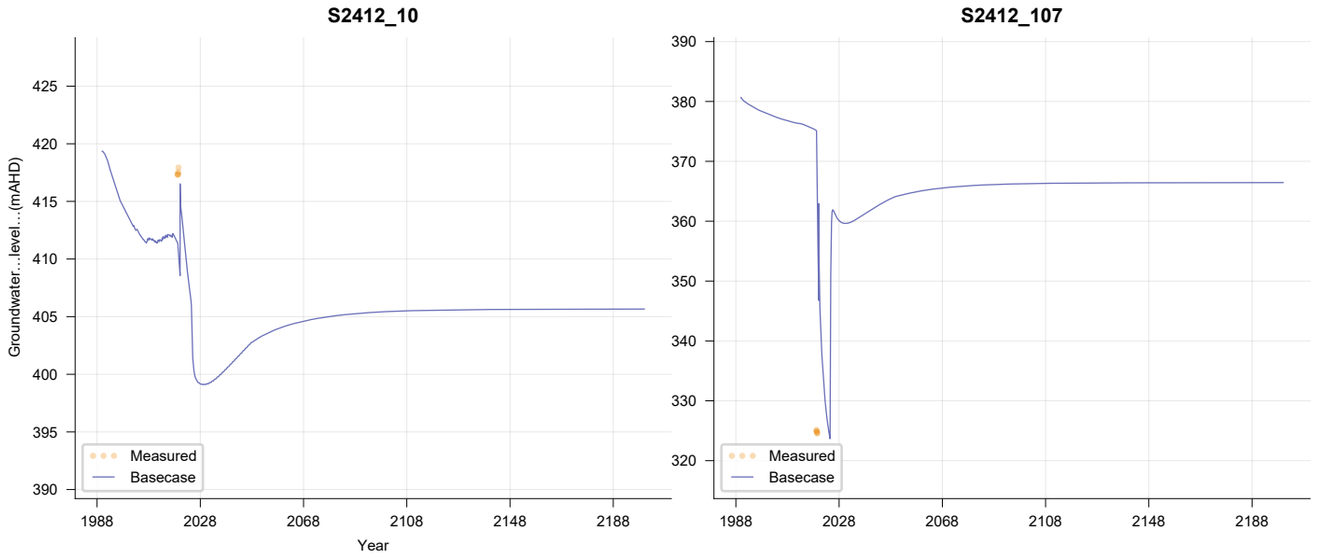

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2148
2188


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Year
Measured
Basecase

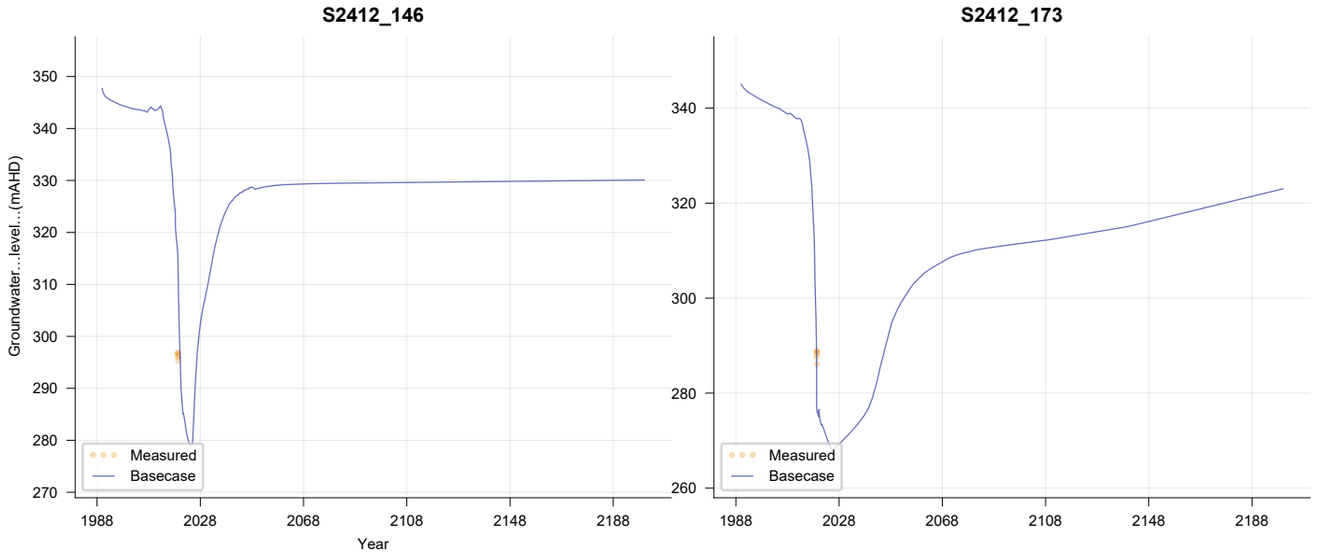

S2398_233
Measured
Basecase


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Year
Measured
Basecase

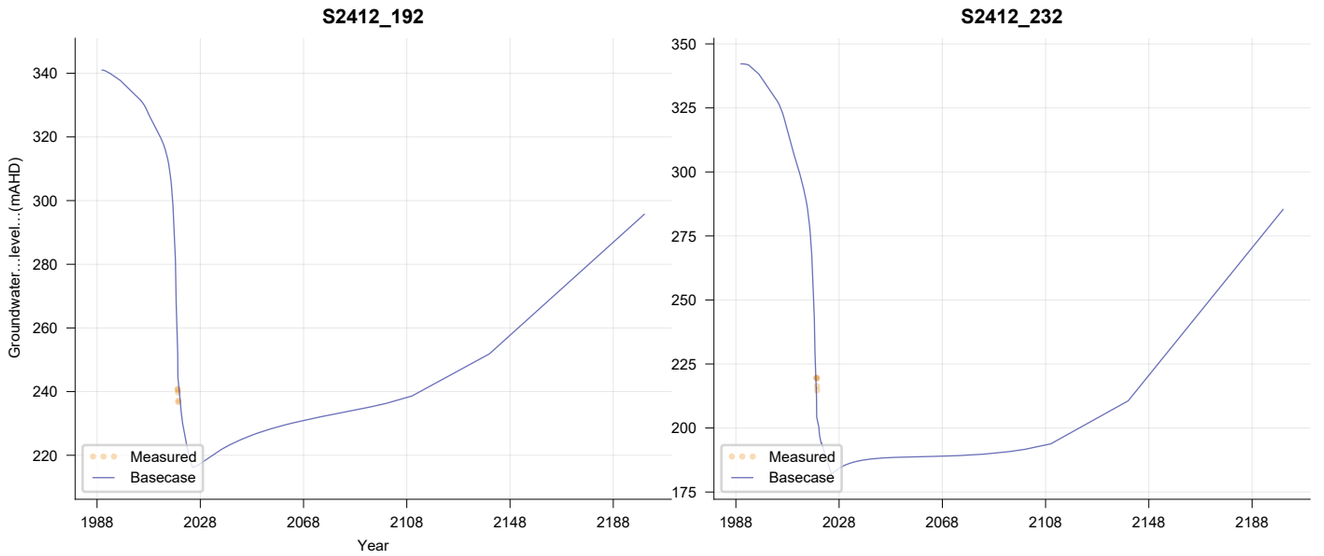

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S2412_10
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Year
Measured
Basecase

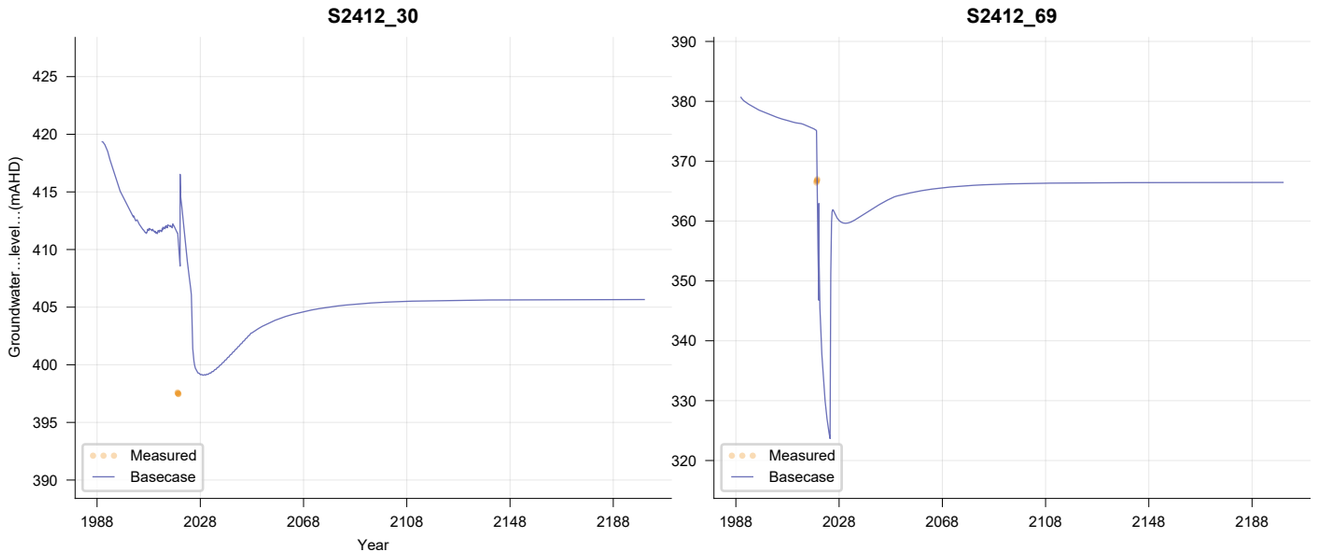

S2412_107
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Basecase


S2412_146
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Year
Measured
Basecase

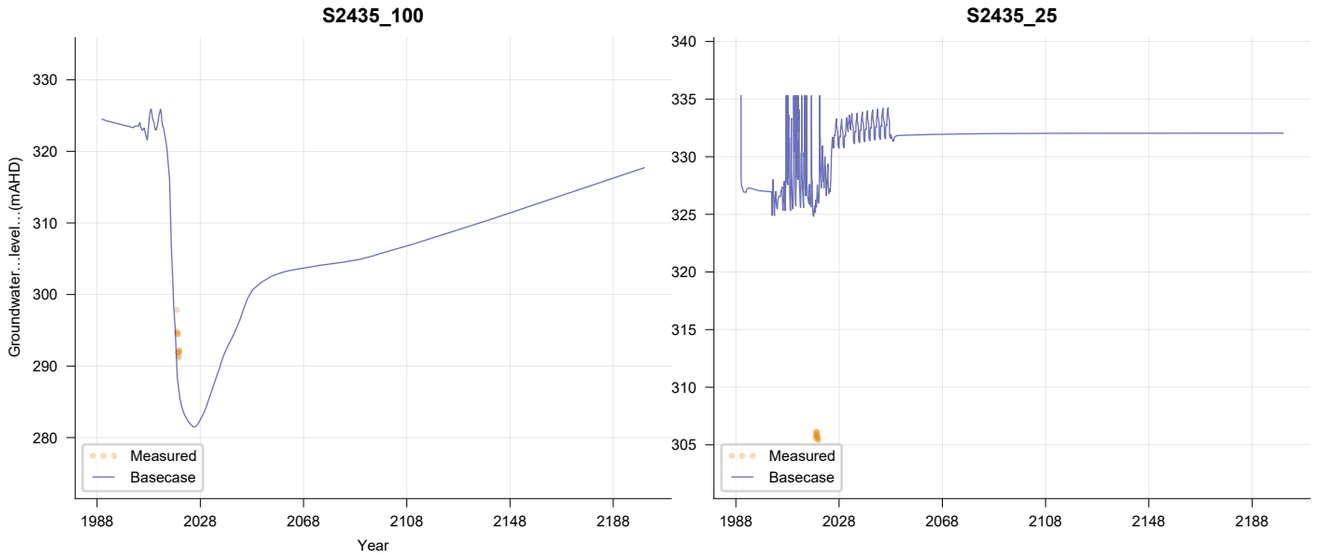

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Basecase


S2412_192
Groundwater...level...(mAHD)
Year
Measured
Basecase

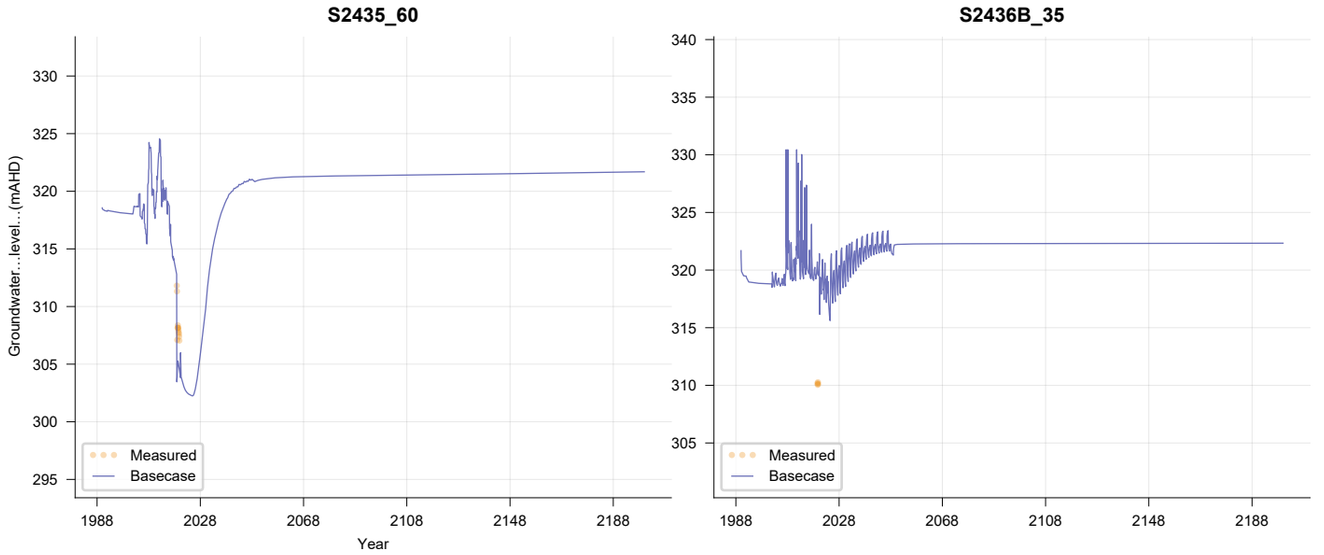

S2412_232
Measured
Basecase


S2412_30
Groundwater...level...(mAHD)
Year
Measured
Basecase

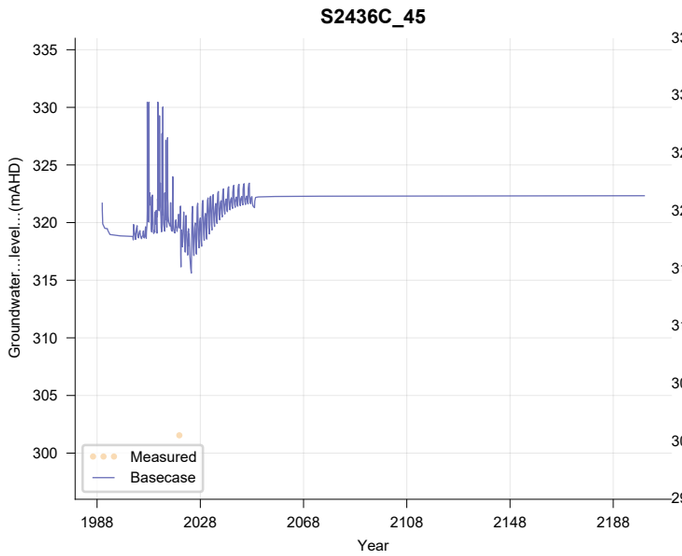

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Basecase

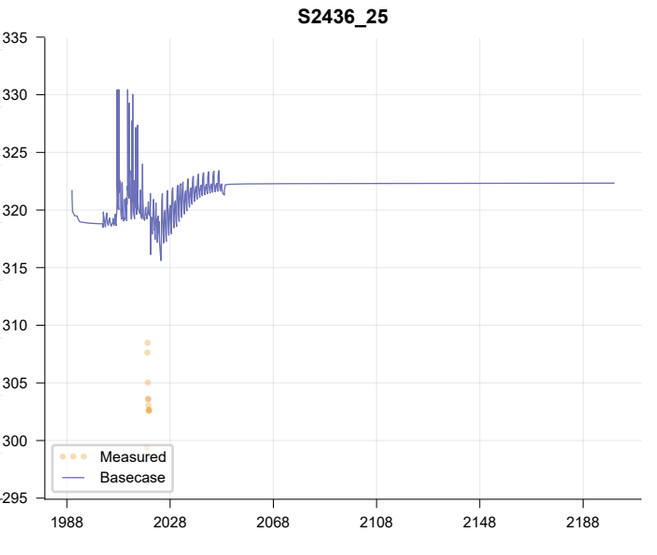

S2435_100
Groundwater...level...(mAHD)
Year
Measured
Basecase

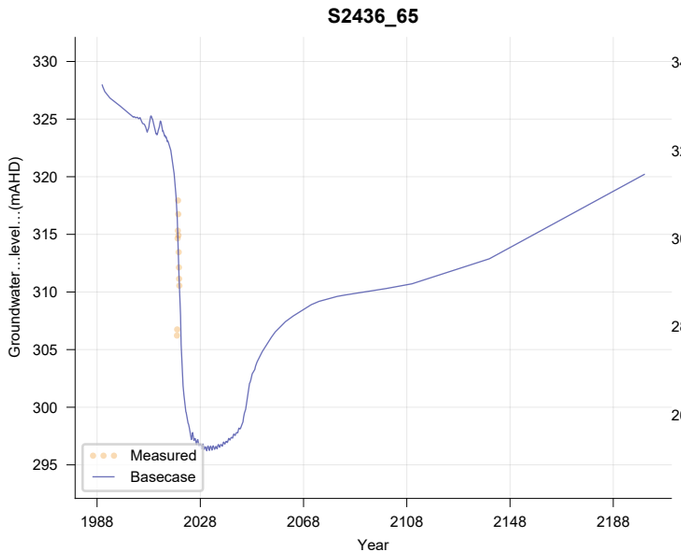

S2435_25
Measured
Basecase

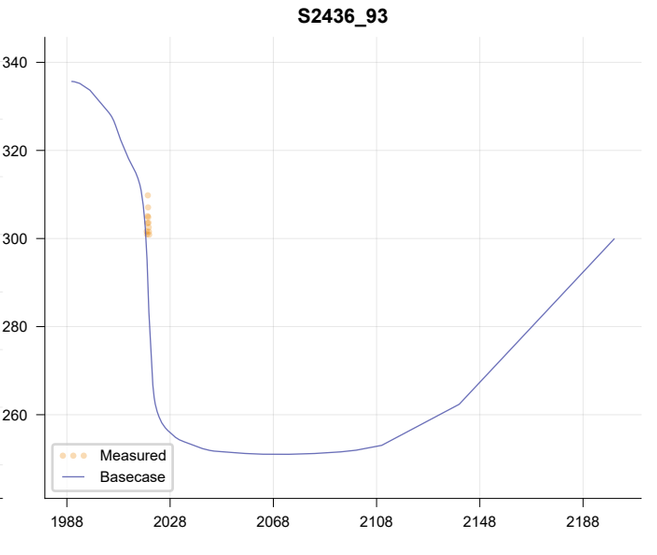

S2435_60
Groundwater...level...(mAHD)
Year
Measured
Basecase

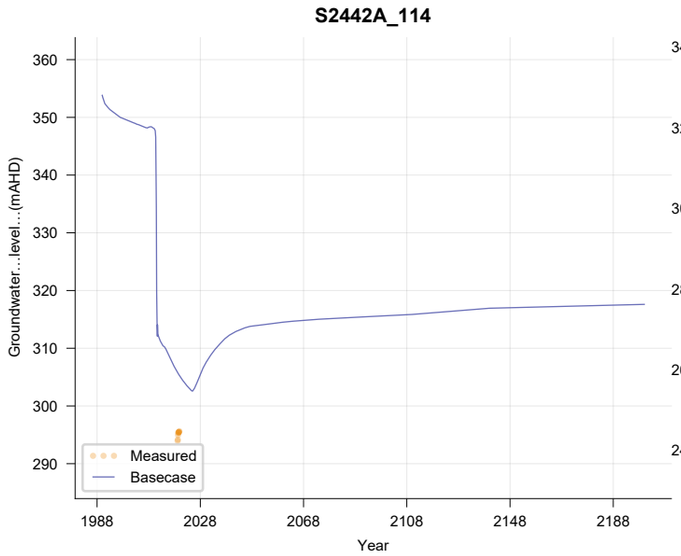

S2436B_35
Measured
Basecase

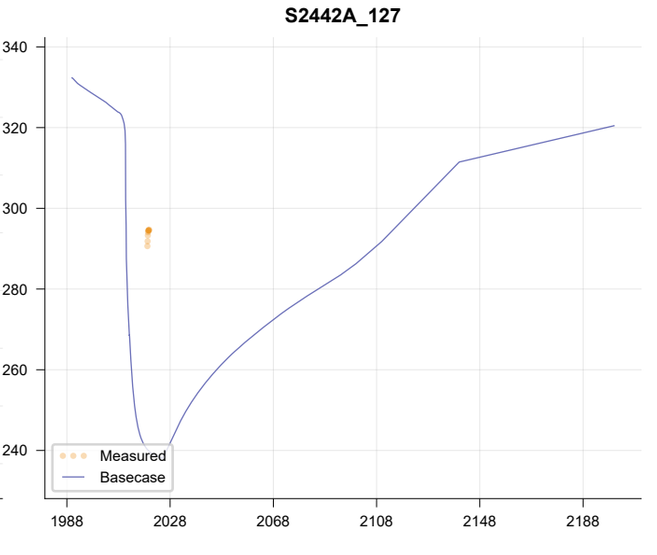

S2436C_45
Groundwater...level...(mAHD)
335
330
325
320
315
310
305
300
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

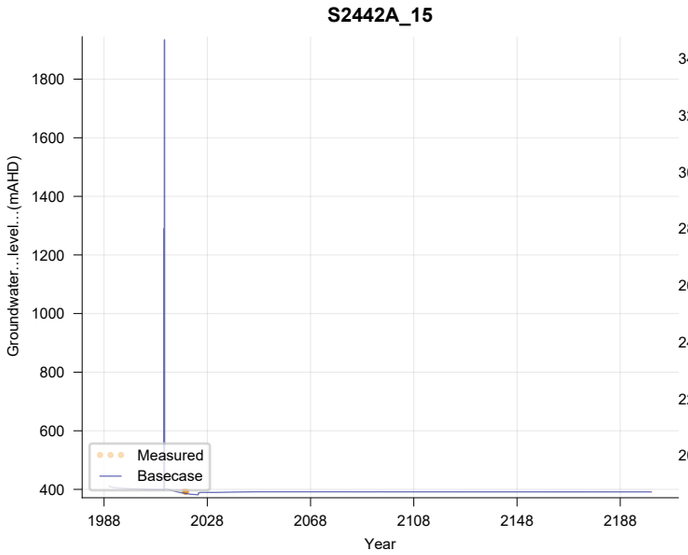

S2436_25
335
330
325
320
315
310
305
300
295
Measured
Basecase
1988
2028
2068
2108
2148
2188

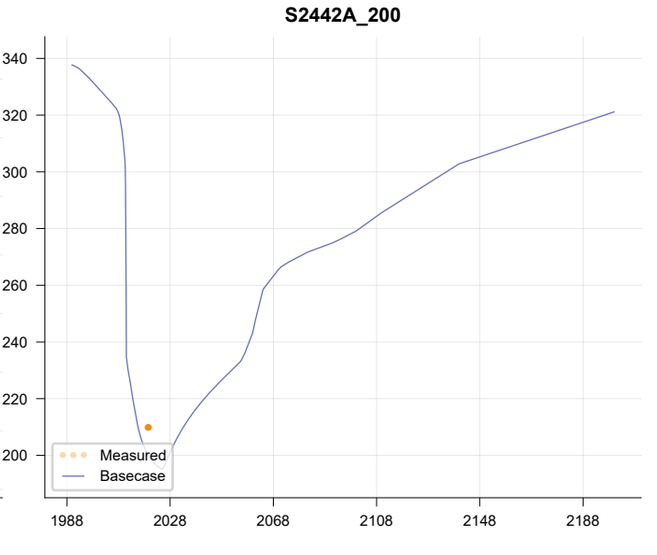

S2436_65
Groundwater...level...(mAHD)
330
325
320
315
310
305
300
295
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

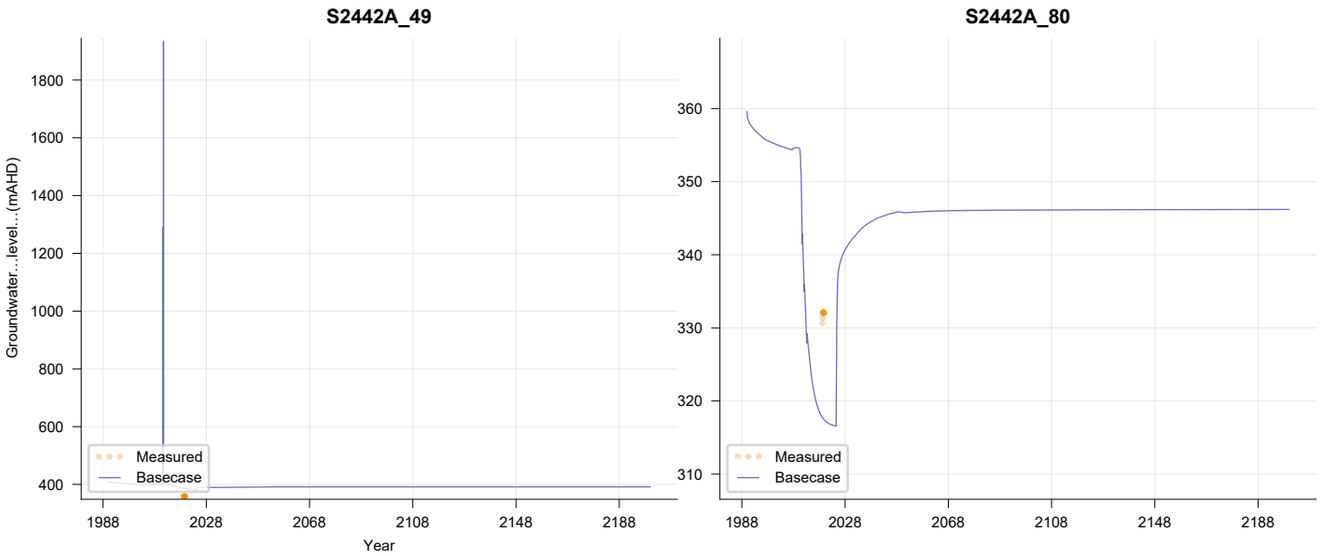

S2436_93
340
320
300
280
260
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2442A_114
Groundwater...level...(mAHD)
360
350
340
330
320
310
300
290
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

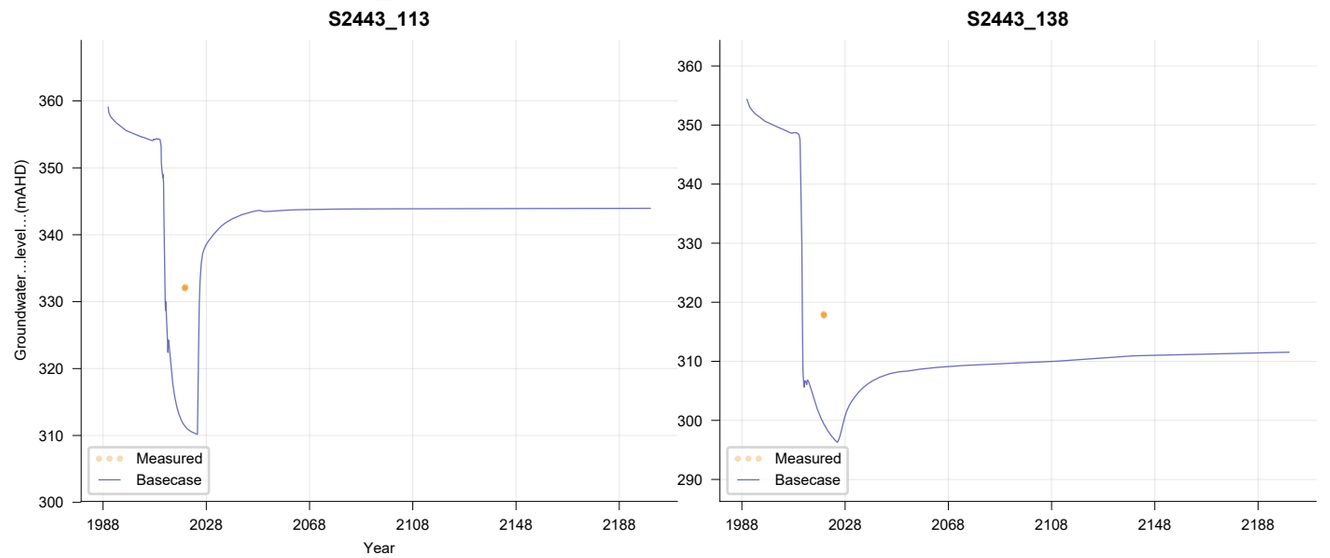

S2442A_127
340
320
300
280
260
240
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2442A_15
Groundwater...level...(mAHD)
1800
1600
1400
1200
1000
800
600
400
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

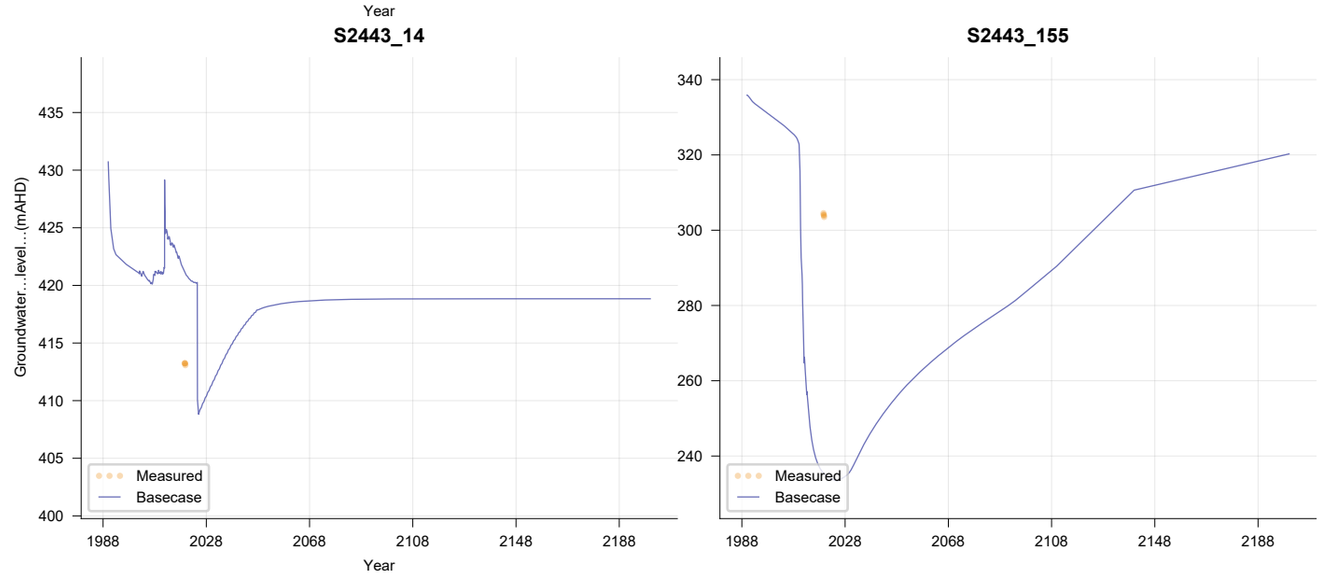

S2442A_200
340
320
300
280
260
240
220
200
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2442A_49
Groundwater...level...(mAHD)
1800
1600
1400
1200
1000
800
600
400
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year

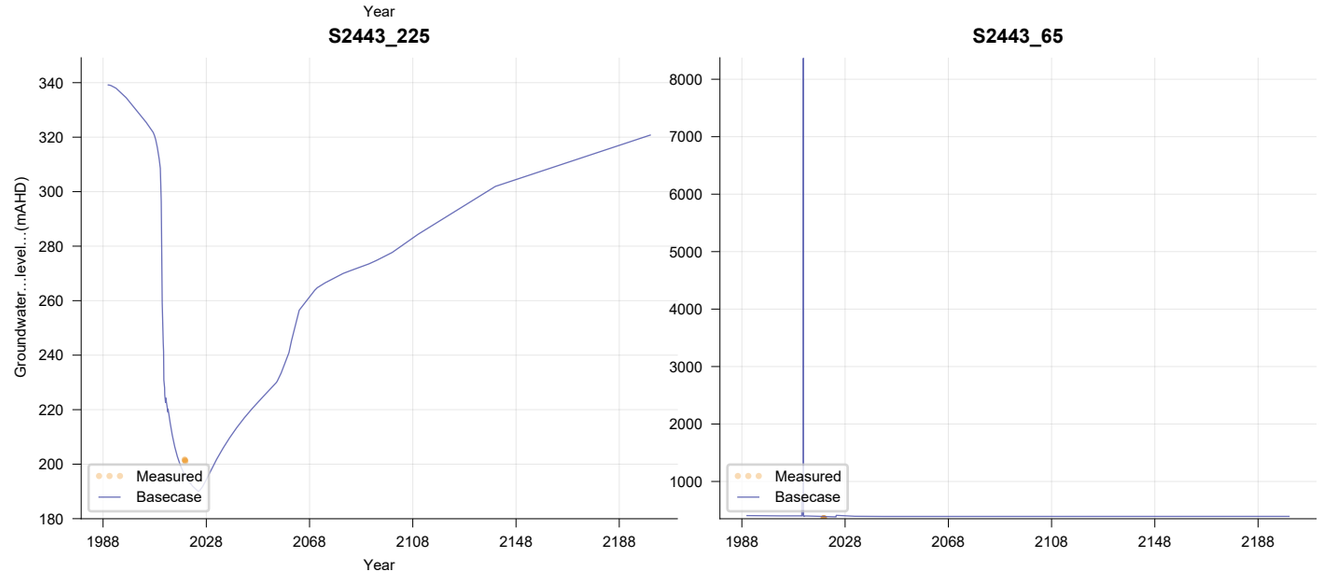

S2442A_80
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340
330
320
310
Measured
Basecase
1988
2028
2068
2108
2148
2188


S2443_113
Groundwater...level...(mAHD)
360
350
340
330
320
310
300
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year


S2443_138
360
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320
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300
290
Measured
Basecase
1988
2028
2068
2108
2148
2188

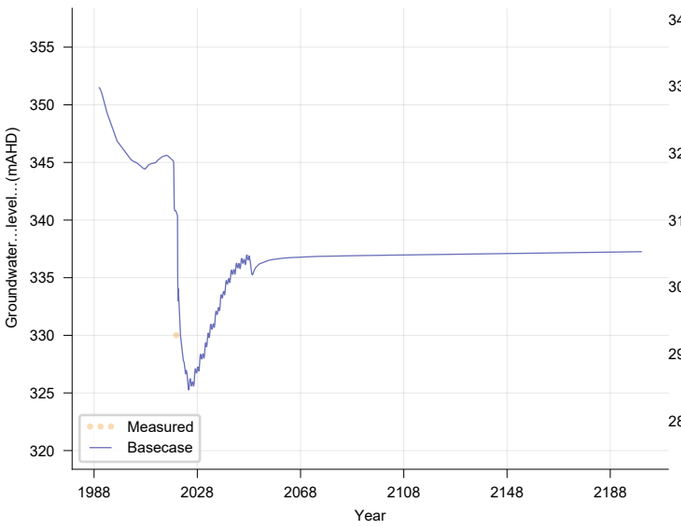

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Groundwater...level...(mAHD)
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430
425
420
415
410
405
400
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year


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340
320
300
280
260
240
Measured
Basecase
1988
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2068
2108
2148
2188

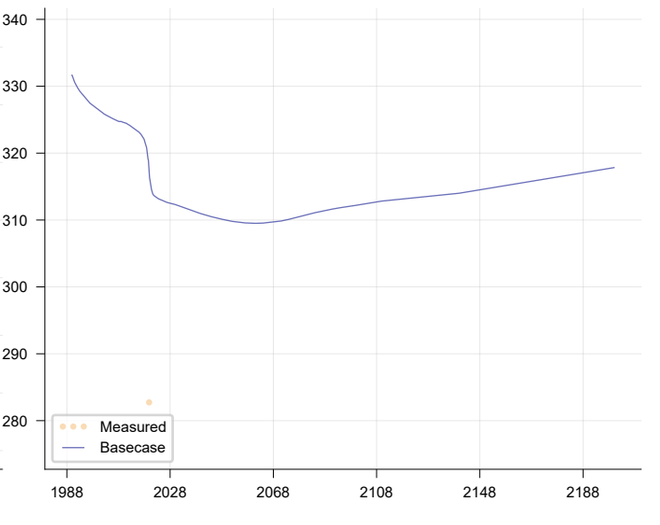

S2443_225
Groundwater...level...(mAHD)
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320
300
280
260
240
220
200
180
Measured
Basecase
1988
2028
2068
2108
2148
2188
Year


S2443_65
8000
7000
6000
5000
4000
3000
2000
1000
Measured
Basecase
1988
2028
2068
2108
2148
2188

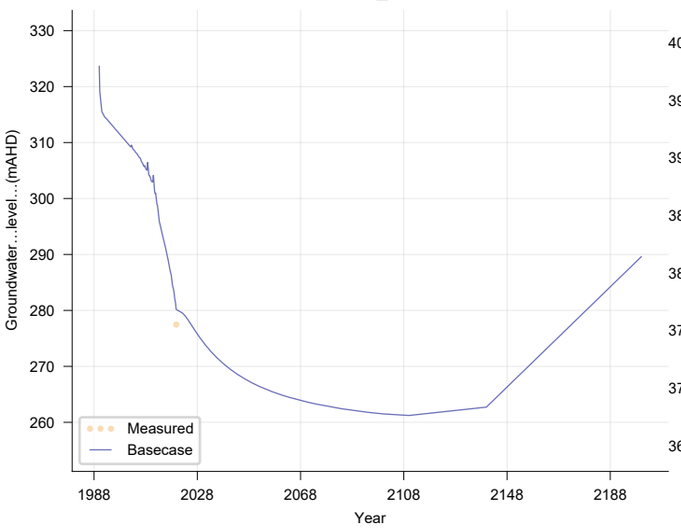
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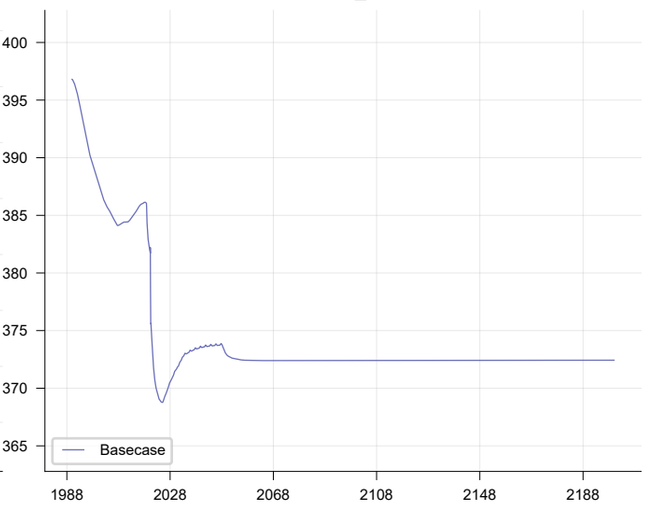

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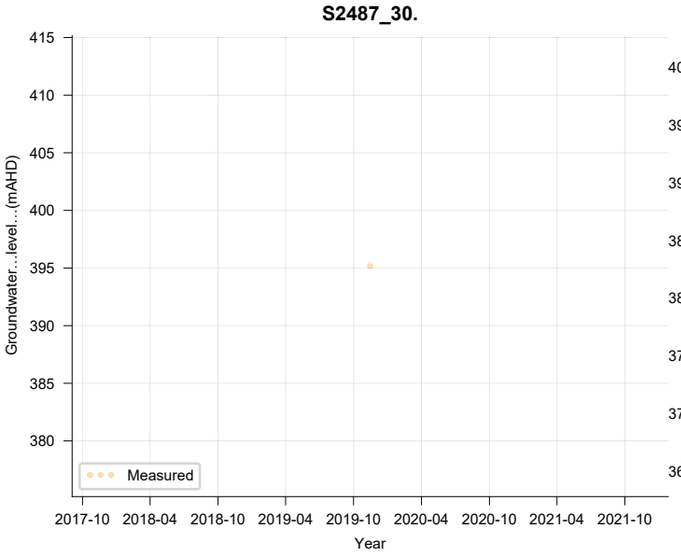

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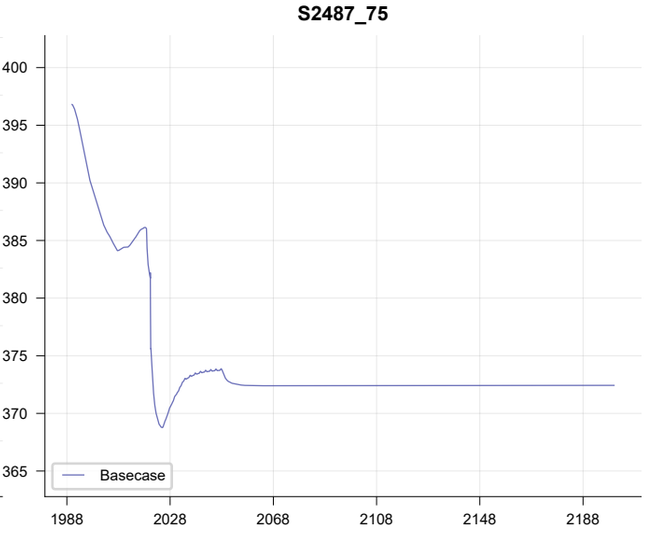

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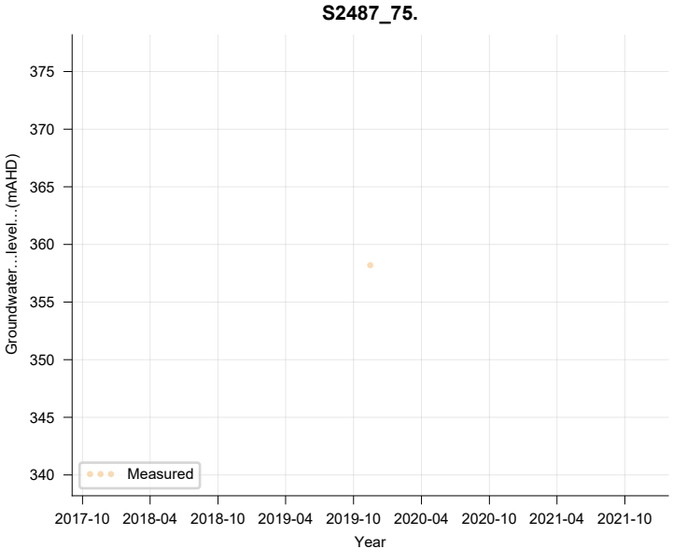

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## S2487_75




## S2487_75.



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## Attachment C – Subsidence Predictions and Impact Assessments

ILLAWARRA METALLURGICAL COAL:

# Dendrobium – Longwall 19

Subsidence Predictions and Impact Assessments for the Natural and Built Features due to the Extraction of the Proposed Longwall 19 in Area 3A at Dendrobium Mine

© MSEC MARCH 2020 | REPORT NUMBER: MSEC1082 | REVISION C

## DOCUMENT REGISTER

| Revision | Description | Author | Checker | Date |
|---|---|---|---|---|
| 01 | Draft Issue | JB | BM | 11 Dec 19 |
| 02 | Draft Issue | JB | BM | 19 Dec 19 |
| A | Final Issue | JB | BM | 9 Jan 20 |
| B | Final Issue | JB | BM | 13 Feb 20 |
| C | Minor updates | JB | BM | 3 Mar 20 |
| | | | | |
| | | | | |
| | | | | |

Report produced to: support the Subsidence Management Plan Application for the proposed Longwall 19 at Dendrobium Mine to be issued to the Department of Planning, Industry and Environment.

Previous reports: WKA77 (January 2001) – Dendrobium Mine Project – Report on the Prediction of Mining Subsidence Parameters and the Assessment of Impacts on Surface Infrastructure – Longwalls 1 to 18 (In support of the EIS).

MSEC311 (Rev. D) – The Prediction of Subsidence Parameters and the Assessment of Mine Subsidence Impacts on Natural Features and Surface Infrastructure Resulting from the Extraction of Proposed Longwalls 6 to 10 in Area 3A and Future Longwalls in Areas 3B and 3C at Dendrobium Mine (October 2007).

MSEC437 (Rev. D) – The Effects of the Proposed Modifications to the Longwalls in Area 3A at Dendrobium Mine on the Subsidence Predictions and Impact Assessments (February 2010).

Background reports available at *www.minesubsidence.com*[1]:

Introduction to Longwall Mining and Subsidence (Revision A)

General Discussion of Mine Subsidence Ground Movements (Revision A)

Mine Subsidence Damage to Building Structures (Revision A)

[1] Direct link: http://www.minesubsidence.com/index_files/page0004.htm

## EXECUTIVE SUMMARY

South32 Illawarra Metallurgical Coal (IMC) has completed the mining of Longwalls 6 to 8 in Area 3A at Dendrobium Mine. IMC proposes to extract Longwall 19 (LW19) within the Wongawilli Seam, which is the final longwall in that series.

The predicted subsidence parameters for the proposed LW19 have been obtained using the Incremental Profile Method (IPM). The IPM has been calibrated for the local conditions at Dendrobium Mine using the available ground movement monitoring data. The maximum predicted total subsidence effects are 3000 mm vertical subsidence, 40 mm/m tilt (i.e. 4 %, or 1 in 25), 1.0 $km^{-1}$ hogging and sagging curvatures (i.e. minimum radius of curvature of 1 km).

The maximum predicted subsidence effects for the existing and proposed longwalls in Area 3A (i.e. LW6 to LW8 and LW19) are less than the maximum predicted values for the existing and approved longwalls in Area 3B (i.e. LW9 to LW17). The predicted subsidence effects are less, as the maximum mining height for Area 3A of 3.9 m is less than the maximum mining height for Area 3B of 4.6 m.

The *Study Area* has been defined, as a minimum, as the surface area enclosed by the: 35° angle of draw line from the extents of the proposed LW19; the predicted incremental 20 mm subsidence contour due to the extraction of the proposed longwall; natural features located within 600 m of the extent of the longwall mining area, in accordance with Condition 8(d), Schedule 3, of the Development Consent (DA 60-03-2001); and features that are expected to experience either far-field horizontal movements, or valley related effects, and which could be sensitive to these movements.

Natural and built features have been identified within or in the vicinity of the Study Area, including Wongawilli Creek, Sandy Creek, drainage lines, cliffs, minor cliffs, rock outcrops, steep slopes, swamps, unsealed roads and tracks, a 330 kV transmission line and Aboriginal heritage sites. Assessments have also been carried out for Sandy Creek Waterfall, Cordeaux and Avon Reservoirs and their associated dam walls, and survey control marks, as these features could be sensitive to far-field effects.

The assessments provided in this report should be read in conjunction with the assessments provided in the reports by other specialist consultants on the project. The main findings from this report are as follows:

- Wongawilli Creek is situated on the western side of the existing LW6 to LW8 and the proposed LW19 in Area 3A. The currently active longwalls in Area 3B are being mined on the western side of the creek. The thalweg (i.e. base or centreline) of the creek is located 175 m south-west of the finishing end of LW19, at its closest point to the proposed longwall.

  The maximum predicted total subsidence effects for Wongawilli Creek, due to the mining in Areas 3A, 3B and 3C, are less than 20 mm vertical subsidence, 150 mm upsidence and 210 mm closure. The maximum predicted incremental movements along the creek, due to the mining of the proposed LW19 only, are less than 20 mm vertical subsidence, 50 mm upsidence and 70 mm closure.

  Fracturing could occur along the section of Wongawilli Creek that is located within a distance of approximately 400 m from the proposed longwall. The rate of Type 3 impacts (i.e. fracturing resulting in surface water flow diversions) has been assessed as low, affecting less than 10 % of rockbars and other stream controlling features located within the Study Area.

- Sandy Creek is located 750 m east of the commencing end of LW19, at its closest point to the proposed longwall. At this distance, the creek is not predicted to experience measurable conventional or valley related effects due to the mining of LW19. It is unlikely, therefore, that Sandy Creek would experience adverse impacts due to the mining of the proposed longwall.

- Sandy Creek Waterfall is located 900 m north-east of the commencing end of LW19. The total closure measured at the waterfall, due to the previous mining of LW6 to LW8 in Area 3A, was 14 mm. The predicted incremental closure for Sandy Creek Waterfall, due to the mining of the proposed LW19, is less than 2 mm, which is in the order of survey tolerance and environmental effects.

  It is considered unlikely, therefore, that Sandy Creek Waterfall would experience adverse impacts due to the mining of LW19.

  It is recommended that the closure across the waterfall is measured monthly during the first 1000 m of mining of LW19. A Trigger Action Response Plan (TARP) should also be established based on these measured movements.

- Drainage lines are located directly above and adjacent to the proposed longwall. These drainage lines are first and second order streams that form tributaries to Wongawilli and Sandy Creeks. The drainage lines could experience the full range of predicted subsidence effects.

  Localised ponding could develop along some sections of the drainage lines, upstream of the chain pillars and the edges of the mining area, and where the natural stream gradients are relatively low.

It is expected that fracturing would occur along the sections of the drainage lines that are located directly above the proposed LW19. Fracturing can also occur outside the extents of the proposed longwall at distances up to approximately 400 m. Surface water flow diversions are also likely to occur along the sections of drainage lines that are located directly above and adjacent to the proposed longwall.

- There are five cliffs that have been identified within the Study Area based on the 35° angle of draw and the predicted 20 mm subsidence contour. Three of these cliffs are partially or wholly located above the proposed LW19. The cliffs have overall lengths ranging between 20 m and 280 m and heights ranging between 10 m and 15 m. The maximum continuous length of cliff directly above the proposed LW19 is 70 m.

  The three cliffs located partially or wholly above the proposed LW19 could experience adverse impacts including rockfalls and instabilities. The impacts are predicted to represent approximately 7 % to 10 % of the total plan length of the cliffs located directly above LW19.

  The two cliffs located outside the mining area and inside the 35° angle of draw could experience minor impacts including isolated rock falls. The remaining cliffs located outside the 35° angle of draw are not expected to experience adverse impacts due to the mining of LW19.

- Rock outcrops and steep slopes are located across the Study Area. These features could experience the full range of predicted subsidence effects. It is likely that fracturing and cracking would occur where these features are located directly above the proposed longwall. The crack widths could be similar to those previously observed at the mine, which were up to approximately 400 mm in width, but typically in the order of 100 mm to 150 mm in width.

- There are four swamps that have been identified wholly or partially within the Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour. There are five additional swamps that are located within the Study Area based on the 600 m boundary.

  Swamp Den148 is partially located above the proposed LW19. Small parts of Swamps Den15a and Den15b are located above the maingate and tailgate, respectively, of LW19. The remaining swamps are located outside the extents of the proposed longwall, at distances ranging between 180 m and 580 m at their closest points. Swamps Den12, Den15b, Den95 and Den146 are located above the previously extracted LW7 and LW8.

  There are small reductions in stream grade within or near to Swamps Den12 and Den15b. There is potential for minor and localised increased ponding upstream of these locations. However, these swamps are located above the existing LW7 and LW8 and, therefore, the potential for increased ponding occurs due to these existing longwalls rather than the proposed LW19.

  Fracturing of the bedrock could occur beneath Swamps Den12 and Den15b and where Swamps Den15a and Den148 are located above and adjacent to the proposed longwall. These swamps have layers of organic soil and, in most cases, cracking would not be visible at the surface within these swamps, except where the depths of bedrock are shallow or exposed.

  The dilated strata beneath the drainage lines could result in the diversion of some surface water flows beneath parts of the swamps where they are located above and adjacent to the proposed longwall. Where there is no connective fracturing to any deeper storage, it is likely that surface water flows will re-emerge at the limits of fracturing and dilation.

  Further discussions on the potential environmental consequences for the swamps are provided by the other specialist consultants on the project.

- Unsealed roads and tracks are located across the mining area. It is likely that cracking and heaving of the unsealed road surfaces would occur where they are located directly above the proposed longwall. It is expected that these features can be maintained in safe and serviceable conditions using normal road maintenance techniques.

- A 330 kV transmission line crosses directly above the existing LW6 to LW8 and the proposed LW19 in Area 3A. There are three suspension towers located within the Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour. Two towers (Refs. T4 and T5) are located directly above the existing LW7 and LW8 and they have cruciform bases. The other tower (Ref. T3) is located 240 m south of the proposed LW19 and it has a piled footing. There are no towers located directly above the proposed LW19.

- The maximum predicted subsidence effects for the towers are 1700 mm vertical subsidence, 15 mm/m tilt (i.e. 1.5 %, or 1 in 67) and 0.35 $km^{-1}$ curvature (i.e. minimum radius of curvature of 2.9 km). The maximum predicted strains are 8 mm/m tensile and compressive based on the 95 % confidence levels.

  The maximum predicted subsidence effects occur at the two towers located above the existing LW7 and LW8. These two towers (i.e. T4 and T5) have cruciform bases. Lesser movements are predicted at the tower located south of the mining area (i.e. T3).

It is recommended that TransGrid undertake a structural analysis of the transmission towers within the Study Area based on the predicted ground movements. If adverse impacts on Tower T3 are anticipated, then these could be managed with the installation of cruciform bases, as previously carried out on Towers T4 and T5. Cable rollers may also need to be installed to accommodate the mining-induced vertical subsidence, tilt and horizontal movements.

- Cordeaux and Avon Reservoirs are located at minimum distances of 0.9 km and 3.1 km, respectively, from the proposed LW19. The Cordeaux Dam Wall and Avon Dam Wall are located at distances of more than 5 km from the proposed longwall.

  The predicted vertical and horizontal movements at the Cordeaux and Avon Reservoirs and their associated dam walls are very small and are unlikely to be measurable. Previous experience of mining in Areas 1, 2, 3A and 3B has not resulted in adverse impacts on these structures. It is unlikely, therefore, that the reservoirs and dam walls would experience adverse impacts due to the extraction of the proposed LW19.

- There are three Aboriginal heritage sites that have been identified within the Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour. There are five additional sites that are located within the Study Area based on the 600 m boundary. These sites comprise two rock shelters with deposits, five rock shelters with art and one rock shelter with art and potential archaeological deposit.

  Three rock shelters are located directly above the proposed LW19. The extraction of the proposed longwall is likely to result in fracturing of the exposed bedrock along the ridgelines and, where the rock is marginally stable, could then result in rockfalls or instabilities. The potential for adverse impacts on the rock shelters located directly above the proposed LW19 has been assessed as unlikely (i.e. less than 10 %) for each of these sites. However, it is possible that these sites could experience fracturing resulting in spalling or rock falls.

  One rock shelter is located above the existing LW8, at a distance of 310 m from the proposed LW19. The remaining four rock shelters are located at distances of 230 m and 580 m outside the mining area. At these distances, it is considered unlikely that these sites would experience adverse impacts due to the mining of the proposed LW19.

- Survey control marks are located within and in the vicinity of the Study Area. The affected survey control marks that are required for future use will need to be re-established after they have stabilised.

The assessments provided in this report indicate that the levels of impact on the natural and built features can be managed by the preparation and implementation of appropriate management strategies. It should be noted, however, that more detailed assessments of some natural and built features have been undertaken by other specialist consultants, and the findings in this report should be read in conjunction with the findings in all other relevant reports.

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## 1.1. Background

Illawarra Metallurgical Coal (IMC), a wholly owned subsidiary of South32 Limited (South32), operates Dendrobium Mine (the Mine), which is located in the Southern Coalfield of New South Wales (NSW). The Mine is located to the west of Wollongong and the Illawarra Escarpment and to the east of the township of Bargo.

IMC previously prepared an Environmental Impact Statement for the Mine that included longwalls in Areas 1, 2 and 3, referred to herein as the 2001 EIS. Mine Subsidence Engineering Consultants (MSEC), formally trading as Waddington Kay & Associates, provided the subsidence predictions and impact assessments for the proposed mining in Report No. WKA77 (January 2001), which supported the 2001 EIS. The Mine was approved by the Minister for Urban Affairs and Planning on the 20 November 2001.

The longwall layout in Area 3A originally comprised five longwalls, referred to as Longwalls 6 to 10 (LW6 to LW10), each with a void width of 250 m. The subsidence predictions and impact assessments for the original longwall layout were provided in Report No. MSEC311 (Rev. D).

The number of longwalls in Area 3A was subsequently reduced to four. The final longwall in the series is referred to as Longwall 19 (LW19), as it is proposed to be extracted after the completion of Longwalls 9 to 18 (LW9 to LW18) in Area 3B and Longwall 21 (LW21) in Area 3C. The commencing and finishing ends of LW6 to LW8 and LW19 were shortened and the void widths of LW8 and LW19 were increased to 305 m. The subsidence predictions and impact assessments for the revised longwall layout were provided in Report No. MSEC437 (Rev. D).

IMC has completed the extraction of LW6 to LW8 in Area 3A. It now proposes to mine the final longwall in in the series, being LW19, after the completion of the currently active series in Area 3B.

The existing LW6 to LW8 and the proposed LW19 in Area 3A are shown in Drawings Nos. MSEC1082-01 and MSEC1082-02, in Appendix D. The proposed LW19 and the Study Area, as defined in Section 2.1, have been overlaid on an orthophoto of the area, and are shown in Fig. 1.1.

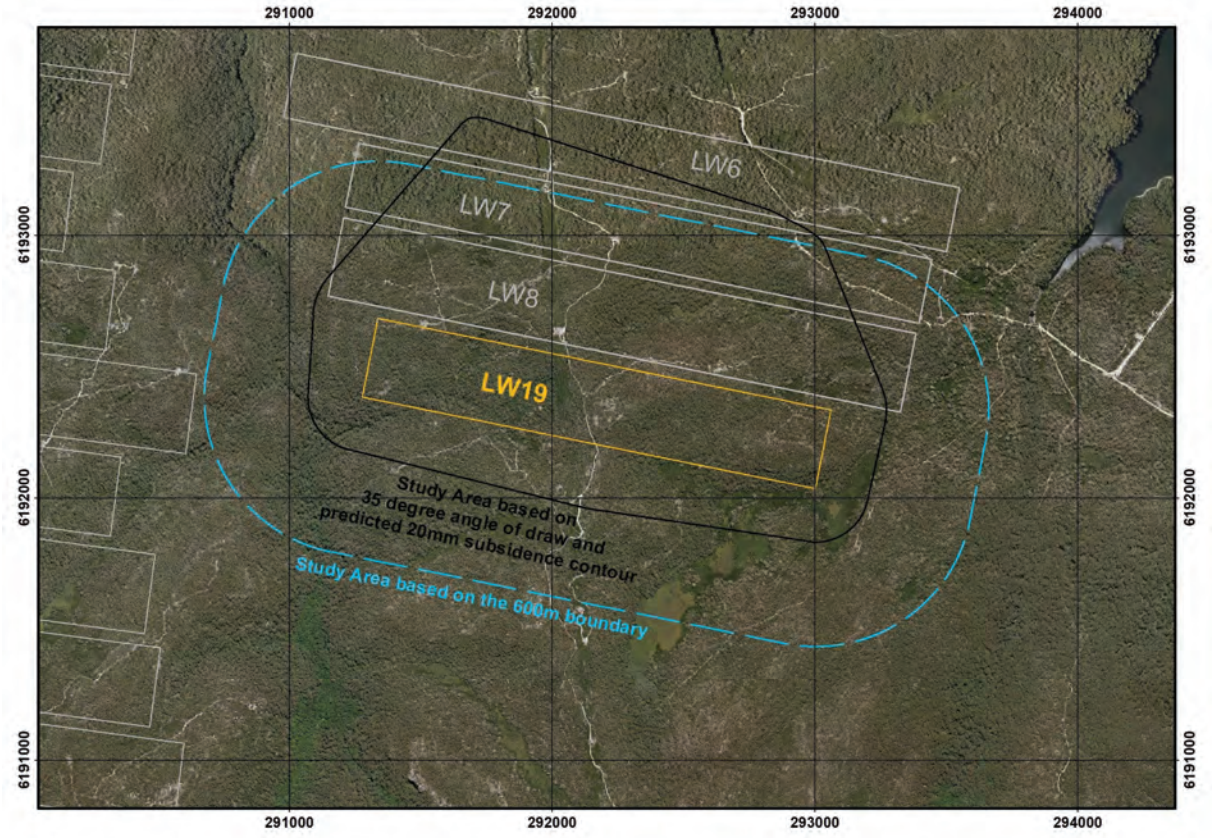



**Fig. 1.1 Orthophotograph showing LW19 and the Study Area**

IMC is preparing a Subsidence Management Plan (SMP) Application for the proposed LW19 in Area 3A. MSEC has been commissioned by IMC to:

- prepare subsidence predictions for the proposed LW19, including the cumulative movements due to the previously extracted and approved longwalls in Areas 3A, 3B and 3C;
- identify the natural and built features in the vicinity of the proposed longwall;
- provide subsidence predictions for each of these features;
- prepare impact assessments, in conjunction with other specialist consultants, for each of the natural and built features; and
- recommend management strategies and monitoring.

This report has been prepared to support the SMP Application for the proposed LW19 which will be submitted to the Department of Planning, Industry and Environment (DPIE). In some cases, this report will refer to other sources of information on specific natural and built features. This report, therefore, should be read in conjunction with the other relevant reports associated with this application.

Chapter 1 provides background information on the study, including the mining geometry, surface and seam and overburden lithology.

Chapter 2 defines the Study Area and provides a summary of the natural and built features identified within this area.

Chapter 3 provides an overview of the methods that have been used to predict the mine subsidence effects resulting from the extraction of the existing and proposed longwalls.

Chapter 4 provides the maximum predicted subsidence effects resulting from the extraction of the existing and proposed longwalls.

Chapters 5 and 6 provide the descriptions, predictions and impact assessments for each of the natural and built features that have been identified within the Study Area. Recommendations for each of these features are also provided, which have been based on the predictions and impact assessments.

## 1.2. Mining geometry

The layout of the proposed LW19 is shown in Drawings Nos. MSEC1082-01 and MSEC1082-02, in Appendix D. A summary of the dimensions for this longwall is provided in Table 1.1. The longwall is proposed to be extracted from the Wongawilli Seam.

**Table 1.1 Geometry of the proposed LW19**

| Longwall | Overall void length including installation heading (m) | Overall void width including first workings (m) | Overall tailgate chain pillar width (m) |
|---|---|---|---|
| LW19 | 1765 | 305 | 45 |

The length of longwall extraction excluding the installation heading is approximately 9 m less than the overall void length provided in the above table, i.e. approximately 1756 m. The longwall face width excluding the first workings is 295 m. The solid chain pillar width between LW19 and the existing LW8 is approximately 45 m.

The longwall will be extracted towards the main headings (i.e. retreat mining from the east towards the west) within the Wongawilli Seam. LW19 will be extracted after LW21 in Area 3C and prior to the extraction of Longwall 20 (LW20) in Area 3C.

## 1.3. Surface and seam levels

The levels of the natural surface and the Wongawilli Seam are illustrated along Section 1 and Section 2 in Fig. 1.2 and Fig. 1.3, respectively. The locations of these sections are shown in Drawings Nos. MSEC1082-03 to MSEC1082-05. The definition of the Study Area is provided in Section 2.1.

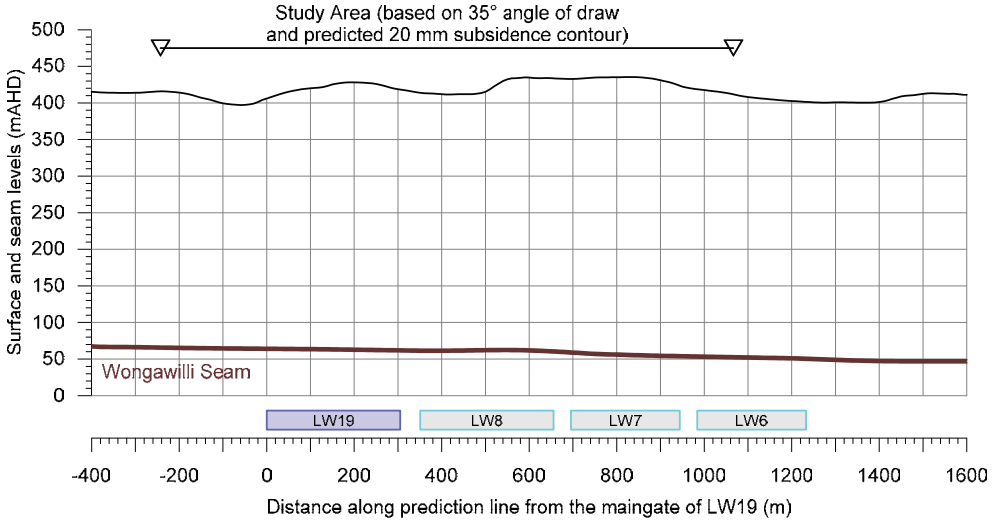



**Fig. 1.2 Surface and seam levels along Section 1 (cross-section)**

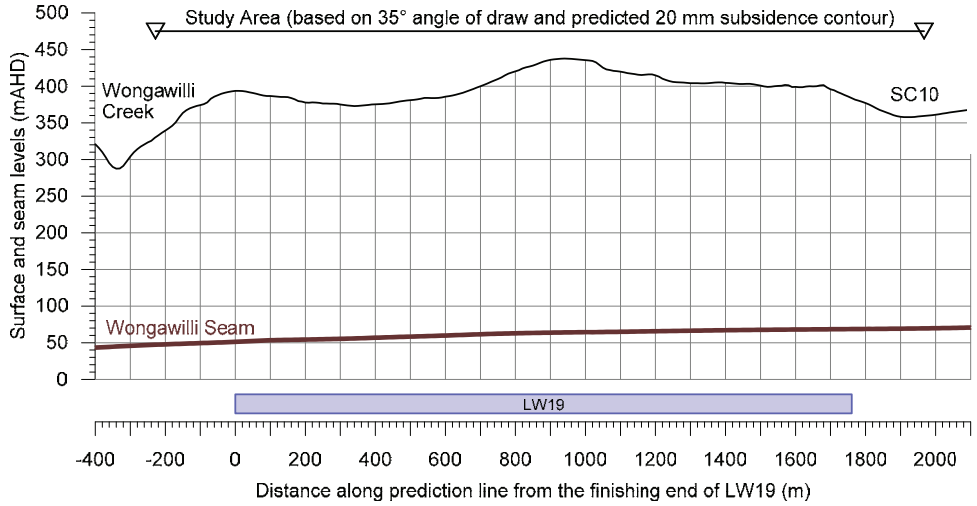



**Fig. 1.3 Surface and seam levels along Section 2 (long-section)**

The surface level contours are shown in Drawing No. MSEC1082-03. The proposed longwall is located between Wongawilli Creek to the west and Sandy Creek to the east. The natural ground falls towards these creeks and their tributaries. The surface levels directly above the proposed LW19 vary between 330 metres above Australian Height Datum (mAHD) near the longwall finishing (i.e. western) end and 445 mAHD towards the middle of the longwall.

The seam floor contours, seam thickness contours (for the basal section) and depth of cover contours for the Wongawilli Seam are shown in Drawings Nos. MSEC1082-04, MSEC1082-05 and MSEC1082-06, respectively. The seam floor generally dips from the south-east to the north-west. The average gradient of the seam within the extents of the mining area is approximately 2 %, or 1 in 50.

The depths of cover to the Wongawilli Seam directly above the proposed LW19 vary between 280 m and 370 m. The minimum depth of cover occurs along Drainage Line WC14 near the finishing (i.e. western) end of the proposed longwall. The maximum depth of cover occurs along the ridgeline towards the middle of the proposed longwall.

The Wongawilli Seam is nominally 9 m thick and contains numerous bands of non-coal material. The economic section of the Wongawilli Seam is the basal 3 m to 5 m. The thickness contours for the basal section of the Wongawilli Seam are shown in Drawing No. MSEC1082-05.

IMC has reviewed the nature of the banding and proposes to extract a maximum height of 3.9 m using conventional longwall mining techniques. The actual mining height may be less than this, depending on the banding, typically ranging between 3.5 m and 3.75 m. The subsidence predictions and impact assessments for the proposed LW19 have been based on a constant cutting height of 3.9 m.

## 1.4. Geological details

The Mine is located in the southern part of the Sydney Basin. The landform is hilly and the area is crossed by the Avon River, the Cordeaux River and their associated creeks and tributaries. The geology mainly comprises sedimentary sandstones, shales and claystones of the Permian and Triassic Periods, which have been intruded by igneous sills. A typical stratigraphic section for the Mine is provided in Fig. 1.4 (Source: IMC).

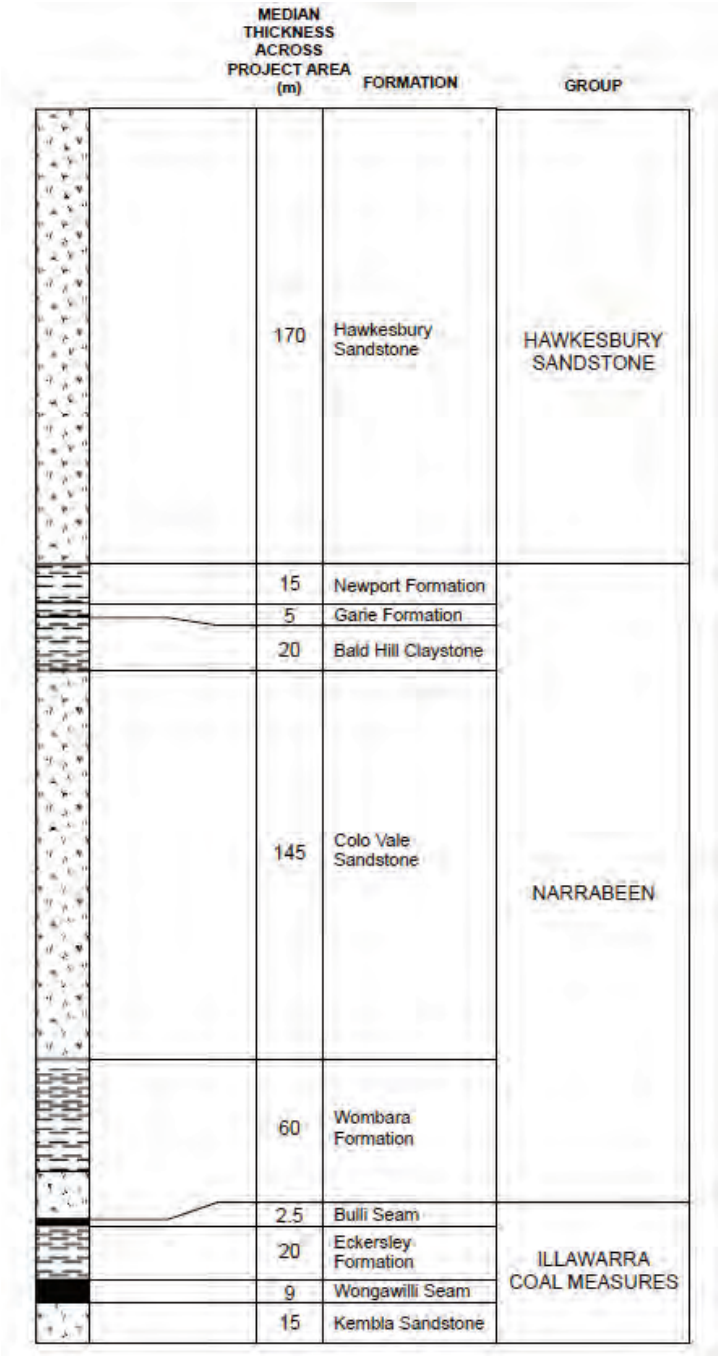



**Fig. 1.4 Typical stratigraphic section for the Mine (Source: IMC)**

The major sedimentary units at the Mine are, from the top down, the Hawkesbury Sandstone, the Narrabeen Group and the Illawarra Coal Measures. The Wianamatta Group is only present as a very limited residual in localised areas.

Hawkesbury Sandstone is the largest member in the overburden, with an average thickness of approximately 170 m at the Mine. The Narrabeen Group contains the Newport Formation (sometimes referred to as the Gosford Formation), Garie Formation, Bald Hill Claystone, Colo Vale Sandstone (also referred to as Bulgo Sandstone), and the Wombarra Formation comprising Stanwell Park Claystone, Scarborough Sandstone, Wombarra Shale and Coalcliff Sandstone.

The Bulli Seam is the top unit in the Illawarra Coal Measures. The interval between the Bulli Seam and the Wongawilli Seam is known as the Eckersley Formation which consists of sandstones, shales and minor coal seams. The proposed LW19 will be extracted from the Wongawilli Seam.

The major claystone units are the Bald Hill and Stanwell Park Claystones that lie above and below the Colo Vale Sandstone and at the base of the Hawkesbury Sandstone. The Wombarra Shale will be located within the collapsed zone above the proposed longwall.

The Mine sits at the southern end of the Nepean/Kurrajong Fault and Lapstone Monocline system. The area is therefore imprinted with the north-westerly trending structures that connect to these large scale geological features to the north. The large north-west and north-north-west displacement faults are the primary deformational set in the area. However, those faults trend north-east in the coastal fault zone. The geological structures identified or inferred at the Mine are shown in Drawing No. MSEC1082-07.

An igneous sill has intruded into the Wongawilli Seam to the south and to the east of the mining area. The longwall has been set back to avoid the cinder zone within the Wongawilli Seam. There are no major faults or dykes identified within the extents of the proposed LW19. The locations and sizes of the geological structures will be better defined through ongoing investigations and the development of the first workings.

Surface lineaments with WNW-ESE orientations have been identified above the western end of the proposed LW19. These structures are not coincident with the valleys or other topographical features and they do not appear to be associated with underground geological structures.

A review was carried out on the effects of lineaments, faults and dykes on the measured surface subsidence above LW9 to LW13 in Area 3B (MSEC, 2019). The available monitoring data suggest that there was no apparent increase in the subsidence measured in the mapped locations of the lineaments, minor faults and dykes. There also does not appear to be an association between the observed surface impacts and the mapped lineaments, minor faults and dykes.

IMC has advised that the surface lineaments, minor faults and dykes above and near to the proposed LW19 are similar to those mapped in Area 3B. It is considered unlikely, therefore, that these structures would adversely affect the subsidence predictions and assessed impacts for the proposed LW19.

The surface lithology in the area can be seen in Fig. 1.5, which shows the existing and proposed longwalls and the Study Area overlaid on Geological Series Sheet *Wollongong 9029*, which was published by the DMR (1999), now known as the Resources Regulator. The surface lithology in Area 3A generally comprises Hawkesbury Sandstone (Rh), with localised areas of Quaternary Alluvium (Qs).

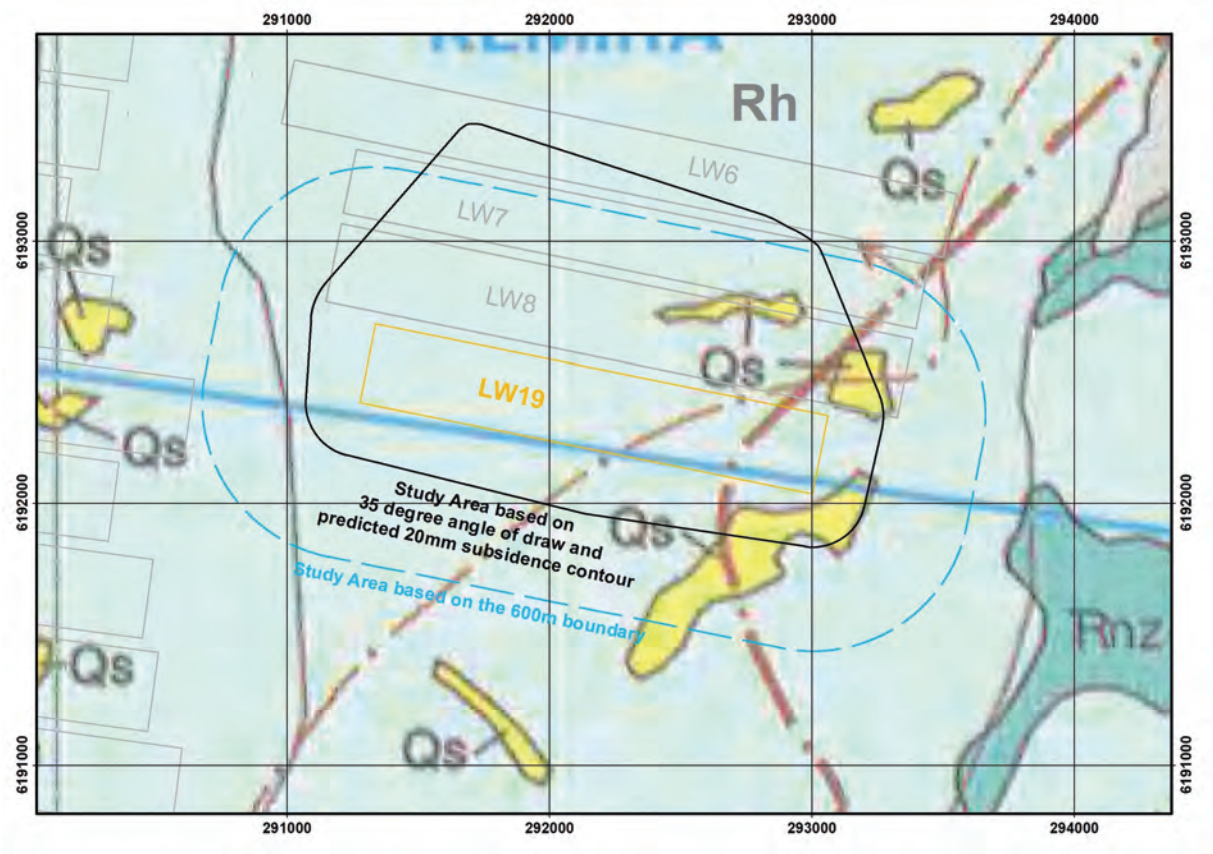



**Fig. 1.5 LW19 overlaid on Geological Series Sheet *Wollongong 9029* (DMR, 1999)**

## 2.1. Definition of the Study Area

The *Study Area* is defined as the surface area that could be affected by the extraction of the proposed LW19. Two areas have been considered in this report, being the *Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour* and the *Study Area based on the 600 m boundary*.

The Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour represents the minimum extent for the assessments for the conventional ground movements (i.e. vertical subsidence and its associated effects). Low level conventional ground movements can extend beyond this area. The natural and built features located outside this area, which could experience these low level movements and could be sensitive to these movements, have also been included in the assessments provided in this report.

The Study Area based on the 600 m boundary represents the minimum extent of the assessments for the valley related effects. This distance is based on the recommendations from the Southern Coalfield Inquiry (DPIE, 2008) for the risk management zones. The natural and built features located outside the 600 m boundary, which could experience valley related effects and could be sensitive to these movements, have also been included in the assessments provided in this report.

The extent of the Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour has been calculated by combining the areas bounded by the following limits:

- The 35° angle of draw line from the extent of the proposed LW19; and
- The predicted limit of vertical subsidence, taken as the incremental 20 mm subsidence contour, due to the mining of LW19 only.

The depths of cover contours for the Wongawilli Seam are shown in Drawing No. MSEC1082-06. The depth of cover varies between 280 m and 370 m directly above the proposed LW19. The 35° angle of draw line, therefore, has been determined by drawing a line that is a horizontal distance varying between 196 m and 259 m around the extents of the longwall void.

The predicted limit of vertical subsidence, taken as the predicted incremental 20 mm subsidence contour due to the mining of LW19, has been determined using the calibrated Incremental Profile Method (IPM), which is described in Chapter 3. The predicted incremental subsidence contours, including the 20 mm subsidence contour, are shown in Drawing No. MSEC1082-11, in Appendix D.

The predicted incremental 20 mm subsidence contour extends beyond the 35° angle of draw above the existing LW6 to LW8. Elsewhere, the contour is located inside the angle of draw. The Study Area based on the 35° angle of draw line and predicted 20 mm subsidence contour is shown in Drawings Nos. MSEC1082-01 and MSEC1082-02, in Appendix D.

The Study Area based on a 600 m boundary around the extents of the proposed LW19 is also shown in Drawings Nos. MSEC1082-01 and MSEC1082-02. The features that are located within the 600 m boundary that are predicted to experience valley related effects and could be sensitive to these movements have been included in the assessments provided in this report, in accordance with Condition 8(d), Schedule 3 of the Development Consent. These features include streams, upland swamps and Aboriginal heritage sites.

There are additional features that are located outside the 600 m boundary that could experience either far-field horizontal or valley related effects. The surface features that could be sensitive to such movements have been identified and have also been included in the assessments provided in this report. These features include Sandy Creek Waterfall, the reservoirs, dam walls and survey control marks.

## 2.2. Natural and built features within the Study Area

A summary of the natural and built features located within the Study Area is provided in Table 2.1. The locations of these features are shown in Drawings Nos. MSEC1082-08 to MSEC1082-10, in Appendix D. The descriptions, predictions and impact assessments for the natural and built features are provided in Chapters 5 and 6. The section number references are provided in Table 2.1.

## Table 2.1 Natural and built features within the Study Area

| Item | Within Study Area | Section number reference |
|---|---|---|
| **NATURAL FEATURES** | | |
| Catchment Areas or Declared Special Areas | ✓ | 5.1 |
| Rivers or Creeks | ✓ | 5.2 to 5.4 |
| Aquifers or Known Groundwater Resources | ✓ | 5.5 |
| Springs | × | |
| Sea or Lake | × | |
| Shorelines | × | |
| Natural Dams | × | |
| Cliffs or Pagodas | ✓ | 5.6 |
| Steep Slopes | ✓ | 5.7 |
| Escarpments | × | |
| Land Prone to Flooding or Inundation | × | |
| Swamps, Wetlands or Water Related Ecosystems | ✓ | 5.10 |
| Threatened or Protected Species | ✓ | 5.11 |
| National Parks | × | |
| State Forests | × | |
| State Conservation Areas | × | |
| Natural Vegetation | ✓ | 5.11 |
| Areas of Significant Geological Interest | × | |
| Any Other Natural Features Considered Significant | × | |
| | | |
| **PUBLIC UTILITIES** | | |
| Railways | × | |
| Roads (All Types) | ✓ | 6.1 |
| Bridges | × | |
| Tunnels | × | |
| Culverts | × | |
| Water, Gas or Sewerage Infrastructure | × | |
| Liquid Fuel Pipelines | × | |
| Electricity Transmission Lines or Associated Plants | ✓ | 6.2 |
| Telecommunication Lines or Associated Plants | × | |
| Water Tanks, Water or Sewage Treatment Works | × | |
| Dams, Reservoirs or Associated Works | ✓ | 6.3 |
| Air Strips | × | |
| Any Other Public Utilities | × | |
| | | |
| **PUBLIC AMENITIES** | | |
| Hospitals | × | |
| Places of Worship | × | |
| Schools | × | |
| Shopping Centres | × | |
| Community Centres | × | |
| Office Buildings | × | |
| Swimming Pools | × | |
| Bowling Greens | × | |
| Ovals or Cricket Grounds | × | |
| Race Courses | × | |
| Golf Courses | × | |
| Tennis Courts | × | |
| Any Other Public Amenities | × | |

| Item | Within Study Area | Section number reference |
|---|---|---|
| **FARM LAND AND FACILITIES** | | |
| Agricultural Utilisation or Agricultural Suitability of Farm Land | × | |
| Farm Buildings or Sheds | × | |
| Tanks | × | |
| Gas or Fuel Storages | × | |
| Poultry Sheds | × | |
| Glass Houses | × | |
| Hydroponic Systems | × | |
| Irrigation Systems | × | |
| Fences | × | |
| Farm Dams | × | |
| Wells or Bores | × | |
| Any Other Farm Features | × | |
| | | |
| **INDUSTRIAL, COMMERCIAL AND BUSINESS ESTABLISHMENTS** | | |
| Factories | × | |
| Workshops | × | |
| Business or Commercial Establishments or Improvements | × | |
| Gas or Fuel Storages or Associated Plants | × | |
| Waste Storages or Associated Plants | × | |
| Buildings, Equipment or Operations that are Sensitive to Surface Movements | × | |
| Surface Mining (Open Cut) Voids or Rehabilitated Areas | × | |
| Mine Infrastructure Including Tailings Dams or Emplacement Areas | × | |
| Any Other Industrial, Commercial or Business Features | × | |
| | | |
| **AREAS OF ARCHAEOLOGICAL OR HERITAGE SIGNIFICANCE** | ✓ | 6.4 |
| | | |
| **ITEMS OF ARCHITECTURAL SIGNIFICANCE** | × | |
| | | |
| **PERMANENT SURVEY CONTROL MARKS** | ✓ | 6.5 |
| | | |
| **RESIDENTIAL ESTABLISHMENTS** | | |
| Houses | × | |
| Flats or Units | × | |
| Caravan Parks | × | |
| Retirement or Aged Care Villages | × | |
| Associated Structures such as Workshops, Garages, On-Site Waste Water Systems, Water or Gas Tanks, Swimming Pools or Tennis Courts | × | |
| Any Other Residential Features | × | |
| | | |
| **ANY OTHER ITEM OF SIGNIFICANCE** | × | |
| **ANY KNOWN FUTURE DEVELOPMENTS** | × | |

# 3.0 OVERVIEW OF MINE SUBSIDENCE AND THE METHODS USED TO PREDICT THE SUBSIDENCE EFFECTS FOR THE EXISTING AND PROPOSED LONGWALLS

## 3.1. Introduction

The following sections provide overviews of conventional and non-conventional mine subsidence effects and the methods that have been used to predict these movements. Further information is also provided in the background reports entitled *Introduction to Longwall Mining and Subsidence* and *General Discussion on Mine Subsidence Ground Movements* which can be obtained from *www.minesubsidence.com*.

## 3.2. Overview of conventional subsidence parameters

The normal ground movements resulting from the extraction of longwalls are referred to as conventional or systematic subsidence movements. These movements are described by the following parameters:

- **Subsidence** usually refers to vertical displacement of a point, but subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements in some cases, where the subsidence is small beyond the longwall goaf edges, can be greater than the vertical subsidence. Subsidence is usually expressed in units of *millimetres (mm)*.
- **Tilt** is the change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of *millimetres per metre (mm/m)*. A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1000.
- **Curvature** is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/kilometres ($km^{-1}$)*, but the values of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *kilometres (km)*.
- **Strain** is the relative differential horizontal movements of the ground. **Normal strain** is calculated as the change in horizontal distance between two points on the ground, divided by the original horizontal distance between them. Strain is typically expressed in units of *millimetres per metre (mm/m)*. **Tensile Strains** occur where the distances between two points increase and **Compressive Strains** occur when the distances between two points decrease. So that ground strains can be compared between different locations, they are typically measured over bay lengths that are equal to the depth of cover between the surface and seam divided by 20.

  Whilst mining-induced normal strains are measured along monitoring lines, ground shearing can also occur both vertically and horizontally across the directions of monitoring lines. Most of the published mine subsidence literature discusses the differential ground movements that are measured along subsidence monitoring lines, however, differential ground movements can also be measured across monitoring lines using 3D survey monitoring techniques.
- **Horizontal shear deformation** across monitoring lines can be described by various parameters including horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index. It is not possible, however, to determine the horizontal shear strain across a monitoring line using 2D or 3D monitoring techniques. High deformations along monitoring lines (i.e. normal strains) are generally measured where high deformations have been measured across the monitoring line (i.e. shear deformations), and vice versa.

The **incremental** subsidence, tilts, curvatures and strains are the additional parameters which result from the extraction of each longwall. The **cumulative** subsidence, tilts, curvatures and strains are the accumulated parameters which result from the extraction of a series of longwalls. The **total** subsidence, tilts, curvatures and strains are the final parameters at the completion of a series of longwalls. The **travelling** tilts, curvatures and strains are the transient movements as the longwall extraction face mines directly beneath a given point.

## 3.3. Far-field movements

The measured horizontal movements at survey marks which are located beyond the longwall goaf edges and over solid unmined coal areas are often much greater than the observed vertical movements at those marks. These movements are often referred to as *far-field movements*.

Far-field horizontal movements tend to be bodily movements towards the extracted goaf area and are accompanied by very low levels of strain. These movements generally do not result in impacts on natural features or built environments, except where they are experienced by large structures which are very sensitive to differential horizontal movements.

In some cases, higher levels of far-field horizontal movements have been observed where steep slopes or surface incisions exist nearby, as these features influence both the magnitude and the direction of ground movement patterns. Similarly, increased horizontal movements are often observed around sudden changes in geology or where blocks of coal are left between longwalls or near other previously extracted series of longwalls. In these cases, the levels of observed subsidence can be slightly higher than normally predicted, but these increased movements are generally accompanied by very low levels of tilt and strain.

Far-field horizontal movements and the method used to predict such movements are described further in Section 4.6.

## 3.4. Overview of non-conventional subsidence movements

Conventional subsidence profiles are typically smooth in shape and can be explained by the expected caving mechanisms associated with overlying strata spanning the extracted void. Normal conventional subsidence movements due to longwall extraction are easy to identify where longwalls are regular in shape, the extracted coal seams are relatively uniform in thickness, the geological conditions are consistent and surface topography is relatively flat.

As a general rule, the smoothness of the profile is governed by the depth of cover and lithology of the overburden, particularly the near-surface strata layers. Where the depth of cover is greater than 400 m, such as is the case over a large part of the Study Area, the observed subsidence profiles along monitoring lines are generally smooth. Where the depth of cover is less than 100 m, the observed subsidence profiles along monitoring lines are generally irregular. Very irregular subsidence movements are observed with much higher tilts, curvatures and strains at very shallow depths of cover where the collapsed zone above the extracted longwalls extends up to or near to the surface.

Irregular subsidence movements are occasionally observed at the deeper depths of cover along an otherwise smooth subsidence profile. The cause of these irregular subsidence movements can be associated with:

- sudden or abrupt changes in geological conditions;
- steep topography; and
- valley related mechanisms.

Non-conventional movements due to geological conditions, steep topography and valley related movements are discussed in the following sections.

### 3.4.1. Non-conventional subsidence movements due to changes in geological conditions

Most non-conventional ground movements are a result of the reaction of near-surface strata to increased horizontal compressive stresses due to mining operations. Some of the geological conditions that influence these irregular subsidence movements are the blocky nature of near-surface sedimentary strata layers and the presence of unknown faults, dykes or other geological structures, cross bedded strata, thin and brittle near-surface strata layers and pre-existing natural joints. The presence of these geological features near the surface can result in a bump in an otherwise smooth subsidence profile and these bumps are usually accompanied by locally increased tilts, curvatures and strains.

Even though it may be possible to explain most observed non-conventional ground movements, there remains some observed irregular ground movements that cannot be explained with available information. The term “anomaly” is therefore reserved for those non-conventional ground movement cases that were not expected to occur and cannot be explained by any of the above possible causes.

It is not possible to predict the locations and magnitudes of non-conventional anomalous movements. In some cases, approximate predictions for the non-conventional ground movements can be made where the underlying geological or topographic conditions are known in advance. It is expected that these methods will improve as further knowledge is gained through ongoing research and investigation.

In this report, non-conventional ground movements are being included statistically in the predictions and impact assessments, by basing these on the frequency of past occurrence of both the conventional and non-conventional ground movements and impacts. The analysis of strains provided in Section 4.4 includes those resulting from both conventional and non-conventional anomalous movements. The impact assessments for the natural and built features, which are provided in Chapters 5 and 6, include historical impacts resulting from previous longwall mining which have occurred as the result of both conventional and non-conventional subsidence movements.

### 3.4.2. Non-conventional subsidence movements due to steep topography

Non-conventional movements can also result from increased horizontal movements in the downslope direction where longwalls are extracted beneath steep slopes. In these cases, elevated tensile strains develop near the tops and on the sides of the steep slopes and elevated compressive strains develop near the bases of the steep slopes. The potential impacts resulting from the increased horizontal movements include the development of tension cracks at the tops and on the sides of the steep slopes and compression ridges at the bottoms of the steep slopes.

Further discussions on the potential for downslope movements for the steep slopes within the Study Area are provided in Section 5.7.

### 3.4.3. Valley related movements

The streams within the Study Area will be affected by valley related movements, which are commonly observed in the Southern Coalfield. Valley bulging movements are a natural phenomenon, resulting from the formation and ongoing development of the valley, as illustrated in Fig. 3.1. The potential for these natural movements is influenced by the geomorphology of the valley.

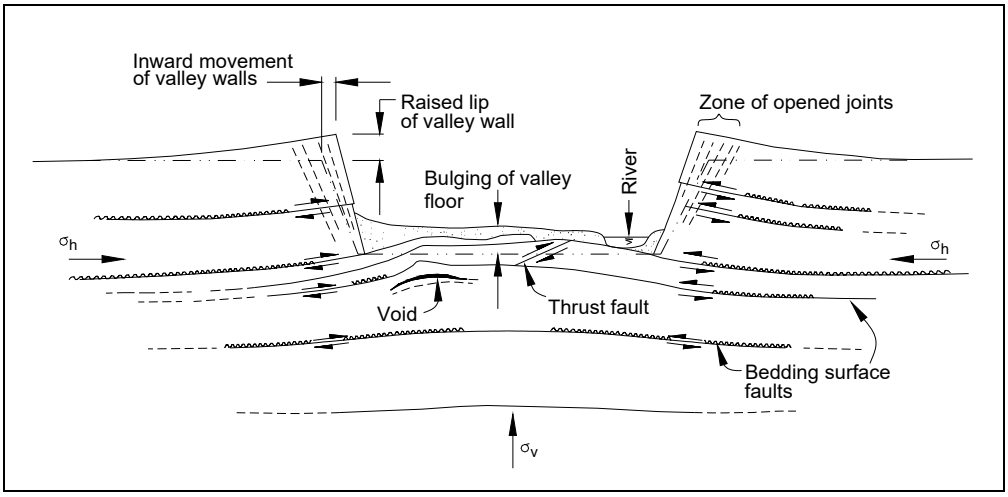



**Fig. 3.1 Valley formation in flat-lying sedimentary rocks (after Patton and Hendren 1972)**

Valley related movements can be caused by or accelerated by mine subsidence as the result of a number of factors, including the redistribution of horizontal in situ stresses and downslope movements. Valley related movements are normally described by the following parameters:

- **Upsidence** is the reduced subsidence, or the relative uplift within a valley which results from the dilation or buckling of near-surface strata at or near the base of the valley. The magnitude of upsidence, which is typically expressed in the units of *millimetres (mm)*, is the difference between the observed subsidence profile within the valley and the conventional subsidence profile which would have otherwise been expected in flat terrain.
- **Closure** is the reduction in the horizontal distance between the valley sides. The magnitude of closure, which is typically expressed in the units of *millimetres (mm)*, is the greatest reduction in horizontal distance between any two points on the opposing valley sides.
- **Compressive Strains** occur within the bases of valleys as a result of valley closure and upsidence movements. **Tensile Strains** also occur in the sides and near the tops of the valleys as a result of valley closure movements. The magnitudes of these strains, which are typically expressed in the units of *millimetres per metre (mm/m)*, are calculated as the changes in horizontal distance over a standard bay length, divided by the original bay length.

The predicted valley related movements for the streams in the existing and approved mining Areas 2, 3A and 3B at the Mine were determined using the empirical method outlined in ACARP Research Project No. C9067 (Waddington and Kay, 2002), referred to as the 2002 ACARP method.

More recently, the empirical prediction method has been refined based on further research undertaken as part of ACARP Research Project No. 18015 (Kay and Waddington, 2014), referred to as the 2014 ACARP method. This method only provides predictions for valley closure and not for upsidence.

The predictions based on the 2002 ACARP method can be directly compared with the predictions provided in previous MSEC subsidence reports for Areas 2, 3A and 3B at the Mine and with other case studies. The assessments provided in this report, therefore, have been based on the predictions obtained using the 2002 ACARP method.

The reliability of the predicted valley related closure movements is discussed in Section 3.6.2.

The predicted strains resulting from valley related movements for the streams in the Study Area have been determined using the ground monitoring data for longwalls that have previously mined beneath or near to streams in the Southern Coalfield, including at Dendrobium Mine. Refer to the impact assessments for the streams in Chapter 5 for further details.

Further details can be obtained from the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained at *www.minesubsidence.com*.

## 3.5. The Incremental Profile Method

The predicted conventional subsidence parameters for the existing and proposed longwalls have been determined using the Incremental Profile Method (IPM), which has been developed by MSEC. The method is an empirical model based on a large database of observed monitoring data from previous mining within the Southern, Newcastle, Hunter and Western Coalfields of New South Wales.

The database consists of detailed subsidence monitoring data from collieries in NSW including: Angus Place, Appin, Baal Bone, Bellambi, Beltana, Blakefield South, Bulli, Chain Valley, Clarence, Coalcliff, Cooranbong, Cordeaux, Corrimal, Cumnock, Dartbrook, Delta, Dendrobium, Eastern Main, Ellalong, Fernbrook, Glennies Creek, Gretley, Invincible, John Darling, Kemira, Lambton, Liddell, Mandalong, Metropolitan, Mt. Kembla, Munmorah, Nardell, Newpac, Newstan, Newvale, Newvale 2, South Bulga, South Bulli, Springvale, Stockton Borehole, Teralba, Tahmoor, Tower, Wambo, Wallarah, Western Main, Ulan, United, West Cliff, West Wallsend, and Wyee.

The database consists of the observed incremental subsidence profiles, which are the additional subsidence profiles resulting from the extraction of each longwall within a series of longwalls. It can be seen from the normalised incremental subsidence profiles within the database, that the observed shapes and magnitudes are reasonably consistent where the mining geometry and local geology are similar.

Subsidence predictions made using the IPM use the database of observed incremental subsidence profiles, the longwall geometries, local surface and seam information and geology. The method tends to over-predict the conventional subsidence parameters (i.e. is slightly conservative) where the mining geometry and geology are within the range of the empirical database. The predictions can be further tailored to local conditions where observed monitoring data is available close to the mining area.

Further details on the IPM are provided in the background report entitled *General Discussion on Mine Subsidence Ground Movements* which can be obtained from *www.minesubsidence.com*.

## 3.6. Calibration of the IPM

The use of the IPM at Dendrobium Mine has been continually reviewed and refined based on the latest available ground movement monitoring data.

Initially, the standard model for the Southern Coalfield was used for the predictions in Areas 1, 2 and 3A at the Mine. This standard model is predominately based on the ground monitoring data for mining in the Bulli Seam in the Southern Coalfield.

The model was then calibrated for Area 3B based on the available monitoring data from the Mine at the time of the SMP Application for LW9 to LW18. The calibration of the model is described in Section 3.6 of Report No. MSEC459 and it was based on the monitoring data from LW3 to LW5 in Area 2 and LW6 in Area 3A at the Mine. The initial calibration of the subsidence model is referred to as the '*MSEC459 prediction curves*' in this report.

The calibrated model based on the MSEC459 prediction curves was then later reviewed based on the additional ground movement monitoring data collected from the Mine, which included LW7 and LW8 in Area 3A and LW9 and LW10 in Area 3B. The review of the calibrated model was discussed in Report No. MSEC792 based on the monitoring data from Areas 2, 3A and 3B.

The mine subsidence movements in Areas 2, 3A and 3B were measured using Airborne Laser Scan (ALS) and Light Detection and Ranging (LiDAR) surveys. The changes in surface level were determined by taking the differences between the measured surface levels before and after the extraction of each longwall.

It was considered that the calibrated IPM based on the MSEC459 prediction curves provided reasonable predictions in Area 2, i.e. LW3 to LW5, based on the ALS surveys. This is not unexpected, as the subsidence model was calibrated using the monitoring data from LW3 to LW5 in Area 2 and LW6 in Area 3B, as described in Section 3.6 of Report No. MSEC459.

However, it was found for LW7 and LW8 in Area 3A and LW9 and LW10 in Area 3B, that the maximum measured vertical subsidence exceeded the predictions, with these exceedances being typically up to 1.3 times the predicted values. The measured subsidence directly above the tailgate chain pillars for LW7 and LW8 in Areas 3A and LW10 in Area 3B were also greater than predicted.

It was considered that the measured vertical subsidence exceeded the predicted values in Areas 3A and 3B due to the higher depths of cover and wider longwall void widths, as compared with those in Area 2. This resulted in pillar compression greater than that predicted by the subsidence model based on the MSEC459 prediction curves.

Vertical subsidence predominately develops from two components: sagging of the overburden strata above the longwall voids; and compression of the chain pillars and the immediate seam floor and roof. At higher depths of cover, the component of vertical subsidence due to pillar compression increases, but the component due to sagging of the overburden strata decreases.

The original IPM over-predicted the component of vertical subsidence due to sagging of the overburden and under-predicted the component due to pillar compression. This model therefore provided reliable predictions of vertical subsidence for the initial longwalls in Area 3A (i.e. lower depth of cover), but the predictions were exceeded in Area 3B (i.e. higher depth of cover).

The subsidence model was then further refined for Areas 3A and 3B based on the latest available monitoring data from the Mine by increasing the component of vertical subsidence due to pillar compression. This resulted in the maximum predicted incremental subsidence increasing by 30 %. The latest calibration of the subsidence model is referred to as the '*MSEC792 prediction curves*' in this report.

Comparisons between the measured ground movements with those predicted using the calibrated IPM based on the MSEC792 prediction curves are provided in the following sections.

### 3.6.1. Review of the calibrated model based on the ALS monitoring data

The changes in surface level due to the previous mining in Area 3A were measured using ALS and LiDAR surveys. The measured changes in surface level due to the extraction of LW6 to LW8 are shown in Fig. 3.2.

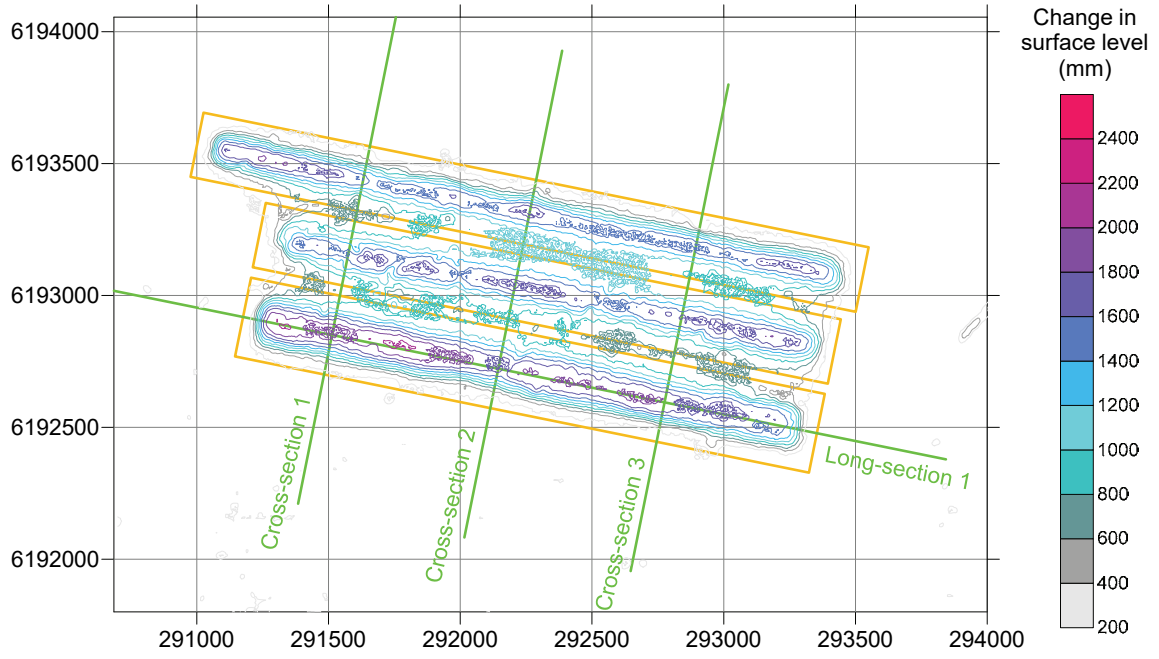



**Fig. 3.2 Measured changes in surface level due to LW6 to LW8 in Area 3A**

The contours of the measured changes in surface level, developed from the ALS / LiDAR, show the change in the heights of two surfaces defined by multiple points, not necessarily the same points. This differs from traditional subsidence contours that include both the vertical and horizontal components of the surface movements of points fixed to the surface. Horizontal movements are usually included in the subsidence profiles, as traditional ground monitoring data is based on the movements of survey marks, which are fixed to the ground.

The contours developed from the ALS / LiDAR can contain artefacts, particularly in the locations of steeply incised terrain, such as at cliffs or steep slopes. The reason for this is that the surface can move horizontally downslope, or towards the centre of the goaf, as the ground subsides and, therefore, the level changes at a fixed position can be large and do not provide a true indication of the actual subsidence at a point on the ground. Where the ground is reasonably flat, however, the contours of the observed changes in surface level should provide a good indication of the actual subsidence.

In comparison to traditional remote sensing topographic mapping techniques, ALS / LiDAR generally offers excellent 'vegetation penetration'. Vegetation penetration can be further enhanced by using narrower swathe angles as per the capture specifications used for mine subsidence determination at the Mine. Despite these attributes there are still limitations and ultimately if there are areas where 'light' cannot get to the ground then any optical or ALS / LiDAR system will have limitations in these locations.

The ALS / LiDAR suppliers state that the default vertical accuracy of each ALS / LiDAR dataset is around ±100 mm and, therefore, the expected accuracy of the measured vertical movements (i.e. the difference between two datasets) is around ±200 mm.

The predicted vertical subsidence has been obtained using the calibrated subsidence model based on the MSEC792 prediction curves. The calibrated model was designed to provide reasonable, but, slightly conservative predictions for the active longwalls in Area 3B. However, it was found that the calibrated model provides overly conservative predictions for LW8 in Area 3A, based on the review of the LiDAR monitoring data at the completion of that longwall.

It was found that the subsidence model provided more reasonable and still conservative predictions for LW8 without the application of the +30 % factor for that longwall. It was therefore considered appropriate to remove this factor for LW8 only. The removal of the +30 % factor for LW8 does not affect the maximum predicted vertical subsidence directly above the proposed LW19.

The subsidence model provides reasonable and conservative predictions for LW6 and LW7 based on the MSEC792 prediction curves. No changes therefore have been made for these two longwalls based on the LiDAR monitoring data (i.e. the +30% factors still apply to LW6 and LW7).

The profiles of measured (i.e. green) and predicted (i.e. red) changes in surface level along Cross-sections 1 to 3 and Long-section 1 are illustrated in Fig. 3.3 to Fig. 3.6. The predicted profiles in these figures have been obtained from the calibrated IPM based on the MSEC792 prediction curves. The locations of the sections are shown in Fig. 3.2.

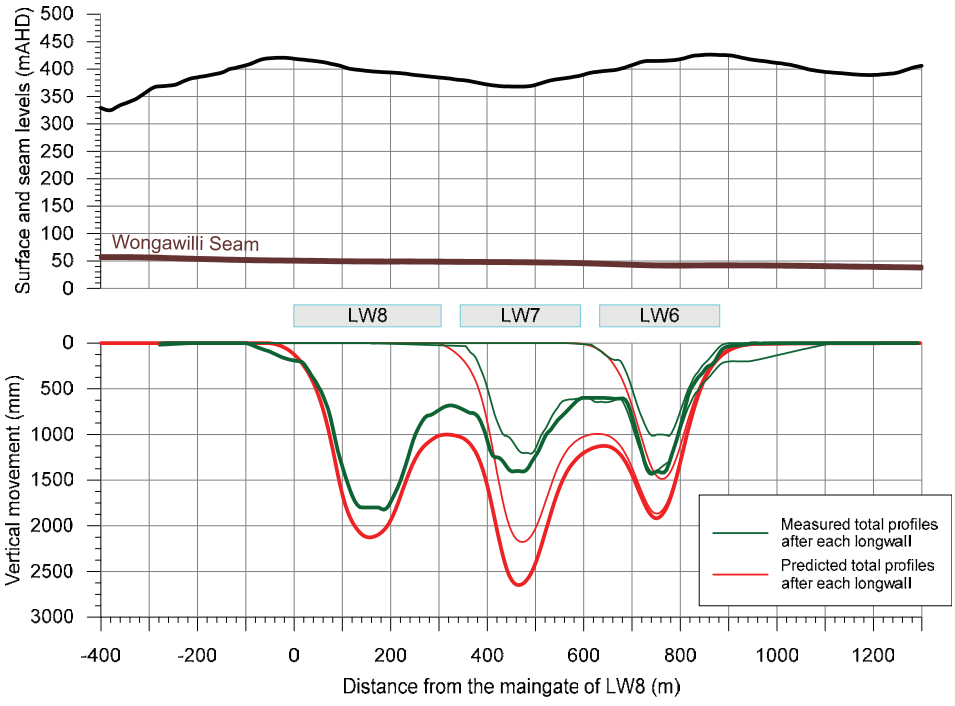



**Fig. 3.3 Measured and predicted changes in surface level along Cross-section 1**

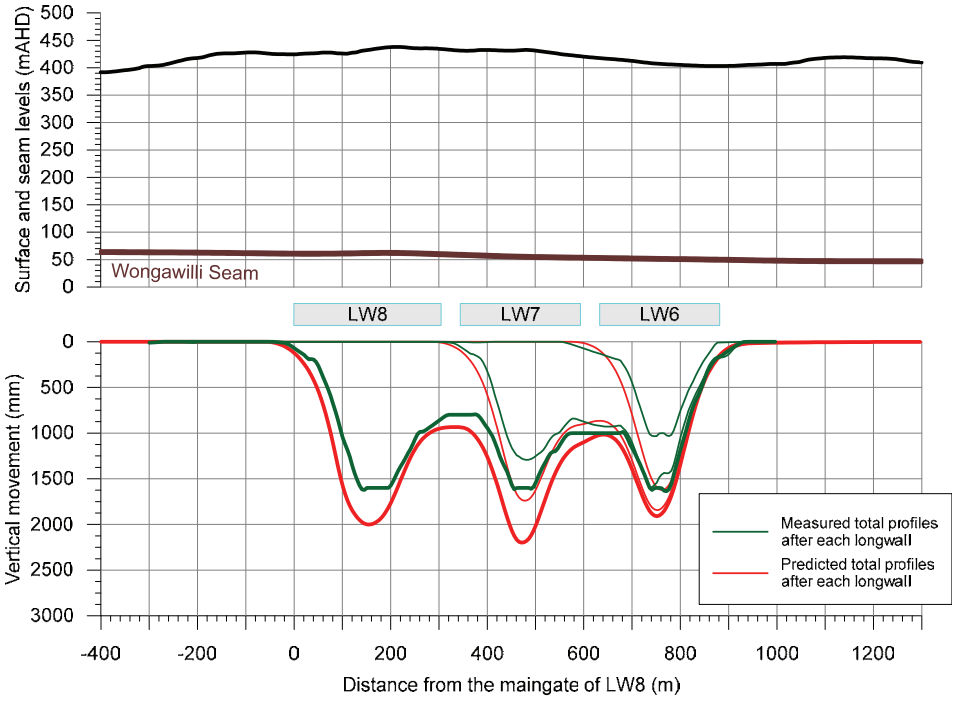



**Fig. 3.4 Measured and predicted changes in surface level along Cross-section 2**

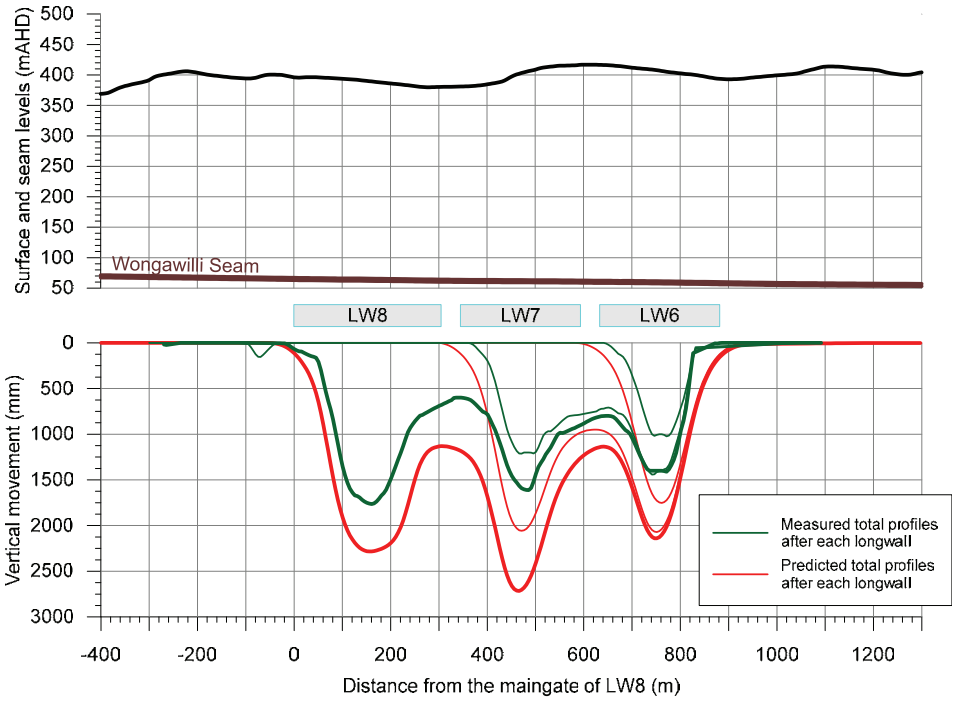



**Fig. 3.5 Measured and predicted changes in surface level along Cross-section 3**

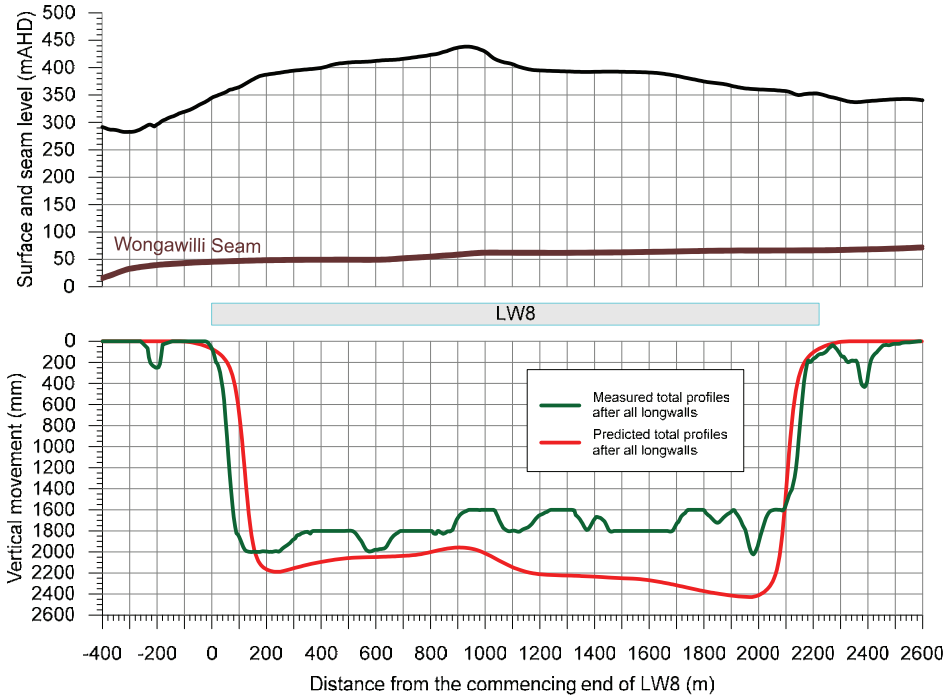



**Fig. 3.6 Measured and predicted changes in surface level along Long-section 1**

The profiles of the measured changes in surface level reasonably match the predicted profiles of vertical subsidence along each of the cross-sections and long-section. The maximum measured changes in surface level above each of the longwalls are less than the maximum predicted values. Also, the measured changes in surface level above each of the chain pillars are similar to or less than the predicted values in these locations.

There are localised areas outside of the longwalls where the measured changes in surface level exceed the predicted vertical subsidence. However, these are artefacts of the LiDAR surveys and are not real movements.

It can be inferred from the slopes of the profiles, that the measured changes in grade are similar to the predicted tilts along each of the cross-sections and long-section. It is not possible to derive the curvature nor the horizontal movements from the LiDAR surveys.

It is considered that the ground movements measured using the LiDAR surveys are consistent with the predictions based on the calibrated IPM based on the MSEC792 prediction curves. This includes the removal of the +30 % factor for LW8 so as to reduce the overly conservative predictions for this longwall. The removal of the subsidence factor for LW8 does not affect the maximum predicted vertical subsidence above the proposed LW19. No changes have been made in the subsidence model for LW6 and LW7.

It is considered appropriate, therefore, to adopt the MSEC792 prediction curves for the proposed LW19. These prediction curves provide an additional 30 % to the maximum incremental vertical subsidence for the proposed longwall, when compared with that predicted using the standard IPM model.

### 3.6.2. Review of the calibrated model based on the traditional ground monitoring data

The vertical subsidence and valley closure were monitored during the extraction of LW9 to LW14 in Area 3B using the Wongawilli Creek Closure Lines, Tributary Cross Lines, Donalds Castle Creek Cross Lines and Swamp Cross Lines.

Comparisons of the measured and predicted total vertical subsidence for the traditional ground monitoring lines at the completion of LW14 are illustrated in Fig. 3.7. The measured versus the predicted values are shown on the left side of this figure. The ratios of the measured to predicted values (for magnitudes greater than 50 mm) are shown on the right side of this figure. The predictions are based on the re-calibrated subsidence model using the MSEC792 prediction curves.

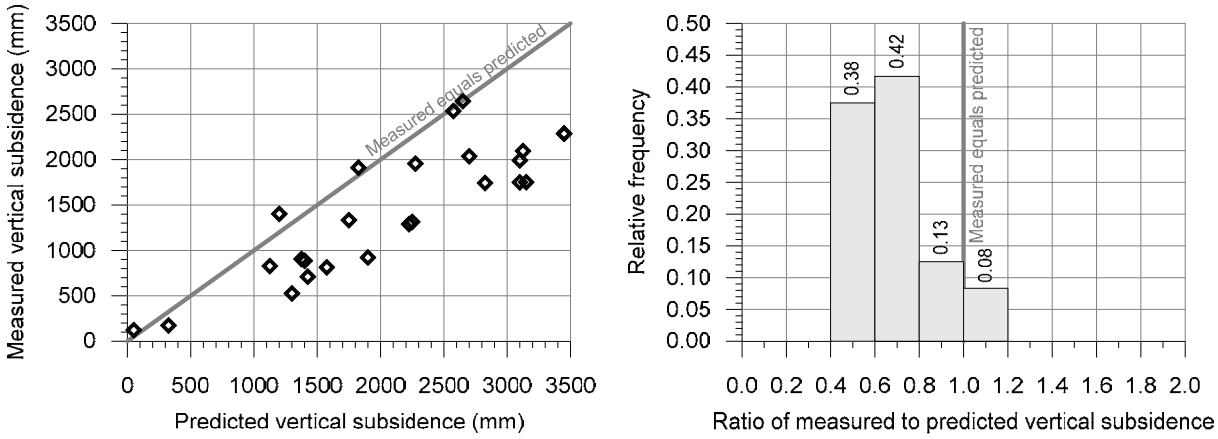



**Fig. 3.7 Comparison of measured and predicted subsidence for the ground monitoring lines**

The measured total vertical subsidence movements are typically less than the predicted total vertical subsidence values for each of the monitoring lines. The average ratio of the measured to predicted vertical subsidence for these monitoring lines is 0.70.

The measured total vertical subsidence movements exceed the predicted values in 3 of the 25 cases (i.e. 12 % of the monitoring lines). The exceedances occur where the monitoring lines are located near to or above the chain pillars and the measured movements are less than the maxima that occur directly above the longwalls. The ratios of the measured to predicted total vertical subsidence for these three monitoring lines range between 1.05 to 1.17 and, therefore, are within the order of accuracy of the predictive method for vertical subsidence of ±15 % to ±25 %.

Comparisons of the measured and predicted total closure for the traditional ground monitoring lines are at the completion of LW14 are illustrated in Fig. 3.8. The measured versus the predicted values are shown on the left side of this figure. The ratios of the measured to predicted values (for magnitudes greater than 50 mm) are shown on the right side of this figure. The predictions are based on the 2002 ACARP method.

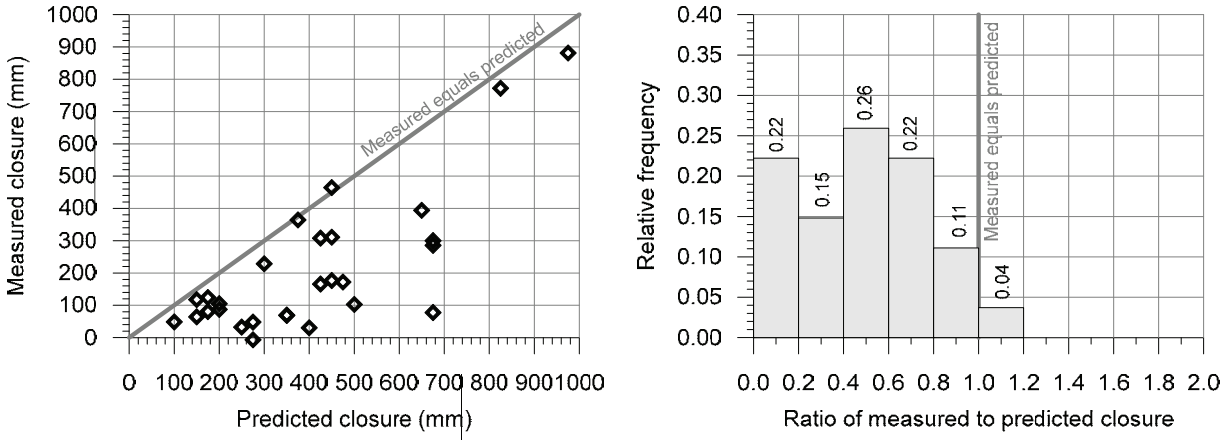



**Fig. 3.8 Comparison of measured and predicted closure for the ground monitoring lines**

The measured total closure movements are typically less than the predicted total closure values for each of the monitoring lines. The average ratio of the measured to predicted total closure for these monitoring lines is 0.50, i.e. the measured closures are, on average, around half of those predicted.

The measured total closure movements exceed the predicted values in one of the 28 cases (i.e. 4 % of the monitoring lines). It is noted that there were two additional cases where the measured closures exceeded the predicted values at the completion of LW12. However, the measured closures for these two cases were less than the predicted values after the completion of LW13 and LW14. The ratio of the measured to predicted total closure for the remaining monitoring line is 1.03 and, therefore, is within the order of accuracy of the predictive method for valley closure of ±15 % to ±25 %.

It is considered that the calibrated prediction model based on the MSEC792 prediction curves provides adequate predictions of vertical subsidence and valley closure based on the available ground monitoring data. The measured movements can be greater than the predicted values, in some cases, but these exceedances are expected to be within the orders of accuracy of the predictive methods of ±15 % to ±25 %.

## 3.7. Numerical model

A numerical model has been developed for Area 3A using Universal Distinct Element Code (UDEC). This method is a two-dimensional Discrete Element Method (DEM) comprising deformable elements that interact via compliant contacts (Itasca, 2015). The numerical modelling has been undertaken to supplement the predictions obtained using the empirical IPM.

The UDEC model has been derived from the *base model* that was developed for the Southern Coalfield for mining in the Bulli Seam (Barbato, 2017). The numerical model has been updated for the local stratigraphy (refer to Section 1.4) and has been calibrated for the local mining conditions using the ground monitoring data from Area 3A.

### 3.7.1. Calibration of the UDEC model for Area 3A

The void widths of the existing longwalls in Area 3A are 250 m for LW6 and LW7 and 305 m for LW8. The solid chain pillar widths between each of the existing longwalls are 40 m. The maximum extraction height for LW6 to LW8 was 3.9 m.

The edges of the numerical model have been taken as the greater of two times the longwall widths and 600 m from the edges of the mining area. The overall width of the model therefore is 2105 m. The average depth of cover to the Wongawilli Seam along Prediction Line 1 and above the existing longwalls is 370 m.

The element (i.e. block) size adopted in the numerical model has been based on Block Type B1 for the *base model* (refer to Section 6.4.3.1 of Barbato, 2017). Minor adjustments of the element sizes have been made to suit the depths of each stratigraphic unit. The element aspect ratio has been taken as 1.5:1.0 (H:V) as per the *base model*. A summary of the stratigraphy adopted in the UDEC model is provided in Table 3.1.

**Table 3.1 Stratigraphy adopted in the UDEC model**

| Unit | Thickness (m) | Depth to base on unit (m) | Block size (H x V, m x m) |
|---|---|---|---|
| Hawkesbury Sandstone | 135 | 135 | 13.5 x 9 |
| Newport/Garie Formation | 20 | 155 | 6 x 4 |
| Bald Hill Claystone | 20 | 175 | 6 x 4 |
| Bulgo Sandstone | 130 | 305 | 15 x 10 |
| Wombarra Claystone | 42 | 347 | 6 x 4 |
| Bulli Coal | 3 | 350 | 4.5 x 3 |
| Eckersley Formation | 20 | 370 | 7.5 x 5 |
| Wongawilli Coal | 10 | 380 | 1.5 x 1 |
| Sub-Wongawilli | 100 | 480 | 15 x 10 |

The horizontal in situ stress has been based on Stress Type S2 for the *base model* (refer to Section 6.4.4 of Barbato, 2017). The stress at the surface is 1.5 MPa and the stress gradient through the overburden strata is 36 kPa/m.

The parametric analysis of the *base model* (refer to Section 6.9 of Barbato, 2017) showed that the appropriate material and joint properties are dependent on the other properties adopted in the numerical model, including the element size and aspect ratio. The appropriate properties are also dependent on the depth of cover and mining height, as these affect the relative contributions of vertical subsidence due to sagging of the overburden strata and pillar compression.

The material and joint properties have been calibrated for the local conditions using the available ground monitoring data from this mining area. The initial calibration of the numerical model using the LiDAR monitoring data from Area 3A found that the *base model* (i.e. Material Type M1 and Joint Type J2) slightly underpredicted the vertical subsidence above the longwalls and above the chain pillars.

The magnitudes and the profiles of vertical subsidence obtained from the numerical model better matched those measured in Area 3A by adopting material bulk and shear moduli that are 70 % of those used in the *base model*. The joint cohesion and friction angles are 90 % of those used in the *base model*. These adjustments to the material and joint properties improve the modelling of the components of vertical subsidence due to sagging of the overburden strata and pillar compression.

Summaries of the material and joint properties adopted in the UDEC model are provided in Table 3.2 and Table 3.3, respectively. The joint normal stiffness and shear stiffness have been taken as 30 GPa/m and 3 GPa/m, respectively. The parameter analysis of the joint stiffness properties found that the numerical model is not sensitive to these two parameters (refer to Section 6.9.4 of Barbato, 2017).

**Table 3.2 Material properties adopted in the UDEC model**

| Unit | ρ (kg/m$^3$) | K (GPa) | G (GPa) | C (MPa) | φ (deg.) | T (MPa) |
|---|---|---|---|---|---|---|
| Hawkesbury Sandstone | 2400 | 2.33 | 1.40 | 7.0 | 34 | 0.5 |
| Newport/Garie Formations | 2400 | 2.42 | 1.74 | 4.0 | 30 | 0.5 |
| Bald Hill Claystone | 2700 | 3.50 | 1.62 | 6.0 | 25 | 0.5 |
| Bulgo Sandstone | 2500 | 3.89 | 2.92 | 10 | 30 | 0.5 |
| Wombarra Claystone | 2600 | 4.83 | 3.47 | 10 | 25 | 0.5 |
| Bulli Coal | 1500 | 1.08 | 0.68 | 2.0 | 25 | 0.5 |
| Eckersley Formation | 2500 | 5.60 | 3.36 | 15 | 25 | 0.5 |
| Wongawilli Coal | 1500 | 1.08 | 0.68 | 2.0 | 25 | 0.5 |
| Sub-Wongawilli | 2500 | 5.60 | 3.36 | 15 | 25 | 0.5 |

**Table 3.3 Joint properties adopted in the UDEC model**

| Unit | Cohesion (MPa) | | Friction angle (deg.) | |
|---|---|---|---|---|
| | Peak | Residual | Peak | Residual |
| Hawkesbury Sandstone | 2.25 | 1.35 | 22 | 13 |
| Newport/Garie Formations | 2.03 | 1.22 | 22 | 13 |
| Bald Hill Claystone | 2.48 | 1.49 | 19 | 11 |
| Bulgo Sandstone | 4.05 | 2.43 | 22 | 13 |
| Wombarra Claystone | 2.70 | 1.62 | 20 | 12 |
| Eckersley Formation | 3.83 | 2.30 | 20 | 12 |
| Sub-Wongawilli | 3.83 | 2.30 | 20 | 12 |

A comparison between the modelled and measure vertical subsidence for LW6 to LW8 in Area 3A is illustrated in Fig. 3.9. The measured subsidence is based on the difference between the LiDAR surface levels measured prior to and after the completion of each longwall.

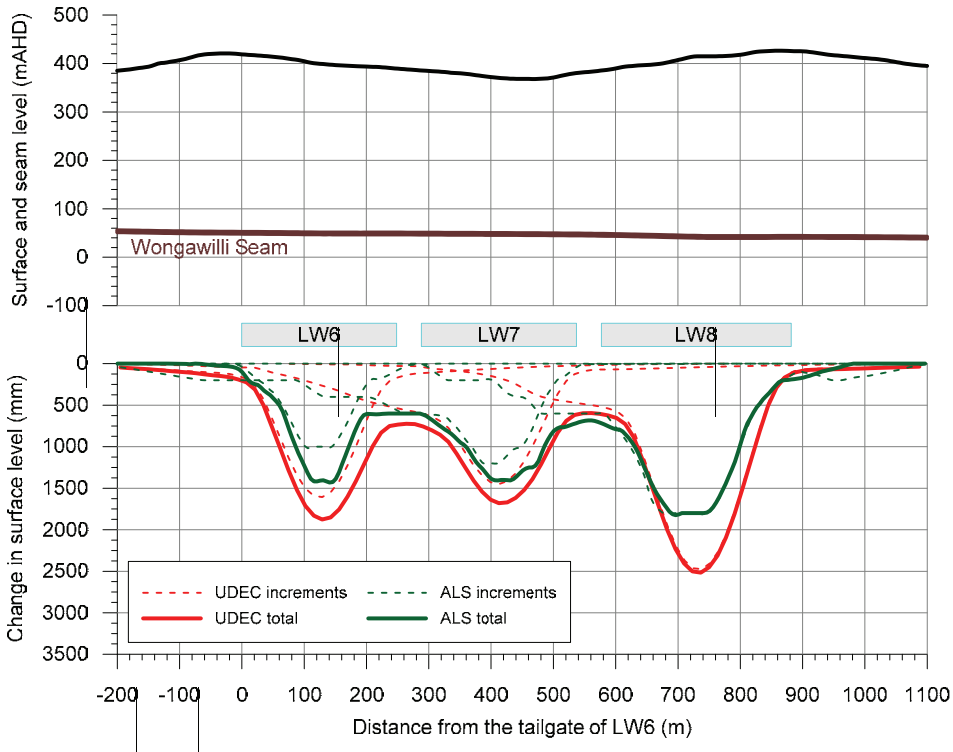



**Fig. 3.9 Comparison of modelled and measured subsidence for Dendrobium Area 3A**

It is considered that the profiles of vertical subsidence obtained from the UDEC model reasonably match the profiles measured using the LiDAR surveys for LW6 to LW8 in Area 3A. However, the numerical model slightly overpredicts the vertical subsidence for LW8 and, to lesser extents, LW6 and LW7.

The mining geometry for the proposed LW19 is similar to that for the existing LW8 in Area 3A. It is considered, therefore, that the numerical model should therefore provide reasonable, if not, slightly conservative predictions of vertical subsidence for the proposed longwall.

### 3.7.2. UDEC model for the proposed longwall

The proposed LW19 has been incorporated into the UDEC model for Area 3A. The modelled profile of vertical subsidence obtained from the numerical model is illustrated as the red line in Fig. 3.10. The predicted profile based on the IPM has also been shown as the blue line for comparison.

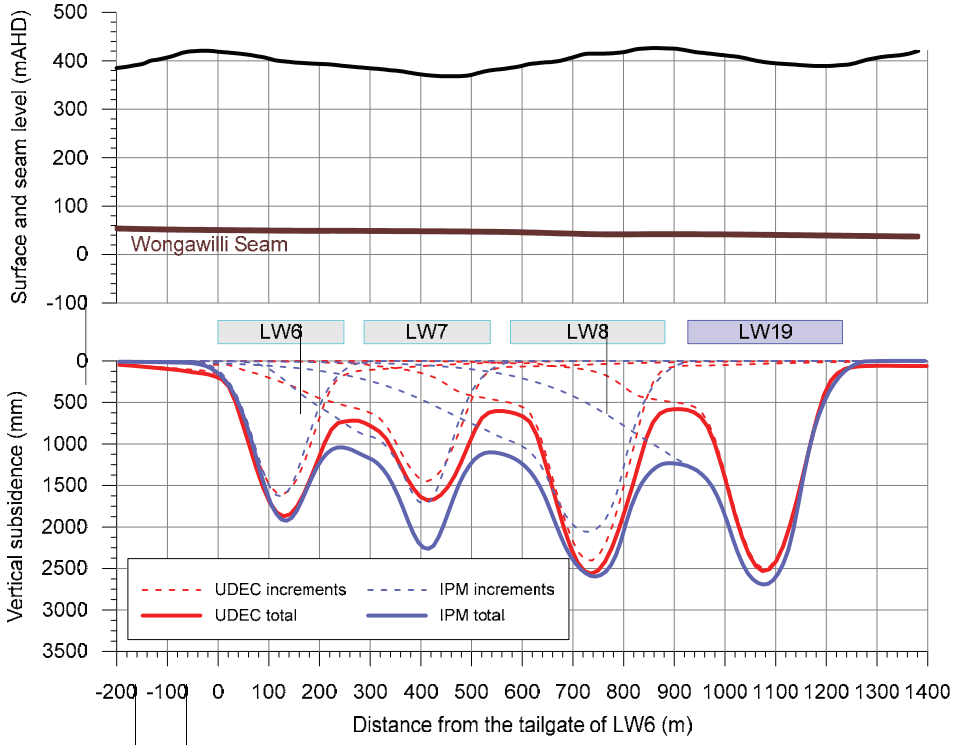



**Fig. 3.10 UDEC modelled and IPM predicted profiles of vertical subsidence**

The profile of total vertical subsidence obtained from the UDEC model reasonably matches the predicted total profile obtained using the IPM. The values of maximum predicted vertical subsidence directly above the proposed LW19 are within ±10 %. The numerical model predicts slightly lower values of vertical subsidence above the existing LW7 and above each of the chain pillars.

The maximum predicted tilts and curvatures obtained from the UDEC model, directly above the proposed LW19, are reasonably similar to the values predicted using the IPM. The predicted tilts and curvatures above the existing longwalls are slightly greater than the values obtained from the IPM due to the lower predicted vertical subsidence above each of the chain pillars.

The predicted subsidence effects from the proposed LW19 obtained from the UDEC model are reasonably similar to the predicted values obtained using the IPM. It is not considered necessary, therefore, to further calibrate the IPM based on the outcomes of the numerical model.

The modelled profiles of vertical subsidence and horizontal movement through the overburden strata are illustrated in Fig. 3.11. The profiles have been taken through the centreline, midway between the centreline and tailgate (referred to as the quarter-point) and the tailgate of the proposed LW19.

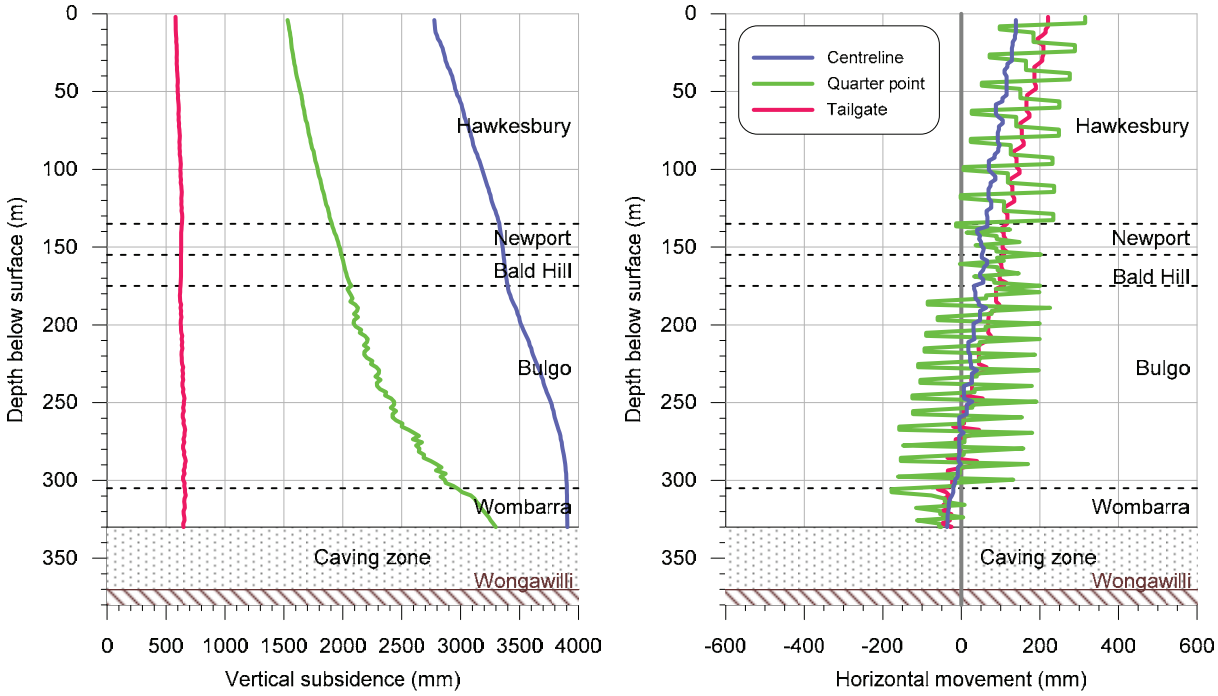



**Fig. 3.11 Modelled profiles of vertical subsidence and horizontal movement through the overburden at the centreline, quarter-point and tailgate of LW19**

The vertical subsidence at the proposed LW19 centreline varies between 70 % of the mining height at the surface through to 100 % of the mining heights at the caving zone. The vertical subsidence adjacent to the longwall tailgate varies between 15 % of the mining height at the surface through to 18 % of the mining height at the caving zone.

The vertical strain (over a 20 m height) within the Hawkesbury Sandstone varies between approximately 4 mm/m at the surface and 6 mm/m at the base of the unit. The maximum vertical strain within the Hawkesbury Sandstone occurs at the longwall centreline, with the strains reducing towards the longwall maingate and tailgate.

The vertical strain within the Bulgo Sandstone varies between approximately 4 mm/m at the top and 16 mm/m at the base of the unit. The vertical strain within the Wombarra Claystone varies between 8 mm/m and 16 mm/m. The maximum vertical strain within these two units occur at the longwall quarter-points, with the strains reducing towards the longwall centreline, maingate and tailgate.

The horizontal shear on the bedding plane partings varies between approximately 150 mm and 250 mm within the Hawkesbury Sandstone and varies between approximately 250 mm and 350 mm within the Bulgo Sandstone. The maximum horizontal shear occurs at the quarter-point within the Bulgo Sandstone.

It is noted that the magnitudes of horizontal shear are dependent on their spacings. Hence, fewer but larger horizontal shears, or more but smaller horizontal shears could develop compared with that predicted, depending on their actual spacing.

## 4.1. Introduction

The following sections provide the maximum predicted conventional subsidence parameters resulting from the extraction of the proposed LW6 to LW8 and LW19 in Area 3A. The predicted subsidence parameters and the impact assessments for the natural and built features are provided in Chapters 5 and 6.

The predicted vertical subsidence, tilt and curvature have been obtained using the IPM, which has been calibrated based on the latest monitoring data from the Mine, as described in Section 3.6. The predicted strains have been determined by analysing the strains measured at Dendrobium and other NSW collieries, where the longwall width-to-depth ratios and extraction heights are similar to those for the existing and proposed longwalls.

The maximum predicted subsidence parameters and the predicted subsidence contours provided in this report describe and show the conventional movements and do not include the valley related upsidence and closure movements, nor the effects of faults and other geological structures. Such effects have been addressed separately in the impact assessments for each feature provided in Chapters 5 and 6.

## 4.2. Maximum predicted conventional subsidence, tilt and curvature

A summary of the maximum predicted values of incremental conventional vertical subsidence, tilt and curvature due to the mining of LW19 is provided in Table 4.1. The incremental values represent the additional movements due to the mining of this longwall only.

**Table 4.1 Maximum predicted incremental vertical subsidence, tilt and curvature due to the mining of LW19**

| Due to longwall | Maximum predicted incremental vertical subsidence (mm) | Maximum predicted incremental tilt (mm/m) | Maximum predicted incremental hogging curvature ($km^{-1}$) | Maximum predicted incremental sagging curvature ($km^{-1}$) |
|---|---|---|---|---|
| LW19 | 2900 | 40 | 1.0 | 1.0 |

The predicted total vertical subsidence contours resulting from the mining of LW6 to LW8 and LW19 are shown in Drawing No. MSEC1082-12, in Appendix D. A summary of the maximum predicted values of total vertical subsidence, tilt and curvature is provided in Table 4.2. The total values represent the accumulated movements within the Study Area due to the extraction of the existing and proposed longwalls.

**Table 4.2 Maximum predicted total vertical subsidence, tilt and curvature resulting from the mining of LW6 to LW8 and LW19**

| After longwalls | Maximum predicted total vertical subsidence (mm) | Maximum predicted total tilt (mm/m) | Maximum predicted total hogging curvature ($km^{-1}$) | Maximum predicted total sagging curvature ($km^{-1}$) |
|---|---|---|---|---|
| LW6 to LW8 | 2900 | 35 | 0.90 | 0.90 |
| LW19 | 3000 | 40 | 1.0 | 1.0 |

The maximum predicted total vertical subsidence of 3000 mm represents 77 % of the proposed extraction height of 3.9 m. This is considered to be conservative as it is greater than the maximum measured vertical subsidence in the NSW coalfields for single-seam mining conditions of 65 % of the mining height.

The maximum predicted total tilt is 40 mm/m (i.e. 4.0 %, or 1 in 25), which occurs adjacent to the maingate of LW19. The maximum predicted total conventional curvatures are 1.0 $km^{-1}$ hogging and sagging, which represent a minimum radius of curvature of 1 km.

The predicted conventional subsidence parameters vary across the Study Area as the result of, amongst other factors, variations in the longwall geometry, depths of cover, seam thickness and overburden geology. To illustrate this variation, the predicted profiles of vertical subsidence, tilt and curvature have been determined along two prediction lines. The predicted profiles of total vertical subsidence, tilt and curvature along Prediction Lines 1 and 2 are shown in Figs. C.01 and C.02, respectively, in Appendix C. The locations of these prediction lines are shown in Drawings Nos. MSEC1082-11 and MSEC1082-12.

## 4.3. Comparison of the maximum predicted subsidence effects for Areas 3A and 3B

A comparison of the maximum predicted total conventional subsidence effects for Areas 3A and 3B is provided in Table 4.3. The predictions for each of these mining areas are based on the calibrated IPM as described in Section 3.6.

**Table 4.3 Comparison of maximum predicted total subsidence effects**

| Area (Longwalls) | Maximum predicted total vertical subsidence (mm) | Maximum predicted total tilt (mm/m) | Maximum predicted total hogging curvature ($km^{-1}$) | Maximum predicted total sagging curvature ($km^{-1}$) |
|---|---|---|---|---|
| Area 3A (LW6 to LW8 and LW19) | 3000 | 40 | 1.0 | 1.0 |
| Area 3B (LW9 to LW18) | 3600 | 50 | 1.4 | 1.4 |

The maximum predicted subsidence effects for LW6 to LW8 and LW19 in Area 3A are less than the maximum predicted values for LW9 to LW18 in Area 3B. The predicted subsidence effects are less, as the maximum mining height for Area 3A of 3.9 m is less than the maximum mining height for Area 3B of 4.6 m.

It is noted that the maximum predicted vertical subsidence for Area 3A was originally provided in Report No. MSEC437 as 2500 mm. Subsequent to that report, the subsidence model was recalibrated based on the LiDAR monitoring data for LW7 and LW8 in Area 3A and LW9 and LW10 in Area 3B. The maximum predicted subsidence for Area 3A based on the calibrated model was then revised to 3600 mm.

The calibrated model was designed to provide reasonable, but, slightly conservative predictions for the active longwalls in Area 3B. However, the calibrated model provides overly conservative predictions for Area 3A, based on the review of the LiDAR monitoring data at the completion of LW6 to LW8, as described in Section 3.6.

The predicted subsidence due to LW8 has been refined based on the LiDAR monitoring data at the completion of that longwall. No adjustments have been made for LW6, LW7 and LW19 based on this monitoring data. The maximum predicted subsidence due to the mining of LW6 to LW18 and LW19 is now 3000 mm, as presented in this report.

## 4.4. Predicted strains

The prediction of strain is more difficult than the predictions of subsidence, tilt and curvature. The reason for this is that strain is affected by many factors, including ground curvature and horizontal movement, as well as local variations in the near-surface geology, the locations of pre-existing natural joints at bedrock, and the depth of bedrock. Survey tolerance can also represent a substantial portion of the measured strain, in cases where the strains are of a low order of magnitude. The profiles of observed strain, therefore, can be irregular even when the profiles of observed subsidence, tilt and curvature are relatively smooth.

In previous MSEC subsidence reports, predictions of conventional strain were provided based on the best estimate of the average relationship between curvature and strain. Similar relationships have been proposed by other authors. The reliability of the strain predictions was highlighted in these reports, where it was stated that measured strains can vary considerably from the predicted conventional values.

Adopting a linear relationship between curvature and strain provides a reasonable prediction for the conventional tensile and compressive strains. The locations that are predicted to experience hogging or convex curvature are expected to be net tensile strain zones and locations that are predicted to experience sagging or concave curvature are expected to be net compressive strain zones. In the Southern Coalfield, it has been found that a factor of 15 provides a reasonable relationship between the predicted maximum curvatures and the predicted maximum conventional strains.

The maximum predicted conventional strains resulting from the mining of LW19, based on applying a factor of 15 to the maximum predicted curvatures, are 15 mm/m tensile and compressive. These strains represent typical values when the ground subsides regularly with no localised or elevated strains due to near-surface geological structures or valley closure effects. The maximum strains can be much greater than these typical values, especially in the locations of near-surface geological structures, on steep slopes or within valleys.

At a point, however, there can be considerable variation from the linear relationship, resulting from non-conventional movements or from the normal scatters which are observed in strain profiles. When expressed as a percentage, observed strains can be many times greater than the predicted conventional strain for low magnitudes of curvature. In this report, therefore, we have provided a statistical approach to account for the variability, rather than just providing a single predicted conventional strain.

There are two traditional ground monitoring lines at Dendrobium Mine that do not cross streams or valleys, being the SCW North and South Lines in Area 3A. The ranges of potential strains due to LW19, therefore, have been determined using these ground monitoring lines as well as data from the NSW coalfields, where the mining geometries are reasonably similar to those at the Mine.

A comparison of the mining geometry for LW19 with that for the previously extracted longwalls used in the strain analysis is provided in Table 4.4. There is a total of 46 ground monitoring lines located above 111 previously extracted longwalls in the Hunter and Newcastle Coalfields.

**Table 4.4 Comparison of the mine geometry for LW19 with the longwalls from the NSW coalfields used in the strain analysis**

| Parameter | Dendrobium LW19 | | Longwalls used in strain analysis | |
|---|---|---|---|---|
| | Range | Average | Range | Average |
| Longwall width | 305 | 305 | 120 ~ 410 | 190 |
| Depth of cover | 280 ~ 370 | 335 | 100 ~ 360 | 180 |
| W/H ratio | 0.82 ~ 1.1 | 0.91 | 0.8 ~ 1.2 | 1.06 |
| Mining height | 3.9 | 3.9 | 3.0 ~ 4.8 | 4.2 |

The range of width-to-depth ratios and mining heights for the longwalls used in the strain analysis are similar to but greater, on average, than the width-to-depth ratio and mining height of the proposed LW19. The strain analysis, therefore, should provide a reasonable indication of the range of potential strains resulting from the mining of LW19.

The data used in the analysis of observed strains included those resulting from both conventional and non-conventional anomalous movements but did not include those resulting from valley related movements, which are addressed separately in this report. The strains resulting from damaged or disturbed survey marks have been excluded.

The survey database has been analysed to extract the maximum tensile and compressive strains that have been measured at any time during the extraction of the previous longwalls in the NSW coalfields, for survey bays that were located directly above the longwalls or the chain pillars between the longwalls, referred to as *above goaf*. A number of probability distribution functions were fitted to the empirical data. It was found that a *Generalised Pareto Distribution (GPD)* provided a good fit to the raw strain data.

A histogram of the maximum observed tensile and compressive strains measured in survey bays located above goaf, for the selected monitoring lines from the NSW coalfields, is provided in Fig. 4.1. The probability distribution functions, based on the fitted GPDs, have also been shown in this figure.

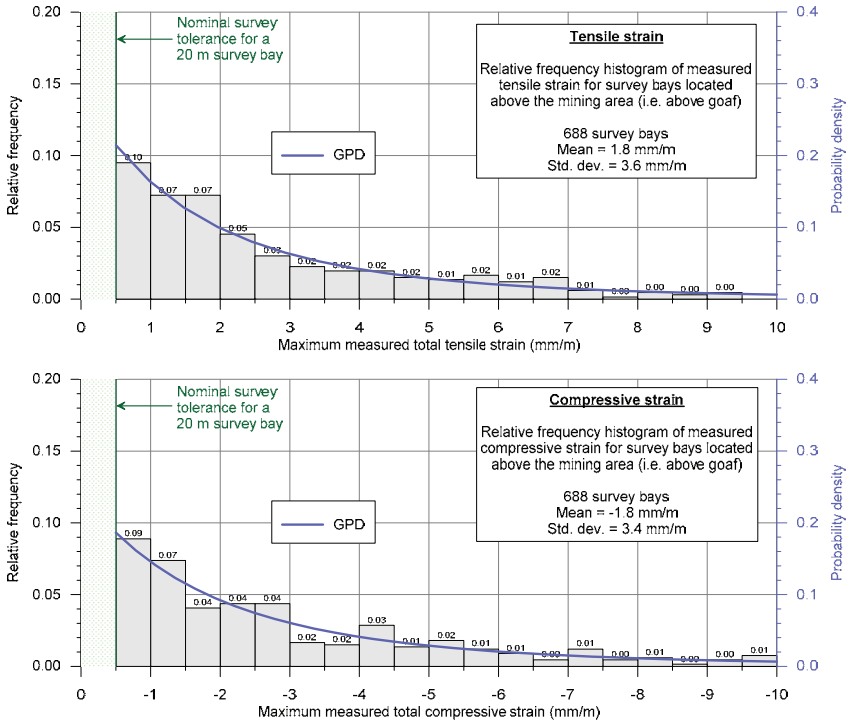



**Fig. 4.1 Distributions of the measured maximum tensile and compressive strains during the mining of previous longwalls in the NSW coalfields for bays located above goaf**

Confidence levels have been determined from the empirical strain data using the fitted GPDs. In the cases where survey bays were measured multiple times during a longwall extraction, the maximum tensile strain and the maximum compressive strain were used in the analysis (i.e. single tensile strain and single compressive strain measurement per survey bay).

The 95 % confidence levels for the maximum total strains that the individual survey bays experienced at any time during mining are 8 mm/m tensile and compressive. The 99 % confidence levels for the maximum total strains that the individual survey bays experienced at any time during mining are 17 mm/m tensile and compressive.

## 4.5. Predicted conventional horizontal movements

The predicted conventional horizontal movements over the existing and proposed longwalls are calculated by applying a factor to the predicted conventional tilt values. In the Southern Coalfield a factor of 15 is generally adopted, being the same factor as that used to determine the conventional strains from the conventional curvatures, and this has been found to give a reasonable correlation with measured data. This factor will vary and will be higher at low tilt values and lower at high tilt values. The application of this factor will therefore lead to over-prediction of horizontal movements where the tilts are high and under-prediction of the movements where the tilts are low.

The maximum predicted conventional tilt for the proposed LW19 is 40 mm/m. The maximum predicted conventional horizontal movement, therefore, is approximately 600 mm, i.e. 40 mm/m multiplied by a factor of 15. Greater movements can develop in incised terrain, due to the increased horizontal movements that develop in the downslope direction.

The distribution of the maximum observed horizontal movements for the 3D survey marks located directly above the longwalls in Dendrobium Areas 1, 2, 3A and 3B is provided in Fig. 4.2. It can be seen from this figure, that horizontal movements have been measured up to 700 mm at the Mine, with an average measured value of approximately 300 mm.

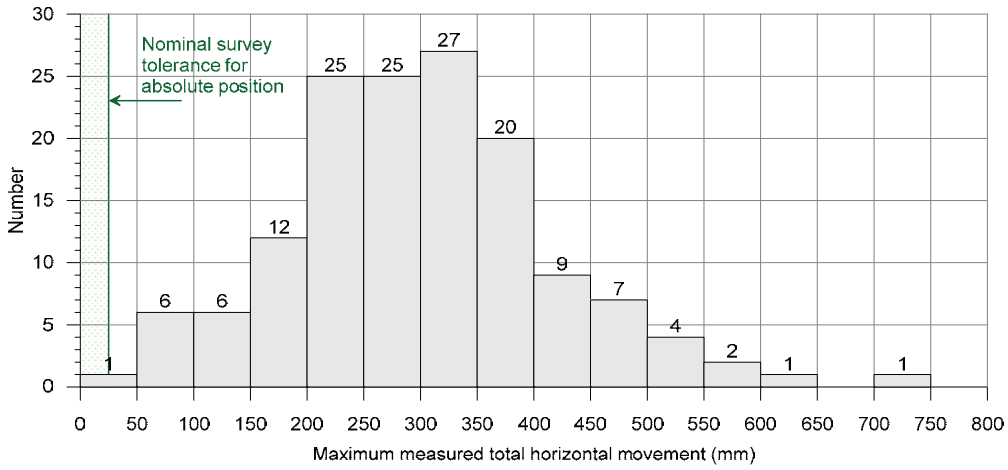



**Fig. 4.2 Distribution of the maximum measured horizontal movements for the 3D marks located directly above the longwalls in Dendrobium Areas 1, 2, 3A and 3B**

Conventional horizontal movements do not directly impact on natural and built features, rather impacts occur as the result of differential horizontal movements. Strain is the rate of change of horizontal movement. The impacts of strain on the natural features and items of surface infrastructure are addressed in the impact assessments for each feature, which have been provided in Chapters 5 and 6.

## 4.6. Predicted far-field horizontal movements

In addition to the conventional subsidence movements that have been predicted above and adjacent to the existing and proposed longwalls, and the predicted valley related movements along the streams, it is also likely that far-field horizontal movements will be experienced during the extraction of the longwall.

An empirical database of observed incremental far-field horizontal movements has been compiled using monitoring data from Dendrobium Mine, as well as from other collieries in the Southern Coalfield, including Appin, Metropolitan, Tahmoor, Tower and West Cliff. The far-field horizontal movements resulting from longwall mining were generally observed to be orientated towards the extracted longwall. At very low levels of far-field horizontal movements, however, there was a high scatter in the orientation of the observed movements.

The measured incremental far-field horizontal movements, resulting from the mining of longwalls at Dendrobium Areas 1, 2, 3A and 3B, as well as other collieries in the Southern Coalfield, are provided in Fig. 4.3. The mean and the 95 % confidence level for the 3D monitoring data at Dendrobium Mine are also shown in this figure.

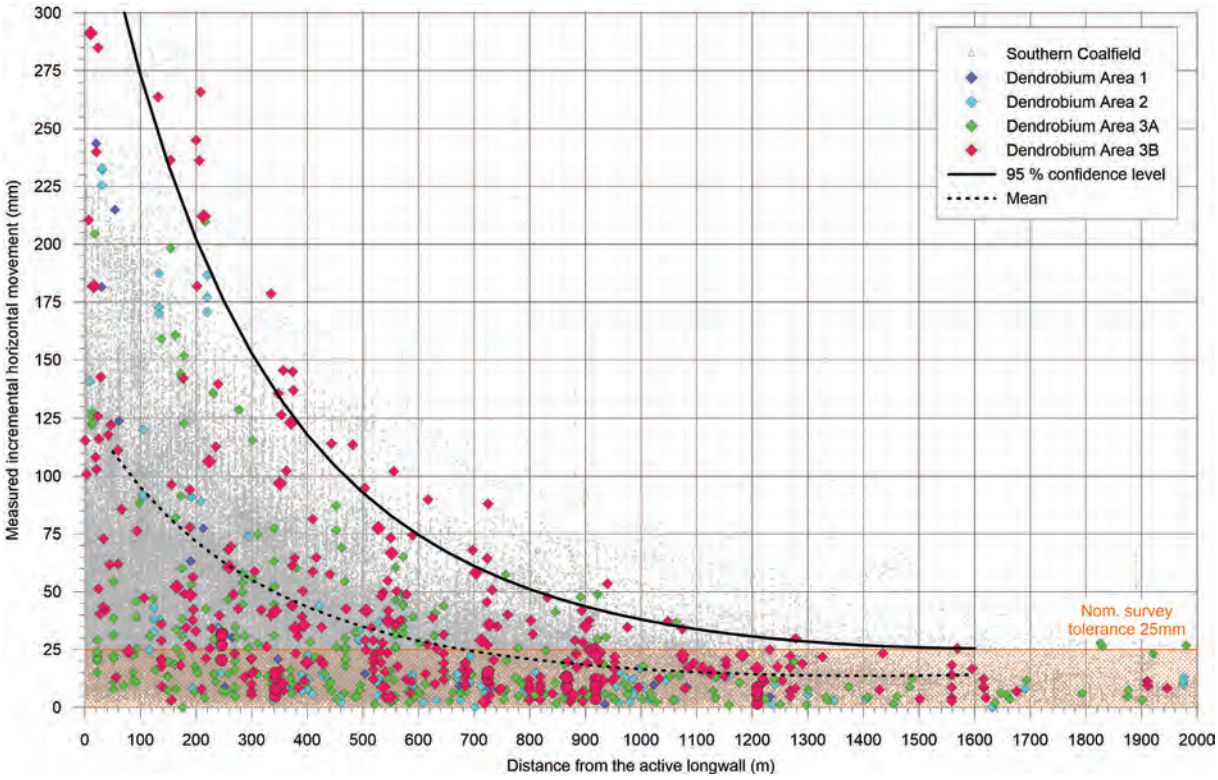



**Fig. 4.3 Measured incremental far-field horizontal movements at Dendrobium Mine and elsewhere in the Southern Coalfield**

As successive longwalls within a series of longwalls are mined, the magnitudes of the incremental far-field horizontal movements tend to decrease. The total far-field horizontal movement is not, therefore, the sum of the incremental far-field horizontal movements for the individual longwalls.

The predicted far-field horizontal movements resulting from the mining of the longwalls are very small and could only be detected by precise surveys. Such movements tend to be bodily movements towards the extracted goaf area, and are accompanied by very low levels of strain, which are generally less than survey tolerance. The impacts of far-field horizontal movements on the natural features and items of surface infrastructure within the vicinity of the Study Area are not expected to be significant, except where they occur at large structures which are sensitive to small differential movements.

## 4.7. Non-conventional ground movements

It is likely non-conventional ground movements will occur within the Study Area, due to near-surface geological conditions, steep topography and valley related movements, which are discussed in Section 3.4. These non-conventional movements are often accompanied by elevated tilts and curvatures that are likely to exceed the conventional predictions.

Specific predictions of upsidence, closure and compressive strain due to the valley related effects are provided for the streams in Sections 5.2 to 5.4. The impact assessments for the streams are based on both the conventional and valley related effects. The potential for non-conventional movements associated with steep topography is discussed in the impact assessments for the steep slopes provided in Section 5.7.

In most cases, it is not possible to predict the exact locations or magnitudes of the non-conventional anomalous movements due to near-surface geological conditions. For this reason, the strain predictions provided in this report are based on a statistical analysis of measured strains in the NSW coalfields, including both conventional and non-conventional anomalous strains and are discussed in Section 4.4. In addition to this, the impact assessments for the natural features and items of surface infrastructure, which are provided in Chapters 5 and 6, include historical impacts resulting from previous longwall mining which have occurred as the result of both conventional and non-conventional subsidence movements.

## 4.8. Surface deformations

Longwall mining can result in surface cracking, heaving, buckling, humping and stepping at the surface. The extent and severity of these mining-induced ground deformations are dependent on a number of factors, including the mine geometry, depth of cover, overburden geology, locations of natural jointing in the bedrock and the presence of near-surface geological structures.

Faults and joints in bedrock develop during the formation of the strata and from subsequent destressing associated with movement of the strata. Longwall mining can result in additional fracturing in the bedrock, which tends to occur in the tensile zones, but fractures can also occur due to buckling of the surface beds in the compressive zones. The incidence of visible cracking at the surface is dependent on the pre-existing jointing patterns in the bedrock as well as the thickness and inherent plasticity of the soils that overlie the bedrock.

Surface deformations can also develop as the result of downslope movements where longwalls are extracted beneath steep slopes. In these cases, the downslope movements can result in the development of tension cracks at the tops and on the sides of the steep slopes and compression ridges at the bottoms of the steep slopes. The impact assessments for downslope movements are provided in Section 5.7.

Fracturing of bedrock can also occur in the bases of stream valleys due to the compressive strains associated with valley related upsidence and closure effects. The impact assessments for valley related movements are provided in Sections 5.2 to 5.4.

Soil crack and rock fracture widths were measured at impact sites located above LW3 to LW5 in Area 2, LW6 to LW8 in Area 3A and LW9 to LW14 in Area 3B. The distribution of the measured widths of these surface deformations is illustrated in Fig. 4.4.

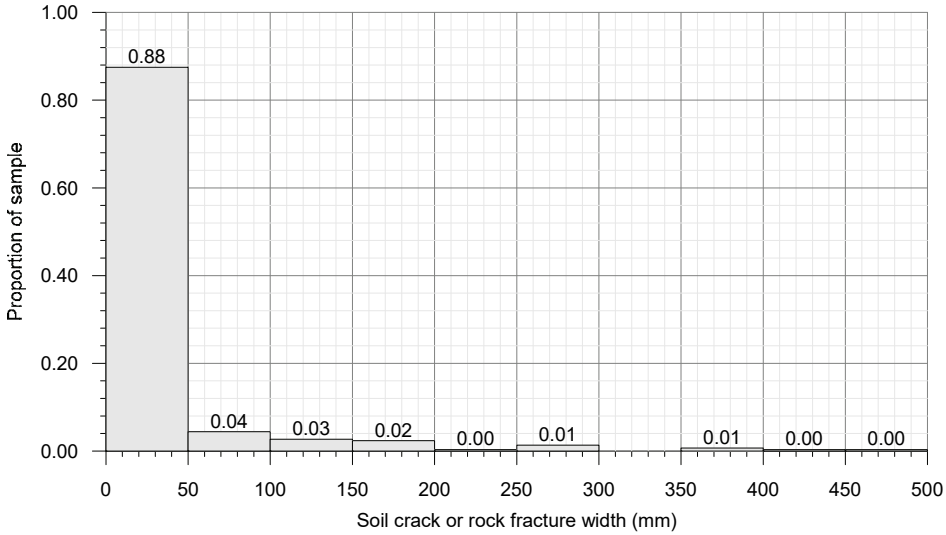



**Fig. 4.4 Distribution of measured soil crack and rock fracture widths in Areas 2, 3A and 3B**

The soil crack and rock fracture widths were generally observed to be less than 50 mm (i.e. 88 % of the cases). However, the widths of the surface deformations were between 50 mm and 150 mm in 7 % of cases, between 150 mm and 300 mm in 3 % of cases and greater than 300 mm in 2 % of cases. The maximum measured crack width was approximately 500 mm.

It is noted, that there was a series of cracks up to 1.5 m wide located above the commencing end of LW3 (not shown in the above figure for clarity) that developed due to downslope movement on the steep slopes, the shallower depth of cover (less than 200 m at that location) and fretting of the crack edges.

The predicted subsidence effects for the proposed LW19 are less than those for the previously extracted longwalls in Area 3B at the Mine, as shown in Table 4.3. Soil crack and rock fracture widths due to the extraction of the proposed longwall, therefore, are expected to be similar or less than those previously measured in Areas 3A and 3B.

The following sections provide the descriptions, predictions and impact assessments for the natural features located within the Study Area. All significant natural features located outside the Study Area, which may be subjected to far-field or valley related effects and may be sensitive to these movements, have also been included as part of this assessment.

## 5.1. Catchment Areas and Declared Special Areas

The Study Area lies entirely within the Metropolitan Catchment Area, which is a special declared area controlled by WaterNSW. The proposed LW19 is located outside the Dams Safety NSW Notification Areas for Cordeaux and Avon Reservoirs. The Study Area based on both the 35° angle of draw and predicted 20 mm subsidence contour and the Study Area based on the 600 m boundary are also located outside the Notification Areas.

The water storages in the Metropolitan Catchment Area provide the sole water supply for the Macarthur and Illawarra regions and the townships of Campbelltown, Camden, Bargo, Picton, Thirlmere, Tahmoor, The Oaks, Buxton and Oakdale, and provide approximately 20 % of the supply to the Sydney Metropolitan Area, via the Prospect Reservoir.

## 5.2. Wongawilli Creek

### 5.2.1. Description of Wongawilli Creek

The location of Wongawilli Creek is shown in Drawing No. MSEC1082-09.

Wongawilli Creek is situated on the western side of the existing LW6 to LW8 and the proposed LW19 in Area 3A. The currently active longwalls in Area 3B are being mined on the western side of the creek. The longwalls in both Areas 3A and 3B have been set back from Wongawilli Creek so that they do not directly mine beneath it.

The thalweg (i.e. base or centreline) of Wongawilli Creek is located at a minimum distance of 175 m south-west of the finishing end of LW19, at its closest point. The minimum distances between the thalweg of the creek and the completed longwalls are 110 m for LW6 in Area 3A and 290 m for LW9 in Area 3B.

The total length of Wongawilli Creek located within the Study Area based on the 35° angle of draw line and predicted 20 mm subsidence contour is approximately 0.1 km. The length of the creek located within the Study Area based on the 600 m boundary is approximately 1.4 km.

Wongawilli Creek is a third order perennial stream with a small base flow and increased flows for short periods of time after each significant rain event. The creek generally flows in a northerly direction and drains into the Cordeaux River more than 5 km north of LW19.

The locations of the mapped stream features along Wongawilli Creek are shown in Drawing No. MSEC1082-09. Summaries of the rockbars and riffles mapped along the section of creek located within the Study Area based on the 600 m boundary are provided in Table 5.1 and Table 5.2, respectively. It is noted that the stream feature labels for Wongawilli Creek shown in the drawing and the tables are temporary and these labels will be updated once re-mapping of the creek is completed.

**Table 5.1 Rockbars mapped along Wongawilli Creek**

| Label | Approximate size | Location at closest point to LW19 |
|---|---|---|
| Rockbar A | 60 m long x 6 m wide | 475 m north-west of LW19 |

**Table 5.2 Riffles mapped along Wongawilli Creek**

| Label | Approximate size | Location at closest point to LW19 |
|---|---|---|
| Riffle Zone A | 9 m long x 3 m wide | 570 m north-west of LW19 |
| Riffle Zone B | 7 m long x 7 m wide | 400 m north-west of LW19 |
| Riffle Zone C | 11 m long x 5 m wide | 360 m north-west of LW19 |
| Riffle Zone D | 1 m long x 2 m wide | 340 m north-west of LW19 |
| Riffle Zone E | 2 m long x 4 m wide | 360 m west of LW19 |
| Riffle Zone F | 30 m long x 5 m wide | 220 m west of LW19 |
| Riffle Zone G | 4 m long x 1 m wide | 290 m south-west of LW19 |
| Riffle Zone H | 22 m long x 4 m wide | 320 m south-west of LW19 |
| Riffle Zone I | 3 m long x 5 m wide | 380 m south-west of LW19 |

| Label | Approximate size | Location at closest point to LW19 |
|---|---|---|
| Riffle Zone J | 9 m long x 6 m wide | 440 m south-west of LW19 |
| Riffle Zone K | 9 m long x 3 m wide | 460 m south-west of LW19 |
| Riffle Zone L | 11 m long x 4 m wide | 510 m south-west of LW19 |
| Riffle Zone M | 57m long x 3 m wide | 540 m south-west of LW19 |
| Riffle Zone N | 15 m long x 2 m wide | 580 m south-west of LW19 |

The locations of riffles are known to change over time, as a result of flooding events and, therefore, the actual locations during the mining period could differ from those shown.

The surface mapping and geological modelling undertaken by IMC indicate that the base of the creek cuts through the stratigraphy as it runs from the south to the north. The creek bed is formed in the Hawkesbury Sandstone to the south of LW19. The creek bed transitions through the Newport Formation and Bald Hill Claystone, adjacent to the existing and proposed longwalls in Area 3A, and is then formed in the Bulgo Sandstone further to the north.

Photographs of Wongawilli Creek are provided in Fig. 5.1.



**Fig. 5.1 Wongawilli Creek (Source: IMC)**

The natural surface level along Wongawilli Creek, within the extents of the Study Area based on the 600 m boundary, varies from 288 mAHD at the upstream end to 283 mAHD at the downstream end. The average natural grade over the 1.4 km length, therefore, is approximately 3.6 mm/m (i.e. 0.36 %, or 1 in 278).

The valley of Wongawilli Creek has an overall height of approximately 100 m to 120 m within the Study Area. The valley is steeply sided, comprising cliffs, minor cliffs and talus slopes in a number of locations. The descriptions of the cliffs, minor cliffs, rock outcrops and steep slopes within the valley are included in Sections 5.6 and 5.7.

Section A has been taken through the valley of Wongawilli Creek and LW19 and it is shown in Fig. 5.2. The location of this section is shown in Drawing No. MSEC1082-09.

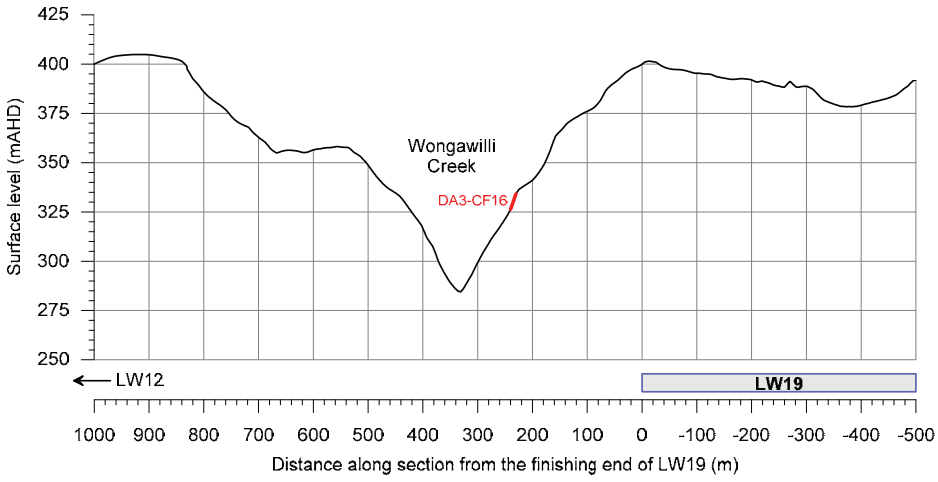



**Fig. 5.2 Section A through Wongawilli Creek and LW19**

Further descriptions of Wongawilli Creek are provided in the reports by other specialist consultants on the project.

### 5.2.2. Predictions for Wongawilli Creek

The predicted profiles of total vertical subsidence, upsidence and closure along Wongawilli Creek are shown in Fig. C.03, in Appendix C. The predicted total profiles after the completion of the existing and future longwalls in Area 3A (LW6 to LW8), Area 3B (LW9 to LW18) and Area 3C (LW20 and LW21) are shown as cyan lines. The predicted total profiles after the extraction of the proposed LW19 are shown as the blue lines.

A summary of the maximum predicted values of total vertical subsidence, upsidence and closure for Wongawilli Creek is provided in Table 5.3. The values are the maximum predicted subsidence effects anywhere along the creek due to the mining in Areas 3A, 3B and 3C.

**Table 5.3 Maximum predicted total vertical subsidence, upsidence and closure for Wongawilli Creek**

| Location | Longwall | Maximum predicted total vertical subsidence (mm) | Maximum predicted total upsidence (mm) | Maximum predicted total closure (mm) |
|---|---|---|---|---|
| Wongawilli Creek | LW6 to LW18, LW20 and LW21 | < 20 | 150 | 210 |
| | LW19 | < 20 | 150 | 210 |

Wongawilli Creek is predicted to experience less than 20 mm vertical subsidence due to the mining in Areas 3A, 3B and 3C. While the creek could experience very low levels of vertical subsidence, it is not expected to experience measurable conventional tilts, curvatures or strains.

The maximum predicted total valley related effects for Wongawilli Creek are 150 mm upsidence and 210 mm closure. The maximum predicted valley related effects within the Study Area occur along the section of creek located between Areas 3A and 3B.

The maximum predicted incremental valley related effects due to the mining of the proposed LW19 only are 50 mm upsidence and 70 mm closure. The maximum predicted incremental valley related effects occur where Wongawilli Creek is located closest to the proposed LW19.

Wongawilli Creek could experience compressive strains due to the valley closure effects. The predicted strains have been determined based on an analysis of ground monitoring lines for valleys with similar heights located at similar distances from previously extracted longwalls in the Southern Coalfield, as for Wongawilli Creek. The maximum predicted compressive strain for Wongawilli Creek due to the extraction of the proposed LW19 is 7 mm/m based on the 95 % confidence level.

Summaries of the maximum predicted values of total vertical subsidence, upsidence and closure at the mapped stream features along Wongawilli Creek are provided in Table 5.4 and Table 5.5. The locations of these features are shown in Drawing No. MSEC1082-09. The values are the total accumulated effects due to the existing and future longwalls in Areas 3A, 3B and 3C. The stream feature labels for Wongawilli Creek are temporary and these labels will be updated once re-mapping of the creek is completed.

**Table 5.4 Maximum predicted total vertical subsidence, upsidence and closure at the mapped rockbars along Wongawilli Creek**

| Location | Label | Maximum predicted total vertical subsidence (mm) | Maximum predicted total upsidence (mm) | Maximum predicted total closure (mm) |
|---|---|---|---|---|
| Rockbars along Wongawilli Creek | Rockbar A | < 20 | 120 | 190 |

**Table 5.5 Maximum predicted total vertical subsidence, upsidence and closure at the mapped riffles along Wongawilli Creek**

| Location | Label | Maximum predicted total vertical subsidence (mm) | Maximum predicted total upsidence (mm) | Maximum predicted total closure (mm) |
|---|---|---|---|---|
| Riffles along Wongawilli Creek | Riffle Zone A | < 20 | 110 | 190 |
| | Riffle Zone B | < 20 | 100 | 200 |
| | Riffle Zone C | < 20 | 100 | 210 |
| | Riffle Zone D | < 20 | 100 | 200 |
| | Riffle Zone E | < 20 | 120 | 180 |
| | Riffle Zone F | < 20 | 85 | 170 |
| | Riffle Zone G | < 20 | 60 | 130 |
| | Riffle Zone H | < 20 | 55 | 120 |

| Location | Label | Maximum predicted total vertical subsidence (mm) | Maximum predicted total upsidence (mm) | Maximum predicted total closure (mm) |
|---|---|---|---|---|
| Riffles along Wongawilli Creek | Riffle Zone I | < 20 | 45 | 100 |
| | Riffle Zone J | < 20 | 45 | 90 |
| | Riffle Zone K | < 20 | 45 | 90 |
| | Riffle Zone L | < 20 | 40 | 80 |
| | Riffle Zone M | < 20 | 40 | 80 |
| | Riffle Zone N | < 20 | 35 | 70 |

Rockbar A is located at a distance of 475 m north-west of LW19. At this distance, the rockbar is predicted to experience incremental upsidence of less than 20 mm and incremental closure of 20 mm due to the mining of LW19 only. The predicted incremental strain due to the valley closure effects at the rockbar is less than 0.5 mm/m based on the 95 % confidence level.

### 5.2.3. Comparison between measured and predicted movements for Wongawilli Creek due to the extraction of LW6 to LW8 and LW9 to LW14

The closure movements across Wongawilli Creek have been measured using the Wong X A-Line, Wong X B-Line, Wong X C-Line and Wong X D-Line. The locations of these monitoring lines are shown in Drawing No. MSEC1082-01.

A review of the ground monitoring data was carried out as part of the End of Panel Report for LW14 and is summarised in Report MSEC1039. The measured and predicted total closures along Wongawilli Creek after the completion of LW14 are illustrated in Fig. 5.3.

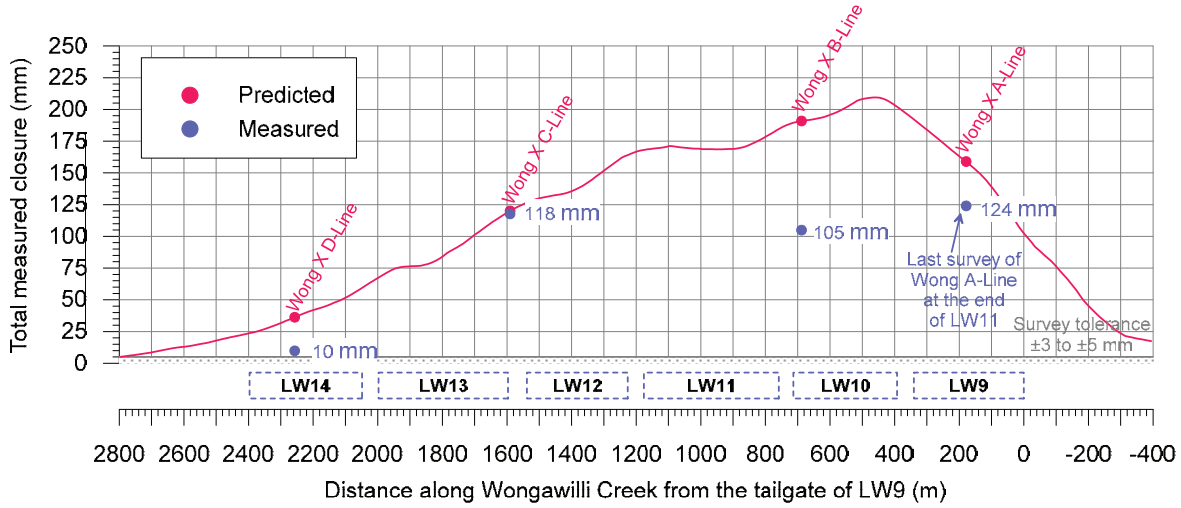



**Fig. 5.3 Measured and predicted closure along Wongawilli Creek**

The measured closures at the Wong X Creek A-Line to D-Line are similar to or less than the predicted closures in the locations of these monitoring lines.

### 5.2.4. Observed impacts along Wongawilli Creek due to LW9 to LW14

The section of Wongawilli Creek upstream of the Study Area is located between the previously extracted LW6 to LW8 in Area 3A and LW9 to LW14 in Area 3B. The minimum distances between the thalweg of the creek and the completed longwalls are 110 m for Area 3A and 290 m for Area 3B.

The reported impacts for Wongawilli Creek have been summarised in the End of Panel reports for each of the extracted longwalls. The extraction of LW6 to LW14 has resulted in one Type 3 impact along Wongawilli Creek. A Type 3 impact is defined as *fracturing in a rockbar or upstream pool resulting in reduction in standing water level based on current rainfall and surface water flow*.

Fracturing was first observed in the bed of Pool 43a after the completion of LW9. This pool is located at distances of 200 m west of LW6 in Area 3A and 410 m east of LW9 in Area 3B. Pool water levels below baseline conditions were observed in this pool during low flow conditions (i.e. Type 3 impact) after the completion of LW13. No other fractures have been observed along Wongawilli Creek due to the longwalls extracted in Areas 3A and 3B.

The longwalls in Areas 3A and 3B were set back from Wongawilli Creek so that the predicted closure is less than 200 mm at the mapped rockbars. It was assessed that the likelihood of significant fracturing resulting in surface water flow diversions along Wongawilli Creek would be low, i.e. affecting less than 10 % of the pools and channels. It is considered that the observed rate of impact (i.e. one Type 3 impact along the 2 km length of Wongawilli Creek) is similar to the MSEC assessments.

### 5.2.5. Impact assessments for Wongawilli Creek

The impact assessments for Wongawilli Creek are provided in the following sections. The assessments provided in this report should be read in conjunction with the assessments provided in the reports by the other specialist consultants on the project.

*Potential for increased levels of ponding, flooding and scouring due to the mining-induced tilts*

Wongawilli Creek is predicted to experience less than 20 mm vertical subsidence due to the extraction of the proposed LW19. While the creek could experience very low levels of vertical subsidence, it is not expected to experience measurable conventional tilts. That is, the predicted changes in grade along the creek due to the conventional movements are less than 0.5 mm/m (i.e. less than 0.05 %, or 1 in 2000).

The maximum predicted incremental upsidence along Wongawilli Creek due to the mining of the proposed LW19 only is 50 mm. The maximum predicted total upsidence along the creek is 150 mm which occurs downstream of LW19. While the magnitudes of the predicted upsidence movements vary along the alignment of the creek, as illustrated in Fig. C.03, the predicted changes in grade are less than 0.5 mm/m (i.e. less than 0.05 %, or 1 in 2000).

The average natural grade of the section of Wongawilli Creek within the Study Area is approximately 3.6 mm/m (i.e. 0.36 %, or 1 in 278). The predicted changes in grade due to the mining of LW19, therefore, are considerably less than the average natural grade. It is unlikely, therefore, that there would be adverse changes in the potential for ponding, flooding or scouring of the banks along the creek due to the mining-induced tilt.

It is possible, however, that there could be some localised changes in the levels of ponding or flooding where the maximum changes in grade coincide with existing pools, steps or cascades along the creek. It is not anticipated that these changes would result in adverse impacts on the creek, due to the mining-induced tilt, since the predicted changes in grade are less than 0.05 %.

*Potential for fracturing of bedrock and surface water flow diversions*

Fractures and joints in bedrock and rockbars occur naturally from erosion and weathering processes and from natural valley bulging movements. Where longwall mining occurs in the vicinity of streams, mine subsidence movements can result in additional fracturing or the reactivation of the existing joints. The main mining-related mechanisms for these impacts are conventional subsidence and valley related upsidence and closure movements.

Diversions of surface water flows also occur naturally from erosion and weathering processes and from natural valley bulging movements. Mining-induced surface water flow diversions into the strata occur where there is an upwards thrust of bedrock, resulting in a redirection of some water flows into the dilated strata beneath the creek beds. At higher depths of cover, where a constrained zone exists or where the creek is not directly mined beneath, the water generally reappears further downstream of the fractured zone as the surface flow is only redirected below the creek bed where the fractured zone exists.

Wongawilli Creek is located at minimum distances of 110 m and 290 m from the existing longwalls in Areas 3A and 3B, respectively, and a minimum distance of 175 m from the proposed LW19. While the creek could experience very low levels of vertical subsidence, it is not expected to experience measurable conventional strains. That is, the strains due to the conventional ground movements are expected to be less than 0.3 mm/m.

The maximum predicted incremental closure along Wongawilli Creek due to the mining of the proposed LW19 only is 70 mm. The maximum predicted total closure along the creek is 210 mm which occurs downstream of LW19. The maximum predicted compressive strain for the creek due to the valley closure effects is 7 mm/m based on the 95 % confidence level.

Fracturing in bedrock has been observed due to previous longwall mining where the tensile strains are greater than 0.5 mm/m or where the compressive strains are greater than 2 mm/m. It is possible, therefore, that fracturing could occur along Wongawilli Creek due to the valley related compressive strains. Fracturing has been observed up to approximately 400 m outside of previously extracted longwalls in the Southern Coalfield. Fracturing has been observed at distances up to 300 m from the completed longwalls in Area 3B.

The impact assessment for Wongawilli Creek has been based on the potential for Type 3 impacts, defined as *fracturing in rockbar or upstream pool resulting in reduction in standing water level based on current rainfall and surface water flow*. The rockbar impact model based on the experience of longwall mining in the Southern Coalfield is described in Section 5.3.4 of Report No. MSEC459 and is illustrated in Fig. 5.4.

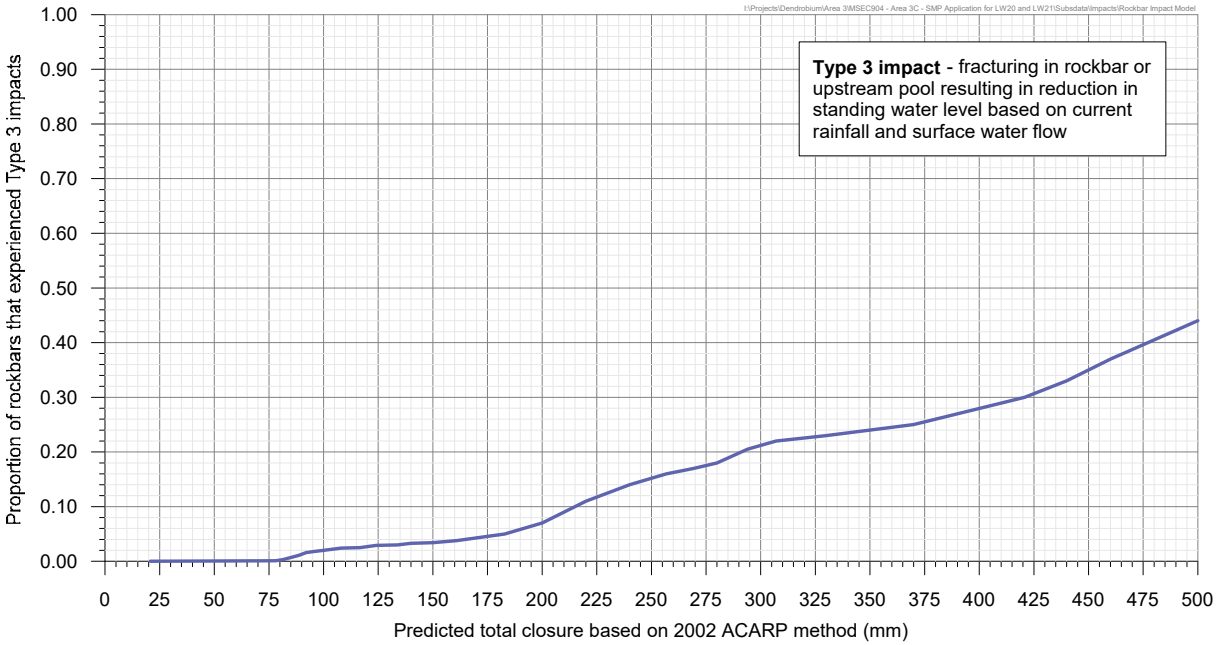



**Fig. 5.4 Rockbar impact model based on predicted valley closure**

The maximum predicted total closure along Wongawilli Creek, after the extraction of the existing LW6 to LW9 in Area 3A, the existing and future LW9 to LW18 in Area 3B, the future LW20 and LW21 in Area 3C and the proposed LW19 in Area 3A is 210 mm. The predicted rate of impact for the rockbars and other stream controlling features along the creek after the extraction of the existing and future longwalls, therefore, is in the order of 7 % based on the maximum predicted closure.

Fracturing has occurred in one pool (Pool 43a) along Wongawilli Creek due to the previous mining in Areas 3A and 3B. The impact site is located 200 m west of LW6 and 410 m east of LW9. The fracturing was first observed during the extraction of LW9. Pool water levels below baseline conditions have been observed in this pool at low flow conditions during the mining of LW13. This site has therefore been considered a Type 3 impact. The total length of creek located within a distance of 400 m of the as-extracted longwalls is 2 km. The rate of impact along Wongawilli Creek due to the previous mining, therefore, is considered to be low.

It has been assessed that the likelihood of fracturing resulting in surface water flow diversions along Wongawilli Creek, due to the extraction of the proposed LW19, is low, i.e. affecting less than 10 % of rockbars and other stream controlling features located within the Study Area. However, minor fracturing could still occur along the creek, at distances up to approximately 400 m from the proposed longwall.

Further assessments of the potential impacts on surface water are provided in the report by HGeo (2020).

### 5.2.6. Recommendations for Wongawilli Creek

It is recommended that the closure movements are measured and that inspections are carried out along Wongawilli Creek during active subsidence. It is also recommended that the Dendrobium Area 3A Watercourse Impact Management Monitoring and Contingency Plan be revised to include the proposed LW19.

## 5.3. Sandy Creek and Sandy Creek Waterfall

The location of Sandy Creek is shown in Drawing No. MSEC1082-09.

Sandy Creek is situated on the eastern side of the existing LW6 to LW8 and the proposed LW19 in Area 3A. The thalweg of the creek is located 750 m from the commencing end of LW19, at its closest point. Sandy Creek is therefore located outside the Study Area based on the 600 m boundary.

The maximum predicted incremental vertical subsidence, upsidence and closure for Sandy Creek, due to the mining of LW19, are all less than 20 mm. While the creek could experience very low levels of these subsidence effects, it is not expected to experience measurable tilts, curvatures or strains.

It is unlikely, therefore, that adverse impacts would occur along Sandy Creek due to the mining of LW19.

Sandy Creek Waterfall (SC-WF1) is situated where Sandy Creek flows into the Cordeaux Reservoir. The centreline of the waterfall is located 900 m north-east of the commencing end of LW19. At this distance, the predicted incremental vertical subsidence, upsidence and closure for Sandy Creek Waterfall are negligible.

The valley closure effects across Sandy Creek Waterfall due to the mining of LW6 to LW8 were measured using the SCW High Resolution Survey (HRS) H1, H2, H3, G1, G2 and AA Lines. The locations of these monitoring lines are shown in Drawing No. MSEC1082-01. The measured total closures for SCW HRS lines are illustrated in Fig. 5.5. The survey accuracy for these high-resolution monitoring lines is in the order of ±0.5 mm to ±1 mm. The measured movements also include a component due to environmental effects (i.e. changes in temperature and rainfall) in the order of ±1 mm to ±2 mm.

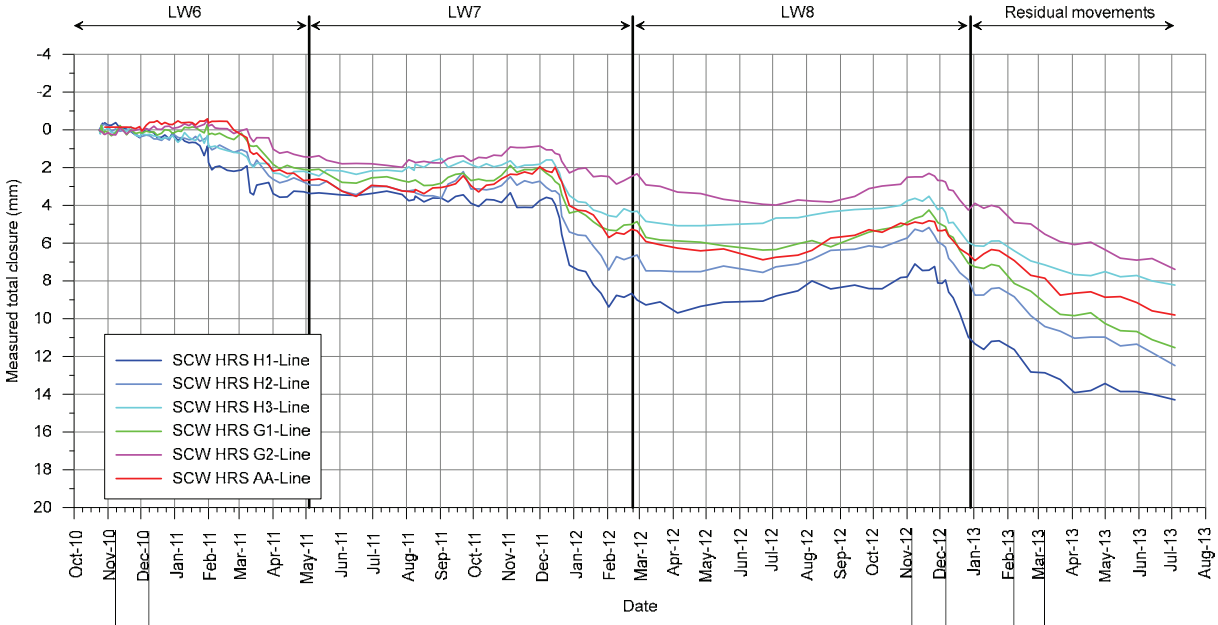



**Fig. 5.5 Measured total closure for the SCW HRS monitoring lines for LW6 to LW8**

The maximum measured total closure across Sandy Creek Waterfall due to the mining of LW6 to LW8 was approximately 14 mm. The greatest closure was measured across the SCW HRS H1-Line located downstream of the waterfall and across the valley of Lake Cordeaux.

A summary of the measured incremental closure movements for the SCW HRS H1-Line, due to the mining of each of LW6 to LW8, is provided in Table 5.6. The distances of the longwalls from the centreline of the waterfall are also provided in the table.

**Table 5.6 Measured incremental closure for the SCW HRS H1-Line due to LW6 to LW8**

| Monitoring line | Longwall | Distance from the centreline of Sandy Creek Waterfall (m) | Measured incremental closure (mm) |
|---|---|---|---|
| SCW HRS H1-Line | LW6 | 390 | 4 |
| | LW7 | 430 | 5 |
| | LW8 | 500 | 5 |

The proposed LW19 is located 900 m from the centreline of Sandy Creek Waterfall. This longwall is between 1.8 to 2.3 times the distances of LW6 to LW8 from the centreline of the waterfall. Also, the eastern end of LW8 extends beyond the eastern end of LW19 and, therefore, it provides shadowing effects. On this basis, the predicted incremental closure for Sandy Creek Waterfall due to LW19 is less than 2 mm. The predicted incremental movement therefore is in the order of the survey tolerance and environmental effects.

It is unlikely that Sandy Creek Waterfall would experience adverse impacts due to the mining of LW19.

It is recommended that the closure across the waterfall is measured monthly during the first 1000 m of mining of LW19. A Trigger Action Response Plan (TARP) should also be established based on the measured movements.

## 5.4. Drainage lines

### 5.4.1. Descriptions of the drainage lines

The locations of the drainage lines are shown in Drawing No. MSEC1082-09. The unnamed drainage lines have been labelled for reference.

SC10 and WC14 are partially located above the proposed LW19. Other drainage lines are partially located above the existing LW6 to LW8. The drainage lines in the western part of the Study Area flow into Wongawilli Creek and the drainage lines in the eastern part of the Study Area flow into Sandy Creek.

The drainage lines are first and second order streams. The beds generally comprise exposed bedrock containing rockbars with some standing pools. There are also steps and cascades along the steeper sections. Debris accumulations have formed along the flatter sections that include loose rocks and tree branches.

A waterfall (SC10-WF15) is situated along SC10 to the east of the proposed LW19. The nearest edge of the waterfall is located 160 m from the commencing (i.e. eastern) end of LW19. The waterfall is approximately 15 m wide, 5 m high and has an overhang of up to approximately 2 m to 3 m.

The natural gradients of the drainage lines typically vary between 50 mm/m (i.e. 5.0 %, or 1 in 20) and 200 mm/m (i.e. 20 %, or 1 in 5), with average natural gradients in the order of 100 mm/m (i.e. 10 %, or 1 in 10). The drainage lines have localised areas with natural grades greater than 500 mm/m where there are steps and cascades.

### 5.4.2. Predictions for the drainage lines

The drainage lines are located across the Study Area and, therefore, could experience the full range of predicted subsidence movements. A summary of the maximum predicted conventional subsidence movements within the Study Area is provided in Chapter 4.

The predicted profiles of total vertical subsidence, upsidence and closure along SC10 and WC17 are shown in Figs. C.04 and C.05, respectively, in Appendix C. The predicted total profiles after the completion of LW6 to LW8 are shown as cyan lines. The predicted total profiles after the mining of LW19 are shown as the blue lines.

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature for the drainage lines located within the Study Area is provided in Table 5.7. The values are the maximum predicted subsidence effects due to the mining of LW6 to LW8 and LW19.

**Table 5.7 Maximum predicted total subsidence, tilt and curvature for the drainage lines**

| Type | Reference | Maximum predicted total vertical subsidence (mm) | Maximum predicted total tilt (mm/m) | Maximum predicted total hogging curvature ($km^{-1}$) | Maximum predicted total sagging curvature ($km^{-1}$) |
|---|---|---|---|---|---|
| Drainage lines | SC10 | 50 | 0.5 | 0.03 | < 0.01 |
| | SC10C | 2750 | 30 | 0.75 | 0.80 |
| | WC14 | 1000 | 10 | 1.0 | 0.10 |
| | WC17 | 2750 | 17 | 0.50 | 0.75 |

The maximum predicted total tilt for the drainage lines is 30 mm/m (i.e. 3.0 %, or 1 in 33). The maximum predicted total conventional curvatures are 1.0 $km^{-1}$ hogging and 0.80 $km^{-1}$ sagging, which represent minimum radii of curvatures of 1 km and 1.3 km, respectively.

The maximum predicted conventional strains for the drainage lines, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 15 mm/m tensile and 12 mm/m compressive. The distribution of the predicted strains due to the extraction of the longwalls is described in Section 4.4. The predicted strains directly above the mining area are 8 mm/m tensile and compressive based on the 95 % confidence levels.

Non-conventional movements can also occur and have occurred in the NSW coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

The drainage lines will also experience valley related effects. The range of closure movements for the drainage lines within the Study Area are expected to be similar to those measured across the streams above the existing longwalls in Area 3B. The data includes monitoring across Donalds Castle Creek, WC21 and the swamp cross-lines. The maximum measured closure for the streams in Area 3B due to the mining of LW9 to LW14 is 880 mm. The average measured values for the streams above the mining area is 210 mm and the 95-percentile is 770 mm.

The predicted compressive strains due to the valley related effects is in the order of 10 mm/m to 20 mm/m.

Summaries of the maximum predicted values of total vertical subsidence, upsidence and closure at the mapped rockbars along drainage lines SC10, SC10C and WC14 are provided in Table 5.8, Table 5.9 and Table 5.10, respectively. The locations of these features are shown in Drawing No. MSEC1082-09.

**Table 5.8 Maximum predicted total vertical subsidence, upsidence and closure at the mapped rockbars along drainage line SC10**

| Location | Label | Maximum predicted total vertical subsidence (mm) | Maximum predicted total upsidence (mm) | Maximum predicted total closure (mm) |
|---|---|---|---|---|
| Rockbars along drainage line SC10 | SC10-RB3 | < 20 | 50 | 80 |
| | SC10-RB4 | < 20 | 60 | 90 |
| | SC10-RB5 | < 20 | 60 | 100 |
| | SC10-RB6 | < 20 | 70 | 100 |
| | SC10-RB7 | < 20 | 70 | 100 |
| | SC10-RB8 | < 20 | 70 | 100 |
| | SC10-RB9 | < 20 | 70 | 100 |
| | SC10-RB10 | < 20 | 70 | 100 |
| | SC10-RB11 | 40 | 90 | 150 |
| | SC10-RB12 | < 20 | 90 | 150 |
| | SC10-RB13 | < 20 | 90 | 125 |
| | SC10-RB14 | < 20 | 90 | 125 |
| | SC10-RB15A | < 20 | 90 | 125 |
| | SC10-RB15B | < 20 | 90 | 125 |
| | SC10-RB16 | < 20 | 90 | 125 |
| | SC10-RB17 | < 20 | 90 | 125 |
| | SC10-RB18 | < 20 | 90 | 150 |
| | SC10-RB19 | < 20 | 100 | 150 |
| | SC10-RB20 | < 20 | 100 | 175 |
| | SC10-RB21 | 20 | 125 | 175 |
| | SC10-RB22 | 30 | 125 | 175 |
| | SC10-RB23 | < 20 | 125 | 200 |
| | SC10-RB24 | < 20 | 125 | 200 |
| | SC10-RB25 | < 20 | 125 | 200 |
| | SC10-RB26 | < 20 | 100 | 175 |
| | SC10-RB27 | < 20 | 40 | 60 |

**Table 5.9 Maximum predicted total vertical subsidence, upsidence and closure at the mapped rockbars along drainage line SC10C**

| Location | Label | Maximum predicted total vertical subsidence (mm) | Maximum predicted total upsidence (mm) | Maximum predicted total closure (mm) |
|---|---|---|---|---|
| Rockbars along drainage line SC10C | SC10C-RB1 | 60 | 80 | 125 |
| | SC10C-RB2 | 80 | 80 | 125 |
| | SC10C-RB3 | 250 | 100 | 150 |
| | SC10C-RB4 | 875 | 100 | 150 |
| | SC10C-RB9 | 1350 | 275 | 425 |
| | SC10C-RB10 | 1350 | 250 | 375 |
| | SC10C-RB11 | 1450 | 275 | 400 |

**Table 5.10 Maximum predicted total vertical subsidence, upsidence and closure at the mapped rockbars along drainage line WC14**

| Location | Label | Maximum predicted total vertical subsidence (mm) | Maximum predicted total upsidence (mm) | Maximum predicted total closure (mm) |
|---|---|---|---|---|
| Rockbars along drainage line WC14 | WC14-RB1 | < 20 | 125 | 250 |
| | WC14-RB2 | < 20 | 175 | 300 |
| | WC14-RB3 | < 20 | 175 | 350 |
| | WC14-RB4 | < 20 | 175 | 350 |
| | WC14-RB5 | < 20 | 200 | 375 |
| | WC14-RB6 | < 20 | 200 | 400 |
| | WC14-RB7 | 100 | 200 | 450 |
| | WC14-RB8 | 125 | 200 | 450 |
| | WC14-RB9 | 175 | 200 | 425 |
| | WC14-RB10 | 225 | 200 | 400 |
| | WC14-RB11 | 275 | 200 | 400 |
| | WC14-RB12 | 525 | 200 | 400 |

Rockbars SC10-RB11 and SC10-RB22 are located directly above the existing LW8 and the proposed LW19, respectively. These two rockbars are predicted to experience up to 40 mm vertical subsidence, 125 mm upsidence and 175 mm closure. The remaining rockbars along drainage line SC10 are located outside the mining area.

All rockbars along drainage line SC10C are located directly above the existing LW8, except for rockbar SC10C-RB1 which is located outside and adjacent to this longwall. The rockbars along drainage line SC10C are predicted to experience up to 1450 mm vertical subsidence, 275 mm upsidence and 425 mm closure. The predicted subsidence effects are partly due to the existing LW7 and LW8.

Rockbars WC14-RB7 to WC14-RB12 are located directly above the proposed LW19. The rockbars along drainage line WC14 are predicted to experience up to 525 mm vertical subsidence, 200 mm upsidence and 450 mm closure.

A summary of the maximum predicted total vertical subsidence, upsidence and closure for the waterfall along SC10 is provided in Table 5.11. The location of this feature is shown in Drawing No. MSEC1082-09

**Table 5.11 Maximum predicted total vertical subsidence, upsidence and closure at the waterfall along drainage line SC10**

| Location | Label | Maximum predicted total vertical subsidence (mm) | Maximum predicted total upsidence (mm) | Maximum predicted total closure (mm) |
|---|---|---|---|---|
| Waterfall along drainage line SC10 | SC10-WF15 | < 20 | 90 | 125 |

### 5.4.3. Observed impacts for the drainage lines due to LW9 to LW14

First and second order drainage lines are located above the previously extracted LW9 to LW14 in Area 3B. The impact assessments for these drainage lines were provided in Report No. MSEC459, which related to the physical impacts, i.e. cracking, fracturing and deformation of the bedrock and surface soils as the result of mining. The assessments of the environmental consequences were provided in the other specialist consultants' reports and, therefore, the discussions below should be read in conjunction with those provided by the other specialist consultants.

The impacts observed along the drainage lines due to LW9 are described in the End of Panel Report (IMC, 2014) and these have been summarised below:

> *Drainage line DC13*: impacts observed at five sites including: change in water appearance with orange precipitate from DC13_Pool20 to DC13_Pool14; multiple fractures upstream of Pool DC13_Pool20, in Rockbar DC13_RB21 and in Rockbar DC13_RB17 from less than 1 mm and up to 5 mm in width and up to 4 metres in length; soil cracking downstream of DC13_RB21; and flow diversions in Pool DC13_Pool20 and upstream of Rockbar DC13_RB21.
>
> *Drainage line WC21*: impacts observed at nine sites (including at and between Pools 10, 11, 16, 17, 18 and 19) including: multiple fractures from 3 mm and up to 20 mm in width and up to 5.5 metres in length; dilation and uplift up to 20 mm; iron staining; and water loss in Pool WC21_Pool16.

The impacts observed along the drainage lines due to LW10 are described in the End of Panel Report (IMC, 2015) and these have been summarised below:

> *Drainage line WC21*: impacts observed at 17 sites including: additional fracturing at the sites previously impacted by LW9; fracturing from hairline and up to 30 mm in width and up to 5.5 metres in length; iron staining; dilation and uplift; and localised flow diversion upstream of Rockbar WC21_RB26 and in Pool WC21_Pool 24.

The impacts observed in the drainage lines due to LW11 are described in the End of Panel Report (IMC, 2016) and these have been summarised below:

> Multiple fractures, uplift and displacement in two locations along WC21, in Rockbar 27 and upstream of Pool 30. Loss of surface water flow along Watercourse WC21 in Pool 30.

The impacts observed along the drainage lines due to LW12 are described in the End of Panel Report (IMC, 2017) and these have been summarised below:

> Rock fractures and uplift were identified at four sites along WC21, LA4 and LA4B with widths up to approximately 50 mm. Loss of surface water flow along stream LA4 and possible diversion along stream LA4B. Fracturing observed outside of mining along LA4B and WC21 at distances of 290 m and 110 m, respectively.

The impacts observed along the drainage lines due to LW13 are described in the End of Panel Report (IMC, 2018) and these have been summarised below:

> Rock fractures and uplift were identified at six sites along WC21, at eight sites along WC15 and two sites along LA4. The fracture widths varied between 2 mm and approximately 220 mm, with the majority (83 %) of the widths being 50 mm or less. The impacts along WC21 occurred directly above LW12 and LW13. The impacts along WC21 and LA4 were located at distances between 120 m and 280 m outside the extents of LW13.
>
> Loss of surface water flow along WC21 observed directly above LW13. Loss of surface flow along WC15 at six sites and along LA4 at one site at distances between 140 m and 260 m from LW13. Iron staining observed in one location along each of WC21, WC15 and LA4.

The impacts observed along the drainage lines due to LW14 were described in the End of Panel Report (IMC, 2019) and these have been summarised below:

> Rock fracturing was observed along WC15, LA4 and LA4B at distances ranging between 30 m and 300 m from the longwall mining area. It was assessed that rock fracturing could occur along the streams up to approximately 400 m from the mining area.
>
> No new surface water diversions were identified due to the mining of LW14. However, fracturing along WC15 is located along the main channel and surface water diversions are possible during higher flow conditions. There are seven sites with identified or with possible Type 3 impacts along WC15 due to the mining of both LW13 and LW14, being Rockbars 0/1, Rockbar 5, Rockbar 18, Rockbar 21, Rockbar 25, Rockbar 26 and Pool 30/Channel 30.

The environmental consequences due to the abovementioned physical impacts are described by the specialist consultants' reports attached to each of the End of Panel reports.

### 5.4.4. Impact assessments for the drainage lines

The impact assessments for the drainage lines are provided in the following sections. The assessments provided in this report should be read in conjunction with the assessments provided in the reports by the other specialist consultants on the project.

*Potential for increased levels of ponding, flooding and scouring due to the mining-induced tilts*

Mining can result in increased levels of ponding in locations where the mining-induced tilts oppose and are greater than the natural drainage line gradients that exist before mining. Mining can also potentially result in an increased likelihood of scouring of the banks in the locations where the mining-induced tilts considerably increase the natural drainage line gradients that exist before mining.

The maximum predicted tilt for the drainage lines within the Study Area is 30 mm/m (i.e. 3.0 % or 1 in 33). The predicted mining-induced tilts are less than the natural gradients of the drainage lines that typically vary between 50 mm/m and 200 mm/m (i.e. 5 % to 20 %).

The natural grades and the predicted post-mining grades along drainage lines SC10, SC10C, WC14 and WC17 are illustrated in Fig. 5.6 to Fig. 5.9, respectively. The locations of these drainage lines are shown in Drawing No. MSEC1082-09.

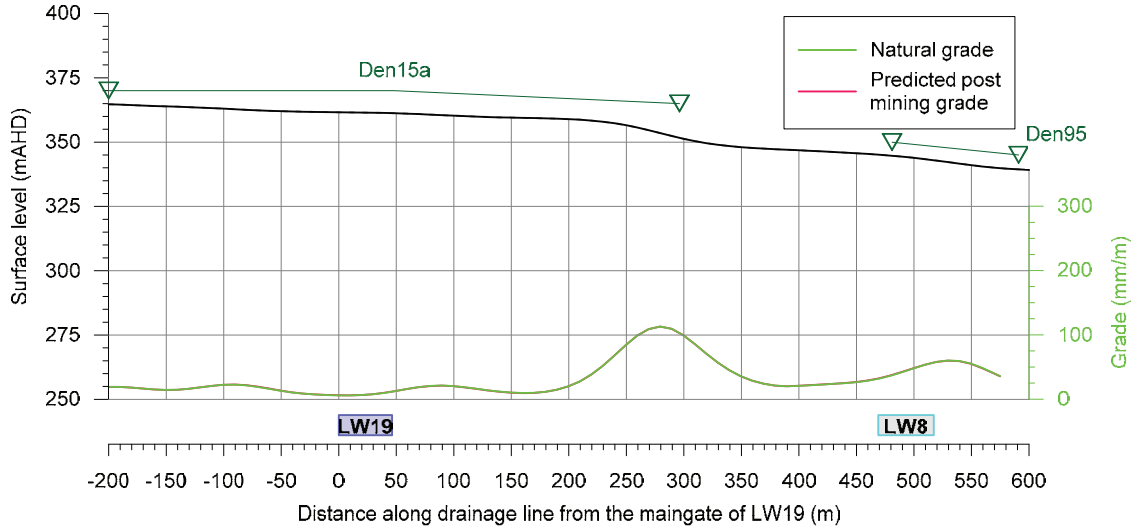



**Fig. 5.6 Natural and predicted post-mining surface levels along SC10**

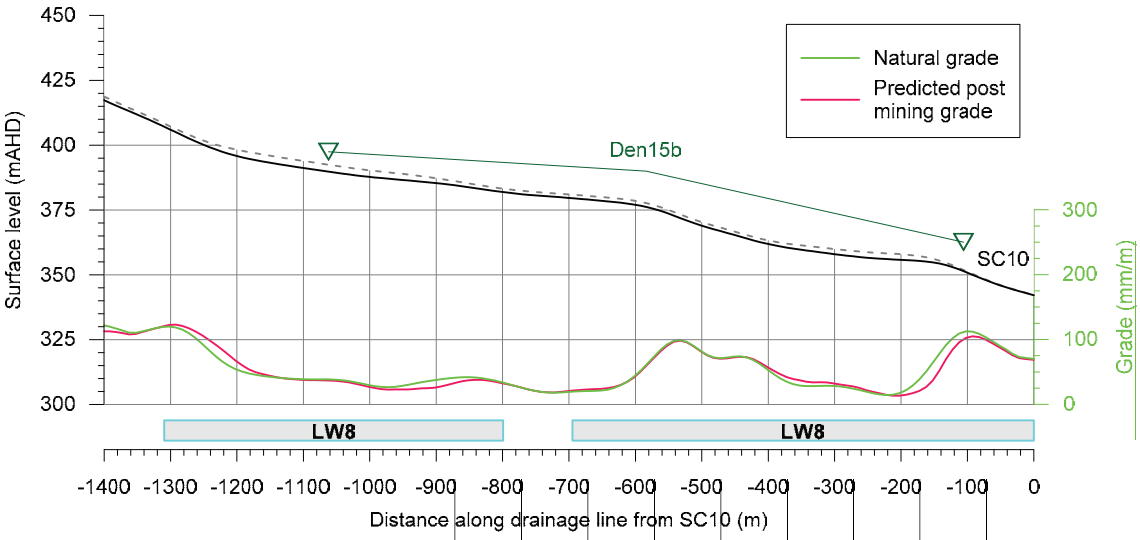



**Fig. 5.7 Natural and predicted post-mining surface levels along SC10C**

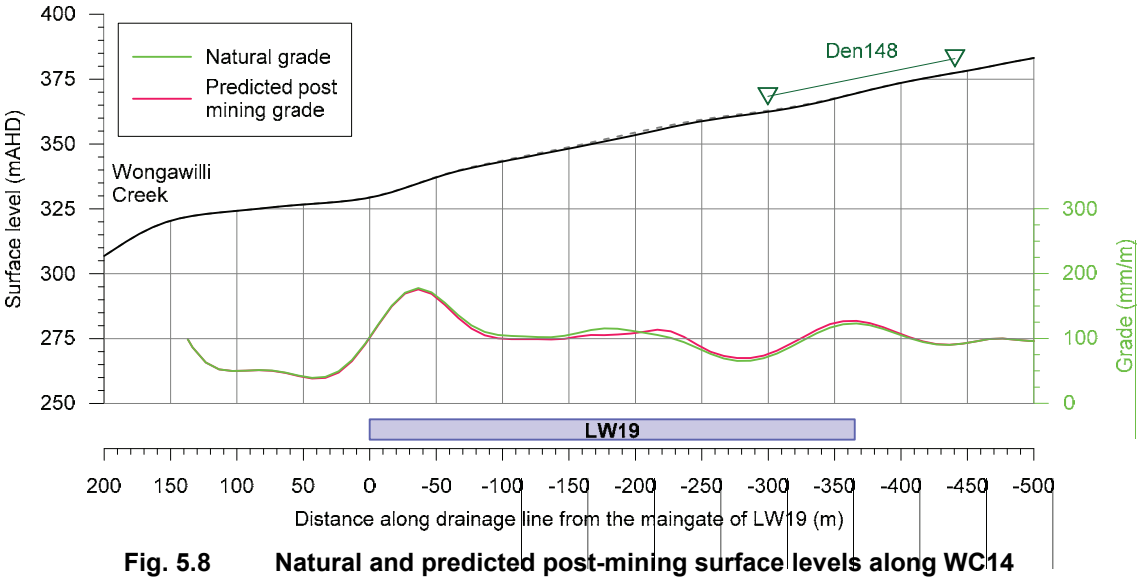



**Fig. 5.8 Natural and predicted post-mining surface levels along WC14**

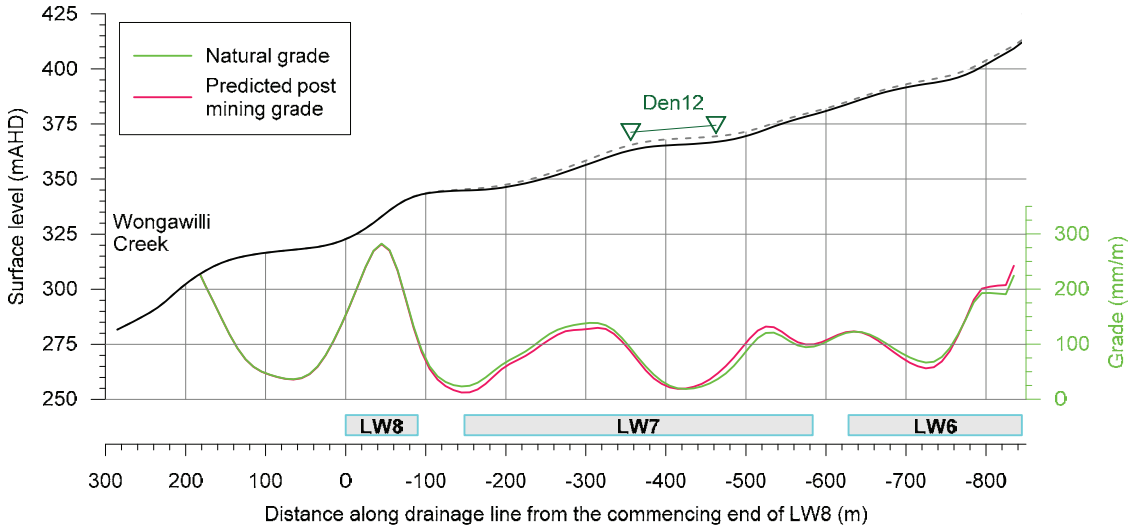



**Fig. 5.9 Natural and predicted post-mining surface levels along WC17**

There are no predicted reversals of stream grade along drainage lines SC10, SC10C, WC14 and WC17. There are slight reductions in grades along drainage lines SC10C and WC17, upstream of the chain pillars and the edges of the mining area. There is potential for minor and localised increased ponding upstream of these locations. However, drainage lines SC10C and WC17 are located above the existing LW7 and LW8 and, therefore, the potential for increased ponding occurs due to these existing longwalls rather than the proposed LW19.

Elsewhere, the predicted post-mining grades are similar to the natural grades. It is unlikely, therefore, that there would be large-scale adverse changes in the levels of ponding or scouring of the banks along these drainage lines due to the mining-induced tilt. It is possible that localised increased ponding could develop in some isolated locations, where the natural grades are small, and upstream of the chain pillars and the edges of the mining area.

The potential impacts of increased ponding and scouring of the drainage lines, therefore, are expected to be minor and localised. Impacts resulting from changes in surface water flows are expected to be small in comparison with those which occur during natural flooding conditions.

*Potential for cracking in the creek bed and fracturing of bedrock*

Impacts have been observed along the drainage lines above and adjacent to the previously extracted LW9 to LW14 in Area 3B, including fracturing in the rockbars and exposed bedrock, dilation and uplift of the bedrock, iron staining, surface water flow diversions and reduction in pool water levels. These impacts predominately occurred directly above the extracted longwalls. However, fracturing was also observed up to 300 m from the extracted longwalls in Area 3B.

The maximum predicted subsidence effects due to the proposed LW19 are similar to but less than the maximum predicted values for the existing longwalls in Area 3B. The potential impacts for the drainage lines within the Study Area, therefore, are expected to be similar to those observed above and adjacent to the existing longwalls in Area 3B.

It is expected that fracturing of the bedrock would occur along the sections of the drainage lines that are located directly above the proposed LW19 and the adjacent existing LW7 and LW8. Fracturing can also occur outside the extents of the longwalls, with minor and isolated fracturing occurring at distances up to approximately 400 m.

The mining-induced compression due to valley closure effects can also result in dilation and the development of bed separation in the topmost bedrock, as it is less confined. This valley closure related dilation is expected to develop predominately within the top 10 m to 20 m of the bedrock. Compression can also result in buckling of the topmost bedrock resulting in heaving in the overlying surface soils.

Surface water flow diversions are likely to occur along the sections of drainage lines that are located directly above and adjacent to the longwalls.

Further assessments of the potential impacts on surface water are provided in the report by HGeo (2020).

### 5.4.5. Impact assessments for waterfall SC10-WC15

The waterfall SC10-WC15 is located 160 m east of the proposed LW19, at its closest point. At this distance, the waterfall is predicted to experience less than 20 mm vertical subsidence. While the waterfall could experience very low levels of vertical subsidence, it is not expected to experience measurable tilts, curvatures or conventional strains.

The maximum predicted total valley related effects at the waterfall are 90 mm upsidence and 125 mm closure. As described above, fracturing in the bed of SC10 could occur up to 400 m outside of the mining area and, hence, near the waterfall. The method of assessment for surface water flow diversions has been predominately based on the previous experience of mining near to and beneath relatively flat streams in the Southern Coalfield. The impact assessments for the pools immediately upstream of the waterfall, therefore, need to consider the steep gradient (i.e. the waterfall) immediately downstream.

A similar sized waterfall is located at Elouera Colliery, along a tributary to Wongawilli Creek, where mining has occurred beneath it and on both sides. The Elouera longwalls were extracted on the western side of the waterfall, with LW2 located at a distance of 160 m from this feature, at its closest point. Delta LW17 was extracted on the eastern side of the waterfall, which was located at a distance of 120 m from this feature, at its closest point. NRE Gujarat has also extracted LW19 directly beneath this waterfall.

The predicted subsidence effects at the waterfall at Elouera Colliery, resulting from the existing longwalls, are 100 mm vertical subsidence, 80 mm upsidence and 110 mm closure. There have been no adverse impacts observed at the waterfall at Elouera Colliery due to this mining.

There is also other extensive experience of mining in the vicinity of cliffs in the Southern Coalfield, including Appin Longwalls 301 and 302, which mined to within 50 m of the cliffs within the Cataract River, and Tower Longwalls 18 to 20 and Appin Longwalls 701 and 702, which mined to within to 50 m of cliffs within the Nepean River. In these cases, there were no large cliff instabilities where the longwalls at Appin and Tower Collieries mined to within 50 m of the cliffs (i.e. not directly mined beneath). However, there were some minor rock falls or disturbances that occurred during mining, of which, some are considered likely to have occurred due to a significant rainfall event and natural instability of the cliff.

Based on the previous experience of mining beneath a similar sized waterfall at Elouera Colliery and near to cliffs elsewhere in the Southern Coalfield, the likelihood of an instability at the waterfall SC10-WF15 is considered to be very low. It is possible, however, that isolated rockfalls could occur at or near the waterfall due to mining, due to natural processes, or both.

### 5.4.6. Recommendations for the drainage lines

IMC has developed management strategies for drainage lines that have been directly mined beneath by previously extracted longwalls at Dendrobium Mine. It is recommended that these management strategies are reviewed and updated to incorporate LW19. It is also recommended that periodic inspections are carried out along the drainage lines during active subsidence.

## 5.5. Aquifers and known groundwater resources

Shallow aquifers have been identified within the Study Area and these are associated with the drainage lines and upland swamps. The potential impacts on the aquifers and groundwater resources are provided by the specialist groundwater consultant.

## 5.6. Cliffs

### 5.6.1. Descriptions of the cliffs

The definitions of cliffs and minor cliffs provided in the NSW DPIE *Standard and Model Conditions for Underground Mining* (DPIE, 2012) are:

> *"Cliff* — *Continuous rock face, including overhangs, having a minimum length of 20 metres, a minimum height of 10 metres and a minimum slope of 2 to 1 (>63.4º)*
>
> *Minor Cliff* — *A continuous rock face, including overhangs, having a minimum length of 20 metres, heights between 5 metres and 10 metres and a minimum slope of 2 to 1 (>63.4º); or a rock face having a maximum length of 20 metres and a minimum height of 10 metres*"

The cliffs and minor cliffs within the Study Area have been identified from LiDAR surface level contours and field investigations. The locations of these features are shown in Drawing No. MSEC1082-08.

There are five cliffs that have been identified within the Study Area based on the 35° angle of draw line and predicted 20 mm subsidence contour. There are also seven additional cliffs located within the Study Area based on the 600 m boundary. While the valleys where the cliffs are located could experience valley related effects, the cliffs themselves are unlikely to experience upsidence and compressive strain due to valley closure, as they are located along the valley sides. The cliffs located outside the Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour, therefore, have not been assessed further.

A summary of the five cliffs identified within the Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour is provided in Table 5.12.

**Table 5.12 Cliffs located within the Study Area**

| Reference | Location | Overall length (m) | Maximum height (m) |
|---|---|---|---|
| DA3-CF7 | Directly above LW19, adjacent to the longwall maingate | 20 | 15 |
| DA3-CF8 | Directly above LW19, adjacent to the longwall commencing end | 25 | 10 |
| DA3-CF16 | 220 m west of the LW19 finishing end | 70 | 10 |
| DA3-CF17 | Partially above LW19, above the longwall maingate and finishing end | 280 (total length)<br>70 (above LW19) | 10 |
| DA3-CF18 | 75 m south of LW19 finishing end | 180 | 15 |

The cliffs have formed predominantly from Hawkesbury Sandstone, with the faces being at various stages of weathering and erosion. The cliffs have many overhangs and undercuts that are generally less than 6 m. A photograph of the Wongawilli Creek valley is provided in Fig. 5.10 (Source: IMC). The cliffs on the western side of the creek (i.e. near the longwalls in Area 3B) are partially visible on the left side of this photograph. The cliffs of the eastern side of the creek (i.e. near the longwalls in Area 3A) are obscured by the trees on the right side of this photograph.



**Fig. 5.10 Wongawilli Creek valley (Source: IMC)**

The minor cliffs within the Study Area are located within the valleys of Wongawilli Creek and the drainage lines. The lengths of each of the minor cliffs typically range between 20 m and 50 m and have heights up to 10 m. There are also many rock outcrops and rock platforms that are located across the Study Area. The rock outcrops are generally less than 5 m in height.

### 5.6.2. Predictions for the cliffs

A summary of the maximum predicted total vertical subsidence, tilt and curvatures for the cliffs located within the Study Area is provided in Table 5.13. The values are the maximum predicted subsidence effects within 20 m of the mapped extents of each of the cliffs due to the mining of LW6 to LW8 and LW19.

**Table 5.13 Maximum predicted total vertical subsidence, tilt and curvatures for the cliffs**

| Reference | Maximum predicted total vertical subsidence (mm) | Maximum predicted total tilt (mm/m) | Maximum predicted total hogging curvature ($km^{-1}$) | Maximum predicted total sagging curvature ($km^{-1}$) |
|---|---|---|---|---|
| DA3-CF7 | 800 | 25 | 0.90 | 0.10 |
| DA3-CF8 | 125 | 3.0 | 0.06 | 0.03 |
| DA3-CF16 | < 20 | < 0.5 | < 0.01 | < 0.01 |
| DA3-CF17 | 50 | 2.0 | 0.06 | < 0.01 |
| DA3-CF18 | < 20 | < 0.5 | 0.01 | < 0.01 |

Cliff DA3-CF7 is located directly above LW19. The maximum predicted tilt for this cliff is 25 mm/m (i.e. 2.5 %, or 1 in 40). The maximum predicted curvatures for DA3-CF7 are 0.90 $km^{-1}$ hogging and 0.10 $km^{-1}$ sagging, which represent minimum radii of curvatures of 1.1 km and 10 km, respectively.

The maximum predicted conventional strains for DA3-CF7, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 14 mm/m tensile and 1.5 mm/m compressive. The distribution of the predicted strains due to the extraction of the longwalls is described in Section 4.4. The predicted strains directly above the mining area are 8 mm/m tensile and compressive based on the 95 % confidence levels.

Non-conventional movements can also occur and have occurred in the NSW coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

Cliffs DA3-CF8 and DA3-CF17 are partially located above commencing end and finishing end, respectively, of LW19. The maximum predicted tilt for these cliffs is 3.0 mm/m (i.e. 0.3 %, or 1 in 333). The maximum predicted curvatures for DA3-CF8 and DA3-CF17 are 0.06 $km^{-1}$ hogging and 0.03 $km^{-1}$ sagging, which represent minimum radii of curvatures of 17 km and 33 km, respectively. The predicted strains for these cliffs are less than the predicted values for DA3-CF7 described above.

Cliffs DA3-CF16 and DA3-CF18 are located outside of the mining area. These cliffs are predicted to experience less than 20 mm vertical subsidence due to the mining of LW6 to LW8 and LW19. While DA3-CF16 and DA3-CF18 could experience low levels of vertical subsidence, they are not expected to experience measurable tilts, curvatures or strains.

### 5.6.3. Impact assessments for the cliffs

It is difficult to assess the likelihood of cliff instabilities based upon predicted subsidence effects. The likelihood of a cliff becoming unstable is dependent on many factors that are difficult to quantify. Some of these factors include jointing, inclusions, weaknesses within the rockmass, groundwater pressure and seepage flow behind the rockface. Even if these factors could be determined, it would still be difficult to quantify the extent to which these factors may influence the stability of a cliff naturally or when it is exposed to mine subsidence movements. It is therefore possible that cliff instabilities may occur during mining that may be attributable to either natural causes, mine subsidence, or both.

The likelihood of instability for Cliffs DA3-CF7, DA3-CF8 and DA3-CF17 has been assessed using the previous experience of mining beneath cliffs at the Mine. The cliffs that were located above the previously extracted longwalls in Area 1 are the most relevant case study.

LW1 and LW2 at the Mine had void widths of 250 m and a solid chain pillar width of 50 m. The longwalls were extracted from the Wongawilli Seam, at depths of cover varying between 170 m and 320 m and were also located beneath existing bord and pillar workings in the overlying Bulli Seam, i.e. partial multi-seam mining conditions. The maximum predicted conventional curvatures, resulting from the extraction of these longwalls, were 0.35 $km^{-1}$ hogging and 0.75 $km^{-1}$ sagging.

These longwalls were extracted directly beneath a ridgeline and rock falls were observed in eight locations directly above mining. The total length of disturbance resulting from the extraction of LW1 and LW2 was approximately 135 m to 175 m. The total plan length of ridgeline located directly above the longwalls was between approximately 1800 m to 2000 m. It should be noted that there are two levels of cliffs in some locations and, therefore, the total length of cliffline is greater than the total plan length of the ridgeline.

The length of ridgeline disturbed due to the extraction of LW1 and LW2 was, therefore, estimated to be between 7 % and 10 % of the total plan length of ridgeline directly above the longwalls. The length of rockfalls that occurred due to the extraction of LW1 and LW2 was, however, less than the length of disturbed ridgeline.

Based on the experience in Area 1 at the Mine, it has been assessed that Cliffs DA3-CF7, DA3-CF8 and DA3-CF17 could be impacted due to the extraction of LW19 directly beneath them. The impacts are predicted to represent approximately 7 % to 10 % of the total plan length of the cliffs located directly above LW19.

Cliffs DA3-CF16 and DA3-CF18 are located outside the mining area and are predicted to experience less than 20 mm vertical subsidence. These cliffs are predicted to experience only low levels of tilt, curvature and strain. Isolated rock falls could occur at some of the cliffs located outside the extents of the proposed longwall and within the angle of draw.

It is unlikely that other cliffs located outside the 35° angle of draw would experience adverse impacts due to their distances outside of the mining area. This is based on the extensive experience of mining near to but not directly beneath cliffs in the NSW coalfields, where no large cliff falls have occurred when the cliffs are located completely outside the angle of draw from mining. It is still possible, but unlikely, that isolated rock falls could occur due to mining, natural processes, or both.

### 5.6.4. Recommendations for the cliffs

It is recommended that periodic inspections of the cliffs and minor cliffs located within the Study Area are undertaken during active subsidence and at the completion of mining.

## 5.7. Rock outcrops and steep slopes

### 5.7.1. Descriptions of the rock outcrops and steep slopes

The definition of a steep slope provided in the NSW DPIE *Standard and Model Conditions for Underground Mining* (DPIE, 2012) is: "*An area of land having a gradient between 1 in 3 (33% or 18.3º) and 2 in 1 (200% or 63.4º)*". The locations of the steep slopes were identified from the 1 m surface level contours which were generated from a LiDAR survey of the area.

The areas identified as having steep slopes are shown in Drawing No. MSEC1082-08.

The steep slopes within the Study Area have been identified within the valleys of Wongawilli Creek and its tributaries. The natural grades of the steep slopes typically vary up to approximately 1 in 2 (i.e. 27°, or 50 %), with isolated areas with natural grades up to 1 in 1 (i.e. 45° or 100 %).

Rock outcrops are defined as exposed rockfaces with heights of less than 10 m or slopes of less than 2 in 1. There are rock outcrops located across the Study Area, primarily within the valleys of Wongawilli Creek and its tributaries. The rock outcrops have not been shown in the drawings, as their specific locations could not be derived from the aerial laser scan or the orthophotograph.

Photographs of typical rock outcropping at the Mine are provided in Fig. 5.11.



**Fig. 5.11 Typical rock outcropping at the Mine**

### 5.7.2. Predictions for the rock outcrops and steep slopes

The rock outcrops and steep slopes are located across the Study Area and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted values of total vertical subsidence, tilt and curvatures for the rock outcrops and steep slopes is provided in Table 5.14. The values in this table are the maximum predicted subsidence effects due to LW6 to LW8 and LW19.

**Table 5.14 Maximum predicted total vertical subsidence, tilt and curvatures for the rock outcrops and steep slopes**

| Location | Longwalls | Maximum predicted total vertical subsidence (mm) | Maximum predicted total tilt (mm/m) | Maximum predicted total hogging curvature ($km^{-1}$) | Maximum predicted total sagging curvature ($km^{-1}$) |
|---|---|---|---|---|---|
| Rock outcrops and steep slopes | LW6 to LW8 and LW19 | 3000 | 40 | 1.0 | 1.0 |

The maximum predicted total tilt for the rock outcrops and steep slopes is 40 mm/m (i.e. 4.0 %, or 1 in 25). The maximum predicted total conventional curvatures are 1.0 $km^{-1}$ hogging and sagging, which represent a minimum radius of curvature of 1 km.

The maximum predicted conventional strains for the rock outcrops and steep slopes, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 15 mm/m tensile and compressive. The distribution of the predicted strains due to the extraction of the longwalls is described in Section 4.4. The predicted strains directly above the mining area are 8 mm/m tensile and compressive based on the 95 % confidence levels.

Non-conventional movements can also occur and have occurred in the NSW coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

### 5.7.3. Impact assessments for the rock outcrops and steep slopes

The maximum predicted tilt for the rock outcrops and steep slopes within the Study Area is 40 mm/m (i.e. 4.0 %, or 1 in 25). The predicted changes in grade are very small when compared to the natural surface grades, which are greater than 1 in 3. It is unlikely, therefore, that the mining-induced tilts themselves would result in any adverse impact on the stability of the rock outcrops or steep slopes.

The rock outcrops and steep slopes are more likely to be impacted by curvature and strain, rather than tilt. The potential impacts would generally result from the increased horizontal movements in the downslope direction, resulting in tension cracks appearing at the tops and on the sides of the rock outcrops and steep slopes, buckling of the bedrock at the bottoms of the rock outcrops, and compression ridges forming at the bottoms of the steep slopes.

The maximum predicted total curvatures for the rock outcrops and steep slopes within the Study Area are 1.0 $km^{-1}$ hogging and sagging. The maximum predicted curvatures and strains for these features are similar to the predicted values for Dendrobium LW1 and LW2, which mined directly beneath a ridgeline comprising cliffs, rock outcrops and steep slopes. The impacts observed from this case study, therefore, can be used to provide an indication of the potential impacts on the rock outcrops and steep slopes located within the Study Area.

Dendrobium LW1 and LW2 mined directly beneath a ridgeline where steep slopes had natural surface gradients of up to 1 in 1 (i.e. 100 %, or an angle to the horizontal of 45°). A number of surface cracks were observed along the steep slopes located directly above Dendrobium LW1 and LW2 which are shown in Fig. 5.12.

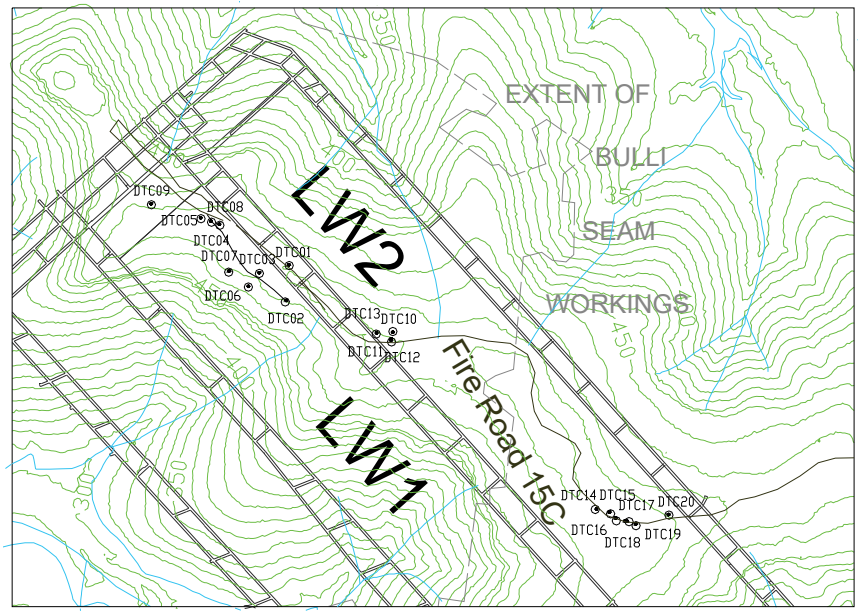



**Fig. 5.12 Locations of observed surface cracking above Dendrobium LW1 and LW2**

The largest surface cracks observed in Dendrobium Area 1 occurred along the top of the ridgeline, having widths of up to 400 mm, which were associated with downslope movement of the surface soils. Additional surface cracks, typically in the order of 100 mm to 150 mm in width, were also observed further down the ridgeline and the steep slopes.

Photographs of the surface cracking at Dendrobium Mine are provided in Fig. 5.13.



**Fig. 5.13 Surface tension cracking due to downslope movements at Dendrobium Mine**

It is expected, therefore, that the downslope movement of the ground would also occur along rock outcrops and steep slopes within the Study Area. The steep slopes are heavily vegetated and erosion due to soil instability (i.e. downslope movements) was not readily apparent from the site investigations undertaken. If tension cracks were to develop, due to the extraction of the proposed longwall, it is possible that soil erosion could occur and require treatment.

It is possible, therefore, that some remediation might be required, including infilling of surface cracks with soil or other suitable materials, or by locally regrading and recompacting the surface. In some cases, erosion protection measures may be needed, such as the planting of additional vegetation in order to stabilise the surface soils in the longer term. Similarly, where cracking restricts the passage of vehicles along the tracks and fire trails that are required to be open for access, it is recommended that these cracks are treated in the same way.

### 5.7.4. Recommendations for the rock outcrops and steep slopes

It is recommended that periodic inspections of the rock outcrops and steep slopes located directly above the proposed longwall are undertaken during or after active subsidence and that any remedial measures required to prevent erosion are implemented in consultation with WaterNSW.

## 5.8. Escarpments

There are no escarpments located within the Study Area. The *Illawarra Escarpment* is located more than 12 km to the east of LW19. At this distance, the escarpment is not expected to experience measurable mine subsidence movements or adverse impacts due to the extraction of the proposed longwall.

## 5.9. Land prone to flooding and inundation

The catchment areas of the streams within the Study Area are relatively small and the land drains freely into Wongawilli Creek and Sandy Creek. There are no major flood prone areas identified within the Study Area. The predicted changes in the surface levels of the streams, resulting from the extraction of the proposed longwall, will have only a marginal effect on their natural gradients, and hence, on their discharge characteristics.

## 5.10. Swamps, wetlands and water related ecosystems

### 5.10.1. Descriptions of the swamps

The swamps are shown in Drawing No. MSEC1082-09. The locations and extents of the upland swamps have been interpreted from detailed aerial photogrammetry and site inspections.

There are four swamps (Refs. Den12, Den15a, Den15b and Den148) that have been identified partially or wholly within the Study Area based on the 35° angle of draw line and predicted 20 mm subsidence contour. There is five additional swamps (Refs. Den34, Den95, Den96, Den146 and Den147) that are partly or wholly located within the Study Area based on the 600 m boundary.

Swamp Den148 is partially located above the proposed LW19. Small parts of Swamps Den15a and Den15b are located above the maingate and tailgate, respectively, of LW19. The remaining swamps are located outside the extents of the proposed longwall. A summary of the swamps located within the Study Area based on the 600 m boundary is provided in Table 5.15.

**Table 5.15 Swamps located within the Study Area based on the 600 m boundary**

| Reference | Location | Description |
|---|---|---|
| Den12 | Directly above LW7 and LW8, 180 m north of LW19 | Base and side of valley for Stream WC17 |
| Den15a | Partially above the maingate of LW19 | Base and side of valley for Stream SC10 |
| Den15b | Directly above LW7 and LW8, partially above LW19 tailgate | Base and side of valley for Stream SC10C |
| Den34 | Outside the mining area, 310 m south of LW19 | Base and side of valley for Stream WC13 |
| Den95 | Partially above LW8, 230 m east of LW19 | Side of valley for Stream SC10 |
| Den96 | Outside the mining area, 210 m south of LW19 | Side of valley for Stream SC10 |
| Den146 | Directly above LW7, 580 m north of LW19 | On the side of a ridgeline |
| Den147 | Outside the mining area, 490 m south-east of LW19 | Side of valley for tributary to Sandy Creek |
| Den148 | Partially above LW19 | Base and side of valley for Stream WC14 |

The upland swamps can be categorised into two types, the *valley infill* swamps that form within the drainage lines, and *headwater* swamps that form within relatively low sloped areas of weathered Hawkesbury Sandstone where hillslope aquifers exist. Photographs of typical valley infill swamps at Dendrobium Mine are provided in Fig. 5.14. Photographs of a typical headwater swamp are provided in Fig. 5.15.



**Fig. 5.14 Typical valley infill swamps**



**Fig. 5.15 Typical headwater swamp**

Further descriptions of the swamps are provided in the report by *Niche Environment and Heritage* (Niche, 2020a).

### 5.10.2. Predictions for the swamps

A summary of the maximum predicted total vertical subsidence, tilt and curvatures for the swamps located within the Study Area is provided in Table 5.16. The values are the maximum predicted subsidence effects within 20 m of the mapped extents of each of the swamps due to the mining of LW6 to LW8 and LW19.

**Table 5.16 Maximum predicted total vertical subsidence, tilt and curvatures for the swamps**

| Reference | Maximum predicted total vertical subsidence (mm) | Maximum predicted total tilt (mm/m) | Maximum predicted total hogging curvature ($km^{-1}$) | Maximum predicted total sagging curvature ($km^{-1}$) |
|---|---|---|---|---|
| Den12 | 2750 | 30 | 0.50 | 0.70 |
| Den15a | 425 | 13 | 0.35 | 0.03 |
| Den15b | 3050 | 35 | 0.90 | 0.80 |
| Den34 | < 20 | < 0.5 | < 0.01 | < 0.01 |
| Den95 | 60 | 2 | 0.04 | 0.02 |
| Den96 | < 20 | < 0.5 | < 0.01 | < 0.01 |
| Den146 | 2350 | 30 | 0.40 | 0.70 |
| Den147 | < 20 | < 0.5 | < 0.01 | < 0.01 |
| Den148 | 2850 | 40 | 0.90 | 0.70 |

The maximum predicted total tilt for the swamps is 40 mm/m (i.e. 4.0 %, or 1 in 25). The maximum predicted total conventional curvatures are 0.90 $km^{-1}$ hogging and 0.80 $km^{-1}$ sagging, which represent minimum radii of curvatures of 1.1 km and 1.3 km, respectively.

The maximum predicted conventional strains for the swamps, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 14 mm/m tensile and 12 mm/m compressive. The distribution of the predicted strains due to the extraction of the longwalls is described in Section 4.4. The predicted strains directly above the mining area are 8 mm/m tensile and compressive based on the 95 % confidence levels.

Non-conventional movements can also occur and have occurred in the NSW coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

Swamps Den12, Den15b and Den146 are located above LW7 and LW8 and, therefore, the predicted subsidence effects are partly due to these existing longwalls. A summary of the maximum predicted incremental vertical subsidence, tilt and curvatures for these swamps is provided in Table 5.17. The values are the maximum predicted subsidence effects within 20 m of the mapped extents of each of the swamps due to the mining of LW19 only.

**Table 5.17 Maximum predicted incremental vertical subsidence, tilt and curvatures for the swamps**

| Reference | Maximum predicted incremental vertical subsidence (mm) | Maximum predicted incremental tilt (mm/m) | Maximum predicted incremental hogging curvature ($km^{-1}$) | Maximum predicted incremental sagging curvature ($km^{-1}$) |
|---|---|---|---|---|
| Den12 | 625 | 8 | 0.15 | 0.13 |
| Den15b | 1350 | 18 | 0.35 | 0.40 |
| Den146 | < 20 | < 0.5 | < 0.01 | < 0.01 |

Swamp Den146 is predicted to experience incremental vertical subsidence of less than 20 mm due to the mining of the proposed LW19. While this swamp could experience very low levels of incremental vertical subsidence, it is not expected to experience measurable incremental tilts, curvatures or strains.

Swamp Den95 is located partially above the existing LW8 and Swamps Den34, Den96 and Den147 are located outside the mining area. These swamps are predicted to experience vertical subsidence of 60 mm, or less, due to the mining of LW6 to LW8 and LW19. Swamp Den95 could experience low levels of tilt, curvature and strain. While Den34, Den96 and Den147 could experience very low levels of vertical subsidence, they are not predicted to experience measurable conventional tilts, curvatures or strains.

Swamps Den12, Den15a, Den15b, Den34 and Den148 are located near the bases of drainage lines WC17, SC10, SC10C, WC13 and WC14, respectively. These swamps could experience valley related effects due to the extraction of the existing and proposed longwalls in Area 3A. The remaining swamps within the Study Area are located on the valley sides and, therefore, they are unlikely to experience upsidence or compressive strain due to the valley closure effects.

A summary of the maximum predicted total upsidence and closure for the swamps within the Study Area is provided in Table 5.18. The values are the maximum predicted valley related effects for each of the swamps due to the mining of LW6 to LW8 and LW19.

**Table 5.18 Maximum predicted total upsidence and closure for the swamps**

| Location | Maximum predicted total upsidence (mm) | Maximum predicted total closure (mm) |
|---|---|---|
| Den12 | 350 | 525 |
| Den15a | 150 | 200 |
| Den15b | 275 | 425 |
| Den34 | 50 | 90 |
| Den148 | 125 | 225 |

Swamps Den12 and Den15b are located above LW7 and LW8 and, therefore, the predicted valley related effects are partly due to these existing longwalls. A summary of the maximum predicted incremental upsidence and closure for these swamps is provided in Table 5.19. The values are the maximum predicted valley related effects for each of the swamps due to the mining of LW19 only.

**Table 5.19 Maximum predicted incremental upsidence and closure for the swamps**

| Location | Maximum predicted incremental upsidence (mm) | Maximum predicted incremental closure (mm) |
|---|---|---|
| Den12 | 150 | 225 |
| Den15b | 125 | 175 |

The swamps will also experience compressive strains due to the valley related effects where they are located near the valley bases. The predicted total compressive strains for Den12 and Den15b, due to the valley related effects, are in the order of 10 mm/m to 20 mm/m. The majority of the predicted compressive strains for these swamps occur due to the existing longwalls.

The predicted total compressive strains based on the 95 % confidence levels are 5 mm/m for Den15a and Den148 and 2 mm/m for Den34. The majority of the predicted strains for these swamps occur due to the proposed LW19.

### 5.10.3. Previous experience of mining beneath swamps at Dendrobium Mine

Discussions on the previous experience of mining beneath swamps at Dendrobium Mine are provided below. These discussions relate to the reported physical impacts, which include surface cracking and fracturing of bedrock at the swamps. Detailed discussions on the environmental consequences are provided by the other specialist consultants on the project.

- *Dendrobium Area 2*

  LW4 and LW5 in Area 2 were extracted directly beneath Swamp Den01, which is both a headwater and valley infill swamp located along Drainage Line A2-14. Cracking was observed within the extent of the swamp in three locations and fracturing was observed in the downstream rockbar. A photograph of the fracturing in the downstream rockbar is provided in Fig. 5.16.



**Fig. 5.16 Fracturing in the rockbar downstream of Swamp Den01 (Source: IMC)**

  Whilst reductions in groundwater levels in the soil were observed in the swamp and the upstream hillslope aquifer, the groundwater levels respond to significant recharge events. Based on the observations to date, there has been no erosion or other physical changes observed within Swamp Den01 resulting from the mining in Area 2.

- *Dendrobium Area 3A*

  LW7 in Area 3A was extracted directly beneath Swamp Den12, which is a headwater swamp located on the valley side of Drainage Line WC17. One fracture was identified in a rock outcrop after mining beneath this swamp. Regular monitoring has been undertaken and, to date, no erosion or other changes have been observed. Four piezometers have been installed in and around the swamp to measure the shallow groundwater levels within the sediments above the sandstone bedrock. One of the piezometers has measured a reduction in the groundwater level, two of the piezometers show no change and one is providing poor quality data.

- *Dendrobium Area 3B*

  LW9 in Area 3B was extracted directly beneath Swamp Den05, which is a valley infill swamp located along the alignment of Donalds Castle Creek. The impacts to this swamp were described in the End of Panel Report (IMC, 2014) which states "*Site DA3B_LW9_006: Multiple fractures and uplift on DC_RB33 at basal step of Swamp 5; up to 0.015m wide, 2m long and 0.040m of uplift. Exfoliation from the step. Associated flow diversion" and "TARP triggers in relation to shallow groundwater levels (reduction and recession rates) in Swamps 1a, 1b and Swamp 5 were also reported during Longwall 9 extraction*".

  Impacts were also observed to the swamps due to the extraction of LW10 to LW14 which were described in each of the End of Panel Reports (IMC, 2015, 2016, 2017, 2018 and 2019). The groundwater levels were lower than baseline and recession rates greater than baseline for Swamps Den03, Den05, Den10, Den11, Den13 and Den14. Soil moisture levels below baseline were also reported in Swamps Den05, Den11 and Den23.

### 5.10.4. Impact assessments for the swamps

The assessments of the potential physical impacts (i.e. soil cracking and rock fracturing) on the swamps based on the predicted mine subsidence movements are provided in the following sections. Discussions on the potential environmental consequences are provided in the reports by the other specialist consultants on the project. The assessments and discussions provided in this report should be read in conjunction with those provided in the reports by the other specialist consultants.

*Potential for changes in surface water flows due to the mining-induced tilts*

Mining can potentially affect surface water flows through swamps, if the mining-induced tilts are much greater than the natural gradients, potentially resulting in increased levels of ponding or scouring, or affecting the distribution of the water within the swamps.

The maximum predicted total tilt for the swamps is 40 mm/m (i.e. 4.0 %, or 1 in 25). The greatest tilts (i.e. 30 mm/m to 40 mm/m) occur at Swamps Den12, Den15b, Den146 and Den148 which are located directly above the existing LW7 and LW8 and the proposed LW19. Swamp Den15a and Den95 are predicted to experience tilts of 13 mm/m (i.e. 1.3 %, or 1 in 77) and 2 mm/m (i.e. 0.2 %, or 1 in 500), respectively. The remaining swamps within the Study Area are located outside the mining area and are predicted to experience tilts of less than 0.5 mm/m (i.e. less than 0.05 %, or 1 in 2000).

Swamps Den12, Den15a, Den15b, Den34 and Den148 are located near the bases of drainage lines WC17, SC10, SC10C, WC13 and WC14, respectively. The predicted changes in grade for the drainage lines are illustrated in Fig. 5.6 to Fig. 5.9. There are no predicted reversals of stream grade along drainage lines nor within the extents of the swamps.

There are small reductions in grades along drainage lines SC10C and WC17, upstream of the chain pillars and the edges of the mining area. There is potential for minor and localised increased ponding upstream of these locations and within or near to Swamps Den12 and Den15b. However, these swamps are located above the existing LW7 and LW8 and, therefore, the potential for increased ponding occurs due to these existing longwalls rather than the proposed LW19.

The remaining swamps are located on the valley sides where the natural grades are greater than 100 mm/m (i.e. 10 %, or 1 in 10). These swamps are also located outside the extents of the proposed LW19 and, therefore, are predicted to experience lower mining-induced tilts. It is unlikely, therefore that increased ponding would occur within the extents of these swamps due to mining-induced tilt.

It is considered unlikely, therefore, that there would be adverse changes in the levels of ponding or scouring for the swamps within the Study Area based on the predicted vertical subsidence and tilt.

*Potential for cracking in the swamps and fracturing of bedrock*

Fracturing of the bedrock has been observed in the past, as a result of longwall mining, where the tensile strains have been greater than approximately 0.5 mm/m or where the compressive strains have been greater than approximately 2 mm/m.

Swamps Den12 and Den15b are located above the existing LW7 and LW8. The maximum predicted compressive strains for these swamps due to the valley related effects are in the order of 10 mm/m to 20 mm/m. However, the valley related effects for these swamps predominately occur due to the existing LW7 and LW8, rather than the proposed LW19. It is likely, therefore, that fracturing would occur in the bedrock beneath these swamps, predominately in areas located above and adjacent to the mining area.

The typical fracture widths in the bedrock beneath Swamps Den12 and Den15b could be similar to the surface deformations previously observed at the Mine, as described in Section 4.8. The soil crack and rock fracture widths were generally observed to be less than 50 mm (i.e. 88 % of the cases). However, the widths of the surface deformations were between 50 mm and 150 mm in 7 % of cases, between 150 mm and 300 mm in 3 % of cases and greater than 300 mm in 2 % of cases. Fracturing would only be visible at the surface where the bedrock is exposed, or where the thickness of the overlying soil is relatively shallow.

Swamps Den15a and Den148 are partially located above the proposed LW19. The maximum predicted compressive strain for these swamps is 5 mm/m based on the 95 % confidence level. Fracturing could also occur beneath these swamps, near the valley base and where they are located above and adjacent to the proposed longwall. Fracture widths in the order of 20 mm to 50 mm have been observed due to valley closure effects at similar distances from previous longwall mining. It is possible that a series of smaller fractures, rather than one single fracture, could develop in the bedrock.

Swamps Den12 and Den15b are located directly above the mining area and are predicted to experience upsidence of 275 mm to 350 mm. The sections of Swamps Den15a and Den148 located above the proposed LW19 are predicted to experience upsidence of 125 mm to 150 mm. These valley related effects could result in the dilation of the strata beneath these swamps. It has been previously observed that the depth of fracturing and dilation of the uppermost bedrock, resulting from valley related movements, is generally in the order of 10 m to 15 m (Mills 2003, Mills 2007, and Mills and Huuskes 2004).

The dilated strata beneath the drainage lines upstream of Swamps Den12 and Den15b, and to a lesser extents Den15a and Den148, could result in the diversion of some surface water flows beneath parts of these swamps. The drainage lines upstream of these swamps flow during and shortly after rainfall events. Where there is no connective fracturing to any deeper storage, it is likely that surface water flows will re-emerge at the limits of fracturing and dilation. Swamps Den12 and Den15b are located directly above LW7 and LW8 and, therefore, the potential impacts predominately occur due to these existing longwalls, rather than the proposed LW19. Only small areas of Swamps Den15a and Den148 are located directly above the proposed LW19.

The downstream controlling feature for Swamp Den15a is rockbar SC10-RB15A. This rockbar is located 150 m east of the proposed LW19 and 170 m south of the existing LW8. The predicted subsidence effects for rockbar SC10-RB15A are provided in Table 5.8 and are less than 20 mm vertical subsidence, 90 mm upsidence and 125 mm closure.

The potential impacts on rockbar SC10-RB15A cannot be assessed using the rockbar impact model, as illustrated in Fig. 5.4, because drainage line SC10 is partially located above the existing LW8 and the proposed LW19. This rockbar has therefore been assessed based on the observations from Area 3B.

Fracturing of rockbars has been observed in Area 3B at distances ranging between 30 m and 300 m outside of the mining area. There has been nine Type 3 impacts (*i.e. fracturing in a rockbar or upstream pool resulting in reduction in standing water level based on current rainfall and surface water flow*) along the drainage lines that are located outside but within 400 m of the completed LW9 to LW14. However, there are also 61 other rockbars that are located outside and within 400 m of the longwall mining area that did not experienced Type 3 impacts.

The observed impact rate of Type 3 impacts for the rockbars located along the drainage lines located outside and within 400 m of LW9 to LW14 was 13 %. Five of the 9 impact sites (i.e. 56 %) occurred at distances of less than 150 m from the mining area, i.e. at distances less than that of rockbar SC10-RB15A from the proposed LW19. It has been assessed, therefore, that the potential for Type 3 impacts at rockbar SC10-RB15A due to the mining of the proposed LW19 is in the order of 13 %.

Discussions on the potential impacts due to changes in the surface water flows, groundwater and the environmental consequences are provided by the specialist surface water, groundwater and ecology consultants on the project.

Swamp Den95 is located partially above the existing LW8 and Swamps Den34, Den96 and Den147 are located outside the mining area. These swamps are located at minimum distances ranging between 210 m and 490 m from the proposed LW19. These swamps are predicted to experience vertical subsidence of 60 mm, or less, due to the proposed longwall. It is unlikely, therefore, that fracturing would occur in the bedrock beneath these swamps. While Swamp Den34 is located along a drainage line, fracturing due to valley related effects have not been previously observed at similar distances outside mining areas elsewhere at the Mine.

Further discussions on the potential environmental consequences for the swamps within the Study Area are provided by the other specialist consultants on the project.

### 5.10.5. Recommendations for the swamps

Management plans have been developed for the swamps at the Mine. It is recommended, that the existing management strategies are reviewed, based on the assessments provided in this report and the reports by other specialist consultants.

## 5.11. Flora and fauna

The land above the longwalls in Area 3A largely consists of undisturbed native bush, as shown in Fig. 1.1. Only limited clearing has been undertaken for the tracks and fire trails within the Study Area. Descriptions of the flora and fauna within the Study Area are provided by the specialist ecology consultant on the project.

The potential for impacts on the vegetation in the mining area is dependent on the surface cracking, changes in surface water and changes in groundwater. Assessments of the physical impacts due to the proposed longwall are provided in Sections 5.2 to 5.10. Assessments of the environmental consequences have been provided by the other specialist consultants on the project.

Assessments for the aquatic and terrestrial ecology are provided by Cardno (2020) and Niche (2020a).

The following sections provide the descriptions, predictions and impact assessments for the built features within the Study Area. All significant features located outside the Study Area, which may be subjected to far-field or valley related effects and may be sensitive to these movements, have also been included as part of these assessments.

## 6.1. Unsealed roads and tracks

### 6.1.1. Descriptions of the unsealed roads and tracks

The locations of the unsealed roads and tracks are shown in Drawing No. MSEC1082-10.

Fire Road 6F crosses directly above the existing LW6 to LW8 and the proposed LW19. Fire Road 6C is located to the north-eastern corner of the Study Area and it crosses directly above the existing LW6 and LW7. There are also other unsealed roads and tracks in the area that are used by WaterNSW and other groups for access to the catchment, fire-fighting and other activities. A photograph of a typical unsealed road in the mining area is provided in Fig. 6.1.



**Fig. 6.1 Typical unsealed road**

### 6.1.2. Predictions for the unsealed roads and tracks

Fire Roads 6F and 6C are located directly above the mining area and, therefore, are expected to experience the full range of predicted subsidence movements. A summary of the maximum predicted values of total vertical subsidence, tilt and curvatures for the fire roads is provided in Table 6.1. The values in this table are the maximum predicted subsidence effects due to LW6 to LW8 and LW19.

**Table 6.1 Maximum predicted total vertical subsidence, tilt and curvatures for the fire roads**

| Location | Longwalls | Maximum predicted total vertical subsidence (mm) | Maximum predicted total tilt (mm/m) | Maximum predicted total hogging curvature ($km^{-1}$) | Maximum predicted total sagging curvature ($km^{-1}$) |
|---|---|---|---|---|---|
| Fire roads | LW6 to LW8 and LW19 | 3000 | 40 | 1.0 | 1.0 |

The maximum predicted total tilt for the fire roads is 40 mm/m (i.e. 4.0 %, or 1 in 25). The maximum predicted total conventional curvatures are 1.0 $km^{-1}$ hogging and sagging, which represent a minimum radius of curvature of 1 km.

The maximum predicted conventional strains for the fire roads, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 15 mm/m tensile and compressive. The distribution of the predicted strains due to the extraction of the longwalls is described in Section 4.4. The predicted strains directly above the mining area are 8 mm/m tensile and compressive based on the 95 % confidence levels.

Non-conventional movements can also occur and have occurred in the NSW coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

### 6.1.3. Impact assessments for the unsealed roads and tracks

Fire Road 6F crosses directly above the proposed LW19. It is possible that cracking, rippling and stepping of the unsealed road surface could occur due to the mining of this longwall. The estimated crack widths in Fire Road 6F, based on the maximum predicted conventional tensile strain of 15 mm/m and a typical bedrock joint spacing of 10 m, is in the order of 150 mm.

The typical fracture widths could be similar to the surface deformations previously observed at the Mine, as described in Section 4.8. The soil crack and rock fracture widths were generally observed to be less than 50 mm (i.e. 88 % of the cases). However, the widths of the surface deformations were between 50 mm and 150 mm in 7 % of cases, between 150 mm and 300 mm in 3 % of cases and greater than 300 mm in 2 % of cases.

Examples of the impacts on unsealed roads and tracks in Areas 3A and 3B are provided in Fig. 6.2 (Source: IMC). The impacts on the unsealed roads and tracks were repaired by regrading and recompacting the road surfaces. Similar impacts are anticipated for Fire Road 6C due to the mining of the proposed LW19.



**Fig. 6.2 Impacts along the unsealed roads and tracks above LW6 in Area 3A (left side) and above LW11 in Area 3B (right side) (Source: IMC)**

It is expected that Fire Road 6F can be maintained in safe and serviceable conditions throughout the mining period using normal road maintenance techniques. The remaining unsealed roads and tracks are located outside of the mining area and it is unlikely that they would experience adverse impacts.

Fire Road 6C is located 470 m north of the proposed LW19. It is unlikely, therefore, that adverse impacts would develop along this fire road due to the mining of the proposed longwall.

### 6.1.4. Recommendations for the unsealed roads and tracks

IMC has developed management strategies for unsealed roads and tracks that have been affected by subsidence at Dendrobium Mine. It is recommended that these management strategies are reviewed and updated to incorporate the proposed LW19. It is also recommended that periodic inspections are carried out along the unsealed roads and tracks during active subsidence.

## 6.2. 330 kV transmission Line

### 6.2.1. Description of the 330 kV transmission line

The Avon-to-Macarthur 330 kV transmission line (Line 17) owned by TransGrid crosses directly above the existing LW6 to LW8 and the proposed LW19 in Area 3A. The location of the 330 kV transmission line is shown in Drawing No. MSEC1082-10.

There are three transmission towers (Refs. T3 to T5) that are located within the Study Area based on the 35° angle of draw and the predicted 20 mm subsidence contour. None of these towers are located directly above the proposed LW19. A summary of the transmission towers within the Study Area is provided in Table 6.2.

**Table 6.2 Transmission towers located within the Study Area based on the 35° angle of draw and the predicted 20 mm subsidence contour**

| Feature | Tower | Type | Footing | Distance from LW19 |
|---|---|---|---|---|
| 330 kV transmission line | T3 | Suspension | Piles | Outside the mining area, 240 m south of LW19 |
| | T4 | Suspension | Cruciform | Directly above LW8 and 85 m north of LW19 |
| | T5 | Suspension | Cruciform | Directly above LW7 and 610 m north of LW19 |

Photographs of a typical transmission tower is provided in Fig. 6.3.



**Fig. 6.3 330 kV transmission tower**

### 6.2.2. Predictions for the 330 kV transmission line

The predicted profiles of vertical subsidence, tilt along and tilt across the alignment of the 330 kV transmission line are shown in Fig. C.06, in Appendix C. The predicted total profiles after the completion of LW6 to LW8 are shown as cyan lines. The predicted total profiles after the mining of LW19 are shown as the blue lines.

A summary of the maximum predicted values of total vertical subsidence, tilt along the alignment and tilt across the alignment of the 330 kV transmission line is provided in Table 6.3. The values are the maximum predicted subsidence effects anywhere along the transmission line (i.e. not necessarily at the tower locations) within the Study Area based on the 35° angle of draw and the predicted incremental 20 mm subsidence contour.

**Table 6.3 Maximum predicted total vertical subsidence and tilt for the 330 kV transmission line**

| Longwall | Maximum predicted total vertical subsidence (mm) | Maximum predicted total tilt along alignment (mm/m) | Maximum predicted total tilt across alignment (mm/m) |
|---|---|---|---|
| LW6 to LW8 | 2300 | 25 | 7 |
| LW19 | 2800 | 35 | 10 |

A summary of the maximum predicted vertical subsidence, tilt and curvature at each of the tower locations is provided in Table 6.4. The values are the maximum predicted subsidence effects within a distance of 20 m from the centre of each tower resulting from the mining of LW6 to LW8 and LW19.

**Table 6.4 Maximum predicted total subsidence and tilt for the transmission towers**

| Tower | Maximum predicted total vertical subsidence (mm) | Maximum predicted total tilt (mm/m) | Maximum predicted total hogging curvature ($km^{-1}$) | Maximum predicted total sagging curvature ($km^{-1}$) |
|---|---|---|---|---|
| T3 | < 20 | < 0.5 | < 0.01 | < 0.01 |
| T4 | 1700 | 15 | 0.35 | 0.09 |
| T5 | 1450 | 10 | 0.25 | 0.06 |

The maximum predicted total tilt at the transmission tower locations is 15 mm/m (i.e. 1.5 %, or 1 in 67). The maximum predicted horizontal movement of the ground associated with the maximum predicted tilt is 250 mm. The maximum predicted horizontal movement at the tops of the transmission towers (assuming a height of 50 m) therefore is approximately 1 m.

The maximum predicted conventional strains for the transmission towers, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 5 mm/m tensile and 1.5 mm/m compressive. The distribution of the predicted strains due to the extraction of the longwalls is described in Section 4.4. The predicted strains directly above the mining area are 8 mm/m tensile and compressive based on the 95 % confidence levels.

Non-conventional movements can also occur and have occurred in the NSW coalfields as a result of, amongst other things, anomalous movements. The analysis of strains provided in Chapter 4 includes those resulting from both conventional and non-conventional anomalous movements.

A summary of the maximum predicted values of total opening and closure between the tops of the transmission towers is provided in Table 6.5. The values are the maxima that occur at any time during or after the extraction of the proposed longwall.

**Table 6.5 Maximum predicted total opening and total closure movements between the tops of the 330 kV transmission towers**

| Span | Maximum predicted transient or total opening (mm) | Maximum predicted transient or total closure (mm) | Final predicted opening (+ve) or closure (-ve) after the completion of the proposed longwall (mm) |
|---|---|---|---|
| T2 to T3 | < +20 | < -20 | < ±20 |
| T3 to T4 | +625 | < -20 | +400 |
| T4 to T5 | < +20 | -1000 | -800 |
| T5 to T6 | +325 | < -20 | +325 |

The maximum predicted total differential movements between the tops of the transmission towers are 625 mm opening and 1000 mm closure. These values are transient and occur as the extraction face of LW19 mines adjacent to the transmission towers. The maximum predicted final movements at the completion of mining are 400 mm opening and 800 mm closure.

### 6.2.3. Impact assessments for the 330 kV transmission line

The maximum predicted total differential movements between the tops of the transmission towers are 625 mm opening and 1000 mm closure. These values represent the total movements including those resulting from the previous mining of LW6 to LW8.

It is recommended that the predicted movements of the tops of the transmission towers are reviewed by TransGrid to assess the potential impacts on the cable catenaries and the subsequent loads induced into the towers. If adverse impacts are anticipated due to the mining-induced horizontal movements and tilt, then the potential impacts could be managed with the installation of cable rollers on these towers.

The predicted total strains at Towers T4 and T5 are 8 mm/m tensile and compressive based on the 95 % confidence levels. These values represent the total movements including those resulting from the previous mining of LW6 to LW8. Towers T4 and T5 have cruciform bases and, therefore, they will not experience the mining-induced strains.

The measured changes in k-point distances for the Towers T4 and T5, due to the previous mining of LW6 to LW8, were in the order of ±1 mm. Only very small movements were measured between the tower legs as they were constrained by the cruciform bases. The transmission towers did not experience adverse impacts due to the previous mining of LW6 to LW8 in Area 3A. It is unlikely, therefore, that these towers would experience adverse impacts due to the mining of the proposed LW19.

The predicted strains for Tower T3, due to the mining of the proposed LW19, are less than 0.5 mm/m tensile and compressive. The predicted changes in the k-point distances based on an 8 m span, therefore, are less than 4 mm opening and closure. It is noted that the predicted strains have been derived from ground monitoring data and these low level movements are likely to largely comprise the survey tolerance. The changes in the k-point distances for Tower T4 are not expected to be measurable due to the distance of this tower from the mining area.

It is recommended that TransGrid undertake a structural analysis of the transmission towers within the Study Area based on the predicted ground movements. If adverse impacts on Tower T3 are anticipated, then these could be managed with the installation of cruciform bases, as previously carried out on Towers T4 and T5.

With the implementation of the appropriate management strategies, it is expected that the 330 kV transmission line could be maintained in a safe and serviceable condition throughout the mining period, similar to that during the previous extraction of LW6 to LW8 in Area 3A.

#### 6.2.4. Recommendations for the 330 kV transmission line

It is recommended that the predicted subsidence effects for the 330 kV transmission line are provided to TransGrid to assess the potential impacts due to mining. It is also recommended that management strategies are developed, in consultation with TransGrid, which could include the installation of cable rollers, the construction of additional cruciform bases, the provision of monitoring points on the tower bases and tops, and the development of a TARP.

### 6.3. Dams, reservoirs or associated works

#### 6.3.1. Descriptions of the reservoirs

Dendrobium Mine is located within the Metropolitan Special Area. There are two reservoirs located in the vicinity of the mining area, as shown in Drawing No. MSEC1082-01.

The Cordeaux Reservoir, also known as Lake Cordeaux, is located 0.9 km east of the proposed LW19, at its closest point. The Cordeaux Dam Wall is located more than 5 km north of the proposed longwall. The Upper Cordeaux No. 1 and No. 2 Dams are located more than 3 km south-east of LW19.

The Avon Reservoir, also known as Lake Avon, is located 3.1 km west of the proposed LW19, at its closest point. The existing longwalls in Area 3B are located between LW19 and the reservoir. The Avon Dam Wall is located more than 5 km north-west of LW19.

#### 6.3.2. Predictions for the reservoirs

The Cordeaux and Avon Reservoirs are located at minimum distances of 0.9 km and 3.1 km, respectively, from the proposed LW19. At these distances, the reservoirs are not predicted to experience measurable conventional or valley related effects.

The dam walls associated with the Cordeaux and Avon Reservoirs are located more than 3 km from the proposed LW19. At these distances, the dam walls are not predicted to experience measurable conventional or far-field effects.

#### 6.3.3. Previous experience of mining near the reservoirs

The longwalls at Dendrobium Mine have been extracted near the Upper Cordeaux No. 2 reservoir. The dam wall is located approximately 1.5 km from LW1 in Area 1 and approximately 0.9 km from LW3 in Area 2 at the mine. The Upper Cordeaux No. 2 reservoir is shown in Drawing No. MSEC1082-01.

The mine subsidence movements at the Upper Cordeaux No. 2 reservoir were measured by the, then, Sydney Catchment Authority (SCA) using 3D survey marks located on and around the dam wall. The latest available survey, Survey No. 9a, was carried out in April 2010, during the extraction of LW6 in Area 2. The results of this survey were provided in the SCA monitoring report entitled *Upper Cordeaux No. 2 – Dam Wall & Ground Monitoring – Survey No 9a Report – April 2010*.

The maximum measured movements at the Upper Cordeaux No. 2 dam wall were ±1 mm vertical, +3 mm horizontal in the downstream direction and ±1 mm in the east and west directions. The SCA monitoring report states that:

*"The centre of the dam crest is at its maximum downstream position near July of each year and maximum upstream position near January of each year. This change is very probably caused by the overall change in dam wall temperature as well as the change in the temperature gradient across the dam wall section. The water storage level has remained within 0.1m of FSL since April 2005 and so has no significant effect on deflection. Towards the right bank the movement on the crest is generally smaller and more complex due to the reduced height and the changing curvature of the dam wall. The several cracks in this section of the dam wall may also be influencing how the dam wall moves as it expands and contracts. The fact that both ground and dam wall are vertically stable reduces the likelihood that mining is a factor in the measured horizontal movement."*

The detailed ground monitoring data indicated that the measured movements were very small and were within the order of survey tolerance. That is, the mining-induced movements at the Upper Cordeaux No. 2 dam wall were not measurable above seasonal variations.

#### 6.3.4. Impact assessments for the reservoirs

The predicted vertical and horizontal movements at the Cordeaux and Avon Reservoirs and their associated dam walls are very small and are unlikely to be measurable. Previous experience of mining in Areas 1, 2, 3A and 3B has not resulted in adverse impacts on these structures.

The dam walls associated with the Cordeaux and Avon Reservoirs are located more than 3 km from the proposed LW19. It is unlikely, therefore, that the reservoirs and dam walls would experience adverse impacts due to the extraction of the proposed LW19.

#### 6.3.5. Recommendations for the reservoirs

It is recommended that IMC consult with WaterNSW and the Dams Safety NSW to develop the appropriate monitoring and management strategies for the reservoirs and dam walls.

### 6.4. Aboriginal heritage sites

#### 6.4.1. Descriptions of the Aboriginal heritage sites

The locations of the Aboriginal heritage sites are shown in Drawing No. MSEC1082-10. The details of the heritage sites have been provided by *Niche Environment and Heritage* (Niche, 2020b).

There are three Aboriginal heritage sites that have been identified within the Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour. There are five additional sites that are located within the Study Area based on the 600 m boundary. Some of these sites could experience far-field or valley related effects and could be sensitive to these movements and they have therefore been included in the assessments.

Details of the Aboriginal heritage sites located within Study Area are provided in Table 6.6.

**Table 6.6 Aboriginal heritage sites identified within the Study Area**

| Reference | Type | Location relative to the longwalls |
|---|---|---|
| 48-2-0056 | Shelter with deposit | Directly above LW8, 310 m north of the LW19 tailgate |
| 52-2-1645 | Shelter with art | Outside the mining area, 500 m south of the LW19 maingate |
| 52-2-1646 | Shelter with art | Outside the mining area, 230 m south of the LW19 maingate |
| 52-2-3639 | Shelter with art | Directly above LW19, near to the longwall finishing end |
| 52-2-3640 | Shelter with art | Outside the mining area, 580 m south-west of the LW19 finishing end |
| 52-2-3641 | Shelter with deposit | Outside the mining area, 480 m west of the LW19 finishing end |
| 52-2-3644 | Shelter with art and Potential Archaeological Deposit (PAD) | Directly above LW19, near to the longwall tailgate |
| 52-5-0273 | Shelter with art | Directly above LW19, adjacent to the longwall maingate |

Further details on the Aboriginal heritage sites are provided in the report by Niche (2020b).

### 6.4.2. Predictions for the Aboriginal heritage sites

A summary of the maximum predicted total vertical subsidence, tilt and curvatures for the Aboriginal heritage sites located within the Study Area based on the 600 m boundary is provided in Table 6.7. The values are the maximum predicted subsidence effects within 20 m of the identified locations of each of the sites due to the mining of LW6 to LW8 and LW19.

**Table 6.7 Maximum predicted total vertical subsidence, tilt and curvatures for the Aboriginal heritage sites**

| Reference | Maximum predicted total vertical subsidence (mm) | Maximum predicted total tilt (mm/m) | Maximum predicted total hogging curvature ($km^{-1}$) | Maximum predicted total sagging curvature ($km^{-1}$) |
|---|---|---|---|---|
| 48-2-0056 | 1850 | 25 | 0.75 | 0.60 |
| 52-2-1645 | < 20 | < 0.5 | < 0.01 | < 0.01 |
| 52-2-1646 | < 20 | < 0.5 | < 0.01 | < 0.01 |
| 52-2-3639 | 1600 | 30 | 0.60 | 0.20 |
| 52-2-3640 | < 20 | < 0.5 | < 0.01 | < 0.01 |
| 52-2-3641 | < 20 | < 0.5 | < 0.01 | < 0.01 |
| 52-2-3644 | 1350 | 4 | 0.10 | 0.09 |
| 52-5-0273 | 900 | 25 | 0.50 | 0.06 |

Site 48-2-056 is located above the previously extracted LW8. This site is predicted to experience less than 20 mm vertical subsidence due to the mining of the proposed LW19. While Site 48-2-056 could experience low level vertical subsidence, due to the proposed longwall, it is not expected to experience measurable tilts, curvatures or strains.

Site 48-2-0056 is located along Drainage Line SC10C. The maximum predicted total valley related effects in this location are 150 mm upsidence and 250 mm closure. However, this site is located on the valley side and, therefore, it is unlikely to experience the valley related upsidence or the compressive strain due to valley closure that occur near the valley base.

Site 52-2-3644 is located at the upper reaches of an unnamed drainage line. The maximum predicted valley related effects in this location are 30 mm upsidence and 50 mm closure. The site is located near the valley base and therefore it could experience these valley related effects.

The remaining sites within the Study Area based on the 600 m boundary are located on the sides of the ridgelines where there are no significant surface incisions. These sites are therefore not expected to experience measurable valley related effects.

### 6.4.3. Impact assessments for the Aboriginal heritage sites

The impact assessments for the Aboriginal heritage sites are provided below. These assessments should be read in conjunction with the assessments by the specialist consultant on the project (Niche, 2020b).

There are two rock shelters with deposits (Site Refs. 48-2-0056 and 52-2-3641), five rock shelters with art (Site Refs. 52-2-1645, 52-2-1646, 52-2-3639,52-2-3640 and 52-5-0273) and one rock shelter with art and PAD (Site Ref. 52-2-3644) within the Study Area based on the 600 m boundary.

Sites 52-2-3639, 52-2-3644 and 52-5-0273 are located directly above the proposed LW19. The maximum predicted total subsidence effects for these sites are 1600 mm vertical subsidence, 30 mm/m tilt (i.e. 3 %, or 1 in 33), 0.60 $km^{-1}$ hogging curvature (i.e. minimum radius of curvature of 1.7 km) and 0.20 $km^{-1}$ sagging curvature (i.e. minimum radius of curvature of 5 km).

The extraction of the proposed longwall is likely to result in fracturing of the exposed bedrock along the ridgelines and, where the rock is marginally stable, could then result in rockfalls or instabilities. The fracturing and rock falls could adversely impact the rock shelters located directly above the proposed longwall.

It is extremely difficult to assess the likelihood of impacts on the rock shelters based upon predicted ground movements. The likelihood of a rock fall or instability is dependent on many factors that are difficult to fully quantify. Some of these factors include jointing, inclusions, weaknesses within the rockmass, groundwater pressure and seepage flow behind the rockface. Even if these factors could be determined, it would still be difficult to quantify the extent to which these factors may influence the stability of the rock shelter naturally or when it is exposed to mine subsidence movements.

It has been assessed that between 7 % and 10 % of the total length, or between 3 % and 5 % of the total face area, of the cliffs located directly or partially above the mining area would be impacted by the extraction of the existing and proposed longwalls. It has also been assessed that between 3 % and 5 % of the total length of the minor cliffs and rock outcrops located directly or partially above the mining area would experience adverse impacts.

The potential for adverse impacts on the rock shelters located directly above the proposed LW19 (i.e. Refs. 52-2-3639, 52-2-3644 and 52-5-0273) has been assessed as *unlikely* (i.e. less than 10 %) for each of these sites. However, it is possible that these sites could experience fracturing resulting in spalling or rock falls.

Site Ref. 48-2-0056 is located directly above the existing LW8, at a distance of 310 m from the proposed LW19. The remaining four rock shelters within the Study Area based on the 600 m boundary (Site Refs. 52-2-1645, 52-2-1646, 52-2-3640 and 52-2-3641) are located at distances of 230 m and 580 m outside the mining area. At these distances, these sites are predicted to experience less than 20 mm vertical subsidence. While these five sites could experience low levels of vertical subsidence, they are not predicted to experience measurable tilts, curvatures or strains. These sites are also located on the valley sides and, therefore, they are not predicted to experience valley related effects.

It is unlikely, therefore, that Sites 48-2-0056, 52-2-1645, 52-2-1646, 52-2-3640 and 52-2-3641 would experience adverse impacts due to the mining of the proposed LW19.

### 6.4.4. Recommendations for the Aboriginal heritage sites

It is recommended that IMC develop an Aboriginal Heritage Management Plan in consultation with the registered parties for the Aboriginal heritage sites.

## 6.5. Survey control marks

The locations of the survey control marks are shown in Drawing No. MSEC1082-10. The locations and details of the survey control marks were obtained from *Spatial Services* using the *SCIMS Online* website (SCIMS, 2019).

There are no survey control marks located within the Study Area based on the 600 m boundary. The nearest mark is SS 66043 located 560 m north of the previously extracted LW6. There are also other survey control marks further afield.

It is possible that the survey control marks could be affected by far-field horizontal movements at distances of 1 km to 2 km outside the proposed longwall. Far-field horizontal movements and the methods used to predict such movements are described further in Sections 3.3 and 4.6.

It is recommended that the survey control marks that are required for future use are re-established after the completion of mining in the area and after the ground has stabilised. Consultation between IMC and Spatial Services will be required to ensure that these survey control marks are reinstated at the appropriate time, as required.

# APPENDIX A. GLOSSARY OF TERMS AND DEFINITIONS

# Glossary of terms and definitions

Some of the more common mining terms used in the report are defined below:

| | |
|---|---|
| **Angle of draw** | The angle of inclination from the vertical of the line connecting the goaf edge of the workings and the limit of subsidence (which is usually taken as 20 mm of subsidence). |
| **Chain pillar** | A block of coal left unmined between the longwall extraction panels. |
| **Cover depth (H)** | The depth from the surface to the top of the seam. Cover depth is normally provided as an average over the area of the panel. |
| **Closure** | **T**he reduction in the horizontal distance between the valley sides. The magnitude of closure, which is typically expressed in the units of *millimetres (mm)*, is the greatest reduction in distance between any two points on the opposing valley sides. It should be noted that the observed closure movement across a valley is the total movement resulting from various mechanisms, including conventional mining-induced movements, valley closure movements, far-field effects, downhill movements and other possible strata mechanisms. |
| **Critical area** | The area of extraction at which the maximum possible subsidence of one point on the surface occurs. |
| **Curvature** | The change in tilt between two adjacent sections of the tilt profile divided by the average horizontal length of those sections, i.e. curvature is the second derivative of subsidence. Curvature is usually expressed as the inverse of the **Radius of Curvature** with the units of *1/kilometres (km-1)*, but the value of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in *kilometres (km)*. Curvature can be either **hogging** (i.e. convex) or **sagging** (i.e. concave). |
| **Extracted seam** | The thickness of coal that is extracted. The extracted seam thickness is thickness normally given as an average over the area of the panel. |
| **Effective extracted seam thickness (T)** | The extracted seam thickness modified to account for the percentage of coal left as pillars within the panel. |
| **Face length** | The width of the coalface measured across the longwall panel. |
| **Far-field movements** | The measured horizontal movements at pegs that are located beyond the longwall panel edges and over solid unmined coal areas. Far-field horizontal movements tend to be bodily movements towards the extracted goaf area and are accompanied by very low levels of strain. |
| **Goaf** | The void created by the extraction of the coal into which the immediate roof layers collapse. |
| **Goaf end factor** | A factor applied to reduce the predicted incremental subsidence at points lying close to the commencing or finishing ribs of a panel. |
| **Horizontal displacement** | The horizontal movement of a point on the surface of the ground as it settles above an extracted panel. |
| **Inflection point** | The point on the subsidence profile where the profile changes from a convex curvature to a concave curvature. At this point the strain changes sign and subsidence is approximately one half of S max. |
| **Incremental subsidence** | The difference between the subsidence at a point before and after a panel is mined. It is therefore the additional subsidence at a point resulting from the excavation of a panel. |
| **Panel** | The plan area of coal extraction. |
| **Panel length (L)** | The longitudinal distance along a panel measured in the direction of mining from the commencing rib to the finishing rib. |
| **Panel width (Wv)** | The transverse distance across a panel, usually equal to the face length plus the widths of the roadways on each side. |
| **Panel centre line** | An imaginary line drawn down the middle of the panel. |
| **Pillar** | A block of coal left unmined. |
| **Pillar width (Wpi)** | The shortest dimension of a pillar measured from the vertical edges of the coal pillar, i.e. from rib to rib. |

| | |
|---|---|
| **Shear deformations** | The horizontal displacements that are measured across monitoring lines and these can be described by various parameters including; horizontal tilt, horizontal curvature, mid-ordinate deviation, angular distortion and shear index. |
| **Strain** | The change in the horizontal distance between two points divided by the original horizontal distance between the points, i.e. strain is the relative differential displacement of the ground along or across a subsidence monitoring line. Strain is dimensionless and can be expressed as a decimal, a percentage or in parts per notation.<br>**Tensile Strains** are measured where the distance between two points or survey pegs increases and **Compressive Strains** where the distance between two points decreases. Whilst mining-induced **strains** are measured **along** monitoring lines, ground **shearing** can occur both vertically, and horizontally **across** the directions of the monitoring lines. |
| **Sub-critical area** | An area of panel smaller than the critical area. |
| **Subsidence** | The vertical movement of a point on the surface of the ground as it settles above an extracted panel, but, 'subsidence of the ground' in some references can include both a vertical and horizontal movement component. The vertical component of subsidence is measured by determining the change in surface level of a peg that is fixed in the ground before mining commenced and this vertical subsidence is usually expressed in units of *millimetres (mm)*. Sometimes the horizontal component of a peg's movement is not measured, but in these cases, the horizontal distances between a particular peg and the adjacent pegs are measured. |
| **Super-critical area** | An area of panel greater than the critical area. |
| **Tilt** | The change in the slope of the ground as a result of differential subsidence, and is calculated as the change in subsidence between two points divided by the horizontal distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. Tilt is usually expressed in units of *millimetres per metre (mm/m)*. A tilt of 1 mm/m is equivalent to a change in grade of 0.1 %, or 1 in 1000. |
| **Uplift** | An increase in the level of a point relative to its original position. |
| **Upsidence** | Upsidence results from the dilation or buckling of near-surface strata at or near the base of the valley. The magnitude of upsidence, which is typically expressed in the units of *millimetres (mm)*, is the difference between the observed subsidence profile within the valley and the conventional subsidence profile which would have otherwise been expected in flat terrain. |

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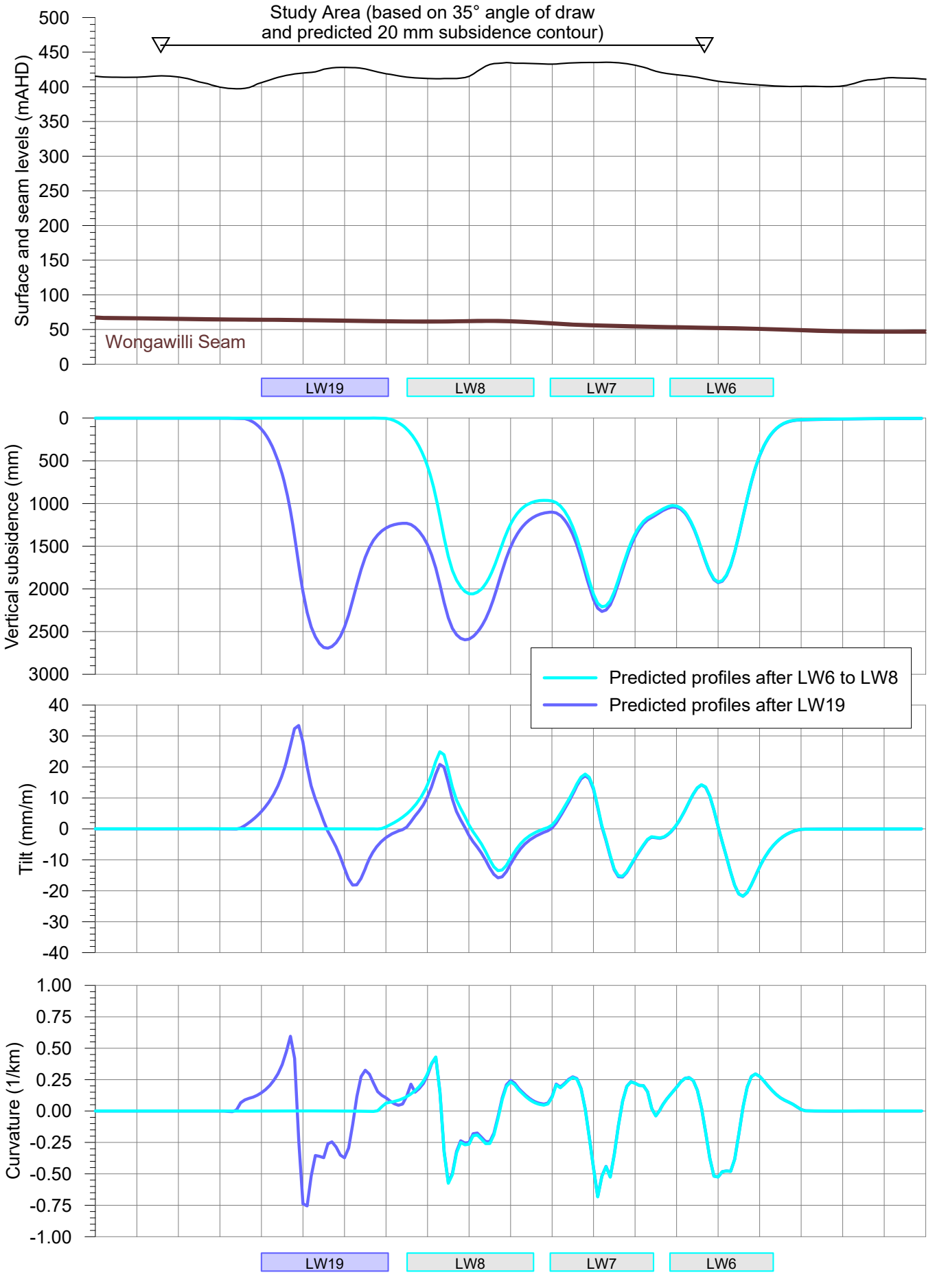
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# APPENDIX C. FIGURES

# Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 1 due to the extraction of LW6 to LW8 and LW19




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**Fig. C.01**

# Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 2 due to the extraction of LW6 to LW8 and LW19

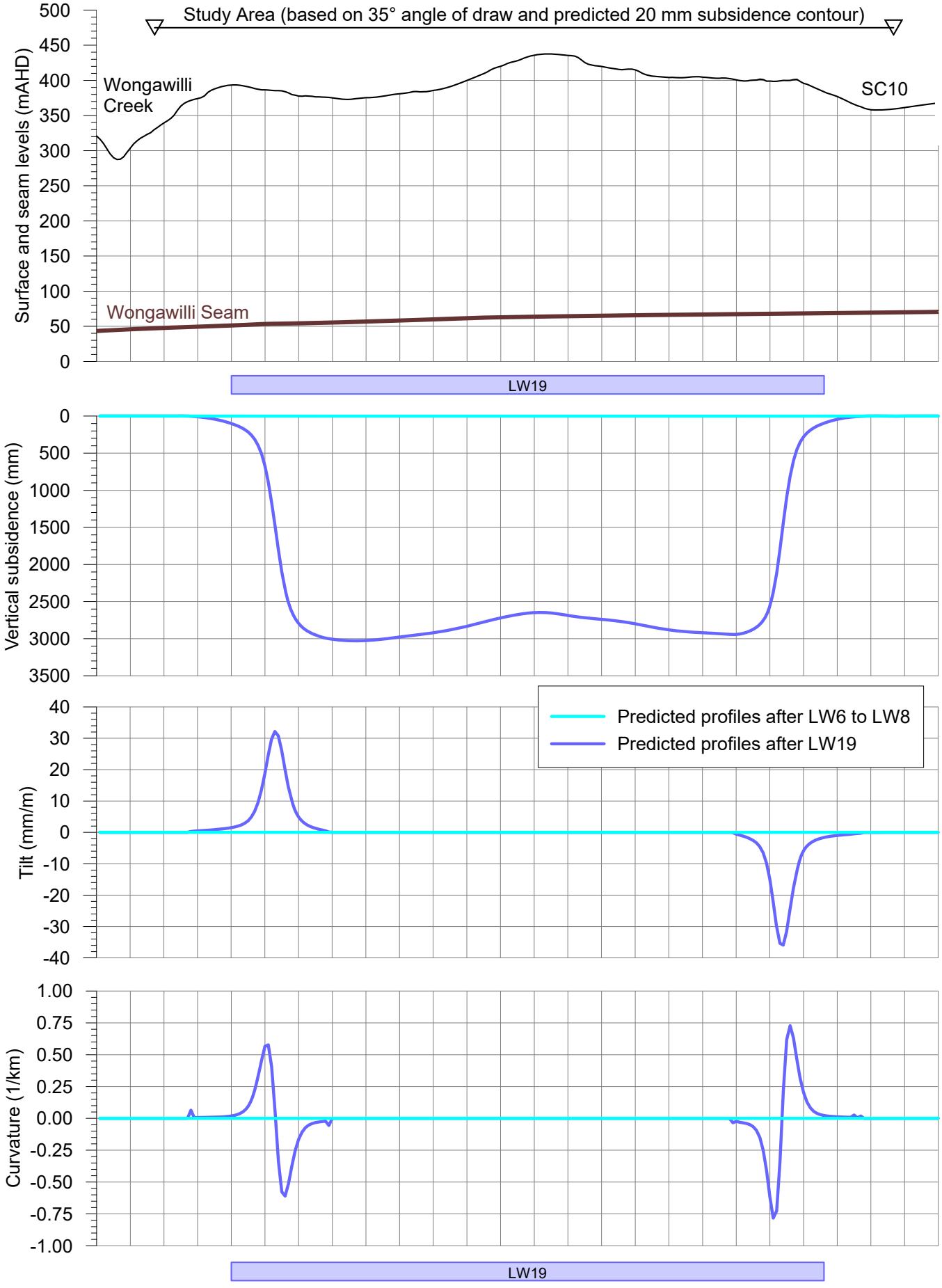



Fig. C.02

# Predicted profiles of vertical subsidence, upsidence and closure along Wongawilli Creek due to mining in Areas 3A, 3B and 3C

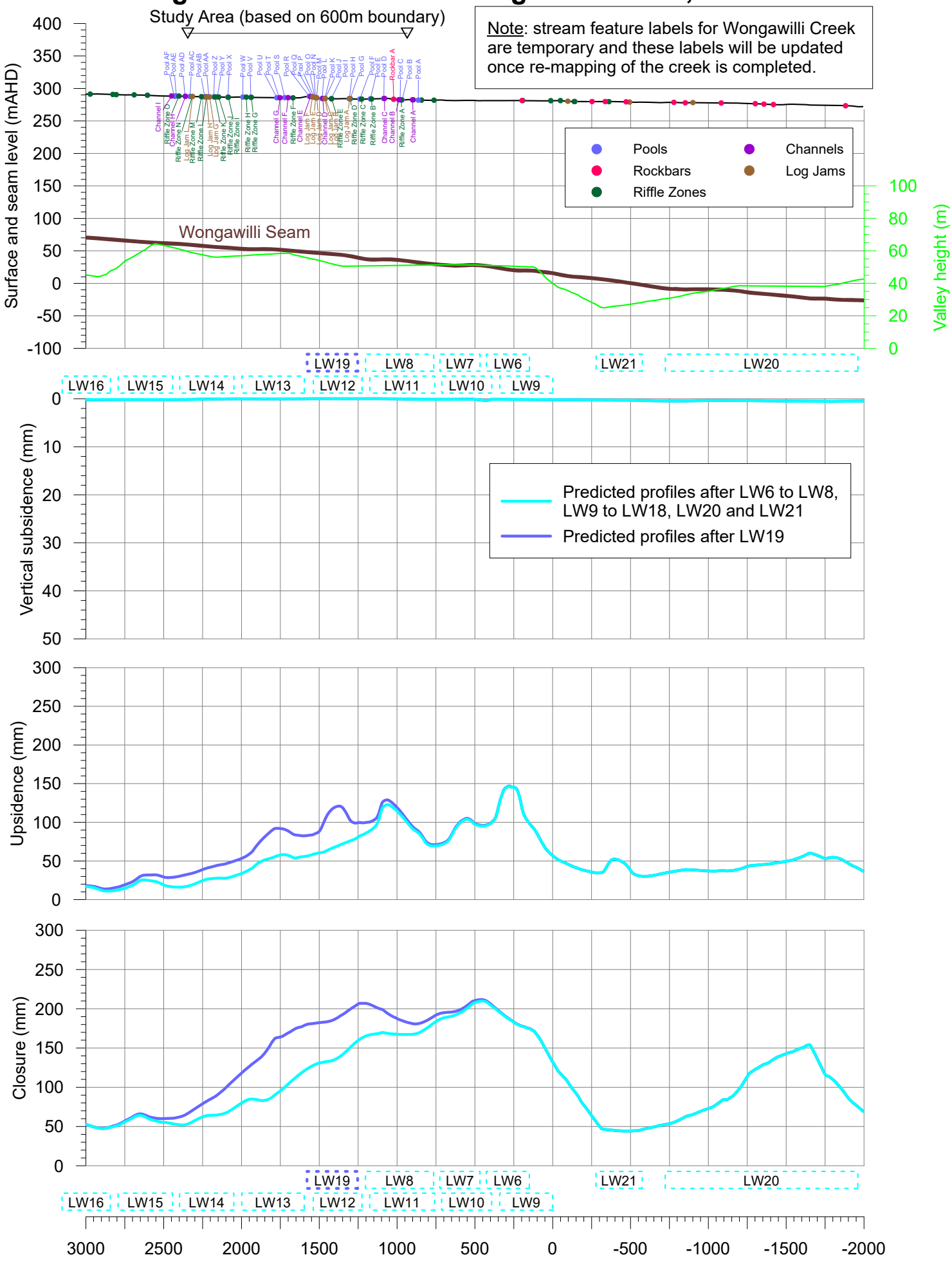
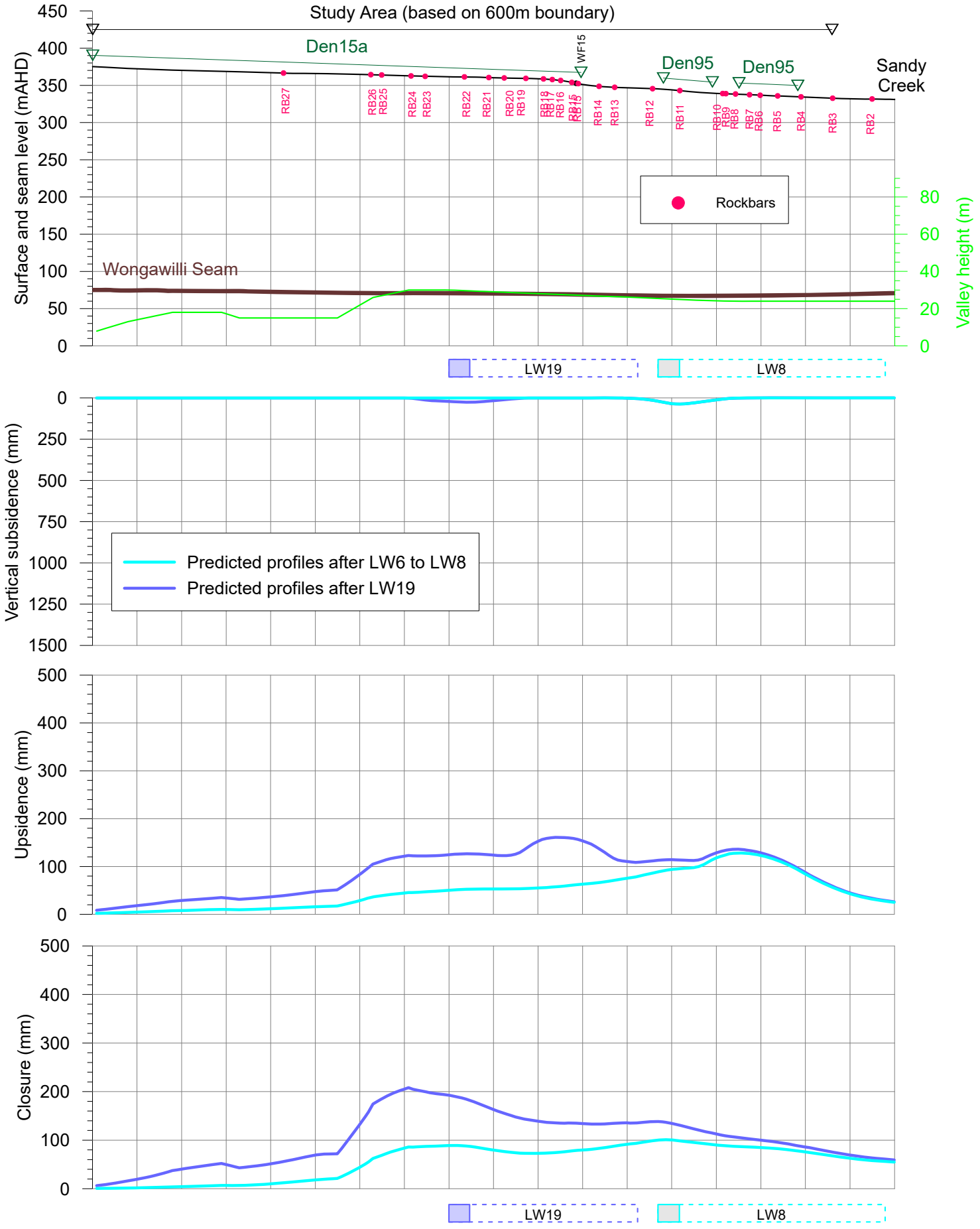



Fig. C.03

# Predicted profiles of vertical subsidence, upsidence and closure along Stream SC10 due to the extraction of LW6 to LW8 and LW19




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Fig. C.04

# Predicted profiles of vertical subsidence, upsidence and closure along Stream WC14 due to the extraction of LW6 to LW8 and LW19

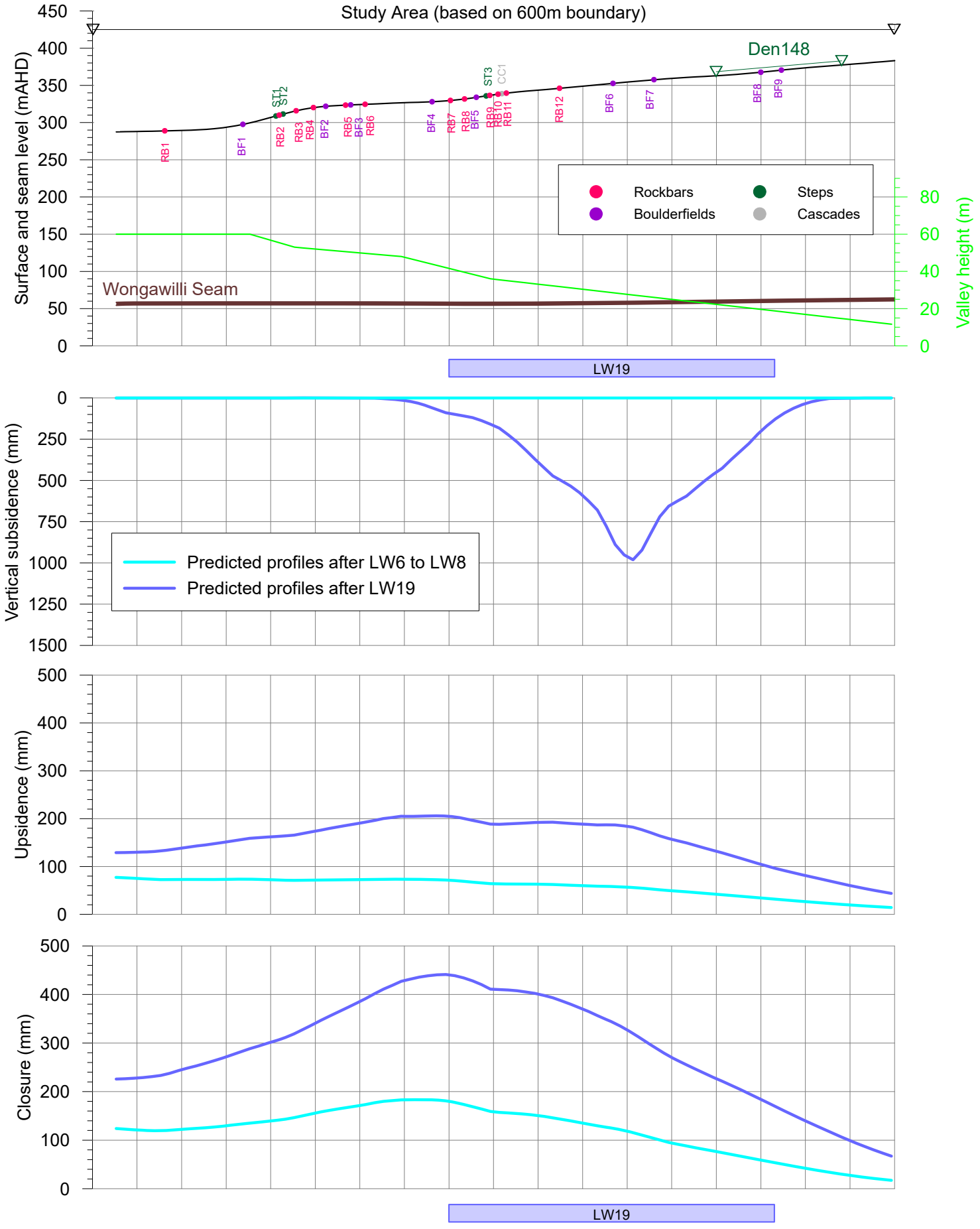
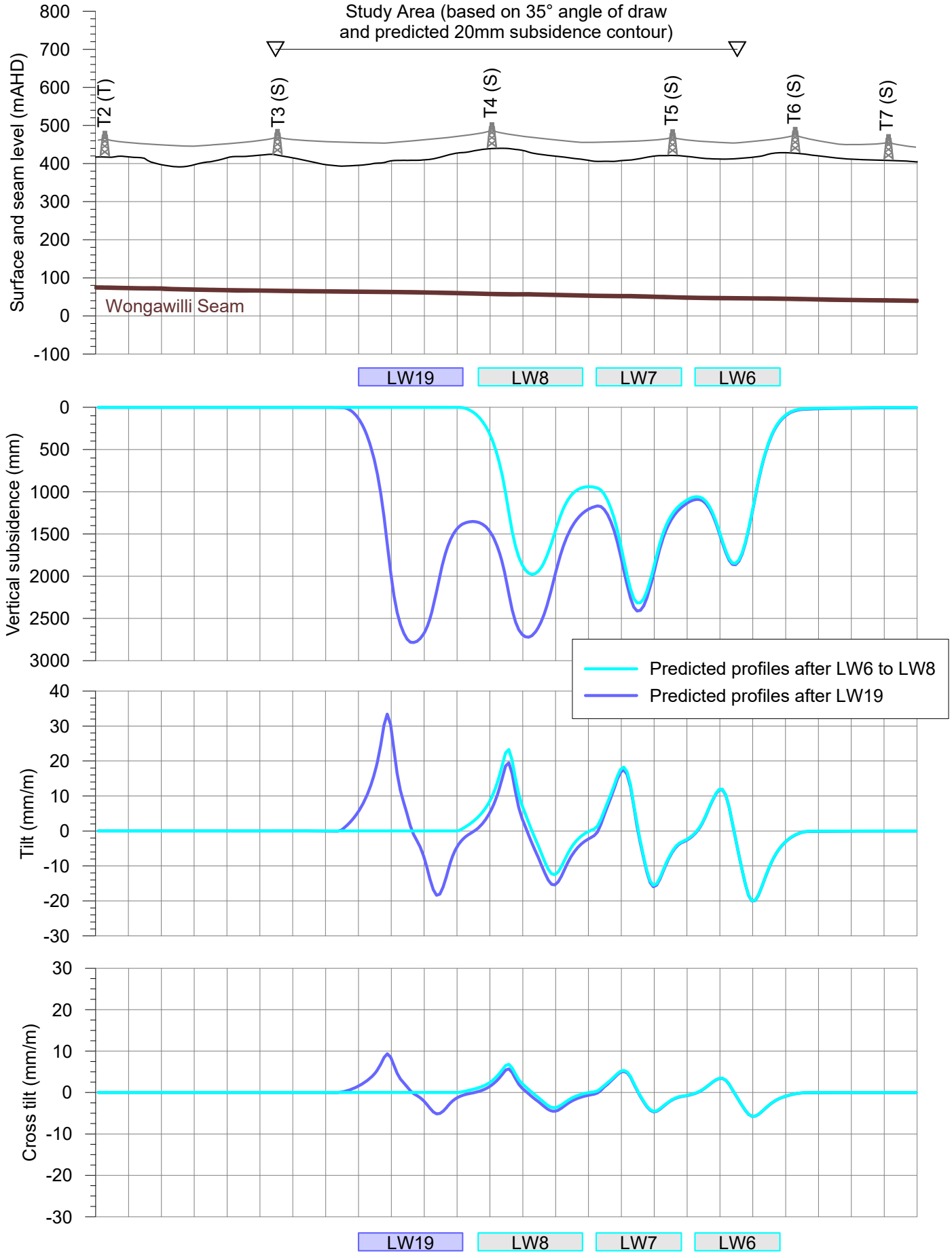



Fig. C.05

# Predicted profiles of vertical subsidence, tilt along and tilt across the 330 kV transmission line due to the extraction of LW6 to LW8 and LW19

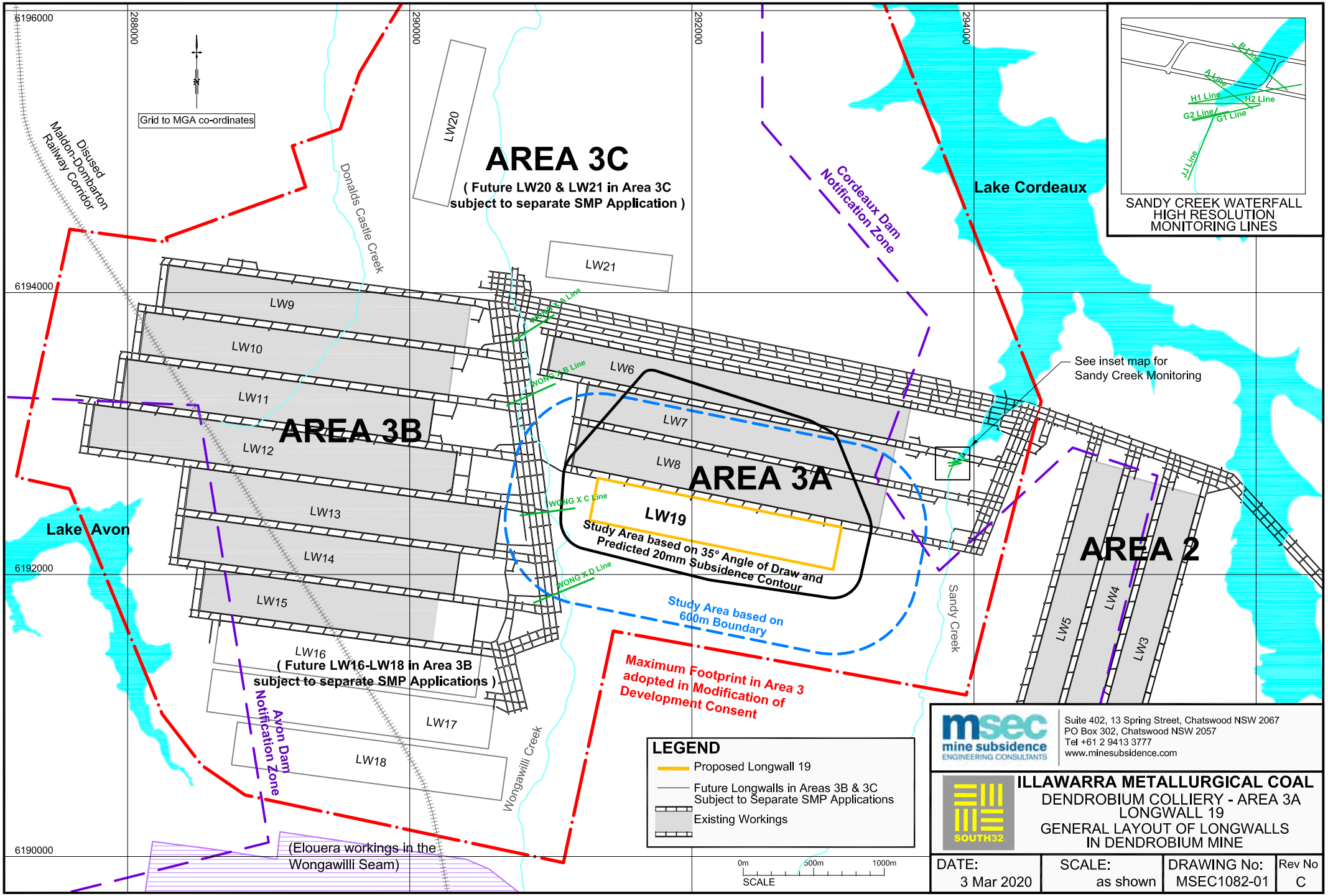



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**Fig. C.06**

# APPENDIX D. DRAWINGS

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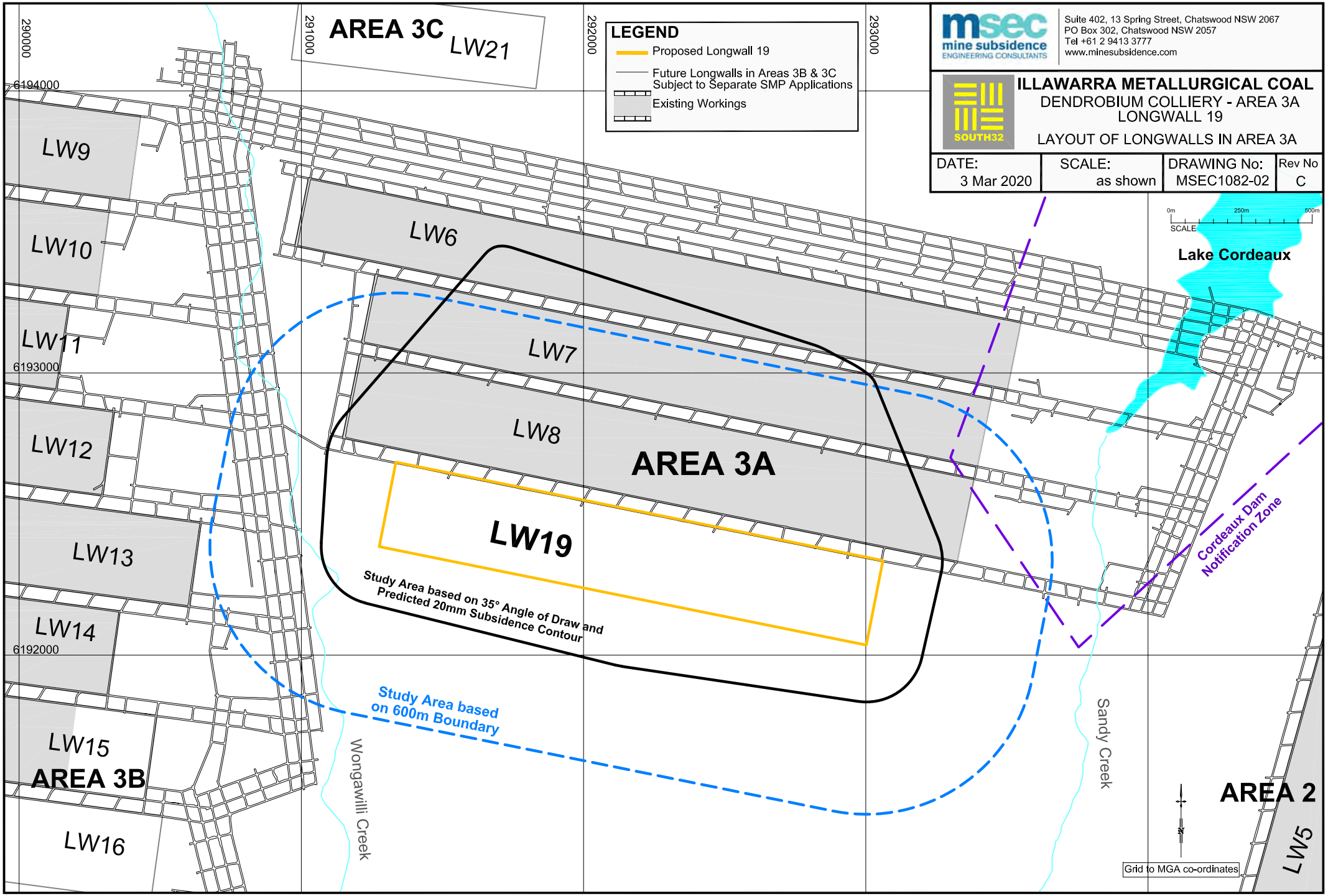

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# ILLAWARRA METALLURGICAL COAL

DENDROBIUM COLLIERY - AREA 3A
LONGWALL 19
GENERAL LAYOUT OF LONGWALLS IN DENDROBIUM MINE

| DATE: | SCALE: | DRAWING No: | Rev No |
|---|---|---|---|
| 3 Mar 2020 | as shown | MSEC1082-01 | C |

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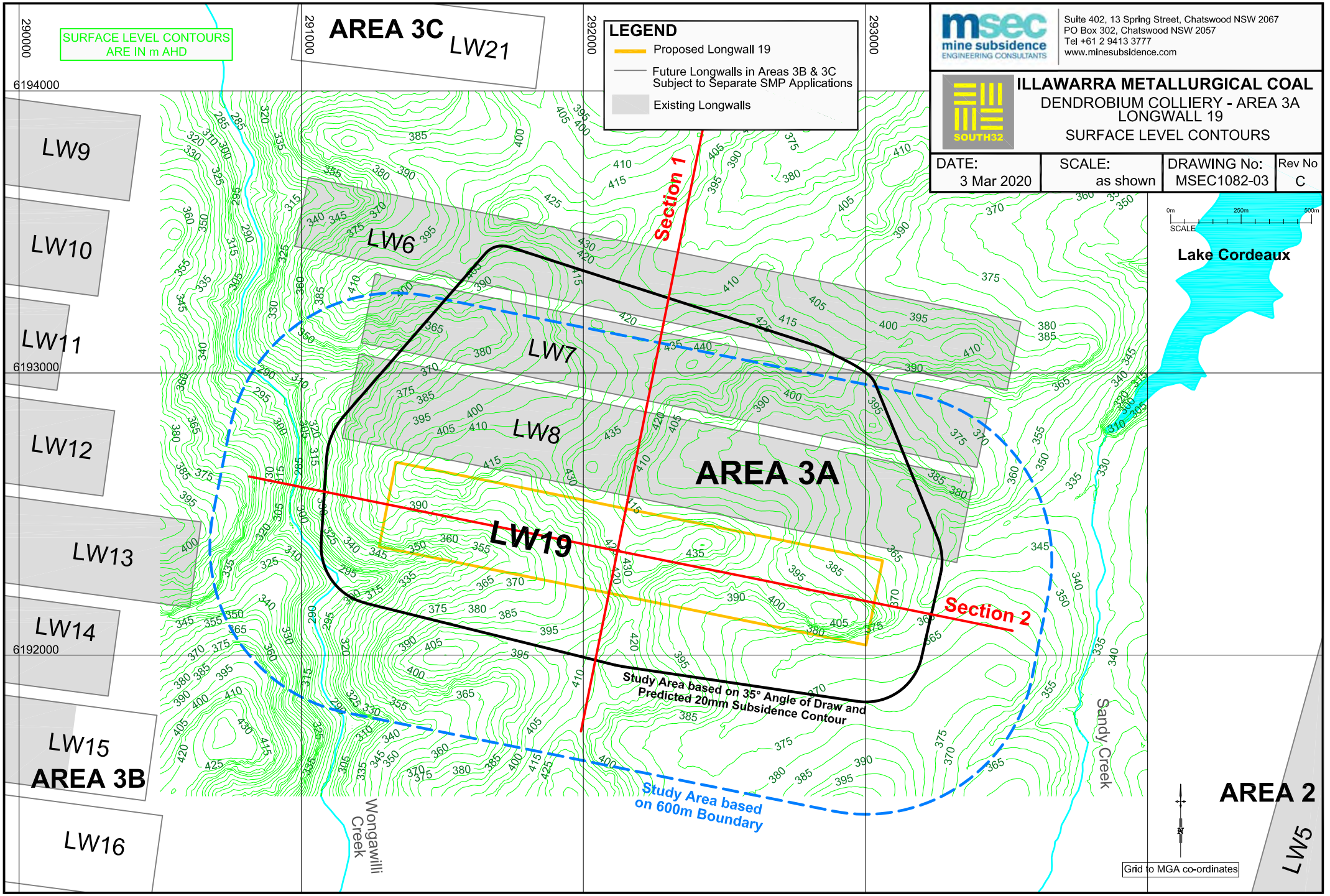
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DENDROBIUM COLLIERY - AREA 3A
LONGWALL 19

LAYOUT OF LONGWALLS IN AREA 3A

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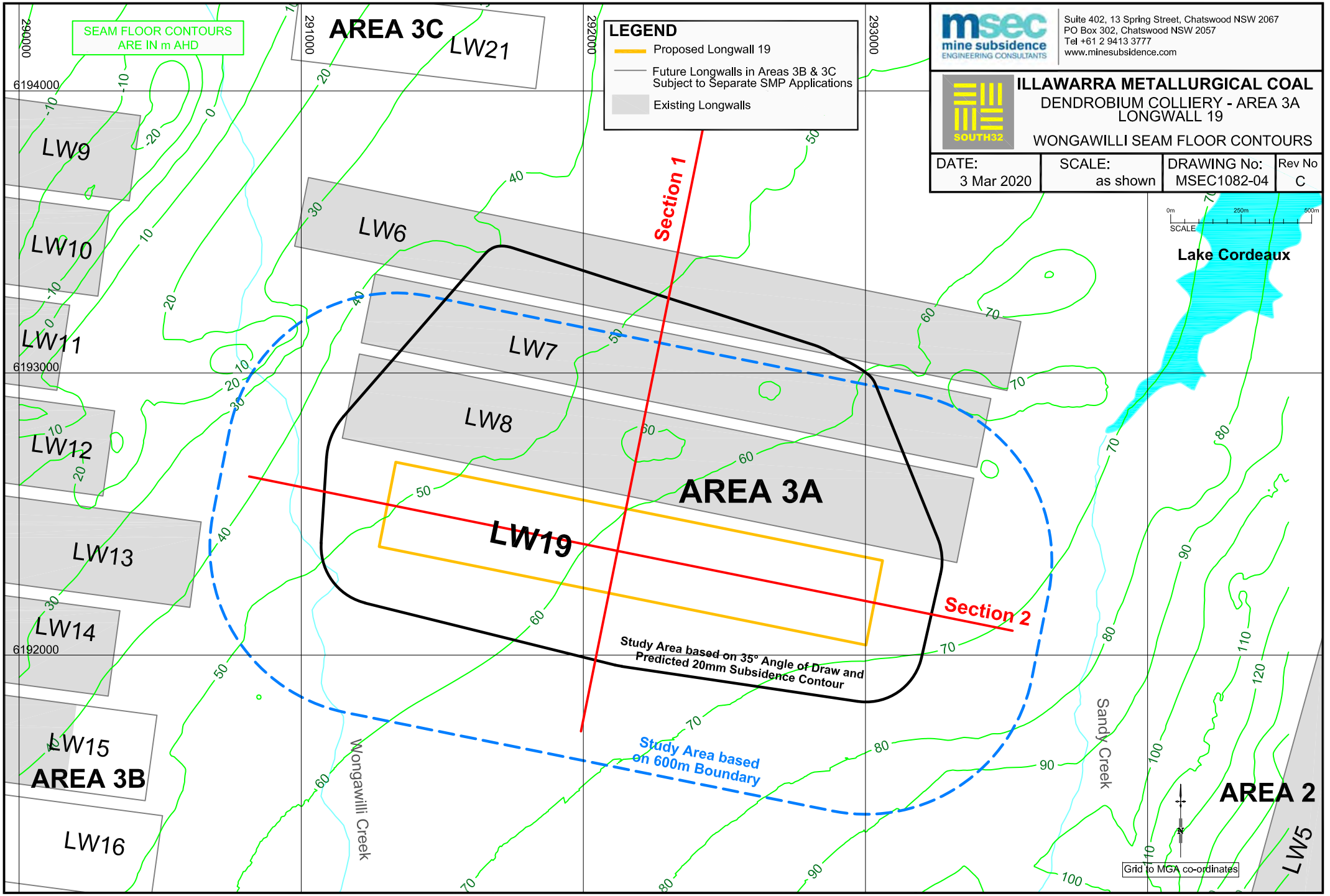
# ILLAWARRA METALLURGICAL COAL

## DENDROBIUM COLLIERY - AREA 3A LONGWALL 19

## SURFACE LEVEL CONTOURS

| DATE: | SCALE: | DRAWING No: | Rev No |
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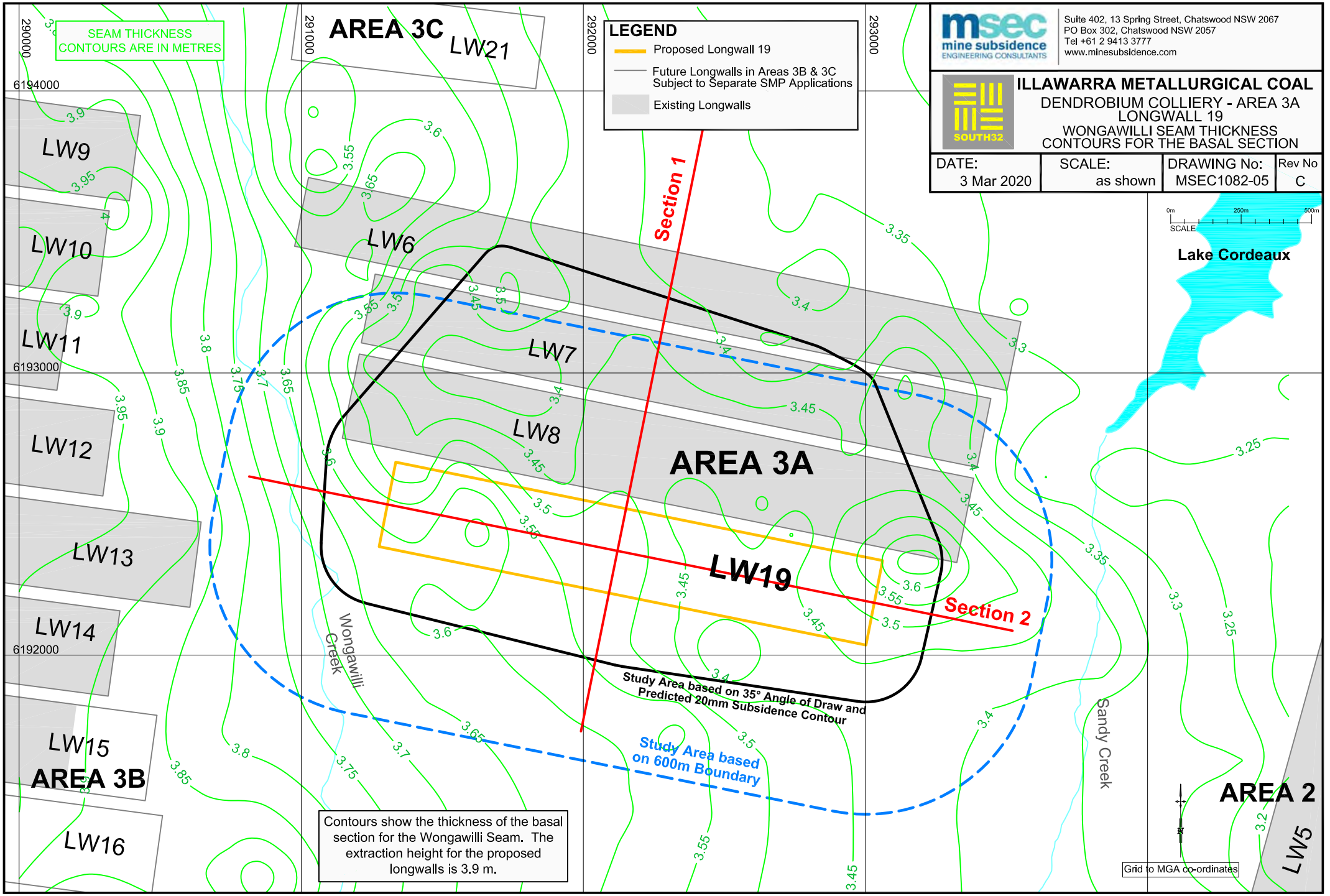
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## WONGAWILLI SEAM FLOOR CONTOURS

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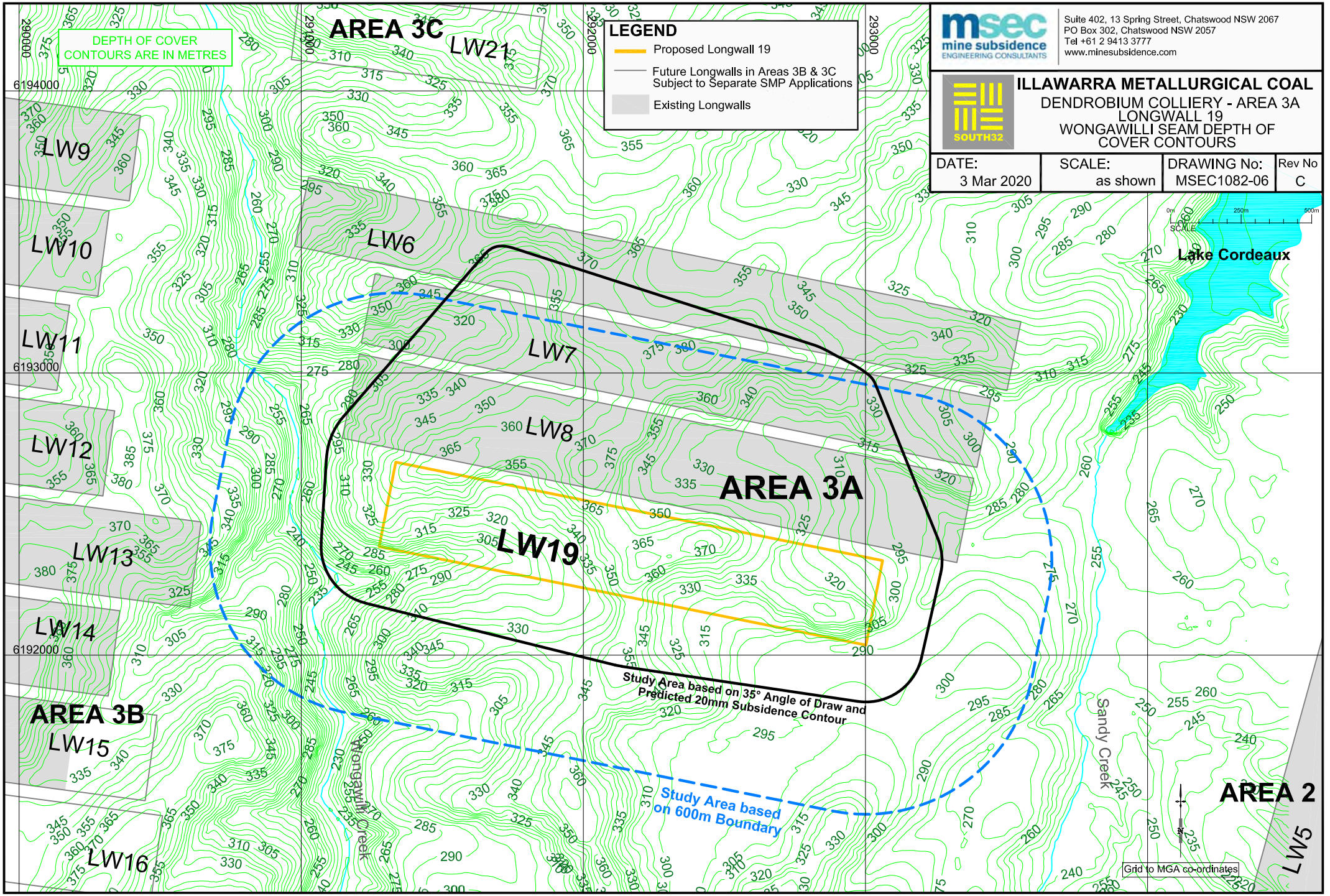

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## DENDROBIUM COLLIERY - AREA 3A
## LONGWALL 19
## WONGAWILLI SEAM THICKNESS CONTOURS FOR THE BASAL SECTION

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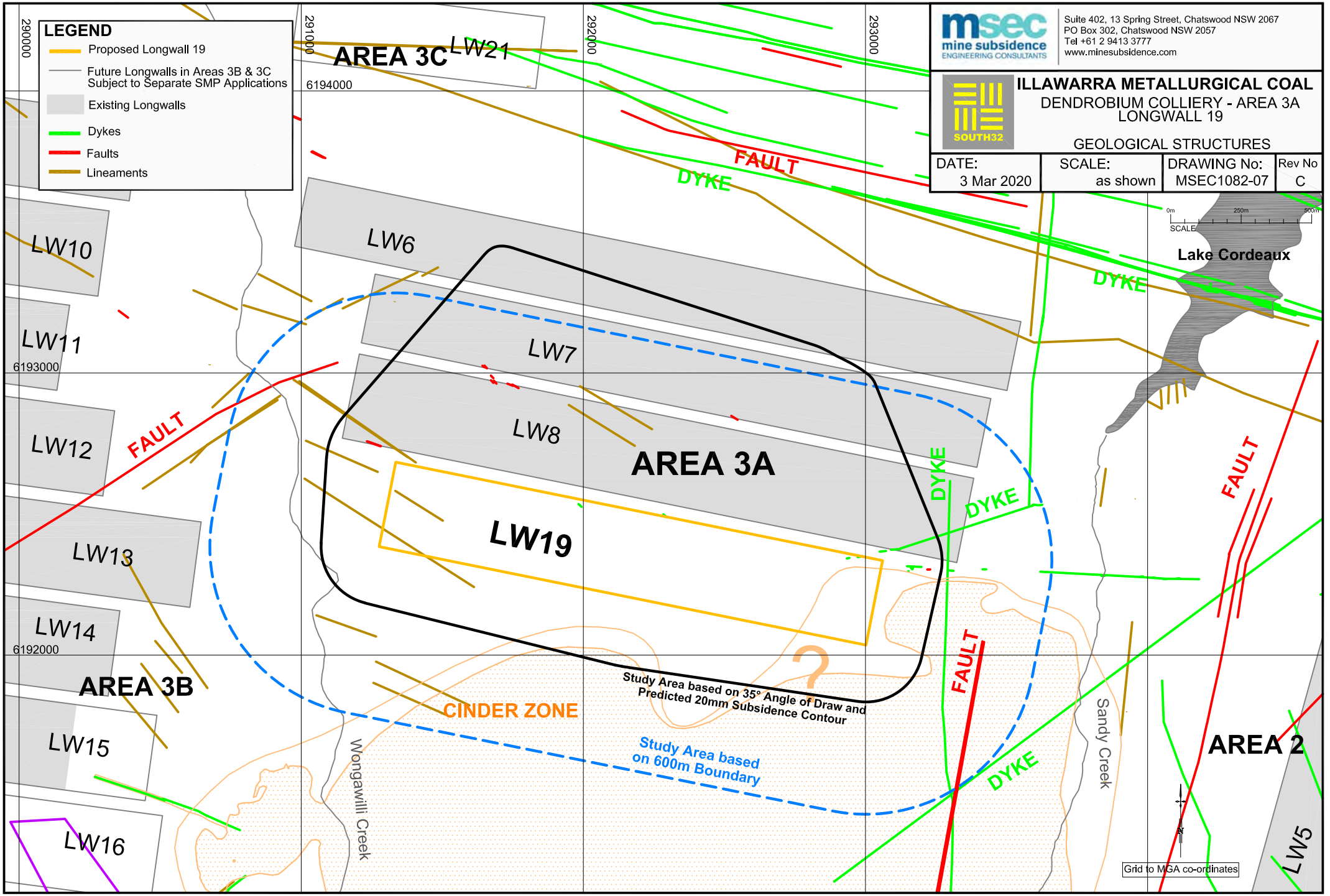

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## DENDROBIUM COLLIERY - AREA 3A
## LONGWALL 19
## WONGAWILLI SEAM DEPTH OF COVER CONTOURS

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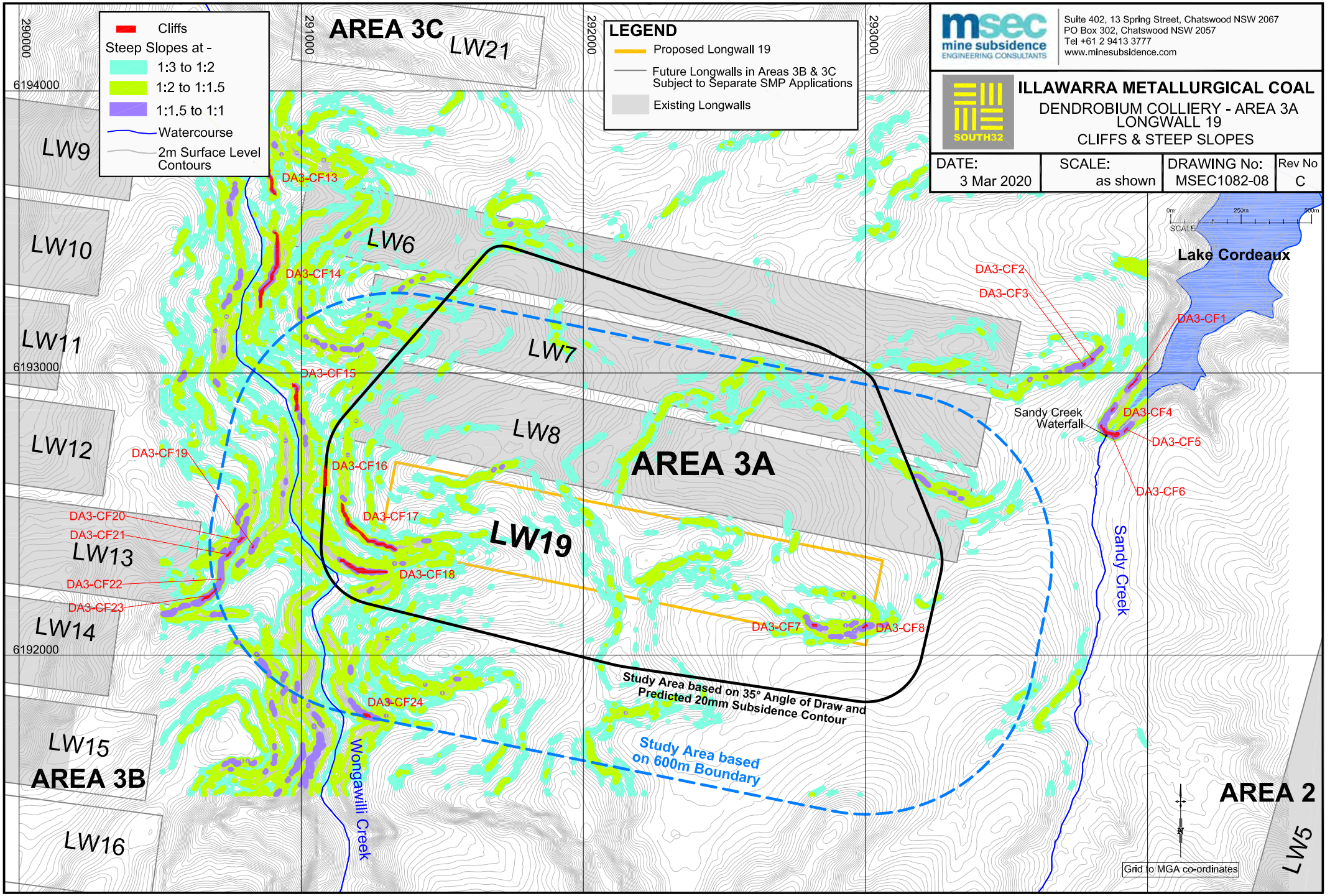
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## DENDROBIUM COLLIERY - AREA 3A LONGWALL 19

GEOLOGICAL STRUCTURES

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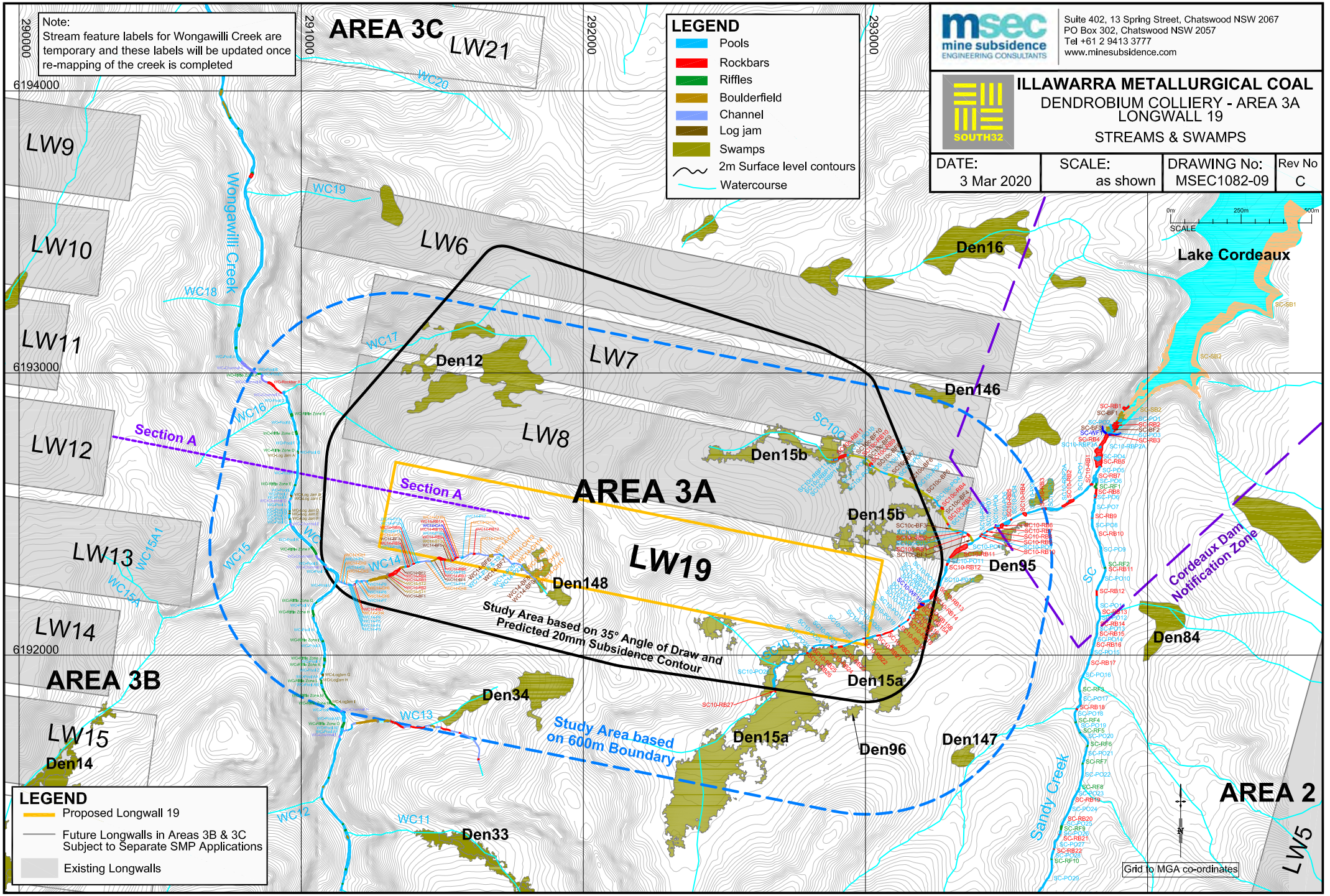

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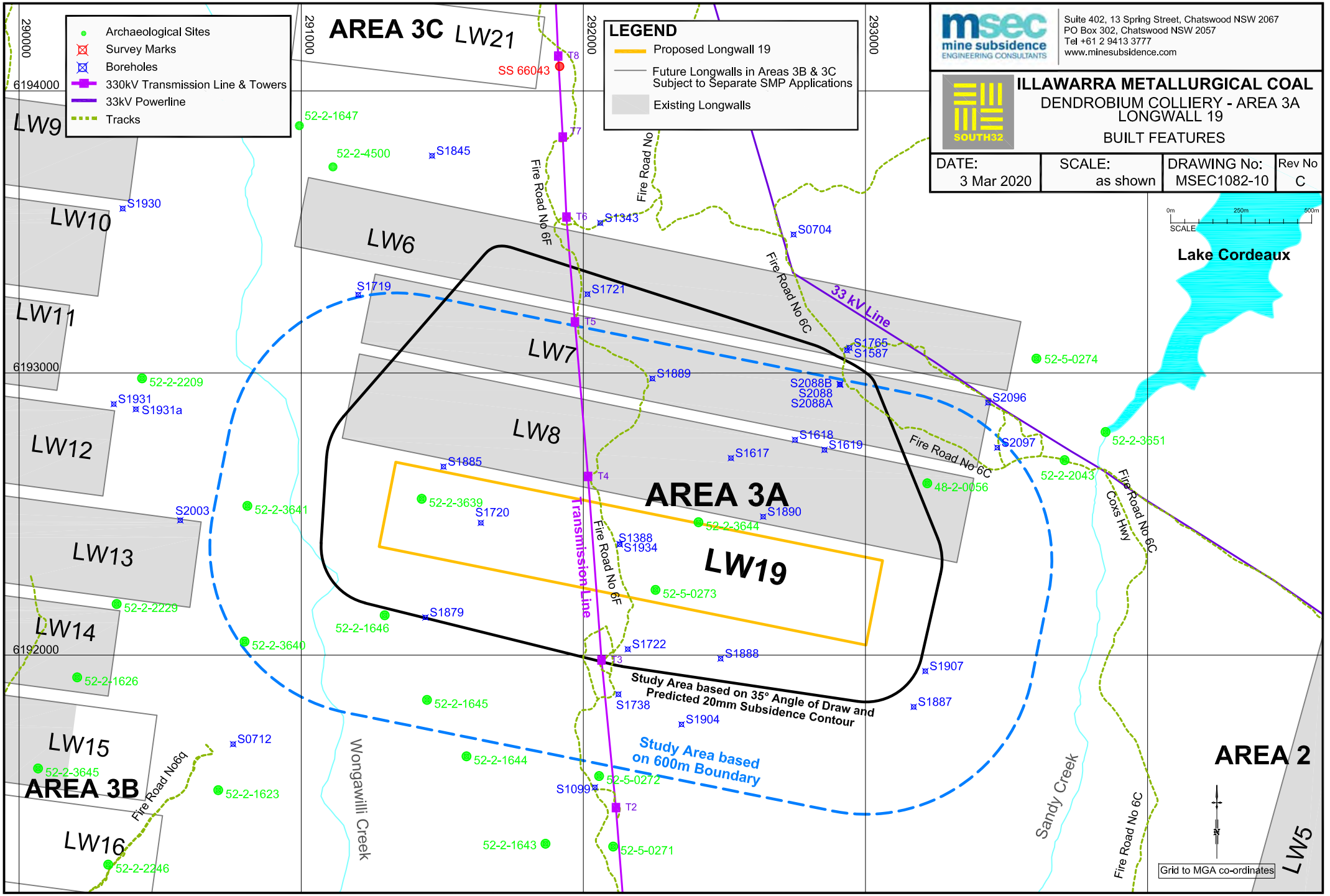
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## LONGWALL 19
## CLIFFS & STEEP SLOPES

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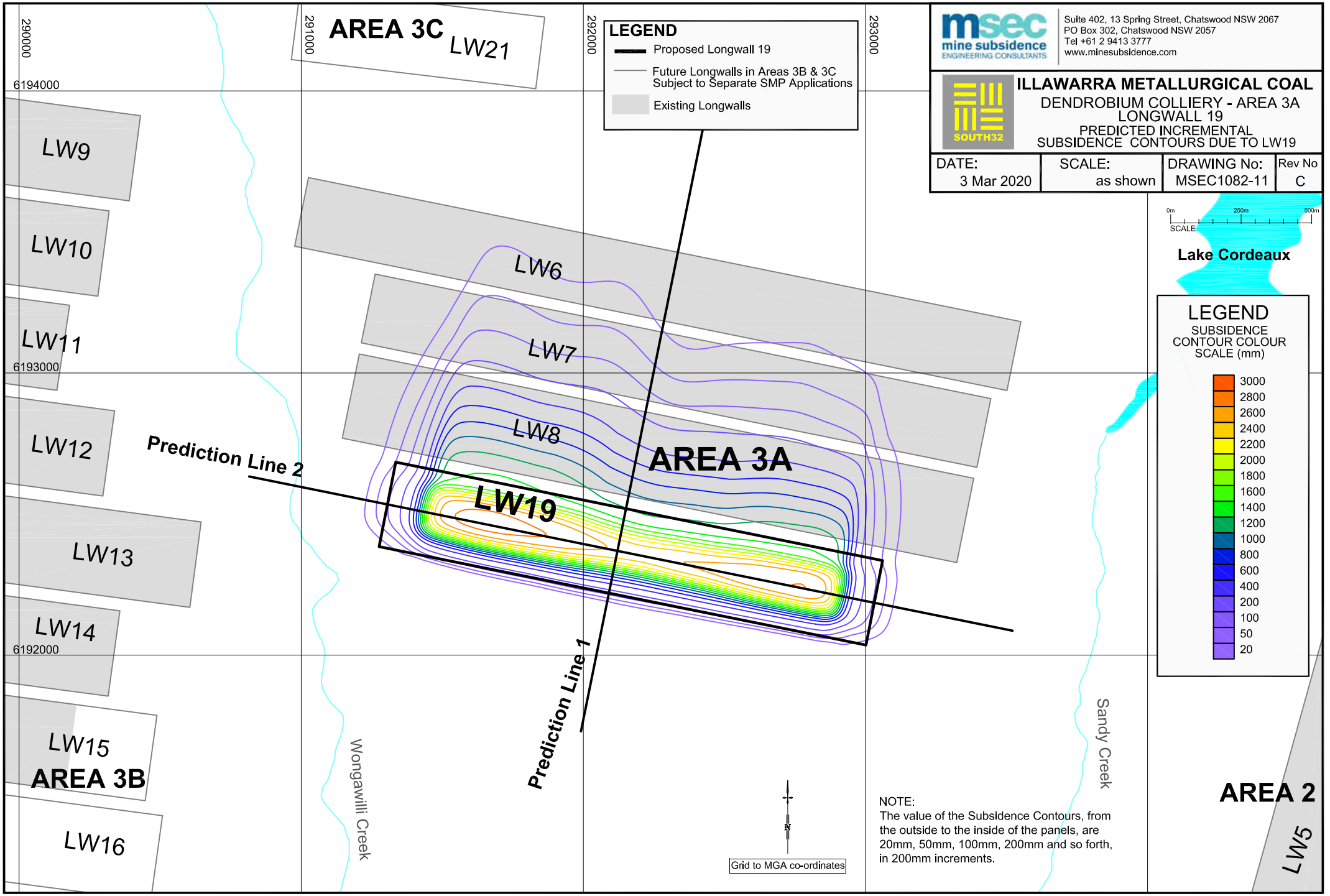
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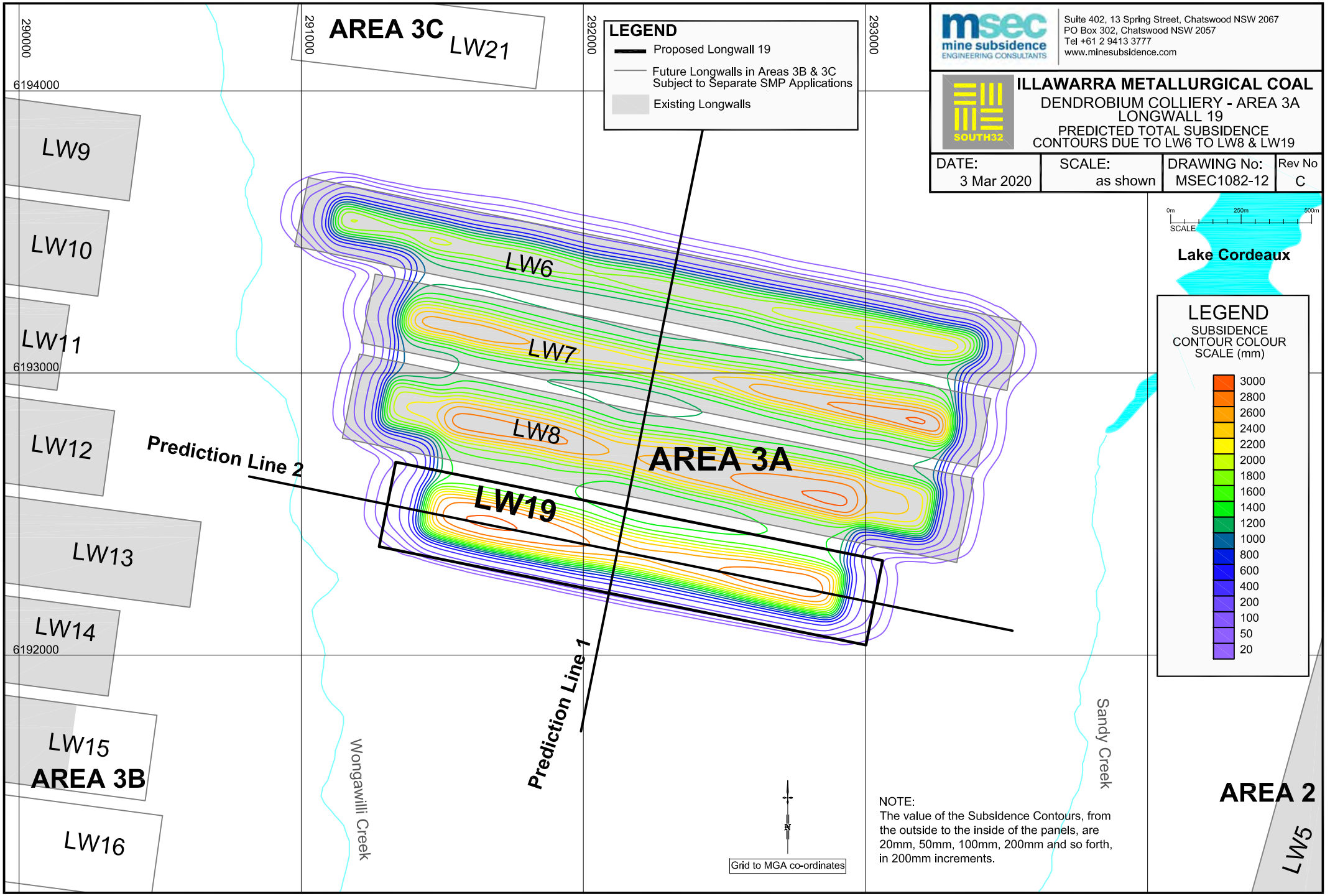

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# ILLAWARRA METALLURGICAL COAL

## DENDROBIUM COLLIERY - AREA 3A
## LONGWALL 19
## PREDICTED INCREMENTAL SUBSIDENCE CONTOURS DUE TO LW19

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# ILLAWARRA METALLURGICAL COAL

## DENDROBIUM COLLIERY - AREA 3A
## LONGWALL 19
## PREDICTED TOTAL SUBSIDENCE CONTOURS DUE TO LW6 TO LW8 & LW19

| DATE: | SCALE: | DRAWING No: | Rev No |
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## Attachment D – Risk Assessment

# South32 - Illawarra Metallurgical Coal

## Review of Dendrobium Longwall 19 Subsidence Management Plan

Risk Assessment Report

AR2817

Revision 3

06 January 2020

Assessment and report completed by;
AXYS Consulting Pty Ltd
PO Box 110, Picton, 2571
NSW, Australia
+61417281115

## 1. Revisions

| Rev No | Date | Description |
|---|---|---|
| 1 | 06 January 2020 | Initial Release |
| 2 | 09 February 2020 | Minor corrections from internal review |
| 3 | 28 February 2020 | Document reviewed to address Professor Bruce Hebblewhite's peer review |

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## 2. Participants

| Name | Position | Relevant Years' Experience |
|---|---|---|
| Danial Baker | South32 - Dendrobium Mine Senior Planner | 15 Years |
| Luke Baker | Niche Environment and Heritage Ecologist | 12 Years |
| Will Minchin | Watergshed HydroGeo Hydrogeologist | 16 Years |
| Daniel Pygas | Cardno Principal Aquatic Ecology | 14 Years |
| James Barbato | Mine Subsidence Engineering Consultants (MSEC) Subsidence Engineer | 15 Years |
| Cody Brady | South32 - Illawarra Metallurgical Coal Principal Mining Approvals | 4 Years |

The following participants were not in attendance at the risk assessment held on 6 January though have reviewed this risk assessment report and provided feedback which has been incorporated. Professor Bruce Hebblewhite was engaged by Illawarra Metallurgical Coal to provide a peer review of the document which is provided in Attachment 8.

| Name | Position | Relevant Years' Experience |
|---|---|---|
| Prof. Bruce Hebblewhite | B K Hebblewhite Consulting Peer Reviewer | 40 Years |
| Dr Stuart Brown | HydroGeo | 25 Years |
| Gary Brassington | South32 - Approvals | 25 Years |

## 3. Introduction

IMC carried out a risk assessment for the Dendrobium Longwall 19 Subsidence Management Plan (SMP) application in accordance with the recommendation from the Independent Expert Panel (Panel) that SMP applications consider the potential implications of mining within a risk assessment context, and in particular any implications for water quantity as a result of faulting, basal shear planes and lineaments.

Upon receiving feedback from the Independent Expert Panel regarding risk assessments undertaken to support recent SMP applications. The risk assessment has incorporated this feedback where appropriate.

The risk assessment identifies the existing controls associated with mining operations at Dendrobium. Several recommendations and actions for further controls have been identified through the risk assessment process

## 4. System Description

Dendrobium Mine is an underground coal mine which commenced construction in January 2002 following approval from the Minister of the then Department of Urban Affairs and Planning on 20 November 2001. Longwall mining commenced at Dendrobium in April 2005 with Longwalls currently being extracted in Area 3B.

The mine is owned and operated by IMC, a wholly owned subsidiary of South32 Ltd. The mine operates on a continuous basis, 24 hours a day and 7 days a week. The mine operates one longwall production panel and development units.

The Panel Report Part 1 (2019) on specific mining activities at Metropolitan and Dendrobium Mines was released in December 202018. The report recommended *that "all applications to extract coal within Special Areas should be supported by independently facilitated and robust risk assessments that conform to ISO 31000 (the international standard for risk management subscribed to Australia)*". The Panel also recommended that the potential implications for water quantity of faulting, bedding plane shears and lineaments need to be very carefully considered and risk assessed at all mining operations in the Special Areas.

The Department of Planning, Industry and Environment (DPIE) have previously provided correspondence to IMC that the Panel have raised concerns regarding mining operations near or under lineaments in special areas of the catchment of the Southern Coalfield. The Panel stated, "*specific regard to the potential impacts on surface water features, including swamps and waterfalls, of mining near and under lineaments".*

Therefore, this Risk Assessment has been carried out to identify the existing controls associated with mining operations of Dendrobium's Longwall 19 in Special Areas of the catchment and to make recommendations for further controls where appropriate.

The main consideration is for compliance with the Dendrobium mine Development Consent, however safety, business interruption, community concerns, reputational damage and environmental issues have been considered where relevant.

The assessment uses the "Workplace Risk Assessment and Control" (WRAC) format as it was decided that this format provides for a more verbal description of any perceived hazards and their identified controls. It was considered that this assessment type provides for easier reading by non-technical persons.

### 4.1 Longwall 19 - Background

IMC has completed the mining of Longwalls 6 to 8 in Area 3A at Dendrobium Mine with Longwall 8 finishing in December 2012. IMC proposes to extract Longwall 19 within the Wongawilli Seam, which is the final longwall in that series. The longwall will be extracted towards the main headings (i.e. retreat mining from the east towards the west) within the Wongawilli Seam. Longwall 19 will be extracted after Longwall 21 in Area 3C and prior to the extraction of Longwall 20 in Area 3C.

The Study Area (Drawing 1082-07 MSEC2020 [Attachment 7]) has been defined, as a minimum, as the surface area enclosed by the: 35° angle of draw line from the extents of the proposed Longwall 19; the predicted incremental 20 mm subsidence contour due to the extraction of the proposed longwall; natural features located within 600 m of the extent of the longwall mining area, in accordance with Condition 8(d), Schedule 3, of the Development Consent (DA 60-03-2001); and features that are expected to experience either far-field horizontal movements, or valley related effects, and which could be sensitive to these movements. Specialist assessments submitted as part of the Longwall 19 SMP application should be read in conjunction with this risk assessment.

The maximum predicted subsidence effects for the existing and proposed longwalls in Area 3A (i.e. Longwall 6 to Longwall 8 and Longwall 19) are less than the maximum predicted values for the existing and approved longwalls in Area 3B (i.e. Longwall 9 to Longwall 17). The predicted subsidence effects are less, as the maximum mining height for Area 3A of 3.9 m is less than the maximum mining height for Area 3B of 4.6 m.

Natural and built features considered in the risk assessment:

- Wongawilli Creek is situated on the western side of the existing Longwall 6 to Longwall 8 and the proposed Longwall19 in Area 3A. The currently active longwalls in Area 3B are being mined on the western side of the creek. The thalweg (i.e. base or centreline) of the creek is located 175 m south-west of the finishing end of Longwall 19, at its closest point to the proposed longwall. The maximum predicted total subsidence effects for Wongawilli Creek, due to the mining in Areas 3A, 3B and 3C, are less than 20 mm vertical subsidence, 150 mm upsidence and 210 mm closure. The maximum predicted incremental movements along the creek, due to the mining of the proposed Longwall 19 only, are less than 20 mm vertical subsidence, 50 mm upsidence and 70 mm closure (MSEC 2020).
- Sandy Creek is located 750 m east of the commencing end of Longwall 19, at its closest point to the proposed longwall. At this distance, the creek is not predicted to experience measurable conventional or valley related effects due to the mining of Longwall 19. It is unlikely, therefore, that Sandy Creek would experience adverse impacts due to the mining of the proposed longwall (MSEC 2020).
- Sandy Creek Waterfall (SC – WF1) is located 900 m north-east of the commencing end of Longwall 19. The total closure measured at the waterfall, due to the previous mining of Longwall 6 to Longwall 8 in Area 3A, was 14 mm. The predicted incremental closure for Sandy Creek Waterfall, due to the mining of the proposed Longwall 19, is less than 2 mm, which is in the order of survey tolerance and environmental effects. It is considered unlikely, therefore, that Sandy Creek Waterfall would experience adverse impacts due to the mining of Longwall 19 (MSEC 2020).
- Drainage lines are located directly above and adjacent to the proposed longwall. These drainage lines are first and second order streams that form tributaries to Wongawilli and Sandy Creeks. The drainage lines could experience the full range of predicted subsidence effects (MSEC 2020).
- There are four swamps that have been identified wholly or partially within the Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour. There are five additional swamps that are located within the Study Area based on the 600 m boundary. (Drawing 1082-09 MSEC2020 [Attachment 7.

- Cordeaux and Avon Reservoirs are located at minimum distances of 0.9 km and 3.1 km, respectively, from the proposed Longwall 19. The Cordeaux Dam Wall and Avon Dam Wall are located at distances of more than 5 km from the proposed longwall. The predicted vertical and horizontal movements at the Cordeaux and Avon Reservoirs and their associated dam walls are very small and are unlikely to be measurable. Previous experience of mining in Areas 1, 2, 3A and 3B has not resulted in adverse impacts on these structures. It is unlikely, therefore, that the reservoirs and dam walls would experience adverse impacts due to the extraction of the proposed Longwall 19 (MSEC 2020).
- Geological Features at both inseam and surface levels considered as part of the risk assessment and are shown on (Drawing 1082-07 MSEC2020 [Attachment 7]). IMC (2020) includes a description of the conditions experienced during mining and inseam drilling of the nepheline syenite intrusion. This memorandum also states the key conclusion that geological conditions predicted in Area 3A are similar to conditions IMC have experienced previously in Area 2, 3A and 3B.

## 5. Context Summary

### 5.1 Strategic Context

IMC is committed to ensuring safety and environmental compliance within its operation. When new equipment or processes are implemented, IMC insist that Risk Assessment techniques are used to reduce the risks to people, equipment, environment and operations.

### 5.2 Corporate Context

As IMC is committed to safety and environmental compliance, when a change to systems or new equipment or systems are introduced into the coal operation, management insist that Risk Assessment techniques are used to identify and minimising exposure to its people and the operations. IMC is also committed to implementing Risk Assessment techniques to identify risk when required by external sources.

### 5.3 Risk Management Context

Due to correspondence received from the Department of Planning and Environment in relation to advice received from the Panel, the management of IMC have conducted a formal Risk Assessment to address the concerns of mining in the catchment that may be affected by the extraction of Longwall 19.

There are a number of considerations during each Risk Assessment, being personal safety, equipment damage, operational loss, reputation or environmental issues. This assessment specifically addressed the risks associated to legal compliance that may result from the extraction of Longwall 19.

## 6. Objectives and Scope

The objective of this Risk Assessment was to support the Longwall 19 SMP application and to address recommendations raised by the Panel. This Risk Assessment addressed the risks associated to legal compliance that may result from the extraction of Longwall 19.

A scoping session was carried out with the assessment team and the following items were agreed to be assessed:

- Groundwater
- Avon and Cordeaux Reservoirs
- Wongawilli Creek
- Sandy Creek
- Sandy Creek Waterfall (SCWF1)
- Swamps, including Den15A
- Swamps, Tributaries to Wongawilli Creek and Sandy Creek

For each of the items above the following concerns (where relevant) were reviewed and assessed:

- Surface subsidence
- Sub surface ground movements
- Valley closures
- Lineaments
- Faults
- Dykes
- Groundwater drawdown

## 7. Assumptions and Constraints

The following assumptions and limitations were applied to this Risk Assessment:

- iPick Document Kiosks and the South32 web site are available and provide access to site documentation
- South32 have a team addressing mining approvals and compliance
- Detailed subsidence predictions and other analysis have been developed to understand the impact from Longwall 19
- Accurate subsidence measurement is available and used
- A detailed understanding of prior experience from mining under the catchment areas and the effect on those areas in the Southern Coalfield are well documented and understood
- Extensive monitoring will be conducted both electronically and physically to identify any adverse impact to areas prior, during and after mining activities associated with the current extraction application

Related documents include:

- AS NZS ISO 31000-2009: Risk Management - Principles and guidelines
- MDG1010 - Risk Management Handbook for the Mining Industry
- MDG1014 - Guide to Reviewing a Risk Assessment of Mine Equipment and Operations
- Work Health and Safety Act 2011
- Work Health and Safety Regulation 2011
- Work Health and Safety (Mines and Petroleum Sites) Act 2013
- Work Health and Safety (Mines and Petroleum Sites) Regulation 2014
- Report from B K Hebblewhite Consulting titled: Dendrobium Mine – Longwalls 14-18 Independent Review – Height of Fracturing (Stage 2) (incorporating all content from March 2018 Stage 1 Report). File Name: 170803.2 (final) (1)
- Letter from Department of Planning and Environment titled: Independent Expert Panel for Mining in the Catchment, Advice Regarding Lineaments
  File Name: 20190219_ltr to South32 Re: lineaments.
- Letter form Emeritus Professor Jim Galvin titled Re: IEPMC advice to Department of Planning and Environment Emerging knowledge regarding lineaments. File Name: IEPMC advice to DPE re-emerging knowledge lineaments.
- Watershed HydroGeo, 2019. Geographic review of mining effects on Upland Swamps at Dendrobium Mine. r008i5, March 2019

## 8. Risk Treatment

The group was introduced to the risk assessment process at the commencement of the session by the facilitator. The various steps were explained, and the group reviewed the likelihood, consequence and risk ranking matrix.

The risk ranking was undertaken with consideration to existing controls being in place.

Risk ranking was undertaken by the risk assessment team with consideration to the consequence of an event occurring and the likelihood of that hazard (event) occurring that leads to the level of consequence identified. The consequence ranking may be one of six identified types i.e. Health and Safety, Natural Environment, Community, Reputation, Legal and Financial. The scales for these consequences are shown in Section 13 “Risk Rank Method” on Page 17.

It is noted that different types of consequences may/will have a different likelihood of occurrence, this equates to a different risk ranking being realised. For example, the ‘Natural Environment’ consequence of an event occurring may be low but with a high likelihood. However, a ‘Legal’ consequence of an event occurring may be high, but with a low likelihood. For any event, the combination of consequence and likelihood which results in the highest risk is documented.

During this assessment the group considered, as far as practicable, all consequences shown in Section 13, however, to reduce the complexity and volume of reporting, only the worst case ‘risk ranking’ for each hazard is documented in the Risk Assessment. Using this process some consequences that are high may have an overall low ‘risk rank’ because the probability of the event (leading to the consequence level identified) is very low, whereby a consequence may have a high ‘risk rank’ because the probability of the event (leading to the consequence level identified) is higher.

Controls were developed using the following forms:

- Avoidance – avoid the risk by deciding not to proceed with the activity likely to generate the risk (where this is practicable).
- Reduction – reduce the likelihood of the event.
- Reduction – reduce the consequences of the event.
- Accept – accept the risk within the organisation and establish an appropriate plan to manage the consequences of these risk if they are to occur.

The above risk control options were applied by reference to the following control methodologies in a hierarchical sequence.

- Design – to the extent reasonable and practicable ensure that hazards are designed out of the proposal.
- Remove the hazard or substitute a less hazardous proposal.
- Adopt a safer process – alter the process, equipment or work practices.
- Enclose or isolate the hazard – provide barriers or other techniques.
- Establish appropriate administrative procedures. Set up, document and implement new procedures that provide for:
  - Scheduling of the proposal to reduce exposure.
  - Routine maintenance and housekeeping procedures
  - Training on hazards associated with the proposal.
- Mitigate, rehabilitate or provide offsets for impacts from the proposal.

## 9. Facilitator

Shane Chiddy holds an Associate Diploma in Engineering (Electrical), is an Officer of the Institution of Engineers (Australia) and is a member of the Asset Management Council of Australia (AMC) and the Mining Electrical and Mining Mechanical Engineering Society (MEMMES). He has also completed Conveyancing Law through Macquarie University, G2 and Establish the Risk Management Systems (Mine 7033 - G3) through Queensland University and is certified as a Functional Safety Engineer by TÜV Rheinland for both Safety Instrumented Systems and Machine Safety.

Prior to commencing his consulting career, Shane Chiddy qualified as an electrician and worked underground for 15 years. He then occupied a number of engineering roles within Rio Tinto, including such roles as electrical supervisor, development engineer and senior production engineer. This latest role was responsible for the longwall, underground diesel equipment and conveyors.

Additionally, Shane Chiddy has been trained and accredited by John Moubray in the UK as a certified RCM II practitioner, and has conducted a number of extensive Reliability-centred Maintenance II analyses including underground and surface equipment such as longwalls, continuous miners and conveying systems. He has facilitated RCM II analysis and delivered training in the mining, defence and telecommunications industries.

His consulting experience includes the application of Reliability-centred Maintenance II and extensive risk management and project management assignments.

## 10. Sub-Systems Considered in the Assessment

| Sub-System | | STEP IN PROCESS | |
|---|---|---|---|
| 1 | Review Dendrobium Longwall 19 Subsidence Management Plan | A | Groundwater |
| | | B | Avon and Cordeaux Reservoir |
| | | C | Wongawilli Creek |
| | | D | Sandy Creek |
| | | E | Sandy Creek Waterfall (SC-WF1) |
| | | F | Swamps, Including Den15A |
| | | G | Swamps, Tributaries to Wongawilli Creek and Sandy Creek |

## 11. Risk Assessment Methodology

### 11.1 Qualitative Risk Analysis

This Risk Assessment has been performed using Qualitative Risk Analysis techniques and has been performed to align with the principles of the Australian Standard AS31000 - Risk Management Principles and Guidelines and the Department of Mineral Resource Guideline MDG1010.

The Risk Assessment has followed the WRAC (Workplace Risk Assessment and Control) principles as outlined in the guideline.

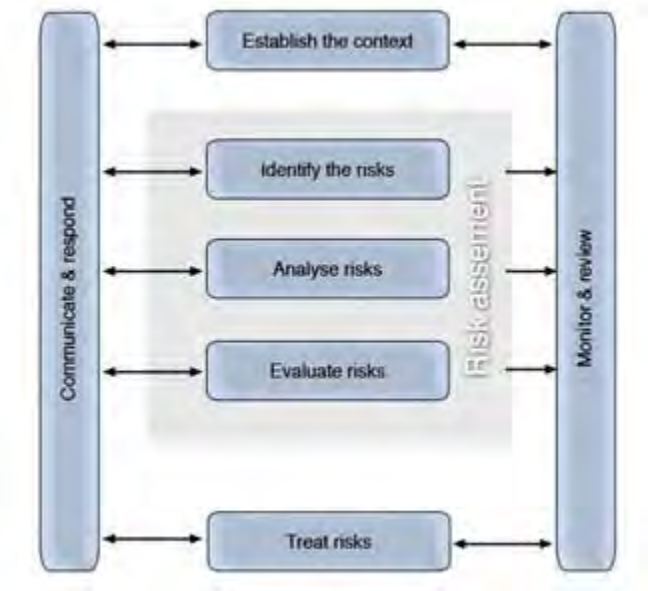
The qualitative approach succeeds by using local expert knowledge and relevant historical data.

This system of analysis uses a participative approach which is very powerful for identifying potential hazard scenarios.

The following steps outline the systematic identification of hazards, ranking of risks, and identification of new and/or improved controls that were used in the Risk Assessment session:

1. Introduce team to the Risk Assessment process and the context of the Risk Assessment. This includes the scope and method of the Risk Assessment
2. Identify discrete components, or elements, of the Project
3. Identify and add potential deviation steps
4. Review each sub-system and identify loss scenarios - (Potential Incidents and Accidents)
5. For those hazards evaluate the risk using the risk rank method by determining the probability, consequence, and risk rank of each loss scenario
6. Identify existing controls for each hazard
7. Specify additional controls required to control the hazard(s)
8. Close the Risk Assessment
9. Document and distribute to the team for proof reading
10. Undertake verification of the assessment by a nominated person

The available Standards on Risk Management (including MDG1010) define the Risk Management process as that shown below.




### 11.2 Establish the Context

This risk analysis has been performed using Qualitative Risk Analysis techniques and is performed in compliance with the Department of Mineral Resources (now the Resources Regulator) Guideline MDG1010.

### 11.3 Identify Hazards

This step involves identification of all the hazards to be managed. To correctly apply this step a well-structured systematic process must be used, because controls may not be able to be implemented to reduce or eliminate any hazards missed at this point in the analysis.

For each hazard, the team identifies:

1. What Can Happen; and
2. How and Why it Can Happen

Checklists, Flowcharts and Brainstorming are used to identify hazards.

### 11.4 Analyse Risks

The main objectives of an analysis is to separate minor risks from major risks and to provide data to assist in the evaluation and treatment of hazards.

Risk Analysis involves considering the following:

1. Likelihood of the hazard occurring (identified as 'L' within the worksheets)
2. Consequences if the hazard does occur (identified as 'C' in the worksheets)
3. Determining any existing controls

The combination of the likelihood and the consequence determines the level of the risk involved. The likelihood and consequence categories used are outlined in Section 13.

During the assessment the consequences are categorised as either hazards to personnel, the environment or to the site operations. Reputation, legal compliance and community are also considered where appropriate.

The consequence category is identified on the Analysis Worksheets in the Column labelled 'T' for Type.

### 11.5 Evaluate Risks

Evaluation involves comparing the level of risk found during the analysis with previously established risk criteria. The output of this part of the process is a list of prioritised hazards for further action.

If the resulting hazards fall into the low or tolerable risk categories, they may be accepted with minimal further treatment. Although, low and tolerable hazards should be monitored and periodically reviewed to ensure that they remain tolerable.

If hazards do not fall into the low or tolerable risk category, then they should be treated using other options.

### 11.6 Treat Risks

Risk treatment involves identifying the range of options for treating risks, assessing the options and preparing risk treatment plans and implementing them.

Risk treatment may be in one of the following forms:

1. Risk avoidance. Decide not to proceed with the activity
2. Reduce likelihood. Reduce the chance of the risk occurring
3. Reduce the risk consequences. Reduce the consequence if the risk occurs
4. Retain (or accept) the risk. Plans should be put in place to mitigate the consequences of these risks in the event that they occur

Risk treatment options should be assessed on the extent of any additional benefits or opportunities created. A number of options may be considered and applied either individually or in a combination.

Risk treatment plans should be developed to identify responsibilities, schedules, budgets and performance measures and the review process that is to be established.

### 11.7 Monitor and Review

It is essential to monitor the effectiveness of the risk management system and the risk treatment implementation.

Risks and the effectiveness of control measures need to be monitored to ensure that the changing environments do not alter risk priorities. Few risks remain static.

Factors affecting likelihood and/or consequence change as do factors regarding suitability of controls.

### 11.8 Communications and Consultation

Communication and consultation are important during the entire risk management process. It is important to develop a communication plan for both internal and external stakeholders.

This should be a two-way consultation not a one-way flow of information.

Effectiveness of internal and external communications is important to ensure that those responsible for implementing risk management understand the basis on which all decisions have been made, and why particular actions are required.

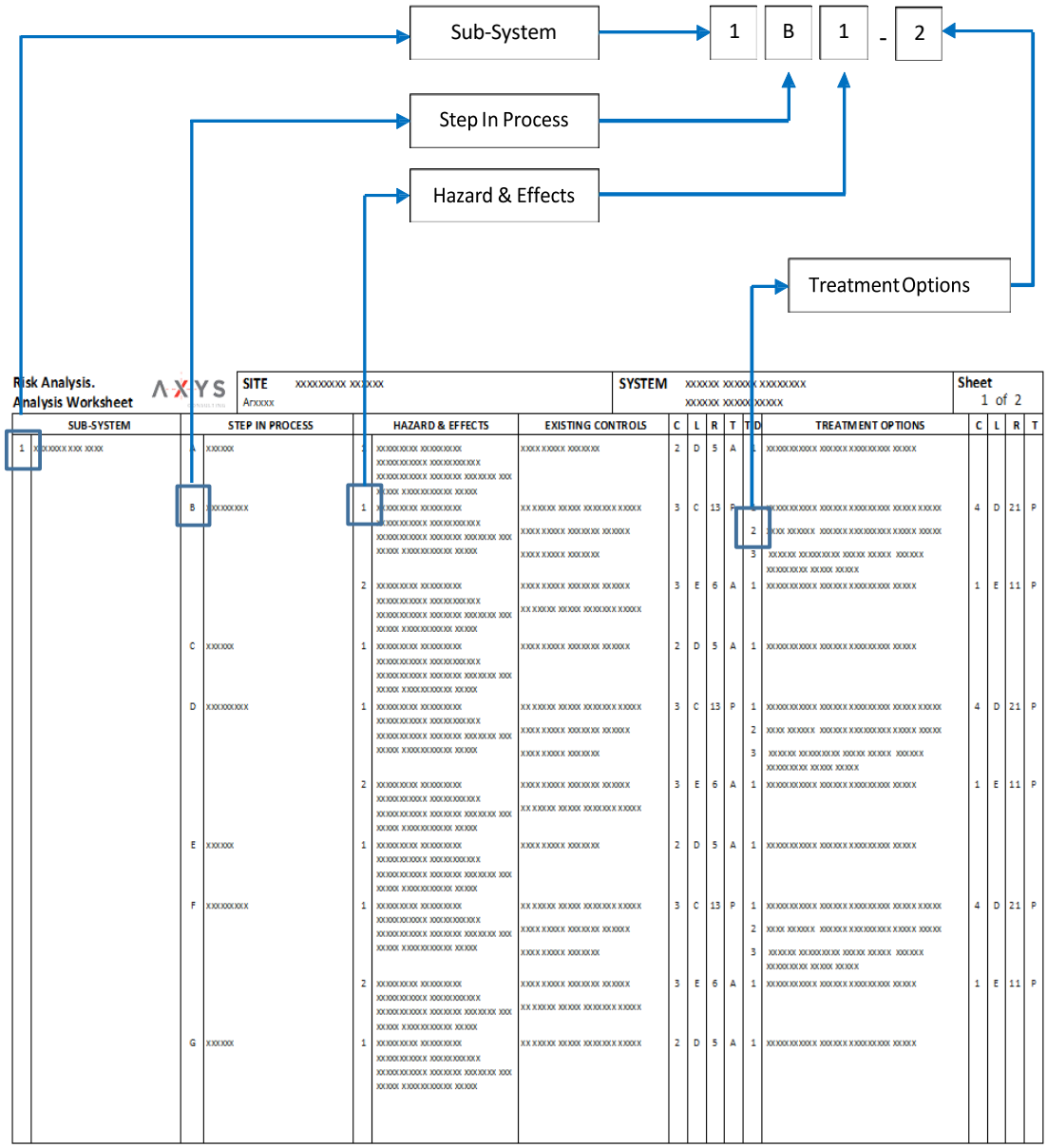
## 12. Risk Assessment Numbering

The assessment uses an alphanumeric numbering system to differentiate each component, the step in the process, the hazard and the treatment options.

The sub system number is found in the first column of the worksheets, the step is identified as a letter and is found in the third column, the hazard number in the fifth column and the treatment options in the TID (Treatment ID) column.

Using this method each hazard and treatment option throughout the analysis has a distinct identifier. This identifier then flows through all of the worksheets and can be referenced back to the Analysis Worksheets.

The example below shows the distinct identifier for the hazard is 1B1, the treatment option identified below would be identified as 1B1-2.



## 13. Risk Rank Method

For each event, the Likelihood and Consequence is determined and selected. If an event affects more than one area of consequence (e.g. affects people and operations), the highest rank number is always selected.

| Risk Matrix | | | | | | | |
|---|---|---|---|---|---|---|---|
| Likelihood | | Consequence | | | | | |
| | | Low 1 | Minor 3 | Moderate 10 | Significant 30 | Major 100 | Catastrophic 300 |
| 10 Almost Certain | Could be expected to occur more than once during the study or project.<br><br>Could occur once per year. | 10 | 30 | 100 | 300 | 1000 | 3000 |
| 3 Likely | Could easily be incurred and has generally occurred in similar studies or projects<br><br>Could be incurred 1 - 2 Years | 3 | 9 | 30 | 90 | 300 | 900 |
| 1 Possible | Incurred in a minority of similar studies or projects.<br><br>Could be incurred within a 5-year strategic budget period | 1 | 3 | 10 | 30 | 100 | 300 |
| 0.3 Unlikely | Known to happen, but only rarely.<br><br>Could be incurred within a 5 -20-year time frame | 0.3 | 0.9 | 3 | 9 | 30 | 90 |
| 0.1 Rare | Has not occurred in similar studies or projects, but could<br><br>Could be incurred 20 – 50 years | 0.1 | 0.3 | 1 | 3 | 10 | 30 |
| 0,03 Very Rare | Conceivable, but only in extreme circumstances.<br><br>Has not happened in industry in the last 50 years | 0.03 | 0.09 | 0.3 | 0.9 | 3 | 9 |

| Area of Effect | Estimated Level of Consequence | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 3 | 10 | 30 | 100 | 300 |
| **Harm to People (P)** | Low level short term subjective symptoms or inconvenience. No medical treatment | Objective but reversible impairment. Medical treatment injury or illness | Permanent impairment <30% of body to one or more persons | Single fatality. Permanent impairment >30% of body to one or more persons | 2-20 fatalities Permanent impairment >3-% of body more than 10 persons | >20 fatalities. Permanent impairment >30% of body to more than 100 persons |
| **Environmental (E)** | Low level impact to land, biodiversity, ecosystem services, water resources or air | Minor Impacts (<3 months) to land, biodiversity, ecosystem services, water resources or air | Moderate impacts. (<1 year) to land, biodiversity, ecosystem services, water resources or air | Major impacts (<5 years) to land, biodiversity, ecosystem services, water resources or air | Serious or extensive impacts (<20 years) to land, biodiversity, ecosystem services, water resources or air | Severe impacts (>20 years) to land, biodiversity, ecosystem services, water resources or air |
| **Community (C)** | Single low-level community health, safety or security impact, low level inconvenience <2 weeks, minor, low level disturbance to a single house or structure. | Minor community health, safety or security impacts (<10 households) or human rights infringements, inconvenience to livelihoods <6 months, moderate damage to <50 houses or community infrastructure | Moderate community health, safety or security impacts (<50 households). Single allegation of human rights violations, moderate disruption to people's lives (<50 households) | Serious community health, safety or security impacts (<50 households). Multiple allegations of human rights violations, extended disruption to people's lives (>50 households) | Serious community health, safety or security impacts (>50 households) or human rights violation, extended disruption to people's lives (>200 households) | Extensive community health, safety or security impacts (>200 households) or human rights violations, extended serious disruption to people's lives (>1000 households) |
| **Reputation (R)** | Public concern restricted to local complaints. Low level interest from local media and/or regulator | Adverse local public or media attention and complaints. Heightened scrutiny from regulator. Asset reputation is adversely affected with a small number of people | Attention from regional media and/or heightened concern by local community. Criticism by community, NGOs or activists. Asset reputation adversely affected. | Adverse national media attention. General public and NGO adverse reaction with interest from regulators with no material outcome. Structured campaigning from employees. | Serious national and international negative media attention. General public and NGO adverse reaction with interest from regulators (<3 months). Structured campaigning from employees. | Crisis event or publication of confidential material information resulting in international media, government, regulator, NGO campaigning and employee condemnation of the company (<6 months) |
| **Legal (L)** | Low level legal issue | Minor legal issues and non- compliance with commitments | Breach of regulation. Lack of valid exploration title | Significant civil litigation | Prosecutions for criminal breaches resulting in gaol terms for employees or agents or defendant to major civil litigation | Lack of valid operating title, forced closure of an operation, competition, anti-corruption, international trade law or tax breach |
| **Financial (F)** | <US$500,000 | US$5,000,000 to >US$500,000 | US$25,000,000 to >US$5,000,000 | US$100,000,000 to >US$25,000,000 | US$250,000,000 to >US$100,000,000 | >$250,000,000 |

# Attachment 1

Analysis Worksheets

| SUB-SYSTEM | | STEP IN PROCESS | | HAZARD & EFFECTS | | EXISTING CONTROLS | C | L | R | T | TID | TREATMENT OPTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Review Dendrobium Longwall 19 Subsidence Management Plan | A | Groundwater | 1 | Surface subsidence and sub-surface ground movements result in impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference Policy and associated Minimal Harm Criteria) on groundwater quantity | Groundwater Licence with sufficient Groundwater allocation<br>Ground and Surface Water Monitoring (Piezometers, Mine water balance and water chemistry) data is analysed in independent studies, results inform surface and groundwater models and analysis. These models are used to ensure compliance with approval conditions and to demonstrate compliance.<br>Mine Design set back from Wongawilli Creek, Sandy Creek and water supply reservoirs<br>Mine Design limiting extraction height to 3.9 metres<br>Calibrated subsidence model is used to design mine setbacks from Wongawilli Creek to limit groundwater impacts/interactions. Subsidence monitoring data is analysed and interrogated against predictions to verify modelling and inform the model.<br>Height of Fracturing Investigation | 10 | 0.3 | 3 | L | 1 | Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals |

| SUB-SYSTEM | | STEP IN PROCESS | | HAZARD & EFFECTS | | EXISTING CONTROLS | C | L | R | T | TID | TREATMENT OPTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Review Dendrobium Longwall 19 Subsidence Management Plan | A | Groundwater | 2 | Lineaments result in impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference policy, minimal harm criteria) on groundwater quantity | Lineaments are mapped and recorded<br>Lineaments are assessed for correlation with know geological conditions<br>Surface Mapping around lineaments to understand if there is an associated geological feature<br>Drilling on both surface and underground targeting known and inferred geology completed<br>The IEP Part 1 Report has been reviewed with the key recommendations of Section 3.6 [Recommendations 1 and 3] implemented to determine mine design constraints to achieve compliance with consent conditions<br>Groundwater Licence with sufficient Groundwater allocation<br>Ground and Surface Water Monitoring (Piezometers, Mine water balance and water chemistry) data is analysed in independent studies, results inform surface and groundwater models and analysis. These models are used to ensure compliance with approval conditions and to demonstrate compliance.<br>Mine Design set back from significant geological features<br>Mine Design limiting extraction height to 3.9 metres<br>Calibrated subsidence model is used to design mine setbacks from Wongawilli Creek to limit groundwater impacts/interactions. Subsidence monitoring data is analysed and interrogated against predictions to verify modelling and inform the model. | 10 | 0.3 | 3 | L | 1<br>2<br>3<br>4<br>5 | Assess any correlation between groundwater fingerprinting (chemistry) and lineaments. Outcomes of this investigation will be considered in future mine design around lineaments.<br>Assess any correlation between piezometers response and lineaments. Outcomes of this investigation may influence future exploration drilling and assessments.<br>Review existing report regarding impacts of surface subsidence associated with lineaments. Outcomes of this investigation will be included in the knowledge base to support subsidence modelling and assessments.<br>Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals<br>In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |

| SUB-SYSTEM | | STEP IN PROCESS | | HAZARD & EFFECTS | | EXISTING CONTROLS | C | L | R | T | TID | TREATMENT OPTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Review Dendrobium Longwall 19 Subsidence Management Plan | A | Groundwater | 3 | Faults and Dykes result in impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference policy, minimal harm criteria) on groundwater quantity | Faults and Dykes are mapped and recorded<br>Surface geological mapping around Faults and Dykes<br>Drilling on both surface and underground targeting known and inferred geology completed<br>Extensive exploration program undertaken to identify location of Faults and Dykes<br>Review of Permeability of Geological Structures in the Dendrobium Area J DOYLE 2007<br>Tonkin, C., & Timms, W. (2015). Geological Structures and Fault-infill in the Southern Coalfields and Implications for Groundwater Flow. Journal of Research Projects Review, 4, 49 -58.<br>Mine Design avoids major geological structures | 10 | 0.3 | 3 | L | 1 | Assess any correlation between mine water chemistry and known geology due to Faults and Dykes. Outcomes of this investigation will be used in assessments of surface and groundwater impacts and mine design around faults and dykes |
| | | | | | | | | | | | 2 | Review Reporting of Geological Features relevant to Longwall 19 to determine if further investigatory actions such as inseam and or surface drilling are required to define geological features |
| | | | | | | | | | | | 3 | Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals |
| | | | | | | | | | | | 4 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1 | | B | Avon and Cordeaux Reservoir | 1 | Surface subsidence and sub-surface ground movements result in impacts in excess of development consent conditions on water quantity. | Longwall Panel is a minimum of 900 metres from Cordeaux Reservoir full supply level<br>Longwall Panel is greater than 3000 metres from Avon Reservoir full supply level<br>Longwall Panel is outside the Dams Safety NSW notification areas for Cordeaux and Avon Reservoirs<br>Ground and Surface Water Monitoring (Piezometers, Mine water balance and water chemistry) data is analysed in independent studies, results inform surface and groundwater models and analysis. These models are used to ensure compliance with approval conditions and to demonstrate compliance.<br>Mine Design avoids major geological structures | 30 | 0.03 | 0.9 | F | 1 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures |

| SUB-SYSTEM | | STEP IN PROCESS | | HAZARD & EFFECTS | | EXISTING CONTROLS | C | L | R | T | TID | TREATMENT OPTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Review Dendrobium Longwall 19 Subsidence Management Plan | B | Avon and Cordeaux Reservoir | 2 | Valley Closure (including basal shear) results in impacts in excess of development consent conditions on water quantity | Subsidence Monitoring - (Closure Lines, Vertical Subsidence, 3D Far-Field, ALS, Visual Inspection) data is analysed in independent studies, results inform the calibrated subsidence model and mine planning decisions<br>Longwall Panel is a minimum of 900 metres from Cordeaux Reservoir full supply level<br>Longwall Panel is greater than 3000 metres from Avon Reservoir full supply level<br>Longwall Panel is outside the Dams Safety NSW notification areas for Cordeaux and Avon Reservoirs<br>Ground and Surface Water Monitoring (Piezometers, Mine water balance and water chemistry) data is analysed in independent studies, results inform surface and groundwater models and analysis. These models are used to ensure compliance with approval conditions and to demonstrate compliance.<br>Groundwater models are informed by recent and ongoing investigations into changes to permeability (including basal shear) along the Avon Reservoir shoreline in order to assess possible reduction in quantity of surface water available for water supply. | 30 | 0.03 | 0.9 | F | 1<br>2 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures<br>Review the findings of recent and ongoing investigations into strata permeability and the role of basal shears by SCT and HGEO |

| SUB-SYSTEM | | STEP IN PROCESS | | HAZARD & EFFECTS | | EXISTING CONTROLS | C | L | R | T | TID | TREATMENT OPTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Review Dendrobium Longwall 19 Subsidence Management Plan | B | Avon and Cordeaux Reservoir | 3 | Lineaments result in impacts in excess of development consent conditions on water quantity | Lineaments are mapped and recorded<br>Lineaments are assessed for correlation with known geological conditions<br>Surface Mapping around lineaments to understand if there are any associated geological features<br>Targeted exploration drilling on both surface and underground<br>The IEP Part 1 Report has been reviewed with the key recommendations of Section 3.6 [Recommendations 1 and 3] implemented to determine mine design constraints to achieve compliance with consent conditions | 30 | 0.03 | 0.9 | F | 1 | Carry out an investigation to compare the impacts on lineaments from mining in the Western Coalfield (Springvale) and the Southern Coalfield. Outcomes of this investigation will inform lineament consideration in mine planning. |
| | | | | | | | | | | | 2 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures |
| | | | | | | | | | | | 3 | Review existing report regarding impacts of surface subsidence associated with lineaments. Outcomes of this investigation will be included in the knowledge base to support subsidence modelling and assessments. |
| | | | | | | | | | | | 4 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |

| SUB-SYSTEM | | STEP IN PROCESS | | HAZARD & EFFECTS | | EXISTING CONTROLS | C | L | R | T | TID | TREATMENT OPTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Review Dendrobium Longwall 19 Subsidence Management Plan | B | Avon and Cordeaux Reservoir | 4 | Faults, dykes and intrusions result in impacts in excess of development consent conditions on water quantity | Faults, Dykes and Intrusions are mapped and recorded<br>Surface geological mapping around Faults, Dykes and Intrusions<br>Targeted geological drilling from the surface and underground<br>Investigation and Reporting of Geological Features<br>Review of Permeability of Geological Structures in the Dendrobium Area J DOYLE 2007<br>Tonkin, C., & Timms, W. (2015). Geological Structures and Fault-infill in the Southern Coalfields and Implications for Groundwater Flow. Journal of Research Projects Review, 4, 49 -58.<br>Mine headings in Dendrobium Area 3A mined through a dyke under Cordeaux Reservoir which do not produce groundwater. This informs groundwater assessments and mine design.<br>Mine design avoids major geological structures<br>Extensive exploration program undertaken to identify location and characteristics of Faults, Dykes and Intrusions | 30 | 0.03 | 0.9 | B | 1<br>2 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures<br>In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |

| SUB-SYSTEM | | STEP IN PROCESS | | HAZARD & EFFECTS | | EXISTING CONTROLS | C | L | R | T | TID | TREATMENT OPTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Review Dendrobium Longwall 19 Subsidence Management Plan | B | Avon and Cordeaux Reservoir | 5 | Groundwater drawdown results in impacts in excess of development consent conditions on water quantity | Longwall Panel is a minimum of 900 metres from Cordeaux Reservoir full supply level<br>Longwall Panel is greater than 3000 metres from Avon Reservoir full supply level<br>Longwall Panel is outside the Dams Safety NSW notification areas for Cordeaux and Avon Reservoirs<br>Ground and Surface Water Monitoring (Piezometers, Mine water balance and water chemistry) data is analysed in independent studies, results inform surface and groundwater models. These models are used to design mining parameters to ensure compliance with approval conditions and to demonstrate compliance.<br>Mine Design avoids major geological structures<br>Regional and site specific Dendrobium Groundwater models are informed by recent and ongoing investigations into changes to permeability (including basal shear) along the Avon Reservoir shoreline in order to assess possible reduction in quantity of surface water available for water supply. | 30 | 0.03 | 0.9 | F | 1 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures |

| SUB-SYSTEM | | STEP IN PROCESS | | HAZARD & EFFECTS | | EXISTING CONTROLS | C | L | R | T | TID | TREATMENT OPTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Review Dendrobium Longwall 19 Subsidence Management Plan | C | Wongawilli Creek | 1 | Valley Closure (including basal shear) results in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences) | Longwall panels setback from Wongawilli Creek considering cumulative movements from Areas 3A, 3B and 3C<br>Calibrated subsidence model is used to assess longwall setback options from Wongawilli Creek to achieve performance measures. Subsidence monitoring data is analysed and interrogated against predictions to verify modelling.<br>Ground and Surface Water Monitoring (Piezometers, Mine water balance and water chemistry) data is analysed in independent studies, results inform surface and groundwater models. These models are used to design mining parameters to ensure compliance with approval conditions and to demonstrate compliance.<br>Mine design avoids major geological structures<br>Environmental Monitoring including visual inspections and aquatic ecology monitoring<br>Experience with mining next to Wongawilli Creek for Longwall Area 3A and 3B. Impact levels from these activities influence setbacks. Impacts to date have been in-line with modelling<br>Subsidence Management Plan - including End of Panel reporting and auditing against performance measures | 30 | 1 | 30 | F | 1<br>2 | Review Subsidence Management TARPS for Wongawilli Creek<br>Submit the Subsidence Management Plan for Longwall 19 |

| SUB-SYSTEM | | STEP IN PROCESS | | HAZARD & EFFECTS | | EXISTING CONTROLS | C | L | R | T | TID | TREATMENT OPTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Review Dendrobium Longwall 19 Subsidence Management Plan | C | Wongawilli Creek | 2 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences) | Lineaments are mapped and recorded<br>Lineaments are assessed for correlation with known geological conditions<br>Surface mapping around lineaments to understand if there is a geological feature associated<br>Targeted exploration drilling on both surface and underground<br>The IEP Part 1 Report has been reviewed with the key recommendations of Section 3.6 [Recommendations 1 and 3] implemented to determine mine design constraints to achieve compliance with consent conditions<br>Subsidence Management Plan - including end of panel reporting and auditing against performance measures<br>Calibrated subsidence model is used to design mine setbacks from Wongawilli Creek.<br>Subsidence Monitoring - (Closure Lines, Vertical Subsidence, 3D Far-Field, ALS, Visual Inspection) data is analysed in independent studies, results inform the calibrated subsidence model and mine planning decisions | 30 | 0.1 | 3 | F | 1 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |

| SUB-SYSTEM | | STEP IN PROCESS | | HAZARD & EFFECTS | | EXISTING CONTROLS | C | L | R | T | TID | TREATMENT OPTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Review Dendrobium Longwall 19 Subsidence Management Plan | C | Wongawilli Creek | 3 | Groundwater drawdown result in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences) | Longwall panels setback from Wongawilli Creek<br>Ground and Surface Water Monitoring (Piezometers, Mine water balance and water chemistry) data is analysed in independent studies, results inform surface and groundwater models. These models are used to design mining parameters to ensure compliance with approval conditions and to demonstrate compliance.<br>Mine Design avoids major geological structures<br>Revised surface water flow TARPS have been developed in consultation with DPIE and WaterNSW using the findings of the Wongawilli Creek Pool 43A Assessment tc assess mining related changes in flow conditions along Wongawilli Creek<br>Subsidence Management Plan - including end of panel reporting and auditing against performance measures | 30 | 1 | 30 | B | 1 | Nil Required |
| 1 | | D | Sandy Creek | 1 | Valley Closure (including basal shear) results in impacts in excess of development consent conditions for Sandy Creek (including no more than minor environmental consequences) | Longwall 19 is setback from Sandy Creek by 750 metres<br>Ground and Surface Water Monitoring (Piezometers, Mine water balance and water chemistry) data is analysed in independent studies, results inform surface and groundwater models. These models are used to design mining parameters to ensure compliance with approval conditions and to demonstrate compliance.<br>Mine design avoids major geological structures<br>Environmental Monitoring including visual inspections and aquatic ecology monitoring<br>Experience with mining next to Sandy Creek for Longwalls 6 to 8 which will inform future monitoring and TARPs<br>Subsidence Management Plan - including end of panel reporting and auditing against performance measures | 30 | 0.1 | 3 | B | 1 | Submit the Subsidence Management Plan for Longwall 19 |

| SUB-SYSTEM | | STEP IN PROCESS | | HAZARD & EFFECTS | | EXISTING CONTROLS | C | L | R | T | TID | TREATMENT OPTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Review Dendrobium Longwall 19 Subsidence Management Plan | D | Sandy Creek | 2 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Sandy Creek (including no more than minor environmental consequences) | Longwall 19 is setback from Sandy Creek by 750 metres<br>Lineaments are mapped and recorded<br>Lineaments are assessed for correlation with known geological conditions<br>Surface mapping around lineaments to understand if there is a geological feature associated<br>Targeted exploration drilling on both surface and underground<br>The IEP Part 1 Report has been reviewed with the key recommendations of Section 3.6 [Recommendations 1 and 3] implemented to determine mine design constraints to achieve compliance with consent conditions<br>Subsidence Management Plan - including end of panel reporting and auditing against performance measures<br>Subsidence Monitoring - (Closure Lines, Vertical Subsidence, 3D Far-Field, ALS, Visual Inspection) data is analysed in independent studies, results inform the calibrated subsidence model and mine planning decisions | 30 | 0.03 | 0.9 | F | 1 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1 | | D | | 3 | Groundwater drawdown result in impacts in excess of development consent conditions for Sandy Creek (including no more than minor environmental consequences) | Longwall 19 is setback from Sandy Creek by 750 metres<br>Ground and Surface Water Monitoring (Piezometers, Mine water balance and water chemistry) data is analysed in independent studies, results inform surface and groundwater models. These models are used to design mining parameters to ensure compliance with approval conditions and to demonstrate compliance.<br>Mine Design avoids major geological structures<br>Subsidence Management Plan - including end of panel reporting and auditing against performance measures | 30 | 0.3 | 10 | F | 1<br>2 | Consult with WaterNSW regarding replacement or improvement of SCL2 Gauging Station<br>Review the existing surface water flow TARPS in consultation with DPIE and WaterNSW. |

| SUB-SYSTEM | | STEP IN PROCESS | | HAZARD & EFFECTS | | EXISTING CONTROLS | C | L | R | T | TID | TREATMENT OPTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Review Dendrobium Longwall 19 Subsidence Management Plan | E | Sandy Creek Waterfall (SC-WF1) | 1 | Valley Closure (including basal shear) results in impacts in excess of development consent conditions for Sandy Creek Waterfall (SC-WF1) | Longwall 19 is setback from Sandy Creek Waterfall in excess of 900 metres<br>Surface Water Monitoring data is analysed in independent studies, results inform surface data analysis and TARPs. These are used to ensure compliance with approval conditions and to demonstrate compliance.<br>Mine design avoids major geological structures<br>Environmental Monitoring - (Visual Inspection)<br>Experience with mining next to Sandy Creek Waterfall for Longwalls 6 to 8.<br>Subsidence Management Plan - including end of panel reporting and auditing against performance measures<br>Ground Monitoring including High Resolution Closure Lines data is reviewed and assessed against the TARP and consent conditions | 30 | 0.1 | 3 | B | 1 | Develop a Sandy Creek Waterfall TARP for Longwall 19 |
| 1 | | E | | 2 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Sandy Creek Waterfall (SC-WF1) | Longwall 19 is setback from Sandy Creek Waterfall in excess of 900 metres<br>Lineaments are mapped and recorded<br>Lineaments are assessed for correlation with known geological conditions<br>Surface mapping around lineaments to understand if there is a geological feature associated<br>Targeted exploration drilling on both surface and underground<br>Subsidence Management Plan - including end of panel reporting and auditing against performance measures<br>Subsidence Monitoring - (Closure Lines, Vertical Subsidence, 3D Far-Field, ALS, Visual Inspection) data is analysed in independent studies, results inform the calibrated subsidence model and mine planning decisions<br>No identified geological structures coincident with the Sandy Creek Waterfal (SC-WF1)<br>Experience with mining next to Sandy Creek Waterfall for Longwalls 6 to 8. | 30 | 0.03 | 0.9 | F | 1 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |

| SUB-SYSTEM | | STEP IN PROCESS | | HAZARD & EFFECTS | | EXISTING CONTROLS | C | L | R | T | TID | TREATMENT OPTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Review Dendrobium Longwall 19 Subsidence Management Plan | F | Swamp Den15A | 1 | Surface subsidence, sub-surface movements or valley closure result in impacts in excess of development consent conditions for Swamp Den15A (subsidence leading to changes in swamp hydrology) Ranking has considered the loss of the entire swamp affecting the ecosystem functionality | Ground and Surface Water Monitoring, including Piezometers and Soil Moisture Probes. Data is analysed in independent studies and reported as part of TARP and end of panel process to assess impacts.<br>Environmental Monitoring including terrestrial and aquatic ecology monitoring programs - (LiDAR or other methods for the mapping of swamp boundaries, floristic monitoring of swamps)<br>Mine Design avoids major geological structures | 10 | 3 | 30 | F | 1 | Review the location of piezometers and soil moisture monitoring with automatic loggers within Swamp Den15A to confirm adequate monitoring of the swamp |
| 1 | | F | | 2 | Surface subsidence, sub-surface movements or valley closure result in impacts in excess of development consent conditions for Swamp Den15A (subsidence leading to swamp scour and erosion) Ranking has considered the loss of the entire swamp affecting the ecosystem functionality | Ground and Surface Water Monitoring, including Piezometers and Soil Moisture Probes. Data is analysed in independent studies and reported as part of TARP and end of panel process to assess impacts.<br>Environmental Monitoring including terrestrial and aquatic ecology monitoring programs - (LiDAR or other methods for the mapping of swamp boundaries, floristic monitoring of swamps)<br>Mine Design avoids major geological structures | 10 | 0.03 | 0.3 | L | 1 | Review the location of piezometers and soil moisture monitoring with automatic loggers within Swamp Den15A to confirm adequate monitoring of the swamp |
| 1 | | F | | 3 | Surface subsidence, sub-surface movements or valley closure result in impacts in excess of development consent conditions for Swamp Den15A (subsidence leading to changes in ecosystem functionality i.e. changes in species richness and composition). Ranking has considered the loss of the entire swamp affecting the ecosystem functionality | Environmental Monitoring including terrestrial and aquatic ecology monitoring programs - (LiDAR or other methods for the mapping of swamp boundaries, floristic monitoring of swamps)<br>Ground and Surface Water Monitoring, including Piezometers and Soil Moisture Probes. Data is analysed in independent studies and reported as part of TARP and end of panel process to assess impacts.<br>Mine Design avoids major geological structures | 300 | 0.03 | 9 | E | 1 | Review the location of piezometers and soil moisture monitoring with automatic loggers within Swamp Den15A to confirm adequate monitoring of the swamp |

| SUB-SYSTEM | | STEP IN PROCESS | | HAZARD & EFFECTS | | EXISTING CONTROLS | C | L | R | T | TID | TREATMENT OPTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Review Dendrobium Longwall 19 Subsidence Management Plan | F | Swamp Den15A | 4 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Swamp Den15A (subsidence leading to changes in hydrology, erosion of the surface or ecosystem functionality i.e. changes in species richness and composition).<br>Ranking has considered the loss of the entire swamp affecting the ecosystem functionality | Lineaments are mapped and recorded<br>Lineaments are assessed for correlation with know geological conditions<br>Surface mapping around lineaments to understand if there is any geological feature<br>Mine Design avoids major geological structures<br>Environmental Monitoring including terrestrial and aquatic ecology monitoring programs - (LiDAR or other methods for the mapping of swamp boundaries, floristic monitoring of swamps)<br>Ground and Surface Water Monitoring, including Piezometers and Soil Moisture Probes. Data is analysed in independent studies and reported as part of TARP and end of panel process to assess impacts. | 300 | 0.03 | 9 | E | 1<br>2<br>3 | Assess any correlation between piezometers response and lineaments for swamps, tributaries to Wongawilli Creek and Sandy Creek. Outcomes of this investigation may influence future exploration drilling and assessment.<br>Review the location of piezometers within Swamp Den15A to confirm adequate monitoring of the swamp<br>In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1 | | F | | 5 | Valley Closure (including basal shear) results in changes to the structural integrity of the Controlling Rockbar (SC10-RB14) in Swamp Den15A | Longwall 19 is setback 190 metres from Controlling Rockbar (SC10-RB14)<br>Experience with mining next to Controlling Rockbar (SC10-RB14) for Longwall 8 which mined within 110 metres of the Rockbar<br>Experience with mining near to (not directly beneath) Rockbars in Area 3B<br>Calibrated subsidence model is used to inform of predicted movements<br>Swamp Impact Monitoring Management and Contingency Plan (SIMMCP) includes mitigation and rehabilitation actions | 3 | 0.3 | 0.9 | F | 1 | Nil Required |

| SUB-SYSTEM | | STEP IN PROCESS | | HAZARD & EFFECTS | | EXISTING CONTROLS | C | L | R | T | TID | TREATMENT OPTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Review Dendrobium Longwall 19 Subsidence Management Plan | G | Swamps, Tributaries to Wongawilli Creek and Sandy Creek | 1 | Surface subsidence, sub-surface movements or valley closure result in impacts to Swamps, Tributaries to Wongawilli Creek and Sandy Creek.<br>Ranking has considered the loss of an individual small swamp. The effect is considered low due to the abundant comparable habitat available in the Cordeaux Catchment area. | Subsidence monitoring data is analysed and interrogated against predictions to verify modelling.<br>Ground and Surface Water Monitoring (Piezometers, Mine water balance and water chemistry) data is analysed in independent studies, results inform surface and groundwater models. The analysis is used to assess impacts and demonstrate compliance.<br>Mine Design avoids major geological structures<br>Subsidence Management Plan - including end of panel reporting and auditing against performance measures<br>Environmental Monitoring including terrestrial and aquatic ecology monitoring programs - (LiDAR or other methods for the mapping of swamp boundaries, floristic monitoring of swamps)<br>Research Programs e.g. Littlejohns Tree Frog, Giant Dragon Fly and Swamp Research Plans<br>Maddens Plains Environmental Offset | 3 | 3 | 9 | E | 1 | Review and update Subsidence Management TARPS in relation to Swamps, Tributaries to Wongawilli Creek and Sandy Creek |

| SUB-SYSTEM | | STEP IN PROCESS | | HAZARD & EFFECTS | | EXISTING CONTROLS | C | L | R | T | TID | TREATMENT OPTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Review Dendrobium Longwall 19 Subsidence Management Plan | G | Swamps, Tributaries to Wongawilli Creek and Sandy Creek | 2 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Swamps, Tributaries to Wongawilli Creek and Sandy Creek.<br>Ranking has considered the loss of an individual small swamp. The effect is considered low due to the abundant comparable habitat available in the Cordeaux Catchment area. | Lineaments are mapped and recorded<br>Lineaments are assessed for correlation with know geological conditions<br>Surface mapping around lineaments to understand if there is any geological feature<br>Targeted exploration drilling on both surface and underground<br>Ground and Surface Water Monitoring (Piezometers, flow observations and water chemistry) data is analysed in independent studies, results inform surface and groundwater models. The analysis is used to assess impacts and demonstrate compliance.<br>Mine Design avoids major geological structures<br>Subsidence Management Plan - including end of panel reporting and auditing against performance measures<br>Environmental Monitoring including terrestrial and aquatic ecology monitoring programs - (LiDAR or other methods for the mapping of swamp boundaries, floristic monitoring of swamps)<br>Subsidence Monitoring - (Closure Lines, Vertical Subsidence, 3D Far-Field, ALS, Visual Inspection) data is analysed in independent studies, results inform the calibrated subsidence model and mine planning decisions | 3 | 3 | 9 | E | 1 | Carry out an investigation to compare the impacts on lineaments from mining in the Western Coalfield (Springvale) and the Southern Coalfield. Outcomes of this investigation will inform lineament consideration in mine planning.<br>2 Assess any correlation between piezometers response and lineaments for swamps, tributaries to Wongawilli Creek and Sandy Creek. Outcomes of this investigation may influence future exploration drilling and assessment.<br>3 In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1 | | G | | 3 | Cumulative impacts, including the impacts of cracking of first and second order watercourses. Leading to changes to water supply quality | Surface Water Monitoring data is analysed in independent studies, results inform surface data analysis and TARPs. These are used to ensure compliance with approval conditions and to demonstrate compliance. | 10 | 0.1 | 1 | R | 1 | Nil Required |

| SUB-SYSTEM | | STEP IN PROCESS | | HAZARD & EFFECTS | | EXISTING CONTROLS | C | L | R | T | TID | TREATMENT OPTIONS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Review Dendrobium Longwall 19 Subsidence Management Plan | G | Swamps, Tributaries to Wongawilli Creek and Sandy Creek | 4 | Cumulative impacts, including the impacts of cracking of first and second order watercourses. Leading to effects on aquatic and terrestrial ecology. | Surface Water Monitoring data is analysed in independent studies, results inform surface data analysis and TARPs. These are used to ensure compliance with approval conditions and to demonstrate compliance.<br>Environmental Monitoring including terrestrial and aquatic ecology monitoring programs - (e.g. Littlejohns Tree Frog Monitoring Programme and other aquatic flora and fauna monitoring)<br>Set-back of the longwalls from Wongawilli Creek [and to a lesser extent, SC10]<br>Existing monitoring at numerous sites on Wongawilli Creek and its tributaries (esp. WC17) and Sandy Creek and its tributaries (esp. SC10 and SC10C). Monitoring frequency at these sites would be increased during and after extraction of LW19 in line with existing management plans. | 30 | 1 | 30 | E | 1 | Update the terrestrial ecology monitoring programme to incorporate detailed water quality analysis in relation to Littlejohns Tree Frog Monitoring sites |

# Attachment 2

Assessment Worksheets
(Risk Rank Order)

## Risk Analysis Risk Order

| REF | Risk | HAZARD | TID | TREATMENT OPTIONS |
|---|---|---|---|---|
| 1C1 | 30 | Valley Closure (including basal shear) results in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences) | 1 | Review Subsidence Management TARPS for Wongawilli Creek |
| | | | 2 | Submit the Subsidence Management Plan for Longwall 19 |
| 1C3 | 30 | Groundwater drawdown result in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences) | 1 | Nil Required |
| 1F1 | 30 | Surface subsidence, sub-surface movements or valley closure result in impacts in excess of development consent conditions for Swamp Den15A (subsidence leading to changes in swamp hydrology) Ranking has considered the loss of the entire swamp affecting the ecosystem functionality | 1 | Review the location of piezometers and soil moisture monitoring with automatic loggers within Swamp Den15A to confirm adequate monitoring of the swamp |
| 1G4 | 30 | Cumulative impacts, including the impacts of cracking of first and second order watercourses. Leading to effects on aquatic and terrestrial ecology. | 1 | Update the terrestrial ecology monitoring programme to incorporate detailed water quality analysis in relation to Littlejohns Tree Frog Monitoring sites |
| 1D3 | 10 | Groundwater drawdown result in impacts in excess of development consent conditions for Sandy Creek (including no more than minor environmental consequences) | 1 | Consult with WaterNSW regarding replacement or improvement of SCL2 Gauging Station. |
| | | | 2 | Review the existing surface water flow TARPS in consultation with DPIE and WaterNSW |
| 1F3 | 9 | Surface subsidence, sub-surface movements or valley closure result in impacts in excess of development consent conditions for Swamp Den15A (subsidence leading to changes in ecosystem functionality i.e. changes in species richness and composition). Ranking has considered the loss of the entire swamp affecting the ecosystem functionality | 1 | Review the location of piezometers and soil moisture monitoring with automatic loggers within Swamp Den15A to confirm adequate monitoring of the swamp |
| 1F4 | 9 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Swamp Den15A (subsidence leading to changes in hydrology, erosion of the surface or ecosystem functionality i.e. changes in species richness and composition).<br>Ranking has considered the loss of the entire swamp affecting the ecosystem functionality | 1 | Assess any correlation between piezometers response and lineaments for swamps, tributaries to Wongawilli Creek and Sandy Creek. Outcomes of this investigation may influence future exploration drilling and assessment. |
| | | | 2 | Review the location of piezometers within Swamp Den15A to confirm adequate monitoring of the swamp |
| | | | 3 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1G1 | 9 | Surface subsidence, sub-surface movements or valley closure result in impacts to Swamps, Tributaries to Wongawilli Creek and Sandy Creek. Ranking has considered the loss of an individual small swamp. The effect is considered low due to the abundant comparable habitat available in the Cordeaux Catchment area. | 1 | Review and update Subsidence Management TARPS in relation to Swamps, Tributaries to Wongawilli Creek and Sandy Creek |
| 1G2 | 9 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Swamps, Tributaries to Wongawilli Creek and Sandy Creek.<br>Ranking has considered the loss of an individual small swamp. The effect is considered low due to the abundant comparable habitat available in the Cordeaux Catchment area. | 1 | Carry out an investigation to compare the impacts on lineaments from mining in the Western Coalfield (Springvale) and the Southern Coalfield. Outcomes of this investigation will inform lineament consideration in mine planning. |
| | | | 2 | Assess any correlation between piezometers response and lineaments for swamps, tributaries to Wongawilli Creek and Sandy Creek. Outcomes of this investigation may influence future exploration drilling and assessment. |
| | | | 3 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |

| REF | Risk | HAZARD | TID | TREATMENT OPTIONS |
|---|---|---|---|---|
| 1A1 | 3 | Surface subsidence and sub-surface ground movements result in impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference Policy and associated Minimal Harm Criteria) on groundwater quantity | 1 | Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals |
| 1A2 | 3 | Lineaments result in impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference policy, minimal harm criteria) on groundwater quantity | 1 | Assess any correlation between groundwater fingerprinting (chemistry) and lineaments. Outcomes of this investigation will be considered in future mine design around lineaments. |
| | | | 2 | Assess any correlation between piezometers response and lineaments. Outcomes of this investigation may influence future exploration drilling and assessments. |
| | | | 3 | Review existing report regarding impacts of surface subsidence associated with lineaments. Outcomes of this investigation will be included in the knowledge base to support subsidence modelling and assessments. |
| | | | 4 | Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals |
| | | | 5 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1A3 | 3 | Faults and Dykes result in impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference policy, minimal harm criteria) on groundwater quantity | 1 | Assess any correlation between mine water chemistry and known geology due to Faults and Dykes. Outcomes of this investigation will be used in assessments of surface and groundwater impacts and mine design around faults and dykes |
| | | | 2 | Review Reporting of Geological Features relevant to Longwall 19 to determine if further investigatory actions such as inseam and or surface drilling are required to define geological features |
| | | | 3 | Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals |
| | | | 4 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1C2 | 3 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences) | 1 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1D1 | 3 | Valley Closure (including basal shear) results in impacts in excess of development consent conditions for Sandy Creek (including no more than minor environmental consequences) | 1 | Submit the Subsidence Management Plan for Longwall 19 |
| 1E1 | 3 | Valley Closure (including basal shear) results in impacts in excess of development consent conditions for Sandy Creek Waterfall (SC-WF1) | 1 | Develop a Sandy Creek Waterfall TARP for Longwall 19 |
| 1G3 | 1 | Cumulative impacts, including the impacts of cracking of first and second order watercourses. Leading to changes to water supply quality | 1 | Nil Required |
| 1B1 | 0.9 | Surface subsidence and sub-surface ground movements result in impacts in excess of development consent conditions on water quantity. | 1 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures |

| REF | Risk | HAZARD | TID | TREATMENT OPTIONS |
|---|---|---|---|---|
| 1B2 | 0.9 | Valley Closure (including basal shear) results in impacts in excess of development consent conditions on water quantity | 1 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures |
| | | | 2 | Review the findings of recent and ongoing investigations into strata permeability and the role of basal shears by SCT and HGEO |
| 1B3 | 0.9 | Lineaments result in impacts in excess of development consent conditions on water quantity | 1 | Carry out an investigation to compare the impacts on lineaments from mining in the Western Coalfield (Springvale) and the Southern Coalfield. Outcomes of this investigation will inform lineament consideration in mine planning. |
| | | | 2 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures |
| | | | 3 | Review existing report regarding impacts of surface subsidence associated with lineaments. Outcomes of this investigation will be included in the knowledge base to support subsidence modelling and assessments. |
| | | | 4 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1B4 | 0.9 | Faults, dykes and intrusions result in impacts in excess of development consent conditions on water quantity | 1 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures |
| | | | 2 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1B5 | 0.9 | Groundwater drawdown results in impacts in excess of development consent conditions on water quantity | 1 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures |
| 1D2 | 0.9 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Sandy Creek (including no more than minor environmental consequences) | 1 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1E2 | 0.9 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Sandy Creek Waterfall (SC-WF1) | 1 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1F5 | 0.9 | Valley Closure (including basal shear) results in changes to the structural integrity of the Controlling Rockbar (SC10-RB14) in Swamp Den15A | 1 | Nil Required |
| 1F2 | 0.3 | Surface subsidence, sub-surface movements or valley closure result in impacts in excess of development consent conditions for Swamp Den15A (subsidence leading to swamp scour and erosion) Ranking has considered the loss of the entire swamp affecting the ecosystem functionality | 1 | Review the location of piezometers and soil moisture monitoring with automatic loggers within Swamp Den15A to confirm adequate monitoring of the swamp |

# Attachment 3

Assessment Worksheets
(Consequence Order)

## Risk Analysis Consequence Order

| REF | Risk | HAZARD | TID | TREATMENT OPTIONS |
|---|---|---|---|---|
| 1F3 | 300 | Surface subsidence, sub-surface movements or valley closure result in impacts in excess of development consent conditions for Swamp Den15A (subsidence leading to changes in ecosystem functionality i.e. changes in species richness and composition). Ranking has considered the loss of the entire swamp affecting the ecosystem functionality | 1 | Review the location of piezometers and soil moisture monitoring with automatic loggers within Swamp Den15A to confirm adequate monitoring of the swamp |
| 1F4 | 300 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Swamp Den15A (subsidence leading to changes in hydrology, erosion of the surface or ecosystem functionality i.e. changes in species richness and composition).<br>Ranking has considered the loss of the entire swamp affecting the ecosystem functionality | 1 | Assess any correlation between piezometers response and lineaments for swamps, tributaries to Wongawilli Creek and Sandy Creek. Outcomes of this investigation may influence future exploration drilling and assessment. |
| | | | 2 | Review the location of piezometers within Swamp Den15A to confirm adequate monitoring of the swamp |
| | | | 3 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1B1 | 30 | Surface subsidence and sub-surface ground movements result in impacts in excess of development consent conditions on water quantity. | 1 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures |
| 1B2 | 30 | Valley Closure (including basal shear) results in impacts in excess of development consent conditions on water quantity | 1 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures |
| | | | 2 | Review the findings of recent and ongoing investigations into strata permeability and the role of basal shears by SCT and HGEO |
| 1B3 | 30 | Lineaments result in impacts in excess of development consent conditions on water quantity | 1 | Carry out an investigation to compare the impacts on lineaments from mining in the Western Coalfield (Springvale) and the Southern Coalfield. Outcomes of this investigation will inform lineament consideration in mine planning. |
| | | | 2 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures |
| | | | 3 | Review existing report regarding impacts of surface subsidence associated with lineaments. Outcomes of this investigation will be included in the knowledge base to support subsidence modelling and assessments. |
| | | | 4 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1B4 | 30 | Faults, dykes and intrusions result in impacts in excess of development consent conditions on water quantity | 1 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures |
| | | | 2 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |

| REF | Risk | HAZARD | TID | TREATMENT OPTIONS |
|---|---|---|---|---|
| 1B5 | 30 | Groundwater drawdown results in impacts in excess of development consent conditions on water quantity | 1 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures |
| 1C1 | 30 | Valley Closure (including basal shear) results in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences) | 1 | Review Subsidence Management TARPS for Wongawilli Creek |
| | | | 2 | Submit the Subsidence Management Plan for Longwall 19 |
| 1C2 | 30 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences) | 1 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1C3 | 30 | Groundwater drawdown result in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences) | 1 | Nil Required |
| 1D1 | 30 | Valley Closure (including basal shear) results in impacts in excess of development consent conditions for Sandy Creek (including no more than minor environmental consequences) | 1 | Submit the Subsidence Management Plan for Longwall 19 |
| 1D2 | 30 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Sandy Creek (including no more than minor environmental consequences) | 1 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1D3 | 30 | Groundwater drawdown result in impacts in excess of development consent conditions for Sandy Creek (including no more than minor environmental consequences) | 1 | Consult with WaterNSW regarding replacement or improvement of SCL2 Gauging Station |
| | | | 2 | Review the existing surface water flow TARPS in consultation with DPIE and WaterNSW. |
| 1E1 | 30 | Valley Closure (including basal shear) results in impacts in excess of development consent conditions for Sandy Creek Waterfall (SC-WF1) | 1 | Develop a Sandy Creek Waterfall TARP for Longwall 19 |
| 1E2 | 30 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Sandy Creek Waterfall (SC-WF1) | 1 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1G4 | 30 | Cumulative impacts, including the impacts of cracking of first and second order watercourses. Leading to effects on aquatic and terrestrial ecology. | 1 | Update the terrestrial ecology monitoring programme to incorporate detailed water quality analysis in relation to Littlejohns Tree Frog Monitoring sites |
| 1A1 | 10 | Surface subsidence and sub-surface ground movements result in impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference Policy and associated Minimal Harm Criteria) on groundwater quantity | 1 | Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals |
| 1A2 | 10 | Lineaments result in impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference policy, minimal harm criteria) on groundwater quantity | 1 | Assess any correlation between groundwater fingerprinting (chemistry) and lineaments. Outcomes of this investigation will be considered in future mine design around lineaments. |
| | | | 2 | Assess any correlation between piezometers response and lineaments. Outcomes of this investigation may influence future exploration drilling and assessments. |
| | | | 3 | Review existing report regarding impacts of surface subsidence associated with lineaments. Outcomes of this investigation will be included in the knowledge base to support subsidence modelling and assessments. |
| | | | 4 | Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals |

| REF | Risk | HAZARD | TID | TREATMENT OPTIONS |
|---|---|---|---|---|
| | | | 5 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1A3 | 10 | Faults and Dykes result in impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference policy, minimal harm criteria) on groundwater quantity | 1 | Assess any correlation between mine water chemistry and known geology due to Faults and Dykes. Outcomes of this investigation will be used in assessments of surface and groundwater impacts and mine design around faults and dykes |
| | | | 2 | Review Reporting of Geological Features relevant to Longwall 19 to determine if further investigatory actions such as inseam and or surface drilling are required to define geological features |
| | | | 3 | Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals |
| | | | 4 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1F1 | 10 | Surface subsidence, sub-surface movements or valley closure result in impacts in excess of development consent conditions for Swamp Den15A (subsidence leading to changes in swamp hydrology) Ranking has considered the loss of the entire swamp affecting the ecosystem functionality | 1 | Review the location of piezometers and soil moisture monitoring with automatic<br>loggers within Swamp Den15A to confirm adequate monitoring of the swamp |
| 1F2 | 10 | Surface subsidence, sub-surface movements or valley closure result in impacts in excess of development consent conditions for Swamp Den15A (subsidence leading to swamp scour and erosion) Ranking has considered the loss of the entire swamp affecting the ecosystem functionality | 1 | Review the location of piezometers and soil moisture monitoring with automatic<br>loggers within Swamp Den15A to confirm adequate monitoring of the swamp |
| 1G3 | 10 | Cumulative impacts, including the impacts of cracking of first and second order watercourses. Leading to changes to water supply quality | 1 | Nil Required |
| 1F5 | 3 | Valley Closure (including basal shear) results in changes to the structural integrity of the Controlling Rockbar (SC10-RB14) in Swamp Den15A | 1 | Nil Required |
| 1G1 | 3 | Surface subsidence, sub-surface movements or valley closure result in impacts to Swamps, Tributaries to Wongawilli Creek and Sandy Creek.<br>Ranking has considered the loss of an individual small swamp. The effect is considered low due to the abundant comparable habitat available in the Cordeaux Catchment area. | 1 | Review and update Subsidence Management TARPS in relation to Swamps, Tributaries to Wongawilli Creek and Sandy Creek |
| 1G2 | 3 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Swamps, Tributaries to Wongawilli Creek and Sandy Creek.<br>Ranking has considered the loss of an individual small swamp. The effect is considered low due to the abundant comparable habitat available in the Cordeaux Catchment area. | 1 | Carry out an investigation to compare the impacts on lineaments from mining in the Western Coalfield (Springvale) and the Southern Coalfield. Outcomes of this investigation will inform lineament consideration in mine planning. |
| | | | 2 | Assess any correlation between piezometers response and lineaments for swamps, tributaries to Wongawilli Creek and Sandy Creek. Outcomes of this investigation may influence future exploration drilling and assessment. |
| | | | 3 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |

# Attachment 4

## Risk Treatment Schedule and Action Plan

| ID | HAZARD | TID | TREATMENT OPTIONS | RESPONSIBILITY | IMPLEMENTATION | COMMENTS | COMPLETED (Sign Off) |
|---|---|---|---|---|---|---|---|
| 1A1 | Surface subsidence and sub-surface ground movements result in impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference Policy and associated Minimal Harm Criteria) on groundwater quantity | 1 | Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals | Cody Brady | Friday, 27 March 2020 | | |
| 1A2 | Lineaments result in impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference policy, minimal harm criteria) on groundwater quantity | 1 | Assess any correlation between groundwater fingerprinting (chemistry) and lineaments. Outcomes of this investigation will be considered in future mine design around lineaments. | Cody Brady (Assessment by HGEO) | Friday, 20 March 2020 | | |
| | | 2 | Assess any correlation between piezometers response and lineaments. Outcomes of this investigation may influence future exploration drilling and assessments. | Cody Brady (Assessment by HGEO) | Friday, 3 April 2020 | | |
| | | 3 | Review existing report regarding impacts of surface subsidence associated with lineaments. Outcomes of this investigation will be included in the knowledge base to support subsidence modelling and assessments. | Cody Brady | Friday, 27 March 2020 | | |
| | | 4 | Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals | Cody Brady | Ongoing | | |
| | | 5 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure | Cody Brady | As required | | |

| ID | HAZARD | TID | TREATMENT OPTIONS | RESPONSIBILITY | IMPLEMENTATION | COMMENTS | COMPLETED (Sign Off) |
|---|---|---|---|---|---|---|---|
| 1A3 | Faults and Dykes result in impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference policy, minimal harm criteria) on groundwater quantity | 1 | Assess any correlation between mine water chemistry and known geology due to Faults and Dykes. Outcomes of this investigation will be used in assessments of surface and groundwater impacts and mine design around faults and dykes | Cody Brady (Assessment by HGEO) | Friday, 20 March 2020 | | |
| | | 2 | Review Reporting of Geological Features relevant to Longwall 19 to determine if further investigatory actions such as inseam and or surface drilling are required to define geological features | Cody Brady | Completed | | |
| | | 3 | Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals | Cody Brady | Ongoing | | |
| | | 4 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure | Cody Brady | As required | | |
| 1B1 | Surface subsidence and sub-surface ground movements result in impacts in excess of development consent conditions on water quantity. | 1 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures | Cody Brady (Assessment by Watershed Hydrogeo) | Friday, 27 March 2020 | | |
| 1B2 | Valley Closure (including basal shear) results in impacts in excess of development consent conditions on water quantity | 1 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures | Cody Brady (Assessment by Watershed Hydrogeo) | Friday, 27 March 2020 | | |
| | | 2 | Review the findings of recent and ongoing investigations into strata permeability and the role of basal shears by SCT and HGEO | Cody Brady | Friday, 27 March 2020 | | |

| ID | HAZARD | TID | TREATMENT OPTIONS | RESPONSIBILITY | IMPLEMENTATION | COMMENTS | COMPLETED (Sign Off) |
|---|---|---|---|---|---|---|---|
| 1B3 | Lineaments result in impacts in excess of development consent conditions on water quantity | 1 | Carry out an investigation to compare the impacts on lineaments from mining in the Western Coalfield (Springvale) and the Southern Coalfield. Outcomes of this investigation will inform lineament consideration in mine planning. | Cody Brady (Assessment by SRK Consulting) | Friday, 1 May 2020 | | |
| | | 2 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures | Cody Brady (Assessment by Watershed Hydrogeo) | Friday, 27 March 2020 | | |
| | | 3 | Review existing report regarding impacts of surface subsidence associated with lineaments. Outcomes of this investigation will be included in the knowledge base to support subsidence modelling and assessments. | Cody Brady | Friday, 27 March 2020 | | |
| | | 4 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure | Cody Brady | As required | | |

| ID | HAZARD | TID | TREATMENT OPTIONS | RESPONSIBILITY | IMPLEMENTATION | COMMENTS | COMPLETED (Sign Off) |
|---|---|---|---|---|---|---|---|
| 1B4 | Faults, dykes and intrusions result in impacts in excess of development consent conditions on water quantity | 1 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures | Cody Brady (Assessment by Watershed Hydrogeo) | Friday, 27 March 2020 | | |
| | | 2 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure | Cody Brady (Assessment by Watershed Hydrogeo) | As required | | |
| 1B5 | Groundwater drawdown results in impacts in excess of development consent conditions on water quantity | 1 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures | Cody Brady | Friday, 27 March 2020 | | |
| 1C1 | Valley Closure (including basal shear) results in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences) | 1 | Review Subsidence Management TARPS for Wongawilli Creek | Cody Brady | Friday, 27 March 2020 | | |
| | | 2 | Submit the Subsidence Management Plan for Longwall 19 | Cody Brady | Friday, 6 March 2020 | | |
| 1C2 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences) | 1 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure | Cody Brady | As required | | |
| 1C3 | Groundwater drawdown result in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences) | 1 | Nil Required | | | | |

| ID | HAZARD | TID | TREATMENT OPTIONS | RESPONSIBILITY | IMPLEMENTATION | COMMENTS | COMPLETED (Sign Off) |
|---|---|---|---|---|---|---|---|
| 1D1 | Valley Closure (including basal shear) results in impacts in excess of development consent conditions for Sandy Creek (including no more than minor environmental consequences) | 1 | Submit the Subsidence Management Plan for Longwall 19 | Cody Brady | Friday, 6 March 2020 | | |
| 1D2 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Sandy Creek (including no more than minor environmental consequences) | 1 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure | Cody Brady | As required | | |
| 1D3 | Groundwater drawdown result in impacts in excess of development consent conditions for Sandy Creek (including no more than minor environmental consequences) | 1 | Consult with WaterNSW regarding replacement or improvement of SCL2 Gauging Station | Cody Brady / Josh Carlon | Completed | WaterNSW approached regarding this in February 2020 | |
| | | 2 | Review the existing surface water flow TARPS in consultation with DPIE and WaterNSW. | Cody Brady | During Longwall 19 SMP Application consultation | | |
| 1E1 | Valley Closure (including basal shear) results in impacts in excess of development consent conditions for Sandy Creek Waterfall (SC-WF1) | 1 | Develop a Sandy Creek Waterfall TARP for Longwall 19 | Cody Brady | Prior to Longwall 19 Extraction | | |
| 1E2 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Sandy Creek Waterfall (SC-WF1) | 1 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure | Cody Brady | As required | | |
| 1F1 | Surface subsidence, sub-surface movements or valley closure result in impacts in excess of development consent conditions for Swamp Den15A (subsidence leading to changes in swamp hydrology)<br>Ranking has considered the loss of the entire swamp affecting the ecosystem functionality | 1 | Review the location of piezometers and soil moisture monitoring with automatic loggers within Swamp Den15A to confirm adequate monitoring of the swamp | Cody Brady / Josh Carlon | Completed | | |

| ID | HAZARD | TID | TREATMENT OPTIONS | RESPONSIBILITY | IMPLEMENTATION | COMMENTS | COMPLETED (Sign Off) |
|---|---|---|---|---|---|---|---|
| 1F2 | Surface subsidence, sub-surface movements or valley closure result in impacts in excess of development consent conditions for Swamp Den15A (subsidence leading to swamp scour and erosion)<br>Ranking has considered the loss of the entire swamp affecting the ecosystem functionality | 1 | Review the location of piezometers and soil moisture monitoring with automatic loggers within Swamp Den15A to confirm adequate monitoring of the swamp | Cody Brady / Josh Carlon | Completed | | |
| 1F3 | Surface subsidence, sub-surface movements or valley closure result in impacts in excess of development consent conditions for Swamp Den15A (subsidence leading to changes in ecosystem functionality i.e. changes in species richness and composition).<br>Ranking has considered the loss of the entire swamp affecting the ecosystem functionality | 1 | Review the location of piezometers and soil moisture monitoring with automatic loggers within Swamp Den15A to confirm adequate monitoring of the swamp | Cody Brady / Josh Carlon | Completed | | |
| 1F4 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Swamp Den15A (subsidence leading to changes in hydrology, erosion of the surface or ecosystem functionality i.e. changes in species richness and composition).<br>Ranking has considered the loss of the entire swamp affecting the ecosystem functionality | 1 | Assess any correlation between piezometers response and lineaments for swamps, tributaries to Wongawilli Creek and Sandy Creek. Outcomes of this investigation may influence future exploration drilling and assessment. | Cody Brady (Assessment by HGEO) | Friday, 3 April 2020 | | |
| | | 2 | Review the location of piezometers within Swamp Den15A to confirm adequate monitoring of the swamp | Cody Brady / Josh Carlon | Completed | | |
| | | 3 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure | Cody Brady | As required | | |
| 1F5 | Valley Closure (including basal shear) results in changes to the structural integrity of the Controlling Rockbar (SC10-RB14) in Swamp Den15A | 1 | Nil Required | | | | |

| ID | HAZARD | TID | TREATMENT OPTIONS | RESPONSIBILITY | IMPLEMENTATION | COMMENTS | COMPLETED (Sign Off) |
|---|---|---|---|---|---|---|---|
| 1G1 | Surface subsidence, sub-surface movements or valley closure result in impacts to Swamps, Tributaries to Wongawilli Creek and Sandy Creek. Ranking has considered the loss of an individual small swamp. The effect is considered low due to the abundant comparable habitat available in the Cordeaux Catchment area. | 1 | Review and update Subsidence Management TARPS in relation to Swamps, Tributaries to Wongawilli Creek and Sandy Creek | Cody Brady | Friday, 27 March 2020 | | |
| 1G2 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Swamps, Tributaries to Wongawilli Creek and Sandy Creek. Ranking has considered the loss of an individual small swamp. The effect is considered low due to the abundant comparable habitat available in the Cordeaux Catchment area. | 1 | Carry out an investigation to compare the impacts on lineaments from mining in the Western Coalfield (Springvale) and the Southern Coalfield. Outcomes of this investigation will inform lineament consideration in mine planning. | Cody Brady (Assessment by SRK Consulting) | Friday, 1 May 2020 | | |
| | | 2 | Assess any correlation between piezometers response and lineaments for swamps, tributaries to Wongawilli Creek and Sandy Creek. Outcomes of this investigation may influence future exploration drilling and assessment. | Cody Brady (Assessment by HGEO) | Friday, 3 April 2020 | | |
| | | 3 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure | Cody Brady | As required | | |
| 1G3 | Cumulative impacts, including the impacts of cracking of first and second order watercourses. Leading to changes to water supply quality | 1 | Nil Required | | | | |
| 1G4 | Cumulative impacts, including the impacts of cracking of first and second order watercourses. Leading to effects on aquatic and terrestrial ecology. | 1 | Update the terrestrial ecology monitoring programme to incorporate detailed water quality analysis in relation to Littlejohns Tree Frog Monitoring sites | Cody Brady | Friday, 27 March 2020 | | |

# Attachment 5

Risk Rank Order
Associated with Lineaments

## Risk Analysis Risk Order (Associated with Lineaments)

| REF | Risk | HAZARD | TID | TREATMENT OPTIONS |
|---|---|---|---|---|
| 1F4 | 9 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Swamp Den15A (subsidence leading to changes in hydrology, erosion of the surface or ecosystem functionality i.e. changes in species richness and composition). Ranking has considered the loss of the entire swamp affecting the ecosystem functionality | 1 | Assess any correlation between piezometers response and lineaments for swamps, tributaries to Wongawilli Creek and Sandy Creek. Outcomes of this investigation may influence future exploration drilling and assessment. |
| | | | 2 | Review the location of piezometers within Swamp Den15A to confirm adequate monitoring of the swamp |
| | | | 3 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1G2 | 9 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Swamps, Tributaries to Wongawilli Creek and Sandy Creek. Ranking has considered the loss of an individual small swamp. The effect is considered low due to the abundant comparable habitat available in the Cordeaux Catchment area. | 1 | Carry out an investigation to compare the impacts on lineaments from mining in the Western Coalfield (Springvale) and the Southern Coalfield. Outcomes of this investigation will inform lineament consideration in mine planning. |
| | | | 2 | Assess any correlation between piezometers response and lineaments for swamps, tributaries to Wongawilli Creek and Sandy Creek. Outcomes of this investigation may influence future exploration drilling and assessment. |
| | | | 3 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1A2 | 3 | Lineaments result in impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference policy, minimal harm criteria) on groundwater quantity | 1 | Assess any correlation between groundwater fingerprinting (chemistry) and lineaments. Outcomes of this investigation will be considered in future mine design around lineaments. |
| | | | 2 | Assess any correlation between piezometers response and lineaments. Outcomes of this investigation may influence future exploration drilling and assessments. |
| | | | 3 | Review existing report regarding impacts of surface subsidence associated with lineaments. Outcomes of this investigation will be included in the knowledge base to support subsidence modelling and assessments. |
| | | | 4 | Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals |
| | | | 5 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1C2 | 3 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences) | 1 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1B3 | 0.9 | Lineaments result in impacts in excess of development consent conditions on water quantity | 1 | Carry out an investigation to compare the impacts on lineaments from mining in the Western Coalfield (Springvale) and the Southern Coalfield. Outcomes of this investigation will inform lineament consideration in mine planning. |
| | | | 2 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. Outcomes of this discussion paper will be used to define future monitoring and management procedures |

| REF | Risk | HAZARD | TID | TREATMENT OPTIONS |
|---|---|---|---|---|
| | | | 3 | Review existing report regarding impacts of surface subsidence associated with lineaments. Outcomes of this investigation will be included in the knowledge base to support subsidence modelling and assessments. |
| | | | 4 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1D2 | 0.9 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Sandy Creek (including no more than minor environmental consequences) | 1 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |
| 1E2 | 0.9 | Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Sandy Creek Waterfall (SC-WF1) | 1 | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure |

# Attachment 6

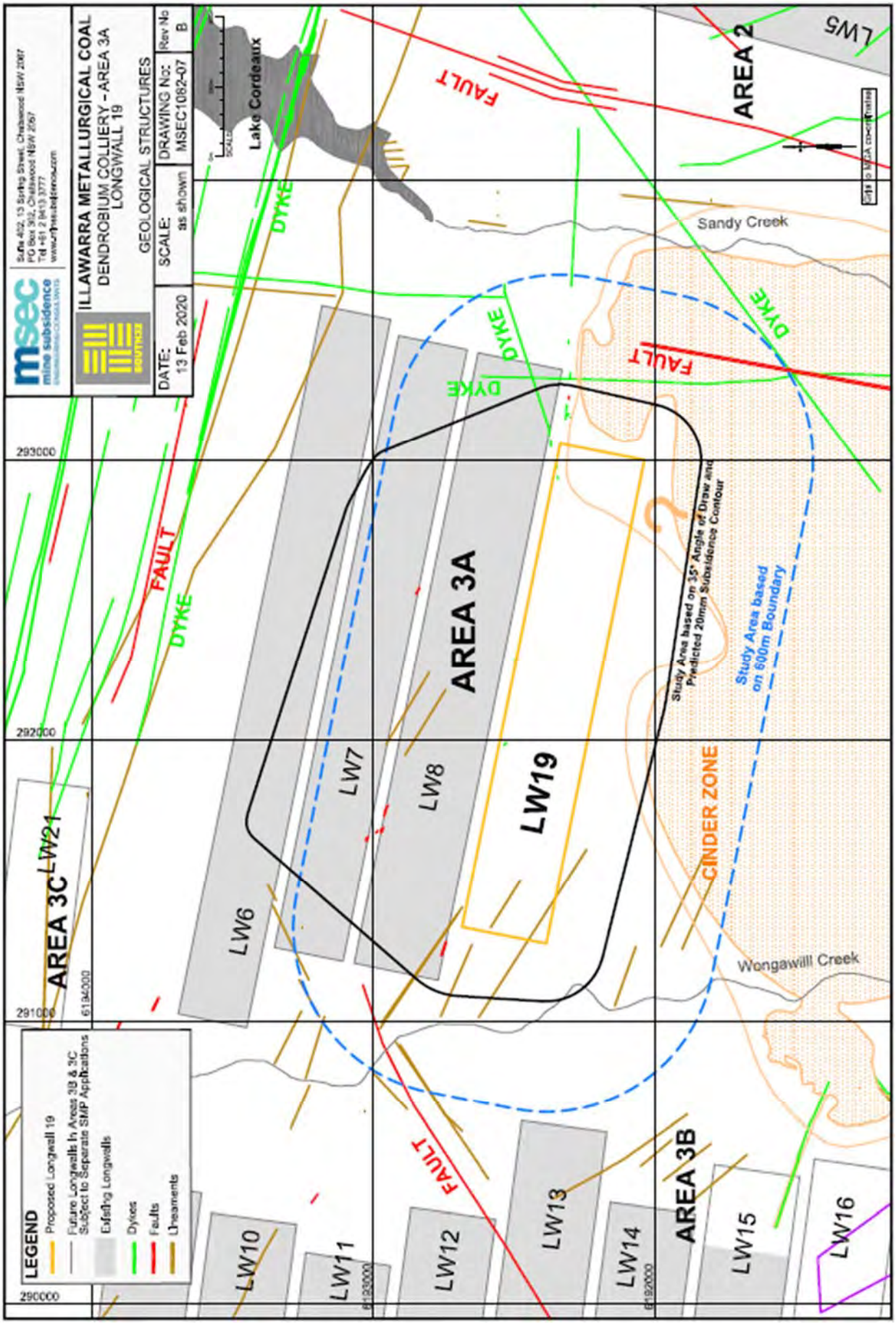
## Summary of Actions and Outcomes

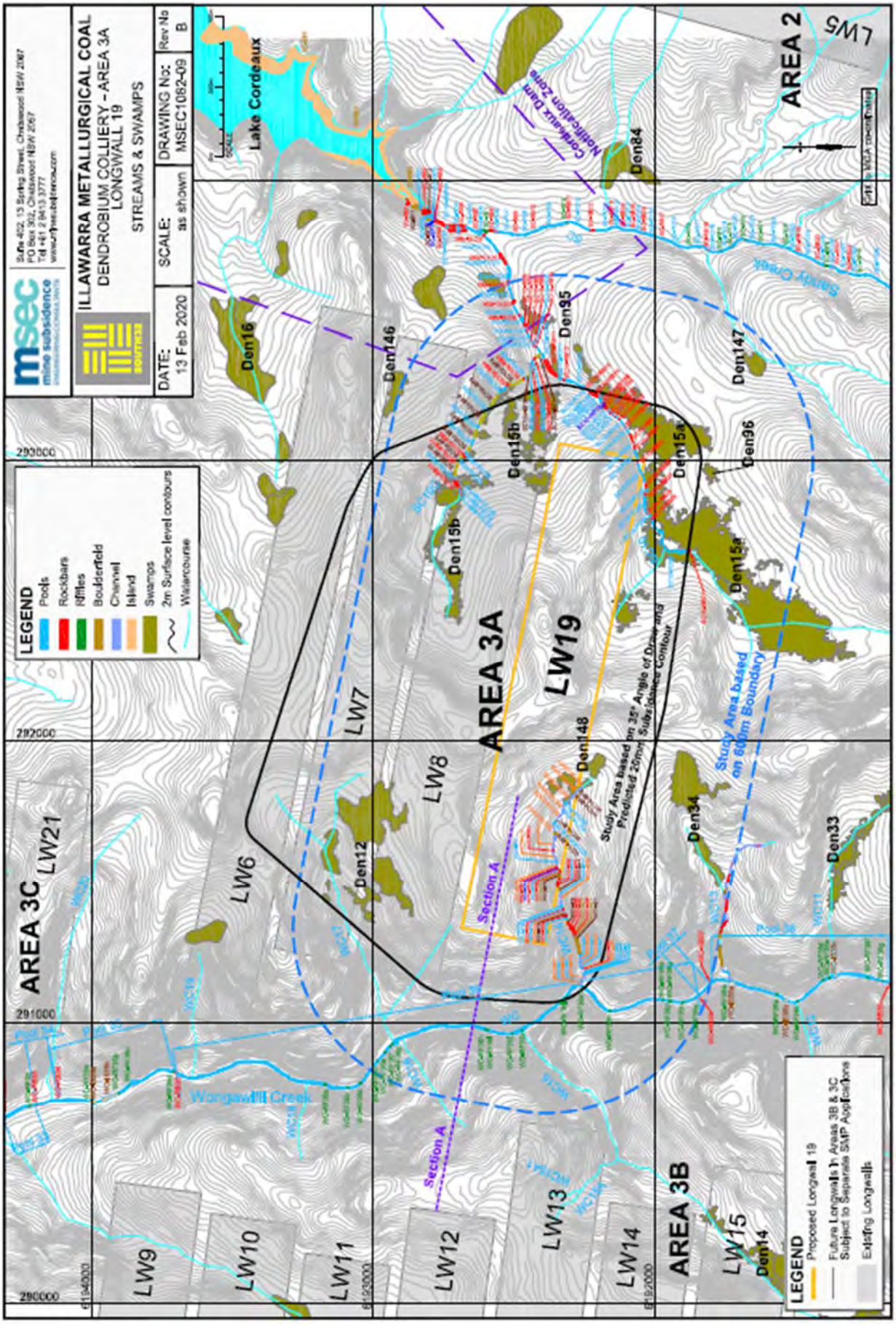
| ID | Treatment Options | Outcome | Action |
|---|---|---|---|
| 1A2 | Assess any correlation between groundwater fingerprinting (chemistry) and lineaments. | Outcomes of these investigations will be considered in future mine design around lineaments. | 1 |
| 1A3 | Assess any correlation between mine water chemistry and known geology due to Faults and Dykes. | Outcomes of this investigation will be used in assessments of surface and groundwater impacts and mine design around faults and dykes | |
| | Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals | Robust groundwater modelling predictions may inform mine design and setback from features | |
| | In the event that an anomalous, unmapped geological structure is encountered:<br>1. Assess the significance of the structure to increase understanding<br>2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling<br>3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure | | |
| 1A2 | Assess any correlation between piezometers response and lineaments. | Commission an investigation that assesses any correlation between piezometers response and lineaments (including Swamps, Tributaries to Wongawilli Creek and Sandy Creek). Outcomes of the investigation to be incorporated into various technical models, drilling exploration plans, mine design considerations. | 2 |
| 1F2, 1G1 | Assess any correlation between piezometers response and lineaments for swamps, tributaries to Wongawilli Creek and Sandy Creek. Outcomes of this investigation may influence future exploration drilling and assessment. | | |
| 1B1, 1B2, 1B3, 1B4, 1B5 | Complete a discussion paper on "Catchment Water Budget and Processes" relevant to the aspects identified in this Risk Assessment. | Outcomes of this investigation will be used in assessments of surface and groundwater impacts and mine design around geological structure and subsidence movements. | 3 |
| 1B3, 1G2 | Carry out an investigation to compare the impacts on lineaments from mining in the Western Coalfield (Springvale) and the Southern Coalfield. | Outcomes of this investigation will be considered in mine design around lineaments. | 4 |
| 1D3 | Consult with WaterNSW regarding replacement or improvement of SCL2 Gauging Station | Upgrade of the SCL2 Gauging Station | 5 |
| 1C1, | Review Subsidence Management TARPS for Wongawilli Creek. | Review Subsidence Management TARPS for Dendrobium Area 3B (including Wongawilli Creek, Sandy Creek, Swamps and Tributaries). | 6 |
| 1E1 | Develop a Sandy Creek Waterfall TARP for Longwall 19 | | |
| 1G1 | Review and update Subsidence Management TARPS in relation to Swamps, Tributaries to Wongawilli Creek and Sandy Creek | Determine if further geological investigations are required | |
| 1D3 | Review the existing surface water flow TARPS in consultation with DPIE and WaterNSW. | | |
| 1F1<br>1F2<br>1F3 | Review the location of piezometers and soil moisture monitoring with automatic loggers within Swamp Den15A to confirm adequate monitoring of the swamp | | |
| 1F4 | Review the location of piezometers within Swamp Den15A to confirm adequate monitoring of the swamp | | |
| 1A3<br>1A2 | Review Reporting of Geological Features relevant to Longwall 19 to determine if further investigatory actions such as inseam and or surface drilling are required to define geological features | | |

| ID | Treatment Options | Outcome | Action |
|---|---|---|---|
| 1B3 | Review existing report regarding impacts of surface subsidence associated with lineaments. Outcomes of this investigation will be included in the knowledge base to support subsidence modelling and assessments. | | |
| 1G4 | Update the terrestrial ecology monitoring programme to incorporate detailed water quality analysis in relation to Littlejohns Tree Frog Monitoring sites | More robust monitoring of potential impacts to Little John's Treefrog | 7 |
| 1B2 | Review the findings of recent and ongoing investigations into strata permeability and the role of basal shears by SCT and HGEO | Outcomes of this review will be considered in mine design around potential basal shears | 8 |
| 1C1, 1D1 | Submit the Subsidence Management Plan for Longwall 19. | Submit the Subsidence Management Plan for Longwall 19. | 9 |

# Attachment 7

Area 3A – Longwall 19
Plans


msec mine subsidence
ILLAWARRA METALLURGICAL COAL
DENDROBIUM COLLIERY - AREA 3A
LONGWALL 19
GEOLOGICAL STRUCTURES
DRAWING No: MSEC1082-07
Rev No B
SCALE: as shown
DATE: 13 Feb 2020
Lake Cordeaux
Sandy Creek
Wongawilli Creek
AREA 2
AREA 3A
AREA 3B
AREA 3C
LW5
LW6
LW7
LW8
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW19
LW21
FAULT
DYKE
CINDER ZONE
Study Area based on 35° Angle of Draw and Predicted 20mm Subsidence Contour
Study Area based on 600m Boundary
LEGEND
Proposed Longwall 19
Future Longwalls in Areas 3B & 3C Subject to Separate SMP Applications
Existing Longwalls
Dykes
Faults
Chainages
290000
291000
292000
293000
6194000
6193000
6192000


msec mine subsidence
ILLAWARRA METALLURGICAL COAL
DENDROBIUM COLLIERY - AREA 3A
LONGWALL 19
STREAMS & SWAMPS
DRAWING No: MSEC1062-09
Rev No B
SCALE: as shown
DATE: 13 Feb 2020
LEGEND
Pools
Rockbars
Riffles
Boulderfield
Channel
Island
Swamps
2m Surface level contours
Watercourse
AREA 3A
AREA 3B
AREA 3C
AREA 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW19
LW21
Lake Cordeaux
Cordeaux Dam Notification Zone
Wongawilli Creek
Section A
Section A
Study Area based on 60m Boundary
Study Area based on 35° Angle of Draw and Predicted 20mm Subsidence Contour
Den12
Den14
Den15a
Den15b
Den16
Den33
Den34
Den35
Den36
Den84
Den146
Den147
Den148
LEGEND
Proposed Longwall 19
Future Longwalls in Areas 3B & 3C Subject to Separate SMP Application
Existing Longwalls

# Attachment 8

Professor Bruce Hebblewhite
External Review

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6th March 2020

**Report No. 1912/02.2**
**Review of Dendrobium Longwall 19 Subsidence Management Plan Risk Assessment (v3.0)**

Review Background

South32 - Illawarra Metallurgical Coal (IMC) has requested an independent review of a Subsidence Management Plan Risk Assessment (RA) carried out for Dendrobium Mine Longwall 19 (LW19). The intention of this independent review is to provide independent, external comment and review of the risk assessment that was carried out by IMC. This report provides a final summary review of the risk assessment documentation provided by Mr Cody Brady, Principal Mining Approvals, IMC.

The risk assessment was carried out on 6 January 2020 under the leadership or facilitation of Mr Shane Chiddy from AXYS Consulting Pty Ltd (*"AXYS"*). A WRAC analysis technique was used to carry out the risk assessment. An interim version of the RA was reported by AXYS in their Report No. AR2817, Revision 2, dated 6 January 2020 (Revision 2 noted as carried out on 9 February 2020). A copy of this Revision 2 report was received from IMC on 18 February 2020. This Revision 2 version was reviewed in detail and a number of recommendations made to IMC and the RA team in a previous report (1912/02.1). These preliminary review comments have now been fully considered and incorporated in the latest, final version of the RA Report (*"the AXYS Report"*), being Revision 3, dated 28 February 2020, received on 4 March 2020.

The original motivation and objectives for the risk assessment came from a reference and subsequent direction from the NSW Independent Expert Panel on Mining in the Catchment (IEPMC), as outlined below:

> *"The Independent Expert Panel for Mining in the Catchment (the Panel) Initial Report on specific mining activities at Metropolitan and Dendrobium Mines was released in December 2018. The report recommended that any Subsidence Management Plan (SMP) application consider the potential implications for water quantity of faulting, basal shear planes and lineaments and that a Risk Assessment be included in applications to extract coal within Catchment Special Areas.*
>
> *The Department of Planning and Environment have recently provided correspondence to South 32 that the Panel have raised concerns regarding mining operations near or under lineaments in special areas of the*

*catchment of the Southern Coalfield. The Panel stated "specific regard to the potential impacts on surface water features, including swamps and waterfalls, of mining near and under lineaments".*

*Therefore, this Risk Assessment has been carried out to identify the existing controls associated with mining operations of Dendrobium's Longwall 19 in Special Areas of the catchment and to make recommendations for further controls where appropriate.*

*The main consideration is for compliance with the Dendrobium mine Development Consent, however safety, business interruption, community concerns, reputational damage and environmental issues have been considered where relevant."*

## Dendrobium Longwall 19 Background

The following background information regarding Dendrobium LW19 is taken directly from the AXYS Report:

*"IMC has completed the mining of Longwalls 6 to 8 in Area 3A at Dendrobium Mine with Longwall 8 finishing in December 2012. IMC proposes to extract Longwall 19 within the Wongawilli Seam, which is the final longwall in that series. The longwall will be extracted towards the main headings (i.e. retreat mining from the east towards the west) within the Wongawilli Seam. Longwall 19 will be extracted after Longwall 21 in Area 3C and prior to the extraction of Longwall 20 in Area 3C.*

*The Study Area (Figure 2) has been defined, as a minimum, as the surface area enclosed by the: 35° angle of draw line from the extents of the proposed Longwall 19; the predicted incremental 20 mm subsidence contour due to the extraction of the proposed longwall; natural features located within 600 m of the extent of the longwall mining area, in accordance with Condition 8(d), Schedule 3, of the Development Consent (DA 60-03- 2001); and features that are expected to experience either far-field horizontal movements, or valley related effects, and which could be sensitive to these movements. Specialist assessments submitted as part of the Longwall 19 SMP application should be read in conjunction with this risk assessment.*

*The maximum predicted subsidence effects for the existing and proposed longwalls in Area 3A (i.e. Longwall 6 to Longwall 8 and Longwall 19) are less than the maximum predicted values for the existing and approved longwalls in Area 3B (i.e. Longwall 9 to Longwall 17). The predicted subsidence effects are less, as the maximum mining height for Area 3A of 3.9 m is less than the maximum mining height for Area 3B of 4.6 m.*

*Natural and built features considered in the risk assessment:*

- *Wongawilli Creek is situated on the western side of the existing Longwall 6 to Longwall 8 and the proposed Longwall19 in Area 3A. The currently active longwalls in Area 3B are being mined on the western side of the creek. The thalweg (i.e. base or centreline) of the creek is located 175 m south-west of the finishing end of Longwall 19, at its closest point to the proposed longwall. The maximum predicted total subsidence effects for Wongawilli Creek, due to the mining in Areas 3A, 3B and 3C, are less than 20 mm vertical subsidence, 150 mm upsidence and 210 mm closure. The maximum predicted incremental movements along the creek, due to the mining of the proposed Longwall 19 only, are less than 20 mm vertical subsidence, 50 mm upsidence and 70 mm closure (MSEC 2020).*

- *Sandy Creek is located 750 m east of the commencing end of Longwall 19, at its closest point to the proposed longwall. At this distance, the creek is not predicted to experience measurable conventional or valley related effects due to the mining of Longwall 19. It is unlikely, therefore, that Sandy Creek would experience adverse impacts due to the mining of the proposed longwall (MSEC 2020).*

- *Sandy Creek Waterfall (SC – WF1) is located 900 m north-east of the commencing end of Longwall 19. The total closure measured at the waterfall, due to the previous mining of Longwall 6 to Longwall 8 in Area 3A, was 14 mm. The predicted incremental closure for Sandy Creek Waterfall, due to the mining of the proposed Longwall 19, is less than 2 mm, which is in the order of survey tolerance and environmental effects. It is considered unlikely, therefore, that Sandy Creek Waterfall would experience adverse impacts due to the mining of Longwall 19 (MSEC 2020).*

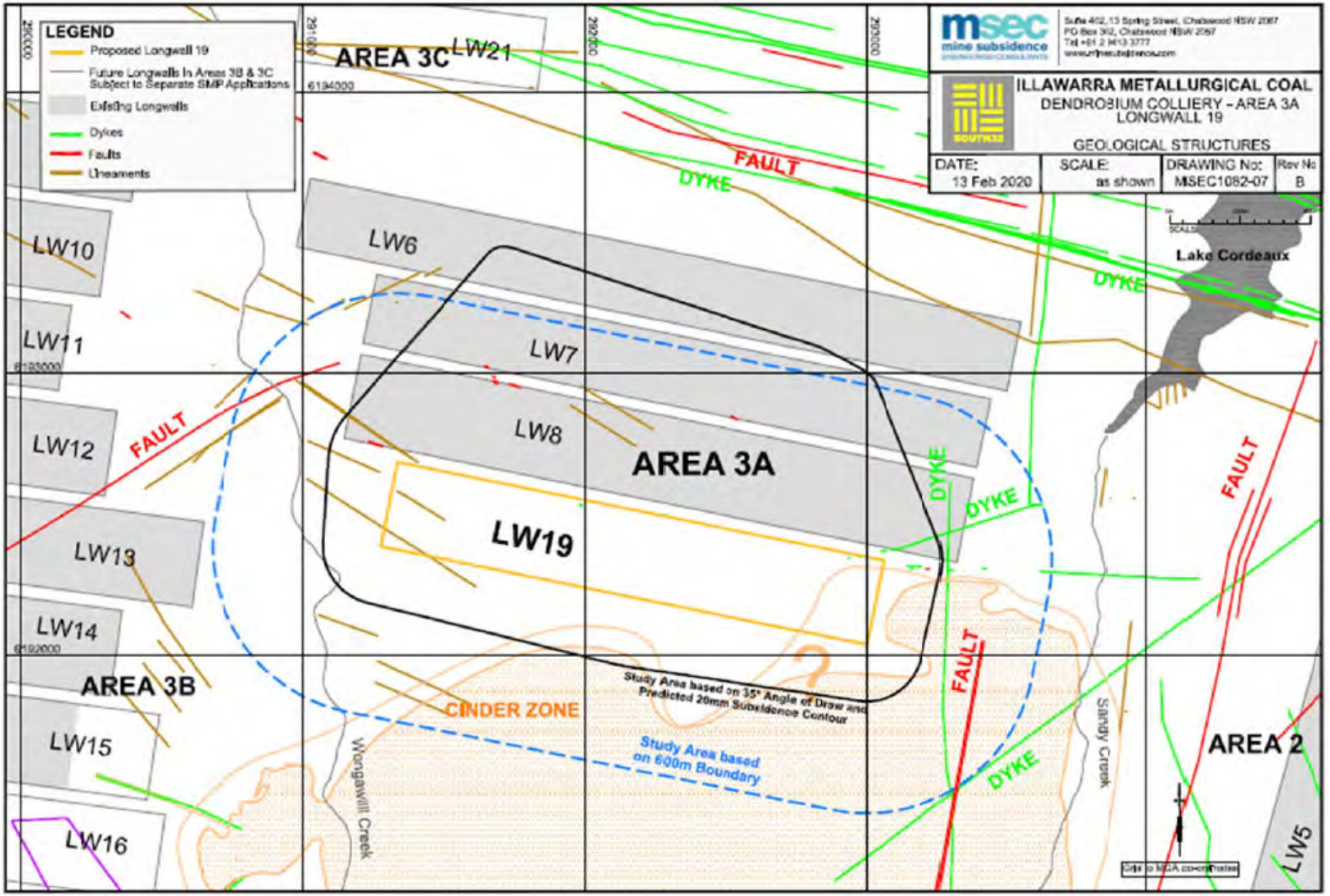
- *Drainage lines are located directly above and adjacent to the proposed longwall. These drainage lines are first and second order streams that form tributaries to Wongawilli and Sandy Creeks. The drainage lines could experience the full range of predicted subsidence effects (MSEC2020).*

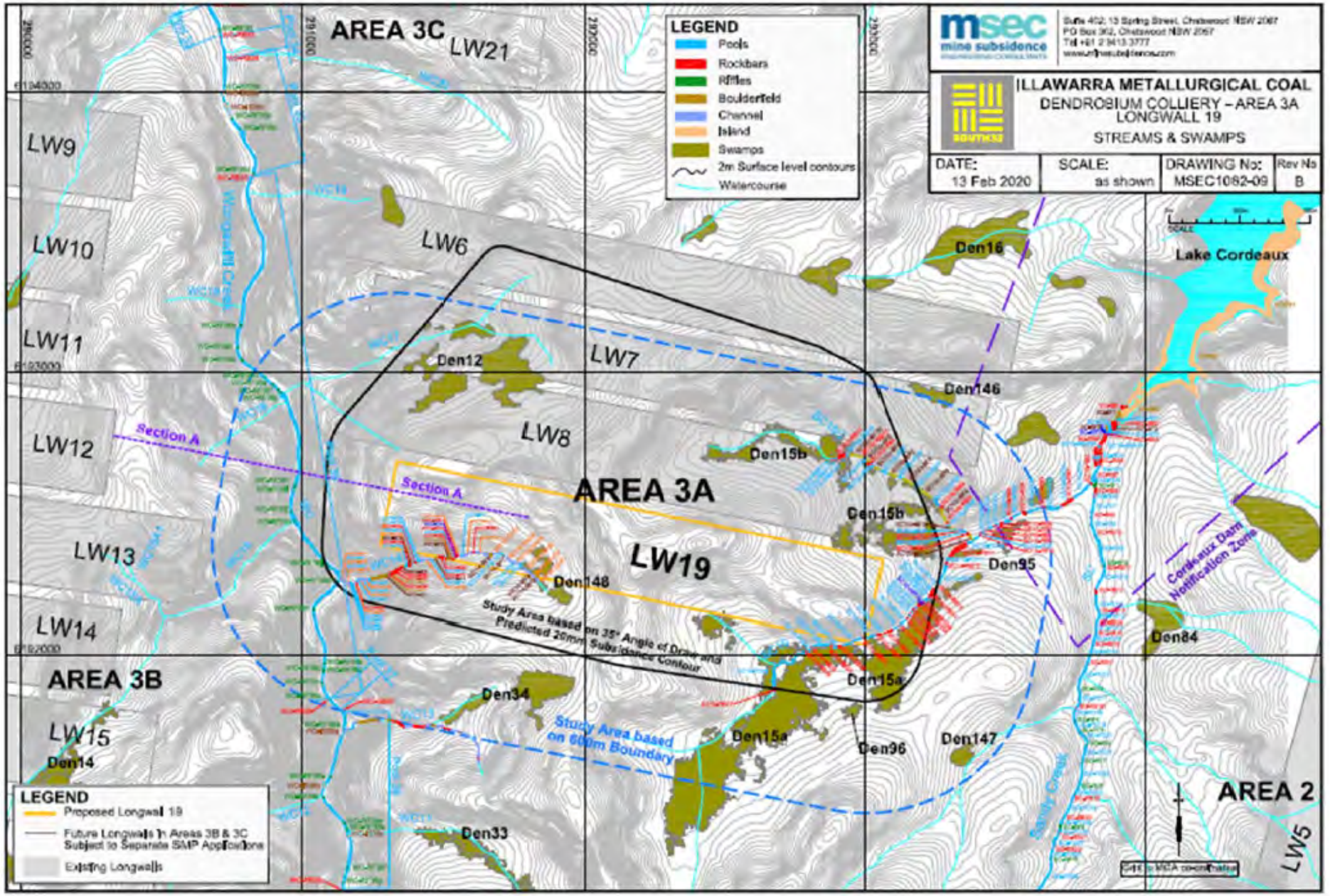
- *Swamps - there are six swamps that have been identified wholly or partially within the Study Area based on the 35° angle of draw and predicted 20 mm subsidence contour. There are six additional swamps that are located within the Study Area based on the 600 m boundary. A small part of Swamp Den15a is located above the south-eastern corner of the proposed Longwall 19. The remaining swamps are located outside the extents of the proposed longwall, at distances ranging between 170 m and 560 m at their closest points. Detailed subsidence predictions and potential impacts are detailed in MSEC 2020 and Niche 2020.*

- *Cordeaux and Avon Reservoirs are located at minimum distances of 0.9 km and 3.1 km, respectively, from the proposed Longwall 19. The Cordeaux Dam Wall and Avon Dam Wall are located at distances of more than 5 km from the proposed longwall. The predicted vertical and horizontal movements at the Cordeaux and Avon Reservoirs and their associated dam walls are very small and are unlikely to be measurable. Previous experience of mining in Areas 1, 2, 3A and 3B has not resulted in adverse impacts on these structures. It is unlikely, therefore, that the reservoirs and dam walls would experience adverse impacts due to the extraction of the proposed Longwall 19 (MSEC 2020).*

- *Geological Features at both inseam and surface levels considered as part of the risk assessment and are shown on Figure 3. Kagg (2020) includes a description of the conditions experienced during mining and inseam drilling of the nepheline syenite intrusion. This memorandum also states the key conclusion that geological conditions predicted in Area 3A are similar to conditions IMC have experienced previously in Area 2, 3A and 3B.*

The following two figures are also extracted from the AXYS Report, providing mine plan details, as referenced above (no figure numbers provided).


LEGEND
Proposed Longwall 19
Future Longwalls in Areas 3B & 3C Subject to Separate SMP Applications
Existing Longwalls
Dykes
Faults
Lineaments
AREA 3C
LW21
LW6
LW7
LW8
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW19
AREA 3A
AREA 3B
AREA 2
FAULT
DYKE
CINDER ZONE
Study Area based on 35° Angle of Draw and Predicted 20mm Subsidence Contour
Study Area based on 600m Boundary
Wongawilli Creek
Sandy Creek
Lake Cordeaux
LW5
msec mine subsidence
ILLAWARRA METALLURGICAL COAL
DENDROBIUM COLLIERY - AREA 3A
LONGWALL 19
GEOLOGICAL STRUCTURES
DATE: 13 Feb 2020
SCALE: as shown
DRAWING No: MSEC1082-07
Rev No B


AREA 3C
LW21
LW9
LW10
LW11
LW6
LW7
LW8
LW12
LW13
LW14
LW19
AREA 3A
AREA 3B
LW15
AREA 2
LW5
Den16
Den12
Den146
Den15b
Den95
Den148
Den84
Den15a
Den34
Den96
Den147
Den14
Den33
Lake Cordeaux
Section A
Section A
Study Area based on 35° Angle of Draw and Predicted 20mm Subsidence Contour
Study Area based on 600m Boundary
Cordeaux Dam Notification Zone
LEGEND
Pools
Rockbars
Riffles
Boulderfield
Channel
Island
Swamps
2m Surface level contours
Watercourse
LEGEND
Proposed Longwall 19
Future Longwalls in Areas 3B & 3C Subject to Separate SMP Applications
Existing Longwalls
msec mine subsidence
ILLAWARRA METALLURGICAL COAL
DENDROBIUM COLLIERY – AREA 3A
LONGWALL 19
STREAMS & SWAMPS
DATE: 13 Feb 2020
SCALE: as shown
DRAWING No: MSEC1062-09
Rev No B

Risk Assessment Scope

The specific scope of the RA was defined by IMC in the RA, as follows:

*"The objective of this Risk Assessment was to support the Longwall 19 SMP application and to address recommendations raised by the Panel. This Risk Assessment addressed the risks associated to legal compliance that may result from the extraction of Longwall 19.*

*A scoping session was carried out with the assessment team and the following items were agreed to be assessed:*

- *Groundwater*
- *Avon and Cordeaux Reservoirs*
- *Wongawilli Creek*
- *Sandy Creek*
- *Sandy Creek Waterfall (SCWF1)*
- *Swamps, including Den15A*
- *Swamps, Tributaries to Wongawilli Creek and Sandy Creek*

*For each of the items above the following concerns (where relevant) were reviewed and assessed:*

- *Surface subsidence*
- *Sub surface ground movements*
- *Valley closures*
- *Lineaments*
- *Faults*
- *Dykes*
- *Groundwater drawdown*

It should be noted that this scope is relatively broad and all-encompassing, including, but not limited to the particular issue identified by the IEPMC, being *"mining operations near or under lineaments in special areas of the catchment"*.

Risk Assessment Supporting Documents

The AXYS Report references the following related documents:

- *AS NZS ISO 31000-2009: Risk Management - Principles and guidelines*
- *MDG1010 - Risk Management Handbook for the Mining Industry*
- *MDG1014 - Guide to Reviewing a Risk Assessment of Mine Equipment and Operations*
- *Work Health and Safety Act 2011*
- *Work Health and Safety Regulation 2011*
- *Work Health and Safety (Mines and Petroleum Sites) Act 2013*
- *Work Health and Safety (Mines and Petroleum Sites) Regulation 2014*
- *Report from B K Hebblewhite Consulting titled: Dendrobium Mine – Longwalls 14-18 Independent Review – Height of Fracturing (Stage 2) (incorporating all content from March 2018 Stage 1 Report). File Name: 170803.2 (final) (1)*
- *Letter from Department of Planning and Environment titled: Independent Expert Panel for Mining in the Catchment, Advice Regarding Lineaments (File Name: 20190219_ltr to South32 Re: lineaments).*
- *Letter form Emeritus Professor Jim Galvin titled Re: IEPMC advice to Department of Planning and Environment Emerging knowledge regarding lineaments. File Name: IEPMC advice to DPE re-emerging knowledge lineaments.*

- *Watershed HydroGeo, 2019. Geographic review of mining effects on Upland Swamps at Dendrobium Mine. r008i5, March 2019*

It is noted that these related documents have not been reviewed as part of this current RA review.

Risk Assessment Review – Summary Commentary

The following overall summary comments are provided in response to the documentation provided by IMC in the form of the AXYS Report (v3.0).

- RA documentation structure – The report provides the detailed RA worksheets (Attachment 1). It is then followed by the same or supplementary material presented in several different forms:

  - Attachment 2 – Risk Rank order
  - Attachment 3 – Consequence order
  - Attachment 4 – Risk Treatment Schedule and Action Plan
  - Attachment 5 – Risk Rank Order associated with Lineaments
  - Attachment 6 – Summary of Actions and Outcomes
  - Attachment 7 – LW19 Mine Plans (as reproduced above).

  This format of reporting provides a useful means of summarising and referencing the outcomes of the RA.

- RA Team Participants – The RA Team Participants and subsequent reviewers are listed by AXYS below (*source: AXYS Report*):

| Name | Position | Relevant Years' Experience |
|---|---|---|
| Danial Baker | South32 - Dendrobium Mine Senior Planner | 15 Years |
| Luke Baker | Niche Environment and Heritage Ecologist | 12 Years |
| Will Minchin | Watergshed HydroGeo Hydrogeologist | 16 Years |
| Daniel Pygas | Cardno Principal Aquatic Ecology | 14 Years |
| James Barbato | Mine Subsidence Engineering Consultants (MSEC) Subsidence Engineer | 15 Years |
| Cody Brady | South32 - Illawarra Metallurgical Coal Principal Mining Approvals | 4 Years |

The following participants were not in attendance at the risk assessment held on 6 January though have reviewed this risk assessment report and provided feedback which has been incorporated. Professor Bruce Hebblewhite was engaged by Illawarra Metallurgical Coal to provide a peer review of the document which is provided in Attachment 8.

| Name | Position | Relevant Years' Experience |
|---|---|---|
| Prof. Bruce Hebblewhite | B K Hebblewhite Consulting Peer Reviewer | 40 Years |
| Dr Stuart Brown | HydroGeo | 25 Years |
| Gary Brassington | South32 - Approvals | 25 Years |

This cross-section of personnel represents an appropriate mix of the different and relevant professional disciplines and experience, including external expertise.

- RA worksheets – The worksheets provide a logical structure of assessment under a series of sub-systems which identify existing controls; followed by a risk ranking; and then a column under the heading of *"Treatment Options"*. The definition of Treatment Options is provided by AXYS on page 13 (section 11.6) and contains a number of either actions or further controls which are recommended to be adopted, either singularly or in combination.

- Treatment Options - It is important to understand clearly the differences between further actions intended to provide greater definition or information regarding the hazard or potential risk; and further controls which will actually reduce or eliminate the risk. It is noted that the RA documentation has been significantly improved in this final version, to provide greater clarity and more precise definition of the outcomes arising from various existing controls and proposed treatment options. Some of these outcomes have immediate impact in relation to LW19. Others provide input for subsequent mine planning and design practices.

- The RA makes frequent reference to the extensive monitoring program that is in place (both groundwater and subsidence-related), as a source of ongoing operational performance management. It is important that such data is used effectively and in a timely manner to provide further information regarding the impact of mining on the environment. This includes direct assessment in the context of TARPs in place; confirmation (or otherwise) of compliance issues; and a further valuable application is for ongoing back-analysis and validation (or future modification) of the various predictive modelling techniques in use – both for groundwater and subsidence modelling. These validation and potential improvement practices are critical and should be conducted on a regular basis, to ensure best-practice modelling and prediction methods.

- The RA addresses a number of potential application areas in relation to valley closure and basal shear impacts. A comprehensive set of appropriate actions and controls are provided, including future treatment options with identified outcomes/applications. It is recommended that every effort be made to increase the level of knowledge and understanding regarding the impact of shear planes (not just basal shears) on increased horizontal permeability; and the regional or far-field extent of such permeability changes resulting from mining. This is an important issue that needs a greater level of understanding and quantification, where possible.

- Turning to the summary attachments which provide risk ranking order, consequence order, and action summary and schedule, it is helpful that a specific table is provided (Appendix 5) which summarises the lineament-related risks and responses, in recognition of the importance of this issue as raised by the IEPMC.

Final Comment

The risk assessment has considered a comprehensive range of hazards and risks. An extensive list of existing controls and proposed further Treatment Options is provided, which is deemed appropriate in this final form of the RA Report.

The report forms a useful document for informing and directing future management, within the context of the LW19 Subsidence Management Plan.

Regards,



Bruce Hebblewhite

# APPENDIX A

Attached is a summary Curriculum Vitae for the author of this report, Bruce Hebblewhite. Bruce Hebblewhite has worked within the Australian mining industry from 1977 to the present time, through several different employment positions. Throughout this period, he has been actively involved in all facets of mining industry operations. In addition, he has visited and undertaken consulting and contract research commissions internationally in such countries as the UK, South Africa, China, New Zealand and Canada. For the majority of his 17 year employment period with ACIRL Ltd he had management responsibility for ACIRL's Mining Division which included specialist groups working within both the underground and surface coal mining sectors, and the coal preparation industry– actively involved in both consulting and research in each of these areas.

In his current employment position with The University of New South Wales, Bruce Hebblewhite is involved in academic management, undergraduate and postgraduate teaching and research, and contract industry consulting and provision of industry training and ongoing professional development programs – for all sectors of the mining industry – coal and metalliferous.

Both past and present employment positions require regular visits, inspections and site investigations throughout the Australian mining industry, together with almost daily contact with mining industry management, operations and production personnel.

---

*Disclaimer*

*Bruce Hebblewhite is employed as a Professor within the School of Minerals & Energy Resources Engineering, at The University of New South Wales (UNSW). In accordance with policy regulations of UNSW regarding external private consulting, it is recorded that this report has been prepared by the author in his private capacity as an independent consultant, and not as an employee of UNSW. The report does not necessarily reflect the views of UNSW and has not relied upon any resources of UNSW.*

**SUMMARY CURRICULUM VITAE**

# Bruce Kenneth Hebblewhite

*Professor, Chair of Mining Engineering,*
*School of Minerals & Energy Resources Engineering,*
*The University of New South Wales (part-time), &*

*Consultant Mining Engineer, B K Hebblewhite Consulting*

---

**DATE OF BIRTH** 1951

**NATIONALITY** Australian

**QUALIFICATIONS**
**1973**: Bachelor of Engineering (Mining) (Hons 1) School of Mining Engineering, Univ. of New South Wales

**1977**: Doctor of Philosophy, Department of Mining Engineering, University of Newcastle upon Tyne, UK
**1991:** Diploma AICD, University of New England

**PROFESSIONAL MEMBERSHIPS; APPOINTMENTS; AWARDS & SPECIAL RESPONSIBILITIES**
Fellow - Australasian Institute of Mining and Metallurgy
Member - Australian Geomechanics Society
Member – Society of Mining and Exploration Engineering (SME), USA
Member - International Society of Rock Mechanics (President – Mining Interest Group (2004 – 2011))
Member – Mine Subsidence Technological Society
Emeritus Member - Society of Mining Professors (SOMP) (President (2008/09); Council Member (2006 - 2018); Secretary-General (2011-2018))
Executive Director – Mining Education Australia (July 2006 – December 2009)
Chair, Governing Board – Mining Education Australia (2015)
Member, Branch Committee – AusIMM Sydney Branch (2017-2019)

---

Expert Witness assisting Coroner: Coronial Inquest (2002-2003): 1999 Northparkes Mine Accident
Chair: 2007-2008 Independent Expert Panel of Review into Impact of Mining in the Southern Coalfield of NSW (Dept of Planning & Dept of Primary Industries)
Expert Witness assisting NSW Mines Safety Investigation Unit – Austar Mine double fatality, April, 2014.
Member (2012 – 2019): Scientific Advisory Board, Advanced Mining Technology Center, Uni. of Chile.
Trustee (2013 – present): AusIMM Education Endowment Fund
2012 Syd S Peng Ground Control in Mining Award – by SME (USA).
2017 Ludwig Wilke Award for contribution to international mining research and education (Society of Mining Professors).
2017 SME Award for Rock Mechanics (presented at 2018 SME Annual Meeting in Minneapolis, USA in Feb 2018).
2020 AusIMM Institute Medal.

**PROFESSIONAL EXPERIENCE**

| | |
|---|---|
| 2014 – present | University of New South Wales, School of Minerals & Energy Resources Engineering (formerly School of Mining Engineering)<br>Professor of Mining Engineering (p/t) |
| 1995 - present | Principal Consultant - B K Hebblewhite Consulting |
| 2003-2014 | University of New South Wales, School of Mining Engineering<br>Head of School and Research Director,<br>(Professor, Kenneth Finlay Chair of Rock Mechanics (to 2006);<br>Professor of Mining Engineering (from 2006)) |
| 2006 – 2009 | Mining Education Australia<br>(a national joint venture between UNSW, Curtin University of Technology, The University of Queensland & The University of Adelaide)<br>Executive Director (a concurrent appointment with UNSW above). |
| 1995-2002 | University of New South Wales, School of Mining Engineering<br>Professor, Kenneth Finlay Chair of Rock Mechanics and Research Director, UNSW Mining Research Centre (UMRC) |
| 1983-1995 | ACIRL Ltd, Divisional Manager, Mining - Overall management of ACIRL's mining activities. Responsible for technical and administrative management of ACIRL's Mining Division covering both research and consulting activities in all aspects of mining and coal preparation. Director of METS Pty. Limited (1990-1992) and MineRisk Management Services Pty. Limited (1991 - 1995). |
| 1981-1983 | ACIRL Ltd, Manager, Mining - Responsibility for ACIRL mining research and commissioned contract programs. |
| 1979-1981 | ACIRL Ltd, Senior Mining Engineer - Assistant to Manager, Mining Research for administrative and technical responsibilities. Particularly, development of geotechnical activities in relation to mine design by underground, laboratory and numerical methods. |
| 1977-1979 | ACIRL Ltd, Mining Engineer Project Engineer for research into mining methods for Greta Seam, Ellalong Colliery, NSW. Also Project Engineer for roof control and numerical modelling stability investigations. |
| 1974-1977 | Cleveland Potash Ltd, Mining Engineer and Department of Mining Engineering, University of Newcastle-upon-Tyne, UK - Research Associate. Employed by Cleveland Potash Limited to conduct rock mechanics investigations into mine design for deep (1100m) potash mining, Boulby Mine, N Yorkshire (subject of Ph.D. thesis). |

**SPECIALIST SKILLS & INTERESTS**

- Mining geomechanics
- Mine design and planning
- Mining methods and practice
- Mine safety and training
- Mine system audits and risk assessments
- Mining education and training

## Attachment E – Surface Water Assessment

Illawarra Metallurgical Coal

# Dendrobium Mine

## Assessment of surface water flow and quality effects of proposed Dendrobium Longwall 19



**HGEO Pty Ltd**
Date: March 2020
Project number: J21495
Report: D20351

Hgeo
hgeo.com.au

# DOCUMENT REGISTER

| Revision | Description | Date | Comments |
|---|---|---|---|
| 01 | 1st Draft | 21/01/2020 | MS Word |
| 06 | Final Draft | 06/03/2020 | Following IMC review |
| 08 | Final | 12/03/2020 | Updated with latest Wongawilli Creek flow observations |

# FILE

C:\OneDrive\HGEO\Projects\Dendrobium\04_Projects\J21495_LW19_SMP_Surface_Water\Report\D20351_Dendrobium_LW19_SW_Impact_Assessment_V09.docx

# QUALITY CONTROL

| Process | Staff | Signature | Date |
|---|---|---|---|
| Authors | Stuart Brown, Will Minchin | | |
| Approved | Stuart Brown |  | 12/3/2020 |

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# ABBREVIATIONS

| Abbreviation/Term | Meaning |
|---|---|
| AHD | Australian Height Datum (Mean Sea Level 1966-1968) |
| bgl | Below ground level |
| IMC | Illawarra Metallurgical Coal |
| IMCEFT | Illawarra Metallurgical Coal Environmental Field Team |
| SMP | Subsidence Management Plan |
| VWP | Vibrating Wire Piezometer |

# EXECUTIVE SUMMARY

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). IMC proposes to extract Longwall 19 (LW19), located immediately to the south of the previously extracted LW8 in Area 3A. This report describes surface water and swamp features within the expected zone of mining influence and provides an assessment of likely impacts from the proposed mining operations.

Dendrobium Mine is located within the catchment of the Upper Nepean River on the Woronora Plateau inland of the Illawarra Escarpment. Drainage is to the north-northwest, towards the Nepean River, with most of the local surface runoff initially captured in Cordeaux and Avon Reservoirs before eventually flowing into the Nepean River. The study area is nominally defined by the area within 600 m of the edge of the proposed LW19. Within the study area, surface runoff drains into Wongawilli Creek and Lake Cordeaux via Sandy Creek.

The main third-order watercourse of Wongawilli Creek passes within 175 m of LW19 at its closest approach, with 925 m of the watercourse passing within 400 m. The upper reaches of a second order tributary (WC14) crosses the longwall footprint and four other second-order tributaries pass within 400 m. Sandy Creek passes to the east of previously extracted Longwalls 6 to 8 in Area 3A and is entirely outside the 600 m study area for LW19. One major tributary of Sandy Creek, SC10 passes within the 400 m study area. SC10 crosses the south west corner of the proposed LW19 and is within 400 m for 1.27 kilometres (km) of its length. SC10C is entirely within 400 m of LW19. SC10C overlies and was previously affected by the extraction of LW8. Predictions of mine subsidence related to LW19 (MSEC, 2020) combined with previous experience and information from Dendrobium, indicate that fracturing and stream diversion is likely to occur in tributaries that cross the longwall footprint. Watercourses that pass within 400 m of the longwall may experience some fracturing and flow diversion.

Where stream flow is partly sustained by the discharge of groundwater from adjacent aquifers (baseflow), mining related groundwater drawdown may result in a reduction of the baseflow component. Conservative estimates based on a regional groundwater model by SLR (2020) indicate that the baseflow components of Wongawilli Creek and Sandy Creek may decline by up to 1.27 and 1.15 megalitres per day (ML/day) (cumulative / whole mine) and up to 0.01 ML/day and 0.06 ML/day (due to LW19 incrementally) following longwall extraction. This equates to approximately 8% and 29% of the mean flow at the downstream gauges (0.1% and 1.5% incremental). Baseflow reduction would occur along the reach of Wongawilli Creek between Areas 3A and 3B following mining of Longwalls 15 to 19. As a result, cease-to-flow events, similar to those observed during the recent severe drought, are likely to occur more frequently under similar weather conditions.

Water quality influence due to mining is expected to be minor in stream reaches within subsidence affected areas. Effects are likely to include temporary changes in water salinity, pH and iron content with local discolouration of streambeds and rock faces by iron hydroxide. Water quality effects on stored waters of the reservoirs are expected to be negligible and undetectable.

Eight Coastal Upland Swamps are mapped wholly or partially within 600 m of the proposed longwalls. Of those, parts of Swamp 15a and Swamp 148 overlap with the proposed longwall footprint. Based on previous experience at Area 3B and subsidence predictions, it is likely that shallow groundwater levels will be affected in approximately 7% of the area of Swamp 15a and most of Swamp 148. Other swamps within 400 m of LW19 were previously impacted by subsidence at Area 3A and may experience further effects due to LW19. The remaining swamps are unlikely to be impacted since they are located more than 400 m from the proposed goaf and/or are predicted to experience negligible ground movement related to subsidence and valley closure.

# 1. INTRODUCTION

## 1.1 Project background

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). The mine is located about 12 kilometres (km) west of Wollongong and within the Metropolitan Special Catchment Area managed by WaterNSW.

Since 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 proposes to extract LW19, the final of four longwalls in Area 3A (Figure 1), following completion of longwalls in Area 3B. Longwall 19 will be located immediately adjacent to, and south of, LW8 which was extracted in 2012.

Previous workings in the Wongawilli Seam are located to the south of the mine at Elouera and Nebo, and to the east at Kemira. The overlying Bulli Seam was mined previously at Mt Kembla to the east of Area 1. IMC is preparing a Subsidence Management Plan (SMP) as part of the approvals process for LW19. HGEO was engaged to carry out an assessment of the potential effects of mining on surface water and shallow groundwater systems. This assessment is to form part of the SMP and should be read in conjunction with that document and other specialist reports referred to in the SMP.

## 1.2 Study area

The study area is nominally defined by the area within 600 m of the edge of the longwall (Approval Condition 8(d)), being the minimum extent of the assessments for the valley related subsidence effects (MSEC, 2020). MSEC (2020) also considers a study area based on the 35° angle of draw and predicted 20 mm subsidence contour. Study areas defined by both criteria are shown in Figure 1. This assessment considers reaches of Wongawilli Creek and Sandy Creek that extend upstream and downstream of the 600 m envelope, as appropriate for the definition of baseline characteristics and long-term impact monitoring.

## 1.3 Scope

The scope of this assessment is to provide supporting information for the SMP for Area 3A which is required under Schedule 3 of the Dendrobium Development Consent. The assessment is to include:

- Description of surface water hydrology within the study area.
- Summary of existing monitoring sites.
- Summary of baseline monitoring data.
- Assessment of potential impacts to surface water systems as a result of subsidence related to LW19, with emphasis on the quantity and quality of flows to Lake Avon, Lake Cordeaux and the Cordeaux River.
- Assessment of the potential impact to the hydrological function of swamps as a result of subsidence related to LW19.
- Provide assessment and recommendations to allow for an update to relevant elements of the Watercourse Impact Monitoring, Management and Contingency Plan (WIMMCP) and Swamp Impact Monitoring, Management and Contingency Plan (SIMMCP).

## 1.4 Relevant approval conditions

**Table 1. Dendrobium Development Consent conditions relevant to this surface water assessment**

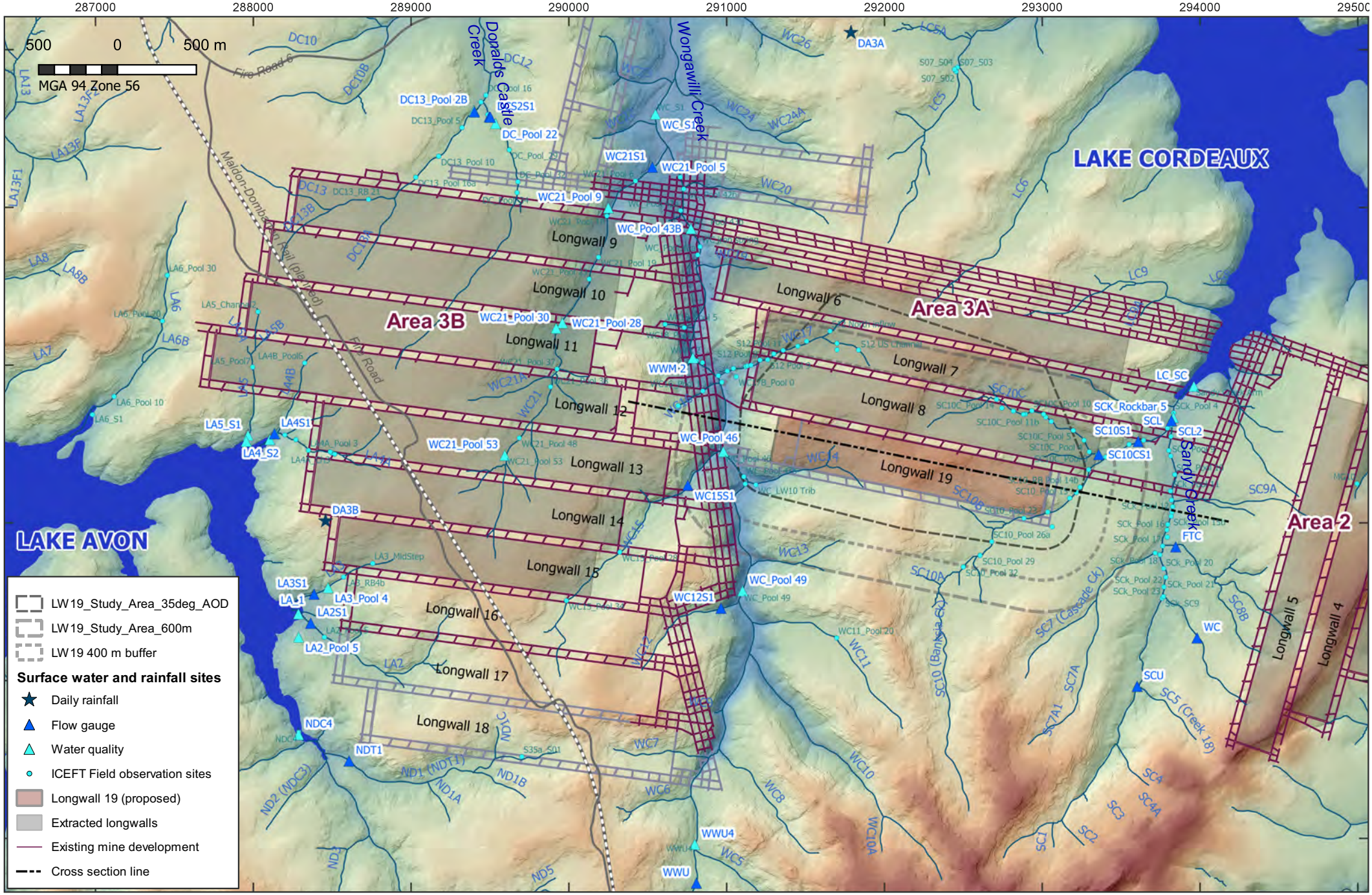
| Condition | | Where addressed |
|---|---|---|
| **Schedule 3 – Specific Environmental Conditions** | | |
| 2 | The Applicant shall ensure that underground mining operations do not cause subsidence impacts at Sandy Creek and Wongawilli Creek other than "minor impacts" (such as minor fracturing, gas release, iron staining and minor impacts on water flows, water levels and water quality) to the satisfaction of the Secretary. | Section 4 (this report) |
| 3 | The Applicant shall ensure the development does not result in reduction (other than negligible reduction) in the quality or quantity of surface water or groundwater inflows to Lake Cordeaux or Lake Avon or surface water inflow to the Cordeaux River at its confluence with Wongawilli Creek, to the satisfaction of the Secretary. | Section 4 (this report) |
| 5 | The Applicant shall ensure that subsidence does not cause erosion of the surface or changes in ecosystem functionality of Swamp 15a and that the structural integrity of its controlling rockbar is maintained or restored, to the satisfaction of the Secretary. | Section 4 (this report)<br>Accompanying report by Niche (2020) |

## 1.5 IEPMC Recommendations

The Independent Expert Panel for Mining in the Catchment (IEPMC) was established in late February 2018 to provide expert advice to the Department of Planning, Industry and Environment (DPIE) on the impact of mining activities in the Greater Sydney Water Catchment Special Areas, with a focus on risks to quantity of water.

The findings of the panel were released in a two-part report in October 2019. Part 1 focusses on modelling and monitoring used in the assessment and management of subsidence-induced effects and impacts on groundwater and surface water at Dendrobium Mine and Metropolitan Mine (IEPMC, 2019a). Recommendations were directed to informing mine design and approvals, monitoring and performance. Part 2 focusses on the impacts of mining in the Greater Sydney Water Catchment Special Areas on water quantity and swamps, including cumulative impacts, and a requirement to review and update relevant findings of the 2008 Southern Coalfield Inquiry (IEPMC, 2019b).

Subsequent to the release of the main findings in Parts 1 and 2, the IEPMC provided advice to the DPIE on the SMP for Dendrobium Mine LW21 (IEPMC, 2019c). Recommendations from the IEPMC reports are referred to throughout this assessment.

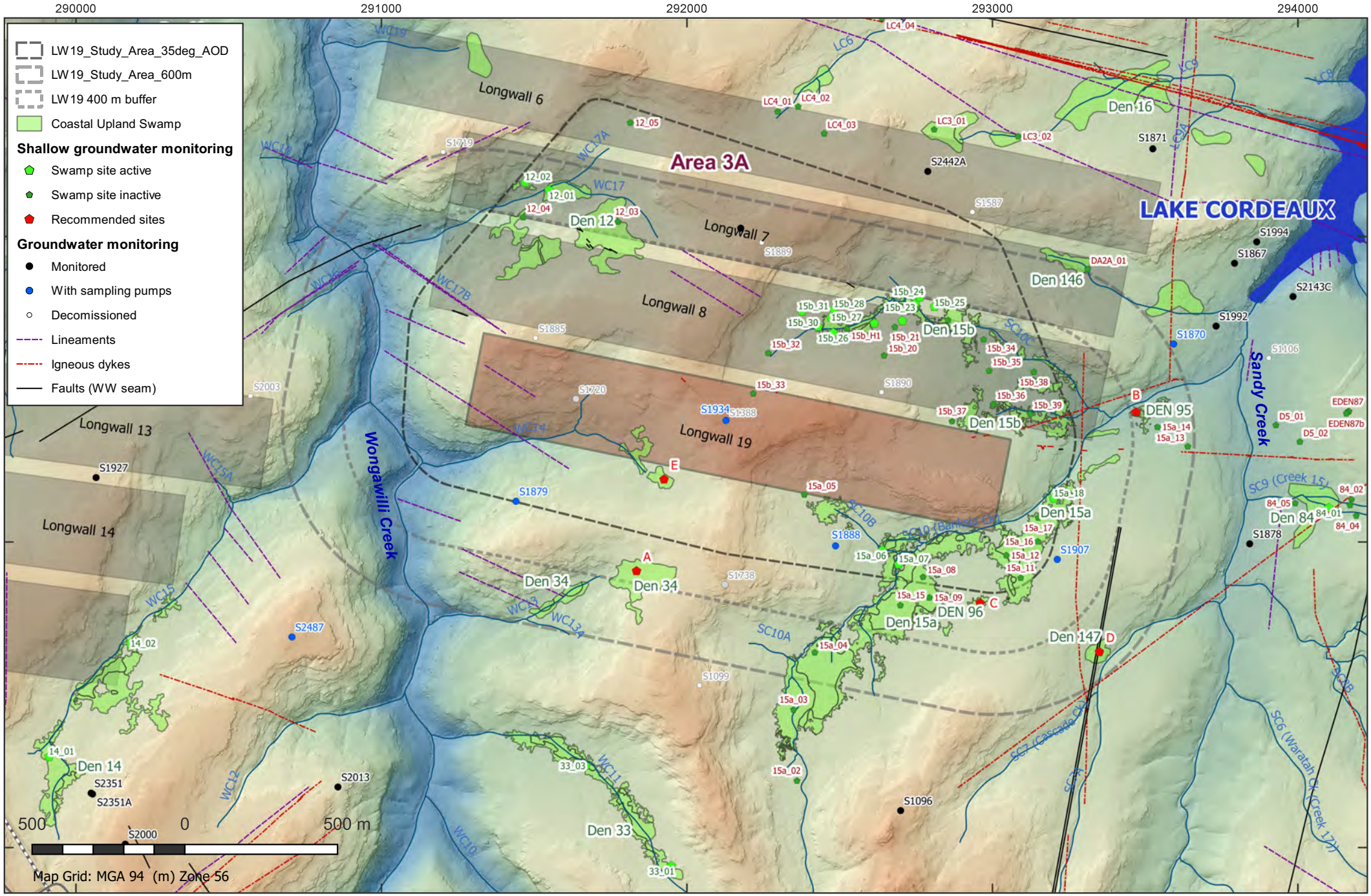



**Dendrobium Longwall 19 Surface water assessment**

Location map and surface water monitoring sites

**Figure 2**

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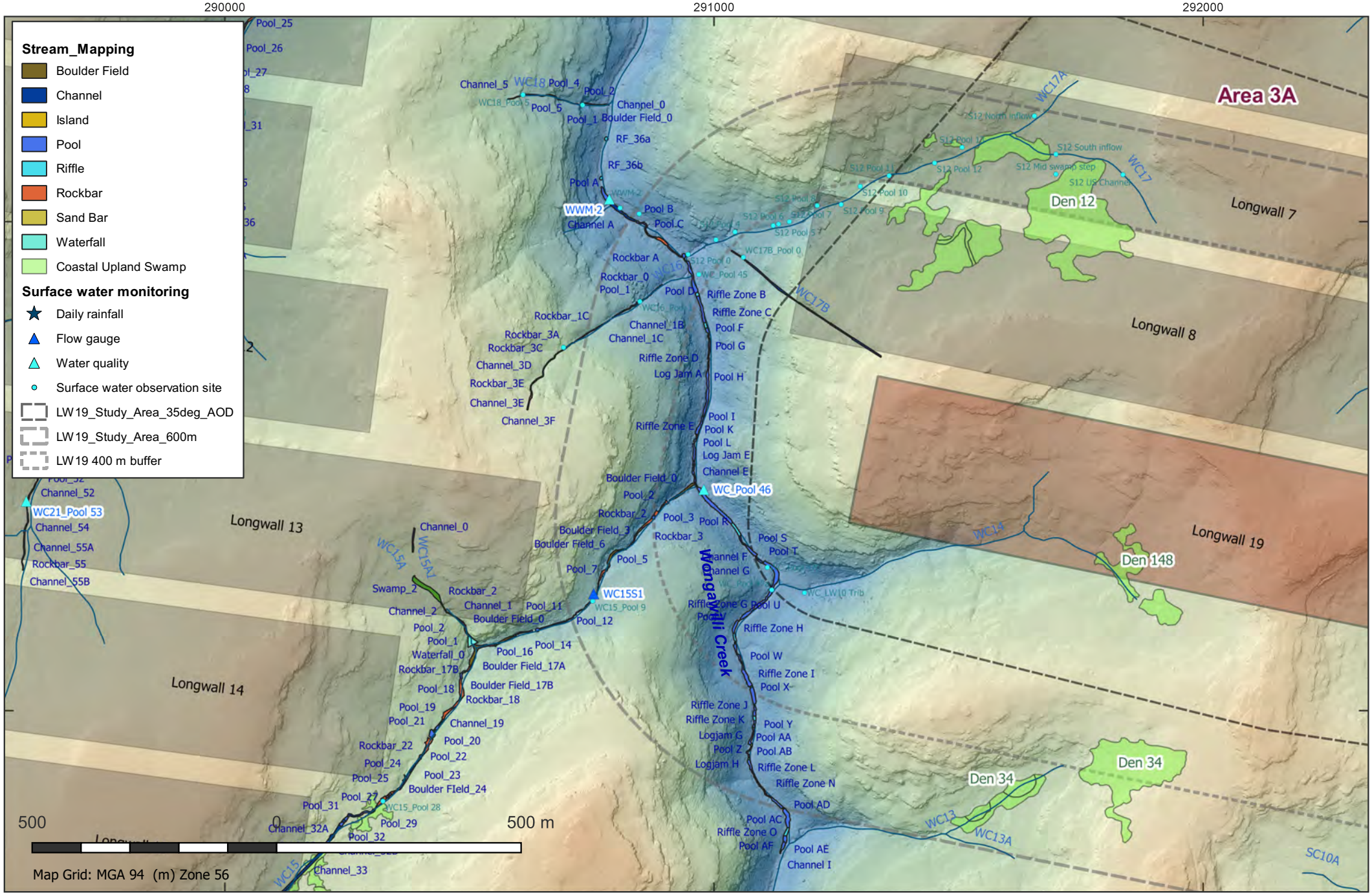



**Dendrobium Longwall 19 Surface water assessment**

Swamp and groundwater montoring

**Figure 2**

file: Dendrobium_2019.qgs.qgz

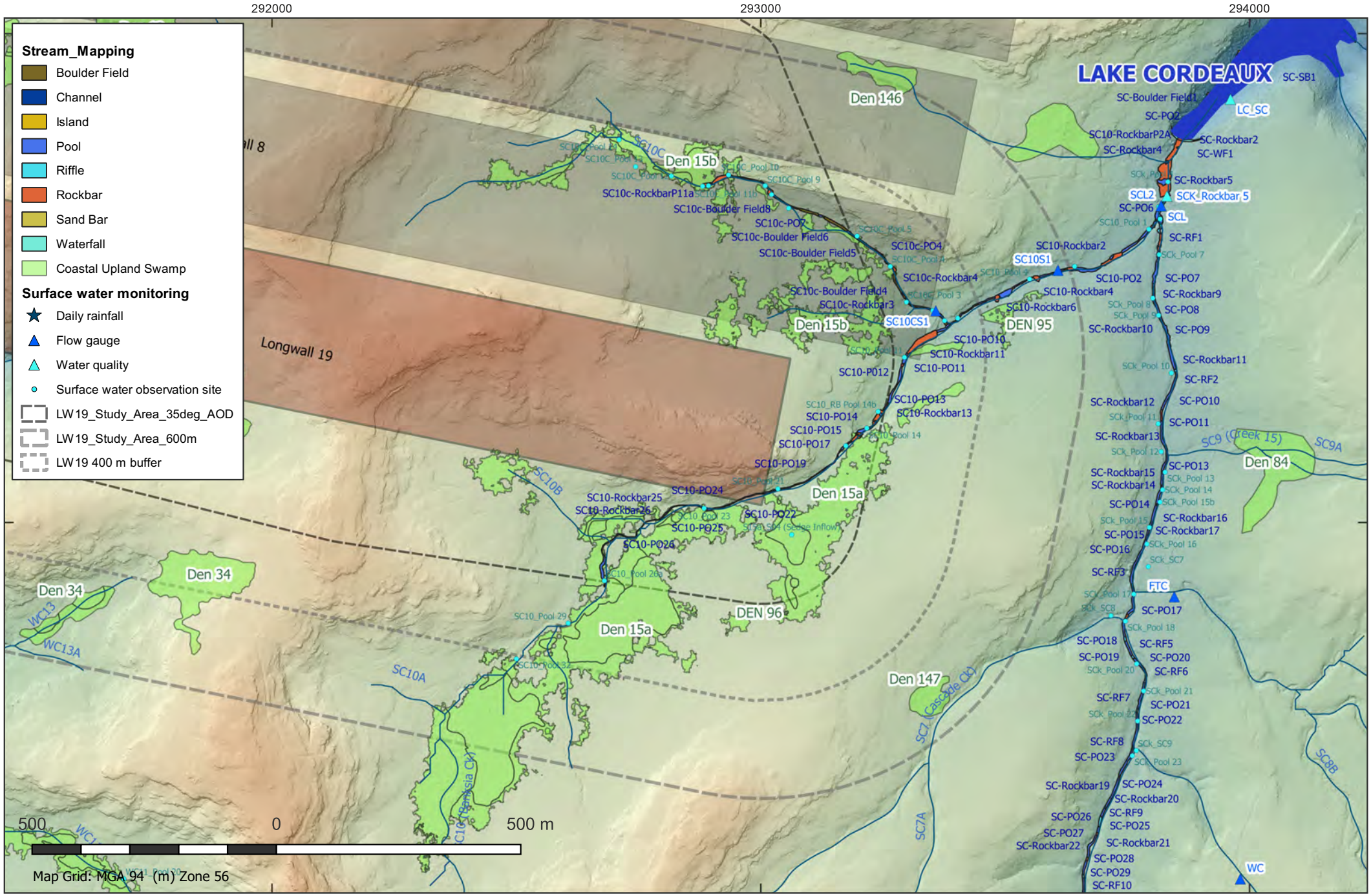



**Dendrobium Longwall 19 Surface water assessment**

Stream mapping features and monitoring locations - Wongawilli Creek

**Figure 3**

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**Dendrobium Longwall 19 Surface water assessment**

Stream mapping features and monitoring locations - Sandy Creek

**Figure 4**

file: Dendrobium_2019.qgs.qgz

## 1.6 Mining geometry

The layout of the proposed LW19 is shown in Figure 1. LW19 will be extracted from the Wongawilli seam, with mining dimensions as follows:

- Void length: 1765 m.
- Width (including first workings): 305 m.
- Extraction height: 3.9 m (maximum), likely to be 3.5 - 3.7 m given the thinner coal seam at this location.
- Depth of cover: 280 – 370 m.

Longwall 19 will be extracted towards the main headings (from east to west). The extent of LW19 within the Wongawilli Coal Seam is shown in an east-west geological cross-section A-A' in Figure 5. The proposed longwall is located between Wongawilli Creek to the west and Sandy Creek to the east. The ground surface ranges between 330 m above Australian Height Datum (mAHD) at the western end and 445 mAHD towards the middle of the longwall. The coal seam dips from the south-east to the north-west. The depth of cover to the Wongawilli Seam directly above the proposed LW19 ranges between 280 m and 370 m. The minimum depth of cover occurs along tributary WC14 near the western end and the maximum depth of cover occurs along the ridgeline towards the middle of the proposed longwall.

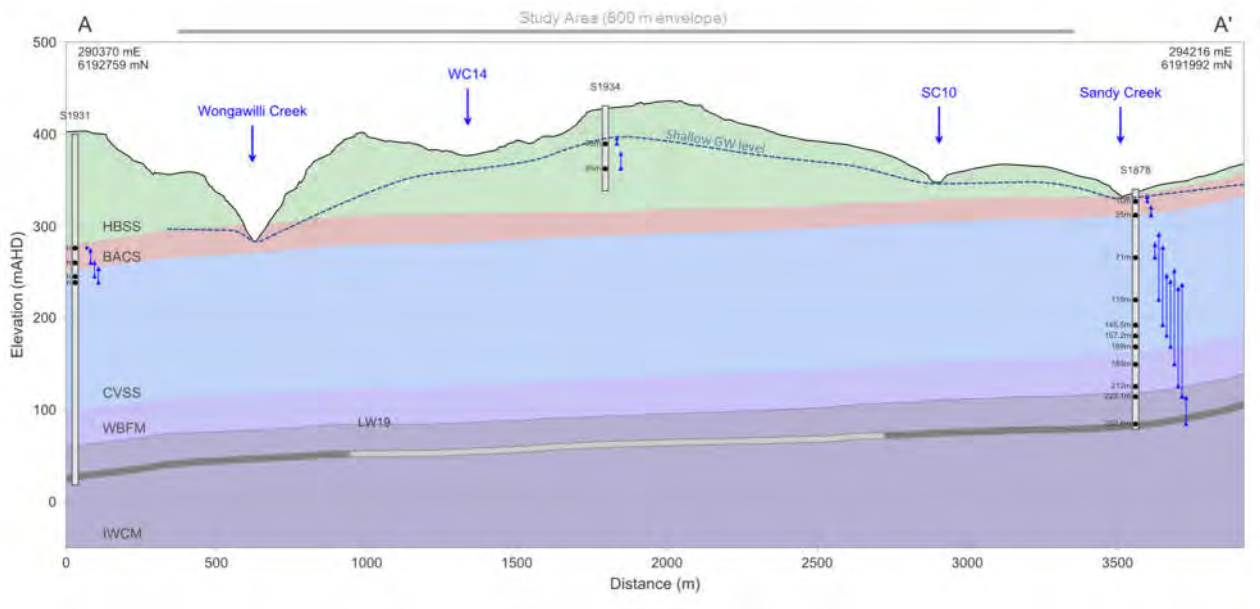



**Figure 5. Geological cross section A-A' through Longwall 19 (West-East)**

# 2. BACKGROUND

## 2.1 Topography

Dendrobium Mine is located on the Woronora Plateau inland of the Illawarra Escarpment. The escarpment rises from the coastal plain to elevations in excess of 400 mAHD around Dendrobium. The plateau generally slopes to the north or northwest, toward the centre of the Sydney Basin. Dendrobium Area 3 is characterised by broad sandstone ridges and plateaus rising to approximately 410 m AHD, incised by relatively steep and rugged gullies. The proposed LW19 is aligned west-norwest across the ridgeline between the Wongawilli Creek and Sandy Creek catchments.

## 2.2 Climate

Weather data have been collected at the Dendrobium Mine since 2003. Mean annual rainfall between 2002 and 2019 was 1014 mm (2.78 mm per day on average). Rainfall decreases westward away from the Illawarra escarpment with Picton, located 20 km to the northwest, recording an average annual rainfall of 803 mm (1886-2018). At Dendrobium, rainfall typically occurs year-round but 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), during which significant surface water runoff and groundwater recharge are generated.

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 calculated using the Penman-Monteith formula is typically between 1 and 3 mm/day in the winter months and between 3 and 6 mm/day in the summer months.

Figure 6 shows rainfall trends at Dendrobium as derived from SILO rainfall data. This figure shows the occurrence of significant dry and wet periods from 1900, including the Millennium Drought and the more recent significant dry period 2017-19.

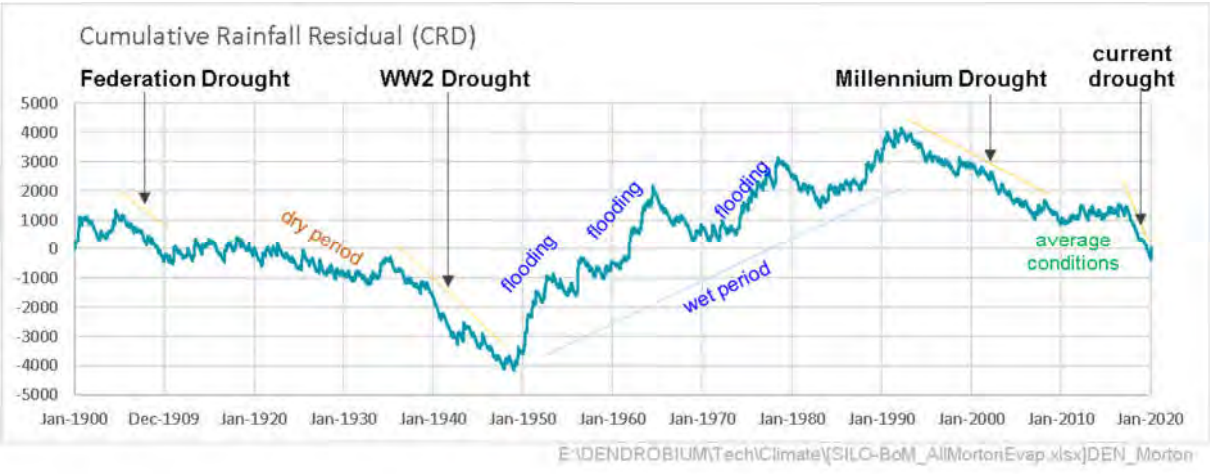



**Figure 6. Long-term rainfall trends at Dendrobium Mine (from SILO daily data)**

Severe dry conditions occurred across much of NSW during 2017-19. The Bureau of Meteorology (BoM) Rainfall Tracker[1] indicates that both the 24 months 2018-19 and the 12 months of 2019 were the driest on record in the area around Dendrobium. Rainfall during this 24-month period was about 66% of the 2002-2019 annual average, resulting in a significant decline in runoff and infiltration rates across the catchment.

## 2.3 Hydrology

Dendrobium Mine is located within the catchments of the Avon and Cordeaux Rivers, which are tributaries of the Upper Nepean River. Drainage is generally to the north-northwest, towards the Nepean River, with most of the local surface runoff initially captured in Cordeaux, Avon, Nepean and Cataract lakes, before eventually flowing into the Nepean River. These lakes are reservoirs operated by WaterNSW as part of the water supply network for Sydney. Lake levels are regulated by controlled releases and overflow at the reservoir dams.

Longwall 19 lies across the divide between the catchments of Wongawilli Creek and Sandy Creek, such that approximately half of the runoff from the study area reports to each catchment.

### 2.3.1 Wongawilli Creek

Wongawilli Creek is a third-order perennial stream that flows north to join the Cordeaux River approximately 5.5 km north of LW19. Wongawilli Creek has two gauging stations along its main third-order watercourse (WWU upstream and WWL downstream of mining operations) and three gauging stations in the lower reaches of major tributaries WC12, WC15 and WC21. Prior to the current drought, Wongawilli Creek (WWL) typically recorded flow on more than 95% of days. Since April 2019, recorded flow days have declined to 57%. Baseflows in Wongawilli Creek are sustained by groundwater discharge from the Hawkesbury Sandstone (HBSS) and to a much lesser extent from formations underlying the HBSS that are exposed in the valley floor within the study area (Bald Hill Claystone) and upstream of the study area (Colo Vale Sandstone).

Longwall 19 directly underlies the upper reaches of WC14, a second-order tributary of Wongawilli Creek. The broader 600 m study area overlaps with the following watercourses within the Wongawilli Creek catchment:

- Wongawilli Creek: 1.4 km of the third-order watercourse crosses the 600 m study area and 925 m crosses within 400 m of LW19. The watercourse passes 175 m from LW19 at its closest approach (Pools 47a and 47b, near the confluence with WC14).
- WC13: The upper reaches of the second-order tributary cross the study area, but do not pass within 400 m of LW19.
- WC15: The lower 390 m of the second-order tributary is within the 600 m study area. The confluence with Wongawilli Creek is the closest point to LW19 at 320 m. Gauging station WC15S1 is located at WC15 Pool 9, within the study area.
- WC16: The lower 240 m of the second-order tributary is within the 600 m study area. The confluence with Wongawilli Creek is the closest point to LW19 at 430 m. There is one regular field observation site on the watercourse within the study area (Pool 1).

[1] http://www.bom.gov.au/climate/drought/#tabs=Rainfall-tracker

- WC17: This second-order tributary crosses previously extracted Longwalls 7 and 8 in Area 3A and is largely within the 600 m study area of LW19. A length of 290 m of the tributary pass within 400 m of LW19 with the closest pass being 350 m (Pools 7 and 8). The hydrology of WC17 is likely influenced by storage within, and drainage from, Swamp 12 which underlies the upper reaches of the tributary. Both the tributary and the swamp were affected by subsidence associated with the extraction of Longwalls 7 and 8, with iron-staining evident along the lower reaches of the watercourse. There are 16 field observation sites along WC17.

### 2.3.2 Sandy Creek

Sandy Creek is a third-order tributary to Lake Cordeaux. Sandy Creek flows from south to north, entering Lake Cordeaux at the Sandy Creek Waterfall. Sandy Creek passes to the east of previously extracted Longwalls 6 to 8 in Area 3A and is entirely outside the 600 m study area for LW19.

Two major tributaries of Sandy Creek, SC10 and SC7 pass within the 600 m study area:

- SC7. This second-order tributary to Sandy Creek is largely outside the 600 m study area, with 280 m of the watercourse passing inside the study area at a closest distance of 560 m from LW19.

- SC10. This second-order tributary has a relatively large sub catchment relative to the total Sandy Creek catchment (40%). SC10 crosses the south west corner of the proposed LW19 over a length of 55 m (Pools 21 and 22 and Rockbar 22). A length of 1.27 km is within 400 m of LW19 (including Pools 7 to 26) and a length of 1.73 km is within the 600 m study area. There are 14 field observation sites along SC10, including a flow gauging site (SC10S1).

- SC10C. This tributary of SC10 is entirely within 400 m of LW19, with much of the main watercourse at a distance of between 250 and 370 m from LW19. The hydrology of SC10C is likely influenced by drainage from Swamp 15b through which the tributary flows. Both the tributary and the swamp were affected by subsidence associated with the extraction of LW8 between August and December 2012. There are 14 field observation sites along SC10C, including a flow gauging site (SC10CS1).

## 2.4 Hydrogeology

Dendrobium Mine is located within the Southern Coalfield which is one of the five major coalfields that lie within the Sydney Geological Basin. The stratigraphy of the Southern Sydney Basin is shown in Figure 7. The Basin is primarily a Permo-Triassic sedimentary rock sequence, underlain by undifferentiated sediments of Carboniferous and Devonian age. The Bulli and Wongawilli Coal Seams are the primary target seams in the top part of the Illawarra Coal Measures and, like previous longwalls at Dendrobium, the Wongawilli Coal seam is the target for LW19.

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

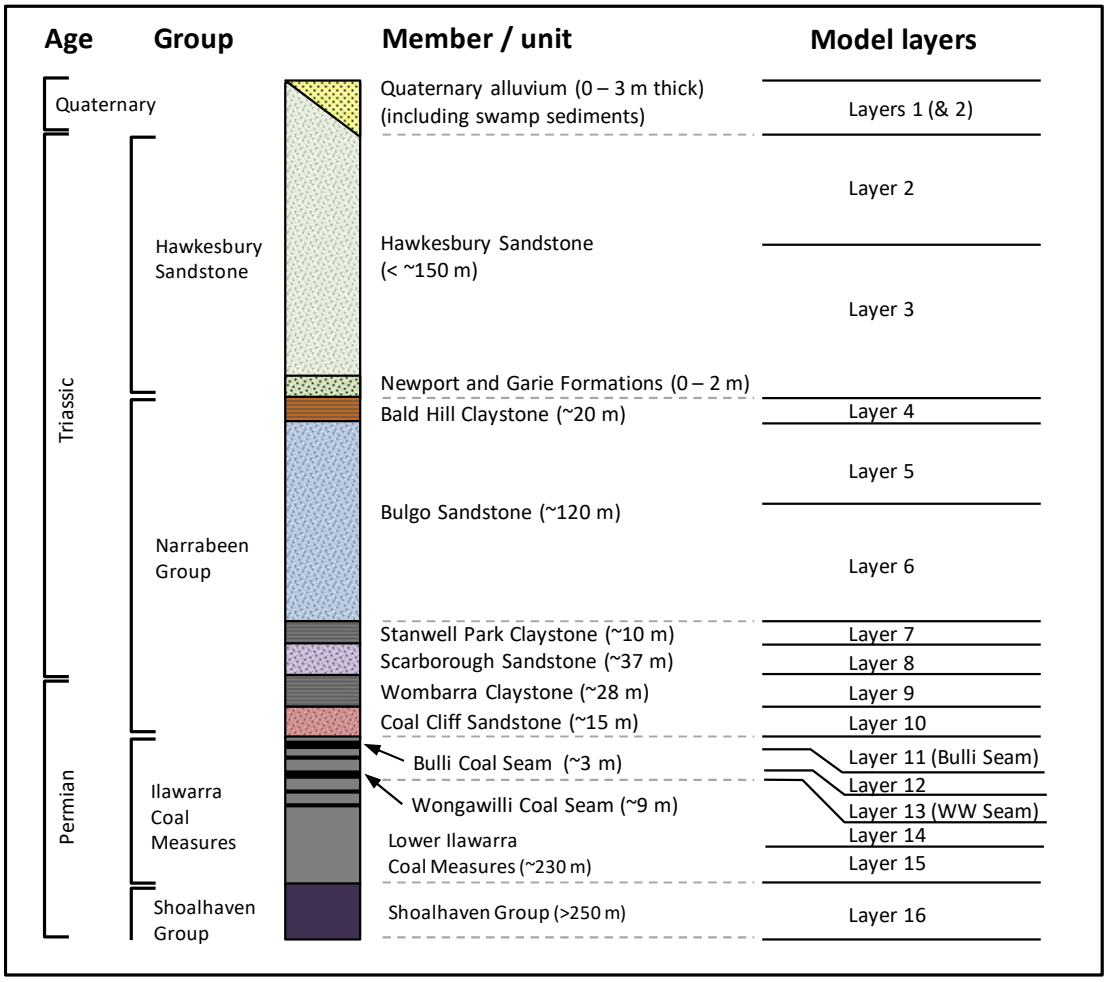



**Figure 7. Stratigraphy of the Southern Coalfield and numerical model layers (of Hydrosimulations, 2019)**

Three main groundwater systems are recognised:

1. Perched groundwater systems associated with swamps and shallow sandstone. These may be ephemeral and/or disconnected from the deeper groundwater systems;
2. Shallow groundwater systems: layered water-bearing zones within the saturated HBSS; and
3. Deeper groundwater systems within the Narrabeen Group and the Illawarra Coal Measures.

Recharge to the aquifer systems comes primarily from rainfall infiltration through outcropping formations, generally the HBSS in the western half of the Dendrobium Mine area and the Bulgo Sandstone in the eastern half. There will be some recharge from the Reservoirs and streams to host formations at times of high water level and creek flooding. In the western part of Area 3B, the Stanwell Park Claystone pinches out such that the Bulgo and Scarborough Sandstones form a single unit, the Colo Vale Sandstone.

Strong topographic relief and recharge drive vertical groundwater flow near the ground surface, but at depth the alternation of aquifers and aquitards promotes horizontal groundwater flow at the base of permeable units. In general, groundwater flow in shallow systems is strongly influenced by local topographical features such as streams and lakes, whereas deeper groundwater systems are influenced by regional topographic and drainage patterns (Toth, 2009). Regional groundwater flow in the deeper sandstone units (pre-development) is predominantly northwest, towards the Nepean River system and away from the Illawarra escarpment.

Discharge from the groundwater systems occurs naturally at the surface to creeks (contributing to stream baseflow) and to the reservoirs as baseflow and seeps, and as evapotranspiration. Along the escarpment to the south-east of Dendrobium Mine, groundwater discharge appears as seeps in cliff faces at the junction of formations with contrasting permeability.

Groundwater piezometric levels are shown on Figure 5 for three monitoring bores located near the LW19 cross-section line. The most recent available data are shown, ranging from 21/5/2019 (S1878) to 30/11/2019 (S1931). The data show that deeper strata are depressurised from previous mining at Area 3A and adjacent areas. Hole S1934 indicates that water levels are maintained at between ~380 to 395 m AHD within the HBSS in the centre of LW19. There is a groundwater divide along the ridgeline and groundwater within the HBSS flows west towards Wongawilli Creek and east towards Sandy Creek (SC10) where it discharges as baseflow.

## 2.5 Upland Swamps

Coastal Upland Swamps are endemic to the eastern part of the Sydney Basin and have a significant role in catchment hydrology. They are listed as an endangered ecological community under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*, and the NSW *Biodiversity Conservation Act 2016*. Upland Swamps are typically located at the headwaters of low order streams, on low relief plateaus on low permeability HBSS. Swamp vegetation is highly variable, ranging from open graminoid (grassy) heaths and sedgelands to fernlands and scrub (Threatened Species Scientific Committee (TSSC), 2014).

The location and extent of known swamps is shown in Figure 2 and is derived from a combination of mapping by the NSW Office of Environment and Heritage (OEH), ecological consultants and the Illawarra Metallurgical Coal Environmental Field Team (IMCEFT). There are six swamps (12a, 12b, 12c, 12d, 15a and 15b) located entirely or partially within the study area based on the 35° angle of draw line and predicted 20 mm subsidence contour. Six additional swamps (34, 95, 96, 146, 147 and 34) are located entirely or partly within the study area based on the 600 m boundary. Longwall 19 overlaps slightly with mapped swamp vegetation in Swamps Den 15a and 15b.

The structure and hydrological function of Coastal Upland Swamps has been well studied by Young (1982), Tomkins and Humphreys (2006), Cowley *et al*. (2016), Fryirs *et al*. (2014), and others. Upland Swamps form on accumulations of sandy and silty sediments on the broad and gently sloping headwater valleys. 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). Fibric mats of live and dead organic matter occur at the swamp surface, up to a depth of approximately 50 cm, providing some protection from erosion during runoff events. Episodes of scouring and erosion occur naturally with a periodicity of several thousand years (Tomkins and Humphreys, 2006) and are thought to be caused by high intensity rainfall-runoff events, possibly following wildfires.

Ground subsidence and near-surface fracturing related to longwall mining can impact swamp hydrology as has been observed during mining at Dendrobium Areas 3A and 3B. Those effects are discussed further in Section 4.

# 3. BASELINE ASSESSMENT

## 3.1 Monitoring

This section outlines the network of monitoring infrastructure and sites operated by IMC that are relevant to the LW19 study area. Further details of monitoring sites and procedures are outlined in the Dendrobium Area 3A WIMMCP (South32, 2020a).

### 3.1.1 Geomorphological mapping

Stream bed morphology has been mapped in detail by the IMCEFT to provide baseline observations in all active and proposed mining areas. Mapping involved characterisation of the watercourse in terms of its bed characteristics (e.g. channel, pool, riffle, rockbar, etc.), sediment type and vegetation. Key features are mapped and photographed for comparison during and after mining. Major streams and tributaries of Wongawilli Creek and Sandy Creek adjacent to proposed LW19 have been mapped as part of previous assessments for mining at Dendrobium Mine (Figure 3 and Figure 4 respectively). The Wongawilli Creek bed within the study area was re-mapped in February 2020. The mapping was carried out in higher resolution than previous mapping, resulting in the definition of additional features such as pools, rock-bars and log-jams (shown in Figure 3). Those new features have been assigned temporary names (e.g. Pool A, Rockbar A), until the mapping is complete and integrated with the previous pool naming convention (Pool 1, Rockbar 1, etc.).

### 3.1.2 Surface Water Monitoring

Monitoring of surface water is carried out at numerous sites across the Dendrobium Mine lease by the IMCEFT on a monthly basis prior to mining and on a weekly basis during mining, as part of the Area 3C SMP (South32, 2020b). There are 52 active monitoring sites on Sandy Creek and Wongawilli Creek (and their tributaries) within 600 m of the proposed longwall. Stream monitoring sites within the study area are shown in Figure 1. Those sites at which flow conditions are recorded and/or water chemistry data is collected are listed in Table 2 and Table 3 (monitoring dates shown). Flow observations consist of records ranging from “no flow observed” through “trickle observed” to “surface flow observed”. The list includes selected gauging sites beyond the study area that provide down-gradient impact monitoring and up-gradient control points.

**Table 2. Surface water monitoring sites on Sandy Creek**

| Watercourse | Site | East (MGA94) | North (MGA94) | Flow gauge | Chemistry | Field parameters |
|---|---|---|---|---|---|---|
| Sandy Creek | SCL2 (Rockbar 5) | 293819 | 6192648 | 2011 - | 2007 - | 2007 - |
| SC10 | SC10S1 (Pool 1) | 293609 | 6192519 | 2007 - | 2008 - | 2008 - |
| SC10 | Pool 4 | 293608 | 6192517 | | | 2016 - |
| SC10 | Pool 10b | 293403 | 6192418 | | | 2016 - |
| SC10 | Pool 11 | 293294 | 6192338 | | | 2017 - |
| SC10 | Pool 14 | 293217 | 6192193 | | | 2016 - |
| SC10 | Pool 15 | 293174 | 6192157 | | | 2016 - |
| SC10 | Pool 21 | 293035 | 6192069 | | | 2016 - |

| Watercourse | Site | East (MGA94) | North (MGA94) | Flow gauge | Chemistry | Field parameters |
|---|---|---|---|---|---|---|
| SC10 | Pool 23 | 292884 | 6192029 | | | 2016 - |
| SC10 | Pool 26a | 292680 | 6191881 | | | 2016 - |
| SC10 | Pool 29 | 292606 | 6191794 | | | 2016 - |
| SC10 | Pool 32 | 292500 | 6191721 | | | 2016 - |
| SC10 | RB Pool 14b | 293240 | 6192227 | | | 2016 - |
| SC10C | SC10**C**S1 (Pool 1) | 293358 | 6192433 | **2007 -** | 2008 - | 2008 - |
| SC10C | Pool 0 | 293376 | 6192413 | | | 2009 - 2018 |
| SC10C | Pool 3 | 293298 | 6192451 | | | 2009 - 2018 |
| SC10C | Pool 4 | 293265 | 6192524 | | | 2009 - 2018 |
| SC10C | Pool 5 | 293197 | 6192586 | | | 2009 - 2018 |
| SC10C | Pool 7 | 293057 | 6192643 | | | 2009 - 2018 |
| SC10C | Pool 8 | 293022 | 6192671 | | | 2009 - 2018 |
| SC10C | Pool 9 | 293009 | 6192689 | | | 2009 - 2018 |
| SC10C | Pool 10 | 292934 | 6192711 | | | 2009 - 2018 |
| SC10C | Pool 11a | 292893 | 6192689 | | | 2009 - 2015 |
| SC10C | Pool 11b | 292881 | 6192688 | | | 2009 - 2015 |
| SC10C | Pool 12 | 292817 | 6192709 | | | 2009 - 2018 |
| SC10C | Pool 13 | 292744 | 6192728 | | | 2009 - 2018 |
| SC10C | Pool 14 | 292710 | 6192783 | | | 2009 - 2018 |

**Table 3. Surface water monitoring sites on Wongawilli Creek**

| Watercourse | Site | East (MGA94) | North (MGA94) | Flow gauge | Chemistry | Field parameters |
|---|---|---|---|---|---|---|
| Wongawilli Creek | WWU / WWU4 | 290808 | 6189716 | 2007 - | 2002 - | 2002 - |
| Wongawilli Creek | WWL Wongawilli Ck (FR6) | 290960 | 6197376 | 2007 - | 2001 - | 2001 - |
| Wongawilli Creek | WC_S1 | 290549 | 6194591 | | 2012 - | 2012 - |
| Wongawilli Creek | WC_Pool 44 | 290847 | 6193016 | | | 2009 - |
| Wongawilli Creek | WC_Pool 45 | 290969 | 6192892 | | 2017 - 2017 | 2009 - |
| Wongawilli Creek | WC_Pool 46 | 290979 | 6192452 | | 2008 - | 2008 - |
| Wongawilli Creek | WC_Pool 47a | 291118 | 6192247 | | | 2009 - |
| Wongawilli Creek | WC_Pool 47b | 291109 | 6192293 | | | 2009 - |
| WC14 | WC_LW10_trib | 291185 | 6192241 | | | 2009 - |
| WC15 | WC15S1 WC15_Pool 9 | 290752 | 6192224 | 2012 - | 2016 - | 2012 - |
| WC16 | WC16_Pool 1 | 290848 | 6192836 | | | 2015 - |

| Watercourse | Site | East (MGA94) | North (MGA94) | Flow gauge | Chemistry | Field parameters |
|---|---|---|---|---|---|---|
| WC17B | WC17B_Pool 0 | 291060 | 6192927 | | | 2012 - 2016 |
| WC17 | S12_Pool 0 | 290947 | 6192933 | | | 2011 - |
| WC17 | S12_Pool 2 | 290979 | 6192959 | | | 2009 - 2018 |
| WC17 | S12_Pool 3 | 291004 | 6192963 | | | 2009 - 2018 |
| WC17 | S12_Pool 4 | 291043 | 6192979 | | | 2009 - 2018 |
| WC17 | S12_Pool 5 | 291121 | 6192992 | | | 2009 - 2018 |
| WC17 | S12_Pool 6 | 291132 | 6192995 | | | 2009 - 2018 |
| WC17 | S12_Pool 7 | 291154 | 6193000 | | | 2009 - 2018 |
| WC17 | S12_Pool 8 | 291211 | 6193033 | | | 2009 - 2015 |
| WC17 | S12_Pool 9 | 291260 | 6193035 | | | 2009 - 2015 |
| WC17 | S12_Pool 10 | 291299 | 6193072 | | | 2009 - 2018 |
| WC17 | S12_Pool 11 | 291358 | 6193094 | | | 2009 - 2018 |
| WC17 | S12_Pool 12 | 291451 | 6193120 | | | 2009 - 2018 |
| WC17 | S12_Pool 13 | 291507 | 6193152 | | | 2009 - 2018 |

The monitoring of water quality parameters provides a means of detecting and assessing the effects of streambed fracturing or the emergence of ferruginous springs. Monitoring includes measurement of field parameters (pH, Electrical Conductivity (EC), Dissolved Oxygen (DO), Oxygen Reduction Potential (ORP) and laboratory tested analytes (DOC, Na, K, Ca, Mg, Filt. SO4, Cl, T. Alk., Total Fe, Mn, Al, Filt. Cu, Ni, Zn, Si).

### 3.1.3 Shallow Groundwater Monitoring

Figure 2 shows areas of swamp vegetation, broadly mapped by OEH and refined through site-scale mapping by ecological consultants and IMC. Hydrological baseline characteristics and mining effects at swamps are monitored using shallow (1 to 3 m) piezometers and soil moisture sensors. Figure 2 shows the locations of shallow groundwater monitoring sites in the vicinity of LW19.

The Trigger Action Response Plan (TARP) related assessments carried out as part of the SMP relate to those piezometers located within areas mapped as Banksia Thicket, Sedgeland-heath complex and Tea Tree Thicket; being listed as Costal Upland Swamp Endangered Ecological Community (EEC). Piezometers located within fringing Eucalypt Woodland are excluded from the TARP related assessment as per the advice from OEH (dated 17/01/2014).

### 3.1.4 Soil moisture monitoring

Soil moisture profiles are monitored at most swamps, with sensor arrays typically positioned near shallow piezometers (where possible). Where possible the monitoring arrays are numbered according to the corresponding piezometer (if present) with an ‘S’ prefix. At most locations, five sensors are installed at 20 cm depth intervals to a total depth of 1 m.

Soil moisture is measured using Sentek sensors which monitor changes in the dielectric constant within a cylinder of soil extending to a radial distance of 10 cm from the access tube. Soil moisture is reported as mm water per 100 mm soil depth (or volumetric % water) at each monitored depth

(Sentek, 2017). The most recent installations are equipped with automated data loggers set to record moisture levels every hour, whereas previous installations are recorded manually during scheduled site visits.

## 3.2 Baseline monitoring

### 3.2.1 Stream flow and catchment yield

Stream flow is gauged at three sites in the Wongawilli Creek catchment and three sites in the Sandy Creek catchment that are relevant to monitoring of baseline conditions for LW19 (Table 2 and Table 3; Figure 1). Table 4 summarises the baseline flow conditions for the gauging stations relevant to this assessment (late 2019). The baseline period to 2019 includes data collected over the last two years of severe drought. The last column of Table 4 summarises the effects on stream flow that are attributed to mining at Area 3A (and 3B) in previous reports.

Sites WWU, WWL, SC10S1 and SC10CS1 have been monitored since 2007, prior to the start of mining in Area 3A, whereas monitoring at SCL and WC15 started in 2011 and 2012 respectively. The available baseline for LW19 as of the end of 2019 ranges from 7.5 years to approximately 12 years. There are >2 years of baseline data available for the longest active gauges prior to the start of mining in Area 3A (9/2/2010).

**Table 4. Stream flow gauge sites relevant to the study area**

| Water-course | Gauge | Catchment Area ($km^2$) | Median flow (ML/day) | Mean flow (ML/day) | Yield (%rain) | Annual no-flow days | Observed mining effects |
|---|---|---|---|---|---|---|---|
| Wongawilli Creek | WWU | 3.211 | 0.30 | 3.09 | 33% | 16 (4-5%) | Although Elouera Colliery did mine in this catchment, it is considered to be an upstream control site. There is no impact from Dendrobium mining. |
| WC15 | WC15S1 | 1.19 | 0.01 (pre-mining: 0.095) | 0.13 (pre-mining: 0.31) | 4% (pre-mining: 9%) | 69 | There is clear evidence that flow in WC15 has been affected by recent Area 3B longwalls. |
| Wongawilli Creek | WWL | 20.08 | 3.57 | 15.3 | 26% | 21 to 37 (6-10%) | No evidence for change of flow at downstream gauge* |
| SC10 | SC10S1 | 2.771 | 0.62 | *8.0*** | *98%*** | 39 | No clear evidence for change in flow due to previous Area 3A mining. |
| SC10C | SC10CS1 | 0.817 | 0.19 | 0.63 | 26% | 111 | Decrease in flow from September-2012 due to LW8 mining near and under the watercourse |
| Sandy Creek | SCL | 7.029 | 1.31 | 3.96 | 20% | 41 | No baseline data for the period before LW7. |

Statistics are based on the full flow record, accounting for QA assessment by ALS hydrographers.
* Qualitative monitoring of flow condition by IMCEFT between WWU and WWL has shown that baseflow losses are evident at very low flows in reaches close to extracted Area 3A and 3B longwalls, even if effects are not clear at the WWL downstream gauge.
** SC10 mean flow data appears erroneously high (all other sub-catchments listed here indicate a yield of 20-33%).

Stream flow duration curves for the baseline period are shown in Figure 8. Limited or no baseline data are available for gauging stations SCL2 prior to the start of mining at Area 3A, however the summary information and flow duration curves illustrate the following:

- The first and second order stream gauges (up-stream or adjacent to LW19) record minor runoff from small headwater catchments that are almost entirely covered by native eucalypt forest and upland swamp vegetation.
- Gauges on third-order reaches indicate average runoff yields of 10% to 30% of rainfall. The baseflow component is low and calculated to be in the order of 8% (HydroSimulations, 2016) at downstream gauges.
- Most streams cease to flow during prolonged dry periods, particularly during the summer months when potential evapotranspiration rates are high. During the baseline period, no-flow conditions occurred 2% to 5% of the monitored period, equating to between 6 and 20 days of the year on average (calculated only for gauges with >1-year baseline).
- A significant prolonged drought has occurred in NSW since 2017 (Section 2.2), and this has been reflected in extended periods of low or cease-to-flow conditions in the period 2017-2019 (Figure 9). These low flow conditions are observed at sites around historical and recent longwalls, as well as at reference sites away from mining.

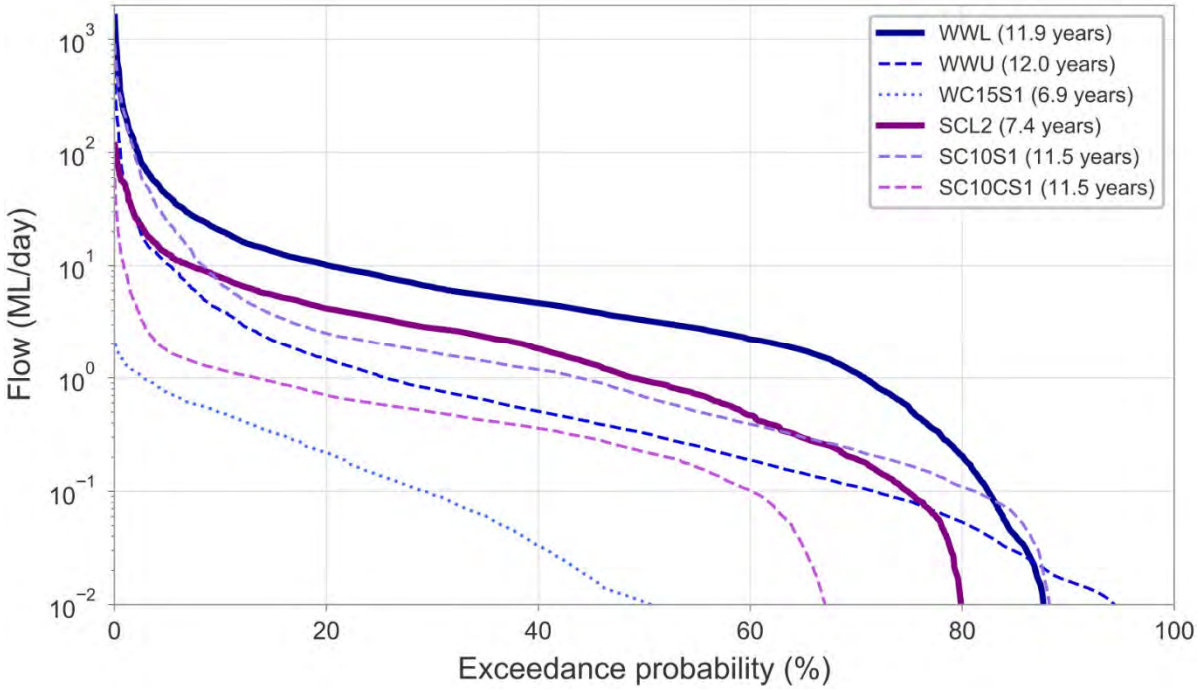



**Figure 8. Stream flow duration curves for baseline period (2007 – 2019)**

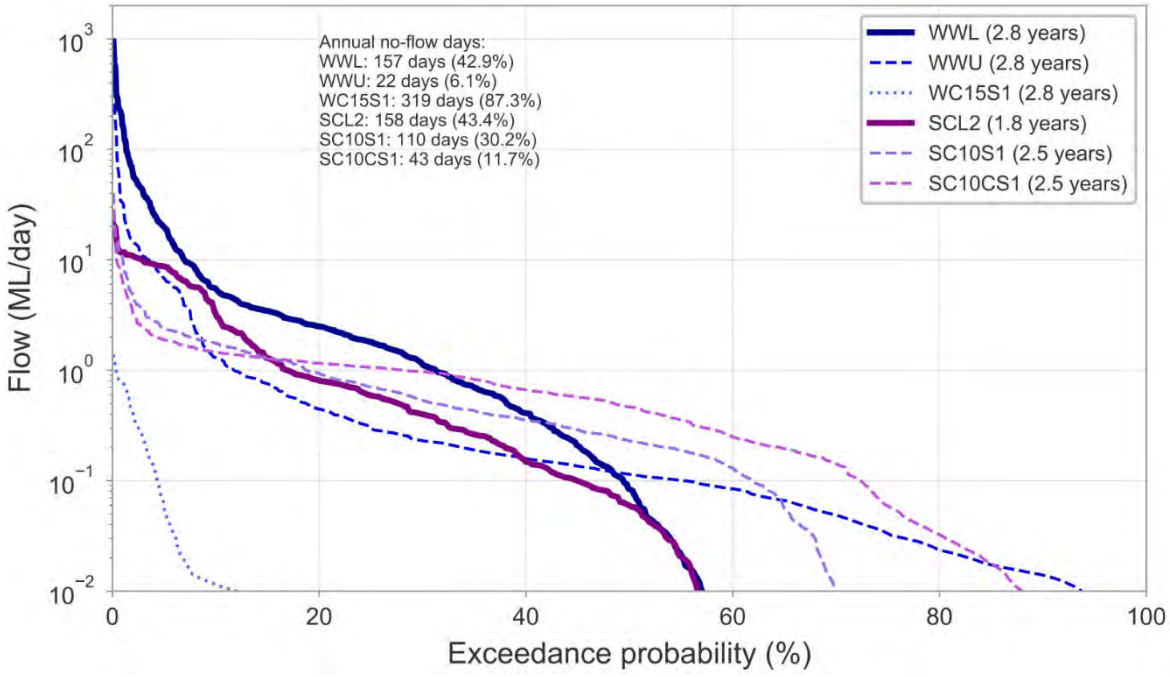



**Figure 9. Stream flow duration curves for the 2017-19 drought**

The 'middle reach' of Wongawilli Creek, located between Area 3A and 3B longwalls, has been identified as experiencing mining-related drawdown and flow loss (Watershed HydroGeo, 2018). There is no permanent flow gauge in this reach, but IMCEFT make regular observations of flow/trickle/no-flow conditions at multiple locations along this part of Wongawilli Creek (as well as at other locations). Using this observation data in tandem with the flow duration curves for the WWU and WWL gauging stations that are upstream and downstream of this reach (Figure 8), we have inferred that pre-mining cease-to-flow frequency along this reach is approximately 4-10%, most likely at the lower end of this range (i.e. ≤5%), more closely approximating flow conditions at WWU.

### 3.2.2 Surface water quality

Water chemistry is monitored at three sites on Wongawilli Creek and three sites on Sandy Creek that are relevant to monitoring of baseline conditions and potential impacts associated with proposed Longwall 19 (Table 2 and Table 3; Figure 1). Regular sampling and analysis have been carried out at the furthest downstream sites (Wongawilli Creek at FR6 and Sandy Creek Rockbar 5) since 2001 and 2007 respectively. Therefore, there are twelve years of baseline water quality data on Wongawilli Creek prior to the development of Area 3B and three years baseline at Sandy Creek prior to development at Area 3A.

ANZECC (2000) provides a framework for conserving the ambient water quality of streams and lakes through the development of Water Quality Objectives (WQO) based on their agreed environmental values. The approach has been adopted by the NSW Government in the management of the Hawkesbury-Nepean River system (HNCMA, 2008; HRC, 1998). Baseline water quality data (pre-LW9) are summarised and compared against guideline levels for the protection of 95% of freshwater aquatic species (Table 5).

While the ANZECC (2000) guideline provides default trigger values for the protection of aquatic species, its preferred approach is to use local (site) reference data when sufficient baseline data are available. Accordingly, the WIMMCP for Dendrobium Mine Area 3A (South32, 2020a) adopts location-

specific trigger levels determined from baseline monitoring data. The TARP levels are set for key water quality parameters (pH, EC and DO; see Section 5).

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 5.0 to 6.5), 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). An exception is dissolved aluminium in up-stream sites on Wongawilli Creek and Sandy Creek which is slightly above the guideline value for near neutral waters (pH >6.5), noting that there is no guideline value set for pH <6.5 more typical of these headwater streams. The slightly elevated aluminium concentrations are to be expected since aluminium (and most metals) are more soluble in waters of low pH. DO levels are variable and typically between 80 and 95% saturation. Time series plots of field parameters and selected dissolved metals for stream sampling sites relevant to this assessment are shown in Appendix 1.

**Table 5. Baseline stream water chemistry (pre-Longwall 9 median values)**

| Median values (mg/L) | Wongawilli Creek (<2013) | | | Sandy Creek (<2010) | | | ANZECC (2000)# Freshwater 95% |
|---|---|---|---|---|---|---|---|
| | WWU4 | WCS1 | Wongawilli Ck (FR6) | | | | |
| Samples | *111* | *12* | *132* | *35* | *15* | *15* | |
| EC (µs/cm) | 89 | 89 | 101 | 104 | 94 | 98 | 30-350[a] |
| pH (pH units) | **5.5** | **6.3** | **6.2** | **6.2** | **5.9** | **5.5** | 6.5-7.5 [a] |
| DO (%) | 93 | **82.6** | 92.5 | n/a | n/a | n/a | 90-110 |
| Total Alk | <0.5 | 3 | 2 | 2 | <0.5 | <0.5 | - |
| Cl | 19 | 20 | 25 | n/a | n/a | n/a | - |
| SO4 | 4 | 2 | 3 | 2 | 2 | 3 | - |
| K | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | - |
| Na | 10 | 11 | 13 | 12 | 13 | 13 | - |
| Ca | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | - |
| Mg | <2 | <2 | <2 | <2 | <2 | <2 | - |
| Al | **0.06** | 0.05 | 0.04 | | **0.12** | **0.12** | 0.055[b] |
| Fe | 0.08 | 0.20 | 0.22 | 0.17 | 0.18 | 0.25 | - |
| Mn | 0.09 | 0.07 | 0.04 | 0.043 | 0.035 | 0.046 | 1.9 |
| Ni | 0.006 | 0.0008 | 0.0005 | <0.001 | <0.001 | <0.001 | 0.011 |
| Si | 1.73 | 2.04 | 1.745 | 1.46 | 1.17 | 1.35 | - |
| Zn | 0.03 | **0.008** | 0.006 | <0.005 | <0.005 | <0.005 | 0.008 |
| Fe (total) | 0.13 | 0.95 | 0.5 | n/a | 0.27 | 0.41 | - |
| Al (total) | 0.08 | 0.085 | 0.07 | n/a | 0.17 | 0.16 | - |
| Mn (total) | 0.08 | 0.08 | 0.05 | n/a | 0.035 | 0.047 | - |
| Total N | 0.005 | 0.020 | 0.005 | n/a | n/a | n/a | 0.25 [a] |
| Total P | 0.005 | 0.005 | 0.005 | n/a | 0.005 | 0.005 | 0.02 [a] |

# Guideline trigger vales for protection of 95% of species; (a) Default trigger levels for Upland river systems in south-east Australia. (b) Trigger for Al in water with pH >6.5.

Extraction of Longwalls 6, 7 and 8 in Area 3A resulted in localised effects on water quality in tributaries of Wongawilli Creek (WC17) and of Sandy Creek (SC10C). Those effects are summarised in Section 4.6.

### 3.2.3 Shallow groundwater

Swamp groundwater levels in the Dendrobium Mine area have been monitored since 2010, providing baseline data with which to assess the natural hydrological characteristics of swamps, and also the impacts of mine-related subsidence on swamp hydrology. Monitoring of shallow groundwater levels and soil moisture content in Coastal Upland Swamps is prescribed in the Area 3A SIMMCP (South32, 2020c).

Hydrographs for shallow piezometers located at swamps within 600 m of LW19 are presented in Appendix 2. Hydrographs for other swamps overlying Dendrobium are included to illustrate typical swamp characteristics. Each hydrograph is plotted relative to ground elevation and the elevation of the piezometer base, longwall timing, rainfall, and the dates that previous longwalls pass under (or within 400 m of) a piezometer. Also plotted on the hydrographs in red is the groundwater level recession rate in mm/day.

Swamp hydrographs display a range of responses reflecting varying hydrological regimes at each swamp and at different locations within each swamp. At most locations, the shallow groundwater level rises sharply to within centimetres of the ground surface after a significant rainfall event (>75 mm in one day), particularly if the event is preceded by rainy days. The shape of the recession curve is characteristic of each swamp and location, with the following responses being common:

- In some swamps, a sharp peak lasting several days following a significant rainfall event, followed by a rapid recession as described below. The sharp peaks represent input from rainfall and subsequent runoff events. An example is at Swamp 87, piezometer 87_01 in Appendix 3.
- In other swamps, a flat-topped or gently sloping peak with a duration of several weeks, indicating that groundwater levels are sustained near the ground surface following the rainfall event or that there is sufficient water entering the swamp (from rainfall or run-on from up-catchment) and the level of water in the swamp is maintained at a constant elevation by surface drainage. An example is Swamp 85, piezometer 85_02 in Appendix 3.
- A concave downward recession (seen in Swamp 1b at piezometer 01b_01, prior to mining).
- A concave upward recession (seen in Swamp 23, piezometer 23_02).

In many cases swamp hydrographs display characteristic combinations of the above responses, suggesting that each is indicative of a hydrological (or hydrogeological) control that becomes dominant as the water supply declines after the rainfall event.

Swamps that have been undermined commonly display hydrological changes shortly following the passage of the longwall beneath the monitoring site. Those hydrological changes are described in Section 4.7.

# 4. POTENTIAL MINING EFFECTS

Ground subsidence and depressurisation of groundwater systems associated with underground mining can result in a range of effects on surface water and shallow groundwater systems. In this section, potential impacts are identified, and their likelihood and severity assessed in relation to the proposed mining activities.

In relation to LW19 the most likely effects are:

1. **Altered drainage and flooding**. Mine subsidence can lead to changes in gradient within a watercourse which in turn may lead to a change in the likelihood of ponding, flooding and erosion.
2. **Flow diversions**. The development of fractures in a stream bed may result in diversion of flow from the stream channel to the sub-surface and a measurable reduction in stream flow at monitoring gauges. This effect has the potential to be long-lasting and possibly permanent.
3. **Groundwater drawdown and reduction in baseflow**. Where stream flow is partly sustained by the discharge of groundwater from adjacent aquifers (baseflow), groundwater drawdown or depressurisation due to mining can lead to a reduction in baseflow and additional cease to flow/pool dry days. This effect is likely to be long-lasting (i.e. decades), but not permanent.
4. **Altered surface water quality**. Fracturing of the stream substrate can result in the development of ferruginous springs (iron staining), alteration of water quality parameters and the mobilisation of trace metals which may in turn affect the health of aquatic ecosystems.
5. **Altered swamp hydrology**. Near-surface fracturing can result in a decline in shallow groundwater levels which may in turn affect soil moisture content, swamp vegetation and dependent ecosystems. Effects on swamp hydrology (water retention and groundwater drainage rates) can be long-lasting and possibly permanent. Potential effects on swamp vegetation will be described in the ecological assessment (Niche, 2020) accompanying this surface water assessment.

## 4.1 Mine subsidence

Most surface water and shallow groundwater impacts are associated with ground subsidence and near-surface fracturing. It is therefore relevant to review predictions of subsidence and surface cracking associated with the extraction of LW19 by mine subsidence consultants MSEC (2020). The MSEC assessment used the Incremental Profile Method (IPM) calibrated to observations and measurements above previously mined longwalls at Dendrobium. The main findings from the MSEC report are listed in Table 6. The reader is referred to the subsidence assessment by MSEC (2020) for further detail.

**Table 6. Summary of predicted subsidence effects (from MSEC2020)**

| Location / feature | Predicted subsidence effects |
|---|---|
| Within longwall footprint | **Incremental movement due to LW19**: Up to 2900 mm subsidence, 40 mm/m incremental tilt, 1.0 $km^{-1}$ incremental hogging curvature and 1.0 $km^{-1}$ incremental sagging curvature.<br>**Total cumulative subsidence** above LW19 as a result of LW6 to LW8 and LW19 is estimated at 3000 mm. Note that the maximum predicted subsidence effects in Area 3A are less than for Area 3B due to the lower mining height in Area 3A (3.9 m) than in Area 3B (4.6 m). |

| Location / feature | Predicted subsidence effects |
|---|---|
| Wongawilli Creek | Wongawilli Creek is located outside the extents of LW19, at a minimum distance of 175 m. The maximum predicted total vertical subsidence along Wongawilli Creek is less than 20 mm; maximum 150 mm upsidence and 70 mm incremental valley closure.<br>Fracturing could occur along the creek within approximately 400 m of the proposed longwalls. The likelihood of significant fracturing resulting in surface water flow diversions at rockbars is considered low (may affect <10% of rockbars). |
| Sandy Creek | The maximum predicted incremental vertical subsidence, upsidence and closure for Sandy Creek, due to the mining of LW19, are all less than 20 mm. While the creek could experience very low levels of these subsidence effects, it is not expected to experience measurable tilts, curvatures or strains. Therefore, it is unlikely that adverse impacts would occur along Sandy Creek, including Sandy Creek Waterfall, due to the mining of LW19. |
| Tributaries | One tributary of Wongawilli Creek crosses the footprint of LW19 (WC14), and two others pass within 400 m of the longwall (WC15 and WC17). Tributary SC10 crosses the footprint of LW19, and both SC10 and SC10SC pass within 400 m over a significant portion of their lengths.<br><br>It is expected that fracturing of stream beds will occur, and flow diversions are likely in sections that directly overlie LW19 (and 7 and 8), with minor and isolated fracturing possible at distances up to approximately 400 m from the longwalls. |
| Swamps | Swamps 15a and 148 are partially located above LW19. Fracturing and diversions of surface water could occur beneath these swamps, near the valley base and where it is located closest to the proposed longwall. Based on observations at Area 3B, the probability of a Type 3 impact at the controlling rockbar of Swamp 15a (SC10_Rockbar15a) is estimated at 13%.<br><br>Swamps 12, 15b and 146 were affected by subsidence associated with extraction of Longwalls 7 and 8. It is likely that [additional] fracturing will occur in the bedrock beneath these swamps in areas located above and adjacent to the mining area.<br><br>Swamps 34, 96, and 147 are located outside the mining area at minimum distances of 210 m to 490 m from LW19. These swamps are predicted to experience less than 60 mm vertical subsidence. Therefore, it is unlikely that fracturing would occur in the bedrock beneath these swamps due to LW19. |

## 4.2 Subsurface fracturing

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

Several authors have developed empirical approaches to estimating the height of connected fracturing or complete groundwater drainage above longwalls (e.g. Ditton and Merrick, 2014; Forster, 1995; Guo *et al.*, 2007; Mills, 2011; Tammetta, 2013). These methods have been used at numerous coal mines in NSW to provide guidance on the height of fracturing for the development of numerical groundwater impact models. At Dendrobium, the methods of Ditton and Merrick (2014) and Tammetta (2013) yield estimates that are significantly different from each other. A review of longwall subsidence fracturing at Dendrobium was commissioned by the then NSW Department of Planning and Environment (DPE). The review by consultants PSM (2017) concluded that such empirical approaches carry significant uncertainty and limitations related to the data on which they were based, and that fracturing above the (305 m wide) panels in Area 3B likely extends to the surface (Galvin, 2017; PSM, 2017). The IEPMC similarly recommended "*erring on the side of caution and deferring to the Tammetta equation*" until the height of fracturing can be confirmed through field investigations and/or geotechnical modelling (IEPMC, 2018).

Recent investigations by IMC support this approach. Between 2018 and 2019, IMC drilled 11 holes above extracted longwalls in Areas 3A and 3B to assess the nature and extent of fracturing above the goaf. The outcomes of the investigation are described in HGEO (2020). The study concluded that mining-induced fracturing, including high -angle fracturing, is highly variable but appears to extend to the surface above longwalls of width 249 m in Area 3A and 305 m in Area 3B. The density of fracturing decreases with height above the goaf, with anomalous fracturing within the BACS and below 120 m above the goaf. Packer tests indicate an increase in permeability of 2 to 3 orders of magnitude relative to pre-mining conditions throughout most strata above the longwall goaf. Vibrating wire piezometers (VWP) installed after longwall extraction indicate significant depressurisation throughout all strata, with near-zero pressure heads recorded in most piezometers. Complete depressurisation is recorded throughout the HBSS in most holes drilled above goaf.

The findings of the drilling investigation can be applied directly to LW19 in Area 3A. It is expected that fracturing associated with LW19 will extend to the surface over at least part of the longwall footprint, resulting in depressurisation of the HBSS and potential for surface-to-seam connectivity above the goaf.

## 4.3 Altered drainage and flooding

Changes in stream bed gradient due to mining can result in increased ponding where the ground tilt opposes the natural gradient or can result in increased flow velocity and bed scouring where mine-induced tilt increases the natural stream gradient. Potential for increased ponding and scouring due to mine-induced changes in stream gradient is assessed by MSEC (2020). The main conclusions in relation to the MSEC assessment of changes in stream-bed gradient are summarised in Table 7.

In summary, changes in stream gradients along Wongawilli Creek and Sandy Creek are expected to be very small in comparison to the natural gradients in the study area and no localised reversals in gradient are predicted. It is therefore considered unlikely that adverse changes in ponding or scouring will occur as a result of subsidence related tilt from LW19. Changes in gradient in the minor first order tributaries located above the longwall and development footprints are predicted to be <3 %, which is considerably less than the natural headwater gradients. There is potential for minor and localised increases in ponding and scouring in those drainage lines. However, those impacts are expected to be small in comparison with those which occur during natural flooding conditions (MSEC, 2020).

**Table 7. Summary of predicted changes to stream gradient (from MSEC 2020)**

| Location / feature | Predicted subsidence effects |
|---|---|
| Wongawilli Creek | The predicted changes in grade due to the mining of LW19 are considerably less than the average natural grade within the study area (0.36%). It is unlikely, therefore, that there would be adverse changes in the potential for ponding, flooding or scouring of the banks along the creek due to the mining-induced tilt. It is possible that there could be some localised changes in the levels of ponding or flooding where the maximum changes in grade coincide with existing pools, steps or cascades along the creek. It is not anticipated that these changes would result in adverse impacts on the creek, due to the mining-induced tilt, since the predicted changes in grade are less than 0.05%. |
| Sandy Creek | Sandy Creek is not expected to experience measurable tilts, curvatures or strains. Therefore, there is unlikely to be a noticeable increase in ponding, flooding or scouring along the watercourse. |
| Tributaries | There are no predicted reversals of stream grade along drainage lines SC10, SC10C, WC14 and WC17. There are slight reductions in grades along drainage lines SC10C and WC17, upstream of the chain pillars and the edges of the mining area. There is potential for minor and localised increased ponding upstream of these locations. However, drainage lines SC10C and WC17 are located above the existing Longwalls 7 and 8 and, therefore, the potential for increased ponding occurs due to these existing longwalls rather than the proposed LW19. |
| Swamps | The maximum predicted total tilt for the swamps is 3.5%. The greatest tilts occur at Swamps 12, 15b, 146 and 148. Swamps 15a and 95 are predicted to experience tilts of 1.3% and 0.2% respectively. The remaining swamps within the study area are located outside the mining area and are predicted to experience tilts of less than 0.05 %. There are no predicted reversals of stream grade along drainage lines nor within the extents of the swamps. It is considered unlikely that there will be adverse changes in the levels of ponding or scouring for the swamps within the study area due to vertical subsidence and tilt associated with LW19. |

## 4.4 Flow diversion

Mining directly under or close to surface watercourses can result in diversion of flow from the watercourse and/or loss of surface flow from the catchment. Water diverted from surface channels can be directed through fracture networks to the water table and may re-emerge downstream, as is commonly observed in the Southern Coalfield. If surface fractures intersect deeper (vertically connected) mining induced fracture networks, there is potential for water to be directed into those deeper fracture storages, or to the mine itself. In the latter case, surface flow would be lost from the catchment. Significant losses would be detected as a decrease in flow (and catchment yield) at downstream gauges.

Surface fracturing, including fracturing of stream-beds, has been observed at distances up to 400 m from previously extracted longwalls in the Southern Coalfield.

Watershed HydroGeo (2019a) assessed three different methods for determining mining impacts on stream flow in Dendrobium Area 3B in addition to the exiting TARP methodology. The results of that assessment are reproduced in Figure 10.

In summary, significant changes in stream flow are discernible in first and second-order watercourses that flow over the goaf footprint (e.g. upper reaches of Donalds Castle Creek, DC13; tributaries of Wongawilli Creek, WC21 and WC15). However, at gauging stations ≥1.5 km downstream of extracted

longwalls (DCU and WWL), there are no discernible impacts to flow beyond natural variability and given the uncertainty in the assessment methods.

| Site / sub-catch. | Results of Assessment to the End of Longwall 14 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Current TARP assessment | | | Proposed assessment methods | | | | | | | Comparison |
| | Change in yield % | TARP Level | Comment | Low flow Q%ile outside Reference Site Q%ile | | Change in cease-to-flow frequency (beyond natural) | | Change in Q50 (beyond natural) | | | |
| | | | | | | | | ML/d | % pre-mining Q50 | | |
| DC13 | -16% | Level 2 | | 62% | Level 3 | +28% | Level 3 | 0.11 ML/d | -90% | Level 3 | All three proposed methods are consistent at Level 3, and quite consistent with the existing method (Level 2). |
| DCS2 | -20% | Level 3 | | 60% | Level 3 | +41% | Level 3 | 0.08 ML/d | -50% | Level 3 | All three proposed methods are consistent at Level 3, and consistent with the existing method (Level 3). |
| DCU | +2% | Not triggered | Possible change at low flows | -4% | Not triggered | +8% | Level 1 | <natural variability or error. | +16% | Not triggered | Two of three proposed methods are consistent at Level 0, and consistent with the existing method (Level 0). One proposed method suggests a mild increase in c-t-f flow frequency – a finding that was made qualitatively in previous EOP reports. |
| WC15 | -12% | Level 1 | | 36% | Level 2 | +7% | Level 1 | 0.03 ML/d | -33% | Level 2 | All methods detect an impact. Two of three proposed methods are consistent at Level 2, and more conservative than the existing method (Level 1). |
| WC21 | -24% | Level 3 | | 27% | Level 2 | +14% | Level 2 | 0.21 ML/d | -44% | Level 3 | All methods detect an impact. Two of three proposed methods are consistent at Level 2, and the third consistent with the existing method (Level 3). |
| WWL | -4% | Not triggered | | 5% | Not triggered | +1% | Not triggered | <natural variability or error | +4% | Not triggered | All three proposed methods are consistent at Level 0, and consistent with the existing method (Level 0), i.e. no impact detected beyond natural variability. |
| LA4 | -6% | Level 1 | | 17% | Level 1 | -2% | Not triggered | 0.03 ML/d | -34% | Level 2 | Two of three new methods detect an impact. One is consistent with the existing method (Level 1), but one suggests a more conservative level of effect (which seems more appropriate). |

**Figure 10. Summary of stream flow impacts at Area 3B (Watershed HydroGeo 2019)**

End of panel assessments for Longwalls 6, 7 and 8 (Ecoengineers, 2013, 2012, 2011) concluded on the basis of data available at the time that there were no significant impacts to stream flow at the downstream gauge on Sandy Creek (SCL). Further review of pool water levels and water chemistry (Appendix 1) indicate effects in upstream watercourses that are likely related to subsidence in Area 3A:

- SC10C. Several pools along tributary SC10C which flows across the footprint of LW8 show rapid declines in water level following extraction of the longwall, indicating diversion of flow due to fracturing of the watercourse substrate (e.g. Pools 0, 3, 4, 5, 7, 8, 10, 11).
- SC10. Monitoring data for the watercourse are too sparse to identify effects with certainty.
- WC17. Evidence for declining pool levels along the watercourse during extraction of Longwalls 7 and/or 8 (e.g. S12 Pools 9, 10, 11, 12).
- Sandy Creek. There is no clear evidence for water level impacts to pools. Pool 9 shows a decline in levels during LW7. However, given the distance to LW7 (490 m) the level changes may be due to other factors such as changes to the pool control bar following a large rainfall event.

A decline in water level has been noted in Pool 43a on Wongawilli Creek, starting around 2012 (LW6) and continuing to 2019 (HGEO, 2019). Fracturing of the stream bed was noted on 18/12/2013 following extraction of LW8 in Area 3A. An assessment of the pool water levels by Watershed HydroGeo (2018) concluded that the decline in pool level was likely due to a combination of baseflow loss due to mining-related depressurisation of the sandstone substrate and severe rainfall deficits over recent years. The rate of baseflow loss is likely within the range predicted from groundwater modelling (HydroSimulations, 2016); however the effects on pool levels are more noticeable during periods of low rainfall.

Based on the subsidence assessment by MSEC (2020), summarised in Table 6, and previous experience at Dendrobium as discussed above, the following effects are expected as a result of LW19 extraction:

- Wongawilli Creek: Fracturing of the stream bed and rockbars is possible within 400 m of LW19 with the likelihood of surface water diversions estimated at 10 %. The cumulative effects of strata depressurisation associated with LW19 and previous longwalls may affect baseflow and water levels in pools adjacent to LW19 and along-strike of major lineaments and joints. Those effects would be most noticeable during periods of low flow and may not result in detectable losses at downstream flow gauges (WWL).
- Upper reaches of the second order tributary WC14 is likely to experience fracturing of the creek beds and diversions during periods of flow. Fracturing and flow diversions are possible within 400 m of LW19, potentially affecting WC17, noting that WC17 was previously impacted by Longwalls 7 and 8.
- Sandy Creek tributaries: Fracturing and diversions of flow are likely to occur on SC10 where the tributary overlaps with the southwest corner of LW19 (55 m length) and are possible up to 400 m from the longwall.
- Tributaries SC10C and SC10B are within 400 m of LW19 and may experience fracturing and flow diversions, noting that SC10C was previously impacted by Longwalls 7 and 8.

### 4.4.1 Sandy Creek Waterfall

Sandy Creek Waterfall is located 900 m north-east of the commencing end of LW19, where Sandy Creek flows into Cordeaux Reservoir. The waterfall is approximately 20 m high, 75 m wide with an overhang of up to 21 m. Condition 1, Schedule 3 of the Dendrobium Development Consent requires that mining does not impact the structural integrity or result on more than negligible water diversions at the waterfall. The waterfall became the focus of detailed assessment during the extraction of Longwalls 6 to 8 in Area 3A between 2010 and 2013. LW6 was completed at 365 m from the waterfall in April 2011; subsequent Longwalls 7 and 8 were completed at 410 m and 490 m from the waterfall. As a result of effective planning, monitoring and assessment Longwalls 6 to 8 were successfully extracted with no visible changes to the waterfall (Walsh *et al.*, 2014). End of panel assessments found no significant impact to stream flow at the downstream gauge on Sandy Creek (SCL) following completions of Longwalls 6, 7 or 8 (Ecoengineers, 2013, 2012, 2011).

The mining subsidence assessment by MSEC (2020) concludes that, due to the large distance of Sandy Creek Waterfall from LW19 compared with the previous longwalls in Area 3A, It is unlikely that the waterfall would experience adverse impacts due to mining of LW19.

A waterfall located 160 m east of LW19 on watercourse SC10 (waterfall SC10-WC15) is assessed by MSEC to undergo vertical subsidence of less than 20 mm. Based on experience of longwall extraction near cliffs at Dendrobium and elsewhere, the likelihood of structural instability at the waterfall is considered very low. However, being located within 400 m of LW19, fracturing of the creek bed and localised flow diversions are considered possible.

## 4.5 Surface water loss due to depressurisation

### 4.5.1 Stream baseflow

Where stream flow is partly sustained by the discharge of groundwater from adjacent aquifers (baseflow), groundwater drawdown or depressurisation due to mining can lead to a reduction in the

baseflow component. The potential reduction in groundwater levels and baseflow in watercourses was assessed using a regional numerical groundwater model by SLR (2020). A summary of the estimated incremental loss of baseflow due to LW19 is shown in Table 8 and the reader is referred to the SLR report for further details.

In relation to estimates of baseflow loss, the IEPMC (2019c) considered that: *errors in modelled pressure heads and inconsistencies between predictions and observations continue to lead to little confidence in the groundwater model's ability to predict surface water flow losses…Recommendations relating to managing uncertainty in model predictions are covered in the Panel's Part 2 Report*. The IEPMC Part 2 report (IEPMC, 2019b) recommends that uncertainty analysis of groundwater and surface water models should follow the uncertainty analysis workflow recommended by the IESC (2018); and that *a precautionary approach should be taken that does not assume groundwater model outputs are accurate. Predictions should be conservatively high to allow for prediction uncertainty and where practicable the associated non-exceedance probability should be stated*. Groundwater consultants SLR (2020) have taken the latter approach by applying conservative assumptions in deriving the estimates in Table 8, including the assumed vertical connectivity between seam (mine workings) and surface, as suggested by PSM, 2017.

**Table 8. Estimated cumulative and incremental change in surface water flow**

| 5-year period | Wongawilli Creek and tributaries (ML/day) | | Lake Cordeaux catchment including Sandy Creek and tributaries | |
|---|---|---|---|---|
| | Whole Mine | LW19 Increment | Whole Mine | Sandy Creek LW19 Increment |
| 2016-20 | 0.74 | 0.000 | 0.74 | 0.000 |
| 2021-25 | 1.27 | 0.014 | 1.15 | 0.060 |
| 2026-30 | 0.98 | 0.003 | 0.60 | 0.038 |
| 2031-35 | 0.36 | 0.008 | 0.32 | 0.030 |
| 2036-40 | 0.05 | 0.008 | 0.19 | 0.019 |
| 2041-45 | 0.05 | 0.008 | 0.15 | 0.008 |
| 2046-50 | 0.09 | 0.008 | 0.11 | 0.005 |

* Incremental flow reductions as ML/d converted from ML/yr shown in Tables 5-1 and 5-2 of SLR (2020)

The potential incremental decrease in stream baseflow as a result of LW19 extraction equates to 2% and 9% of the cumulative (whole mine) losses over the period 2020-2035 for Wongawilli Creek and Sandy Creek respectively. At the time of the maximum expected loss (5 years post extraction) the peak cumulative losses are estimated at 8% and 29% of the mean flow (0.1% and 1.5% incremental). After 2035 both the cumulative and incremental losses are expected to decline to 0.05 ML/day or less.

Decreases in baseflow will be most apparent during periods of low rainfall and low-flow in the catchments and may manifest as an increase in no-flow days compared with baseline conditions, as illustrated in Section 4.5.3.

### 4.5.2 Leakage from reservoirs

SLR (2020) carried out several numerical modelling scenarios in which the permeability of strata between Area 3B and Avon Reservoir where enhanced to reflect changes due to subsidence movements such as valley closure. The estimated total leakage losses from Avon and Cordeaux Reservoirs, and incremental losses due to the extraction of LW19 are shown in Table 9.

The estimated incremental leakage losses from both reservoirs as a result of extraction of LW19 is estimated to be less than 0.001 ML/day, or effectively nil. This is due to the distance of LW19 from both reservoirs and the effects of previously extracted longwalls on the intervening strata.

**Table 9. Estimated leakage from reservoirs (SLR 2020)**

| Reservoir | Whole mine cumulative loss (ML/day) | Incremental loss due to LW19 (ML/day) |
|---|---|---|
| Lake Avon | 0.15 – 0.47 | <0.001 |
| Lake Cordeaux | 0.04 – 0.1 | <0.001 |

### 4.5.3 Predicted effects on stream flow characteristics

The predicted effects of baseflow depletion on stream flow characteristics are well-illustrated using flow duration curves. A flow duration curve shows the percentage of time that a stream carries flow exceeding a given rate, and it is useful for defining low-flow and no-flow characteristics. Figure 11 and Figure 12 show flow duration curves for flow gauges SCL2 on Sandy Creek and WWL on Wongawilli Creek respectively, which are the two catchments most relevant to LW19.

On each plot, the post-mining assessment period (2011 – 2019 and 2010 – 19 respectively), as modelled using parameters from the baseline, is represented by a dashed green line. This line indicates what natural flows would have been during that period without the influence of mining. The observed flows for the same post-mining period are shown as the dotted purple line. The difference between the dotted purple and green lines is indicative of the actual effect of mining in these catchments has been (notwithstanding uncertainties related to flow gauging errors and calibration, as discussed in IEPMC, 2019b).

For each plot, modelled flows for the full period 1990-2019 are shown as the heavy green line (i.e. natural conditions). The *maximum* predicted impacts from the groundwater assessment (from Tables 5-1 and 5-2 of SLR, 2020) for both Sandy Creek and Wongawilli Creek have then been applied for two cases: the predicted impacts as for the approved Dendrobium Area 3B and 3A (blue line) and Dendrobium approved plus proposed LW19 effects (red line). The difference between each of the blue or red lines and the solid green line indicates the maximum predicted impact or flow depletion at each site, based on the groundwater model.

#### Sandy Creek (SCL2)

The flow duration curves for SCL2 (Figure 11) indicate that:

- The flow at SCL2 including the actual effects of Approved Dendrobium mining (dashed purple line) have been greater at low flows than predicted (green dashed line), based on the 2011-2019 data. Average pre-mining flow at SCL2 was approximately 5.2 ML/d, and actual effects at average flows are similar to predicted (i.e. within 0.3 ML/d), but at lower flows, the magnitude of actual effects have not been discerned through comparison against rainfall-runoff modelling (noting that gauge accuracy at low flows is an issue that has been discussed between IMC and WaterNSW - see Section 5.1.2).

- The groundwater model predicts that the effect of Area 3A longwalls will result in a significant decline in low-flows (dashed blue line) and a significant increase in the number of days with no-flows at SCL2 (from 5-8% of the time to 40%). This is a conservative prediction based on the first bullet point.
- The predicted maximum incremental effect of LW19 is approximately 22 ML/yr (0.06 ML/d). The cumulative effects of all Area 2 and 3A predicted by the groundwater model (SLR, 2020) would be to reduce flows by about 0.6 ML/d (dashed red line). This could result in cease-to-flow conditions up to 40% of the time at SCL2, although an increase of approximately 5% (to about 10-13% of the time) is considered more likely based on comparison against other sites' historical flow data, such as that analysed in Watershed HydroGeo (2019). The discrepancy is directly related to the conservatism imposed in the groundwater model configuration and predictions, as described earlier in Section 4.5.1.
- Considering the conservative predictions made by the groundwater model and the evidence from analysis of data, the likely change in cease-to-flow conditions range between an increase in the frequency of such conditions by 5 to 20%, where the lower end is based on review of data at the other downstream gauging sites WWL and DCU (Watershed HydroGeo, 2019).

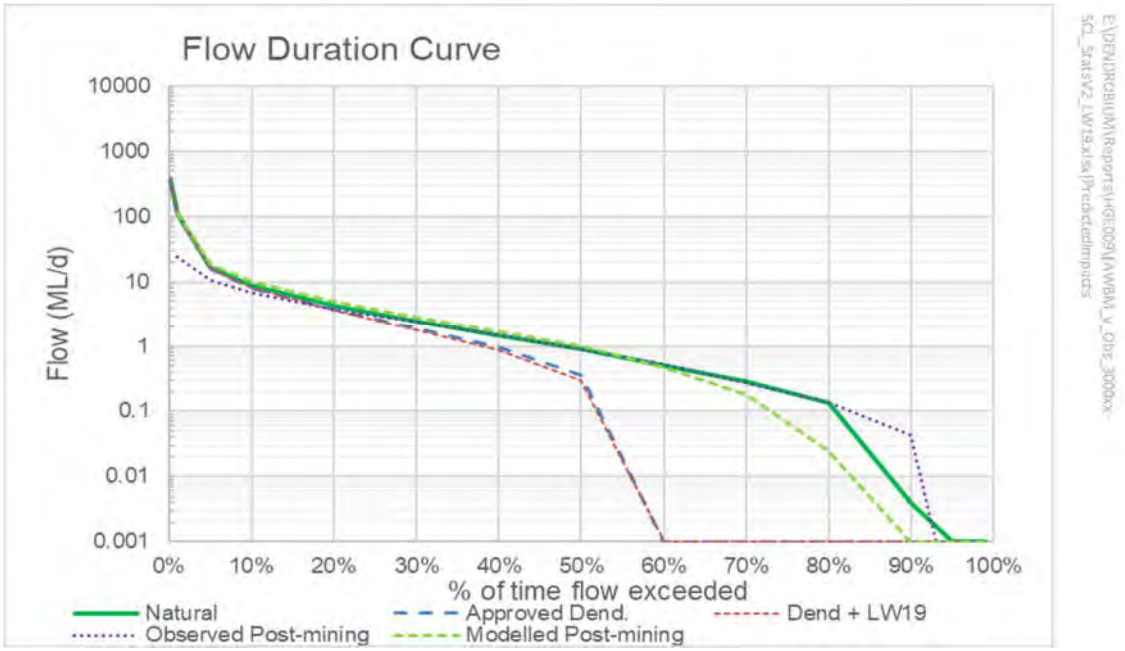



**Figure 11 Flow duration curve for SCL2 on Sandy Creek**

### Wongawilli Creek (WWL)

The flow duration curves for WWL (Figure 12) indicate that:

- Baseline cease-to-flow frequency is approximately 6-10%, based on the purple and solid green lines on Figure 12 and the statistics in Table 4.
- The actual effects of the Approved Dendrobium mining at WWL have been less than predicted, based on the 2013-2019 data and modelling (comparison of purple and dotted green lines), and also as described in End of Panel analysis and more recent analysis carried out to inform revised flow TARPs (Watershed HydroGeo, 2019).
- The groundwater model predicts, again conservatively, that the effect of Areas 3A and 3B longwalls would be to result in a significant decline in low-flows (dashed blue line) and a significant increase in the number of days with no-flows on WWL (from about 10% of the time to 24%). Such a decline has not been observed to date.
- The predicted maximum incremental effect of LW19 is 62 ML/yr (0.16 ML/d). The cumulative effects of Area 3B, 3A (including LW19) and Longwalls 20-21 would be to further reduce flows (dashed red line) by about 1.3 ML/d. This could result in cease-to-flow conditions up to 28% of the time, although such an increase is considered highly unlikely based on analysis of pre- and post-mining data in Watershed HydroGeo (2019) – see discussion of the conservatism in the groundwater model predictions in Section 4.5.1 and below.

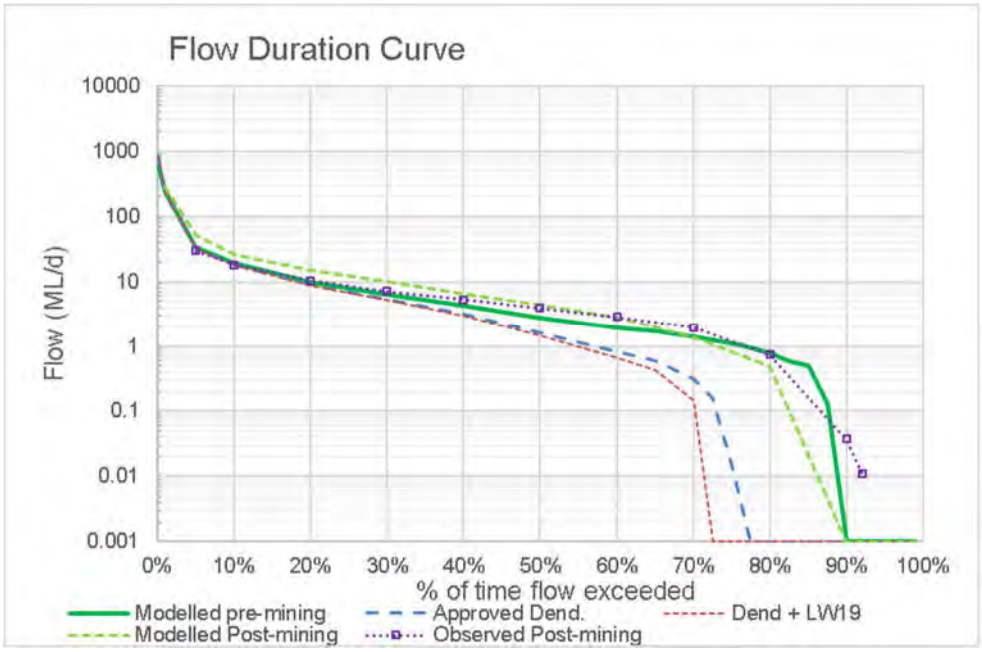



**Figure 12 Flow duration curve for WWL on Wongawilli Creek**

Effects on flows at WWL have not yet been identified in the End of Panel Reports (using comparison against AWBM rainfall-runoff modelling) or in more recent analysis using comparison against reference gauge records (Watershed Hydrogeo, 2019a). This is despite several upstream gauging sites in Area 3B showing flow reductions or pool level decline (e.g. Pool 43a, Wongawilli Creek, located between Area 3A and 3B; HGEO, 2018a; Watershed Hydrogeo, 2018 and 2019). Therefore, it is possible that effects upstream of, or between, gauging stations may be more significant than those observed at downstream gauging stations.

### Wongawilli Creek between Areas 3A and 3B

The previous point is pertinent to LW19's position along the 'middle' reach of Wongawilli Creek, where reductions in baseflow due to groundwater drawdown in the near-surface strata (HBSS and Colo Vale or Bulgo Sandstone) have caused reductions in baseflow which, while small in absolute magnitude, can be a significant portion or all of the flow down this reach of Wongawilli creek in extreme drought periods, as have been experienced 2017-2019. It is expected that extraction of LW19 would cause a small increase in the duration and length over which cease-to-flow conditions can occur in drought periods. The analysis and conceptual model of this process is presented in Watershed HydroGeo, 2018, and a new flow TARP has been proposed to assess the occurrence of this (Watershed Hydrogeo, 2019a).

There is no permanent gauging station in this 'middle' reach of Wongawilli Creek. If compared to catchment-area scaled flows using upstream and downstream WWU and WWL records, the groundwater model predictions of baseflow loss along this middle reach suggest that cease-to-flow conditions could be occurring approximately 20-25% of the time in 2020 due to historical mining of Area 3A and 3B (as suggested by the blue line on Figure 12). As noted above, this prediction of cease-to-flow frequency is considered highly conservative.

Appendix 2 presents summary charts comparing IMCEFT's surface water flow observation data at four representative locations ('downstream sites' – the inflow and outflow at both Pool 43A and Pool 44 and the inflow observations at two 'upstream sites' at Pool 47B and 49) and reference gauge flow exceedance statistics. The charts compare 'no flow' observations (or observations of some surface flow) against the flow percentiles from reference sites WWU and O'Hares Creek on the same day. It is important to note that there is a lack of historical data for the pre-mining period for the downstream sites, and the drought period of 2017-19 is indicated to be as severe as any on record (Section 2.2).

The data from Pool 43A Inflow (Appendix 2, Figure A2-1) indicates that in the post-mining period (specifically and conservatively in the severe drought period post-2017):

- No flow observations occurred consistently when reference gauge flow percentiles were often Q95-Q90 (through 2018 into 2019)
- Flow was observed at this site during mid 2019 when flows were consistently in the range Q83-Q87.
- This suggests that the cease-to-flow frequency at this site, following the extraction of Longwall 14 (i.e. following 9 of 14 planned longwalls[2] adjacent to this reach of Wongawilli Creek) is <13% (see the purple line on the Pool 43A chart in Appendix 2).

Pool 43 Outflow (Figure A2-2) has an additional observation in early Feb-2020, and this indicates that cease-to-flow conditions are evident at Q95, so the critical range between no-flow and flowing conditions is 6-13% at this site.

The data from Pool 44 Inflow (Figure A2-4) indicates that in the post-mining period:

- No flow observations occurred consistently when reference gauge flow percentiles were often Q95-Q90 (during 2018)
- Flow was observed at this site during late 2018 and mid-2019 when flows were consistently in the range Q80-Q90.
- Observations of some flow were made in mid-2018 at this site when flow was at Q90-93.

[2] excludes Dendrobium Area 3C.

- This suggests that the cease-to-flow frequency at this site (following 9 of 14 planned longwalls adjacent to this reach of Wongawilli Creek) is <10% (purple line on the Pool 44 chart in Appendix 2), but could be lower, at about 7% (dashed purple line on the same chart).

Pool 44 Outflow (Figure A2-5) has an additional observation in early Feb-2020, and this indicates that flowing conditions are evident at Q95, so the critical range between no-flow and flowing conditions is 6-10% at this site.

These flow statistics and observations of 'flow' or 'no-flow' along this section of Wongawilli Creek suggest that the frequency of cease-to-flow events up to 2019 (after 9 of the 14 proposed longwalls adjacent to this watercourse have been extracted) was in the range of 7-13%. This range represents the cumulative effects of weather/climate plus any mining effect. The effect due to mining is difficult to separate, noting that at the downstream flow gauge WWL, the effect of mining can be separated out to a greater degree due to the continuous nature of the flow record, and has been shown to be about a 1% increase in cease-to-flow days (range of -3 to 5%) at the end of Longwall 14 (Watershed HydroGeo).

Review of the two sites located further upstream suggests that the post-mining cease-to-flow is about 5% (Pool 47B - (Figure A2-7)) and that at this site, flows of Q98 previously did not result in cease-to-flow (in 2013). The inference is that mining could have increased the frequency of cease-to-flow conditions (by 0-5%), but this is inference only, and may not be entirely reliable.

At Pool 49 (Figure A2-8), pre-mining observations suggest that cease-to-flow conditions occur at Q98 (2013) but did not occur again in 2018, under even drier conditions. The different classification (flow observation = 1, rather than 0) confuses the comparison against the other sites.

The over-arching conclusions from the comparison of cease-to-flow events that occurred along this reach during the recent severe drought compared to the flow percentiles regarding this analysis are that:

- It is difficult to reliably separate any mining signal or response from this data from the weather-related response, especially when considering geomorphological differences between sites and considering different pre- vs post-mining records. However, the mining effect in this middle reach is inferred as follows (in the context of the upstream and downstream flow records; Table 10)

**Table 10. Estimate of the impact of mining on stream flow in Wongawilli Creek**

| Gauge or reach | Baseline | At end LW14 | Estimated mining effect to end LW14 |
|---|---|---|---|
| WWU | 4% | = baseline | n/a |
| middle reach | <5 to 10% | 5 to 13% | 0 to 3% |
| WWL | 10% | 6 to 8%* | 1%* |
| * from comparison of reference site records as recommended by IEPMC, 2018 (Watershed HydroGeo, 2019b) | | | |

- The cumulative weather and mining-related cease-to-flow frequency for this 'middle' reach of Wongawilli Creek between Area 3A and 3B longwalls is:
    - approximately 5-13% at the end of Longwall 14, which supports the idea that the groundwater model predictions of an increase solely due to mining of 20-25% in 2020, are

highly conservative, and should be considered to be similar (i.e. 5 to 13%) following remaining longwalls up to Longwall 19, occurring over a greater length of the creek adjacent to the additional panels 15-19. However, conservatively, it is considered possible that the cease-to-flow frequency could increase with additional panels, and scaling the inferred mining effect to the end of LW14 (0 to 3%, as above) by 5 of 14 remaining longwalls would yield a mining effect of a 0-5% increase in cease-to-flow frequency to a total of 5-15% (being the combined effect of weather and mining).

### 4.5.4 Potential role of lineaments

The Groundwater Assessment for LW19 (SLR, 2020) describes geological features in the vicinity of the longwall. Figure 13 shows a high-resolution ground surface relief map (LiDAR) and mapped lineaments near the western end of LW19.

A number of the mapped lineaments reflect a pervasive sub-vertical joint set in the HBSS striking ~121°. One of the lineaments intersects LW19 and extends close to the channel of Wongawilli Creek; another joint pair intersects LW8 and Wongawilli Creek tributary 17 (WC17). It is unclear whether the joint set extends into the Bald Hill Claystone which outcrops in the creek bed adjacent to Area 3A. However, it is noted that the same joint pattern and lineament orientation is apparent between LW6 and Pool 43a which experienced a decline in water levels in recent years. Therefore, it is recommended that work be carried out to assess the orientations, extent and continuity of jointing within and adjacent to Wongawilli Creek and second-order tributaries WC14 and WC17 and that dataloggers be installed in selected Wongawilli Creek pools that are located along-strike from LW19.

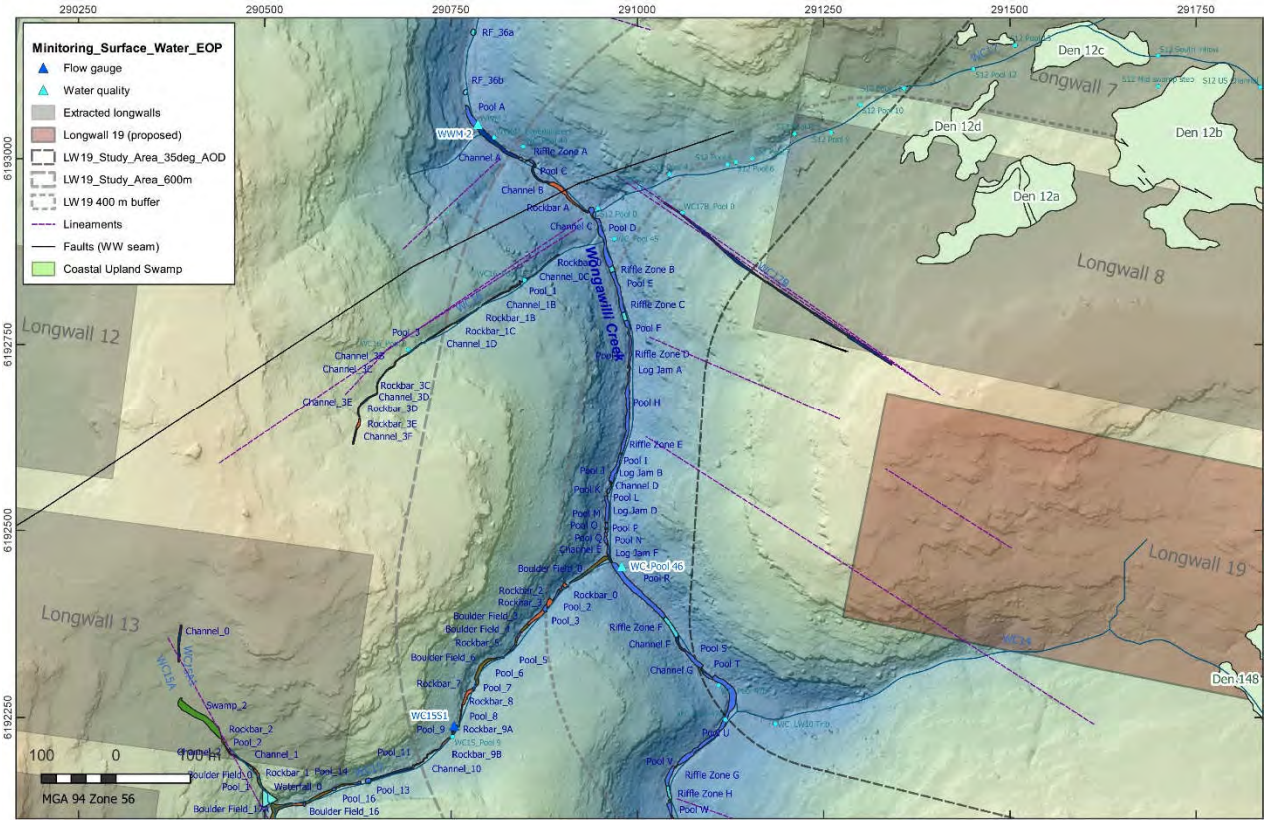



Figure 13. Lineaments and joint patterns near Longwall 19

## 4.6 Stream water quality

Longwall subsidence can result in fracturing of streambeds and this fracturing can lead to changes in stream water quality due to the following processes:

- Diversion of surface flows through shallow fractures resulting from valley closure and the unconfined nature of near-surface strata (to ~10 to 15 m depth);
- Oxidation and dissolution of minerals in the freshly fractured bedrock (notably marcasite [$FeS_2$], ankerite [$Ca(Mg,Fe^{2+},Mn)(CO_3)_2$] and siderite [$Fe_2+CO_3$]);
- Leaching of ions from the bedrock strata present within the surface fracturing zone; and
- Enhanced drainage and discharge of groundwater (with higher EC and dissolved iron and lower DO) to creeks via subsidence induced fractures.

Oxidation of $Fe^{2+}$ in sulphide and carbonate minerals can result in a decrease in pH and release of Fe, Mn and Mg into solution. This can manifest as ferruginous springs, iron staining of stream beds and rock faces, and localised accumulation of ferruginous sediment. The release of hydrogen ions (decrease in pH) may be offset or buffered by pH increases caused by $CO_2$ outgassing from turbulent stream sections and by ankerite dissolution.

Watercourses within the LW19 study area have been affected by subsidence associated with previous mining in Areas 3A and 3B. Impacts to water quality from previous mining are summarised in Table 11.

**Table 11. Previous impacts to steam water quality**

| Water-course | Monitoring sites | Observations | Water quality effects |
|---|---|---|---|
| Wongawilli Creek | Pool 43a | Decline in water level at Pool 43a is apparent from 2013 following extraction of Longwalls 6 to 8 in Area 3A. | No adverse trends in EC or pH associated with the water level decline. Increases in EC in some pools during 2017-2019 likely related to drought conditions. |
| WC17 | S12 Pools 9, 10, 11, 12 | Tributary crosses previously extracted Longwalls 7 and 7. Evidence for declining pool levels along the watercourse during extraction of Longwalls 7 and/or 8. | Iron staining in creek bed. Increase in pool water pH during LW7 from ~pH 5 to pH ~6 to 7. Fluctuating EC in some pools. |
| SC10C | Pools 0, 1, 3, 4, 5, 7, 8, 9, 10, 11 | Tributary crosses previously extracted LW8. Decline in pool levels and/or drying of pool during or following LW8. | Iron staining and local accumulation of ferruginous sediment. Increase in pool water pH during Longwalls 6 – 8 from ~pH 5 to pH ~6 to 7. Decline in EC in some pools, similar to trends in Sandy Creek. Increase in EC to ~300+ µS/cm (Pools 0, 3 10) from 2014. Increase in dissolved Fe, Mn, Al, Zn following mining in Area 3A. |
| SC10 | Rockbar 3 | Tributary crosses the south east corner of LW8. Data too sparse to identify water level effects with certainty. | No adverse water quality effects noted; Increase in EC at Rockbar 3 associated with dry conditions in 2017-2018. |
| Sandy Creek | Pool 9 | Decline in water level in Pool 9 likely unrelated to mining. No other effects. | A general decline in EC from ~110 to ~75 µS/cm in most pools. No trend in pH. |

Watercourses that have been affected by subsidence (including WC21, LA4 and DC13 in Area 3B) typically show temporary increases in dissolved Fe and Mn (+/- Zn and Al), and an increase in pH to near neutral (pH 7) at sampling locations immediately down-gradient of the affected area. The overall salinity of stream waters (as estimated from EC) is controlled largely by rainfall patterns, with EC

tending to increase during periods of low rainfall. This reflects evaporative concentration of salts and the relative increase in contribution from groundwater discharge (baseflow). In most cases, there is no discernible change in EC and other water quality parameters at monitoring sites down-gradient of noted effects or impacts. One possible exception is at Donalds Castle Creek (the upper reaches of which cross Longwalls 9 and 10) in which EC has been elevated for the last two years at the downstream site (DCL3 and at FR6). The anomalous EC trend coincides with the recent drought period and will continue to be assessed. Time series plots of field parameters and selected dissolved metals for stream sampling sites relevant to this assessment are shown in Appendix 1.

Based on previous observations, it is expected that water quality influence due to mining would be minor in stream reaches within subsidence affected areas (SC10 and SC10C; upper reaches of WC14). Local discolouration of streambeds and rock faces by iron hydroxide precipitation can continue for a number of years but is a temporary impact. Water quality effects on stored waters of the reservoirs are expected to be negligible and undetectable.

## 4.7 Swamp hydrology

Swamps that have been undermined commonly display hydrological changes shortly following the passage of the longwall beneath the monitoring site. Hydrographs of piezometers at affected locations may show one or more of the following (see Appendix 3):

- A decrease in the average shallow groundwater elevation;
- A decrease in the duration of saturation of the swamp sediments following a significant rainfall event; or
- A change in the shape of saturation peak and recession curves (and recession rate) in response to significant rainfall events.

A recent assessment of shallow groundwater impacts due to mining at Dendrobium was carried out by (Watershed Hydrogeo, 2019b). The assessment concluded that almost all shallow piezometers that are directly mined under by longwalls extracted in Dendrobium Area 3A and 3B show responses to mining. Changes in shallow groundwater levels or groundwater fluctuation characteristics are not evident in shallow piezometers located in swamp sediments more than 60 m from the extracted longwall margin.

Observations at the Springvale Mine in the Western Coalfield show that hydrological impacts can occur in swamps overlying connected geological structures (faults or other lineaments) at distances greater than 1200 m from the longwall (Galvin et al., 2016). The same effect is not apparent at Dendrobium. Recent studies have identified no anomalous subsidence specifically related to mapped lineaments (MSEC, 2019), and no hydrological impacts at swamp piezometers located near mapped lineaments that are greater than 60 m from the goaf (Watershed HydroGeo, 2019b). However, it is prudent to consider the possibility of distant impacts where swamps overlie mapped lineaments that intersect the mine footprint.

The hydrological changes are most likely due to the development of surface fracturing and bedding plane openings in the sandstone substrate of the swamp and/or a rockbar at the swamp outlet. The formation of fractures in the substrate may change the swamp from a perched system to a connected system. The impact on the swamp will be dependent on the head difference between the swamp sediments and the sandstone substrate. Where the hydraulic gradient is downwards (into the sandstone, which is common) then the fracturing will lead to greater flows of water from the swamp and a decline in average swamp groundwater levels. It is not yet known whether the hydrological characteristics recover to some degree as fractures are filled with fine sediments and on-going monitoring is required to assess longer-term impacts.

Drying of upland swamps can result in further impacts, including:

- reduction of soil moisture levels and loss of cohesiveness of the swamp sediments.
- decline of groundwater-dependent plant species and consequent changes in vegetation structure.
- decline of groundwater-dependent fauna including macroinvertebrates and stygofauna.
- oxidation of peaty sediments resulting in increased hydrophobicity, lower water holding capacity, potential changes in nutrient cycling, and changes in water quality.
- increased risk of channelization and gully erosion.
- reduced resilience to bushfires.

The locations of mapped swamp vegetation communities relative to the planned longwalls are shown in Figure 1. Swamps located within 600 m of the planned longwalls are listed in Table 12, with a qualitative assessment of the likelihood that the shallow groundwater regime will be affected by subsidence related ground movements associated with LW19 (as described above). The likelihood is based on observations at swamps in Area 3B during and after longwall extraction (e.g. HGEO, 2018b; Watershed Hydrogeo, 2019b) and predictions of subsidence related to longwall extraction and other ground movement related to valley closure (MSEC, 2020).

**Table 12. Summary of predicted impacts to Upland Swamps**

| Swamp | Area (Ha) | Distance from LW19 goaf (m) | % Area within 60 m of Longwall | Predicted vertical ground movement (mm; MSEC, 2020) | | Likelihood of shallow groundwater effects |
|---|---|---|---|---|---|---|
| | | | | Subsidence | Tilt (mm/m) | |
| 12 | 5.4 | 180 | 100 | 2750 | 30 | Previously impacted |
| 15a | 18.0 | 0 | 7 | 425 | 13 | Likely (for ~7% of swamp area) |
| 15b | 5.0 | 0 | 100 | 3050 | 35 | Previously impacted |
| 34 | 2.4 | 330 | 0 | <20 | <0.5 | Unlikely |
| 95 | 1.09 | 400 | 0 | 60 | 2 | Unlikely |
| 96 | 0.17 | 230 | 0 | <20 | <0.5 | Unlikely |
| 146 | 0.60 | 570 | 100 | 2350 | 30 | Previously mined under |
| 147 | 0.44 | 340 | 0 | <20 | <0.5 | Unlikely |
| 148 | 0.86 | 0 | 92 | 2850 | 40 | Likely |

Given their proximity to the proposed longwall panel, it is likely that shallow groundwater levels will be affected at Swamp 15a (7% of the mapped area of Swamp 15a is within 60 m of the goaf footprint) and Swamp 148 (92% within 60 m of the goaf footprint). Swamps 15b, 12, and Den 146 either directly

overlie, or are entirely within 60 m of, previously extracted Longwalls 7 and 8 and are known or likely to have been impacted already. It is possible that additional impacts may occur in Swamps 12, 15b and 146. The remaining swamps are unlikely to be impacted since they are located more than 400 m from the proposed goaf and/or are predicted to experience negligible ground movement related to mine subsidence (<60 mm) and valley closure (MSEC, 2020).

The IEPMC (2019b) review concluded that monitoring of vegetation change in upland swamps has not, to date, provided a clear and timely measure of possible changes in ecosystem functionality. This is likely due to the decadal timescales of ecosystem response and the difficulty in distinguishing between mining-induced variations and natural variations (for example to drought and climate change). Further discussion of swamp ecology and ecosystem functionality is provided in Niche (2020).

# 5. PERFORMANCE MEASURES

The performance measures and monitoring of surface water and shallow groundwater in relation to mining at Area 3A are defined in the Area 3A SMP (South32, 2020b). The Trigger Action Response Plan (Appendix A of the SMP) specifies trigger levels and a three-tiered management response for assessing and responding to impacts from mining. The triggers are based on environmental data collected before mining commenced (baseline period).

Stream monitoring sites reviewed as part of this assessment are included in the Area 3A SMP, including sites upstream and downstream of the proposed LW19. Therefore, the existing TARPs are considered generally applicable to future monitoring and management of mining effects related to LW19 immediately adjacent and down-stream of Area 3A. These TARPs are under review by South32, DPIE and WaterNSW (Watershed Hydrogeo, 2019a) and will be finalised prior to the commencement of LW19. The existing TARPs for surface water flow, water chemistry and shallow groundwater is reproduced in Appendix 4. Specific recommendations for revision of the monitoring program and trigger levels are given below.

## 5.1 Surface water monitoring

Watercourses within the study area are (or have been) monitored at multiple sites as part of the previous SMP for Area 3A and the current SMP for Area 3B. The following improvements to the monitoring network are recommended to form part of the updated SMP for Area 3A.

### 5.1.1 Wongawilli Creek

Continue current monitoring at active Wongawilli Creek Monitoring sites as specified in the Area 3A and Area 3B SMPs.

It is recommended that work be carried out to assess the orientations, extent and continuity of jointing within and adjacent to Wongawilli Creek and second-order tributaries WC14 and WC17. If practical, dataloggers should be installed in selected Wongawilli Creek pools that are adjacent to LW19 and along the strike of apparent lineaments and joint orientations in the HBSS.

**WC17**: IMC should consider reinstatement of monitoring sites on the lower reaches of WC17 that are within the study area and/or along the strike of lineaments and joint sets in the HBSS (S12 Pools 0, 2, 3, 4 and 5). Pool 3 is located on a mapped lineament that crosses LW8 and proposed LW19.

### 5.1.2 Sandy Creek

The current flow gauging site on SC10 (SC10S1) has a long record. While it seems to over-estimate high flow, median flows and low flows appear to be captured reasonably well and it should be suitable for comparison of median and low flows as per the recent TARPs developed for Area 3B (Watershed Hydrogeo, 2019a).

Based on advice from IMCEFT, a site on SC10 upstream of LW19 is considered impractical given the presence of Swamp 15a and the associated poor structural control for a weir.

The accuracy of flow gauging at SCL2, particularly at low flows, is likely to be affected by a leaky control. The need to improve this site is the subject of on-going discussion between IMC and WaterNSW. Should LW19 be approved, and if improvements can be made more than 2-years before LW19 is to be extracted, then it is recommended that such improvements be made.

Qualitative monitoring of the flow/trickle/no flow conditions, as per regular IMCEFT observations currently carried out, is recommended to understand the pre-LW19 behaviour of SC10 and tributaries under varying wet and dry conditions.

Reinstate monitoring at field sites along SC10 and SC10C which were previously monitored during extraction of Longwalls 6 to 8.

Monitoring should include field observation (and photography), analysis of field water quality parameters, pool water levels and collection of grab samples for laboratory analysis (at selected sites), consistent with existing monitoring sites and the Area 3A SMP. If possible, it is recommended that automated water level loggers are installed at major pools to provide high frequency data (at least one measurement per day, preferably hourly).

The exact location and specification for each monitoring point should be determined in consultation with an appropriately qualified and experienced specialist.

## 5.2 Shallow groundwater

Because swamps are groundwater dependent features, piezometric levels within the swamps, and in the substrate to the swamps, provide a key early indicator of change to the dependent ecosystems (IEPMC, 2019b). Piezometric levels therefore form an important component of TARPs for the management of impacts to upland swamps.

In addition to the existing active monitoring sites, it is recommended that the following inactive shallow piezometers within mapped swamps are re-instated, upgraded or replaced as necessary to allow continued monitoring of shallow groundwater levels:

**Table 13. Recommended swamp groundwater monitoring sites for reinstatement**

| Swamp | Piezometer | Swamp | Piezometer |
|---|---|---|---|
| **Swamp 12** | 12_03 | **Swamp 15b** | 15b_H1 |
| | 12_04 | | 15b_H2 |
| **Swamp 15a** | 15a_03 | | 15b_H3 |
| | 15a_04 | | 15b_39 |
| | 15a_12 | **Swamp 146** | DA2A_01 |
| | 15a_15 | | |
| | 15a_17 | | |

Consider installation of additional shallow piezometers and paired soil moisture sensor arrays at one or more of the following locations (see Figure 2):

**Table 14. Recommended new swamp groundwater monitoring sites**

| Swamp | Piezometer location | Easting | Northing |
|---|---|---|---|
| Swamp 34 | A | 291835 | 6191905 |
| Swamp 95 | B | 293470 | 6192425 |
| Swamp 96 | C | 292960 | 6191800 |
| Swamp 147 | D | 293350 | 6191640 |
| Swamp 148 | E | 291925 | 6192205 |

Piezometers should be equipped with automated water level dataloggers with at least one reading per day. Installations should be completed at least two years prior to the commencement of mining, if possible. The exact location and construction details of the installation will need to be determined in consultation with an appropriately qualified and experienced specialist.

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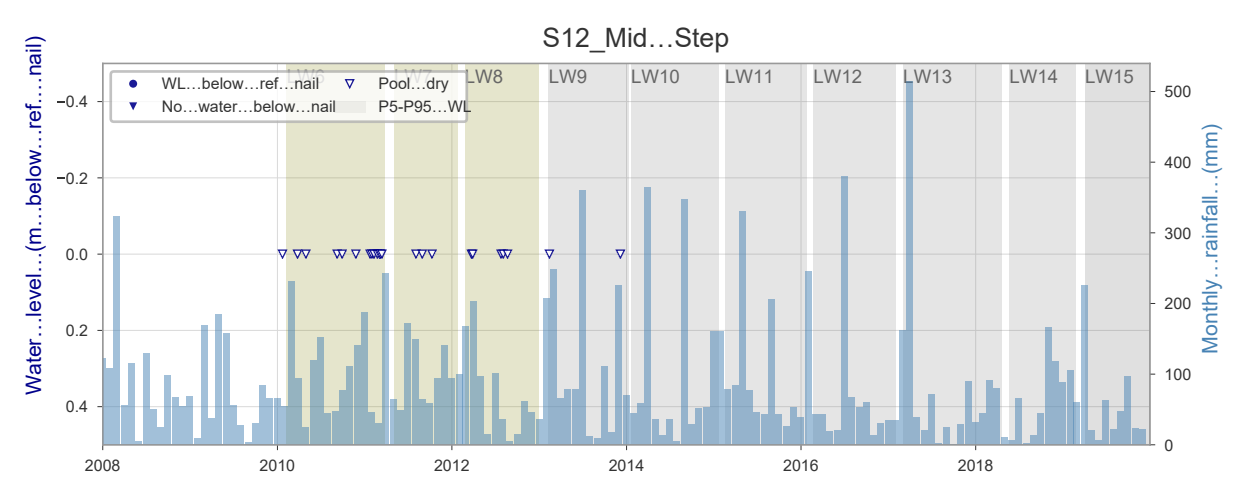
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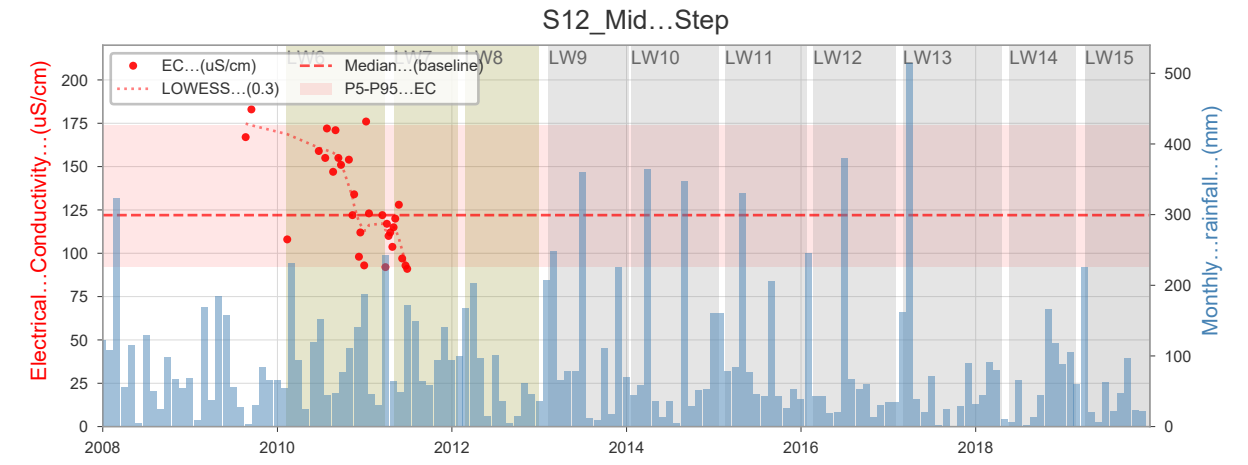
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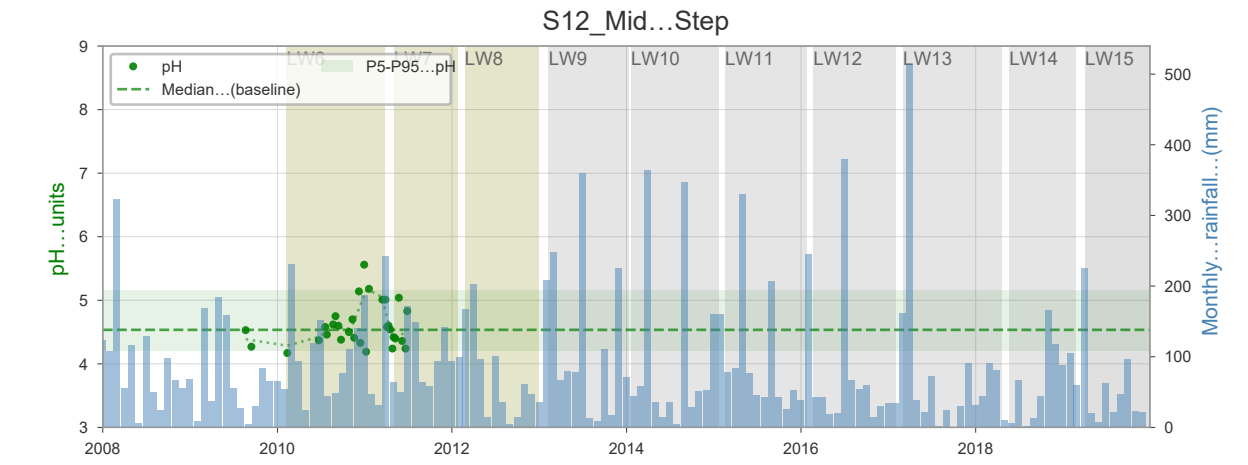
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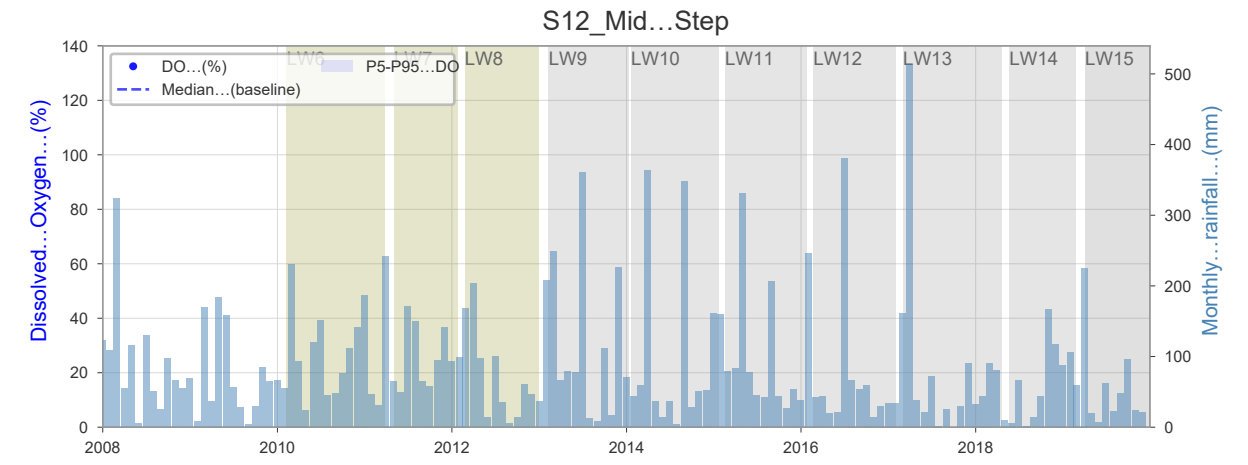
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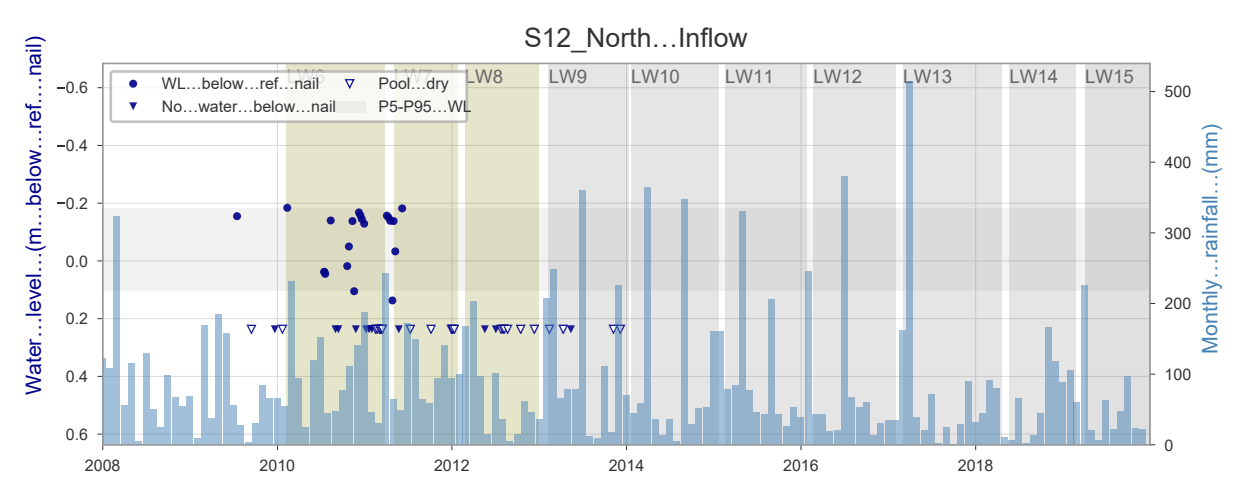
# APPENDIX I – Surface water chemistry time-series

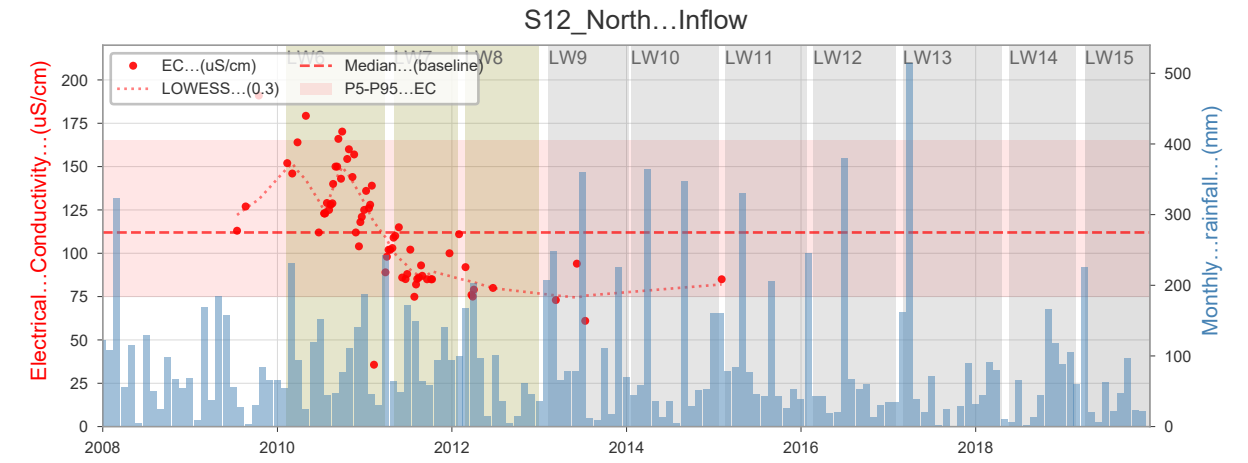

S12_Mid…Step
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

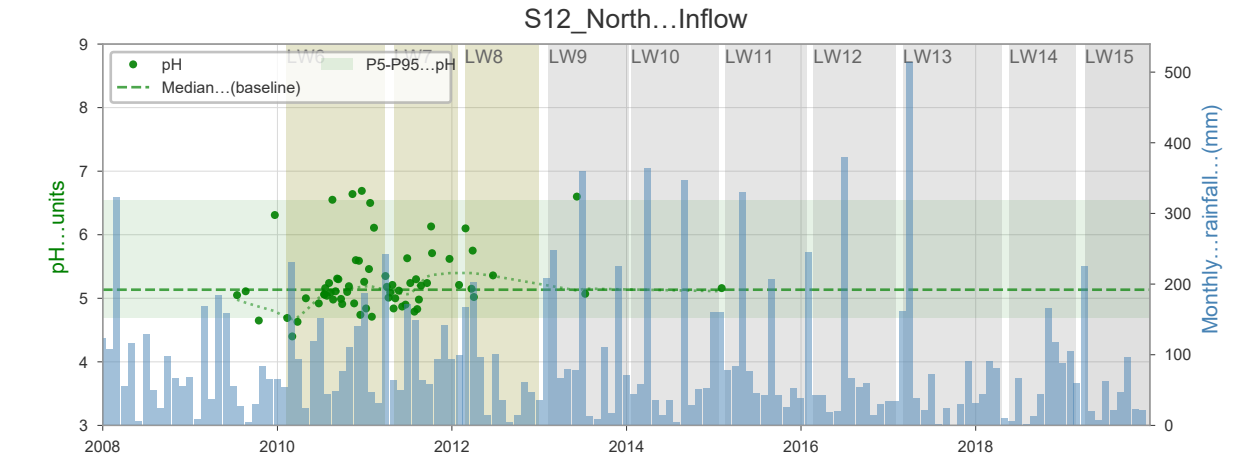

S12_Mid…Step
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

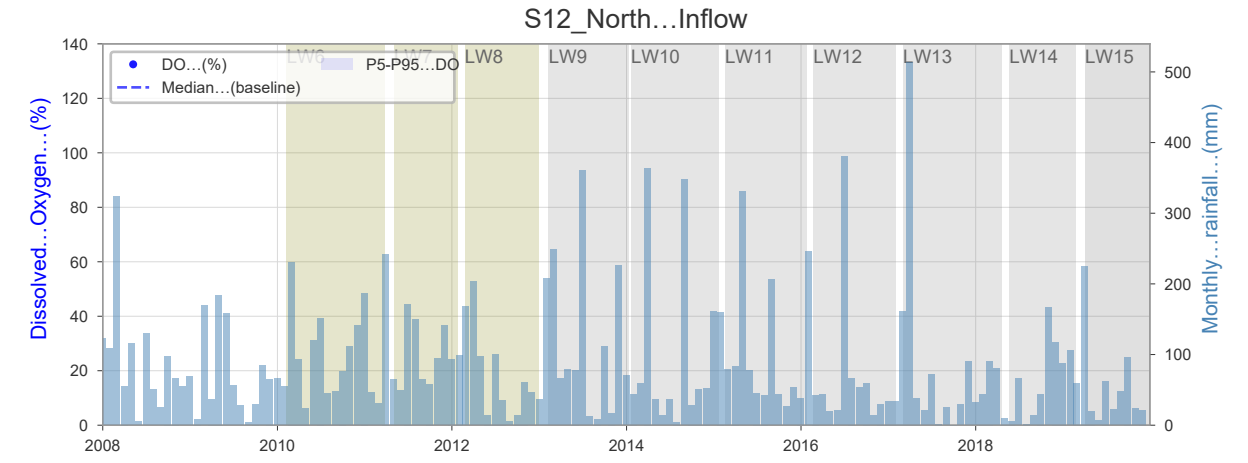

S12_Mid…Step
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

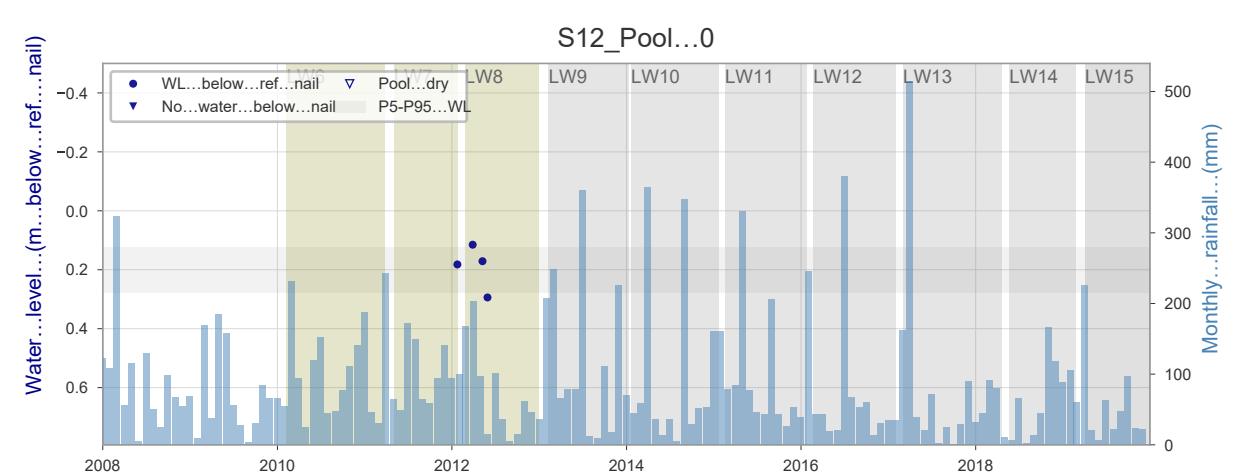

S12_Mid…Step
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

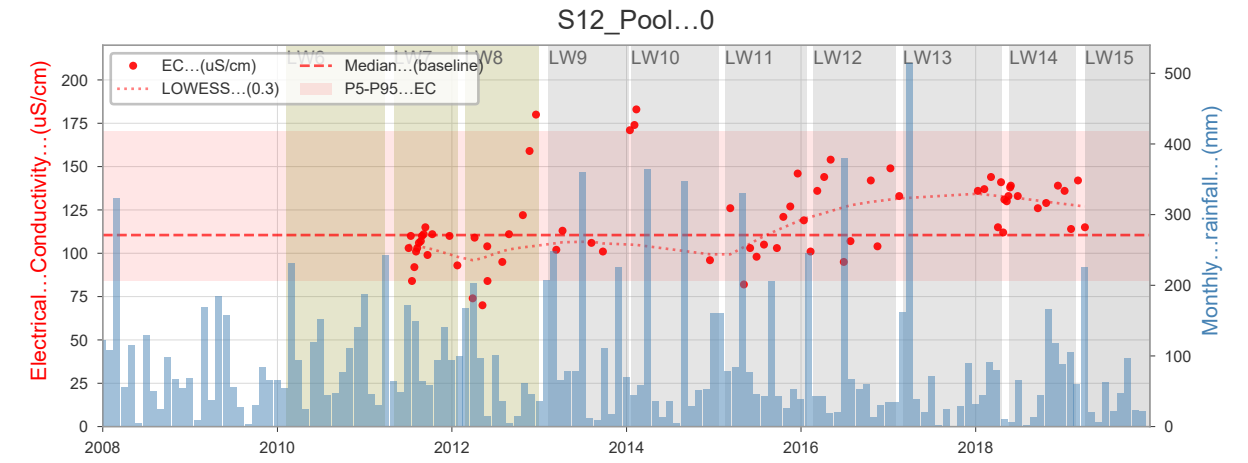

S12_North…Inflow
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

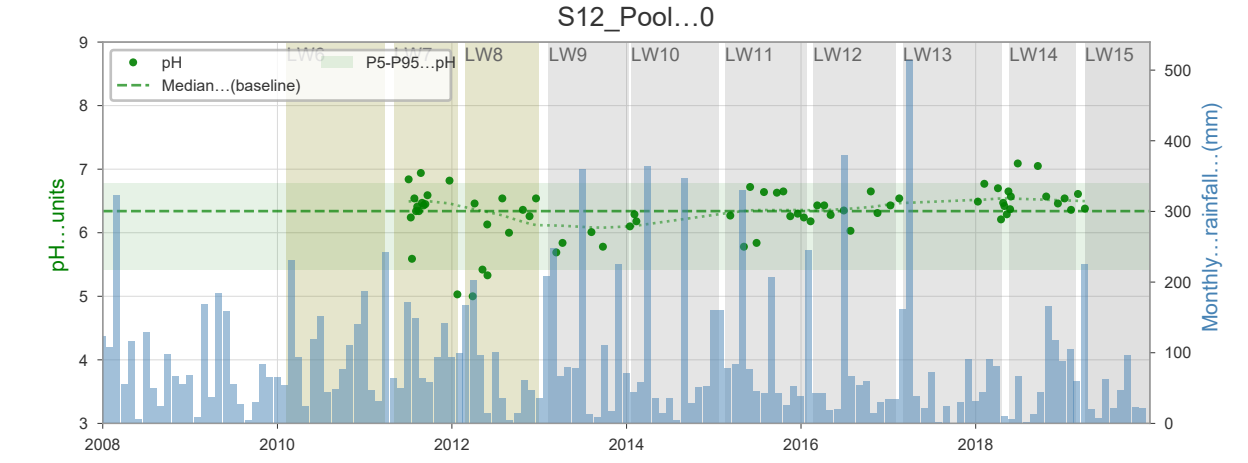

S12_North…Inflow
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

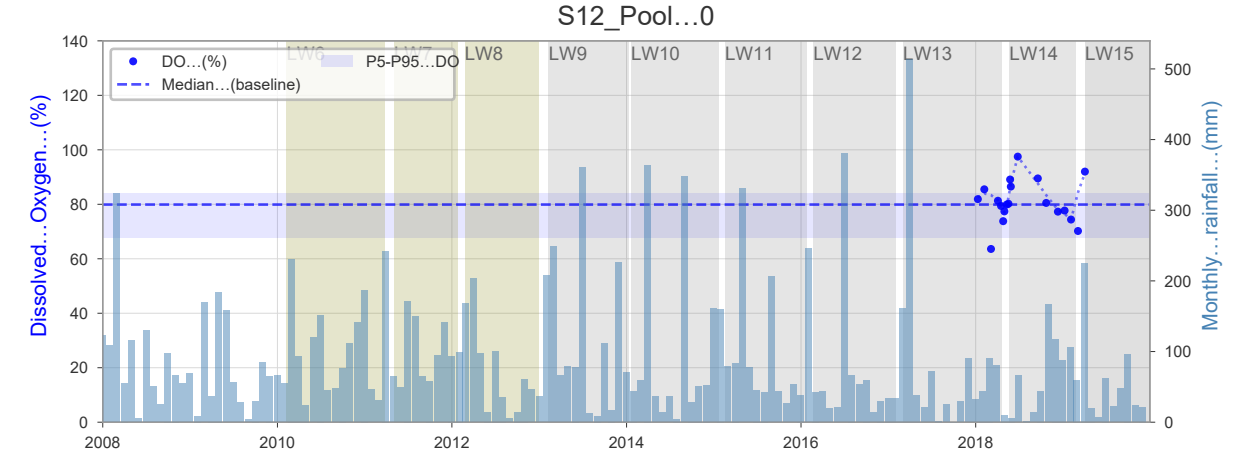

S12_North…Inflow
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

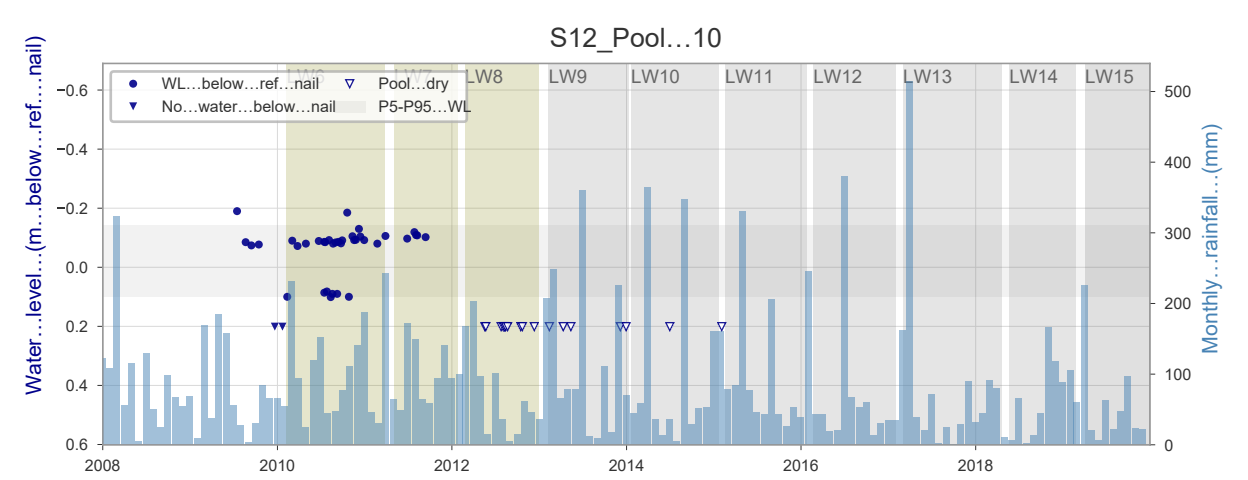

S12_North…Inflow
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

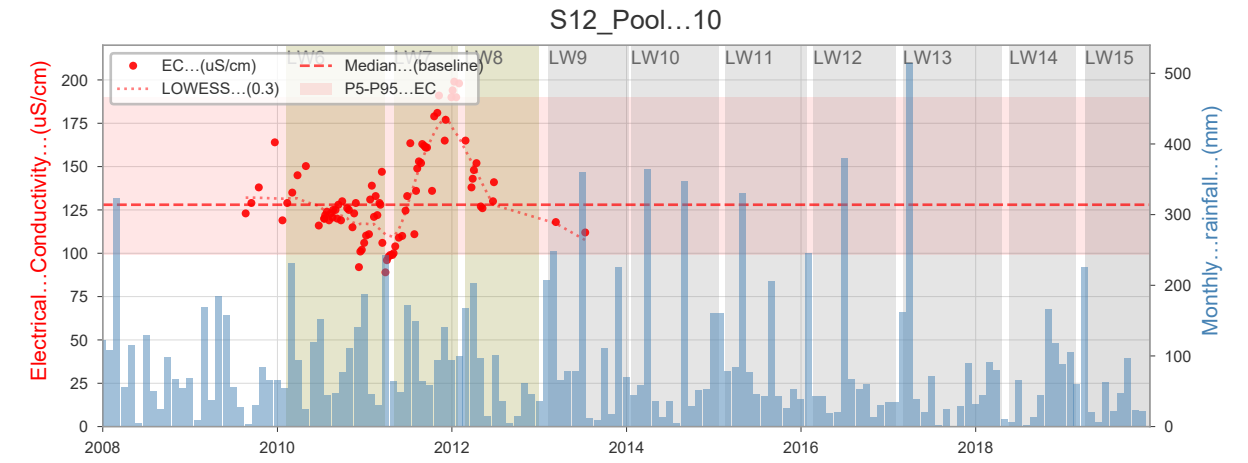

S12_Pool…0
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

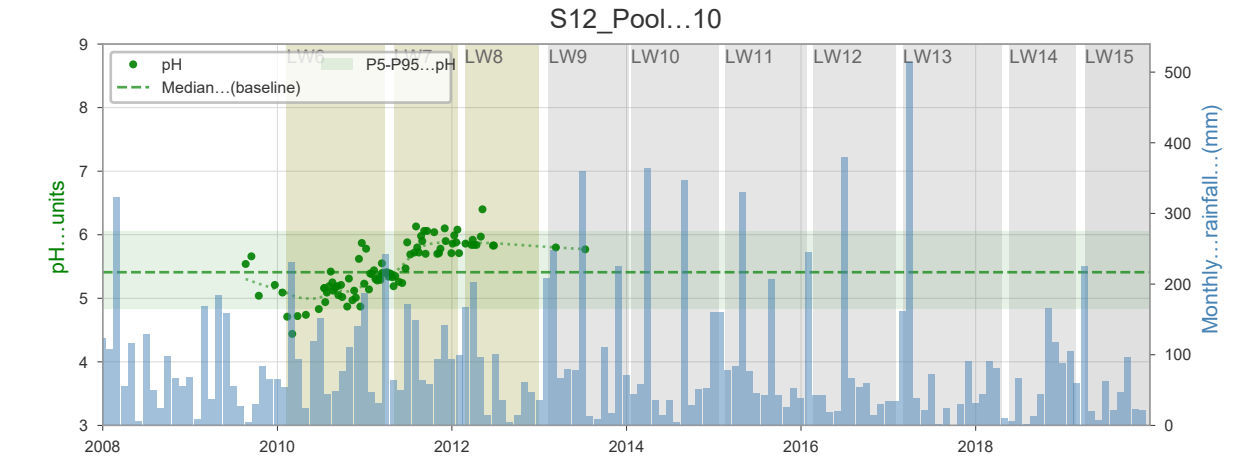

S12_Pool…0
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

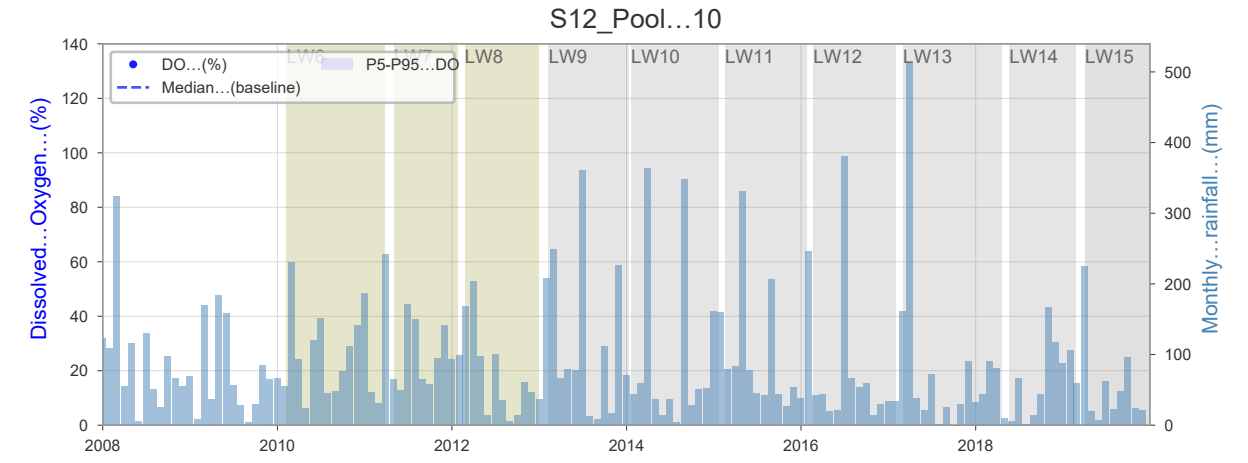

S12_Pool…0
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

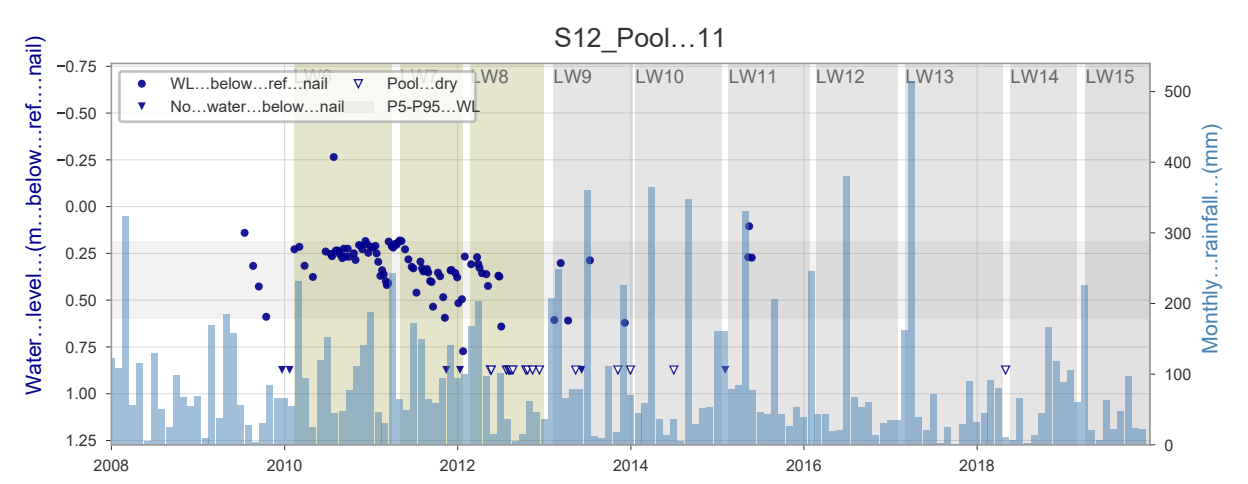

S12_Pool…0
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

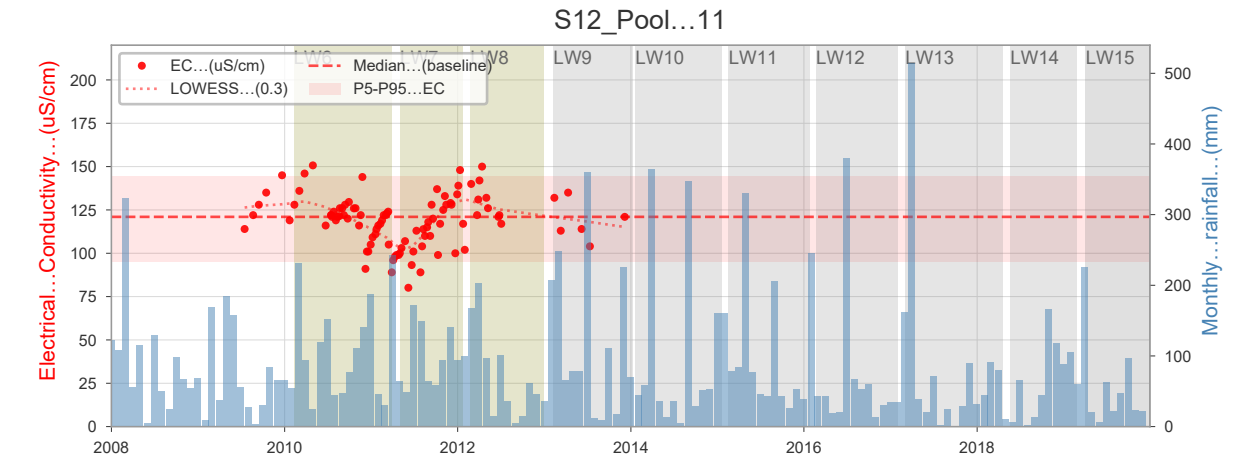

S12_Pool…10
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

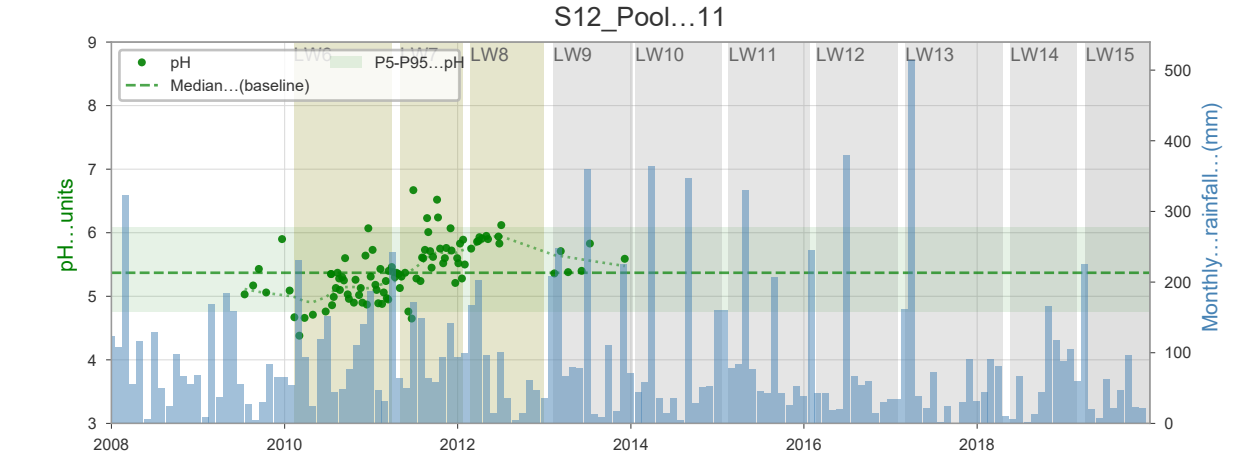

S12_Pool…10
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
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2012
2014
2016
2018

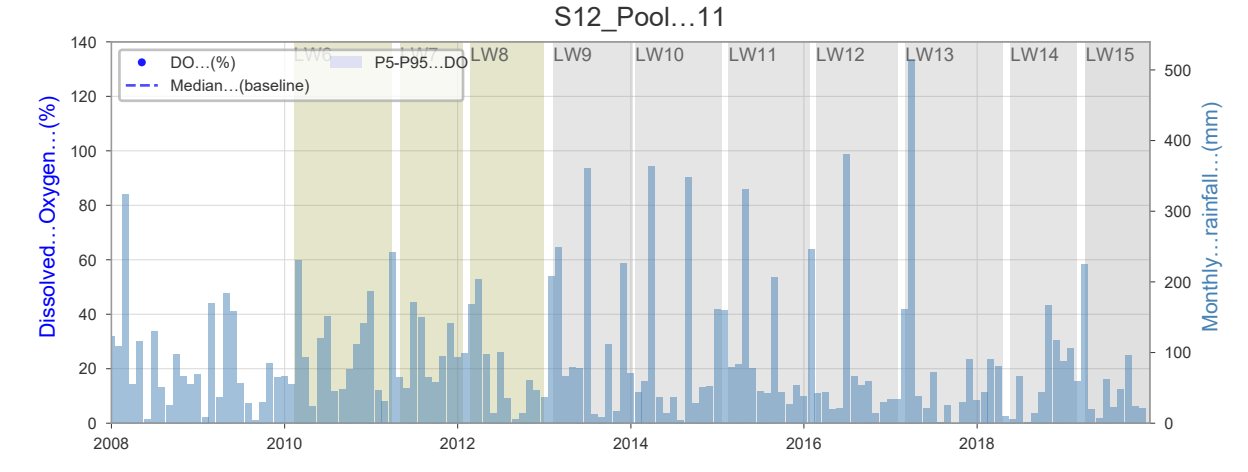

S12_Pool…10
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

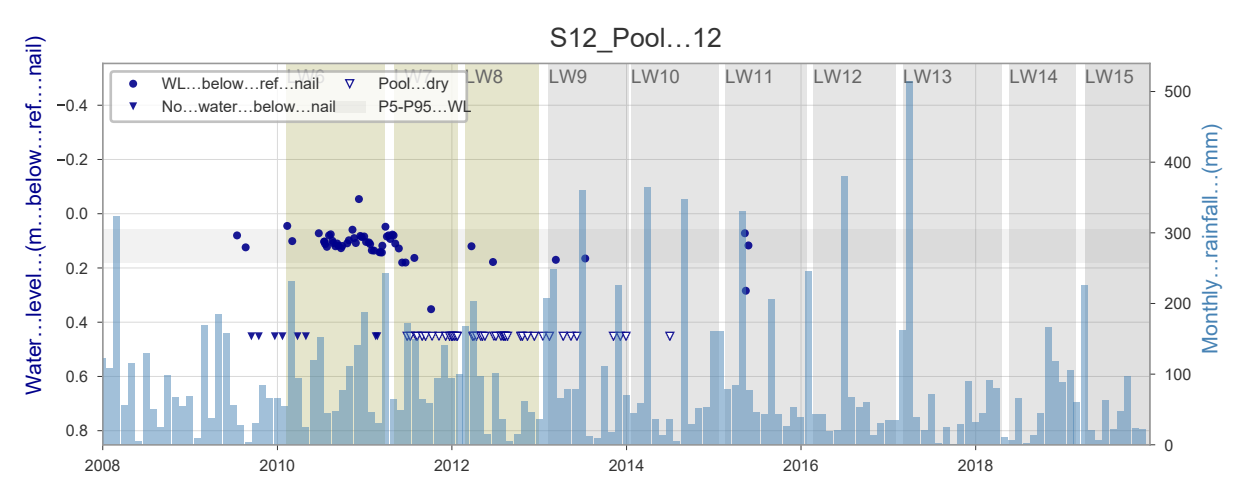

S12_Pool…10
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

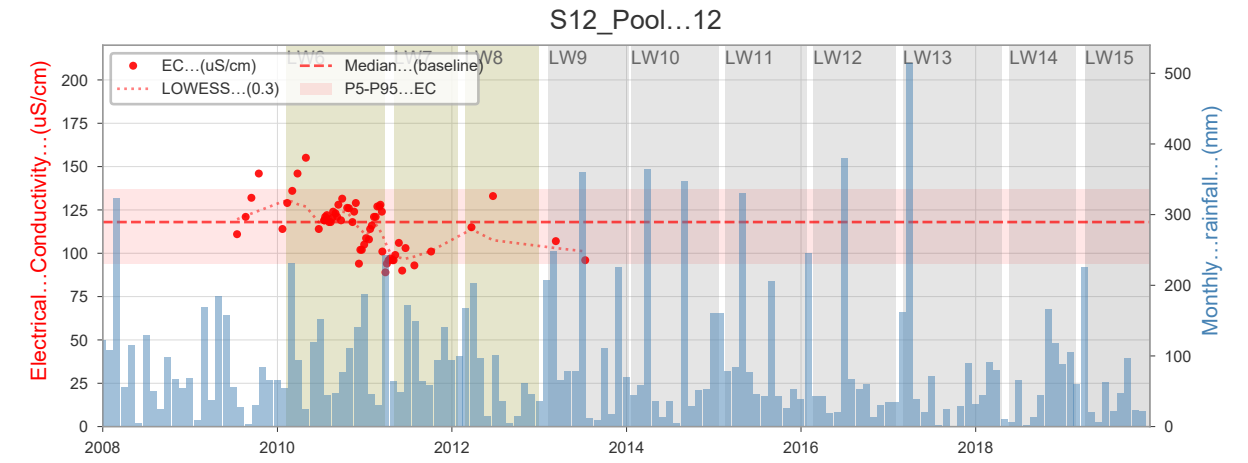

S12_Pool…11
WL…below…ref…nail
No…water…below…nail
Pool…dry
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….…nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

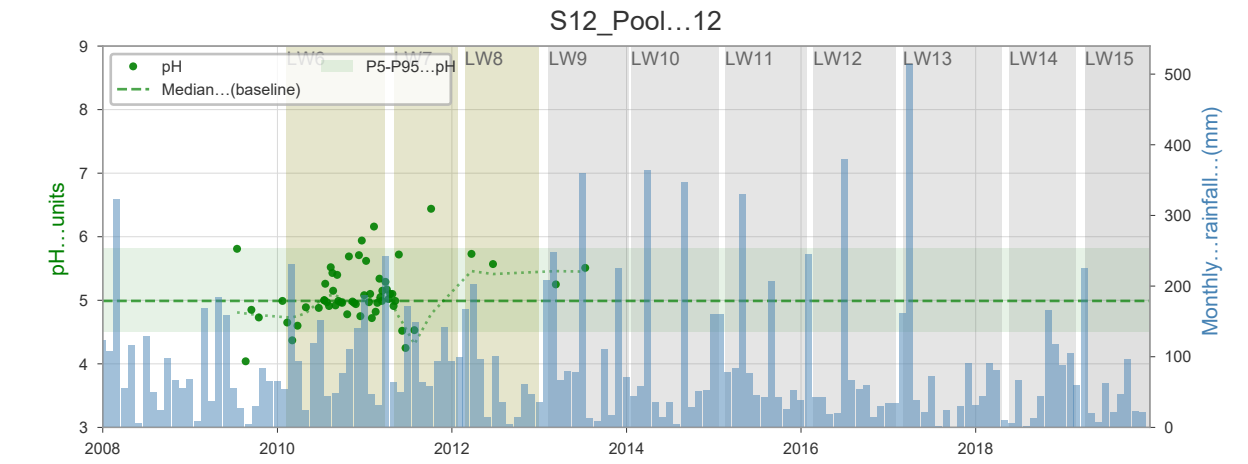

S12_Pool…11
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
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2018

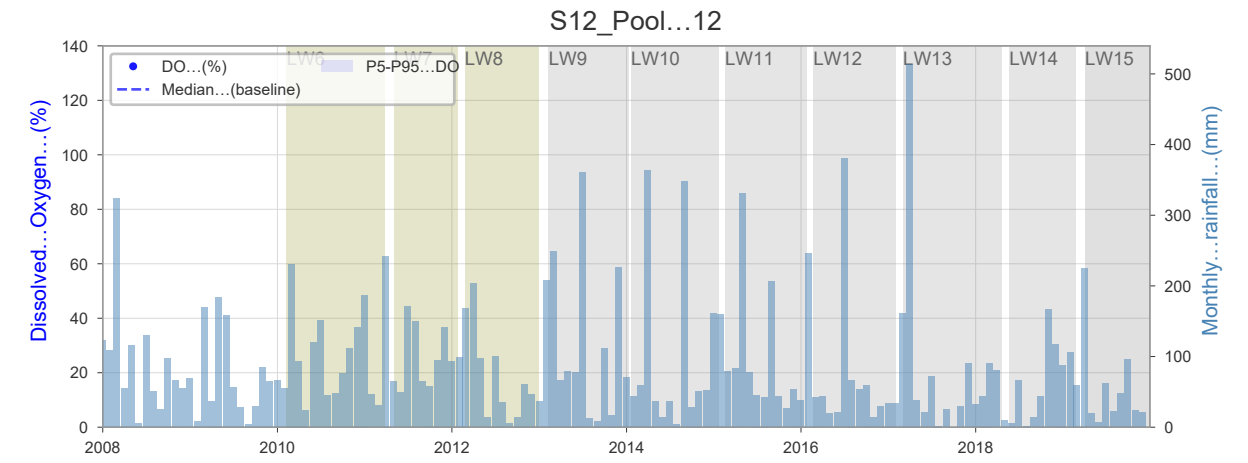

S12_Pool…11
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
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2012
2014
2016
2018

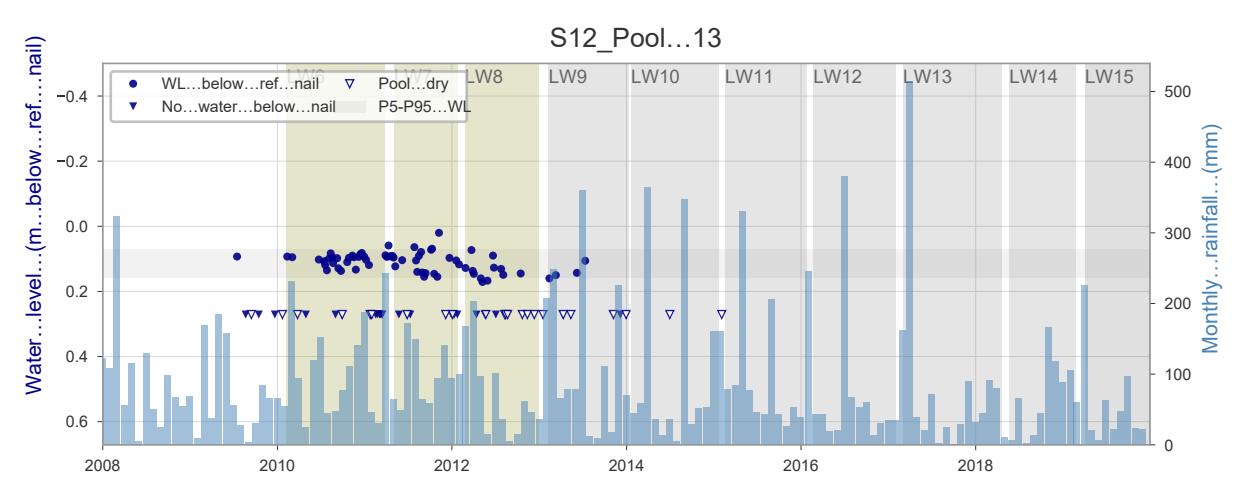

S12_Pool…11
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
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2016
2018

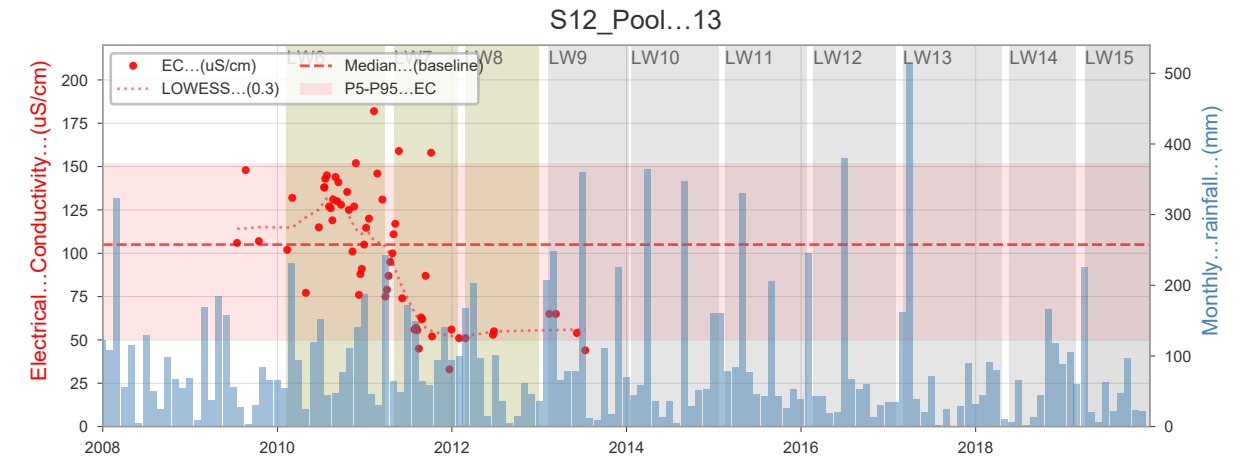

S12_Pool…12
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
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LW13
LW14
LW15
Water…level…(m…below…ref….…nail)
Monthly…rainfall…(mm)
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2010
2012
2014
2016
2018

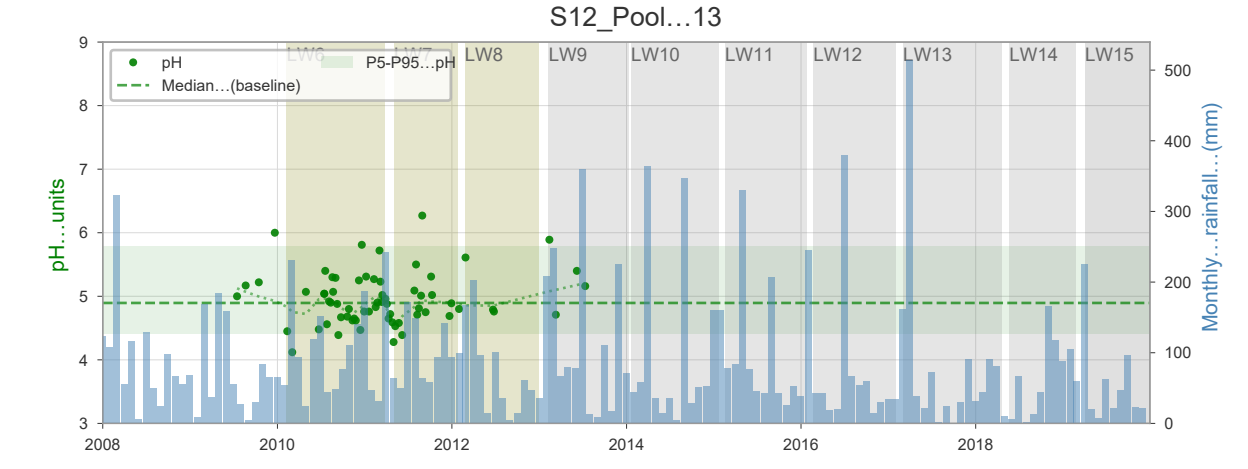

S12_Pool…12
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

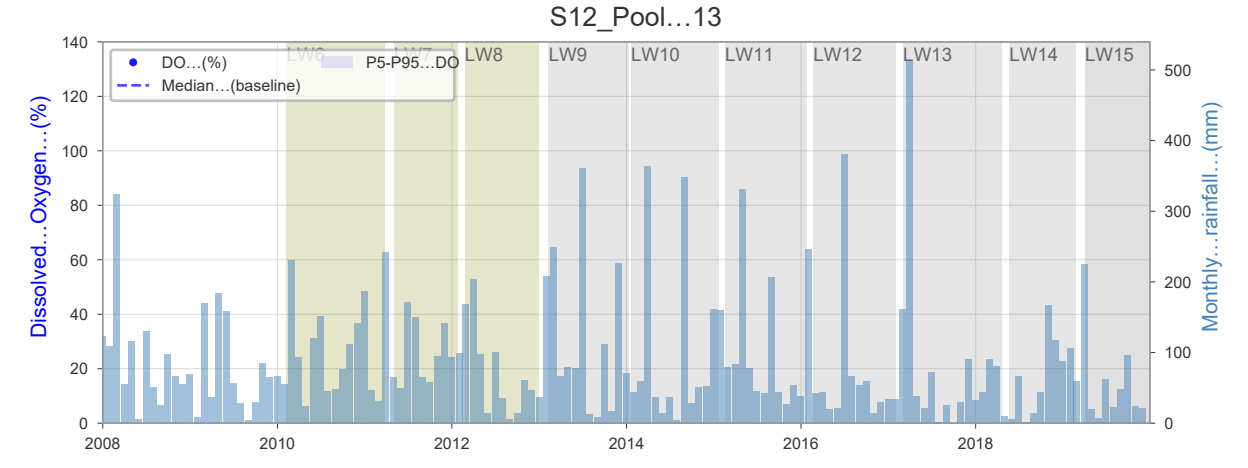

S12_Pool…12
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

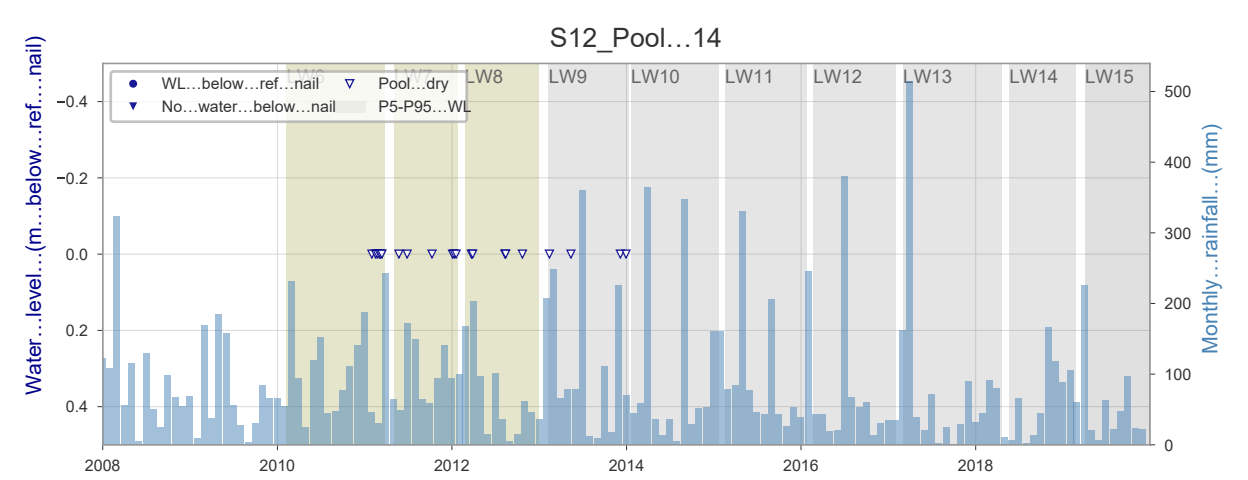

S12_Pool…12
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

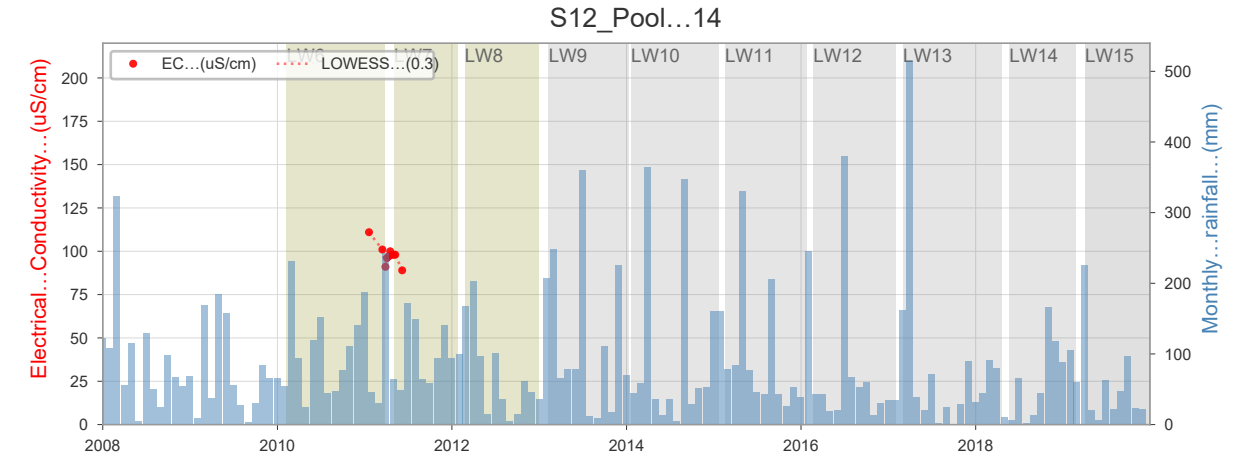

S12_Pool…13
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

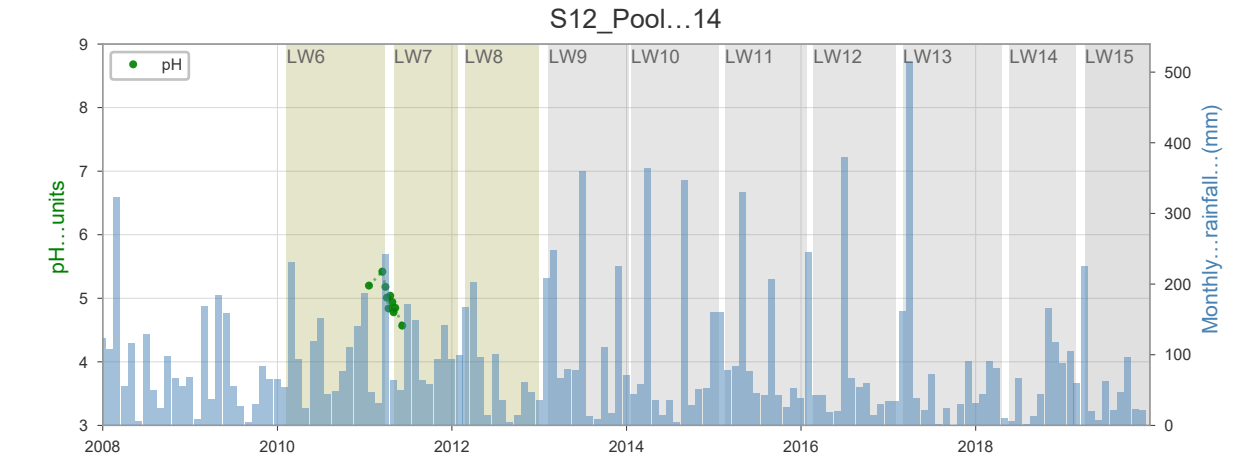

S12_Pool…13
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

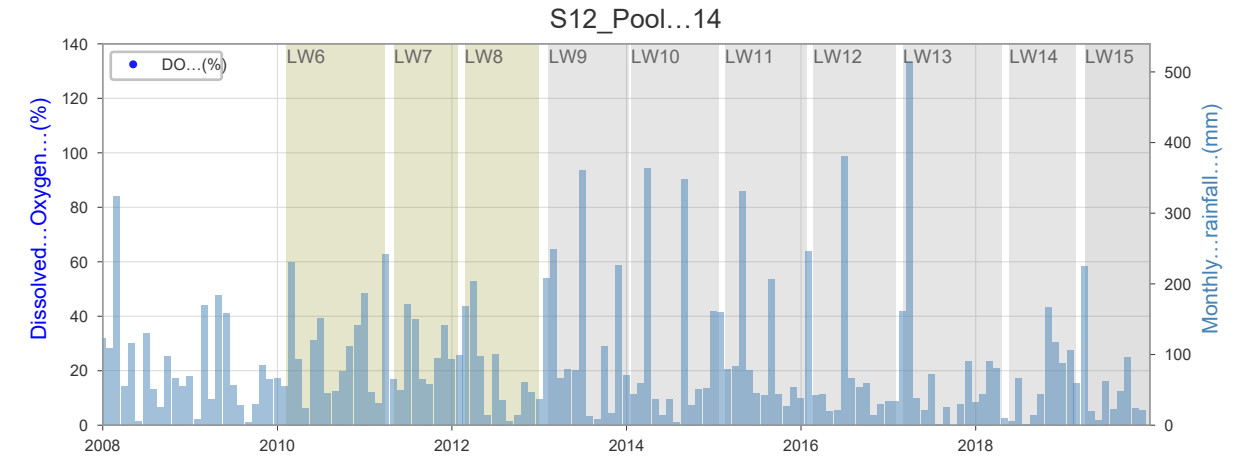

S12_Pool…13
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

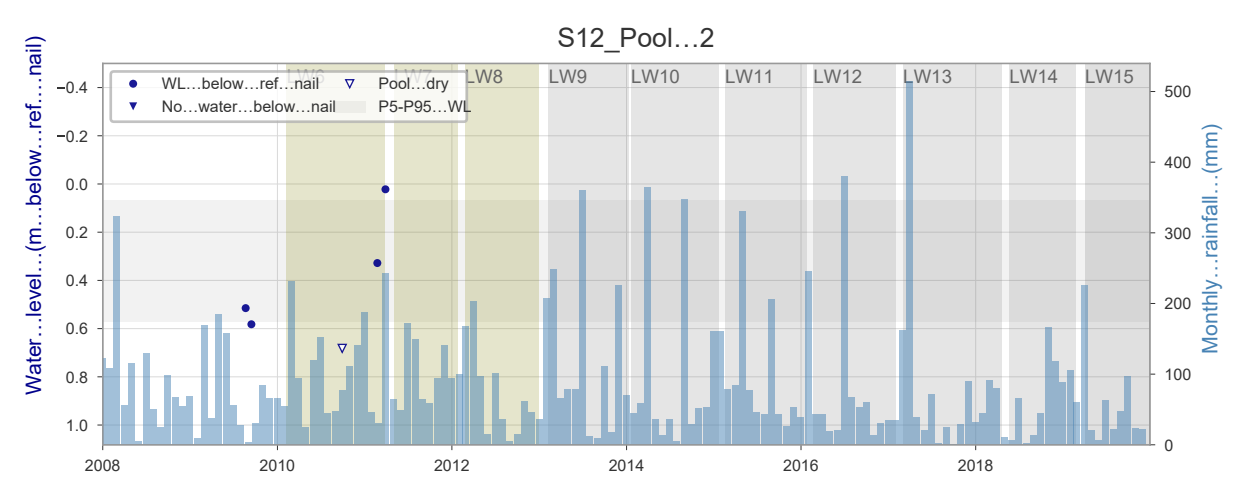

S12_Pool…13
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

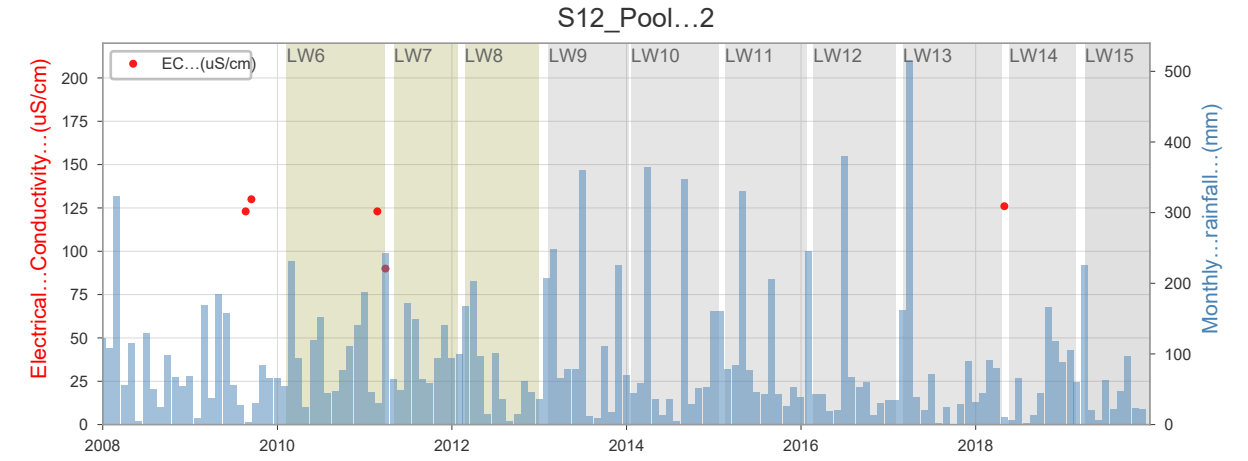

S12_Pool…14
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

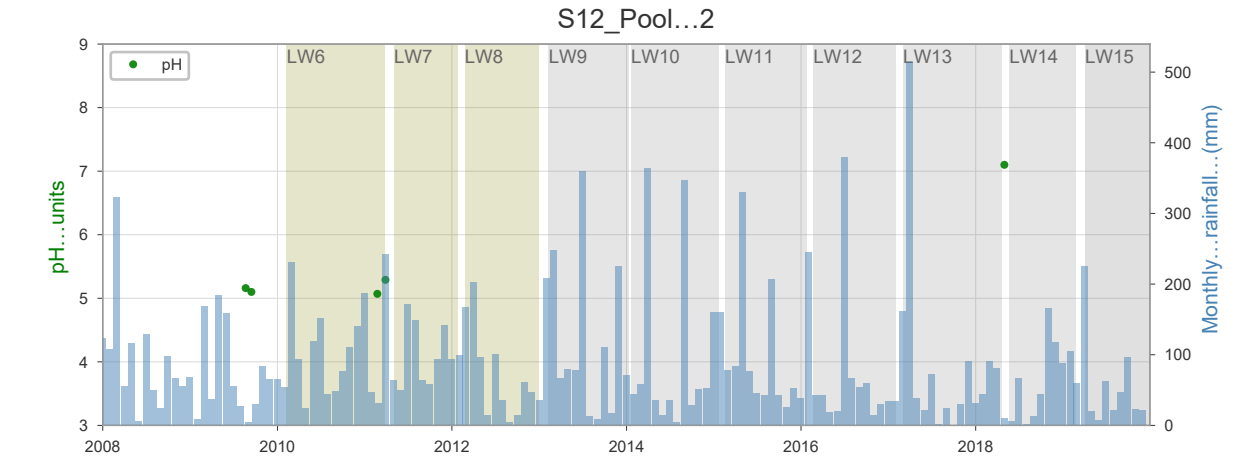

S12_Pool…14
EC…(uS/cm)
LOWESS…(0.3)
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

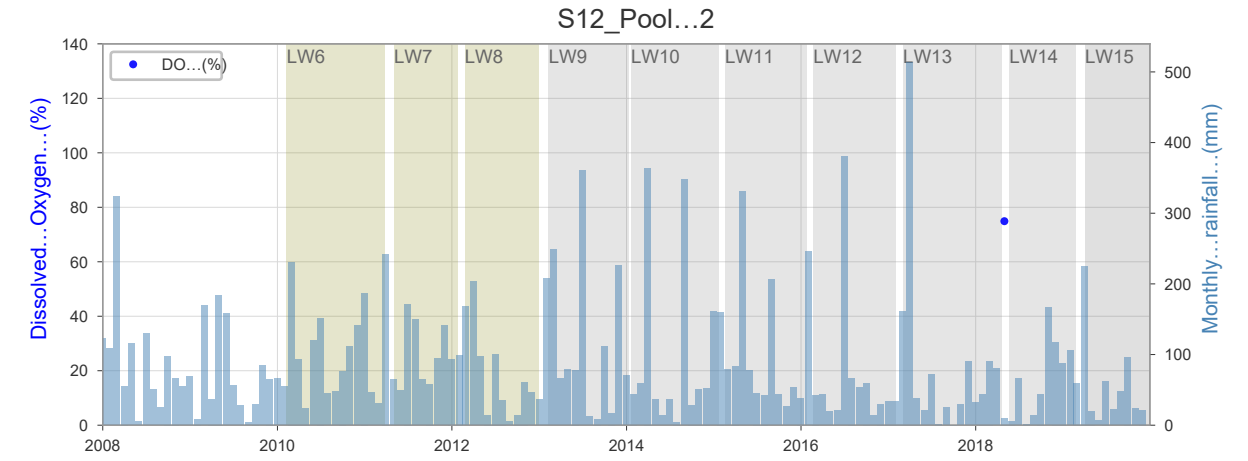

S12_Pool…14
pH
pH…units
Monthly…rainfall…(mm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

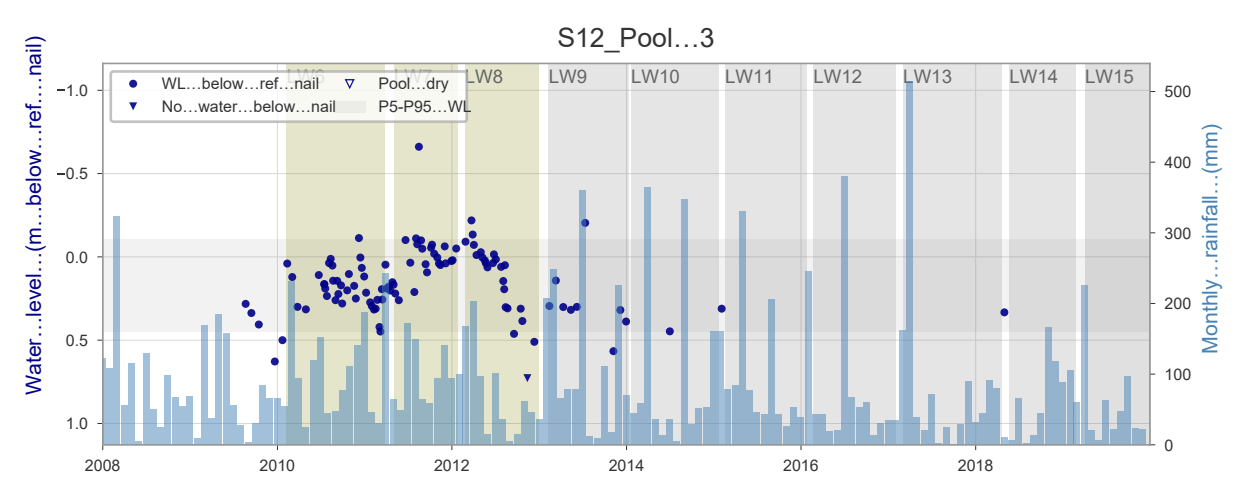

S12_Pool…14
DO…(%)
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

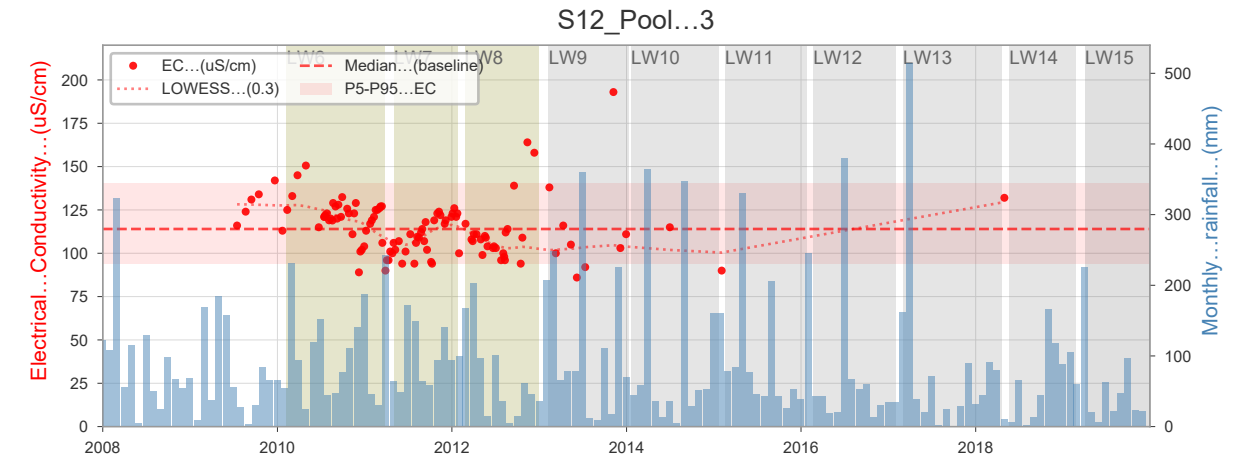

S12_Pool…2
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

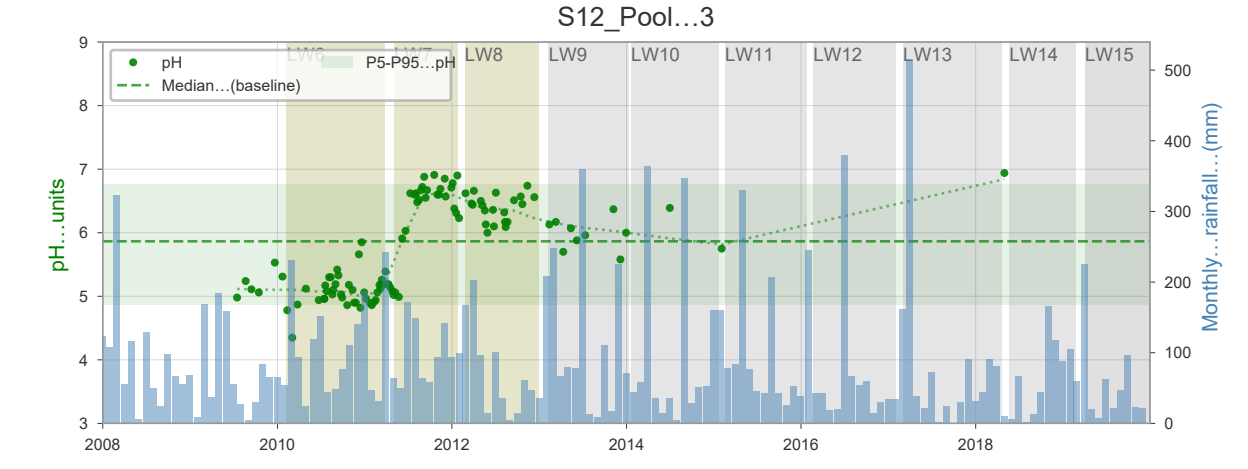

S12_Pool…2
EC…(uS/cm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

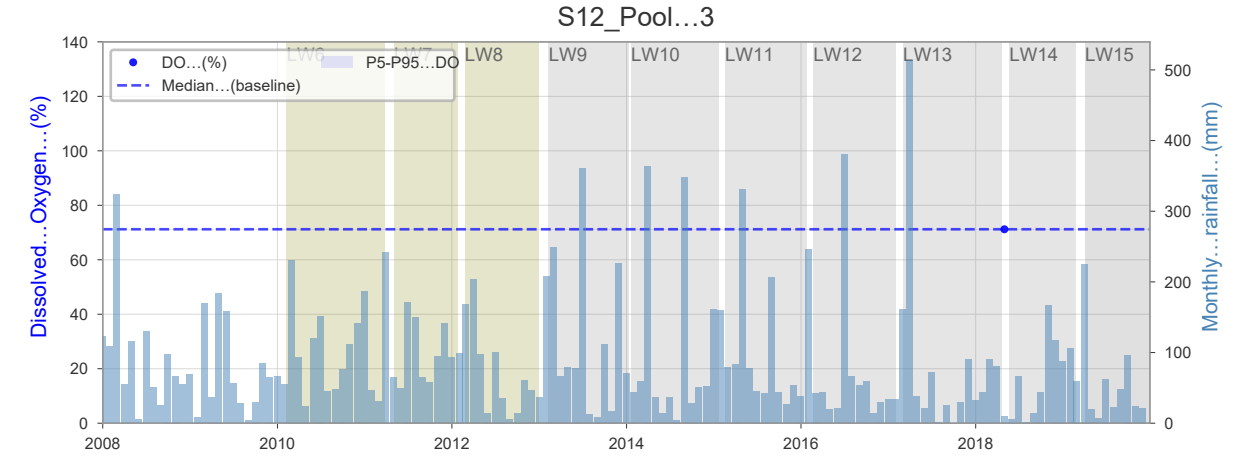

S12_Pool…2
pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

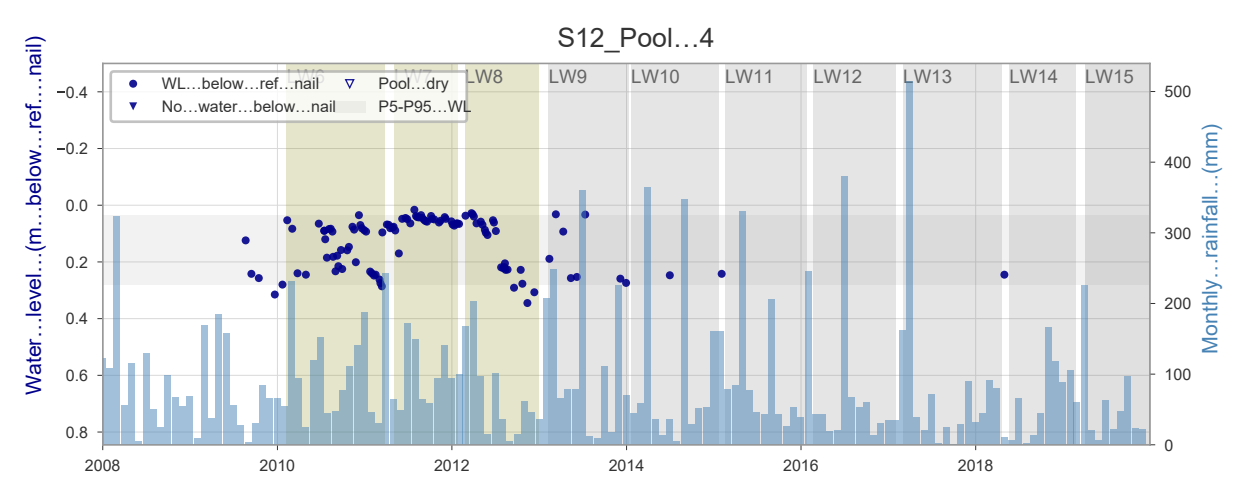

S12_Pool…2
DO…(%)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

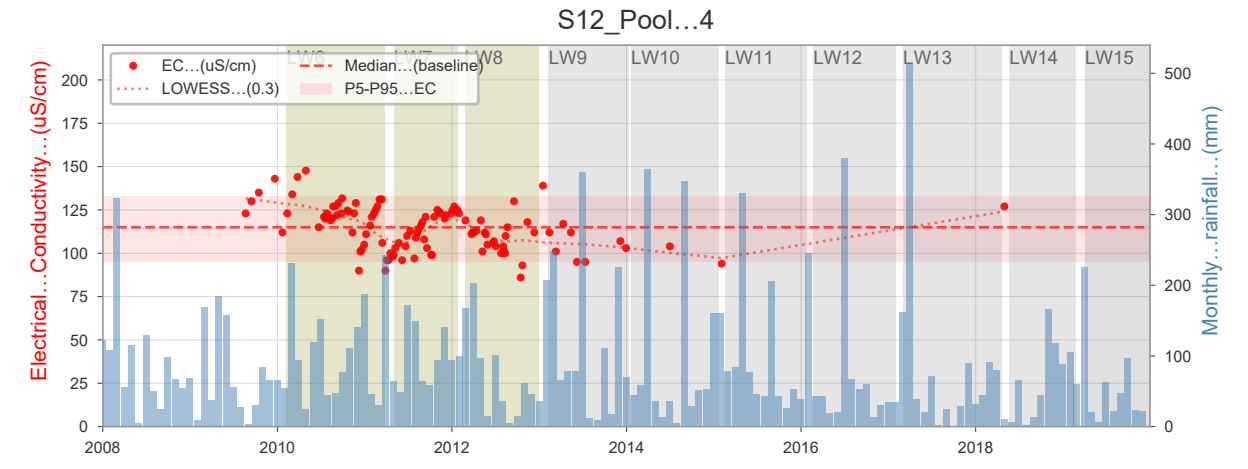

S12_Pool…3
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

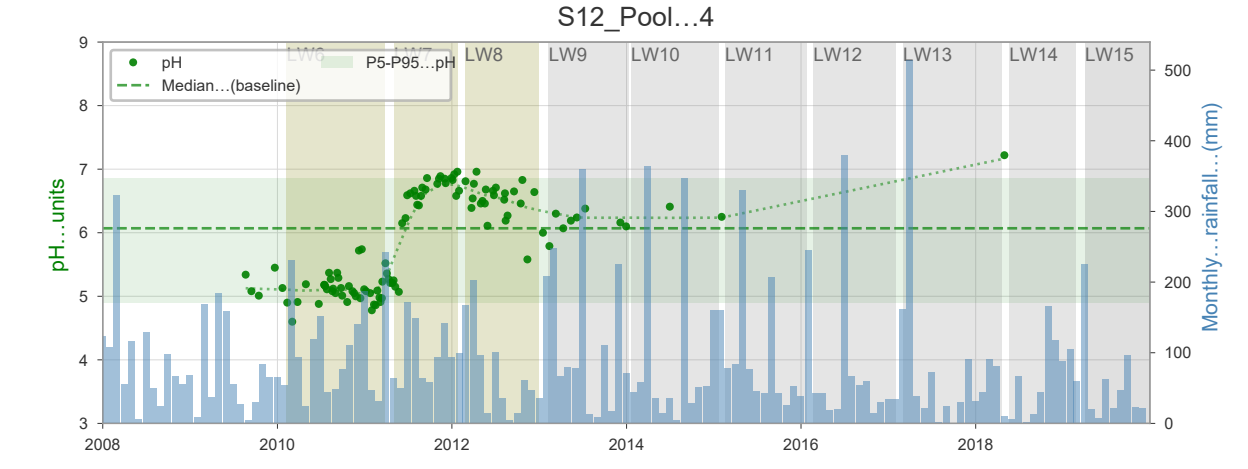

S12_Pool…3
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

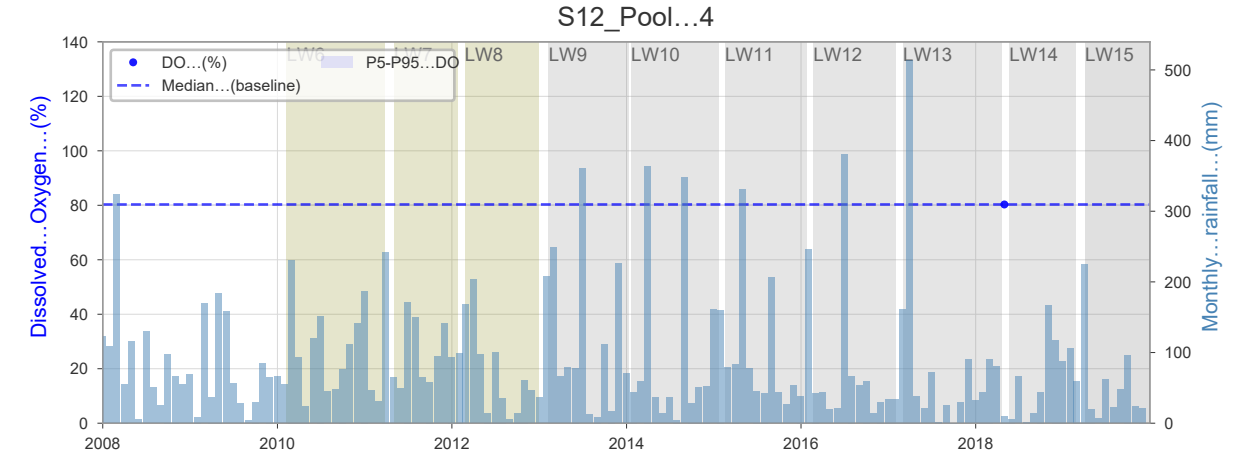

S12_Pool…3
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

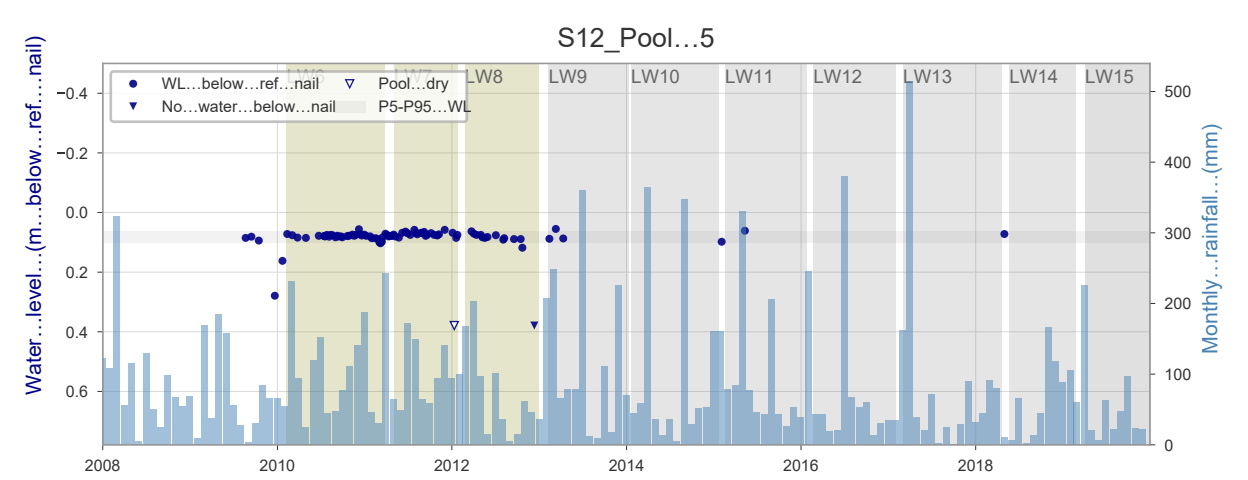

S12_Pool…3
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

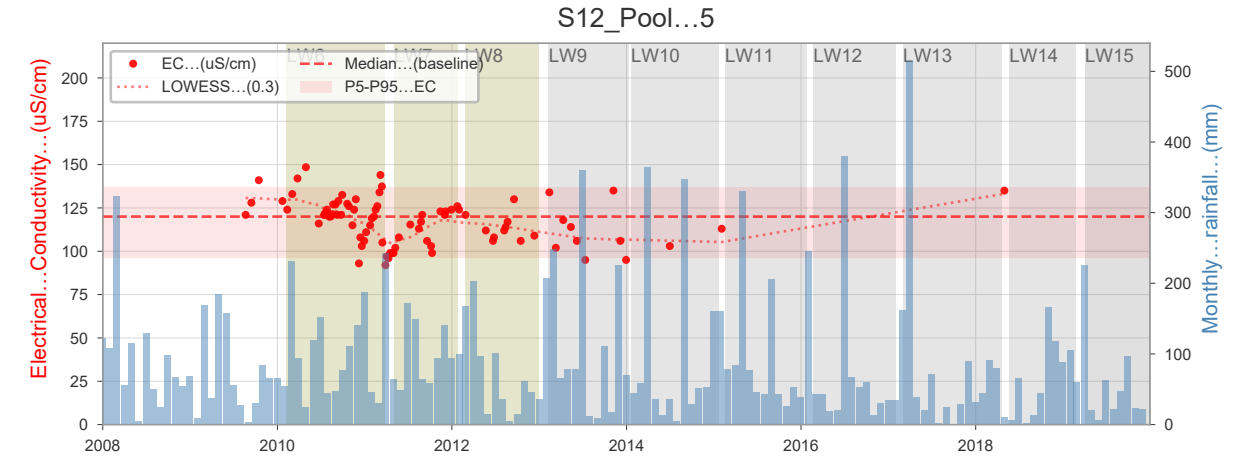

S12_Pool…4
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

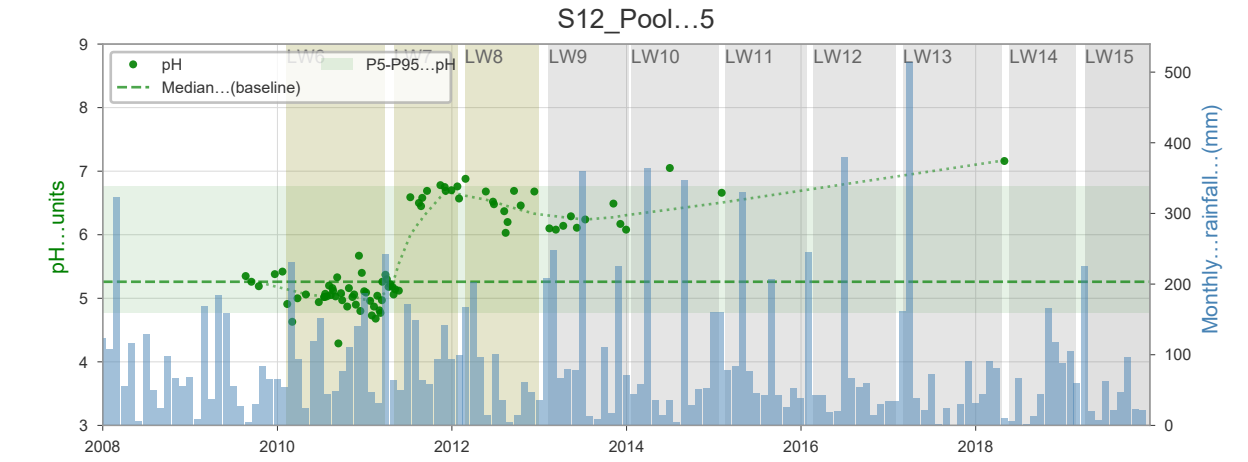

S12_Pool…4
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

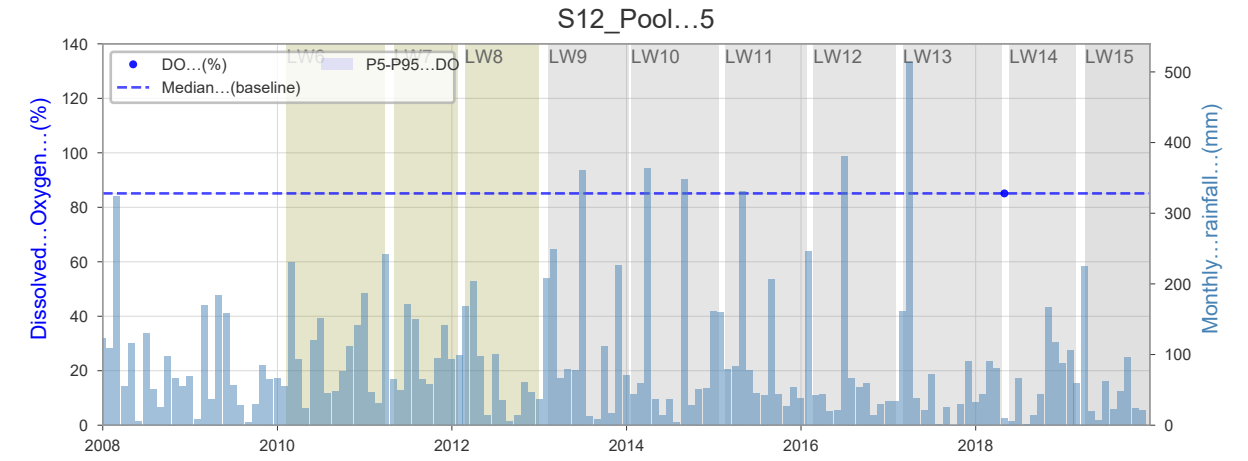

S12_Pool…4
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

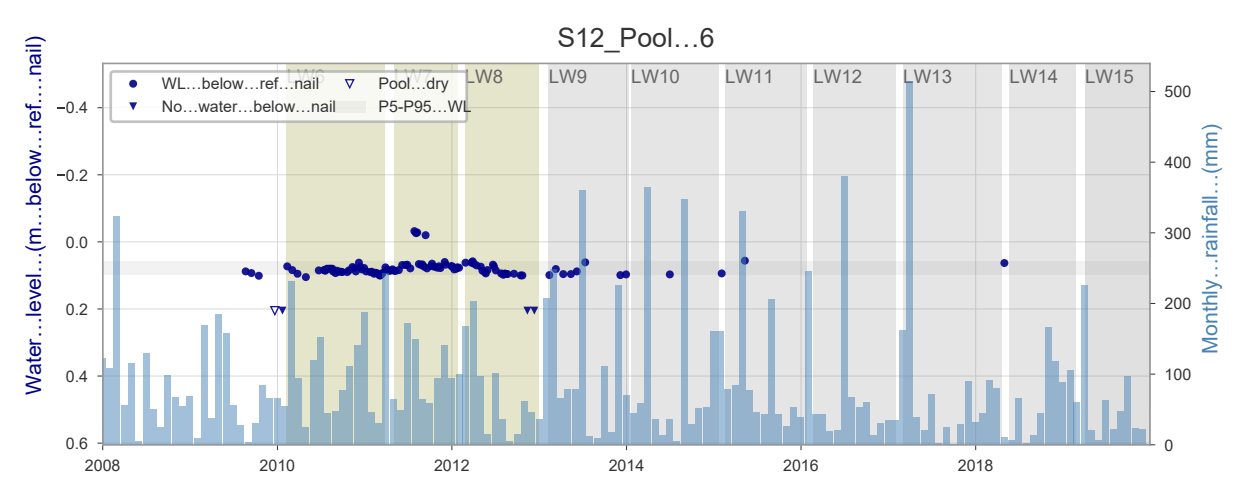

S12_Pool…4
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

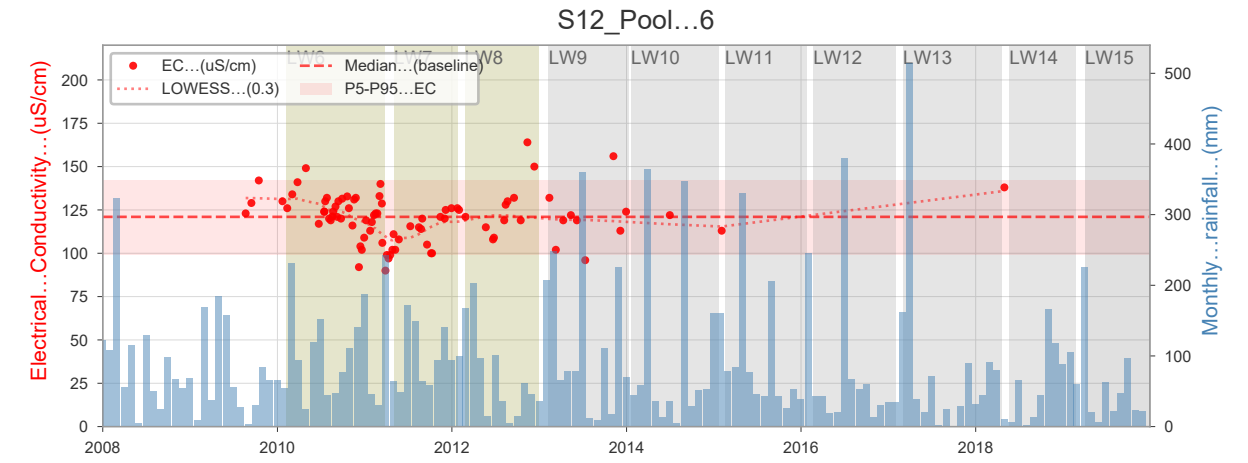

S12_Pool…5
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

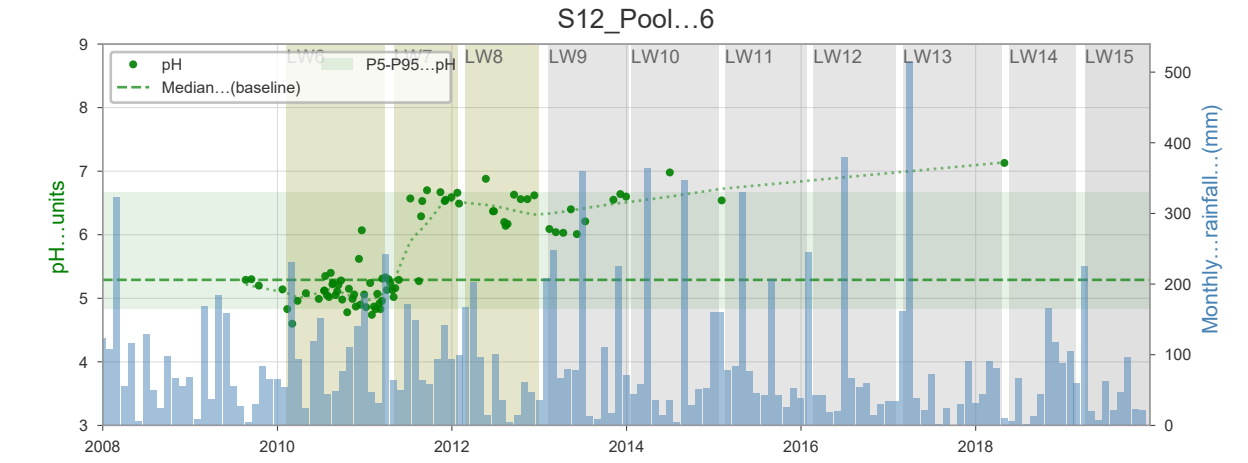

S12_Pool…5
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

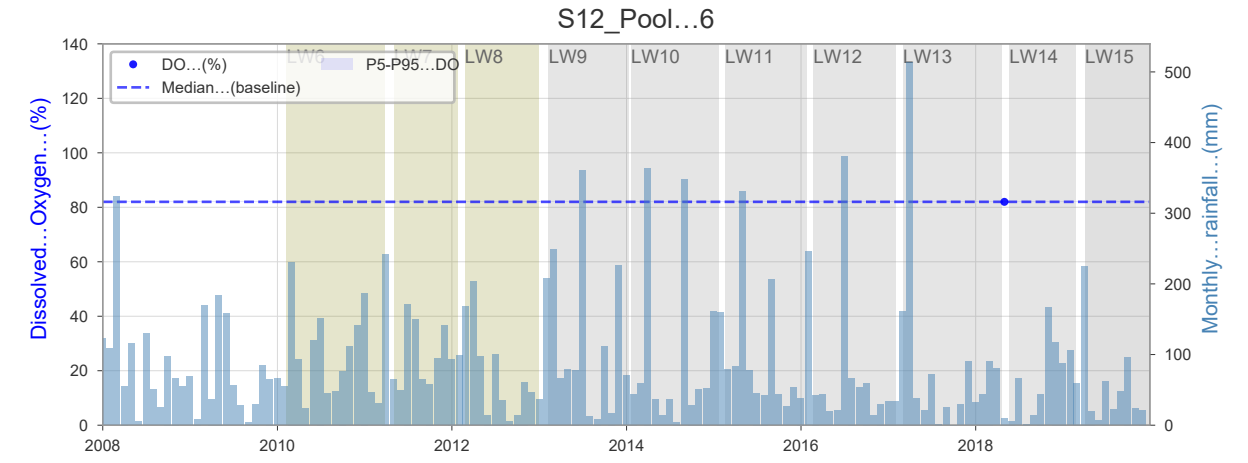

S12_Pool…5
pH
P5-P95…pH
Median…(baseline)
pH…units
Monthly…rainfall…(mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

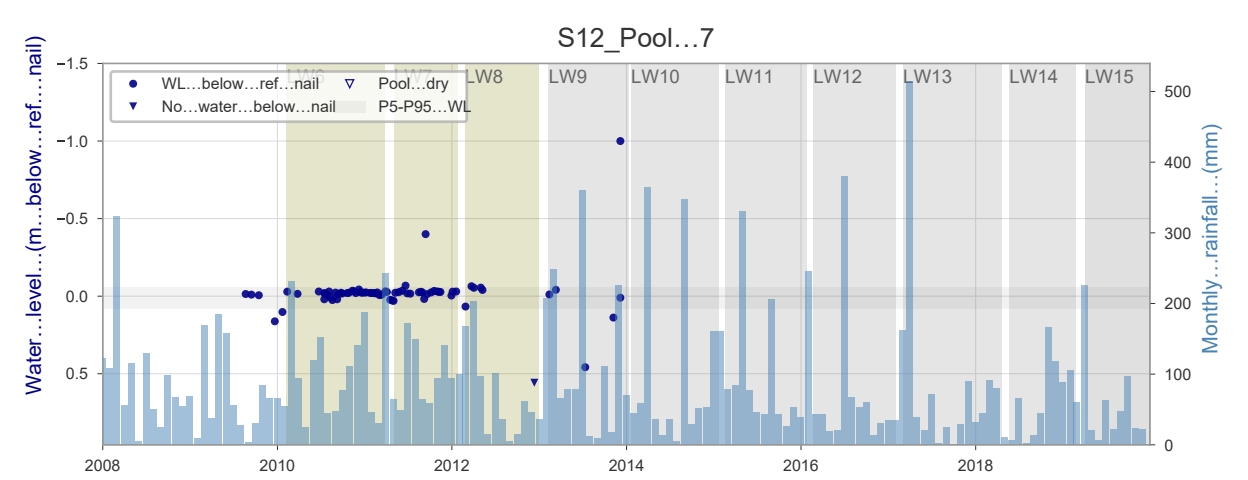

S12_Pool…5
DO…(%)
P5-P95…DO
Median…(baseline)
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

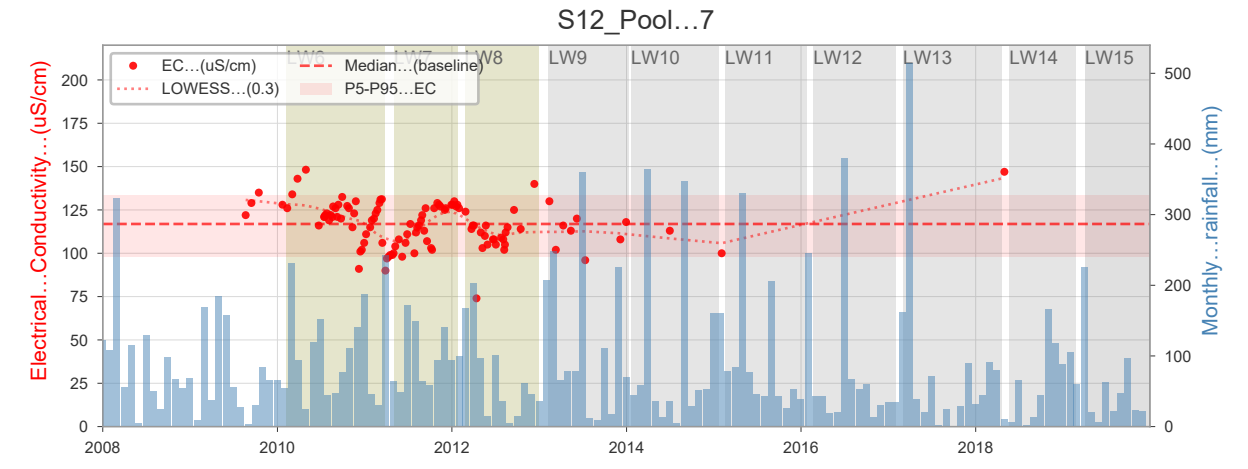

S12_Pool…6
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

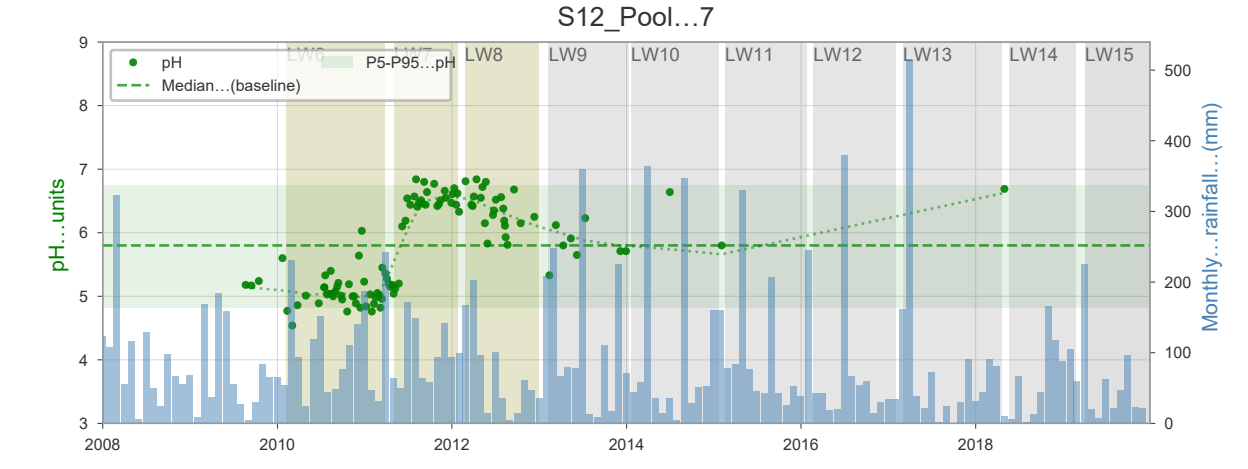

S12_Pool…6
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

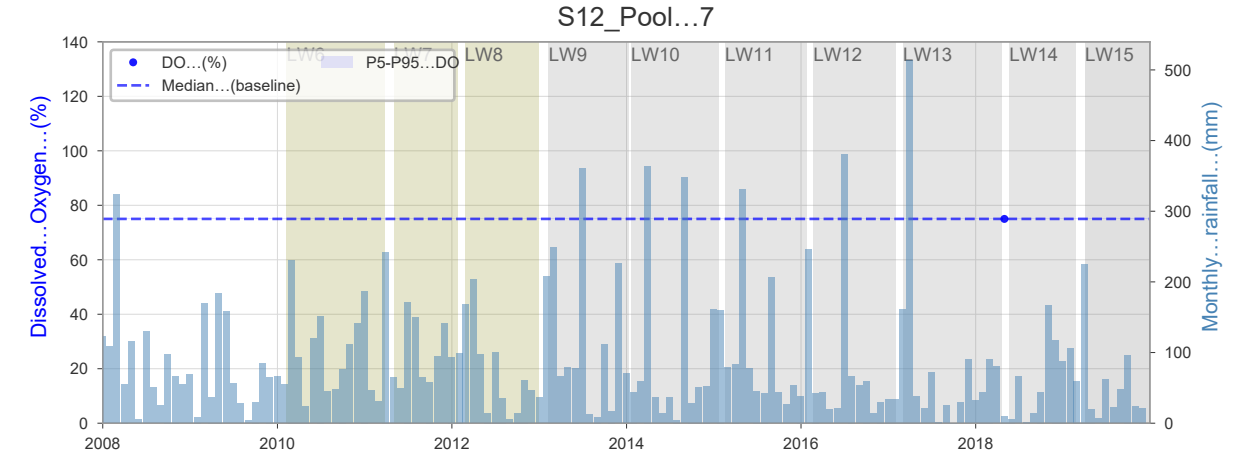

S12_Pool…6
pH
P5-P95…pH
Median…(baseline)
pH…units
Monthly…rainfall…(mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

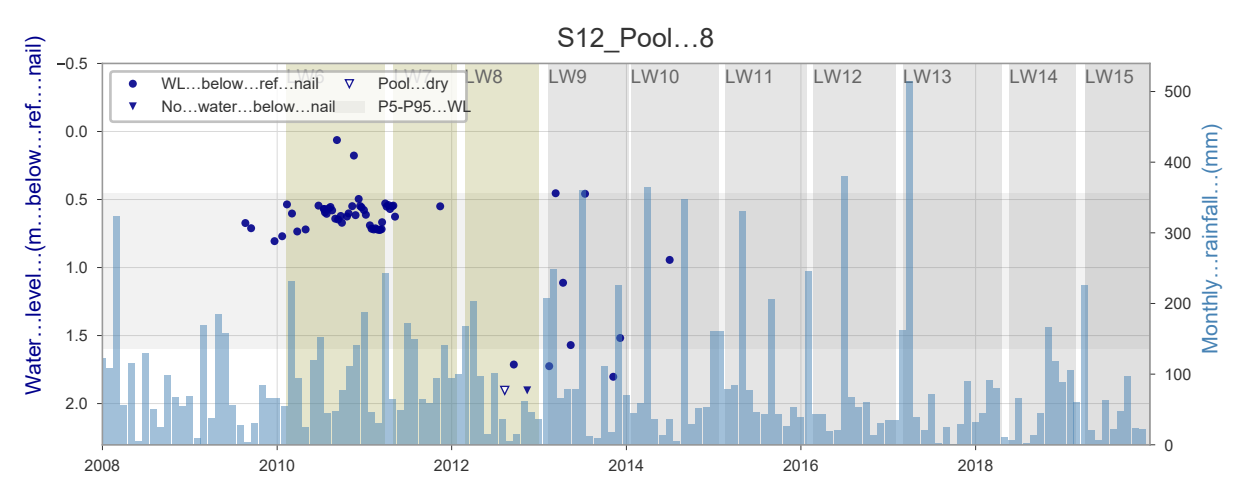

S12_Pool…6
DO…(%)
Median…(baseline)
P5-P95…DO
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

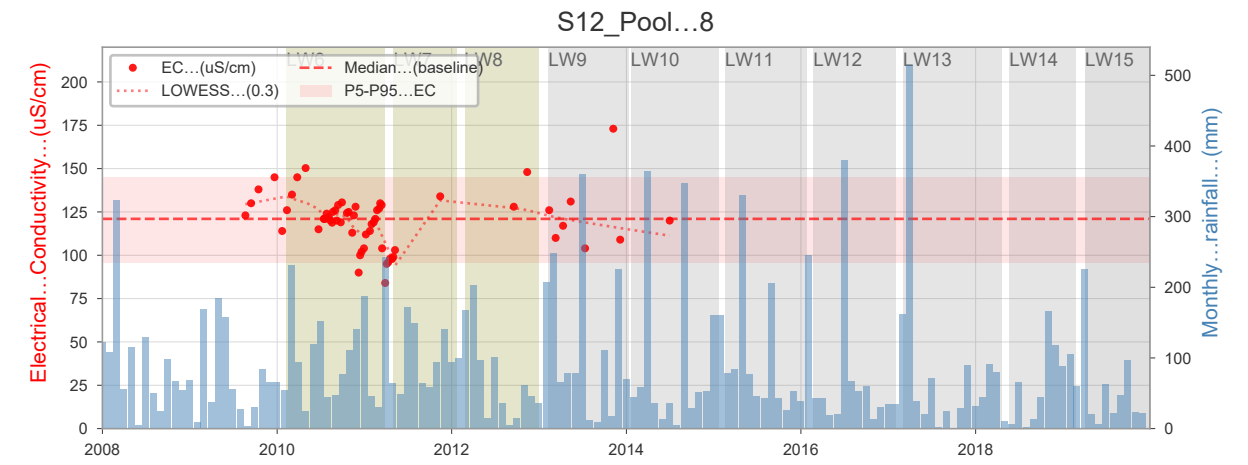

S12_Pool…7
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….…nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

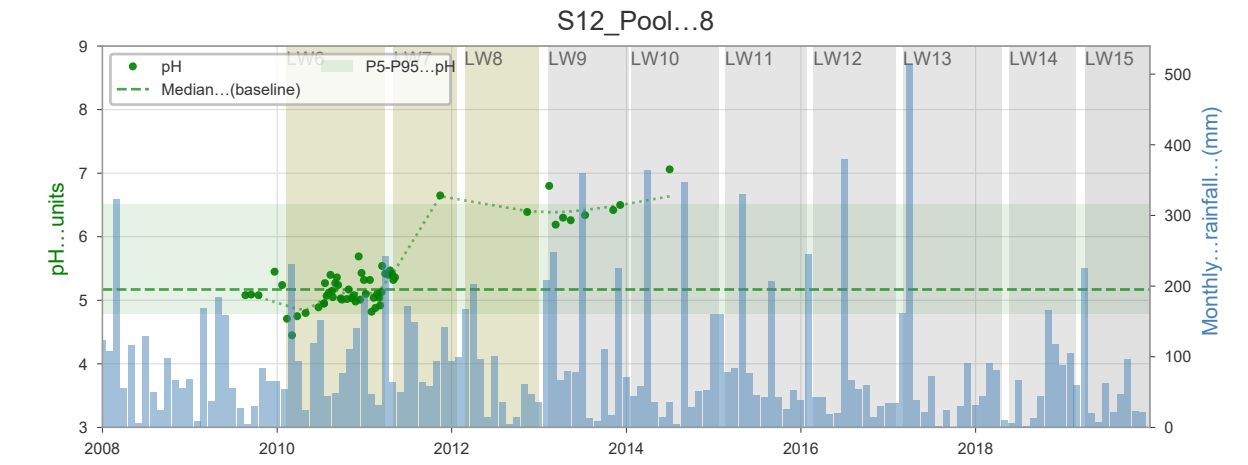

S12_Pool…7
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

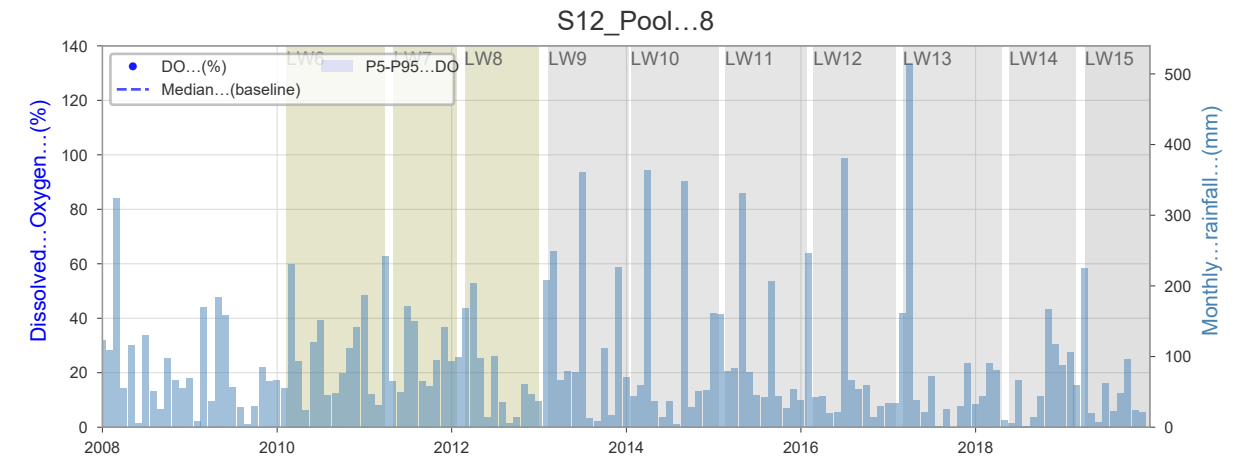

S12_Pool…7
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

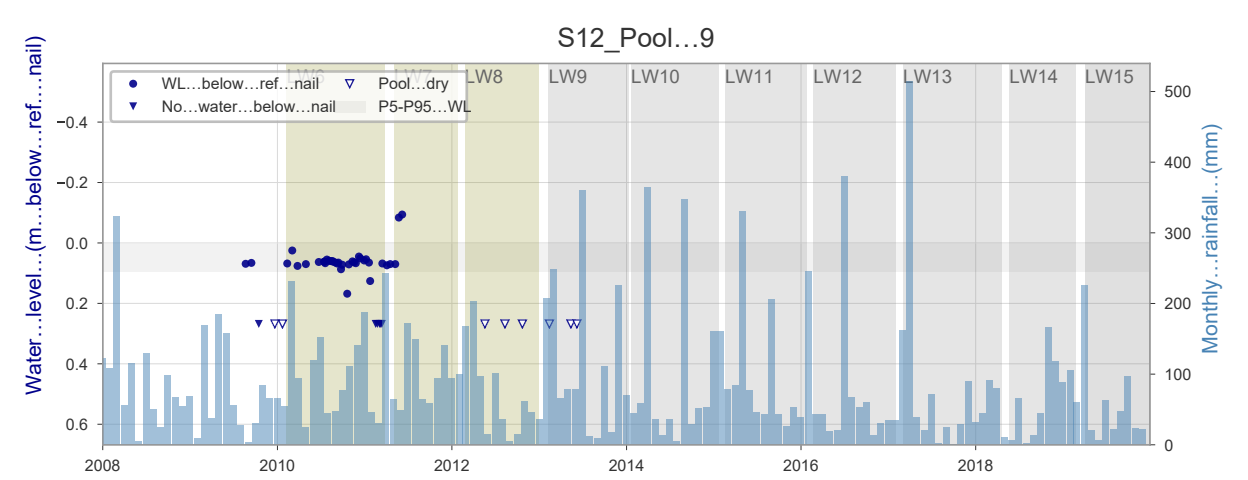

S12_Pool…7
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

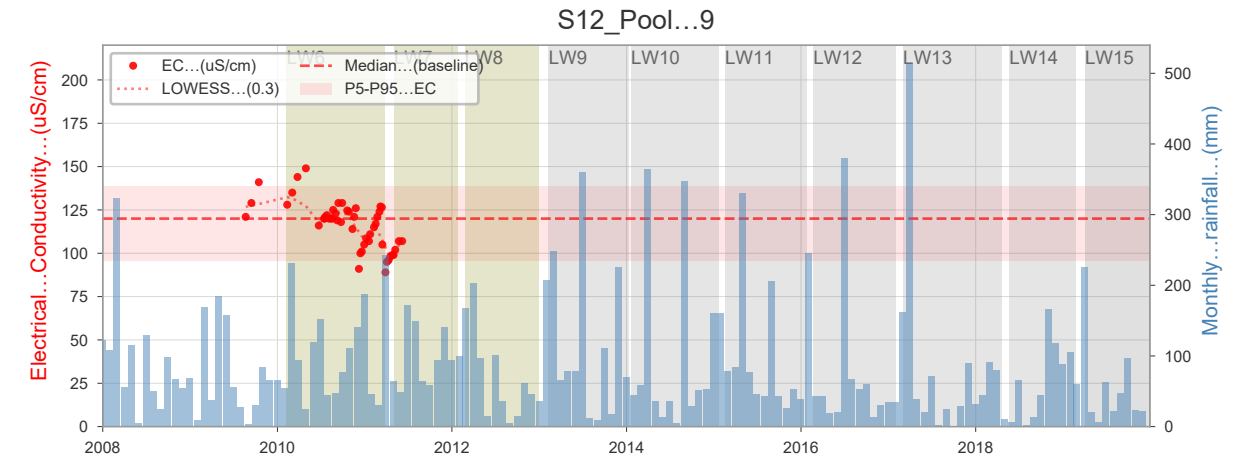

S12_Pool…8
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

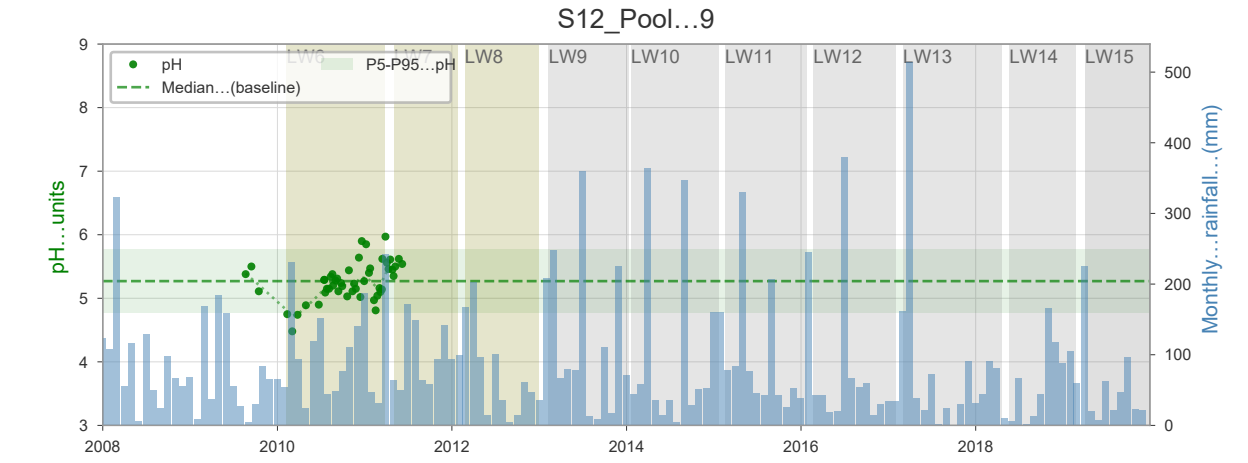

S12_Pool…8
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

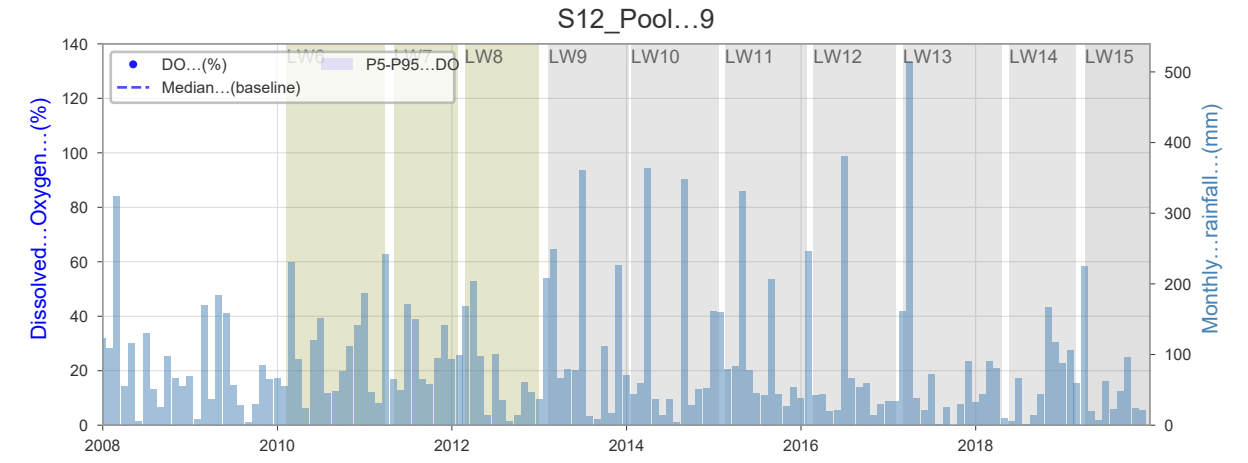

S12_Pool…8
pH…units
Monthly…rainfall…(mm)
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

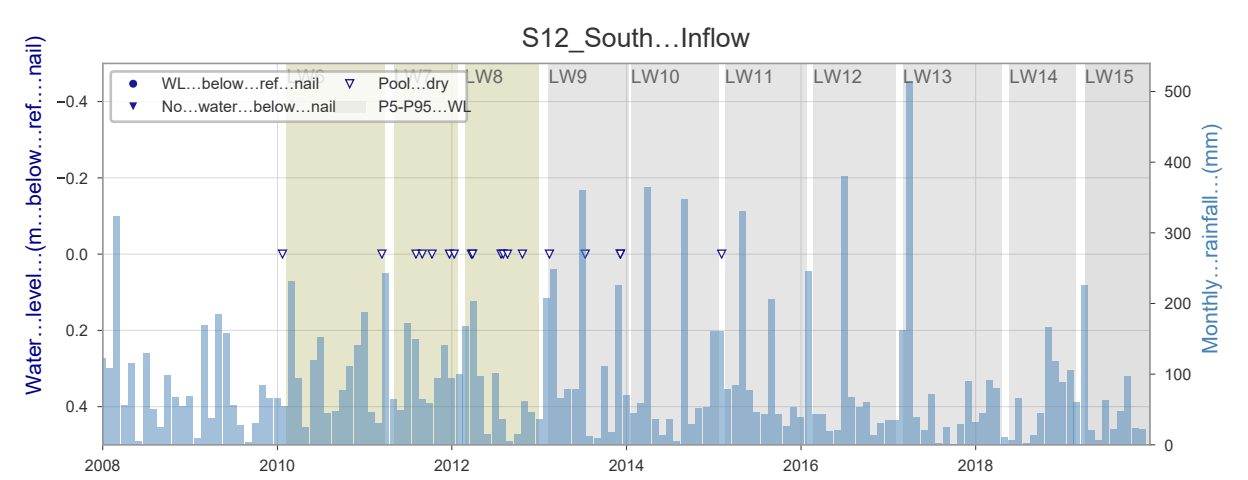

S12_Pool…8
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

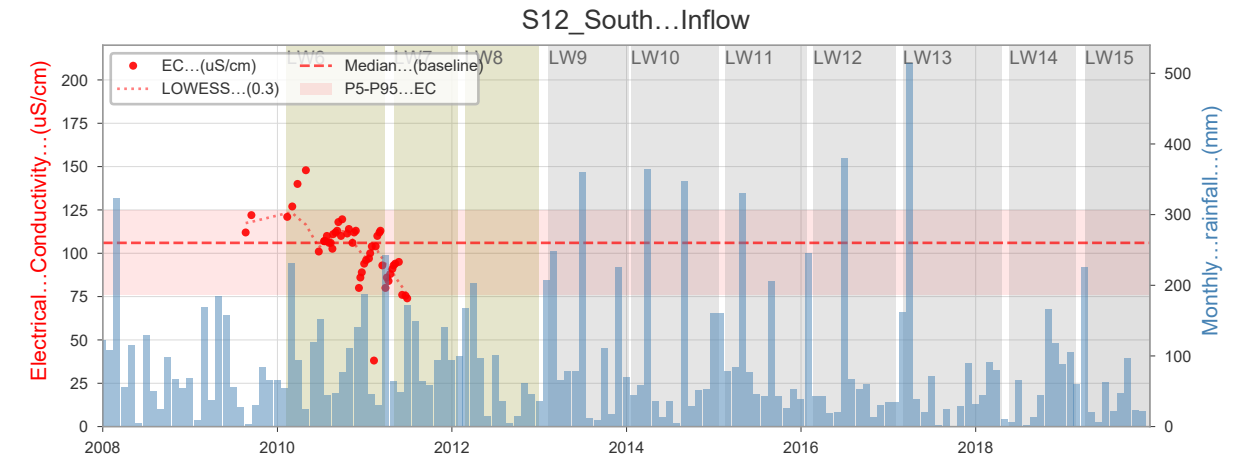

S12_Pool…9
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

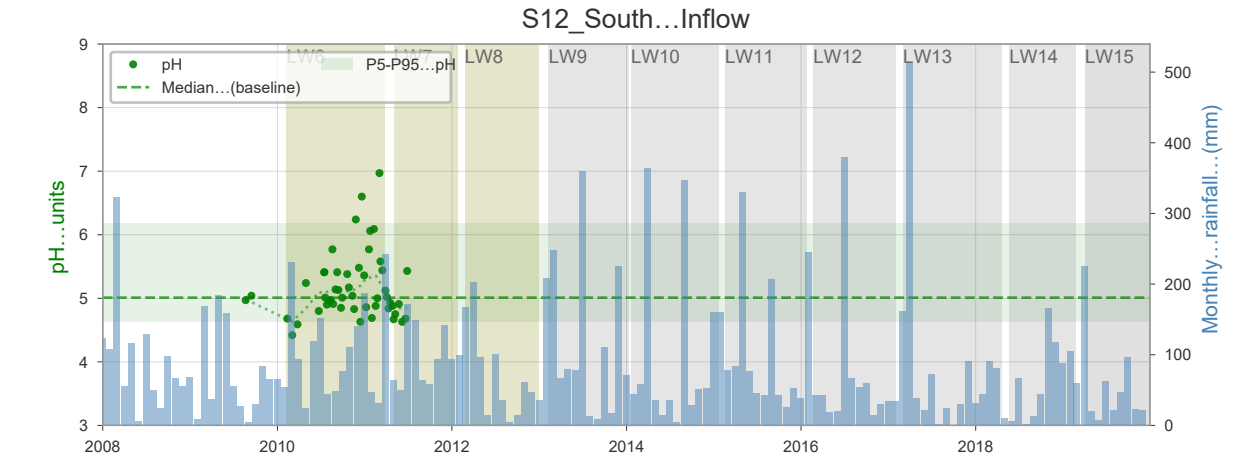

S12_Pool…9
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

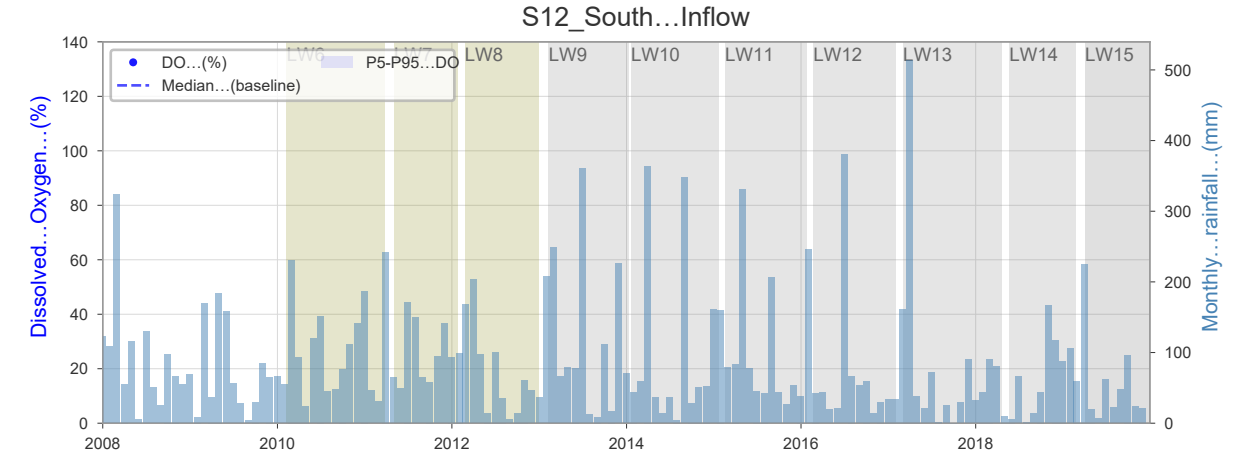

S12_Pool…9
pH
P5-P95…pH
Median…(baseline)
pH…units
Monthly…rainfall…(mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

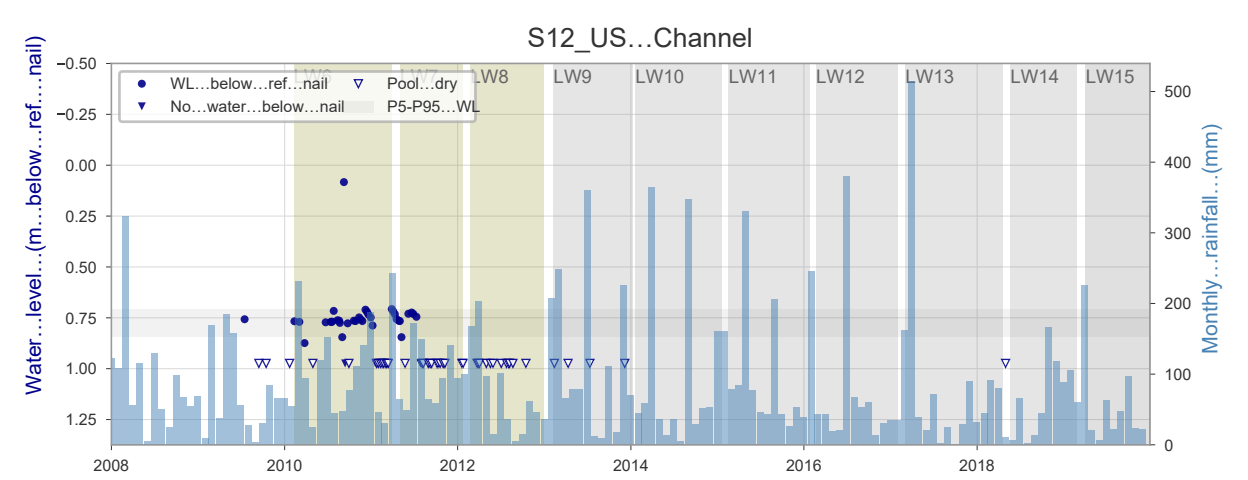

S12_Pool…9
DO…(%)
P5-P95…DO
Median…(baseline)
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

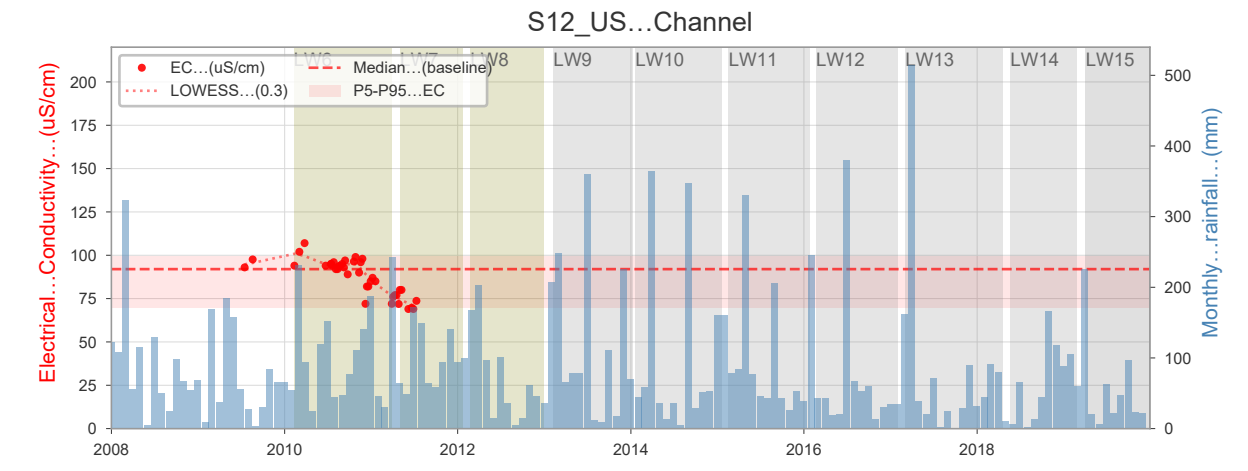

S12_South…Inflow
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

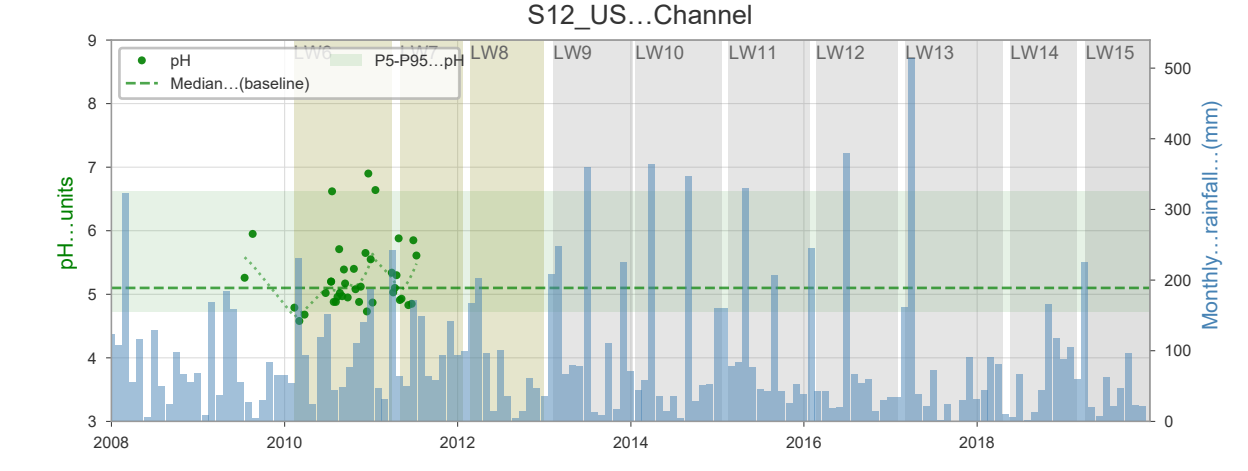

S12_South…Inflow
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

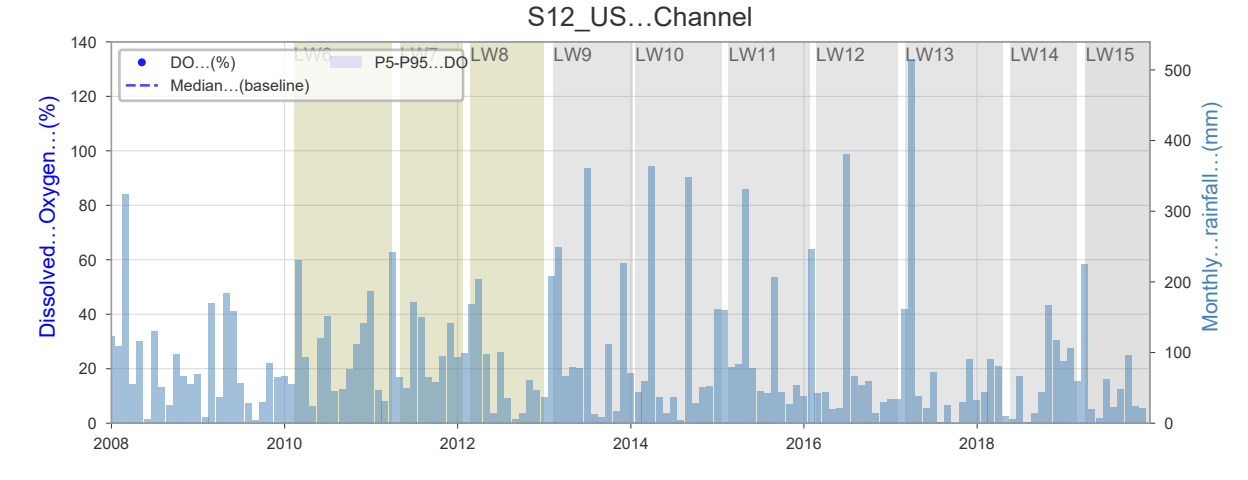

S12_South…Inflow
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

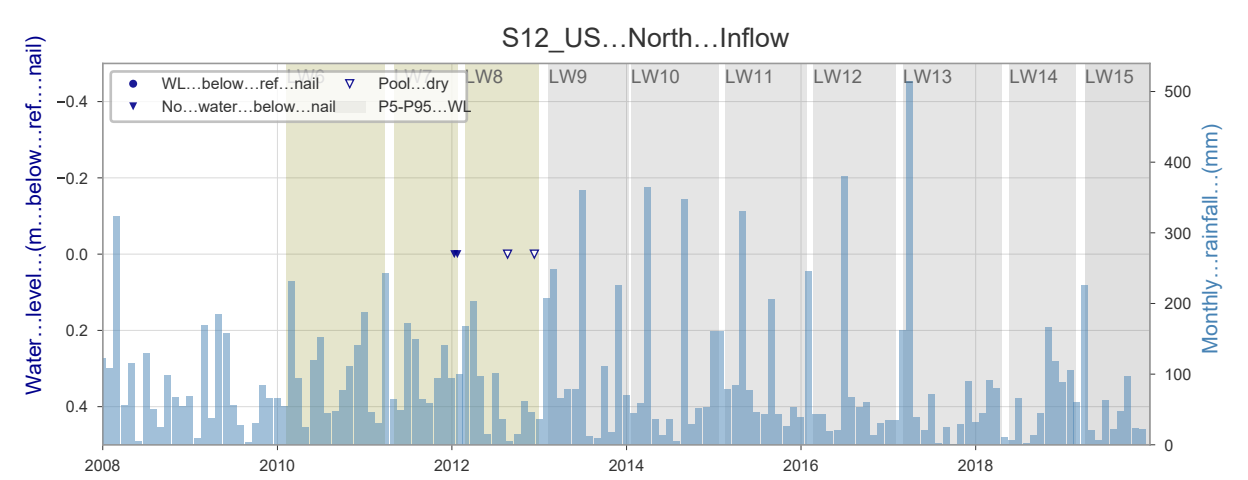

S12_South…Inflow
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

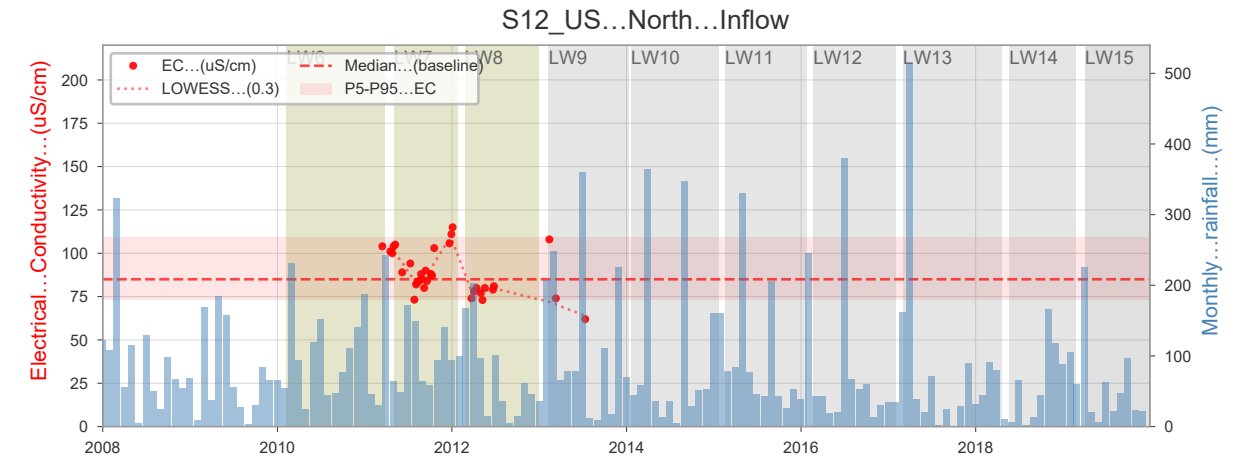

S12_US…Channel
WL…below…ref…nail
No…water…below…nail
Pool…dry
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….…nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

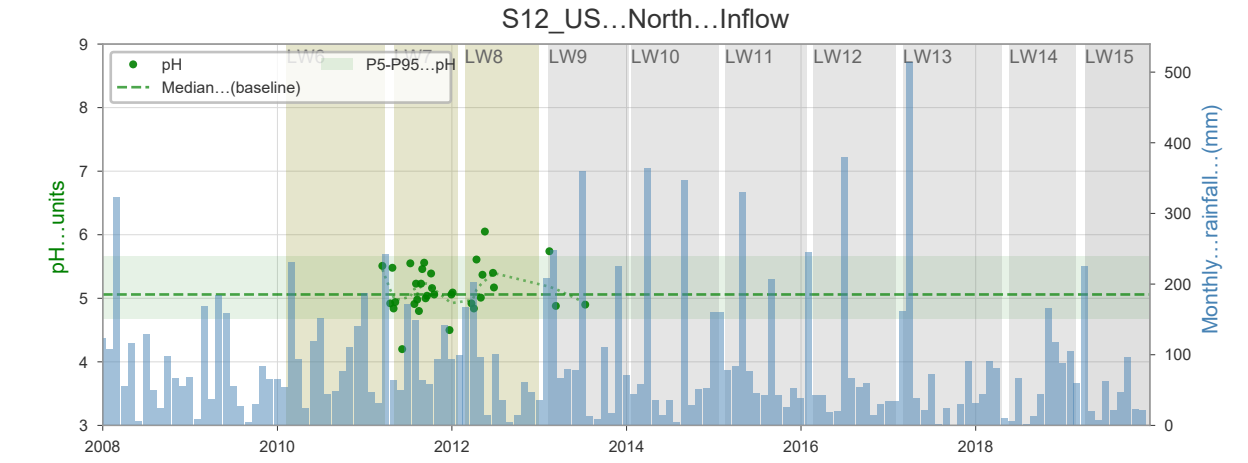

S12_US…Channel
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

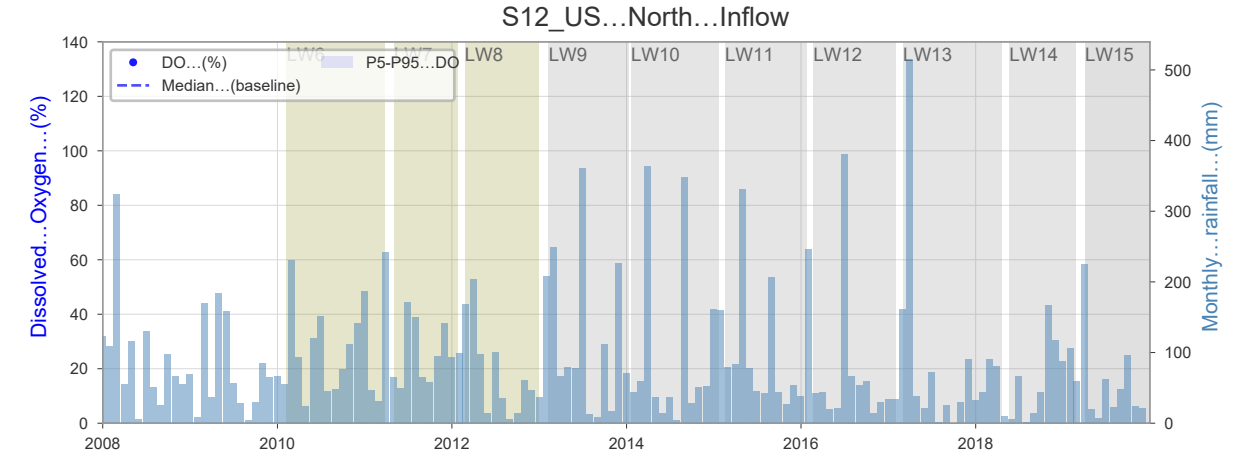

S12_US…Channel
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

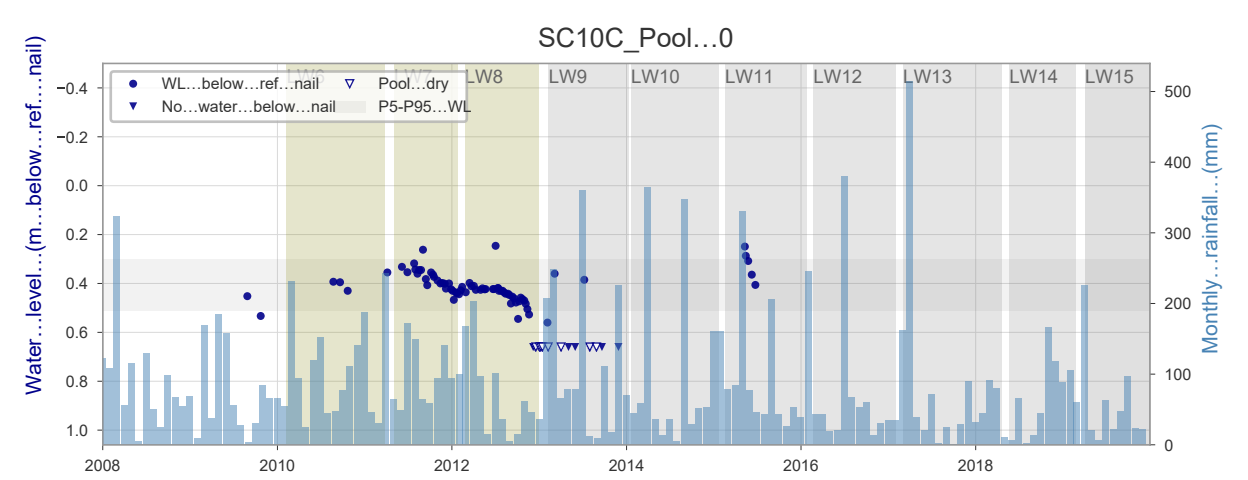

S12_US…Channel
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

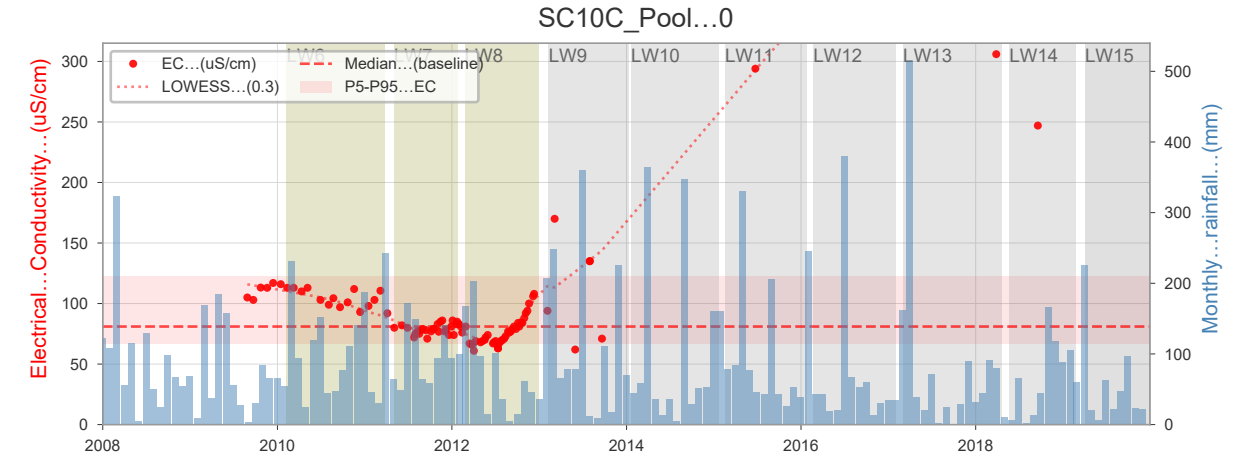

S12_US…North…Inflow
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

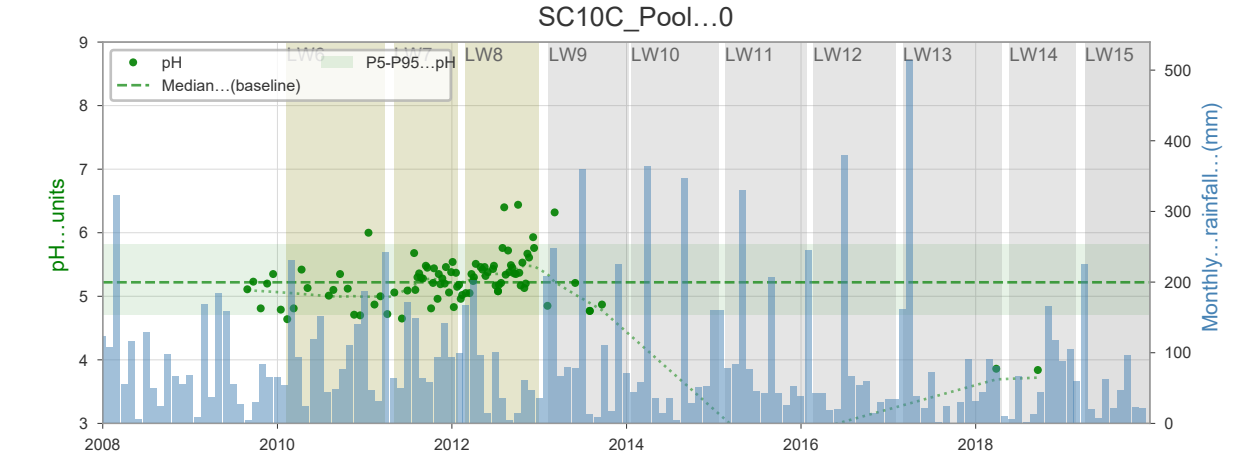

S12_US…North…Inflow
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

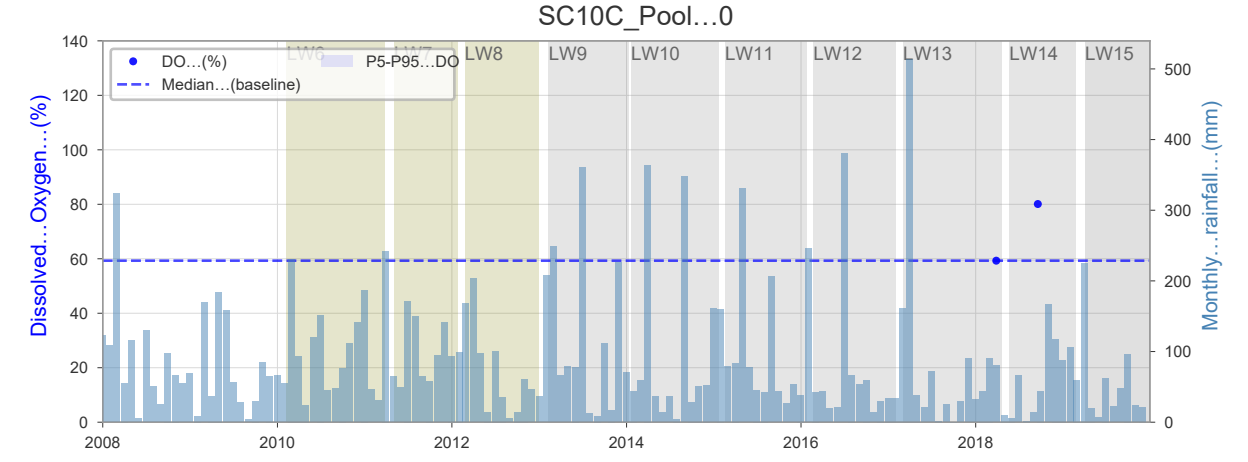

S12_US…North…Inflow
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

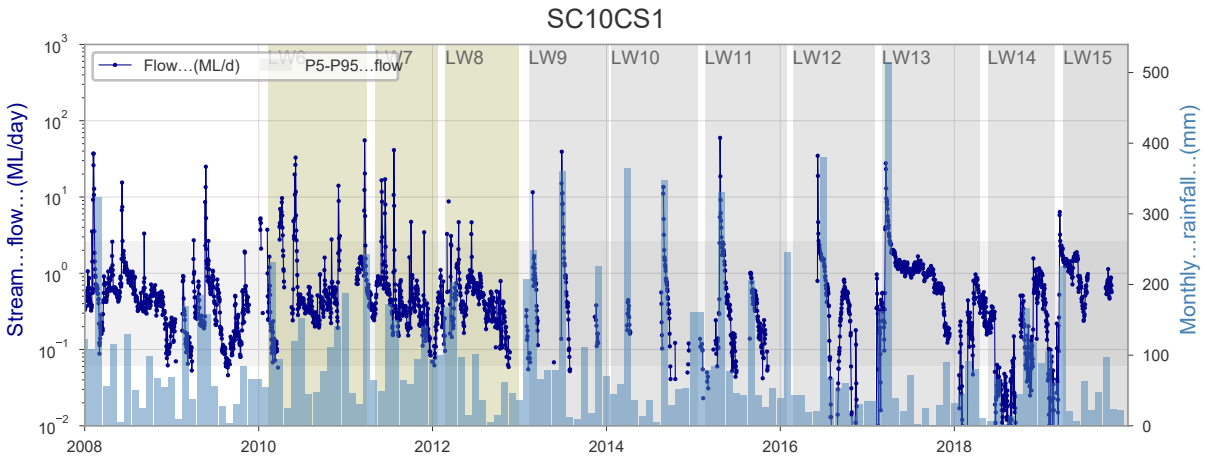

S12_US…North…Inflow
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

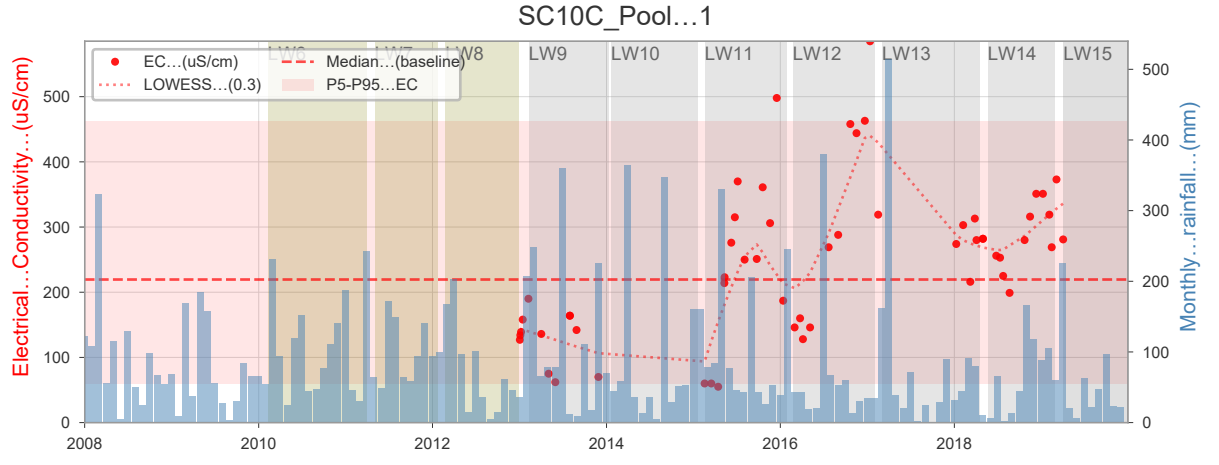

SC10C_Pool…0
WL…below…ref…nail
No…water…below…nail
Pool…dry
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

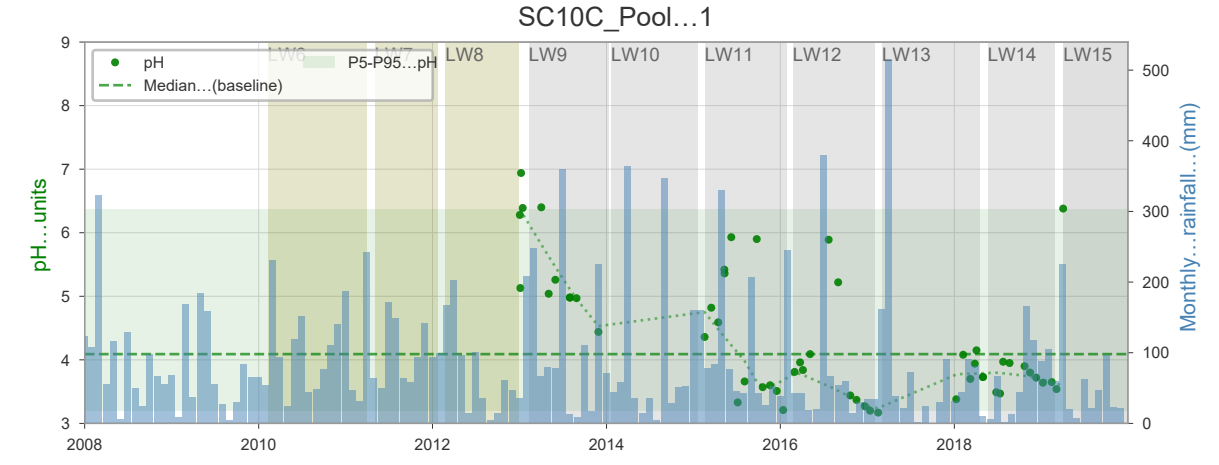

SC10C_Pool…0
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

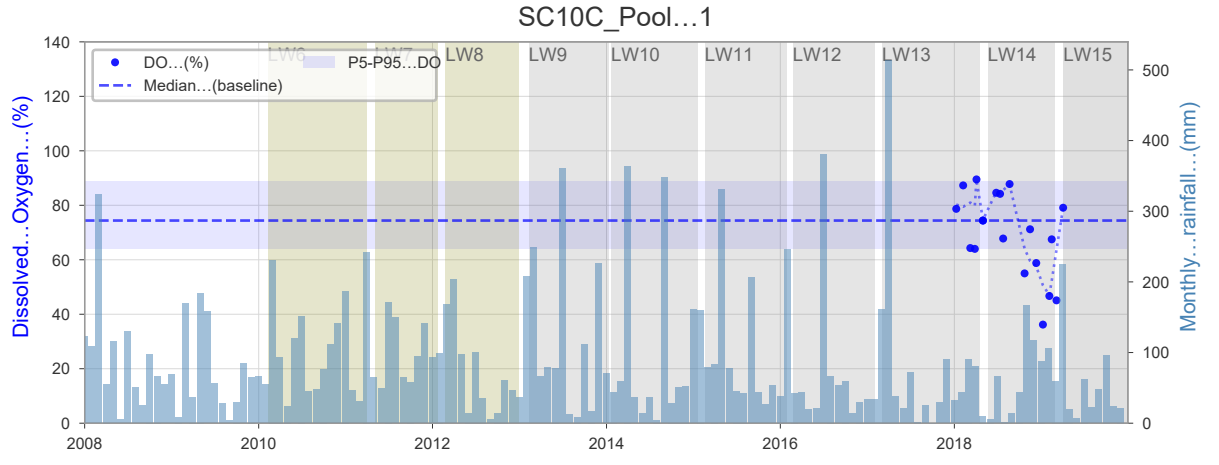

SC10C_Pool…0
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

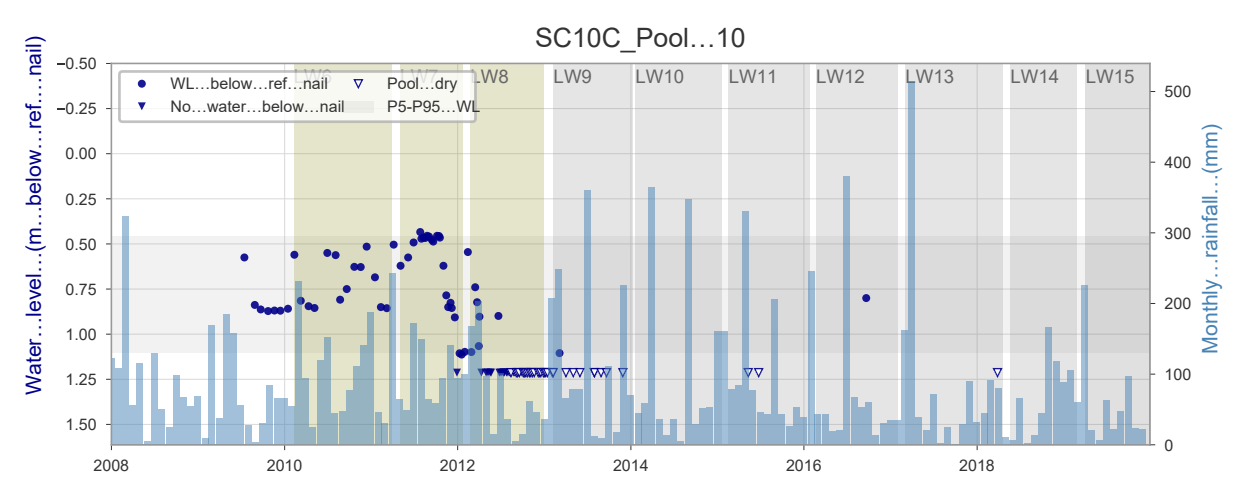

SC10C_Pool…0
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

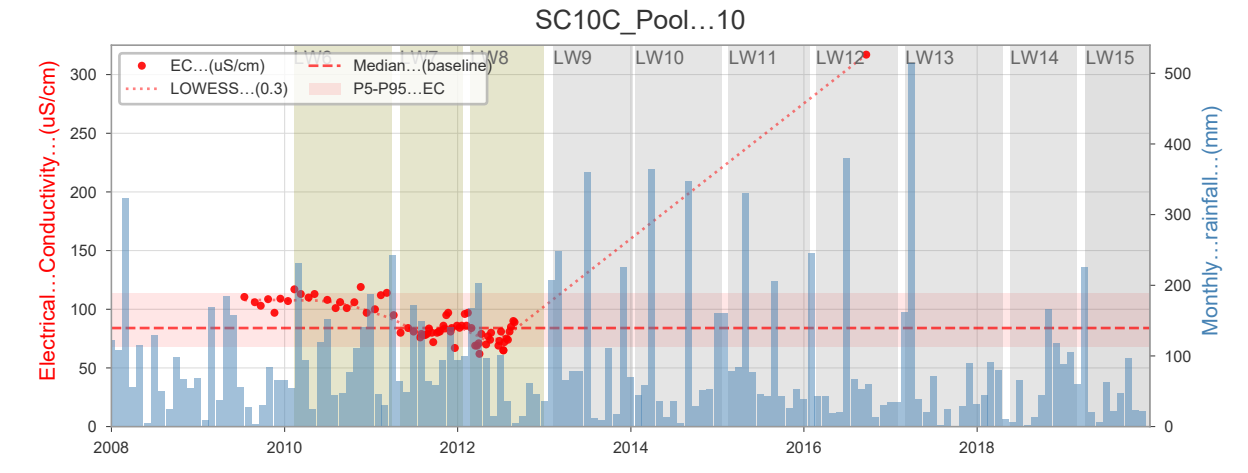

SC10CS1
Flow…(ML/d)
P5-P95…flow
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Stream…flow…(ML/day)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

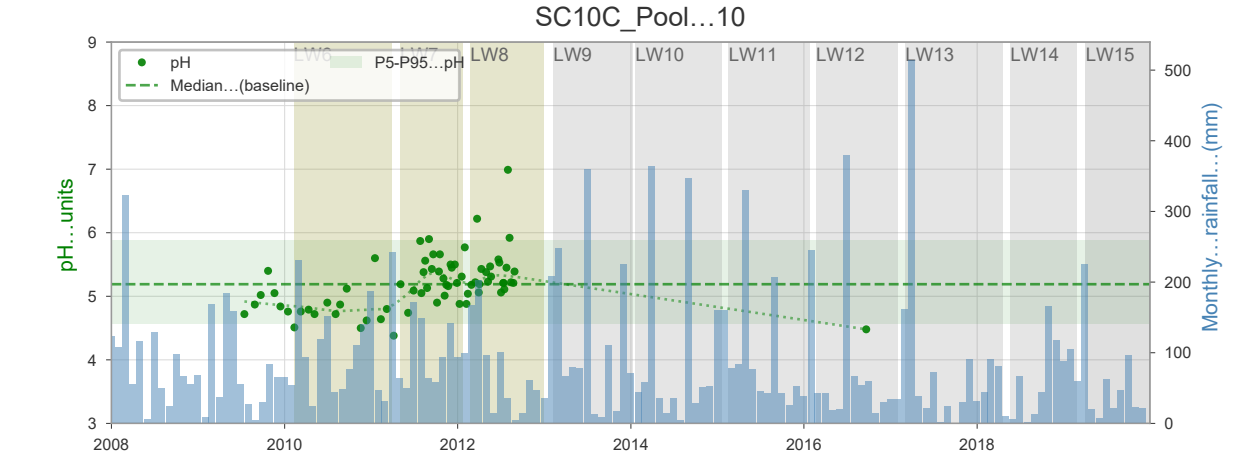

SC10C_Pool…1
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

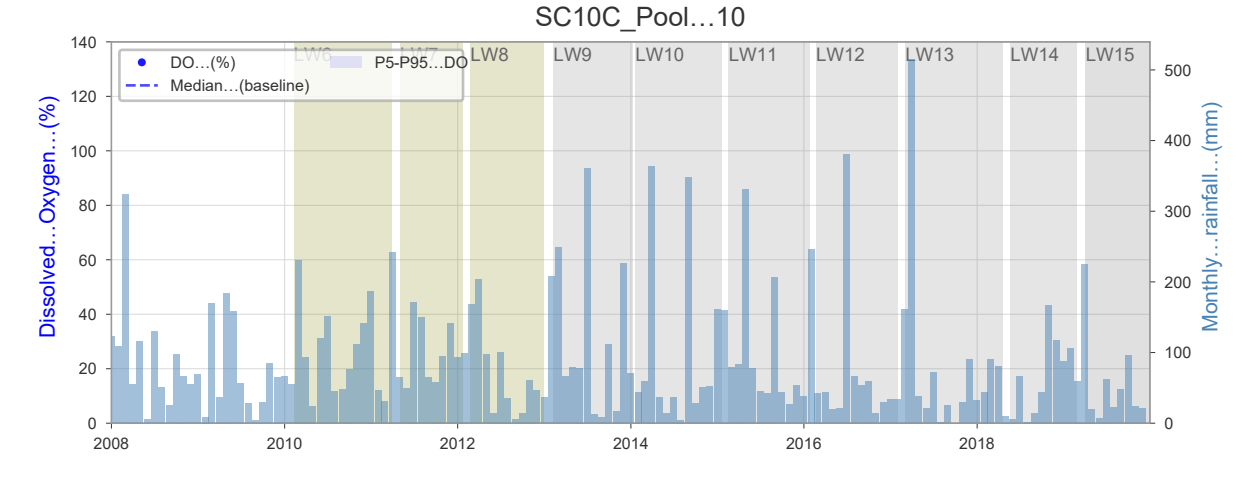

SC10C_Pool…1
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

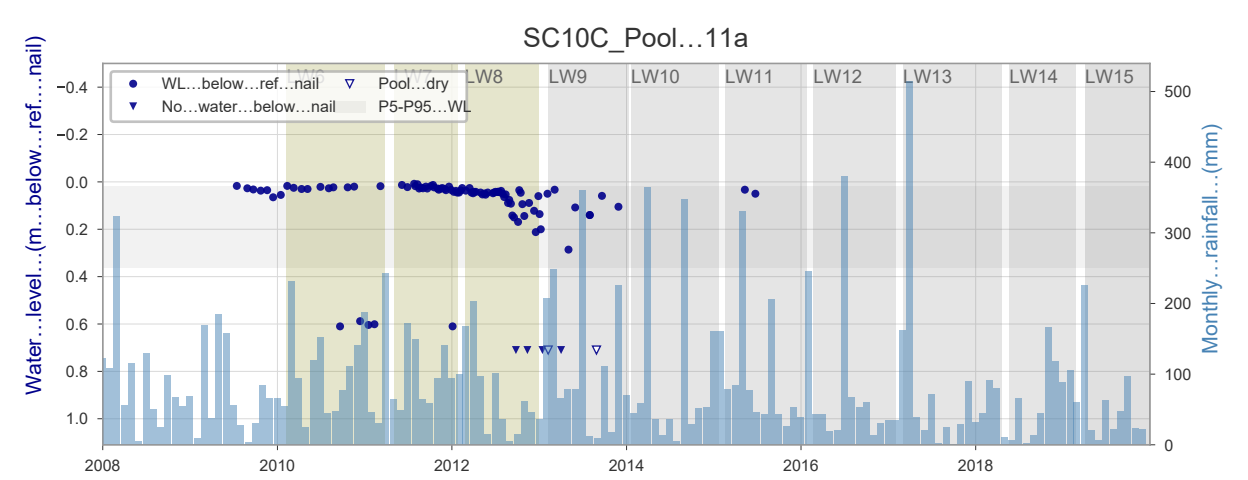

SC10C_Pool…1
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

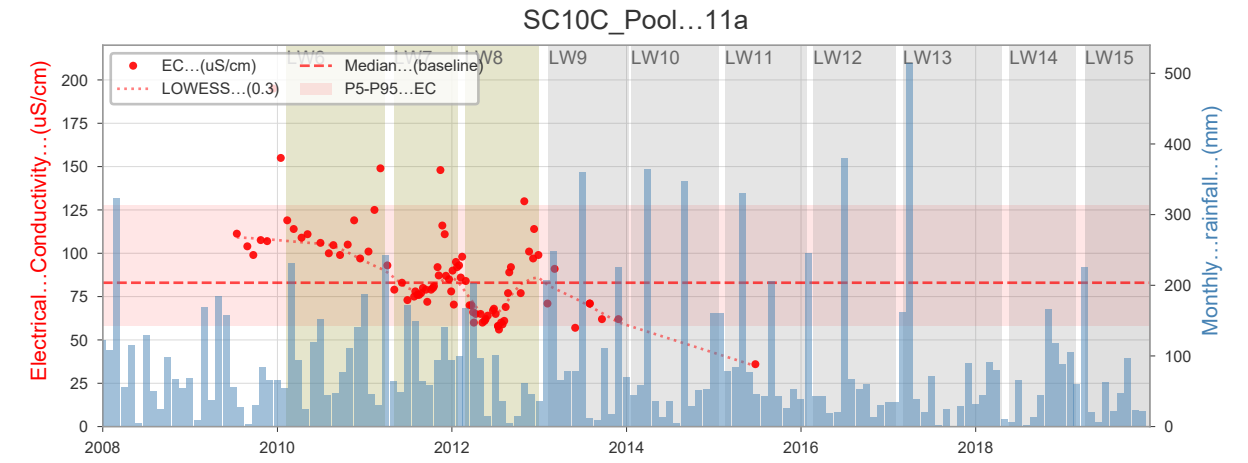

SC10C_Pool…10
WL…below…ref…nail
No…water…below…nail
Pool…dry
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref.…nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

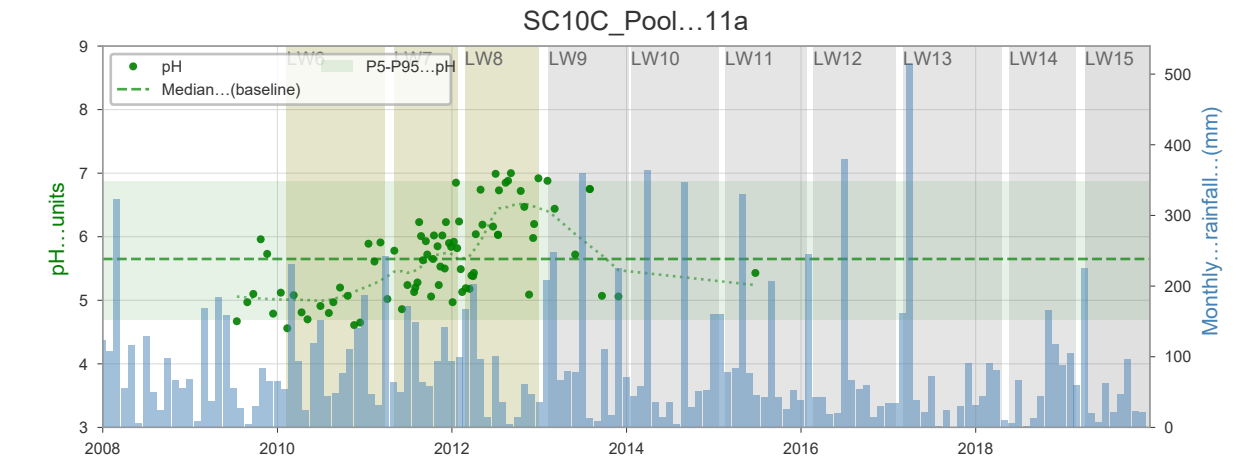

SC10C_Pool…10
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

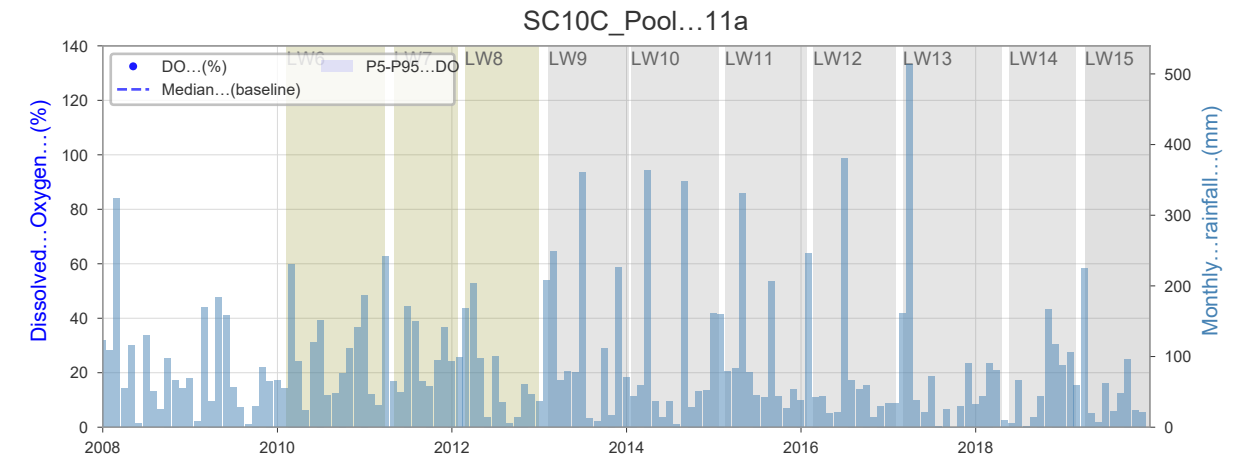

SC10C_Pool…10
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

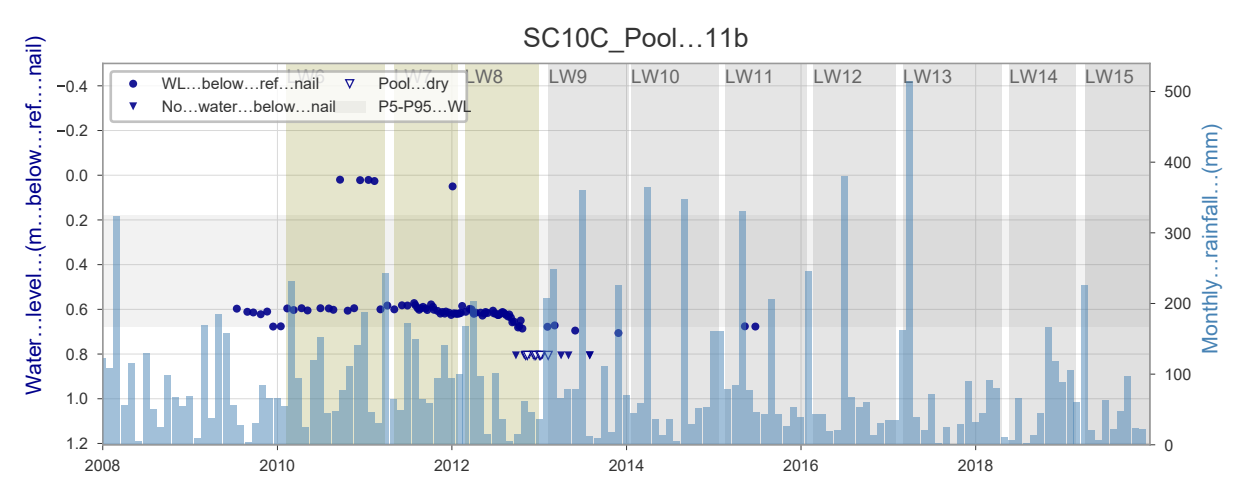

SC10C_Pool…10
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

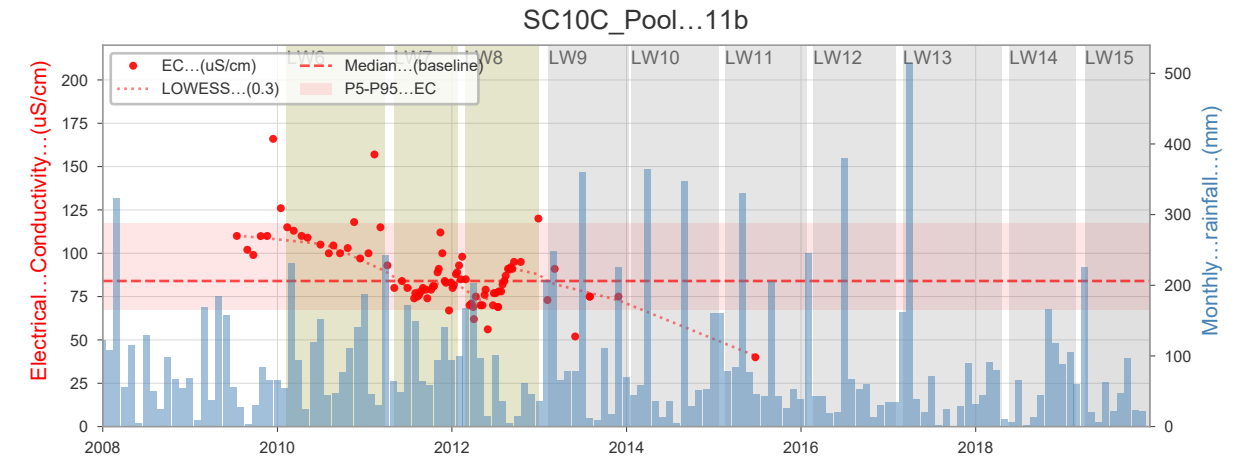

SC10C_Pool…11a
WL…below…ref…nail
No…water…below…nail
Pool…dry
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

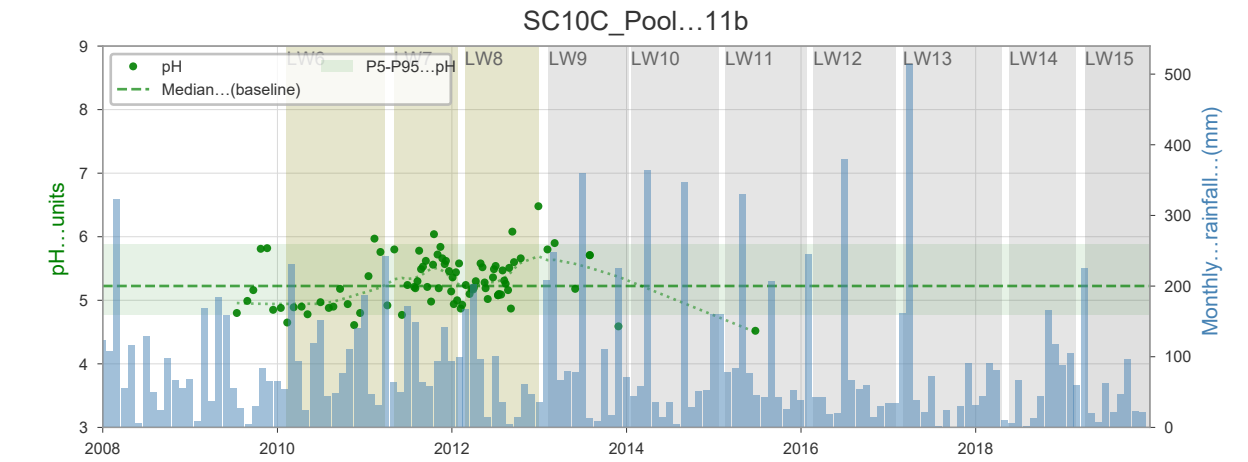

SC10C_Pool…11a
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

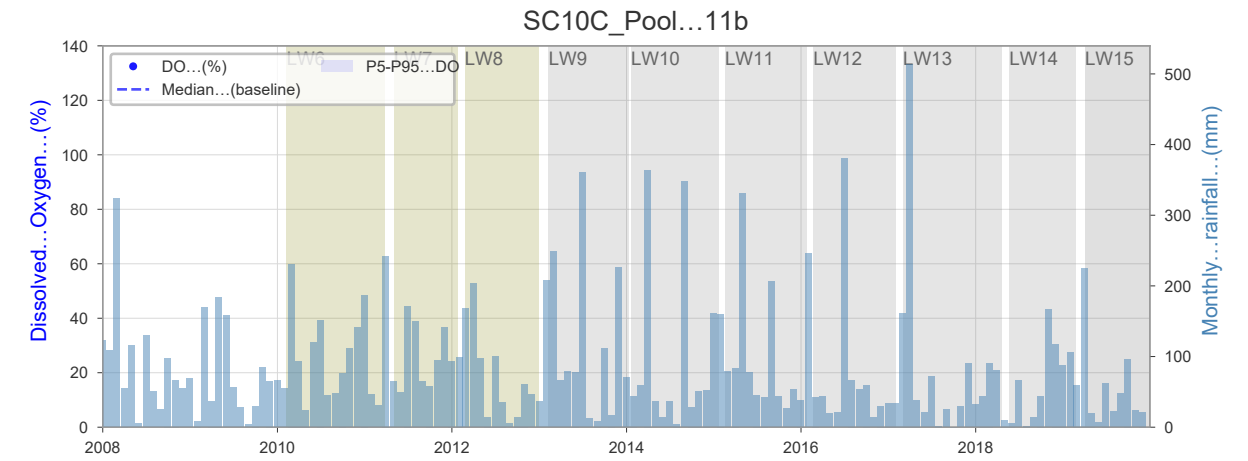

SC10C_Pool…11a
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

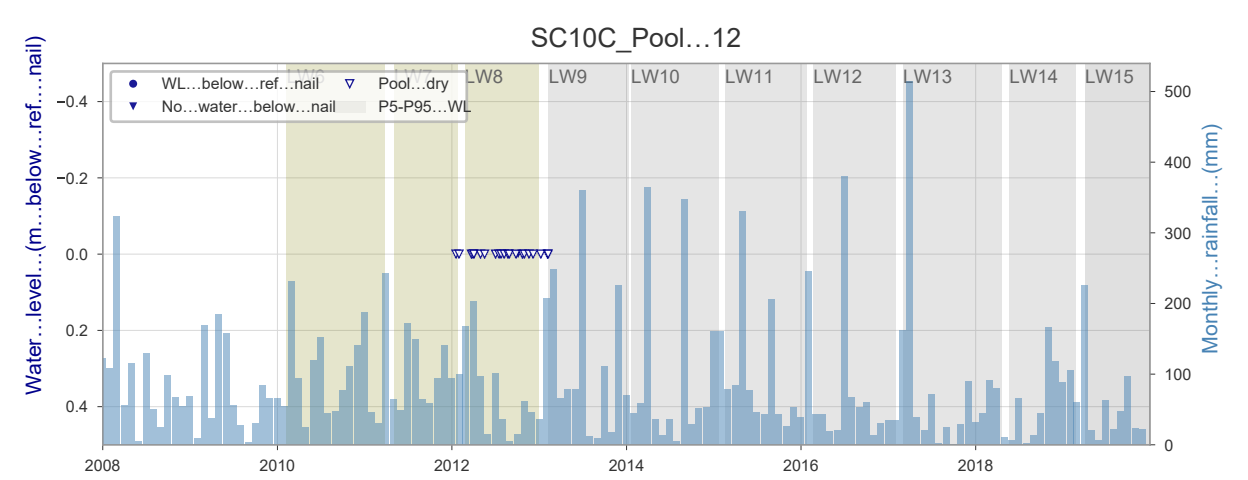

SC10C_Pool…11a
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

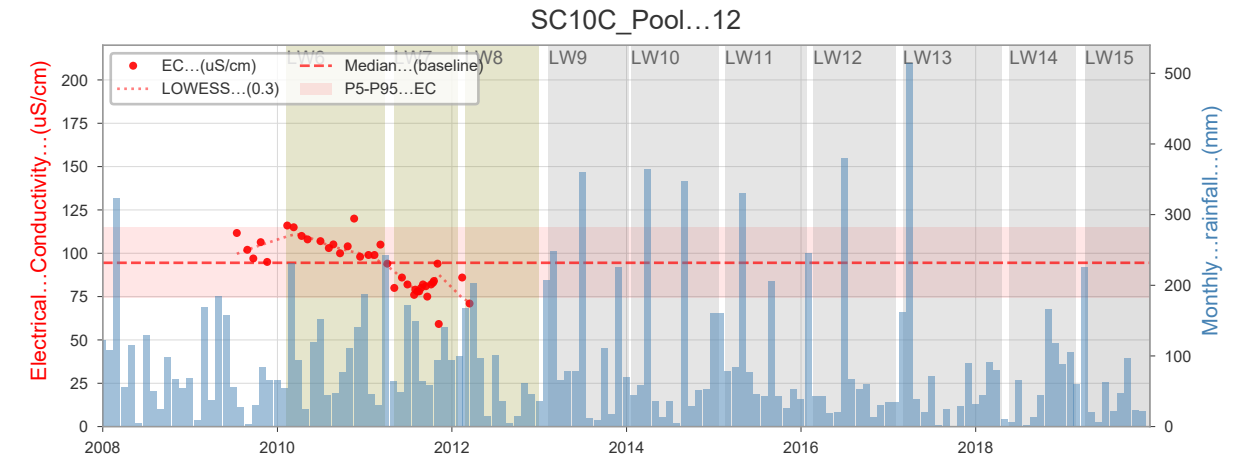

SC10C_Pool…11b
WL…below…ref…nail
No…water…below…nail
Pool…dry
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

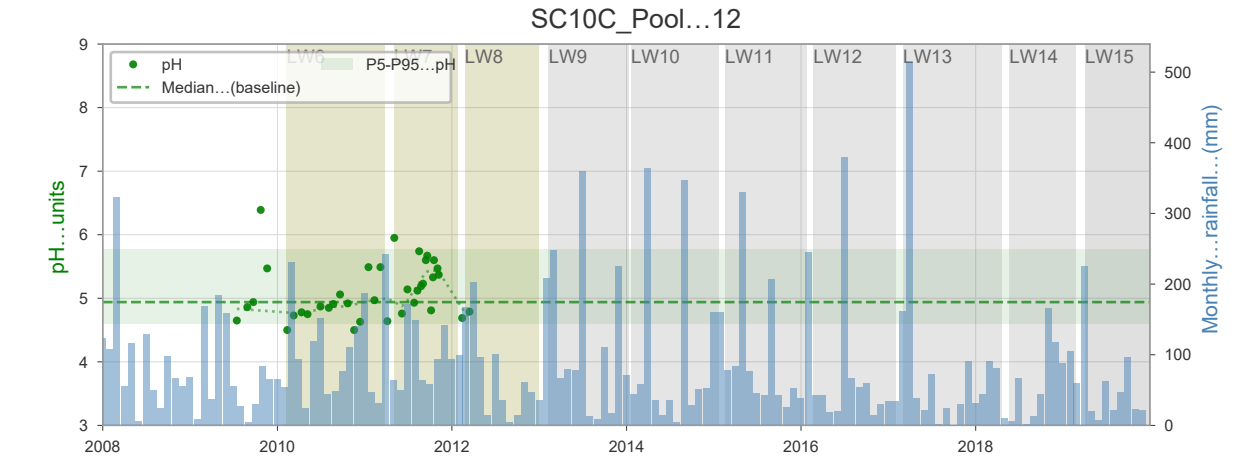

SC10C_Pool…11b
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

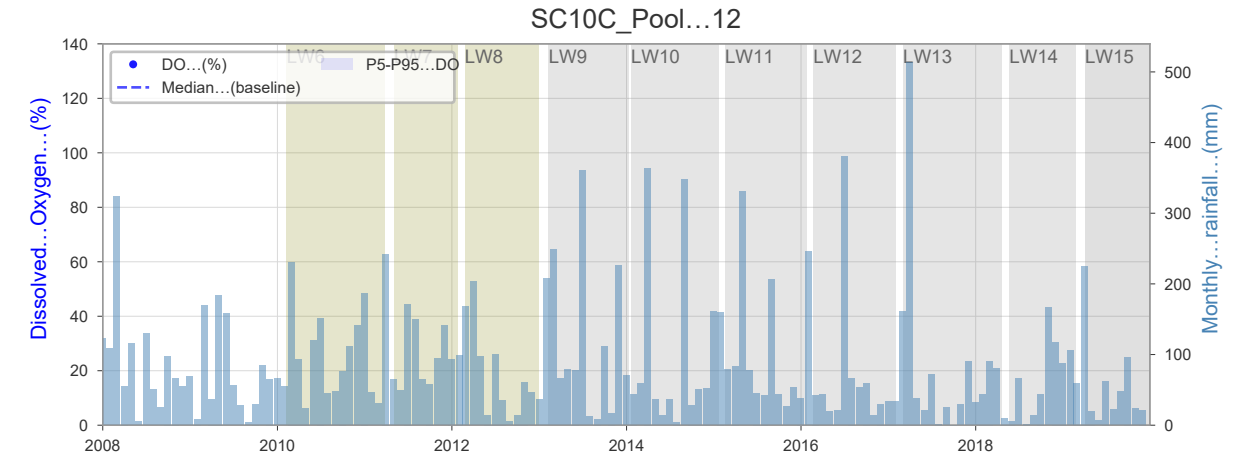

SC10C_Pool…11b
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

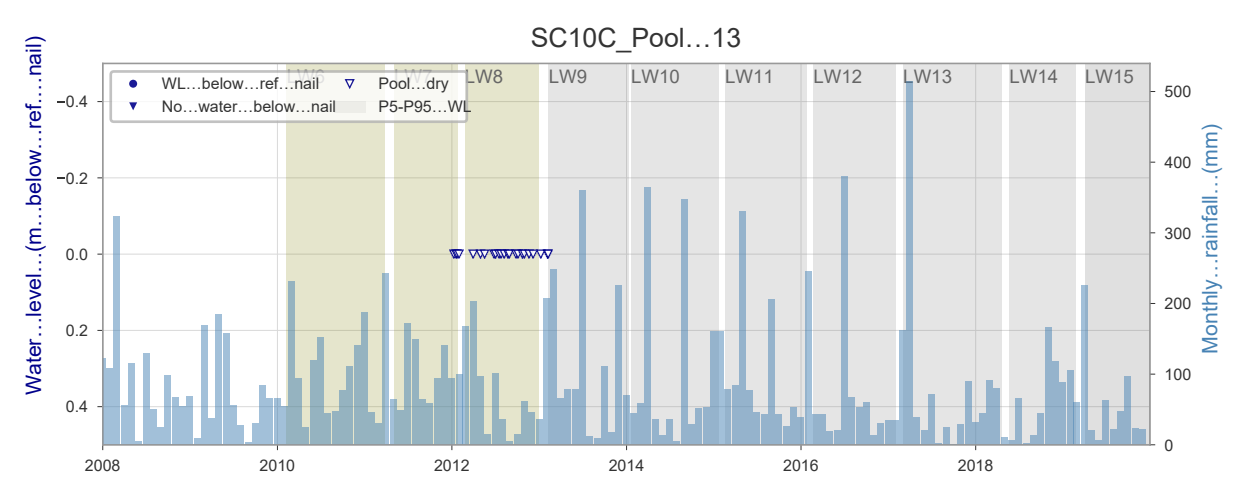

SC10C_Pool…11b
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

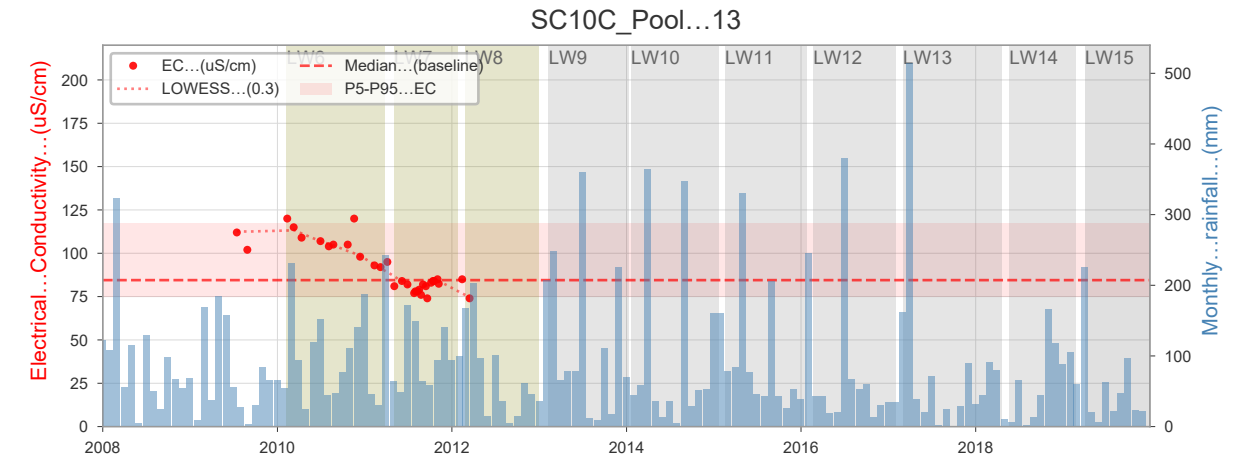

SC10C_Pool…12
WL…below…ref…nail
No…water…below…nail
Pool…dry
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

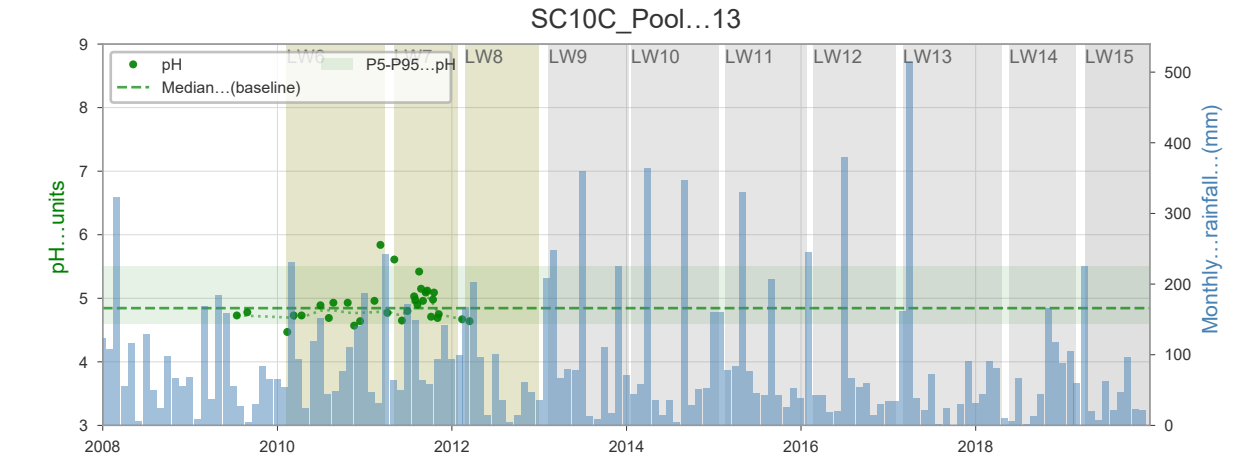

SC10C_Pool…12
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

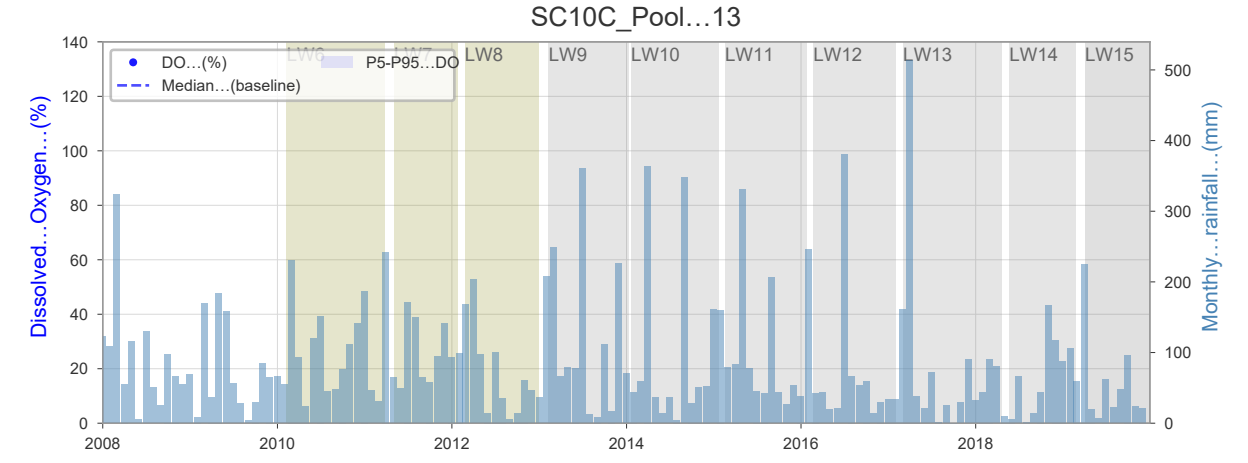

SC10C_Pool…12
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

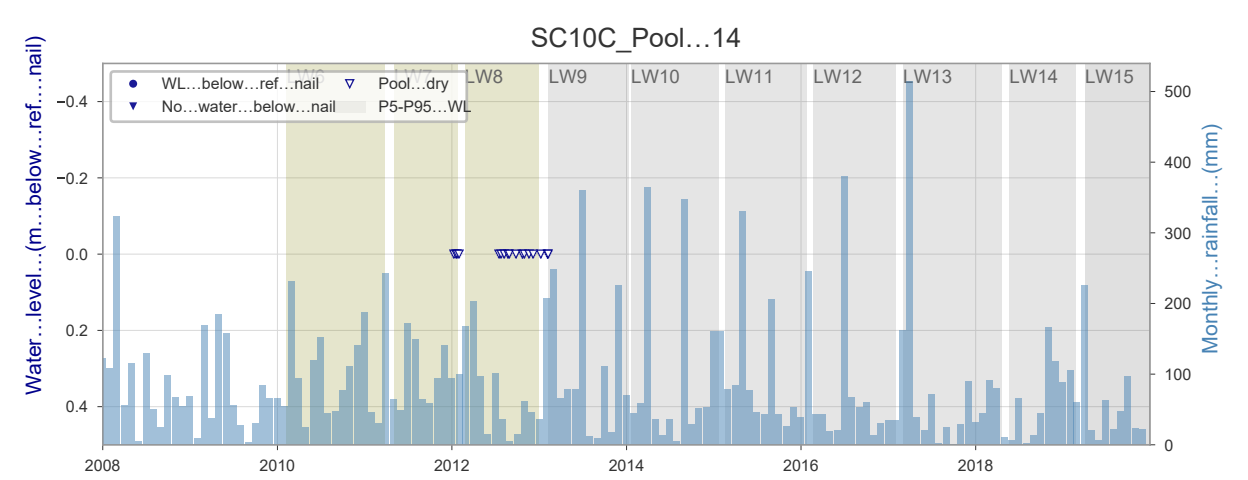

SC10C_Pool…12
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

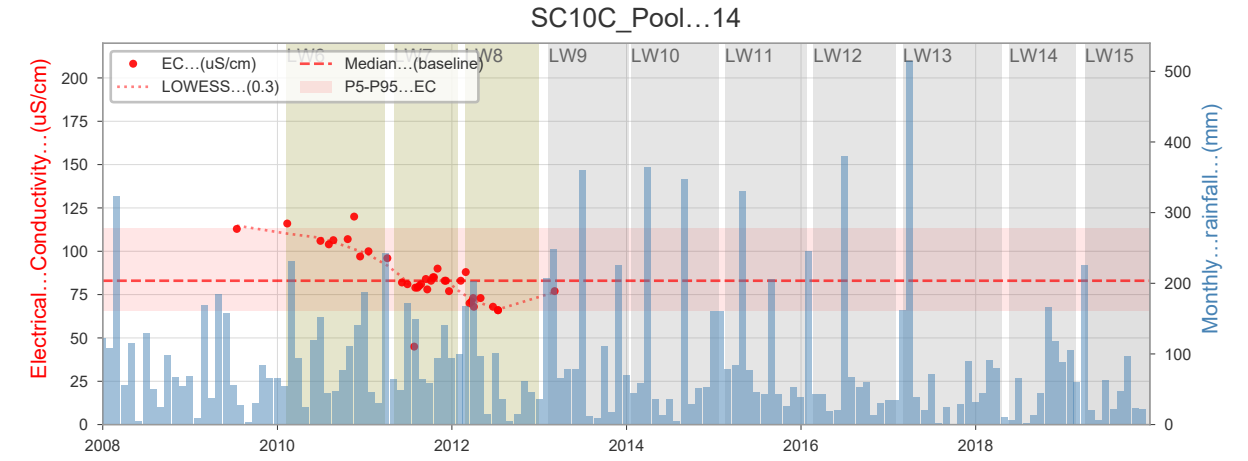

SC10C_Pool…13
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

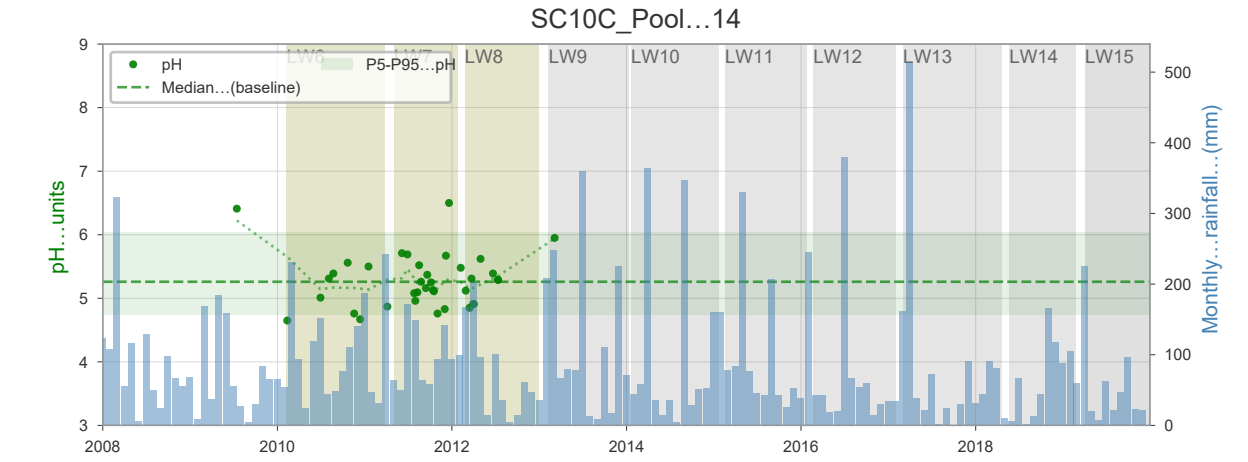

SC10C_Pool…13
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

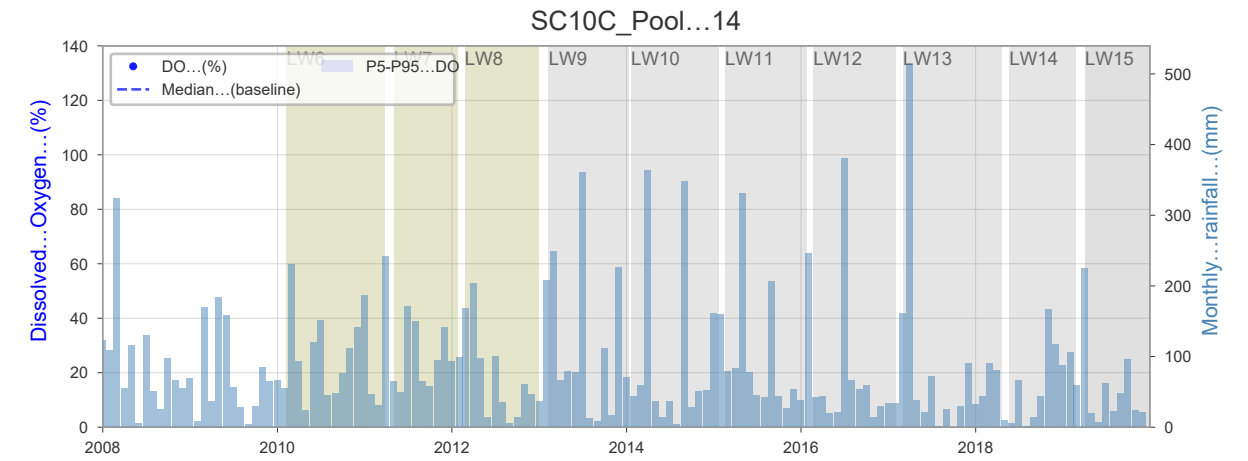

SC10C_Pool…13
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

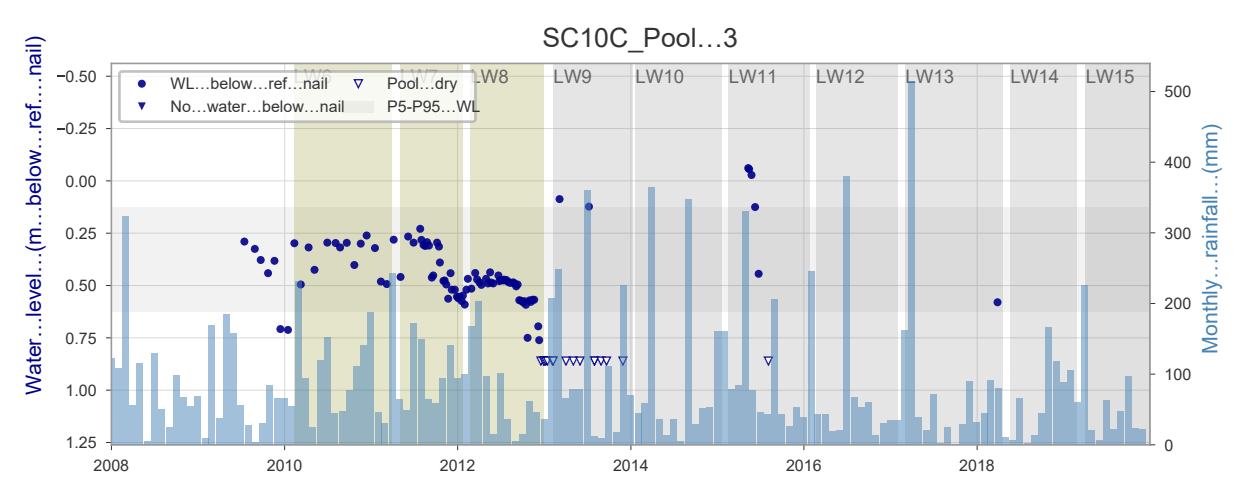

SC10C_Pool…13
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

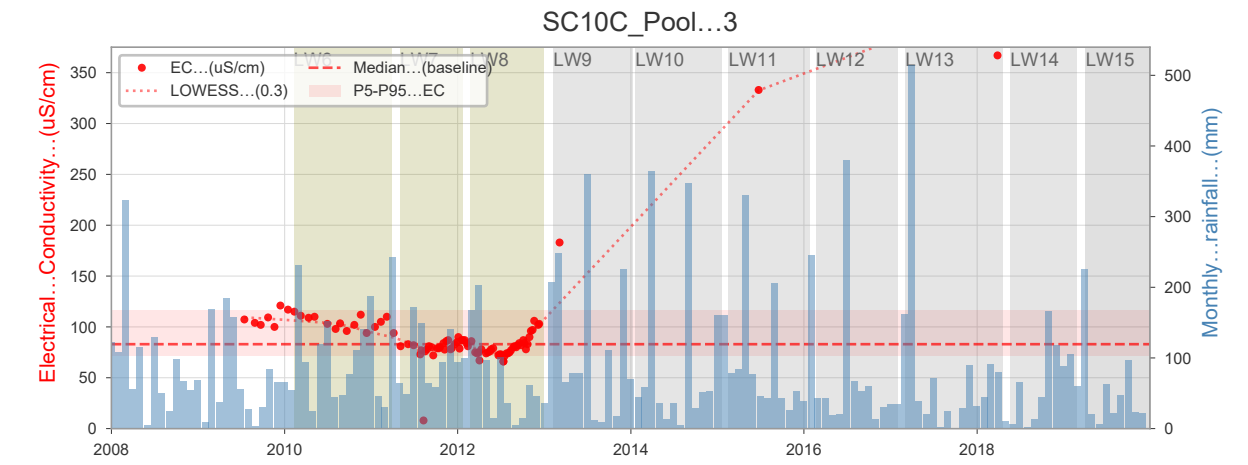

SC10C_Pool…14
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

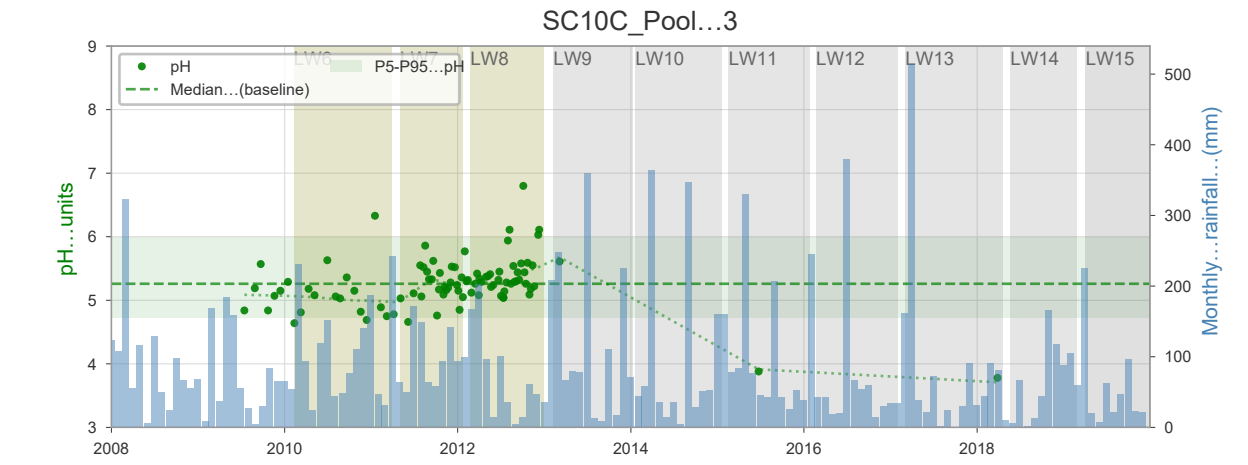

SC10C_Pool…14
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

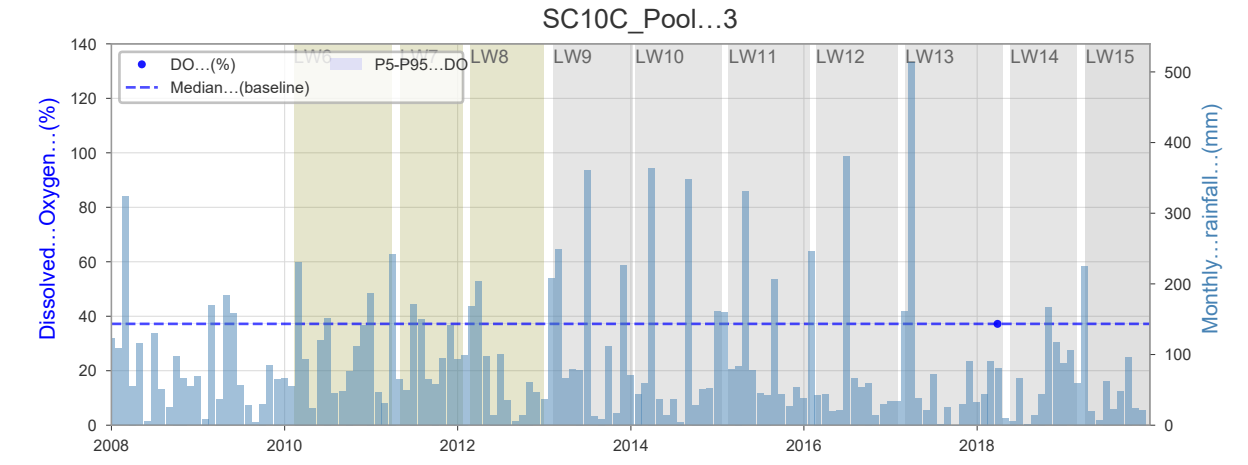

SC10C_Pool…14
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

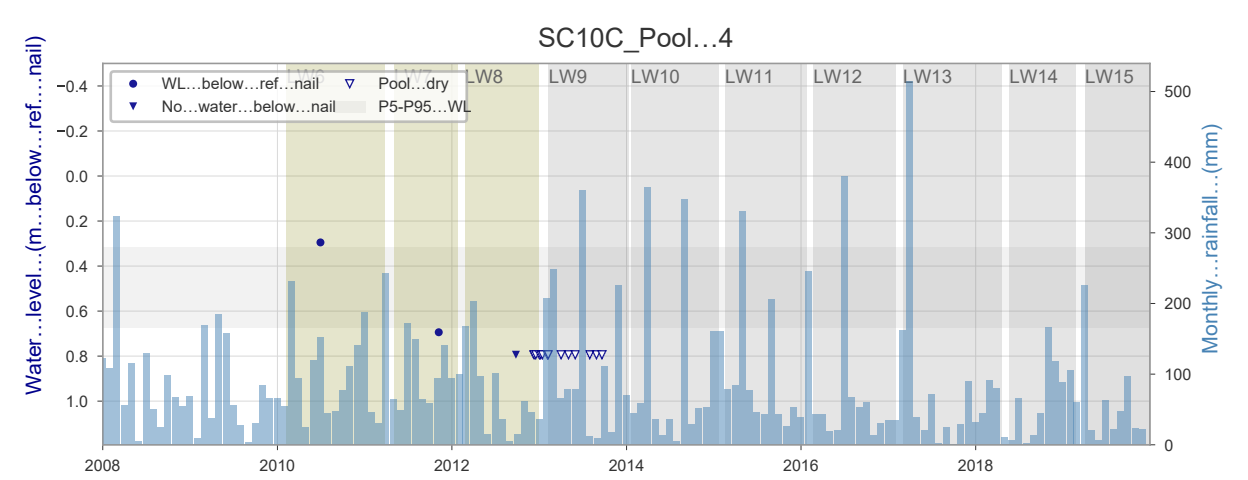

SC10C_Pool…14
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

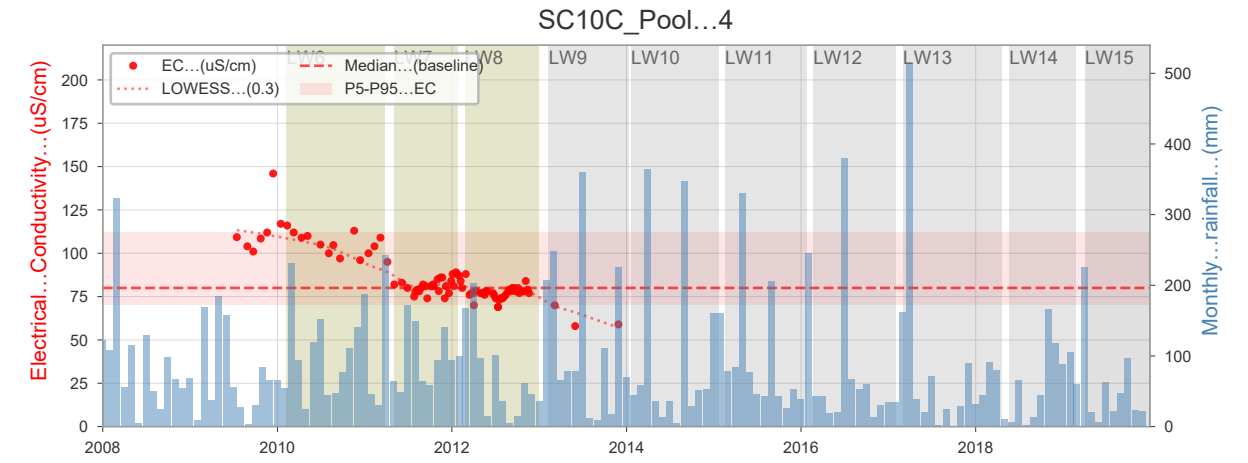

SC10C_Pool…3
WL…below…ref…nail
No…water…below…nail
Pool…dry
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….…nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

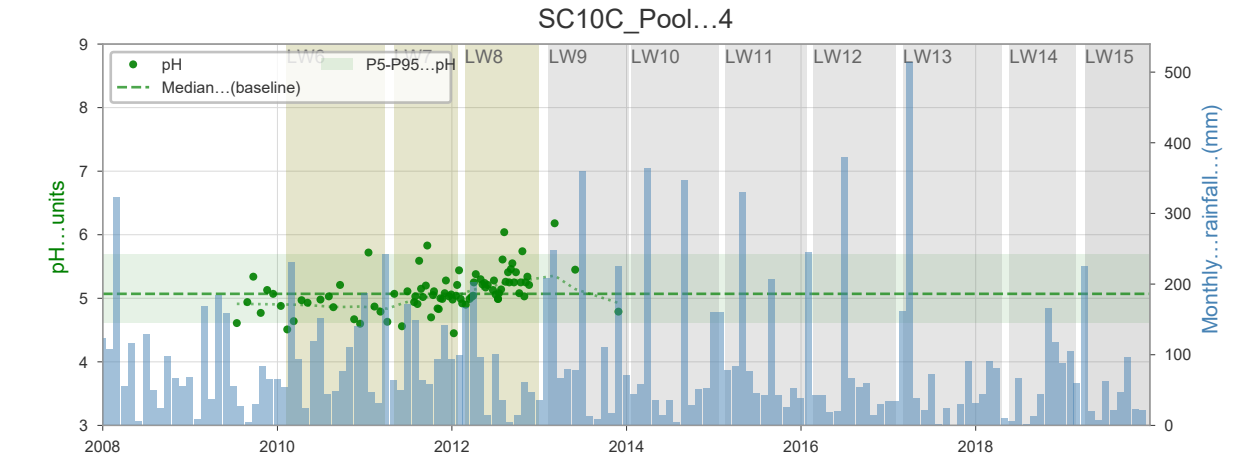

SC10C_Pool…3
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

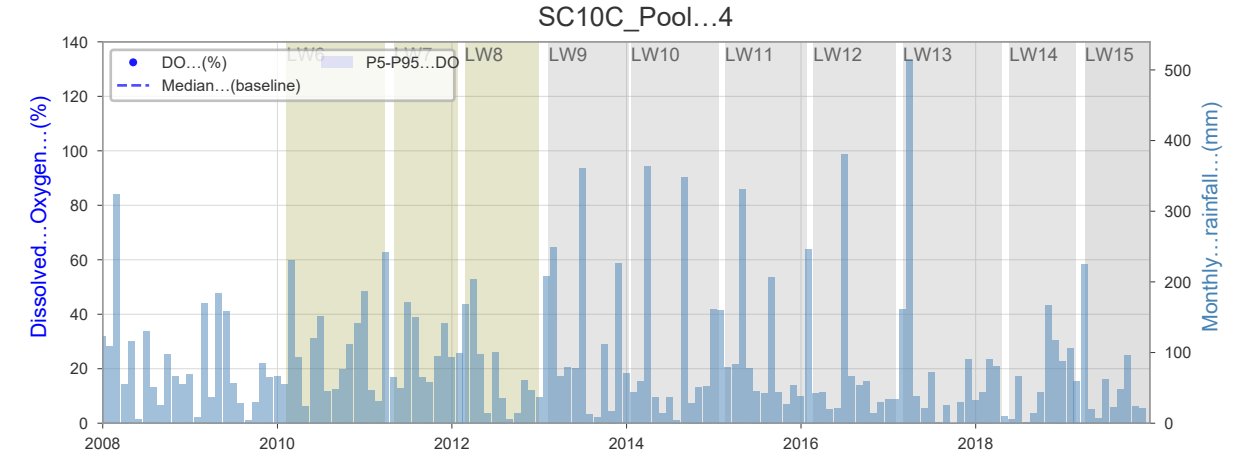

SC10C_Pool…3
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

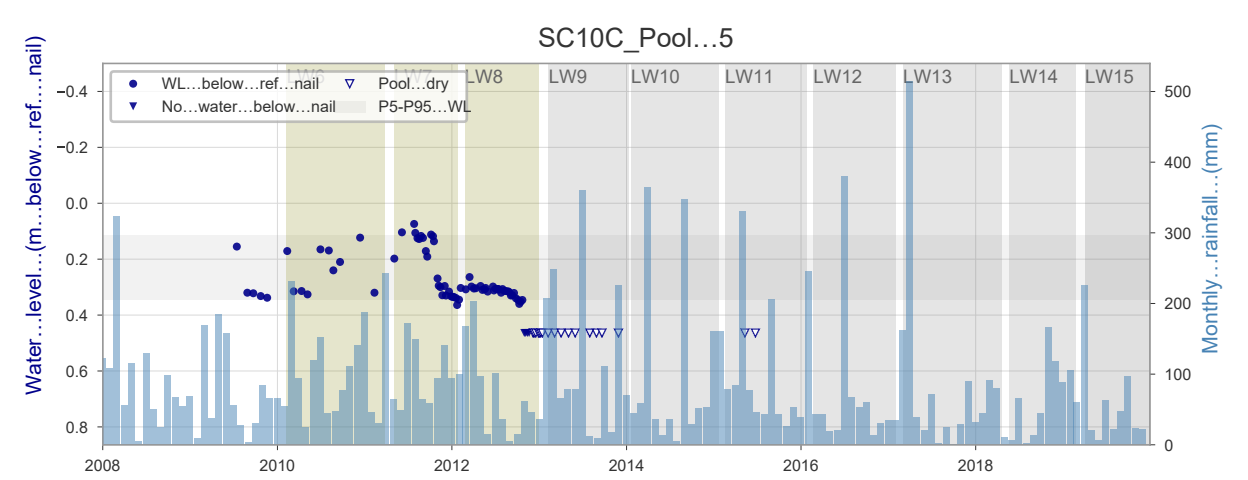

SC10C_Pool…3
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

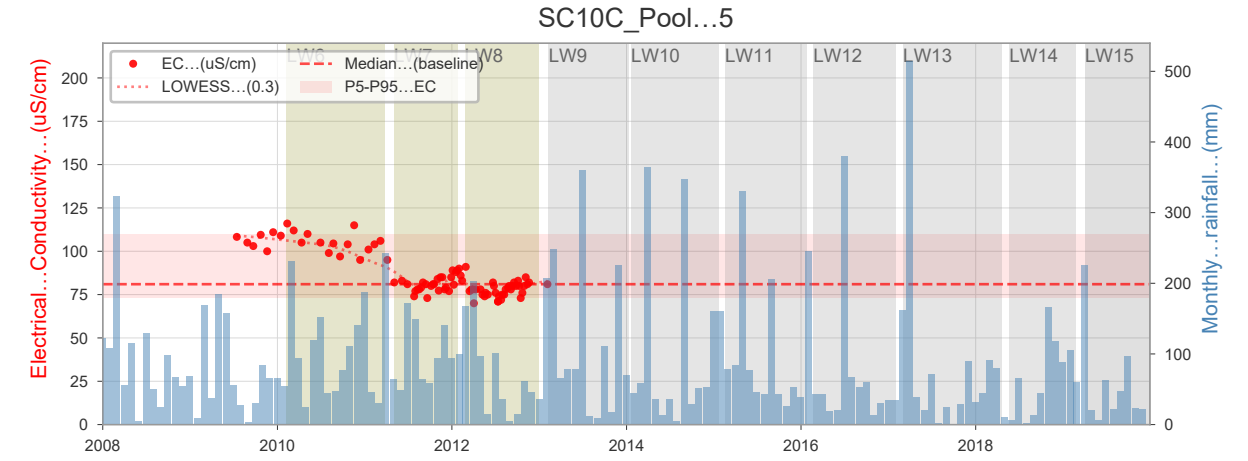

SC10C_Pool…4
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref…nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

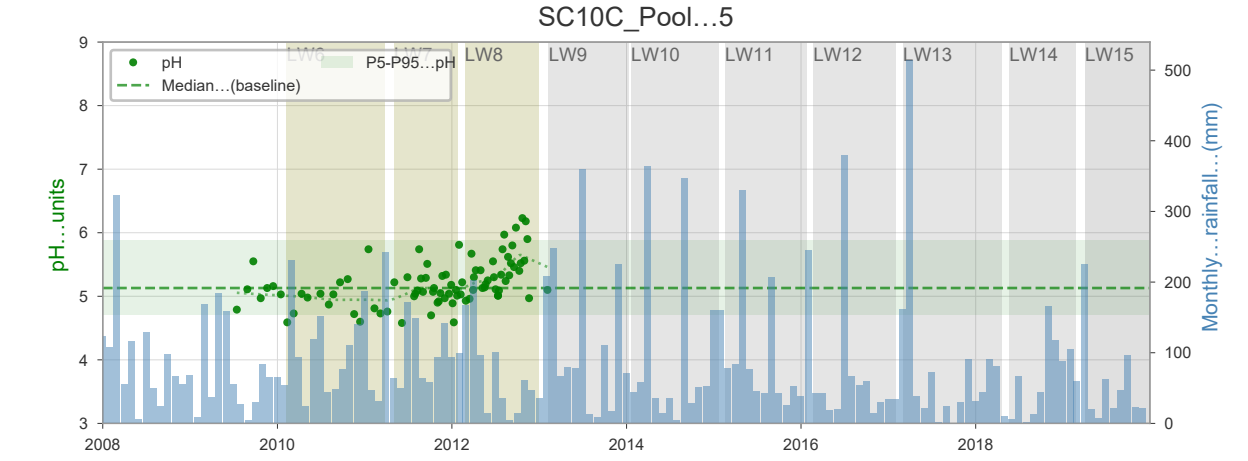

SC10C_Pool…4
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

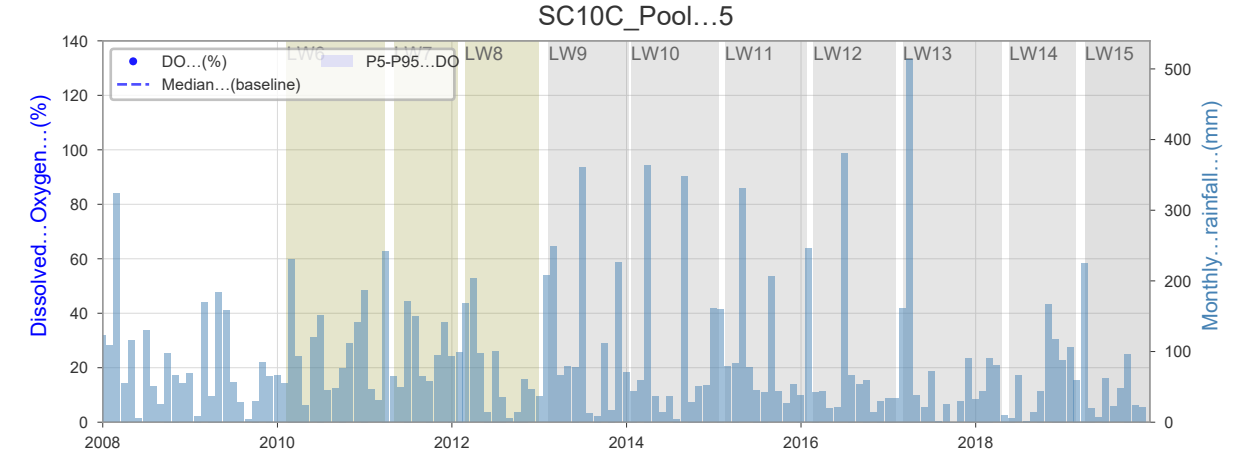

SC10C_Pool…4
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

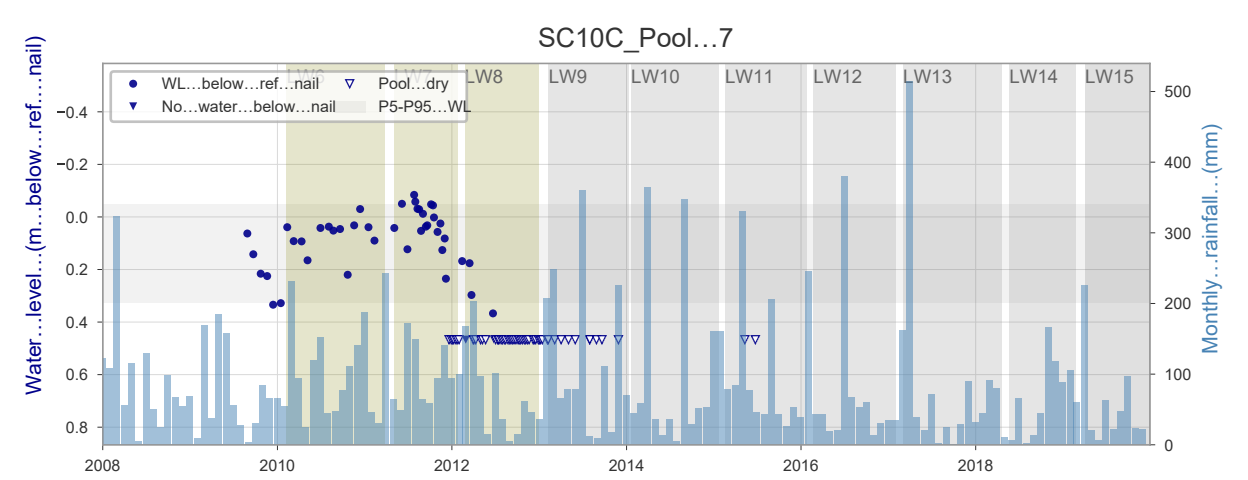

SC10C_Pool…4
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

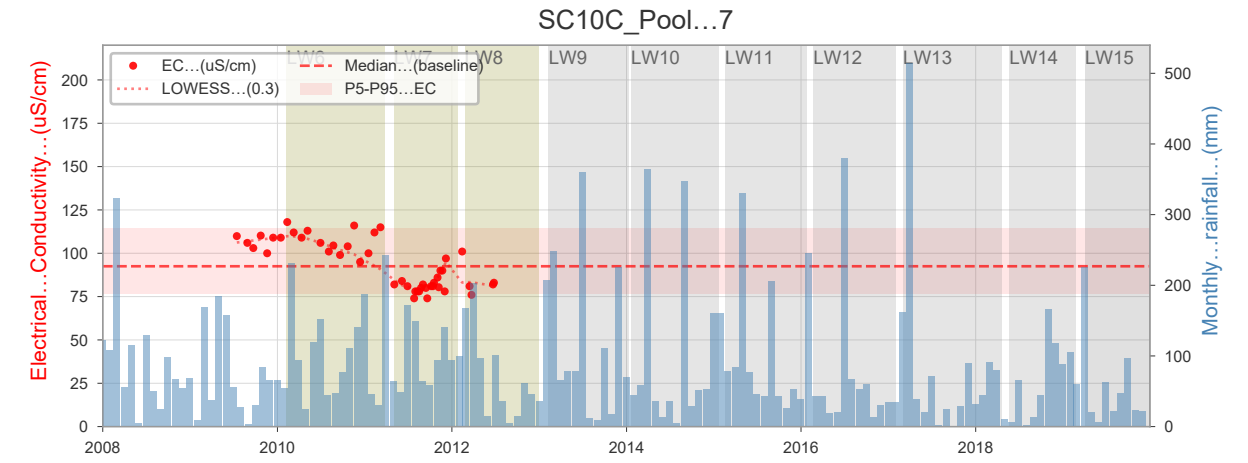

SC10C_Pool…5
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

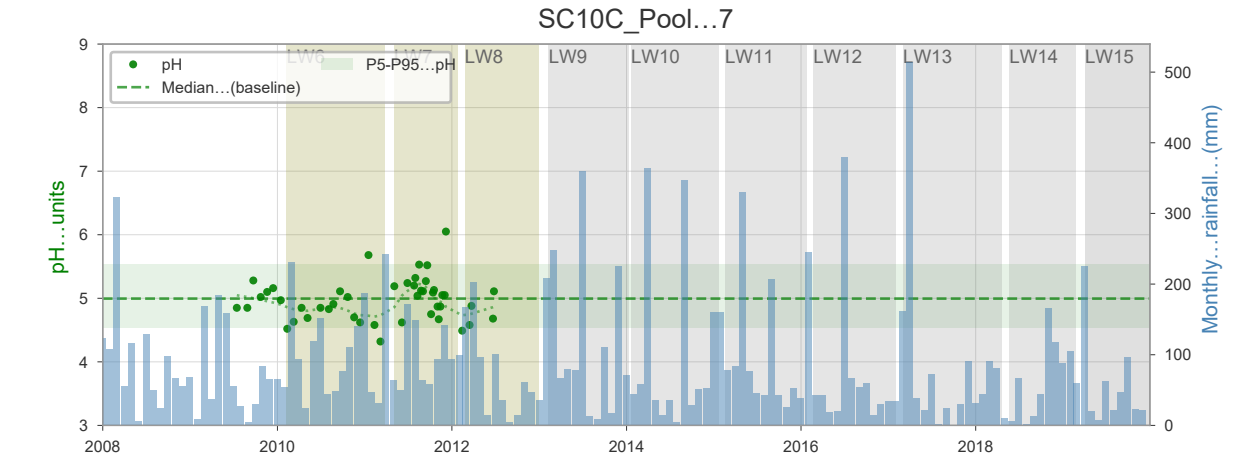

SC10C_Pool…5
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

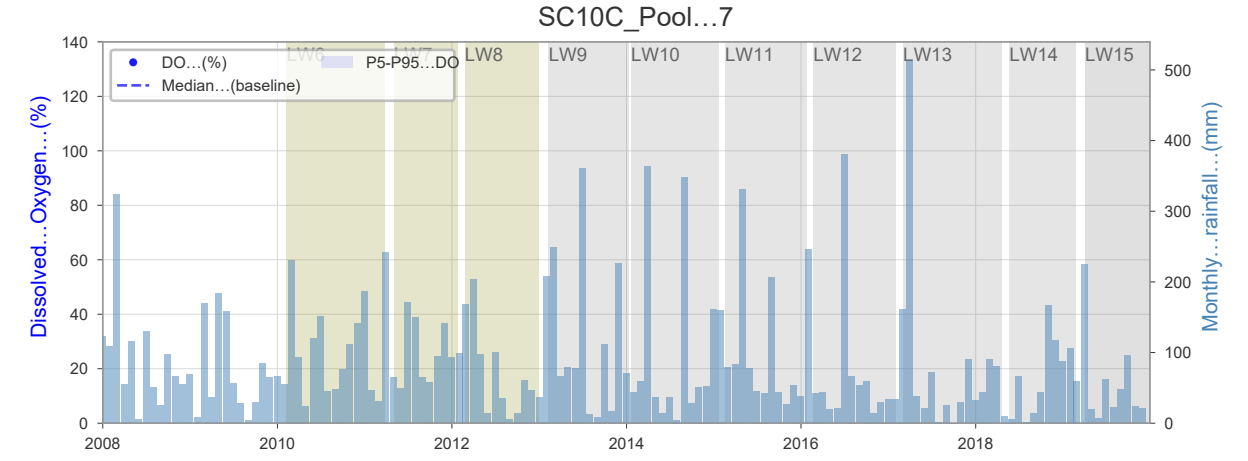

SC10C_Pool…5
pH…units
Monthly…rainfall…(mm)
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

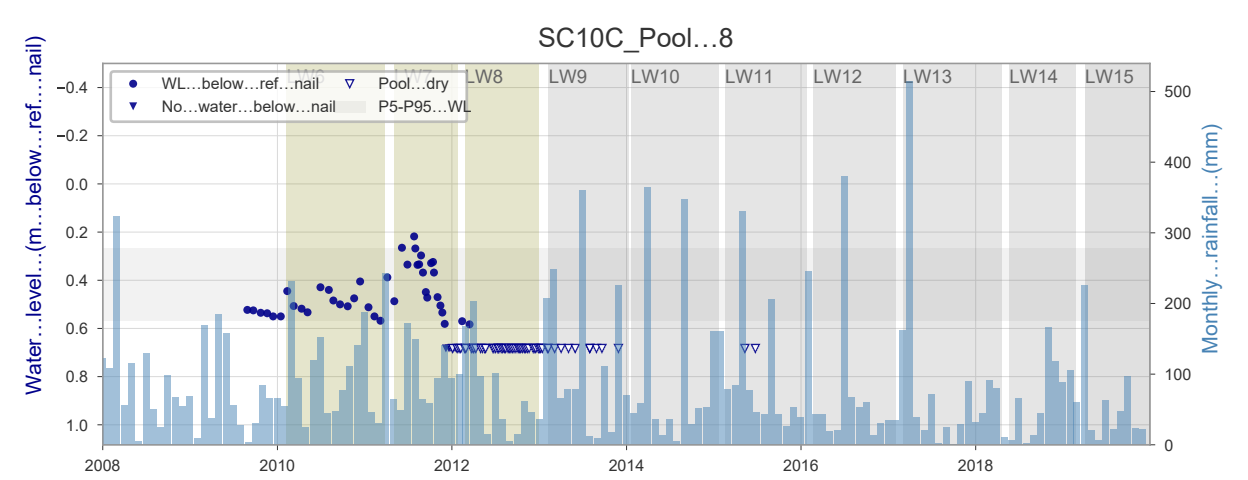

SC10C_Pool…5
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

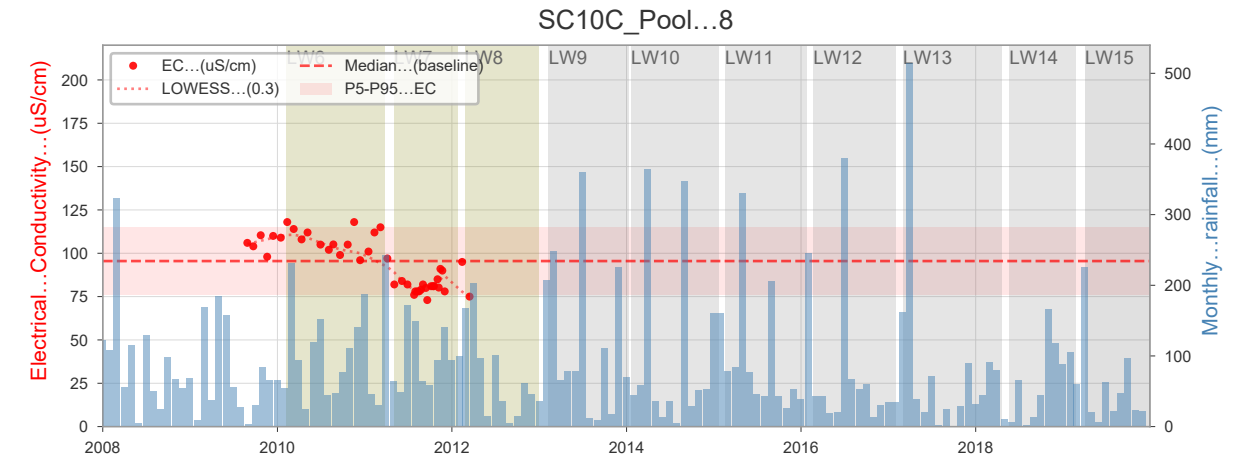

SC10C_Pool…7
WL…below…ref…nail
No…water…below…nail
Pool…dry
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

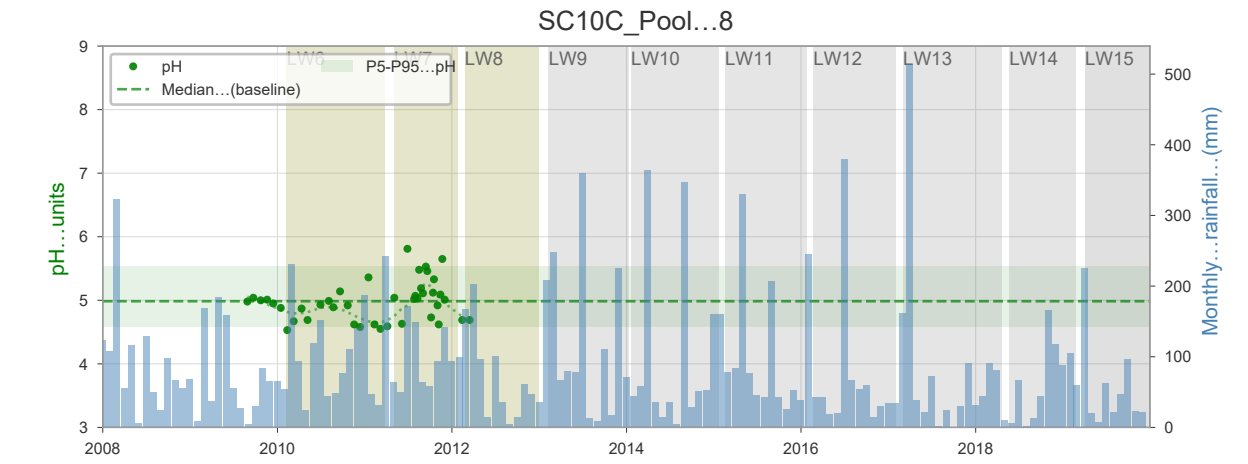

SC10C_Pool…7
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

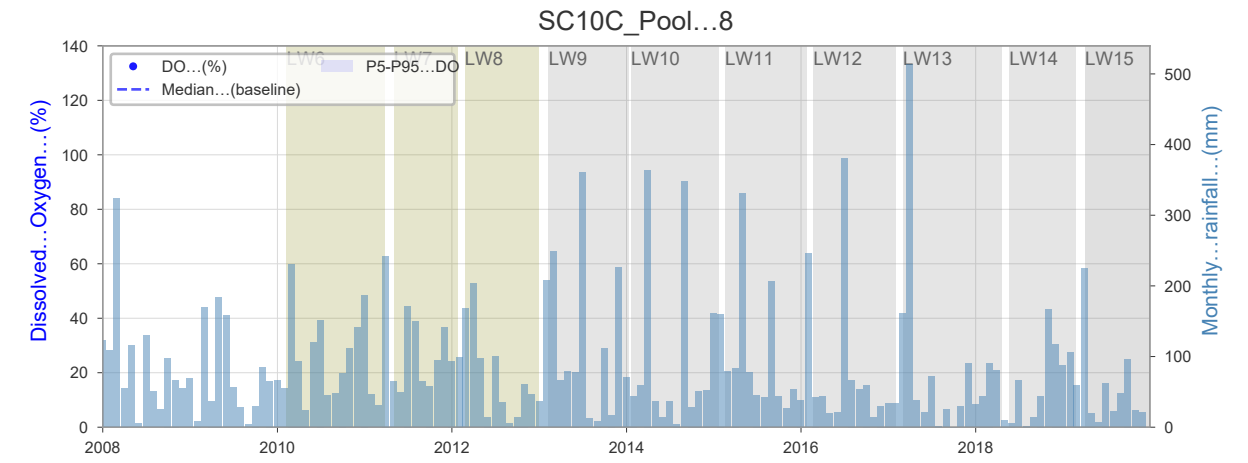

SC10C_Pool…7
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

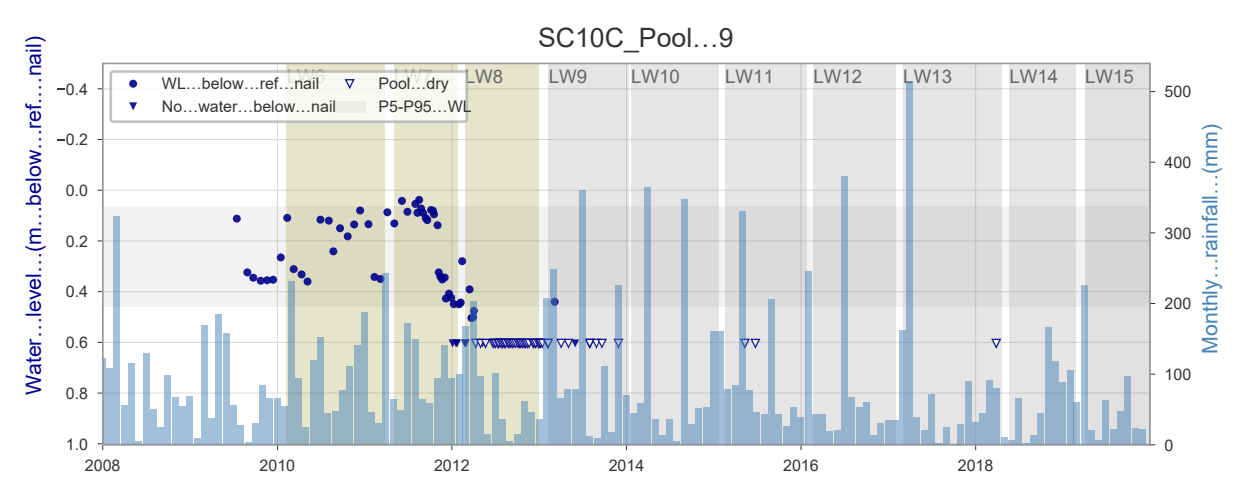

SC10C_Pool…7
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

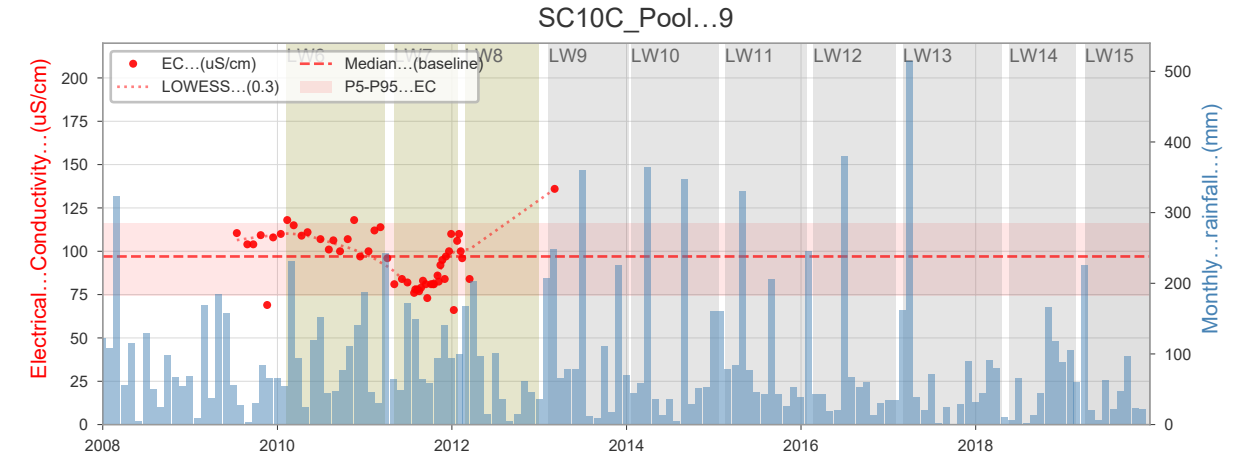

SC10C_Pool…8
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

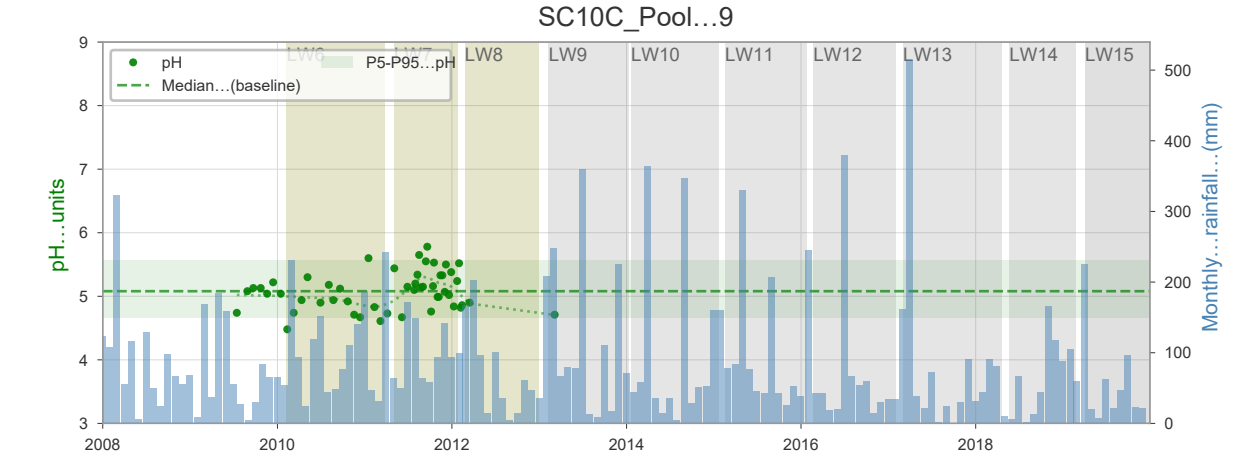

SC10C_Pool…8
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

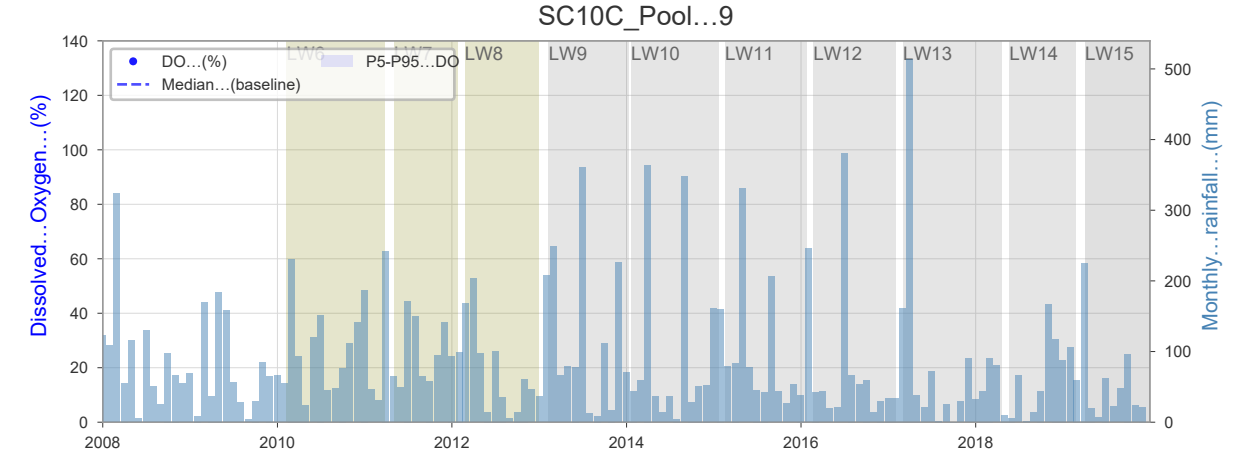

SC10C_Pool…8
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

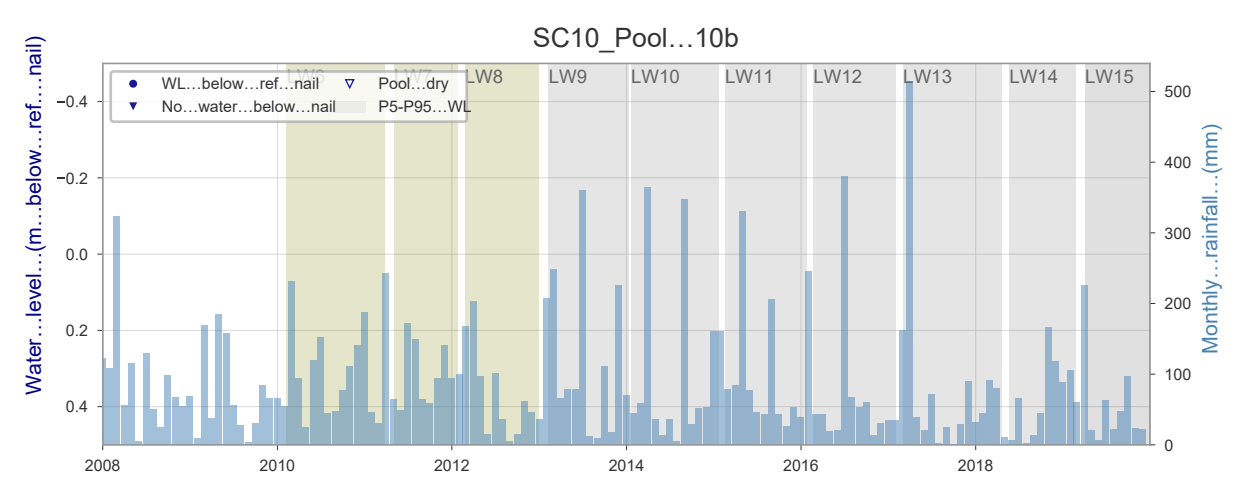

SC10C_Pool…8
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

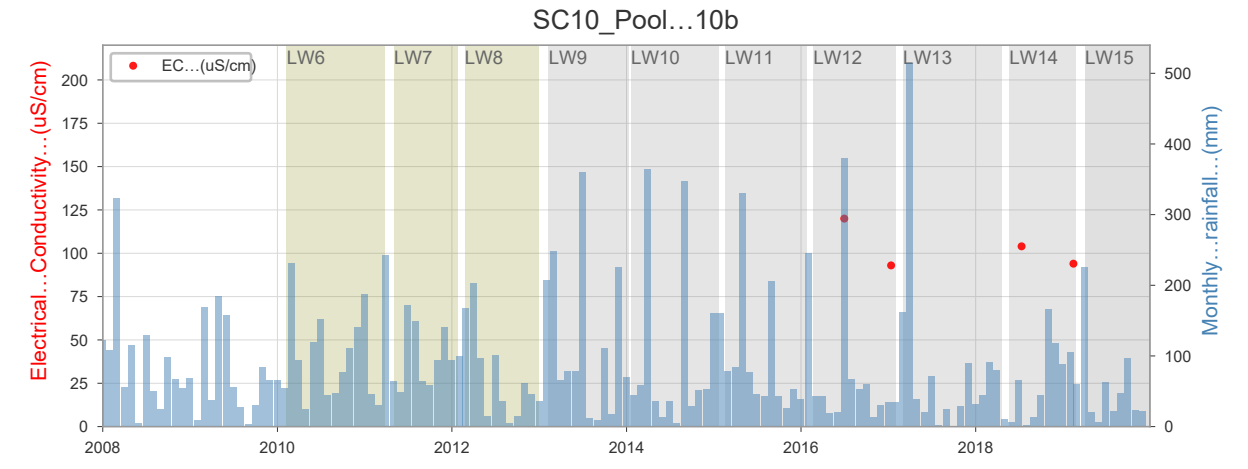

SC10C_Pool…9
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

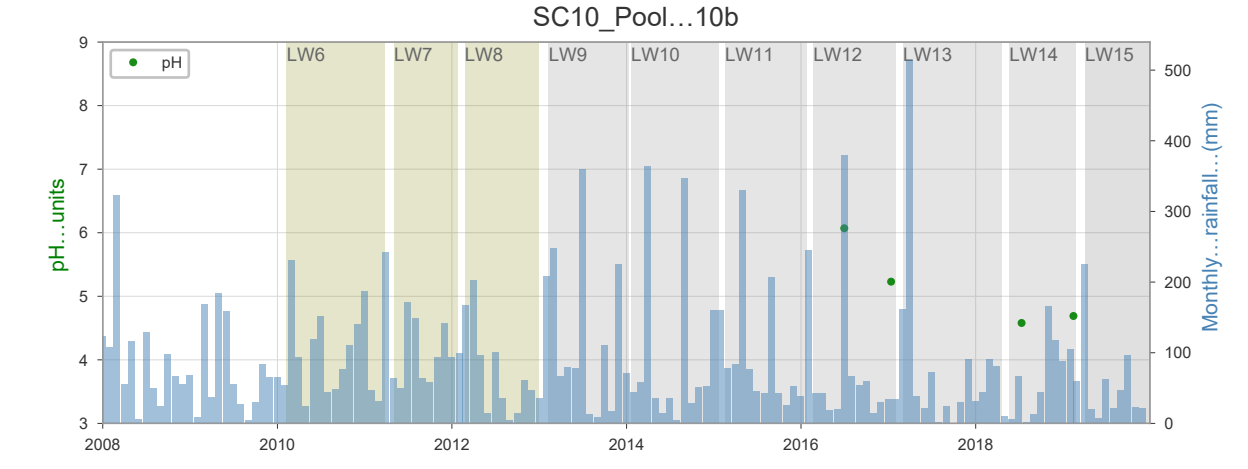

SC10C_Pool…9
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

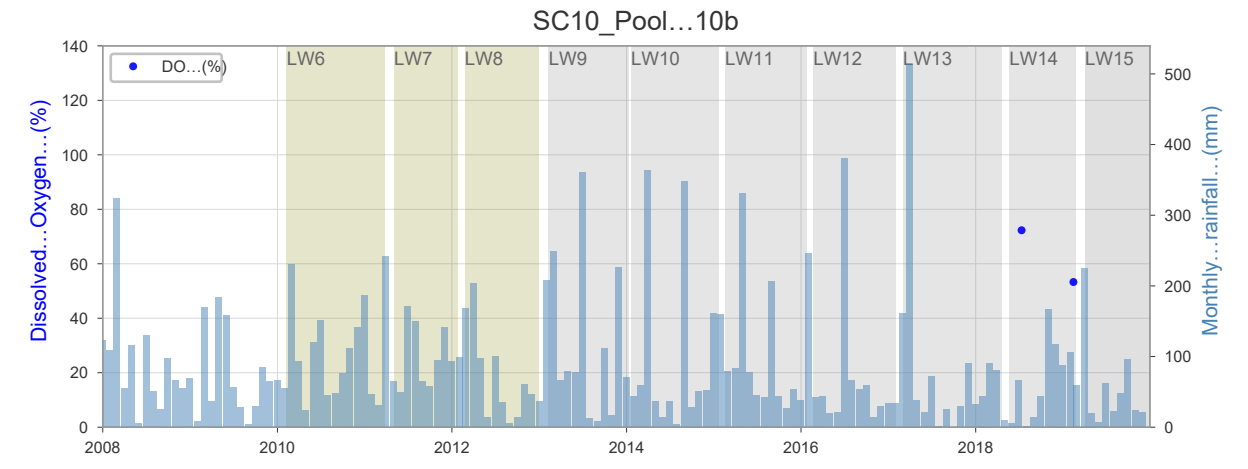

SC10C_Pool…9
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

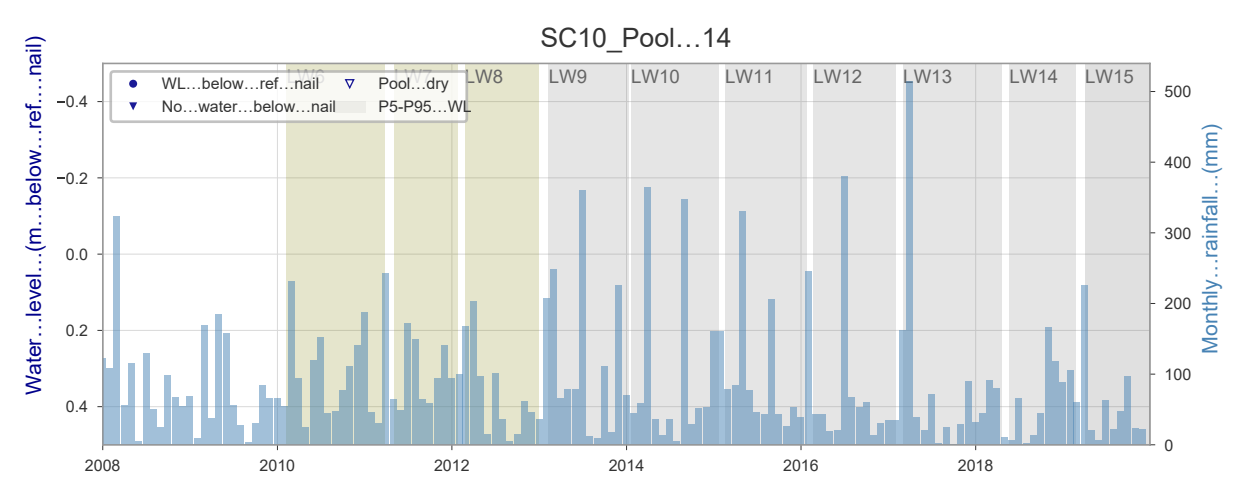

SC10C_Pool…9
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

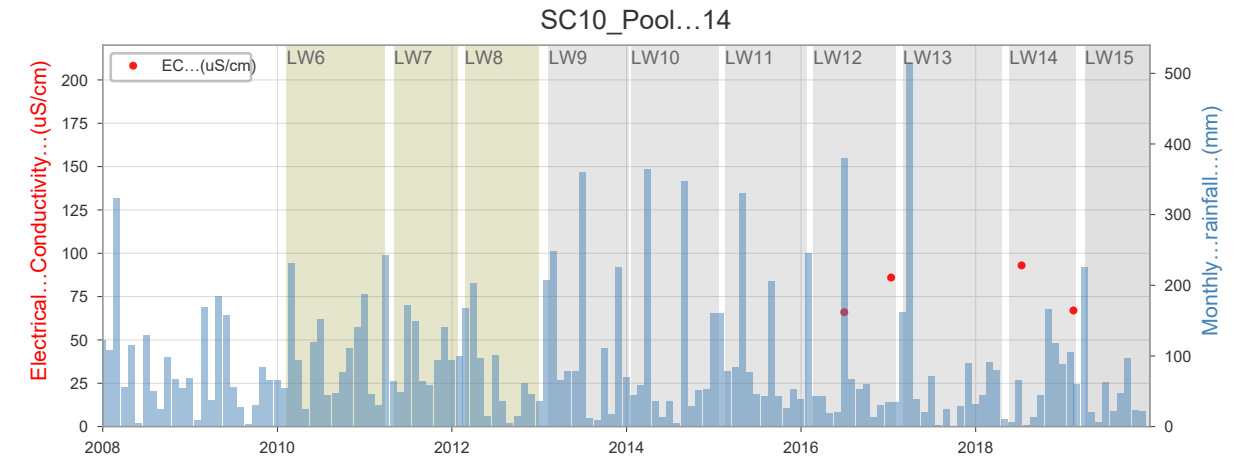

SC10_Pool…10b
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….…nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

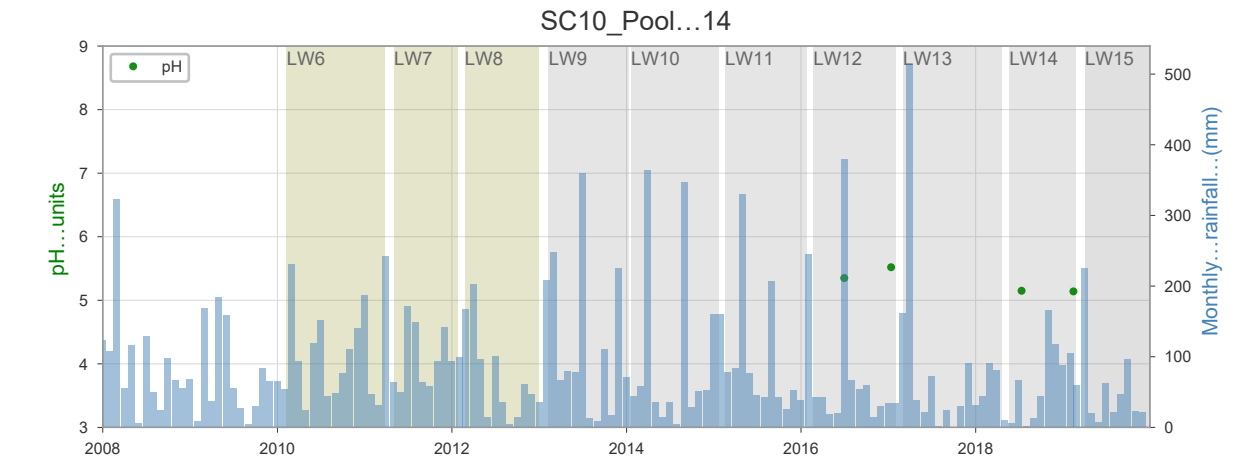

SC10_Pool…10b
EC…(uS/cm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

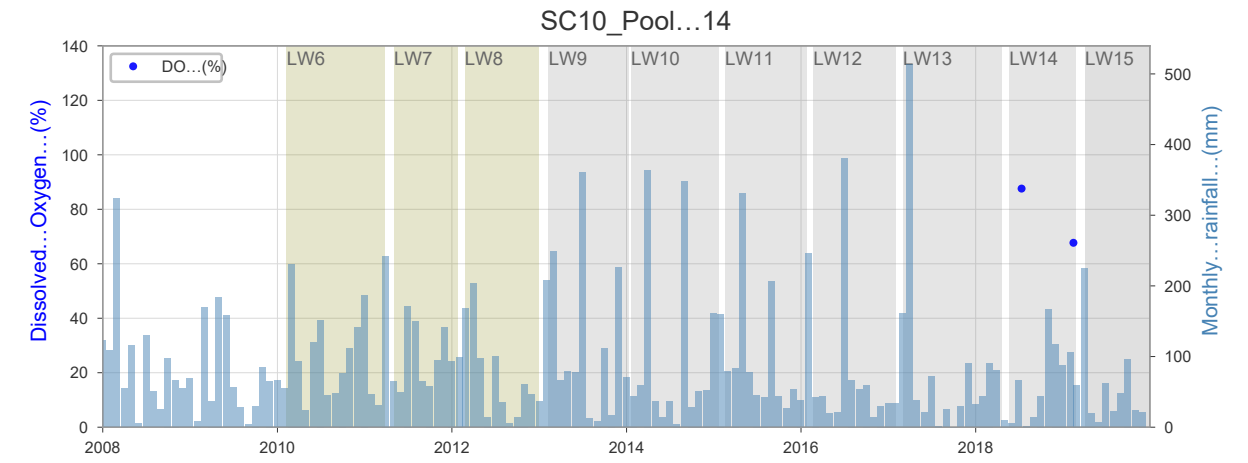

SC10_Pool…10b
pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

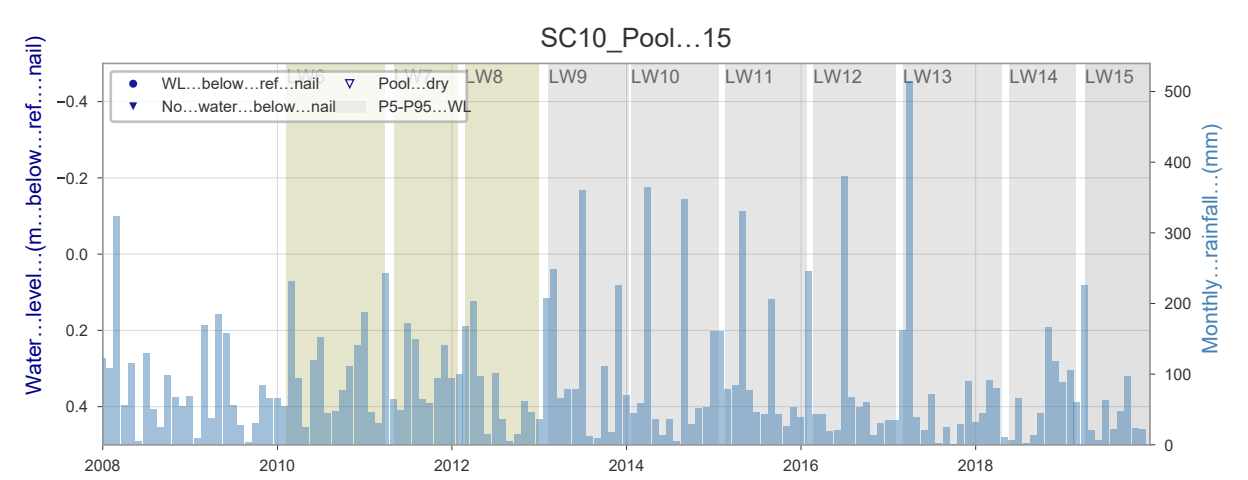

SC10_Pool…10b
DO…(%)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

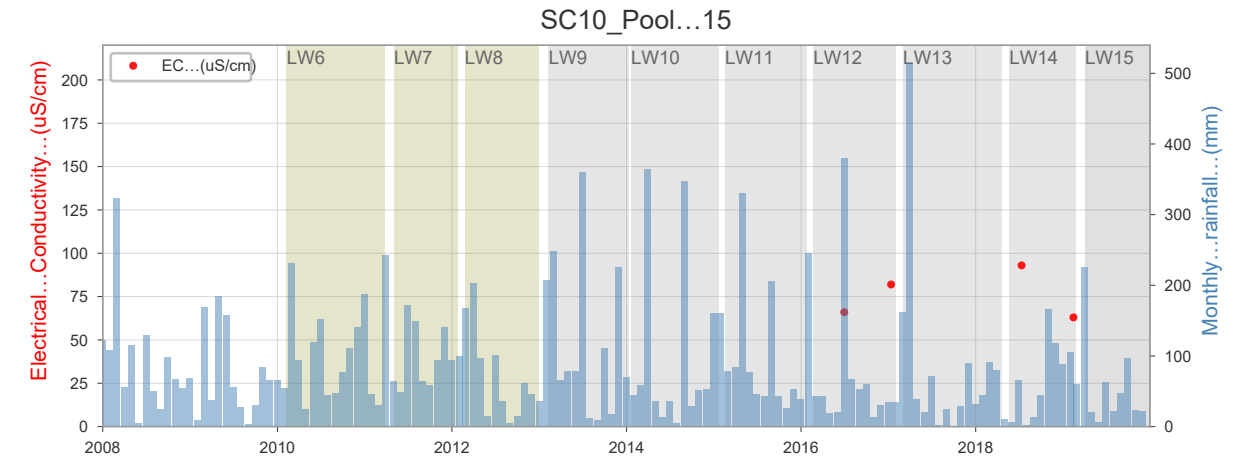

SC10_Pool…14
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

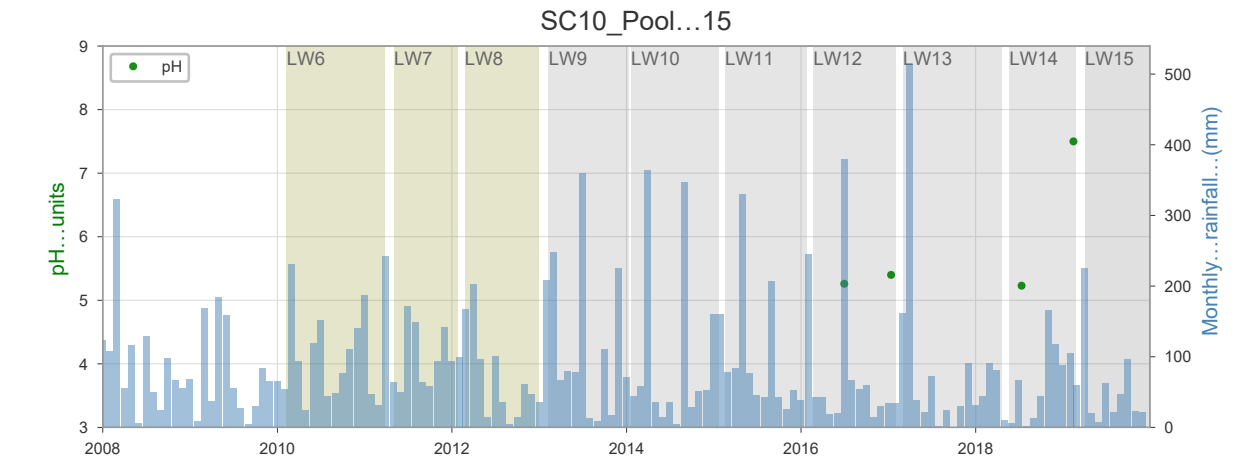

SC10_Pool…14
EC…(uS/cm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

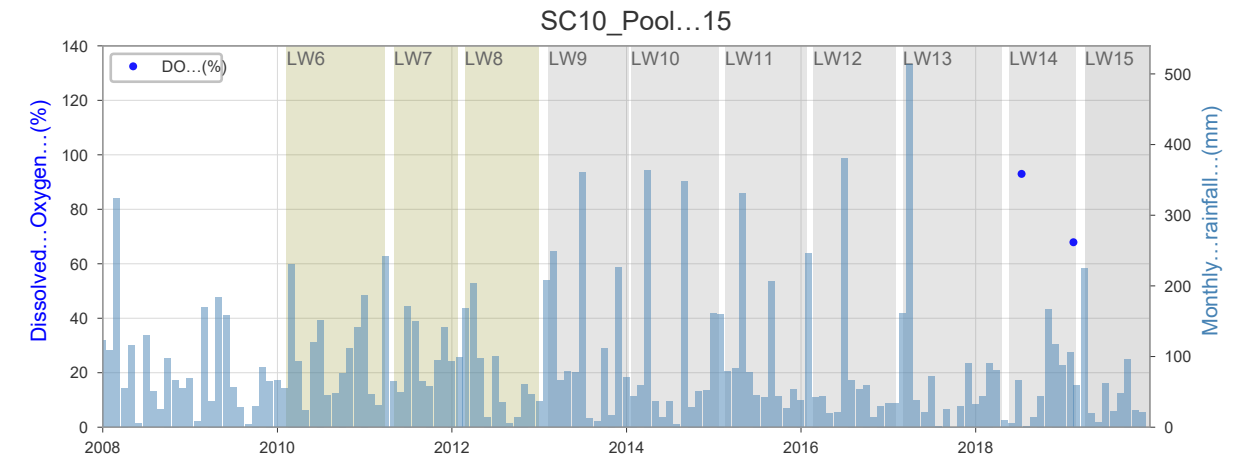

SC10_Pool…14
pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

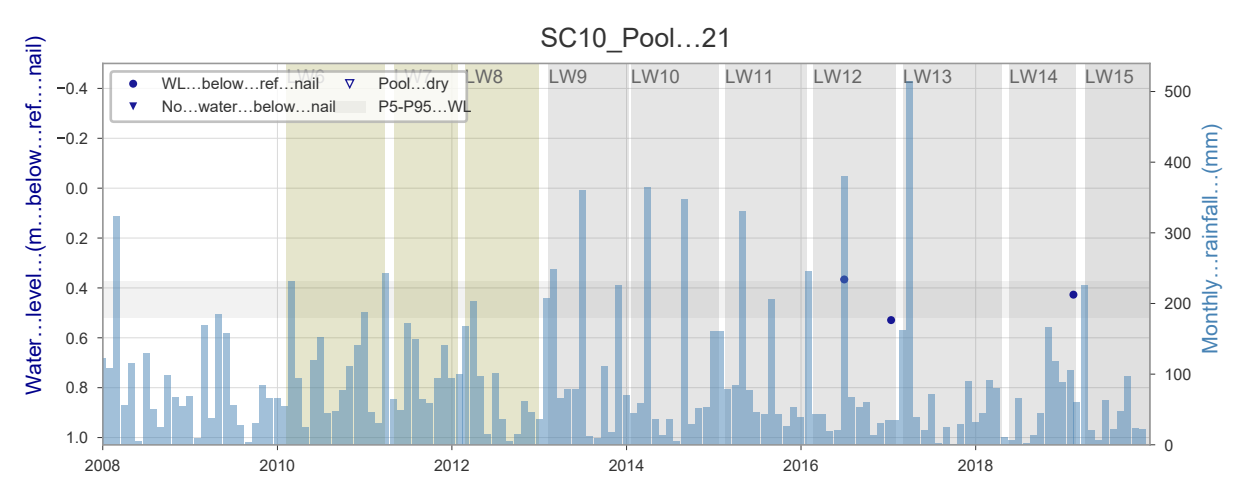

SC10_Pool…14
DO…(%)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

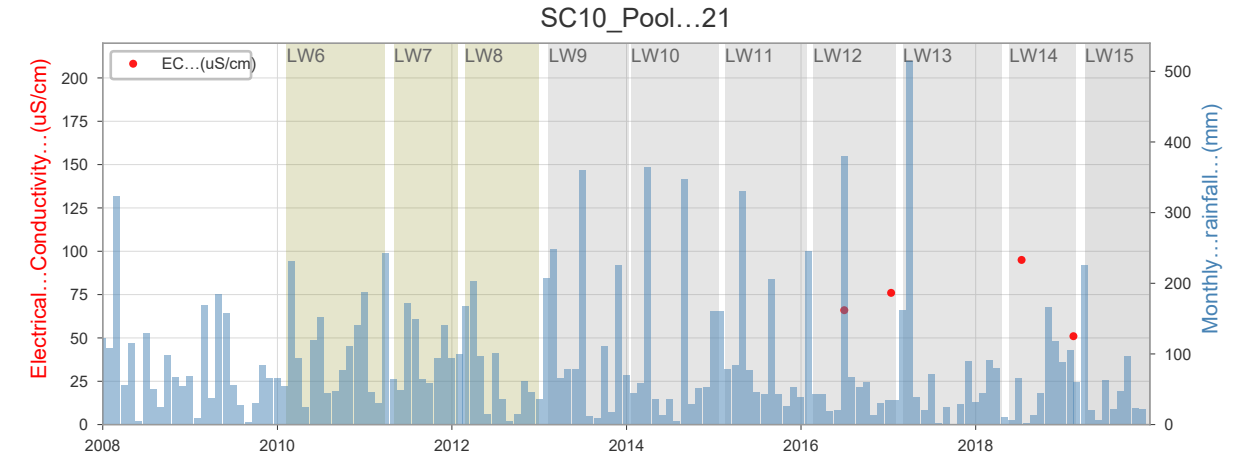

SC10_Pool…15
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

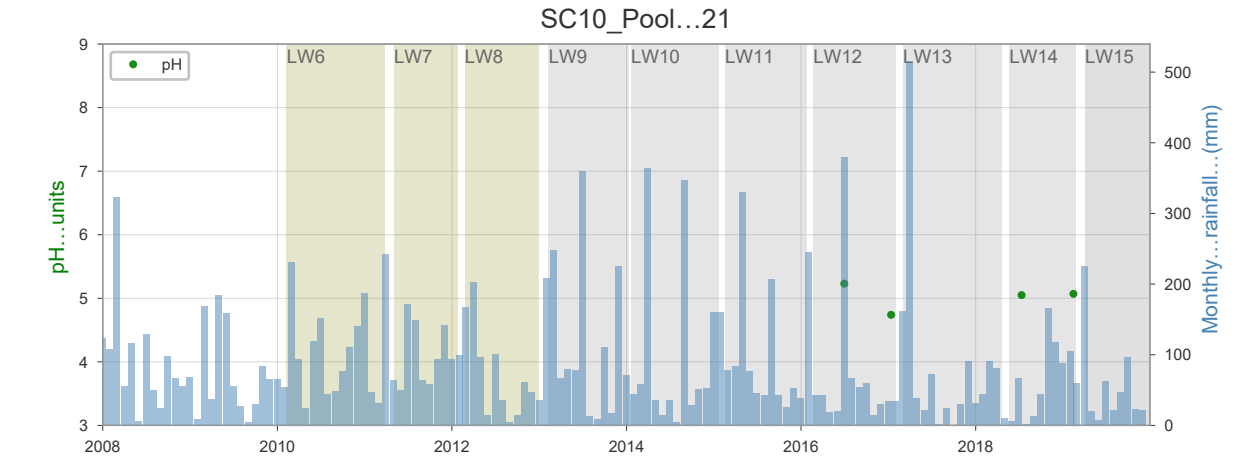

SC10_Pool…15
EC…(uS/cm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

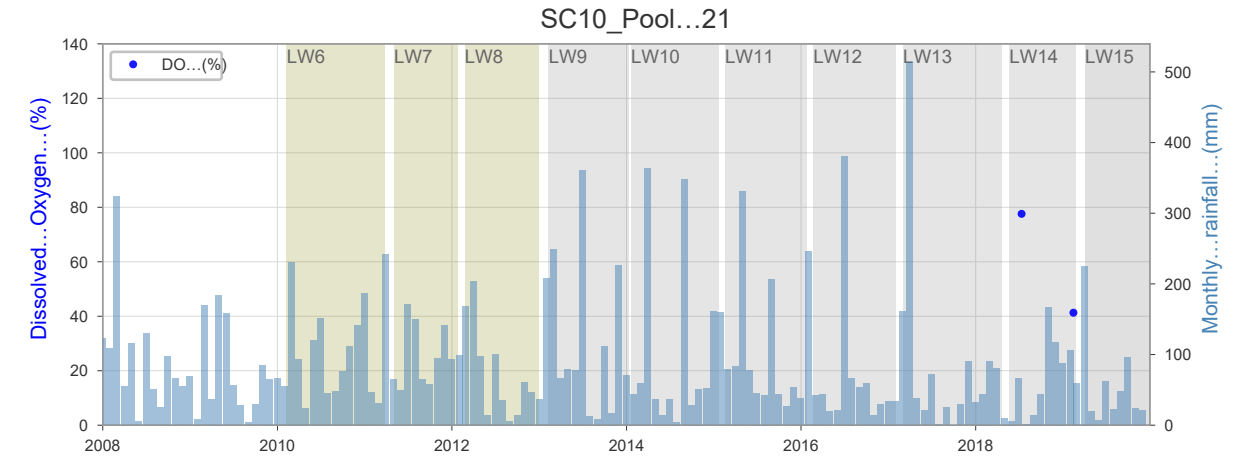

SC10_Pool…15
pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

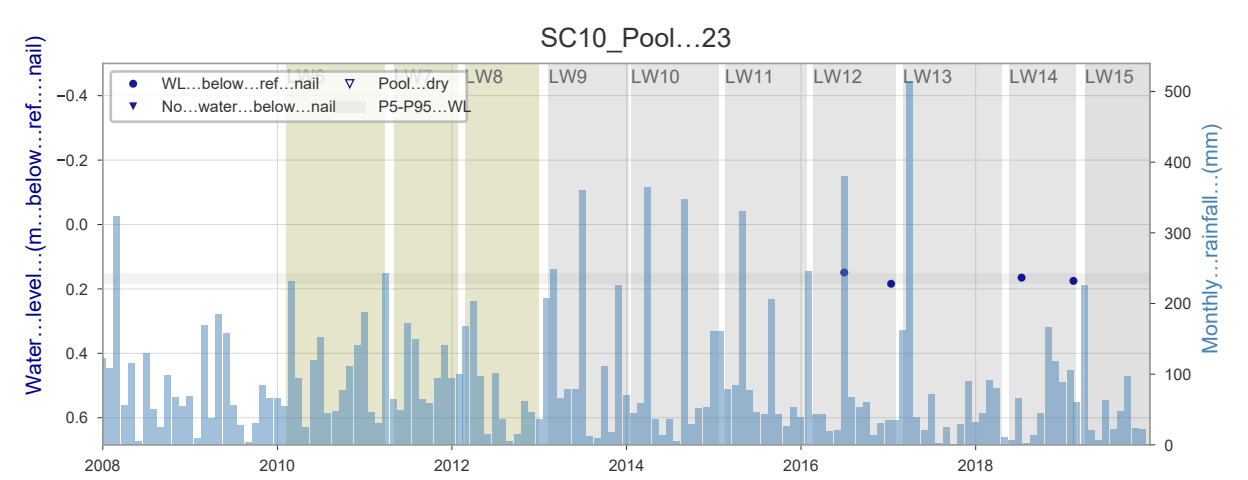

SC10_Pool…15
DO…(%)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

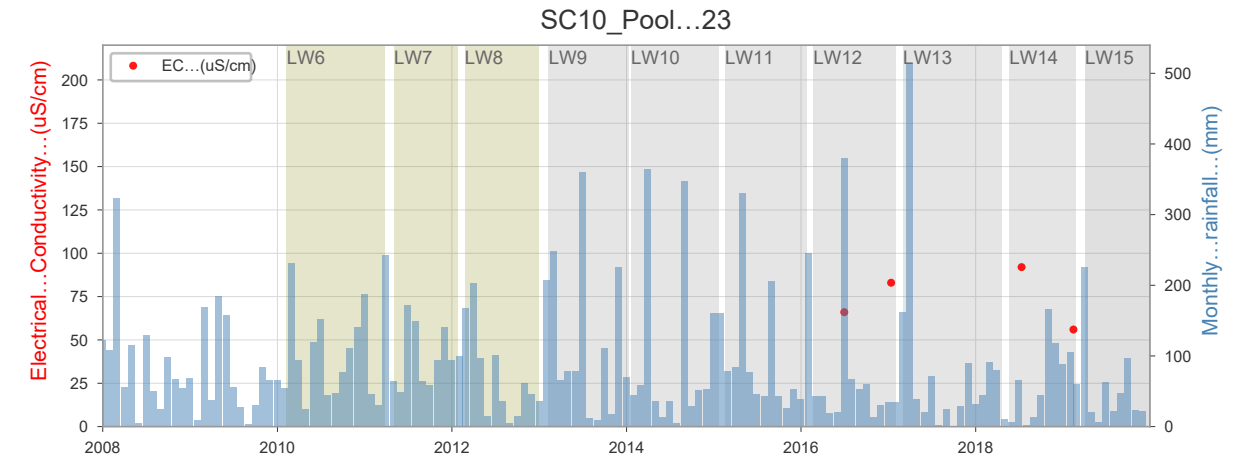

SC10_Pool…21
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

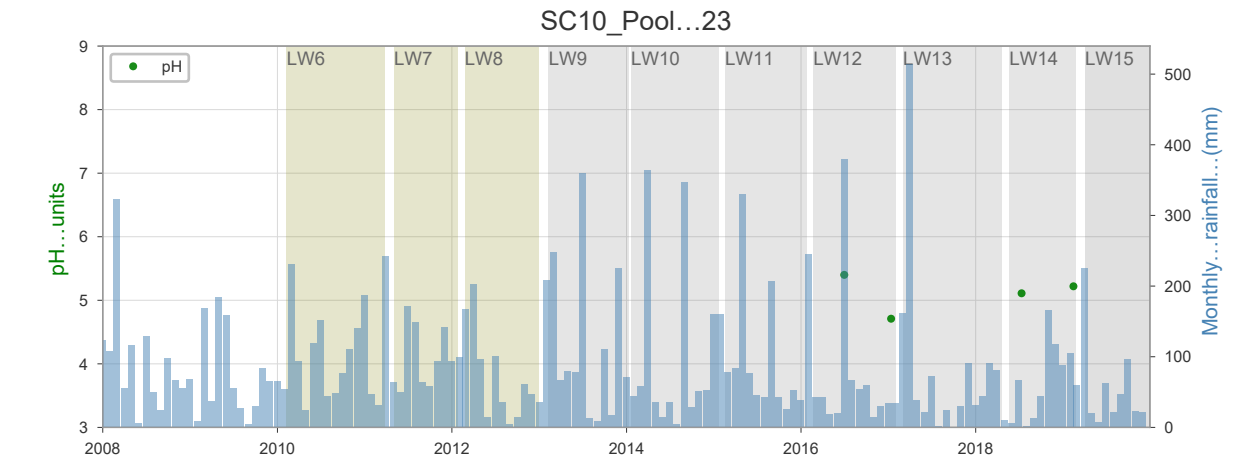

SC10_Pool…21
EC…(uS/cm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

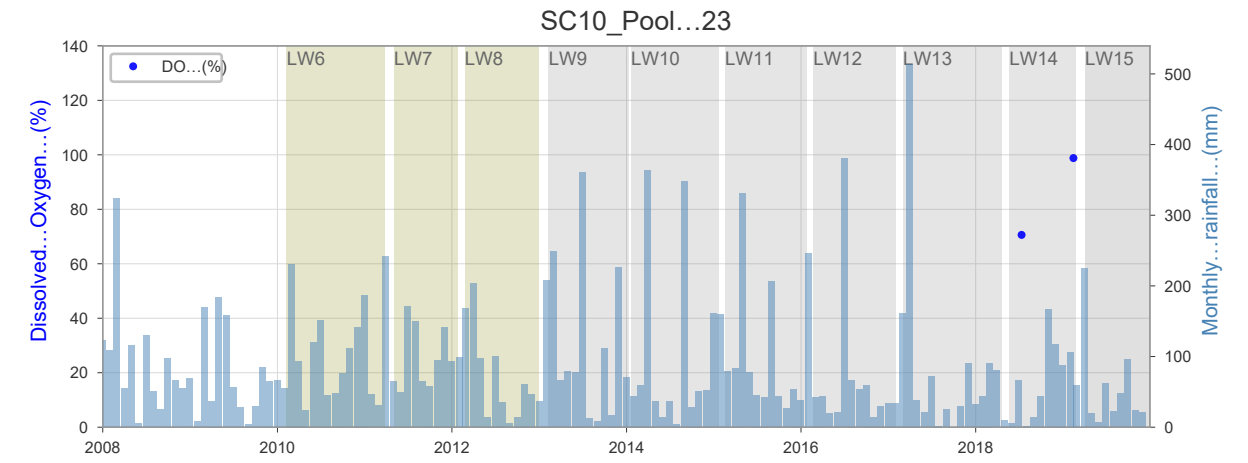

SC10_Pool…21
pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

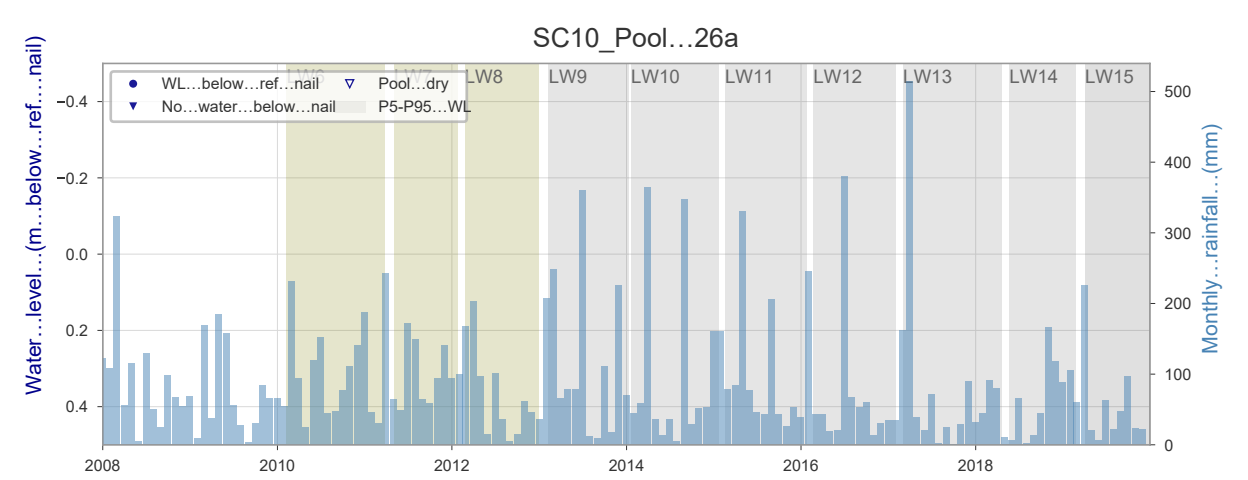

SC10_Pool…21
DO…(%)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

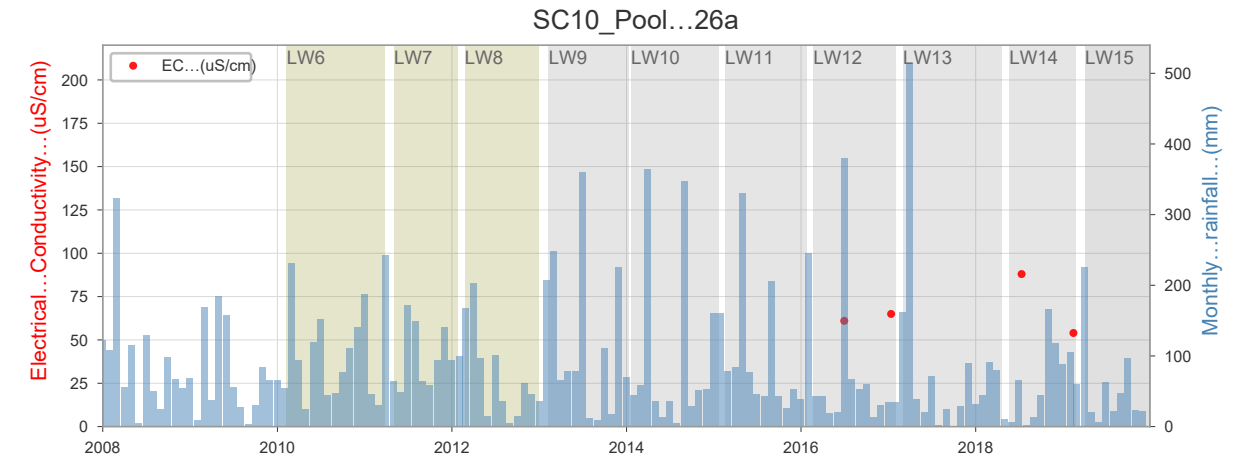

SC10_Pool…23
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

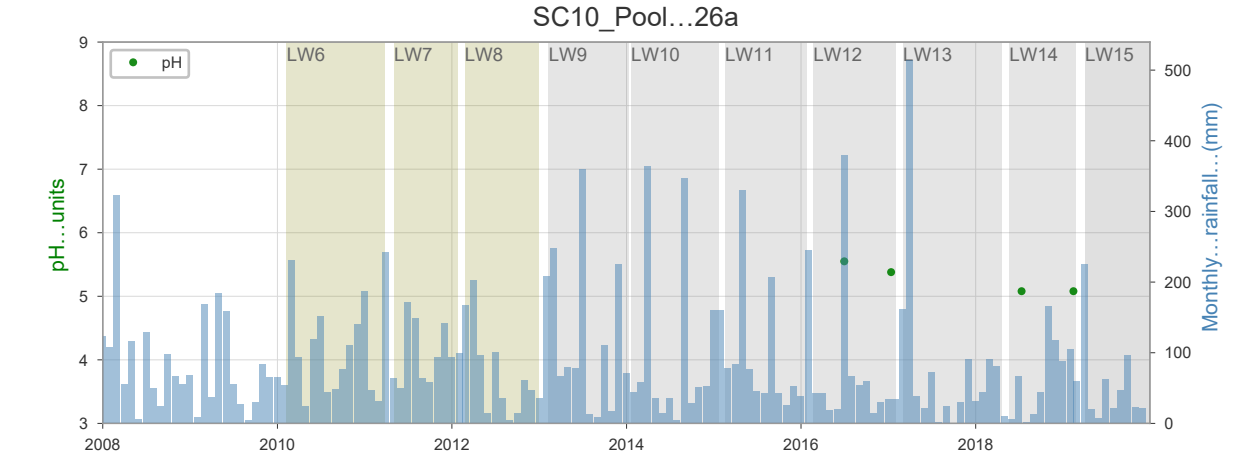

SC10_Pool…23
EC…(uS/cm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

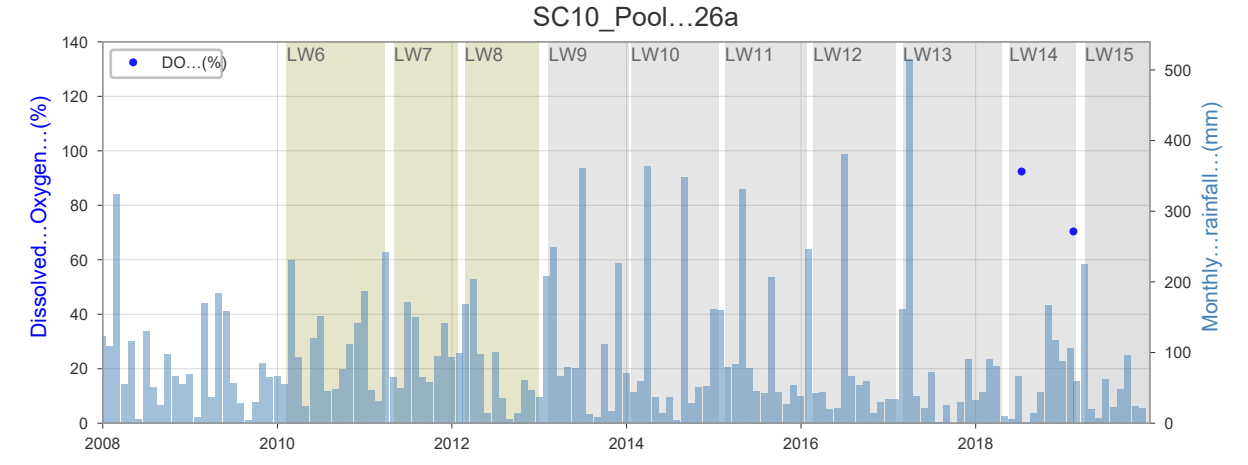

SC10_Pool…23
pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

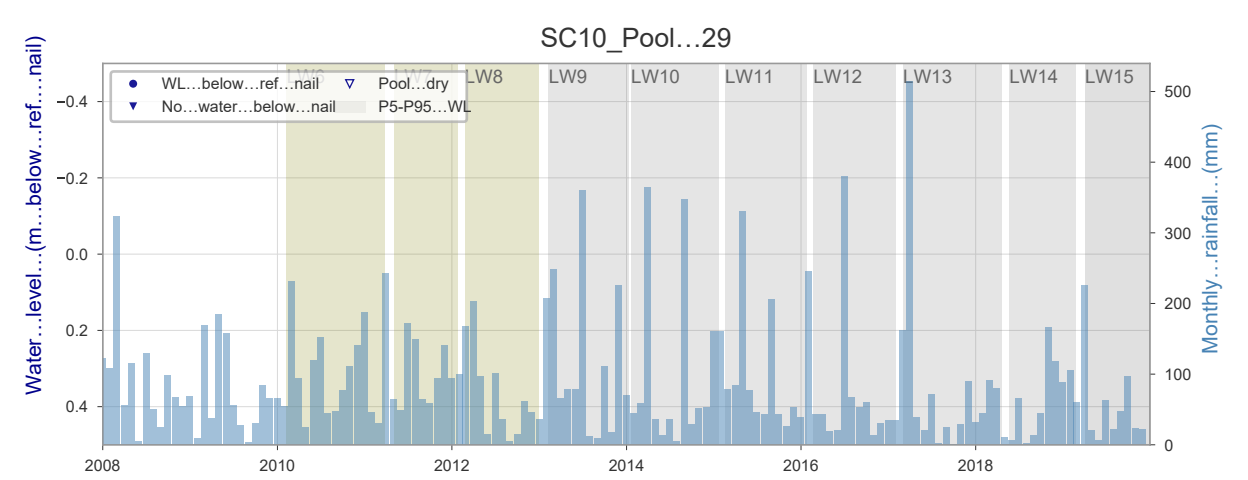

SC10_Pool…23
DO…(%)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

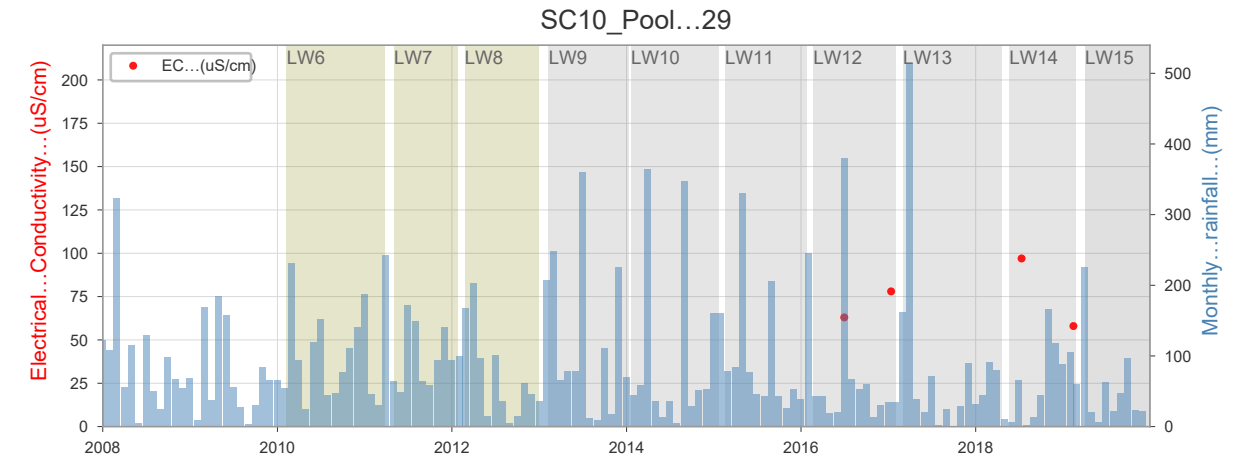

SC10_Pool…26a
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

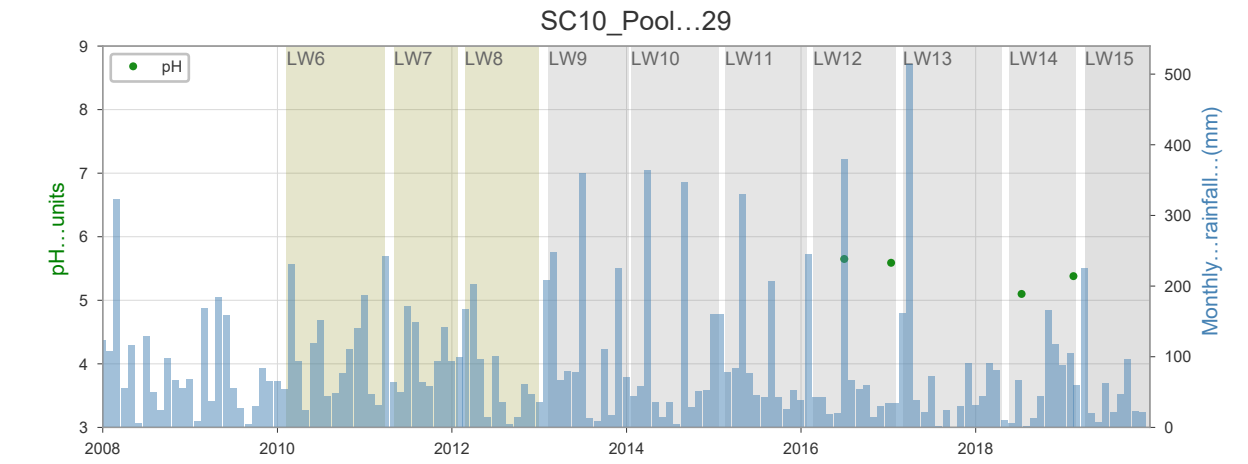

SC10_Pool…26a
EC…(uS/cm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

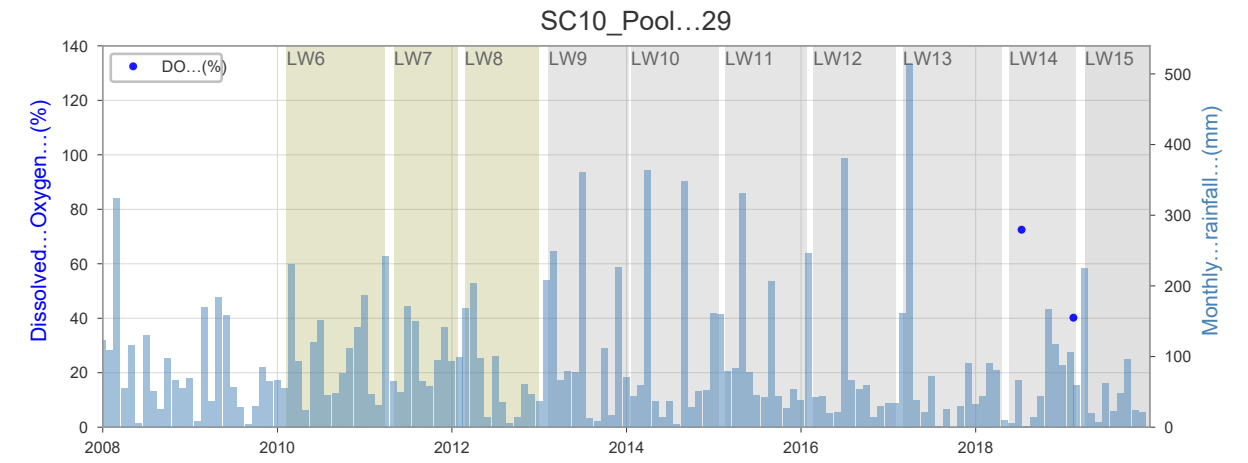

SC10_Pool…26a
pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

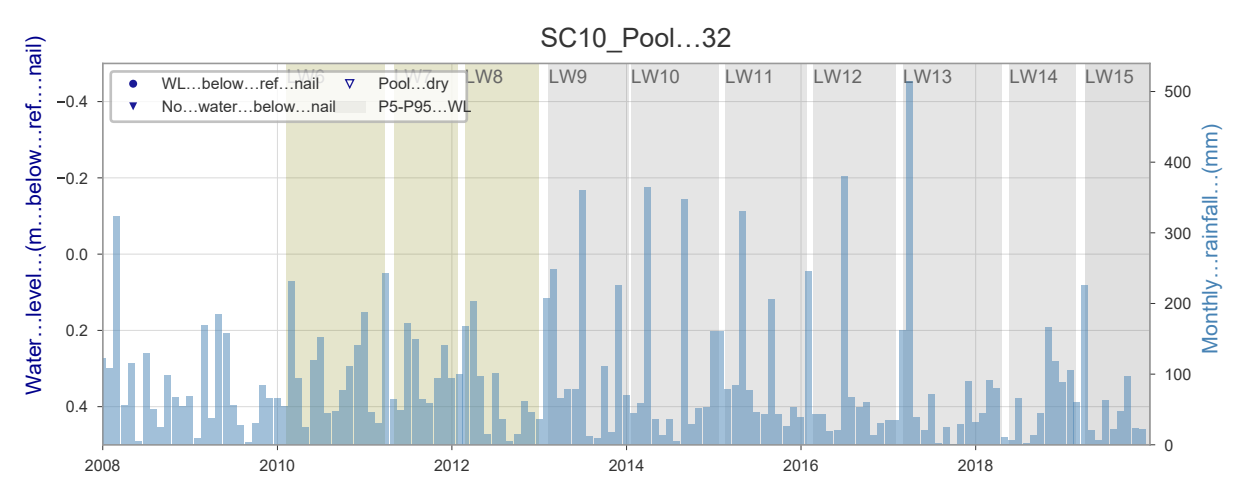

SC10_Pool…26a
DO…(%)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

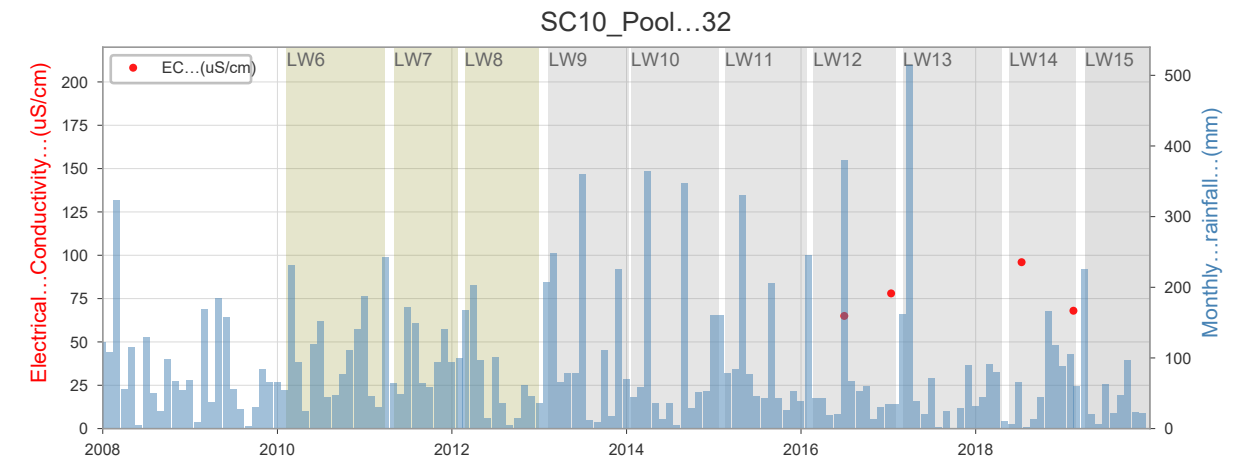

SC10_Pool…29
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….…nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

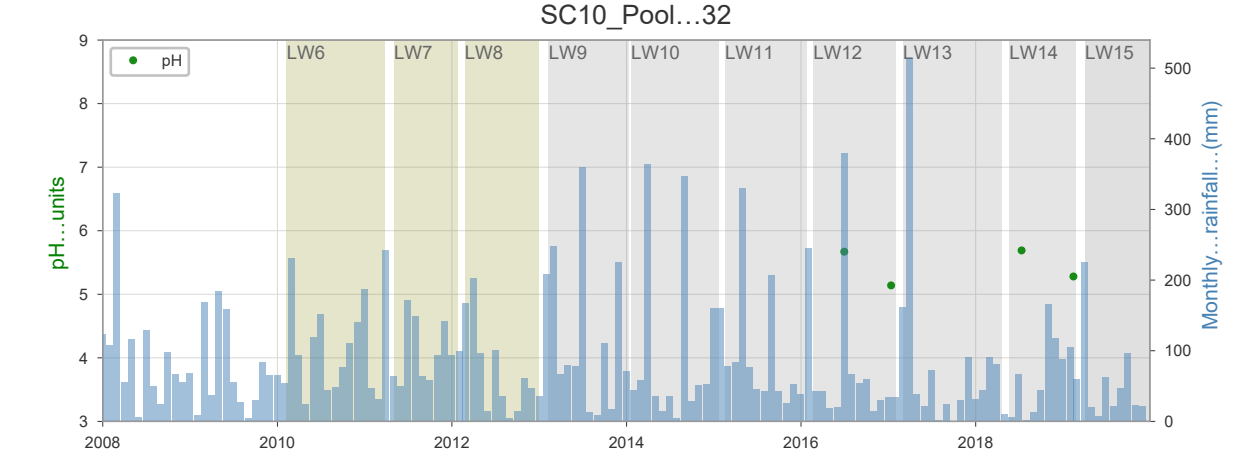

SC10_Pool…29
EC…(uS/cm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

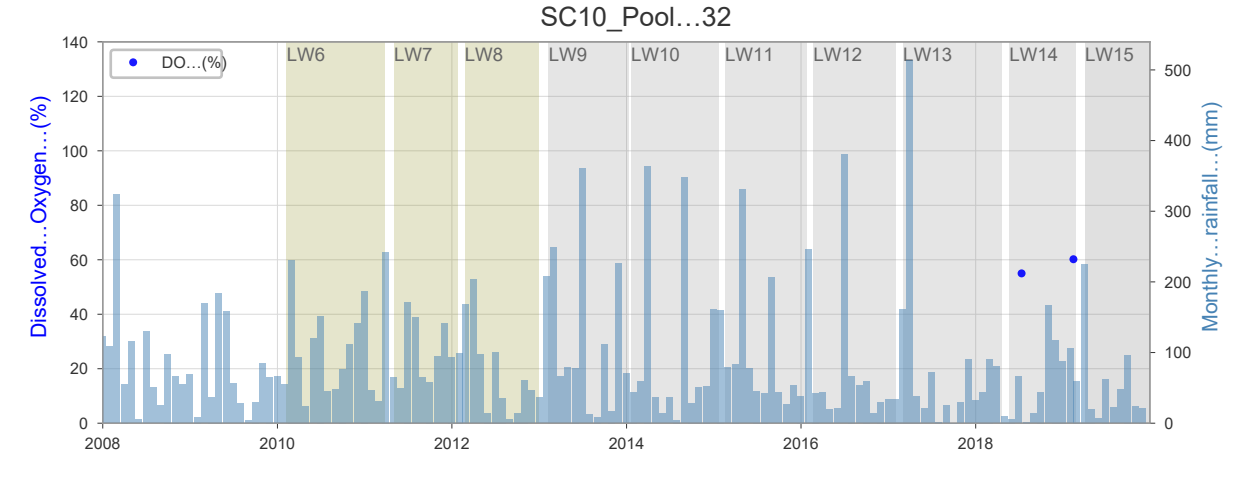

SC10_Pool…29
pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

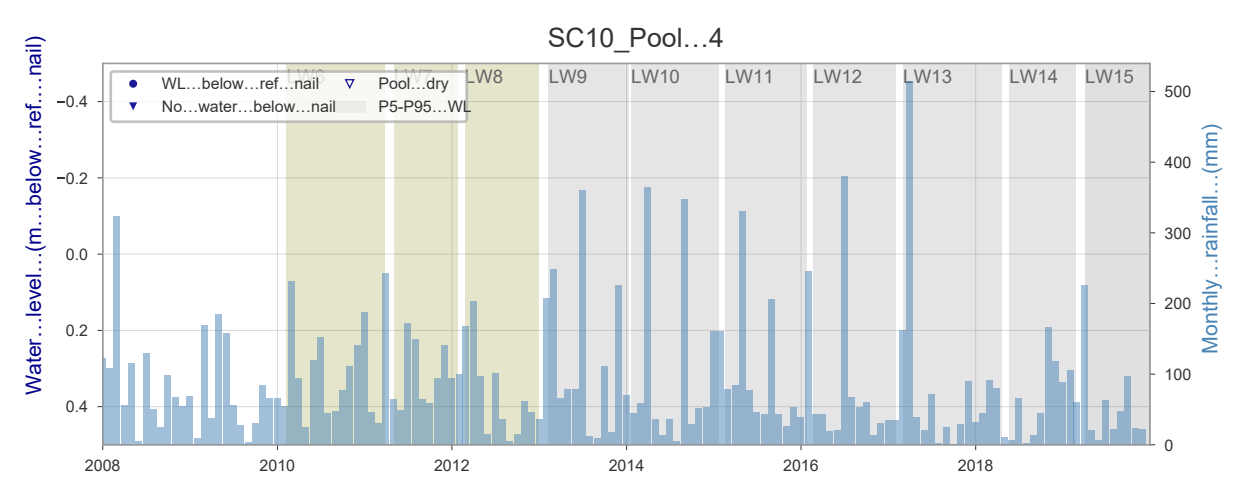

SC10_Pool…29
DO…(%)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

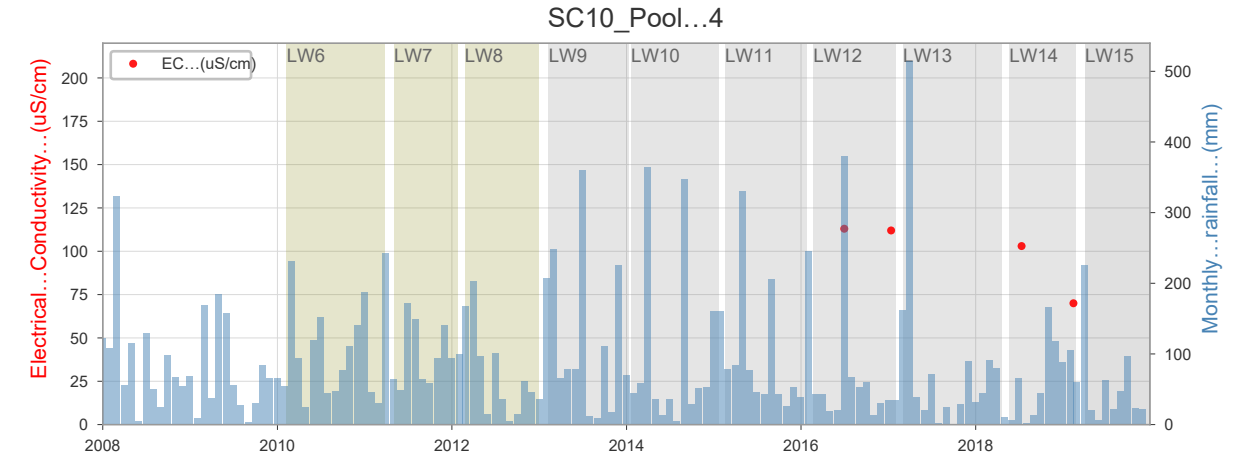

SC10_Pool…32
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….…nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

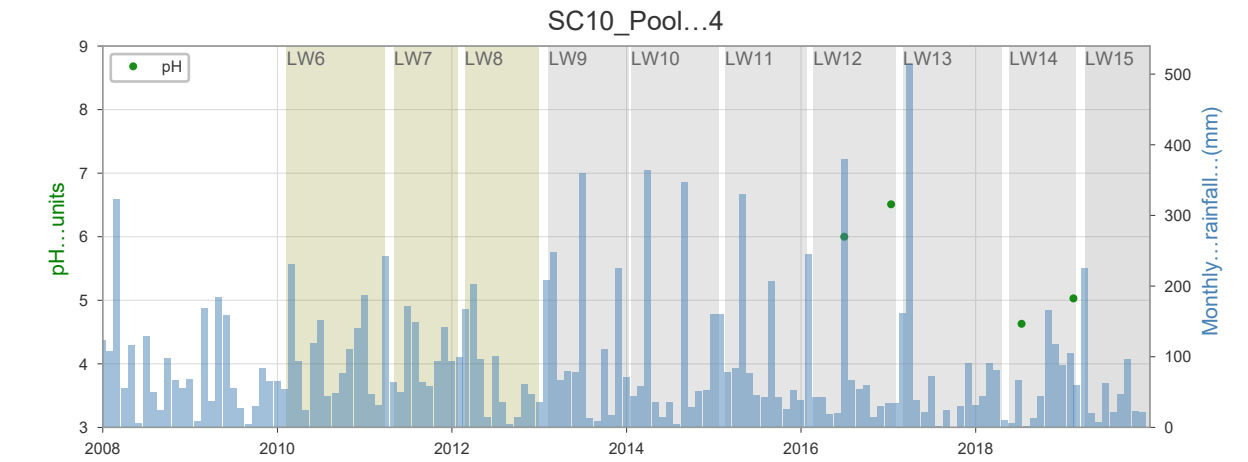

SC10_Pool…32
EC…(uS/cm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

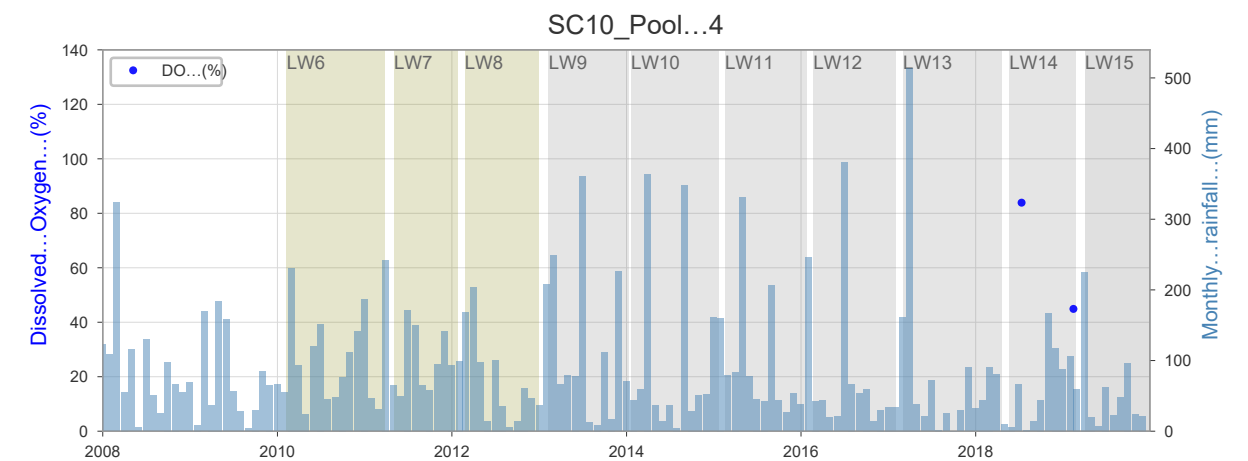

SC10_Pool…32
pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

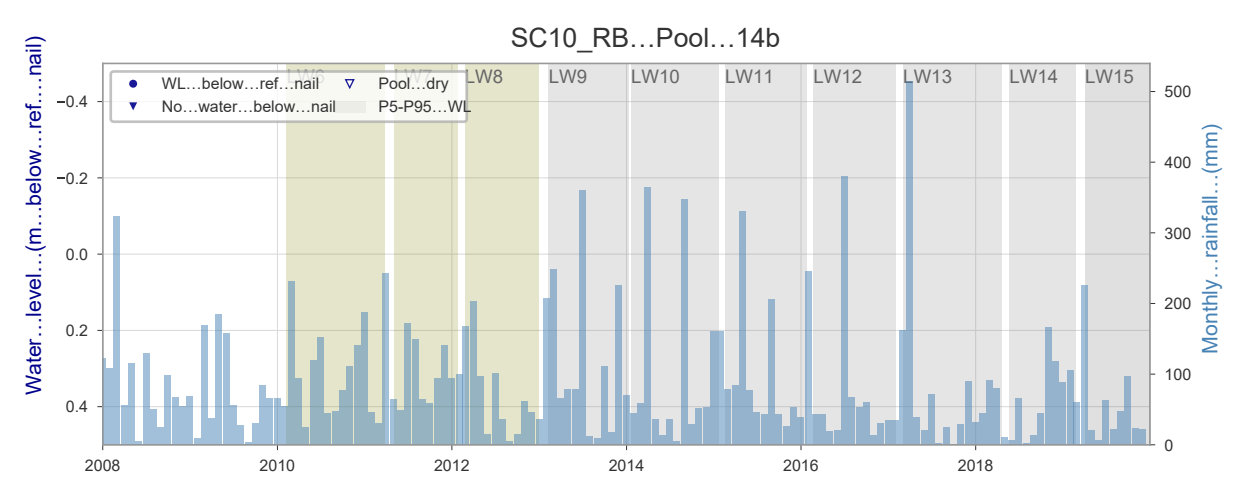

SC10_Pool…32
DO…(%)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

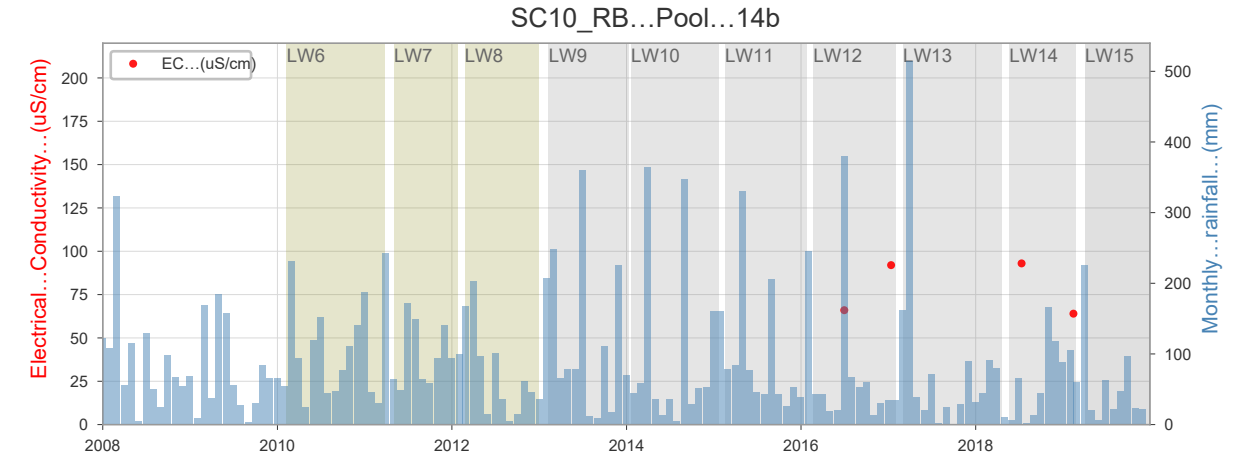

SC10_Pool…4
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….…nail)
Monthly…rainfall…(mm)

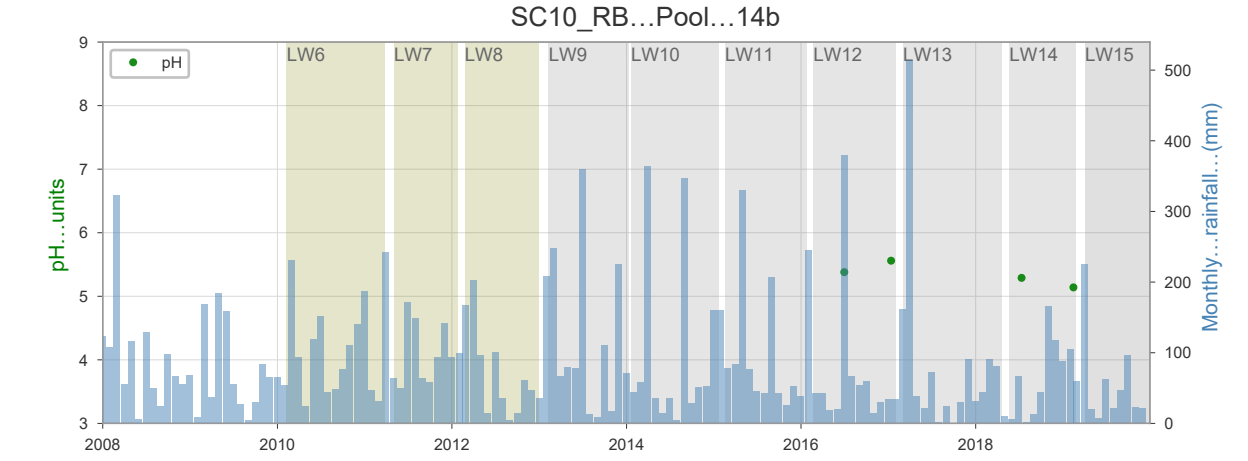

SC10_Pool…4
EC…(uS/cm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)

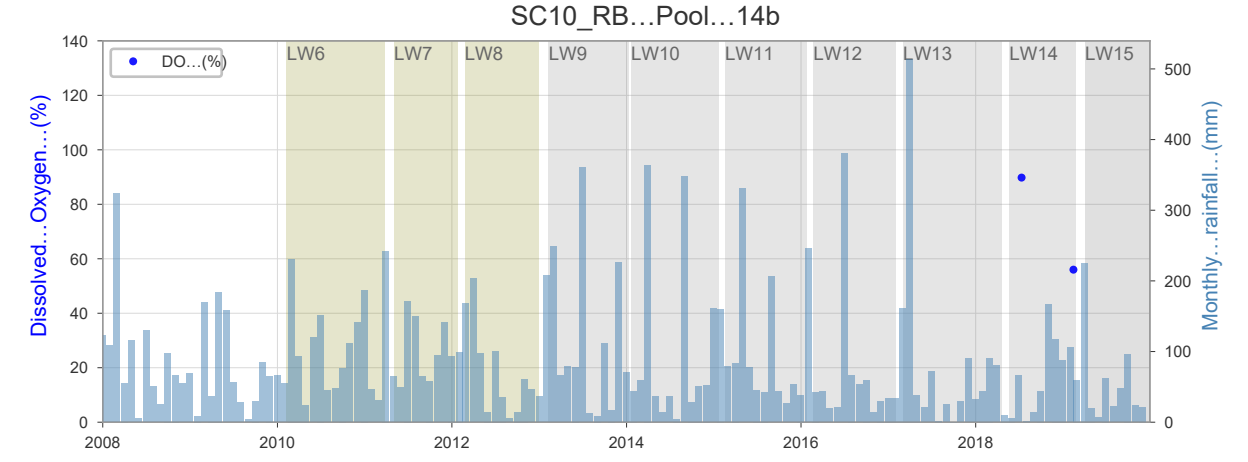

SC10_Pool…4
pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)

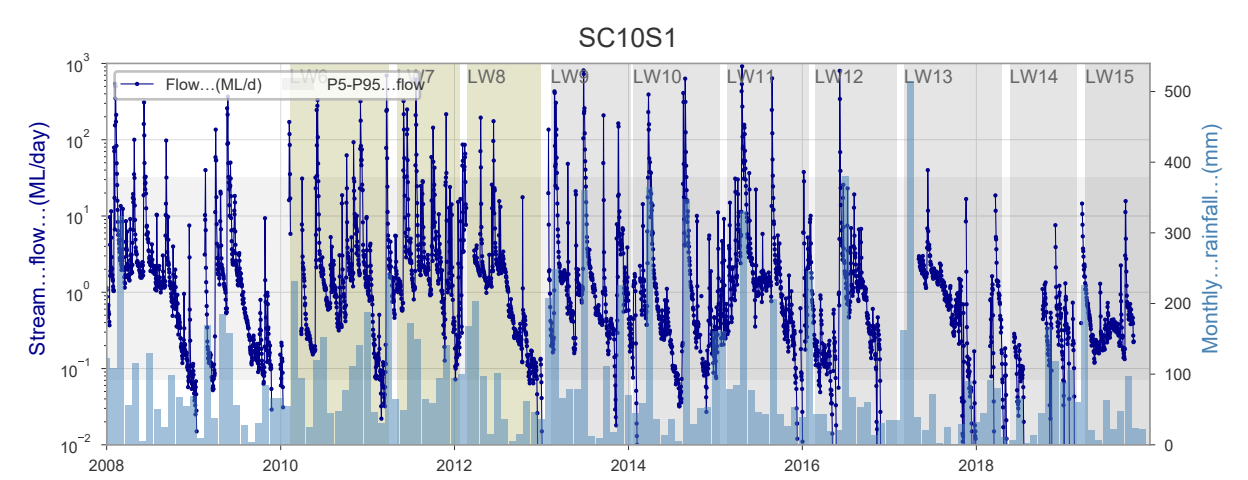

SC10_Pool…4
DO…(%)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)

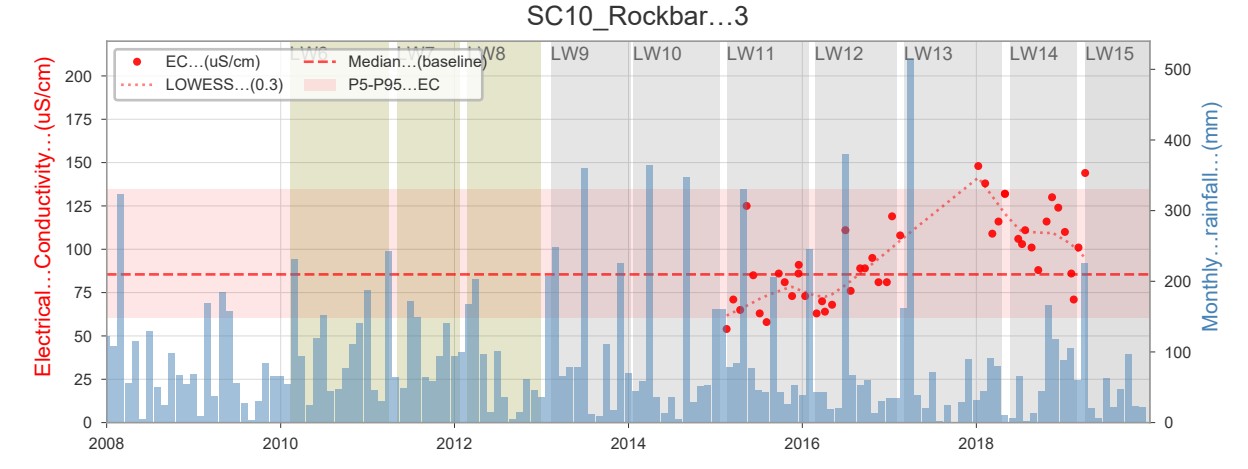

SC10_RB…Pool…14b
WL…below…ref…nail
No…water…below…nail
Pool…dry
P5-P95…WL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

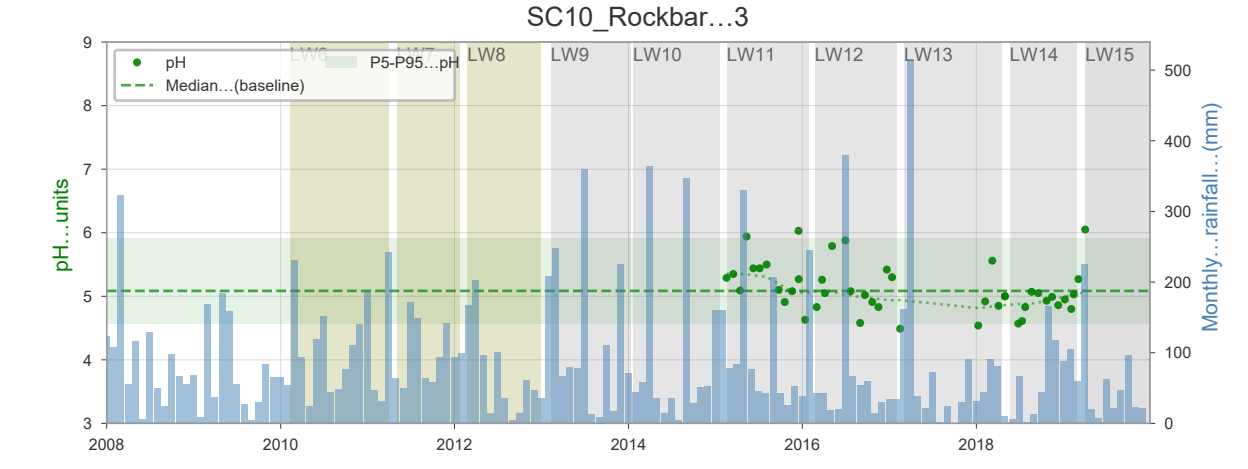

SC10_RB…Pool…14b
EC…(uS/cm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

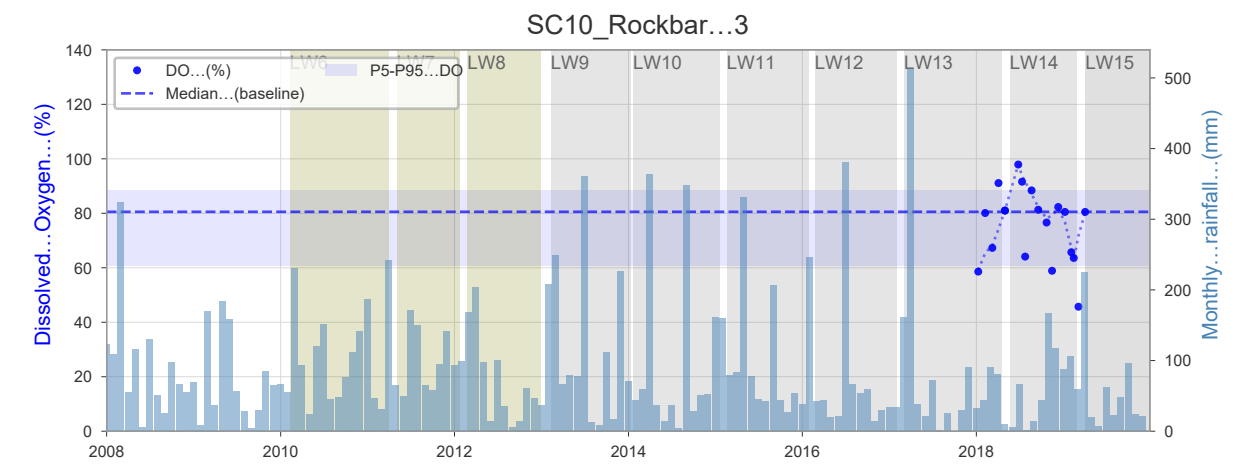

SC10_RB…Pool…14b
pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

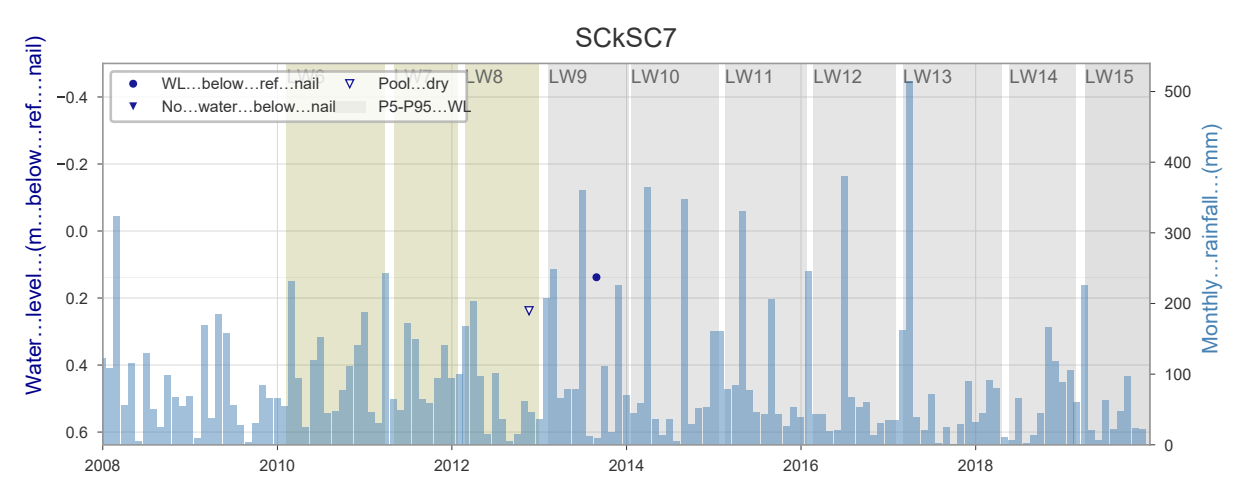

SC10_RB…Pool…14b
DO…(%)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

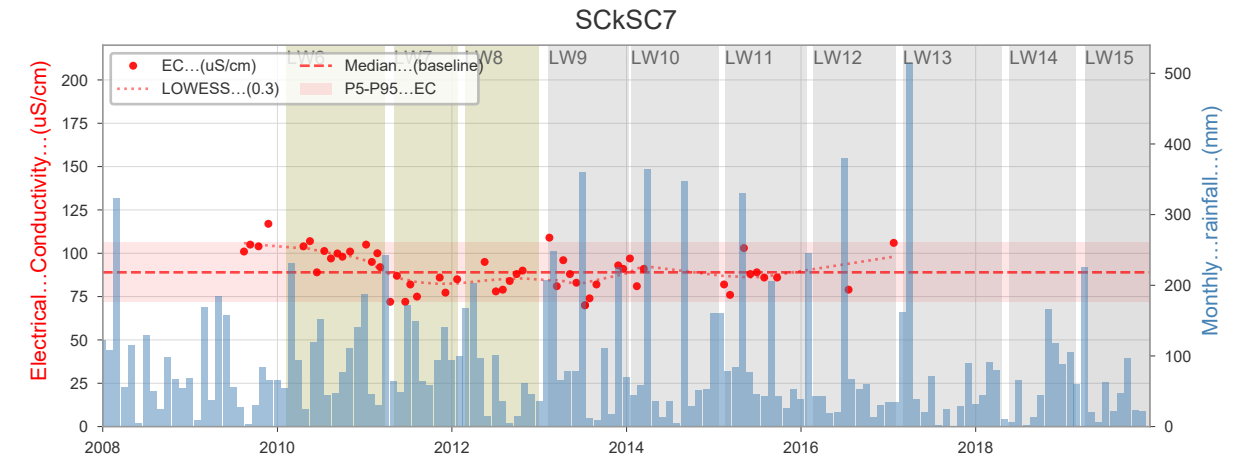

SC10S1
Flow…(ML/d)
P5-P95…flow
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Stream…flow…(ML/day)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

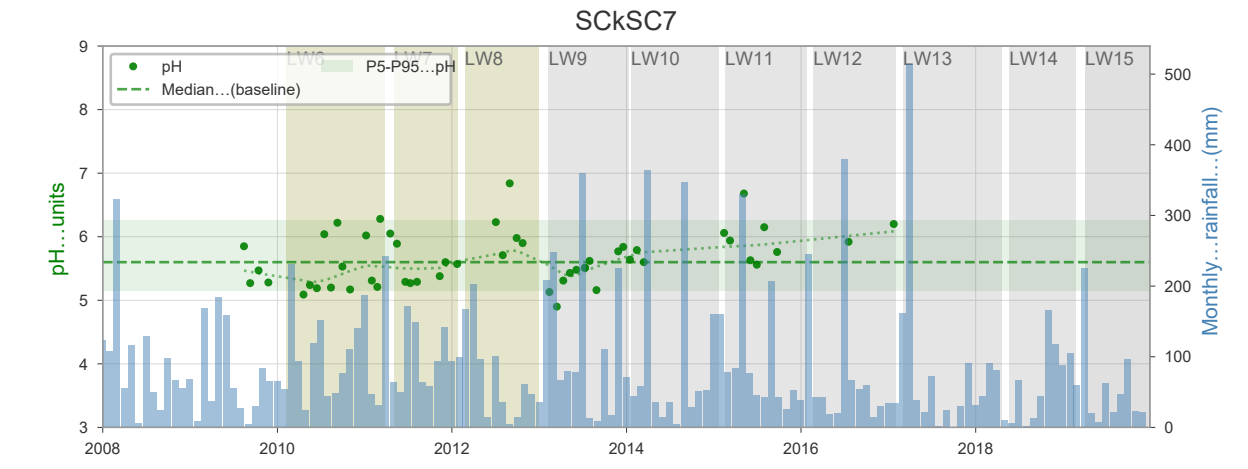

SC10_Rockbar…3
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

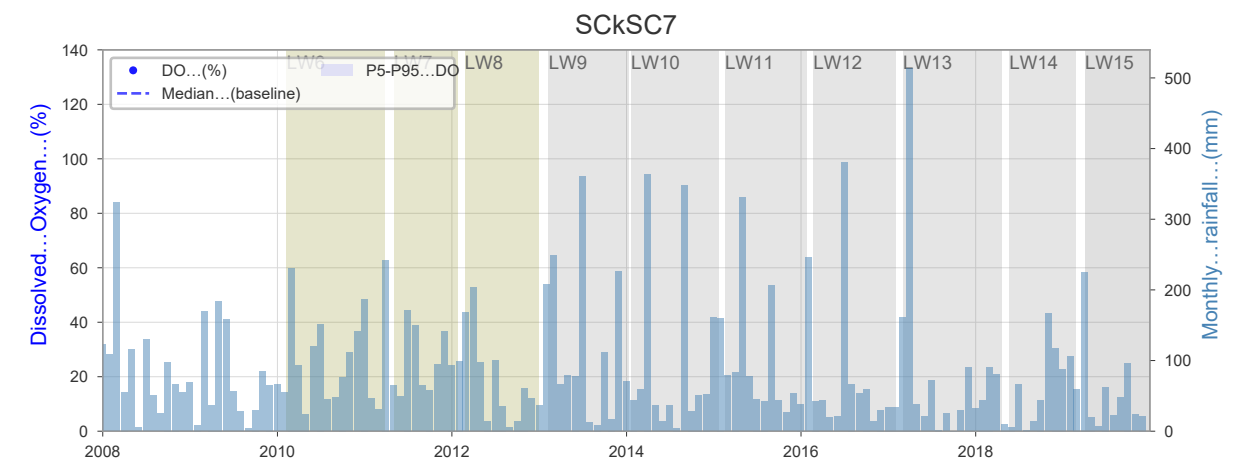

SC10_Rockbar…3
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

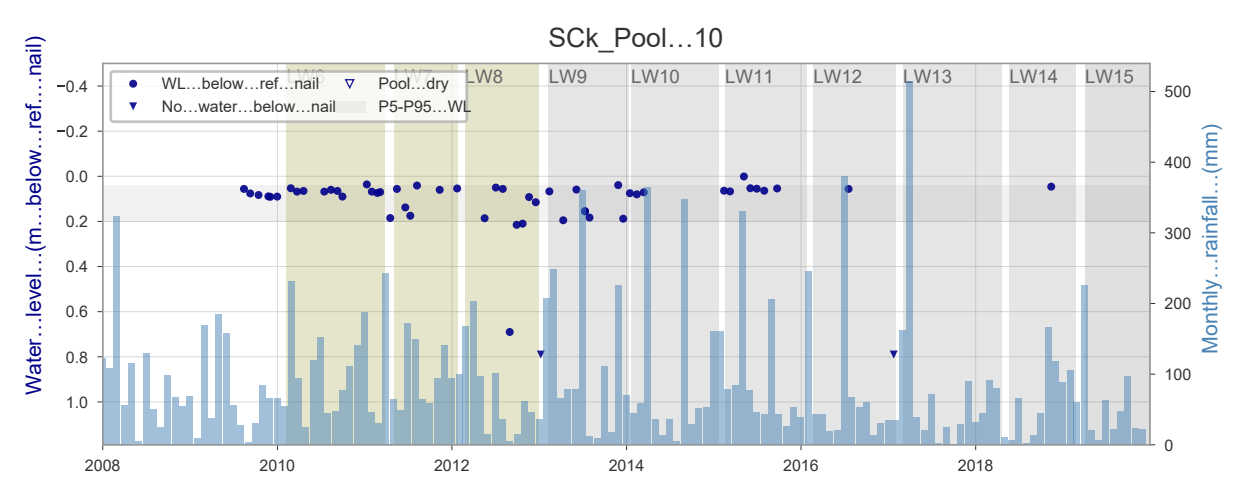

SC10_Rockbar…3
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

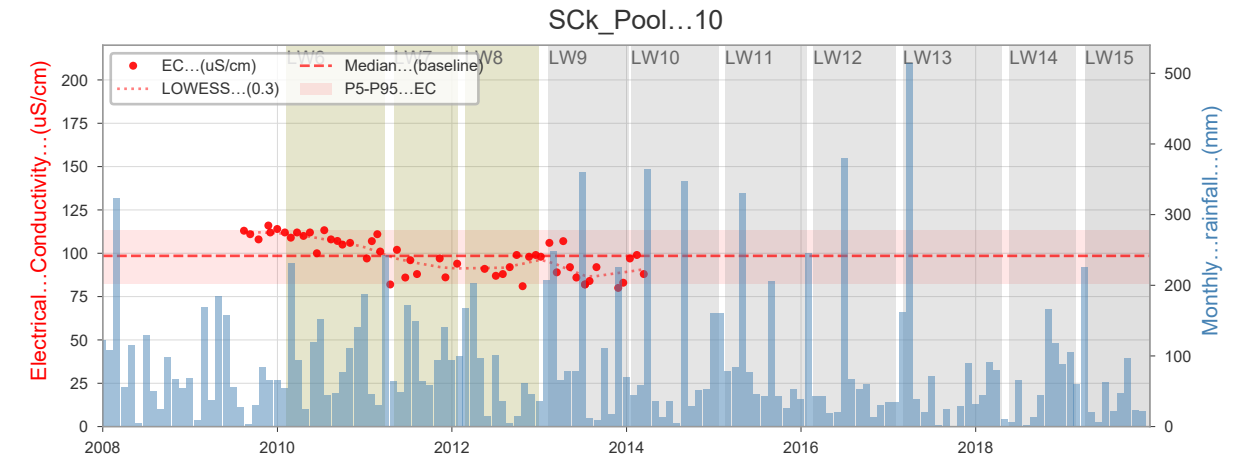

SCkSC7
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

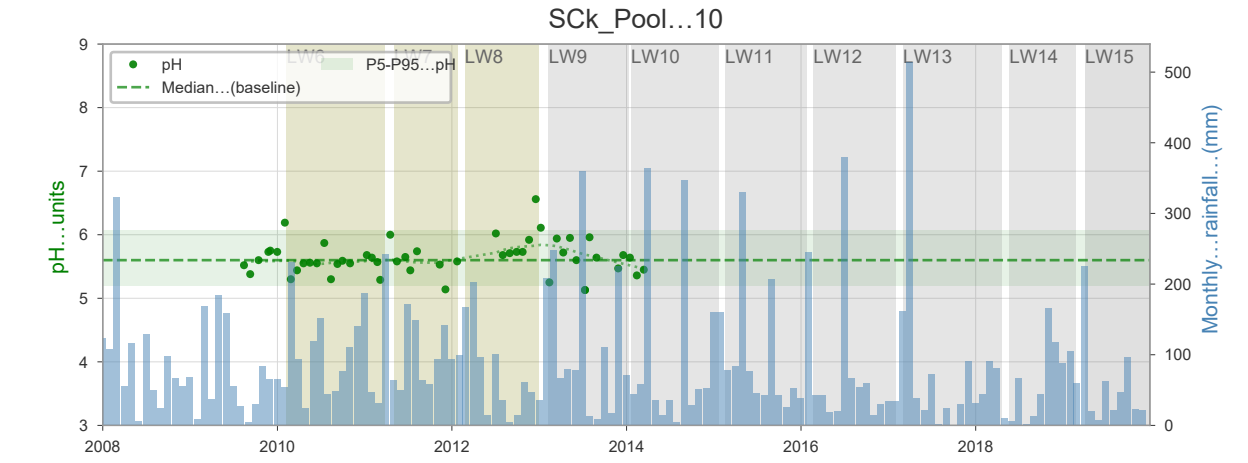

SCkSC7
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

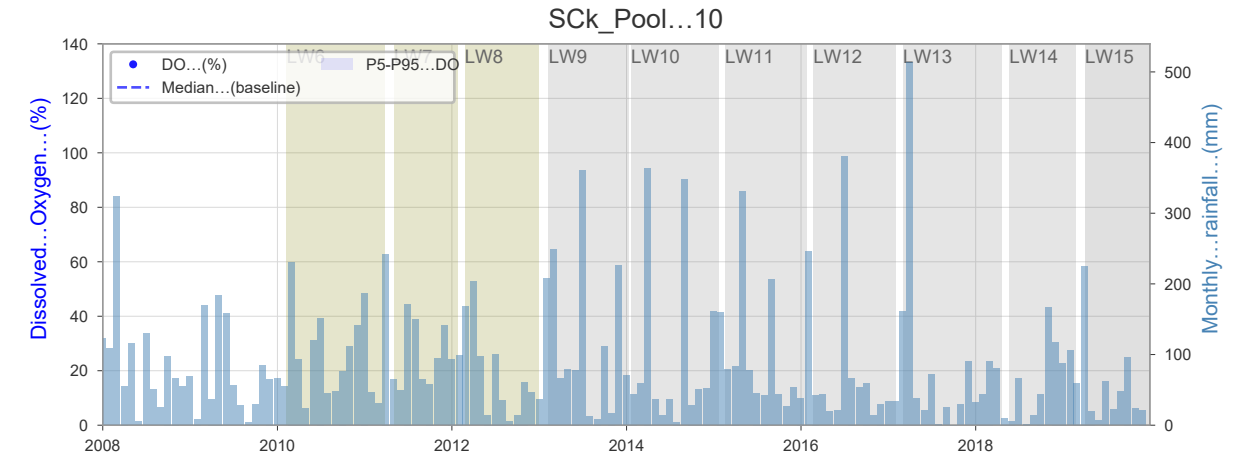

SCkSC7
pH…units
Monthly…rainfall…(mm)
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

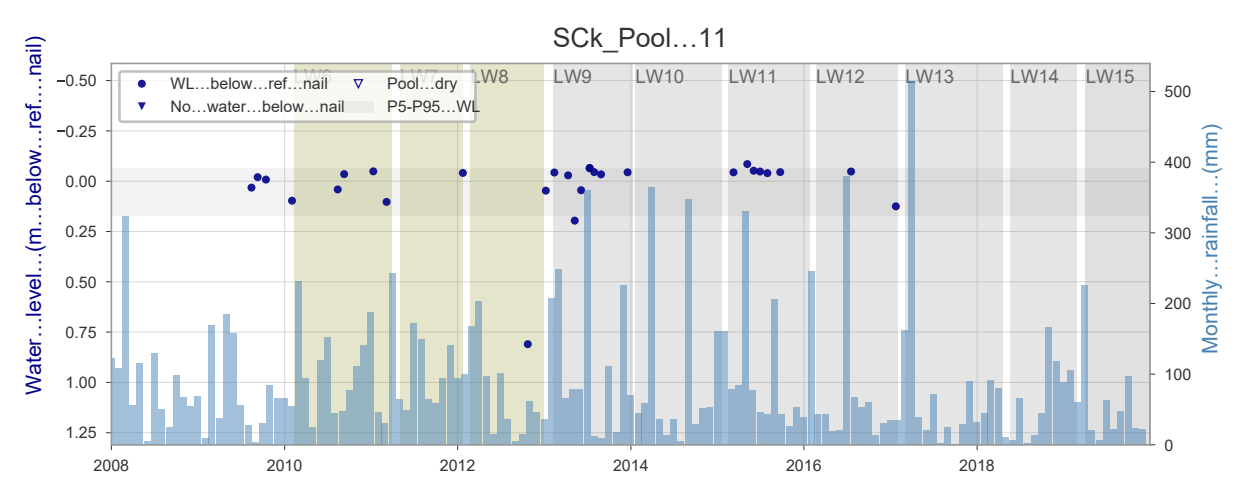

SCkSC7
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

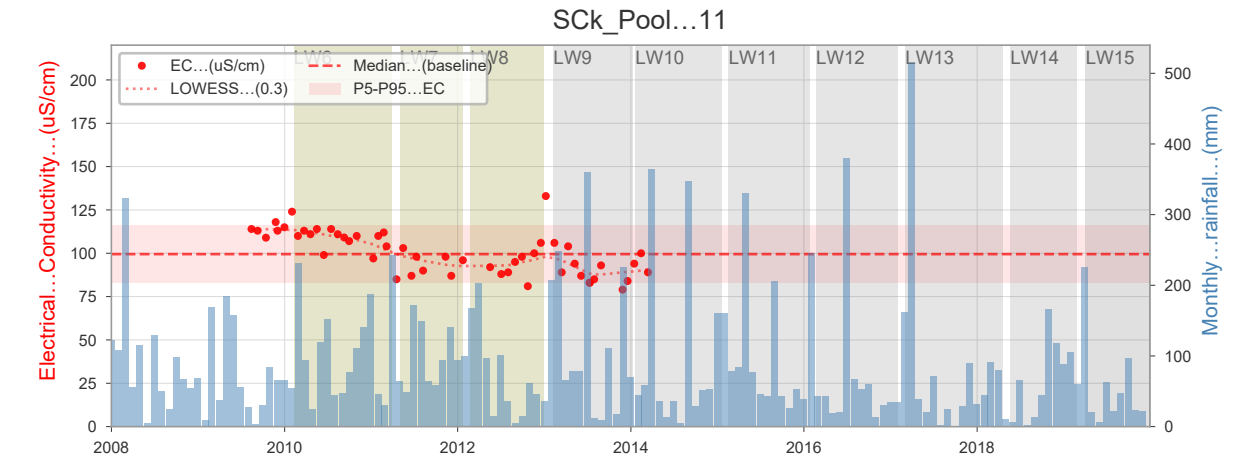

SCk_Pool…10
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

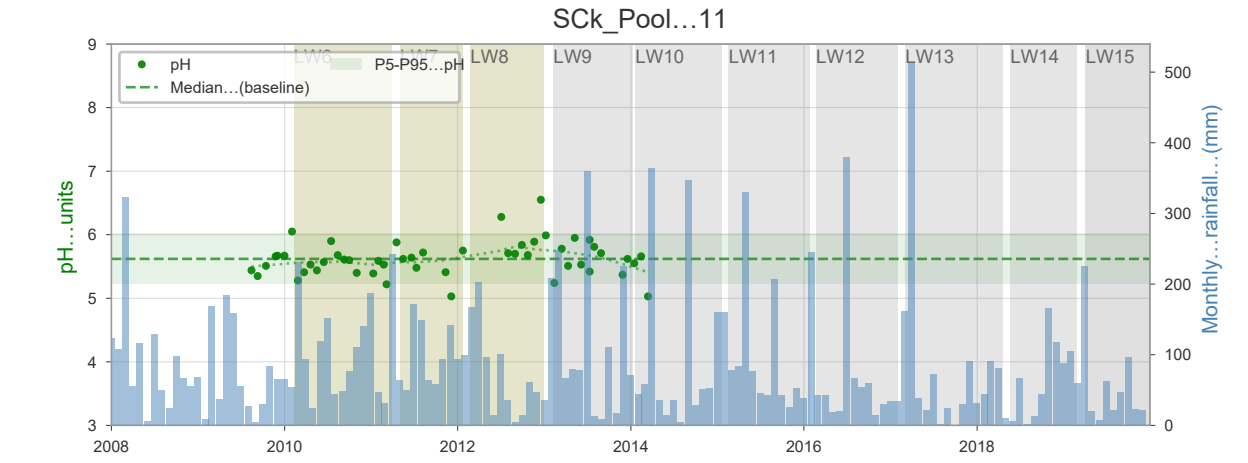

SCk_Pool…10
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

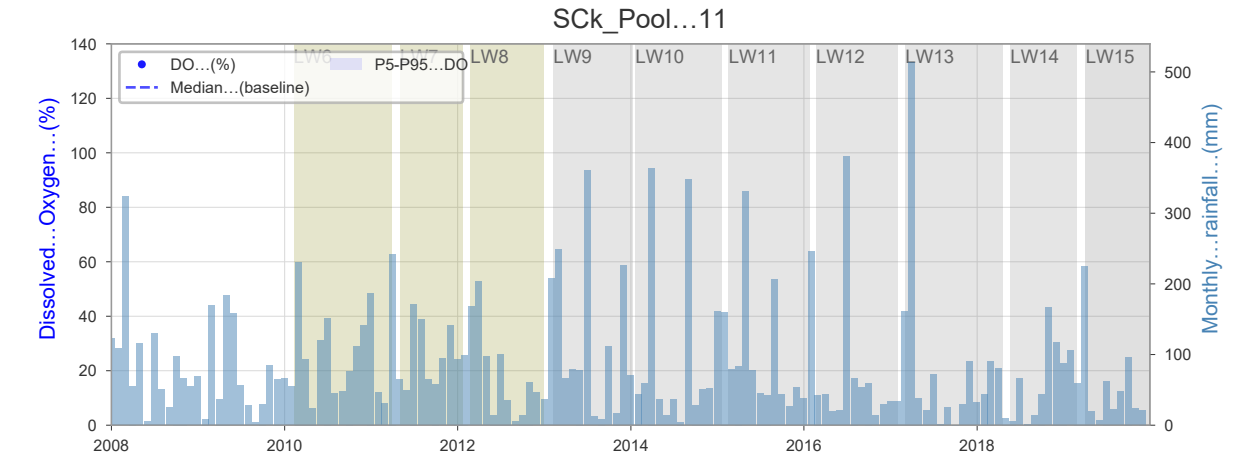

SCk_Pool…10
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

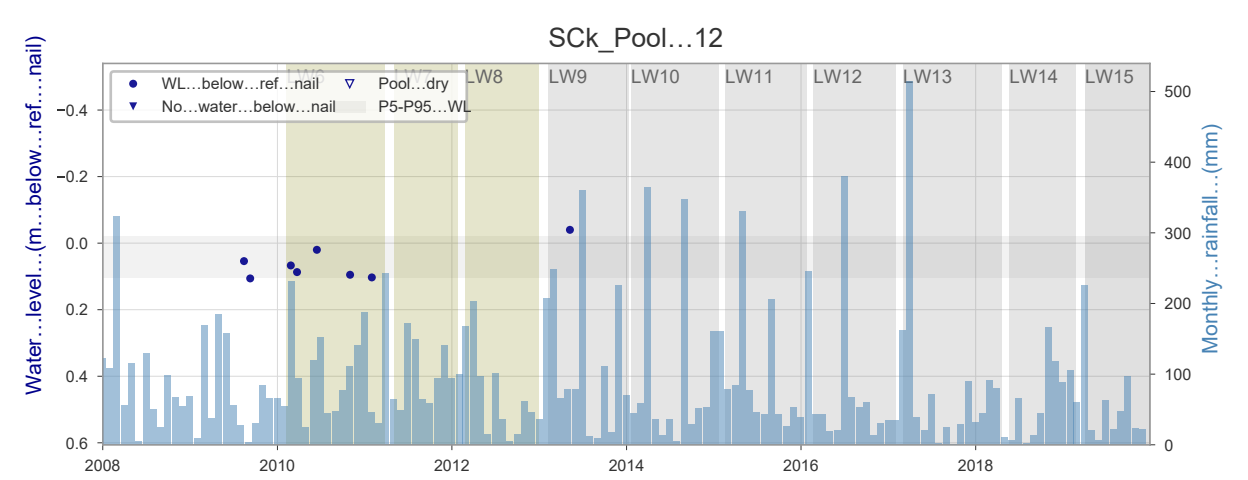

SCk_Pool…10
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

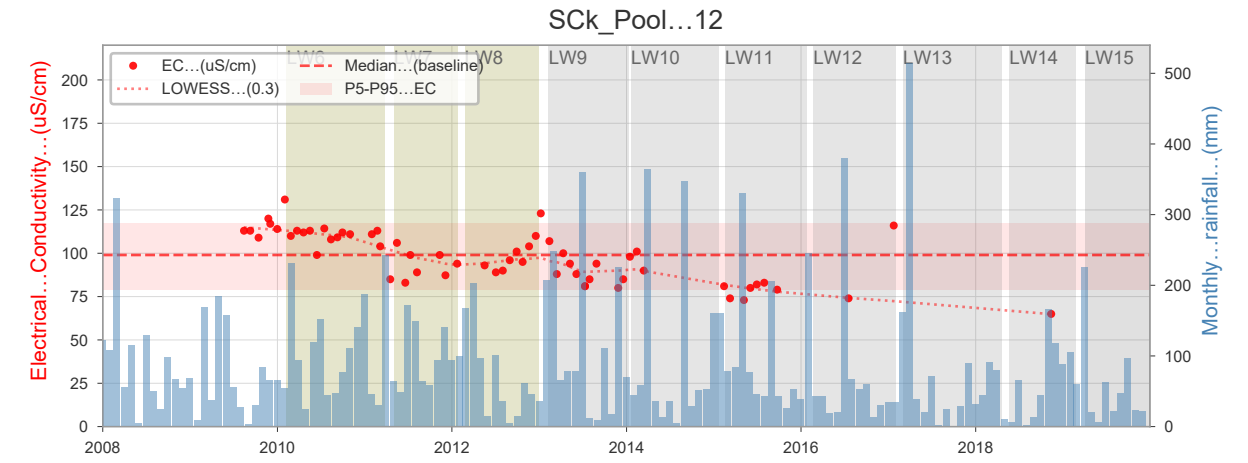

SCk_Pool…11
WL…below…ref…nail
No…water…below…nail
Pool…dry
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….…nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

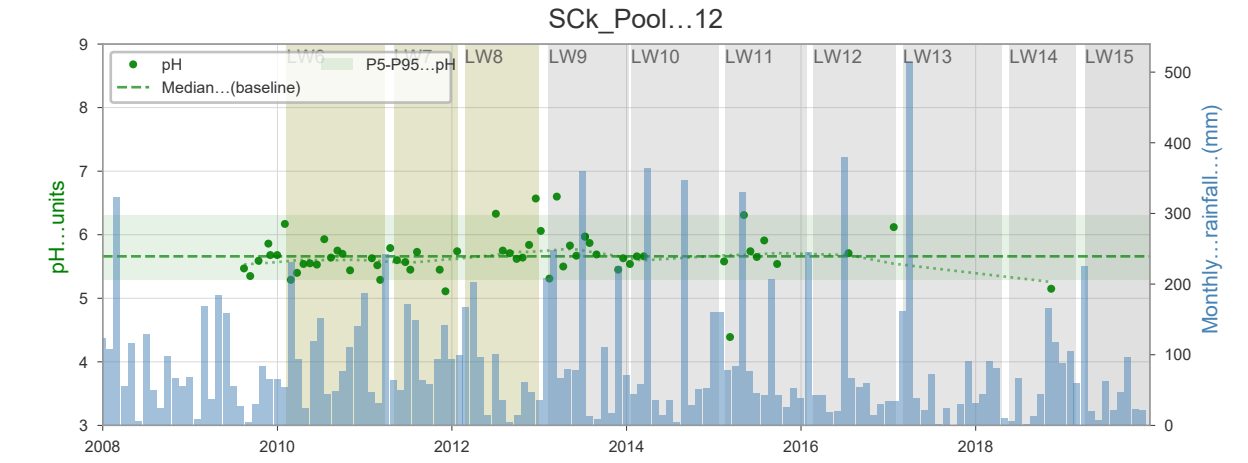

SCk_Pool…11
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

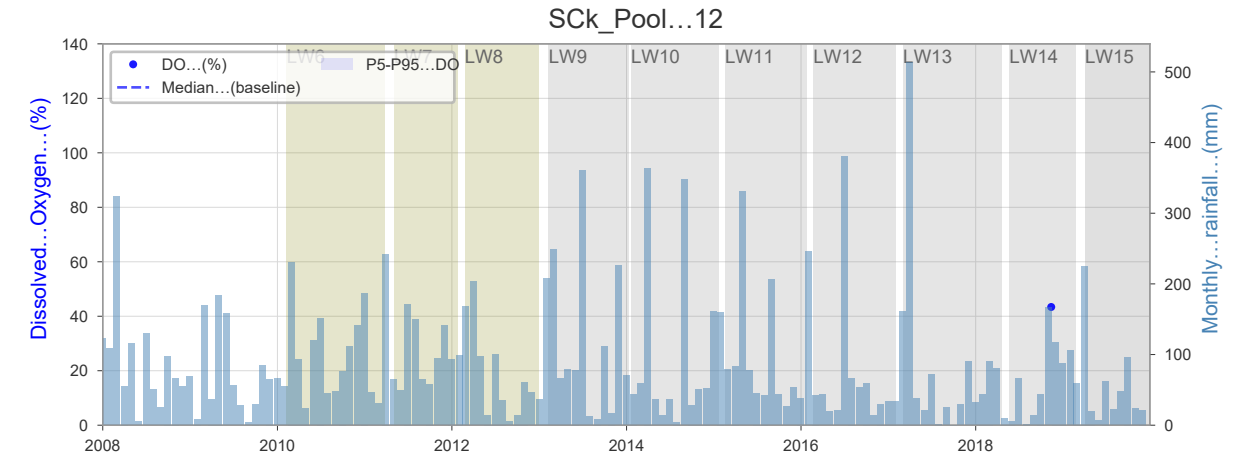

SCk_Pool…11
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

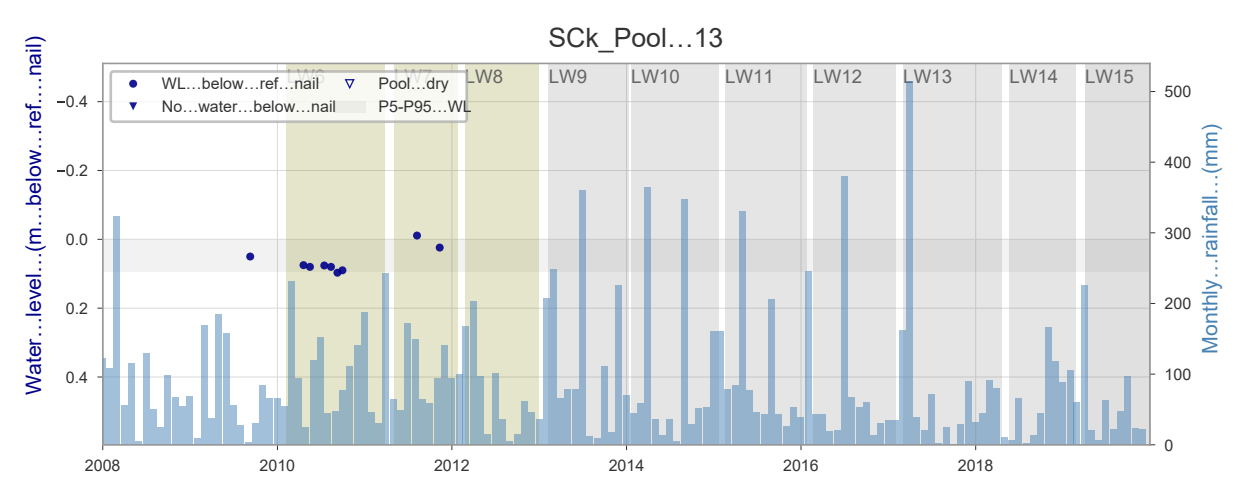

SCk_Pool…11
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

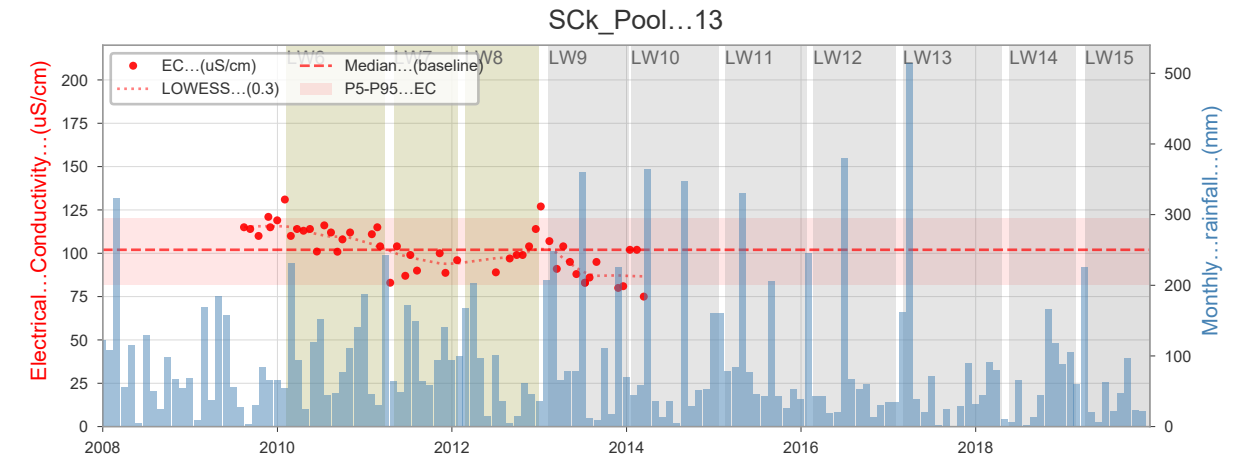

SCk_Pool…12
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

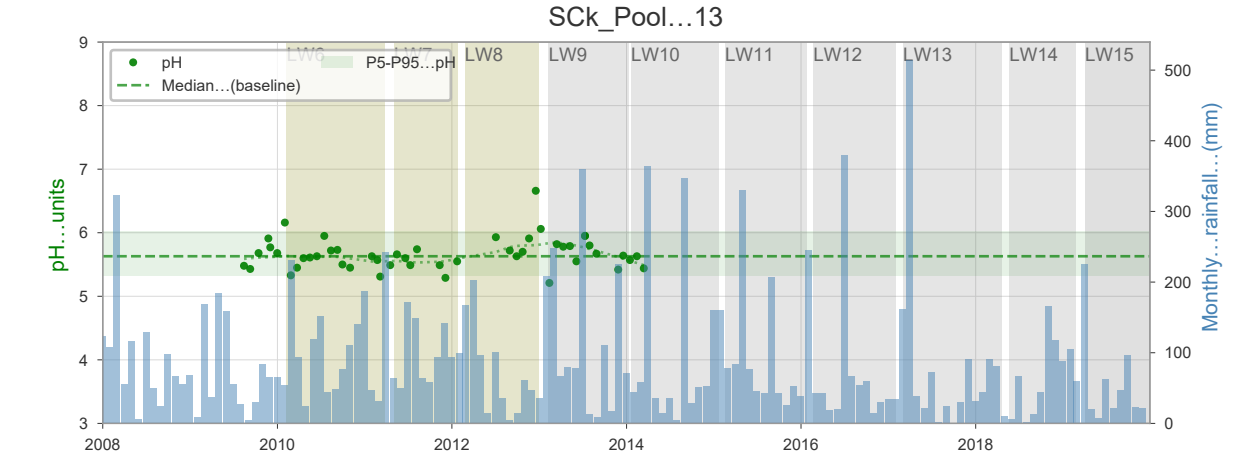

SCk_Pool…12
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

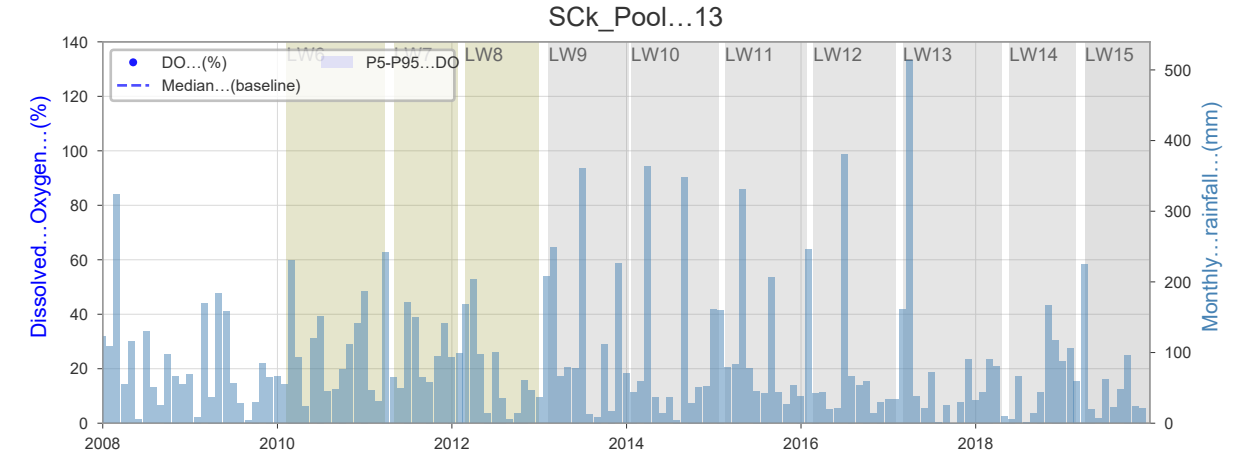

SCk_Pool…12
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

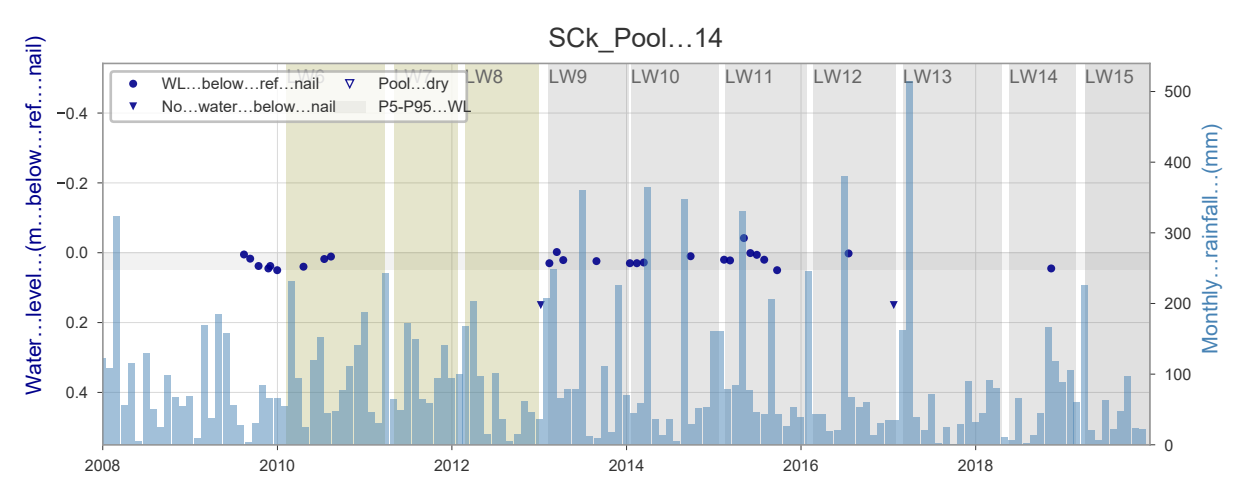

SCk_Pool…12
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

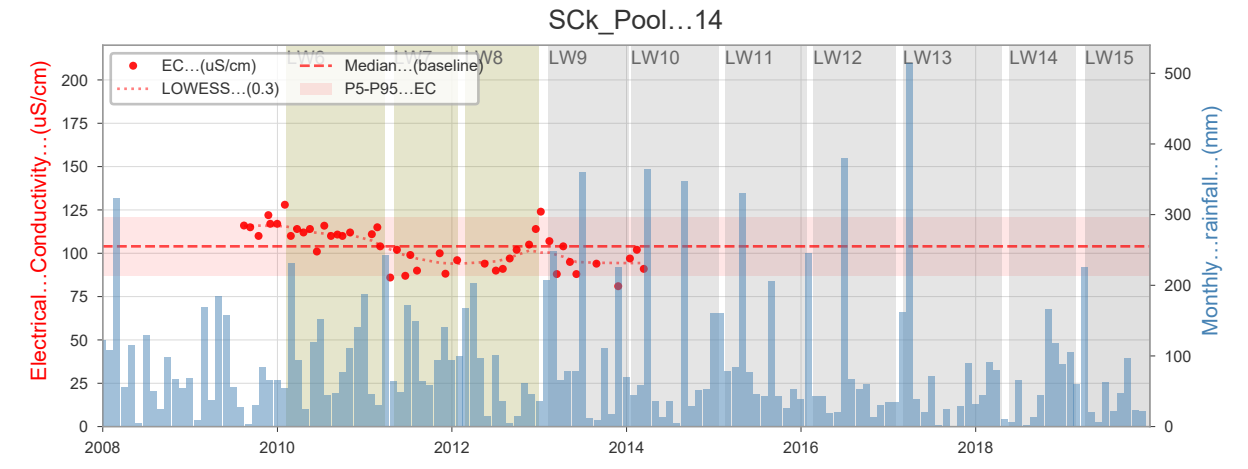

SCk_Pool…13
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

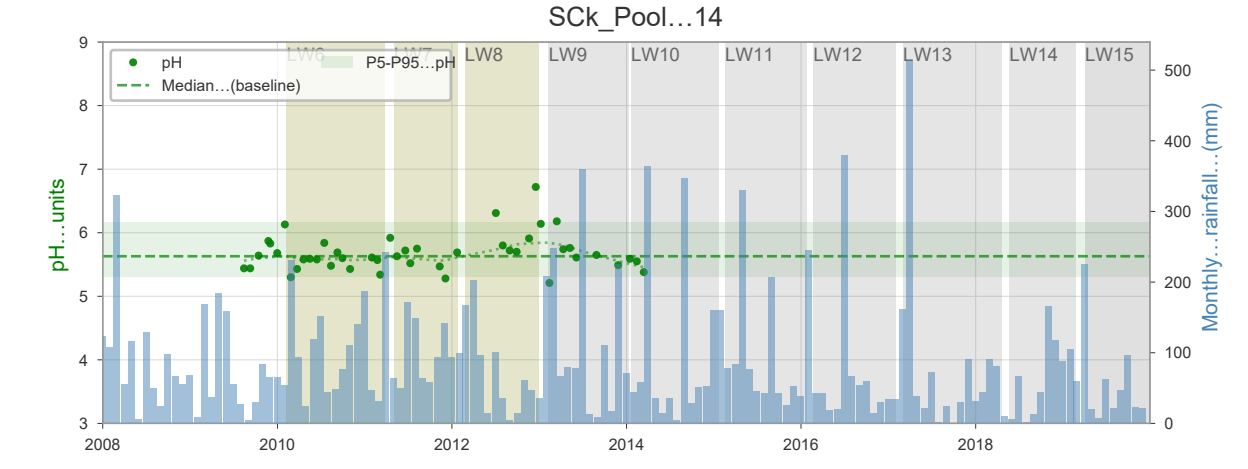

SCk_Pool…13
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

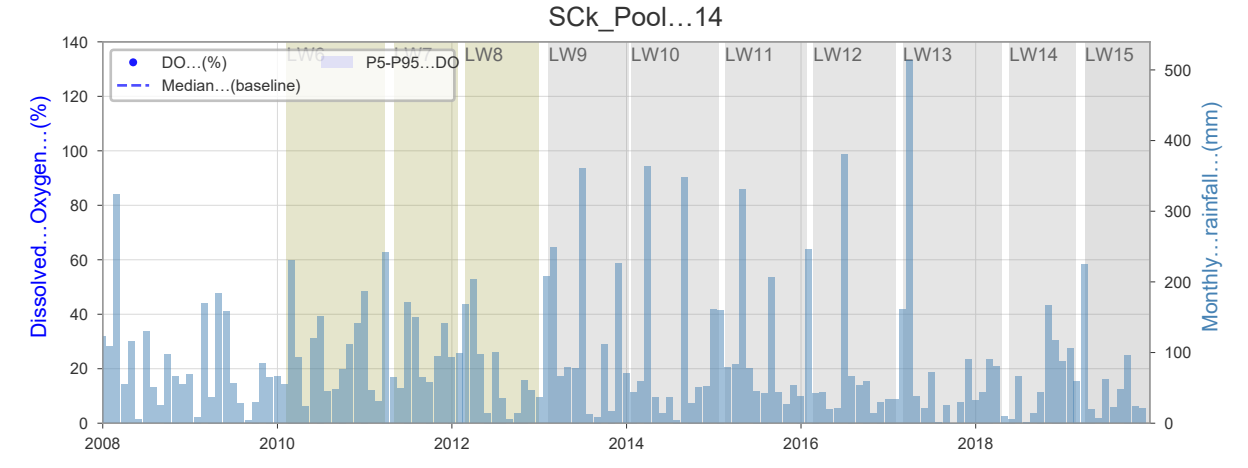

SCk_Pool…13
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

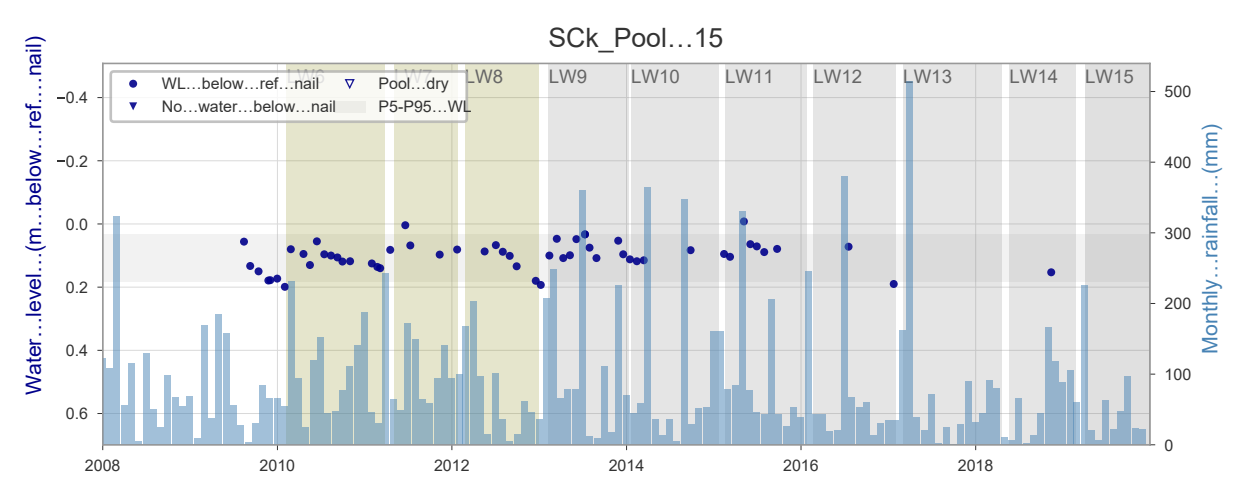

SCk_Pool…13
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

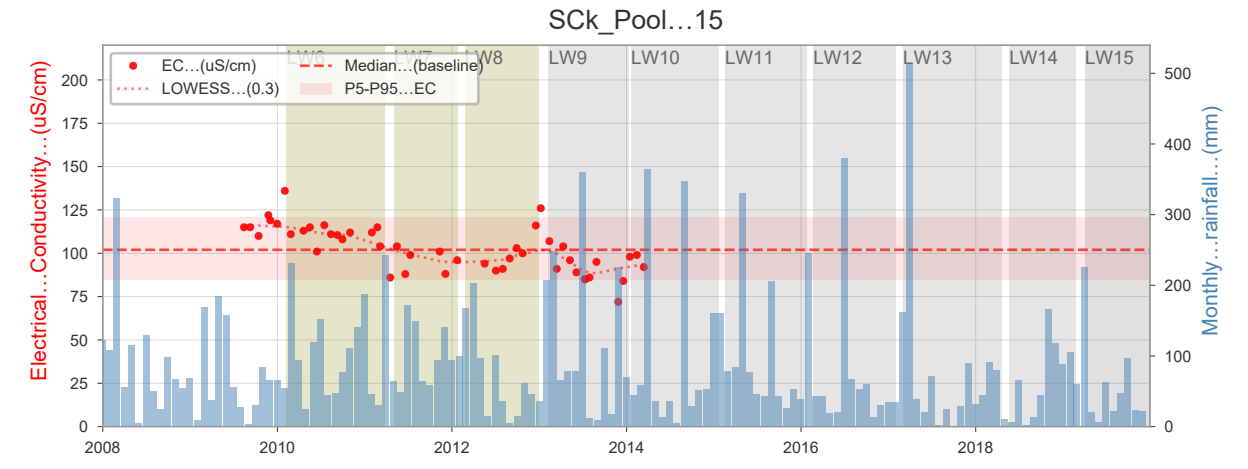

SCk_Pool…14
WL…below…ref…nail
No…water…below…nail
Pool…dry
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref.…nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

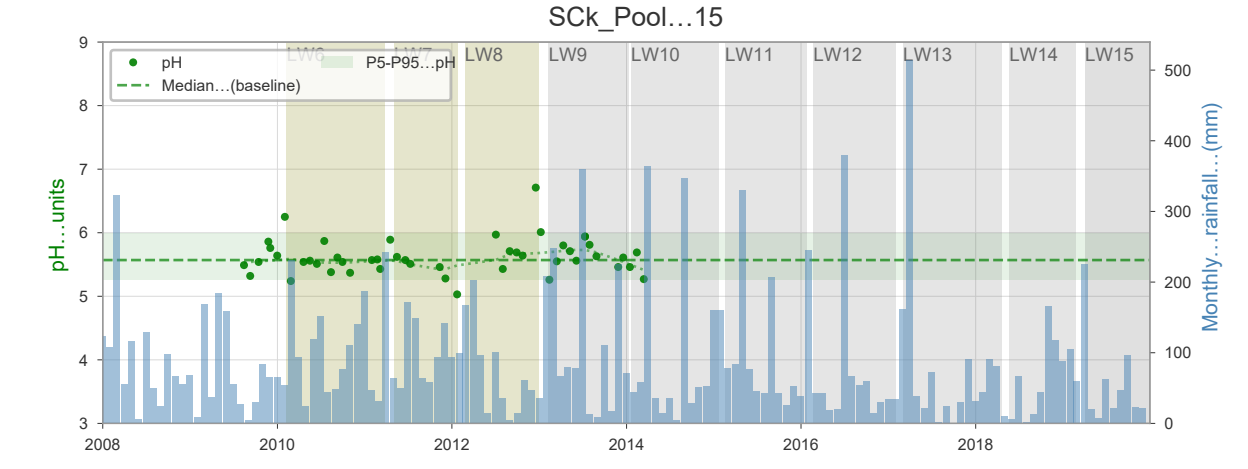

SCk_Pool…14
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

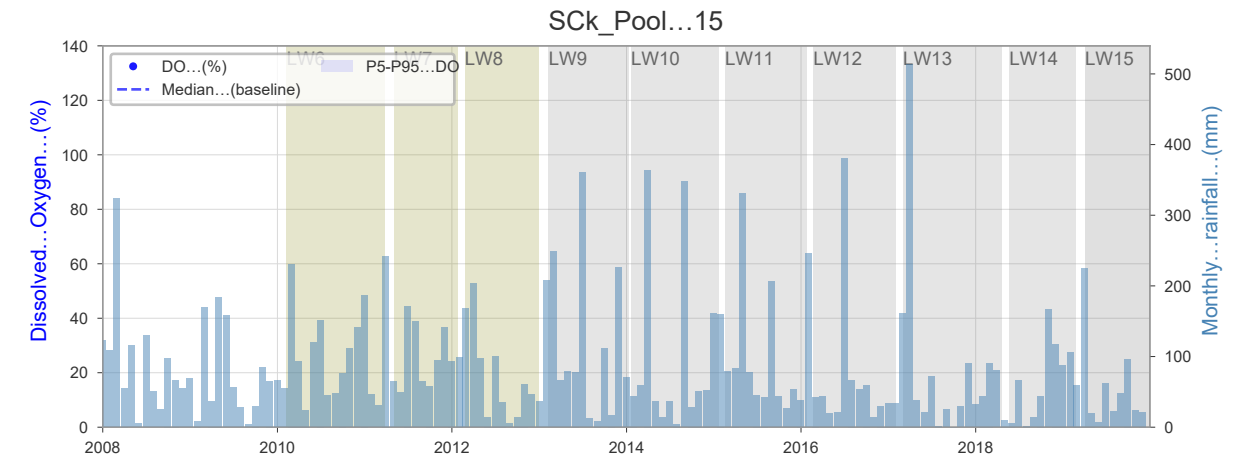

SCk_Pool…14
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

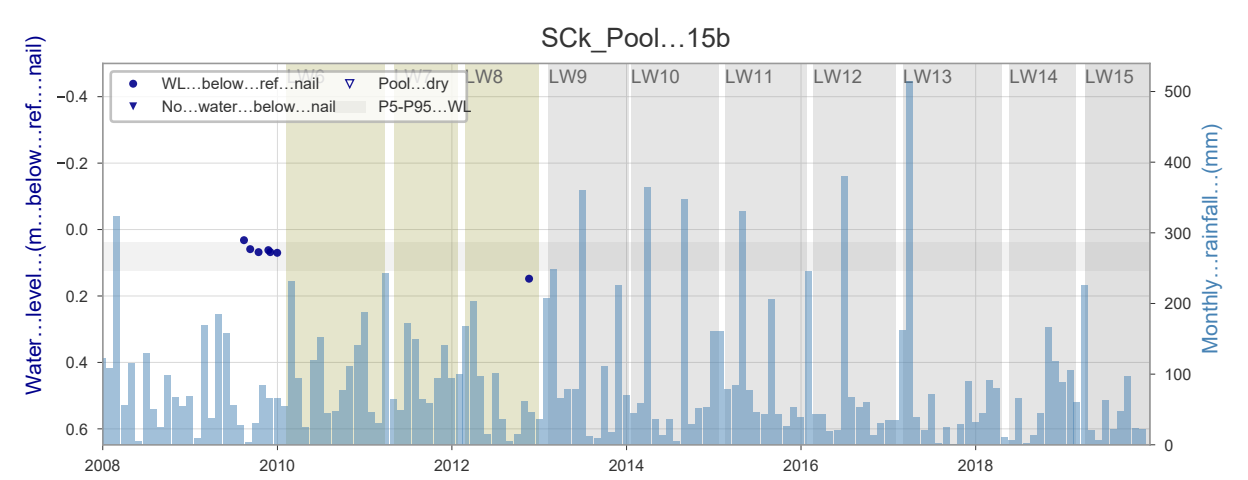

SCk_Pool…14
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

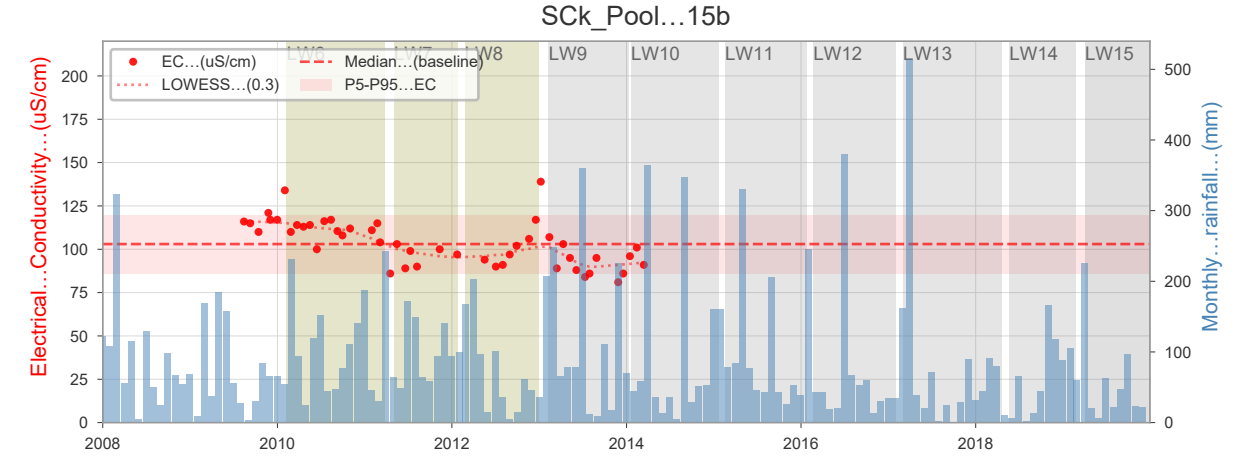

SCk_Pool…15
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

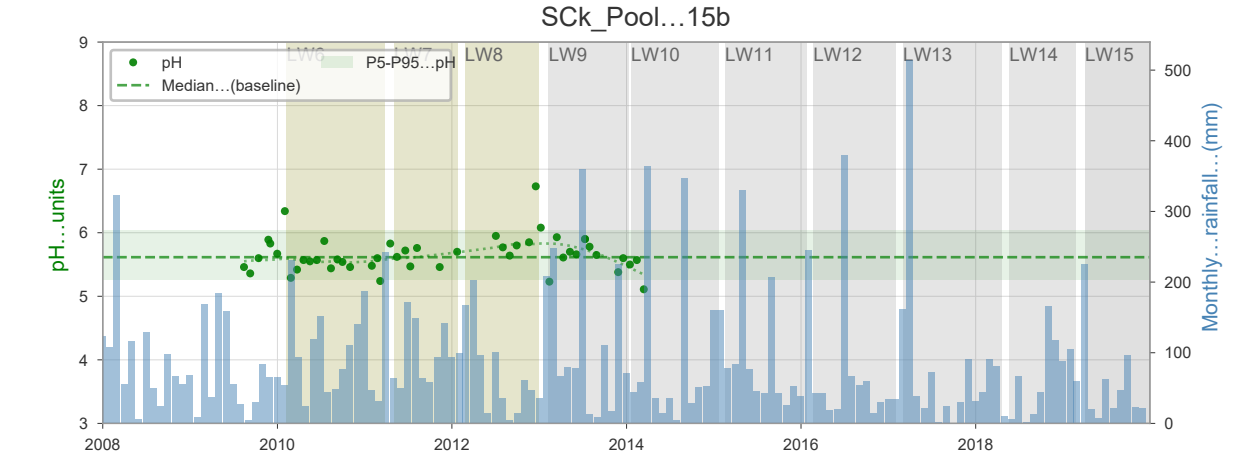

SCk_Pool…15
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

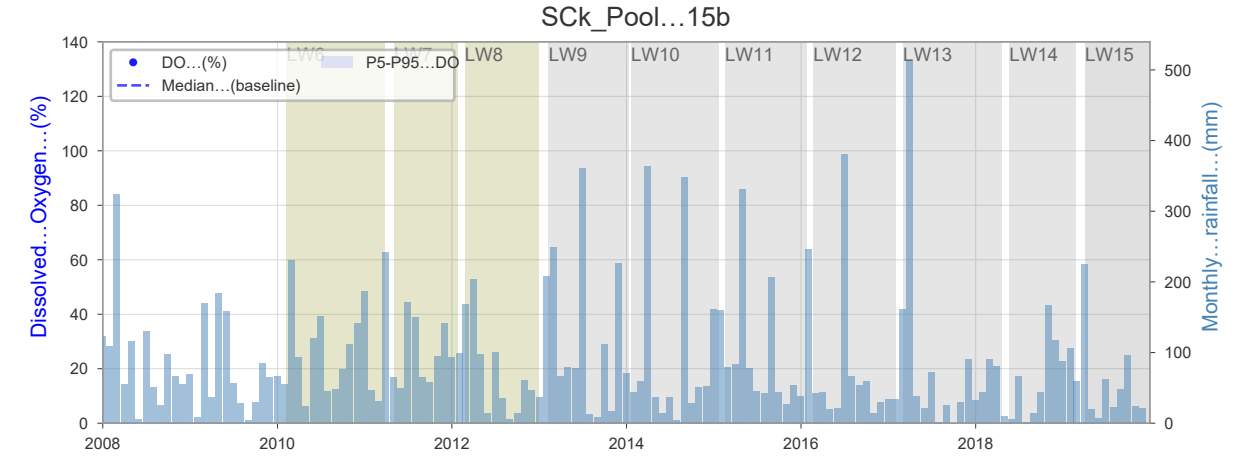

SCk_Pool…15
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

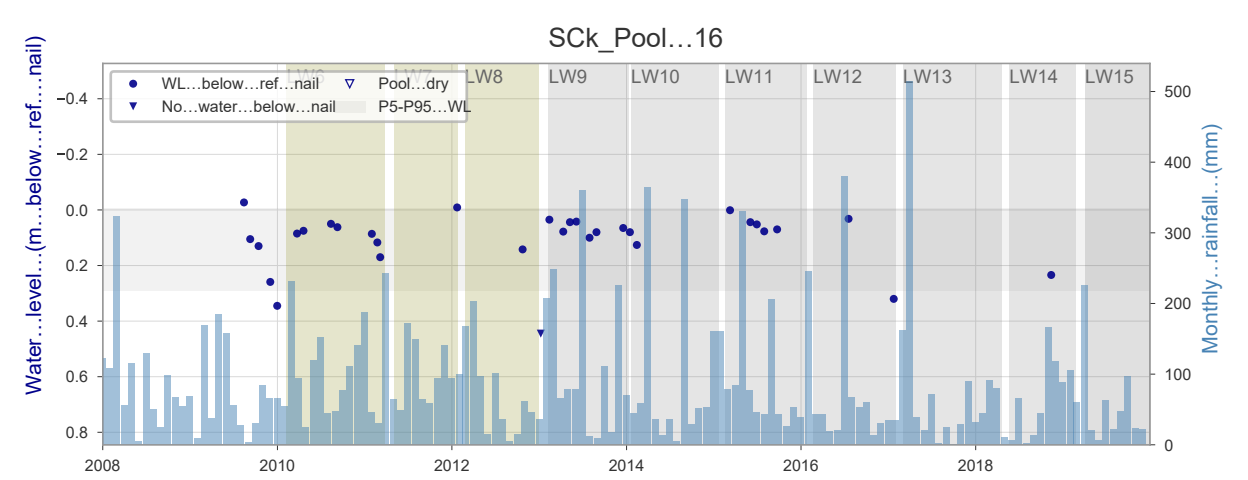

SCk_Pool…15
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

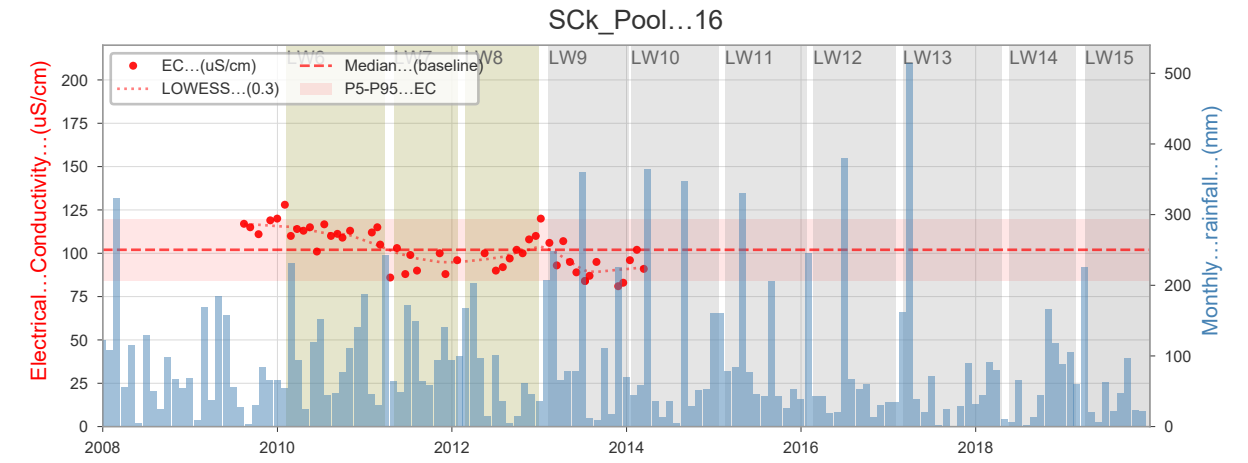

SCk_Pool…15b
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

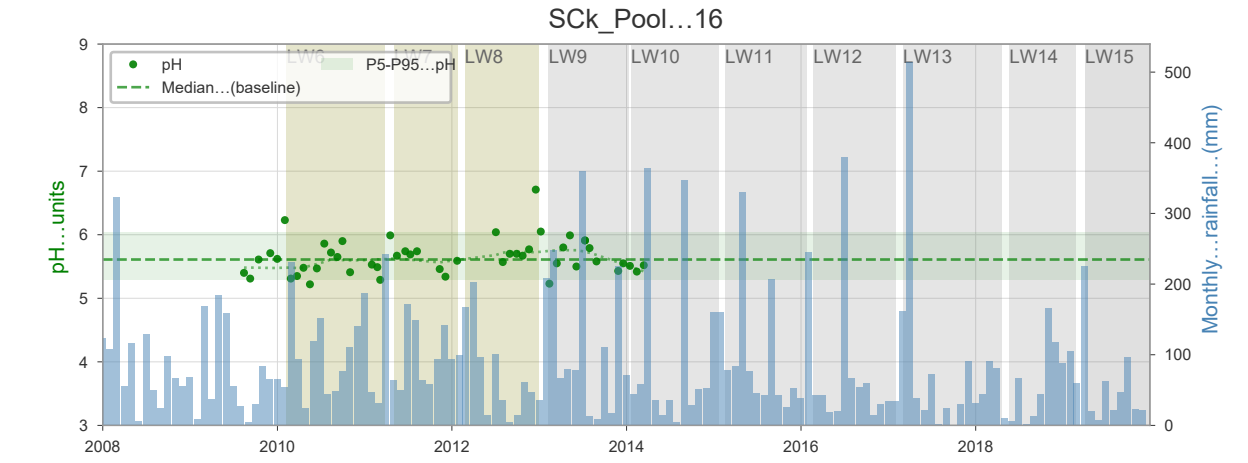

SCk_Pool…15b
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

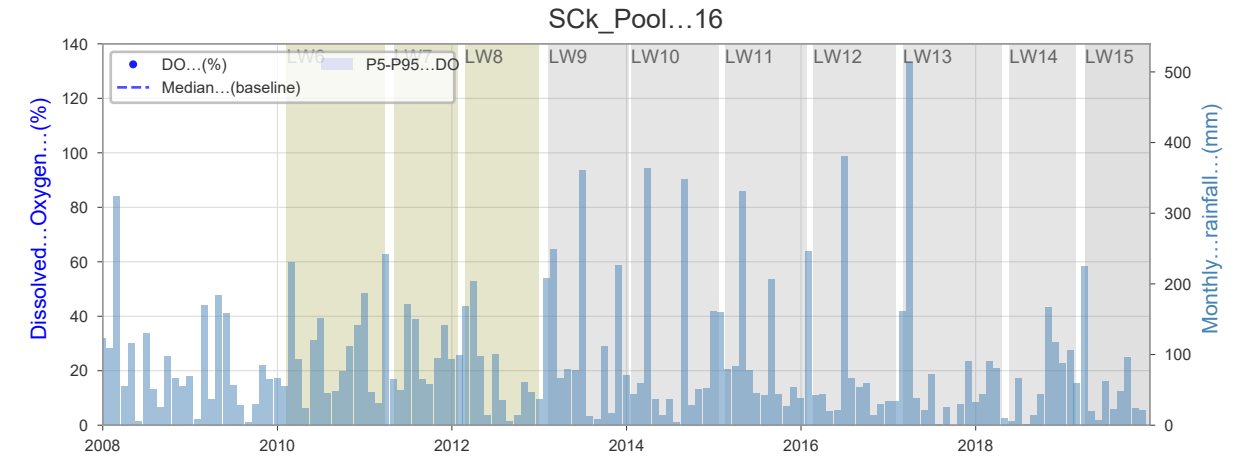

SCk_Pool…15b
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

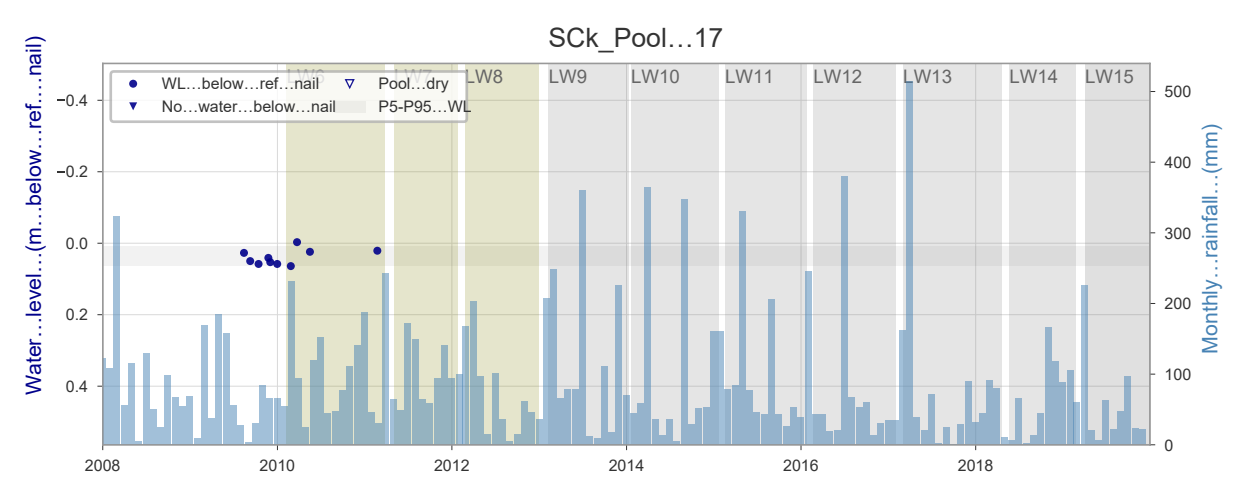

SCk_Pool…15b
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

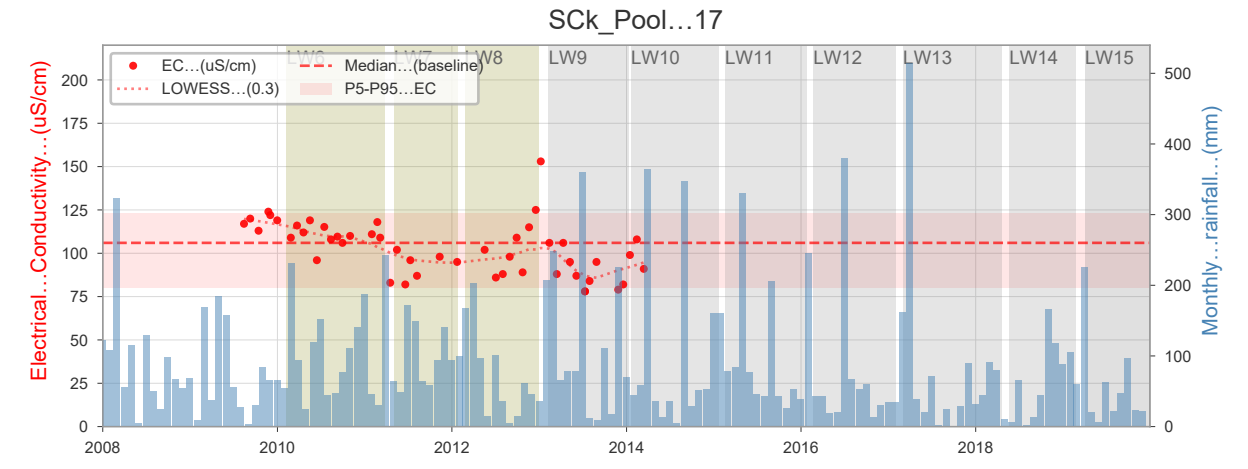

SCk_Pool…16
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

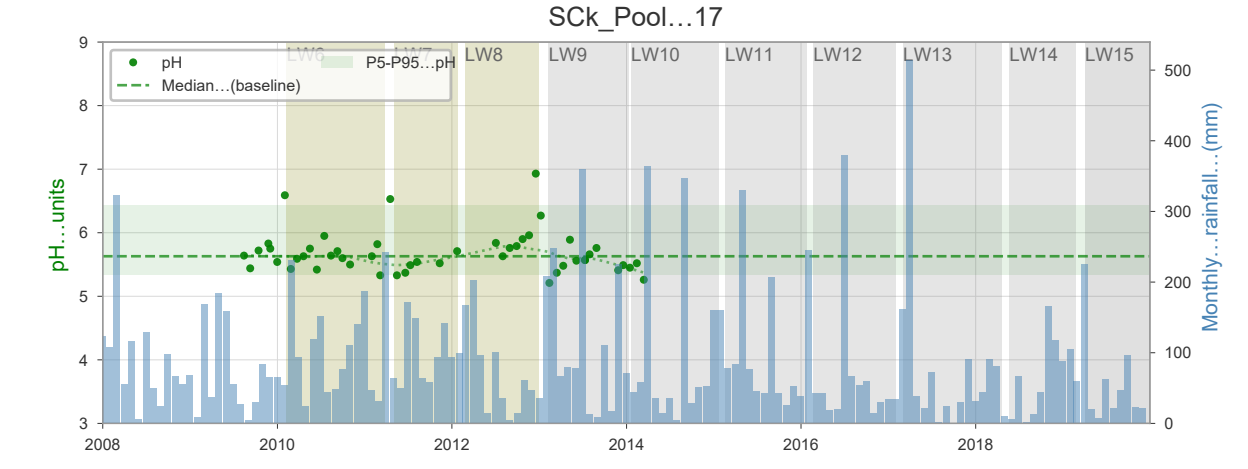

SCk_Pool…16
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

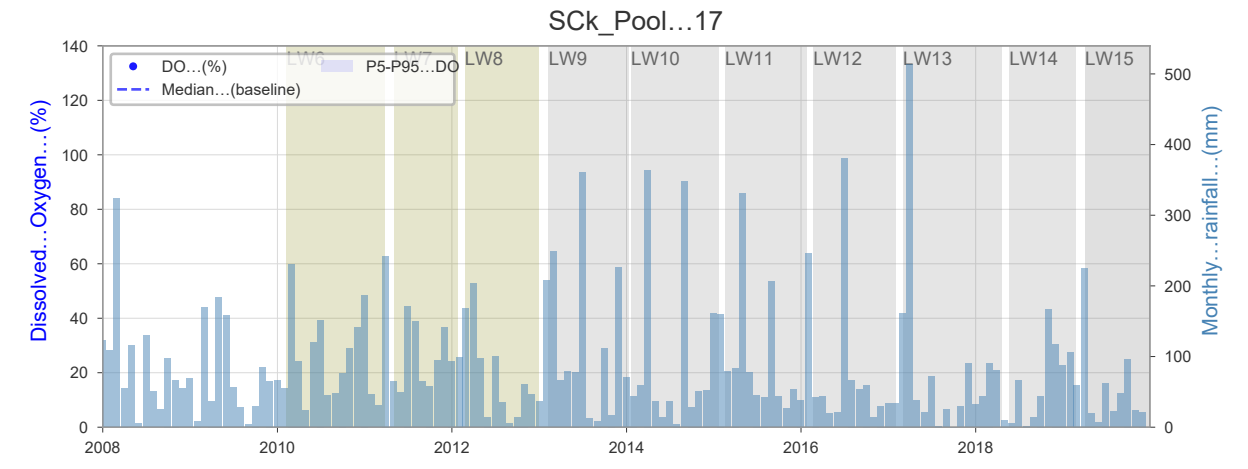

SCk_Pool…16
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

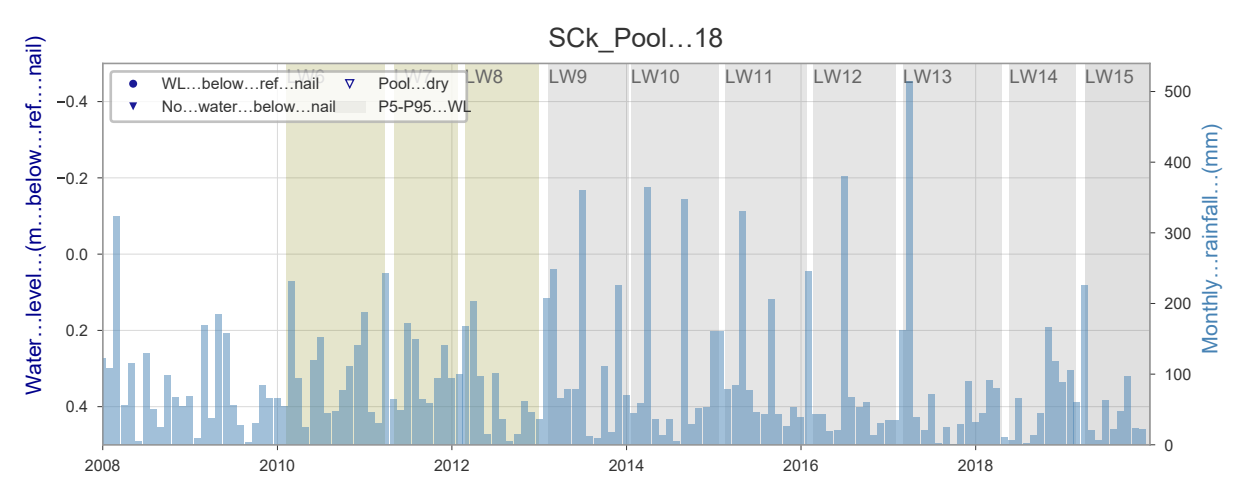

SCk_Pool…16
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

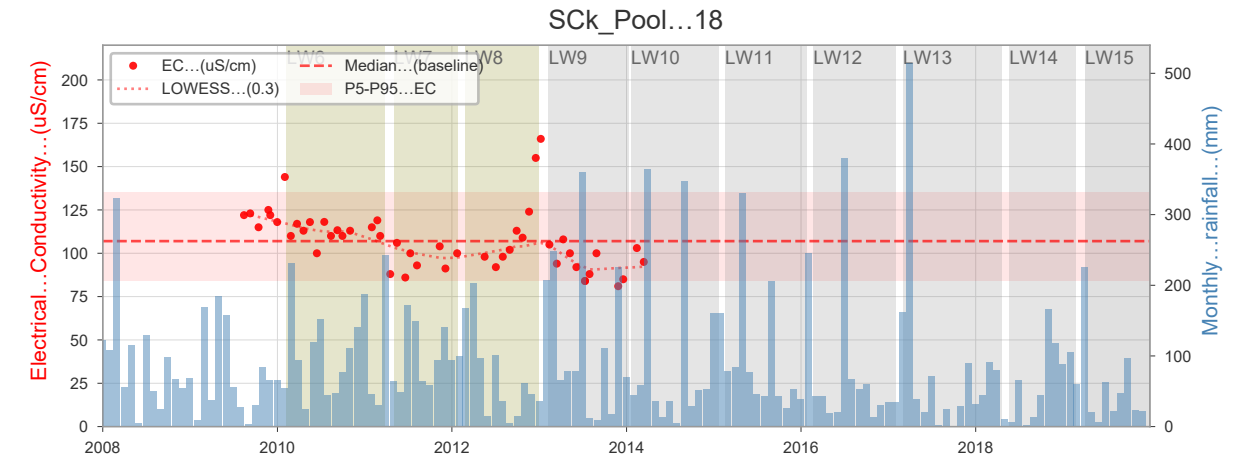

SCk_Pool…17
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

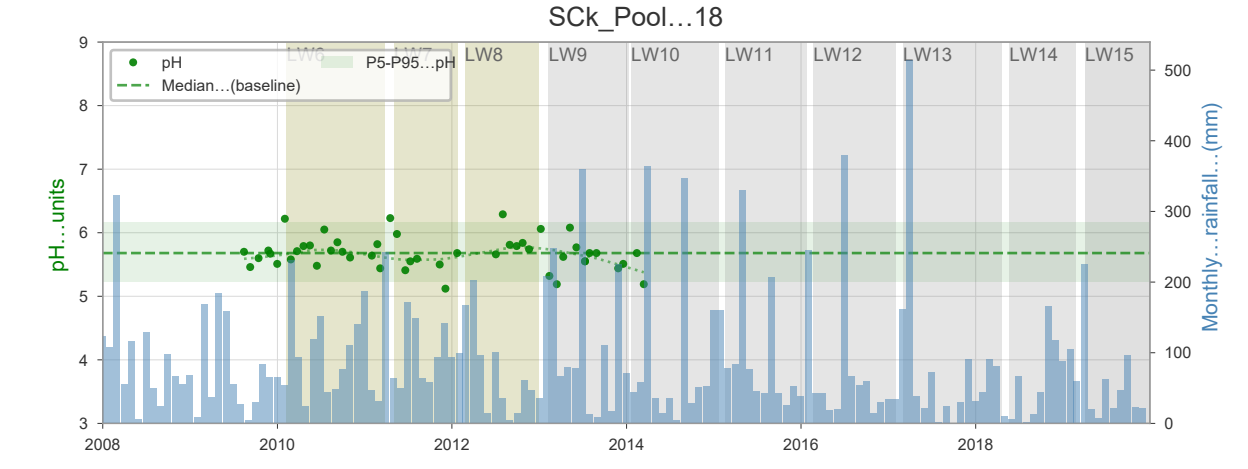

SCk_Pool…17
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

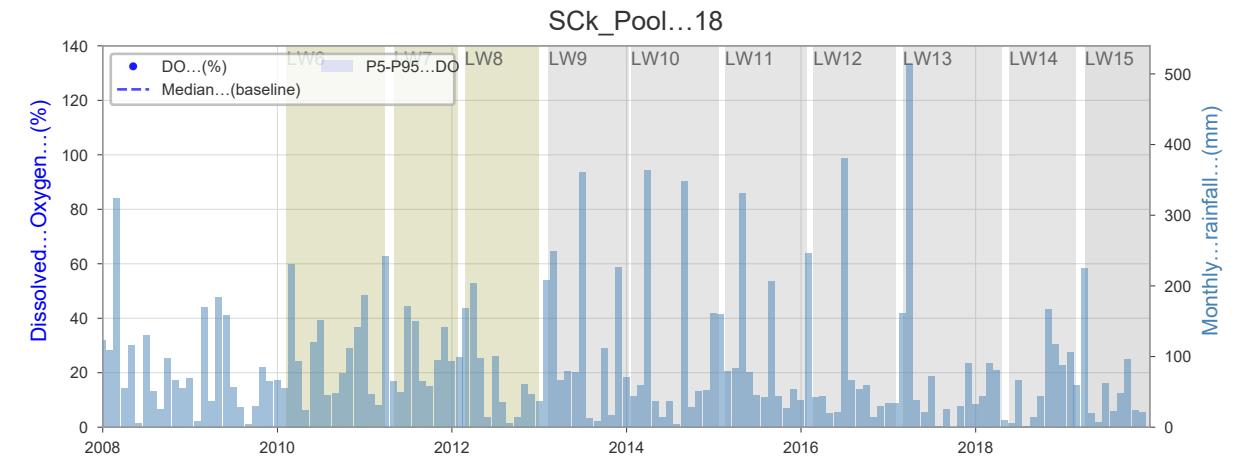

SCk_Pool…17
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

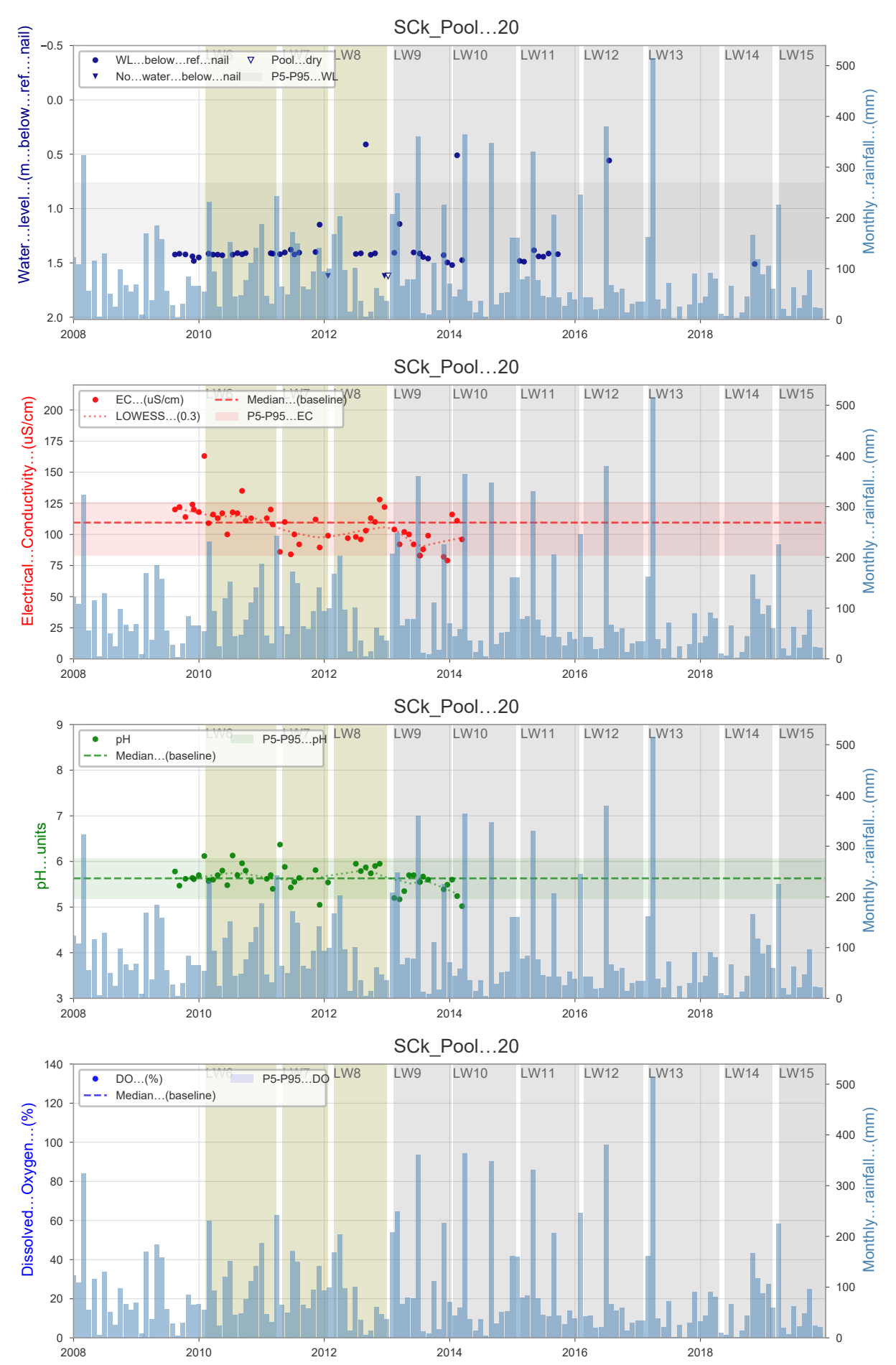

SCk_Pool…17
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

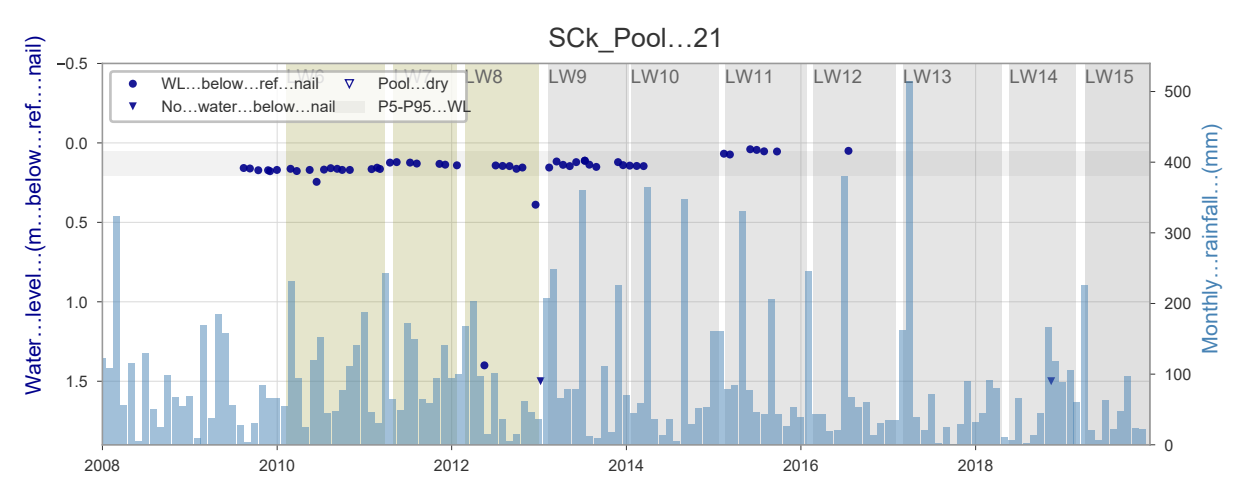

SCk_Pool…18
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

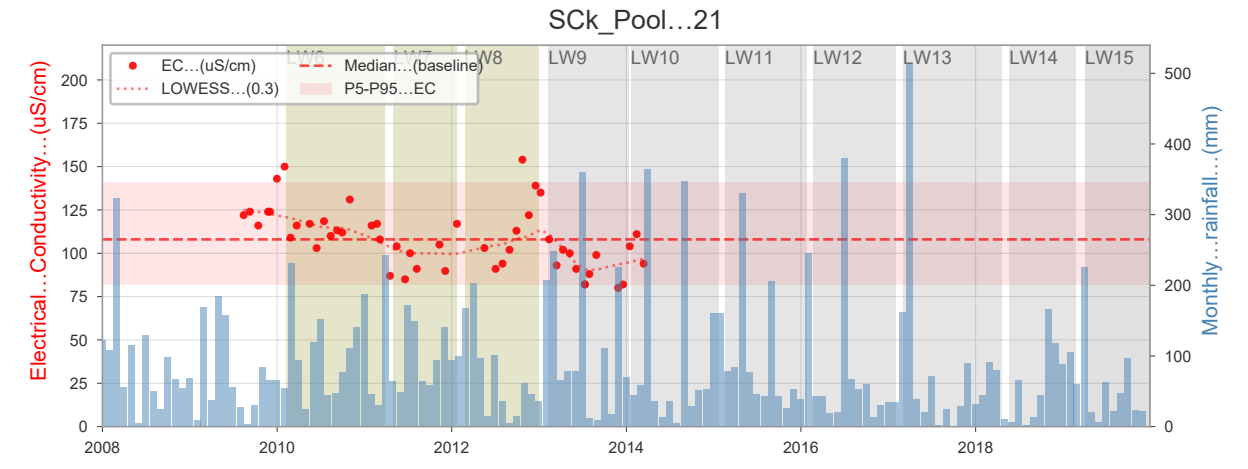

SCk_Pool…18
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

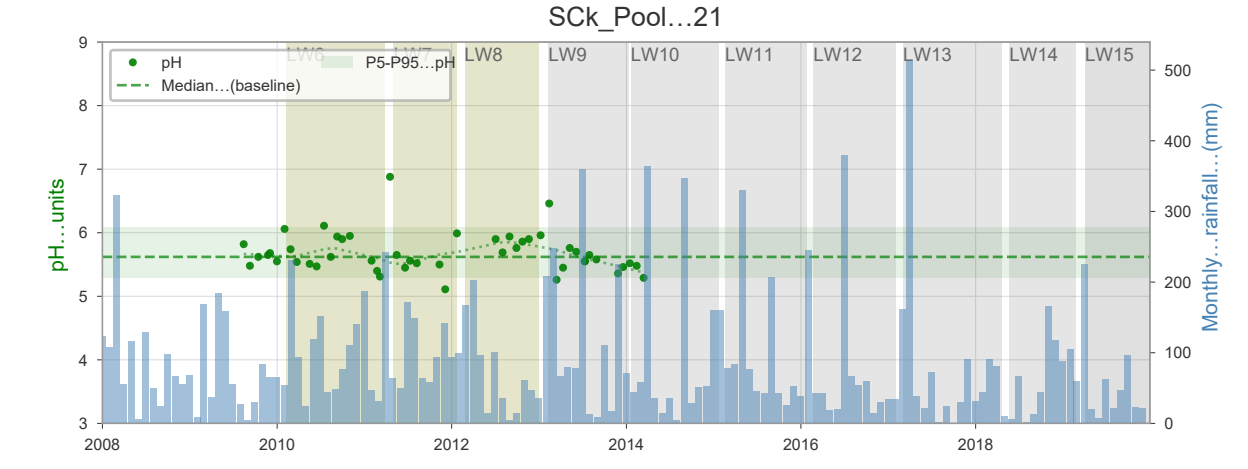

SCk_Pool…18
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

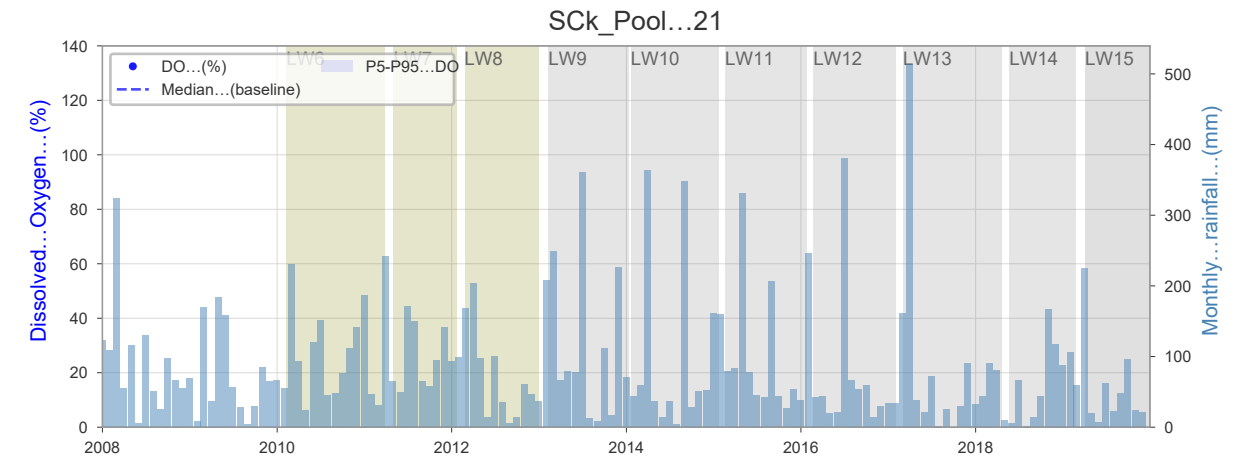

SCk_Pool…18
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

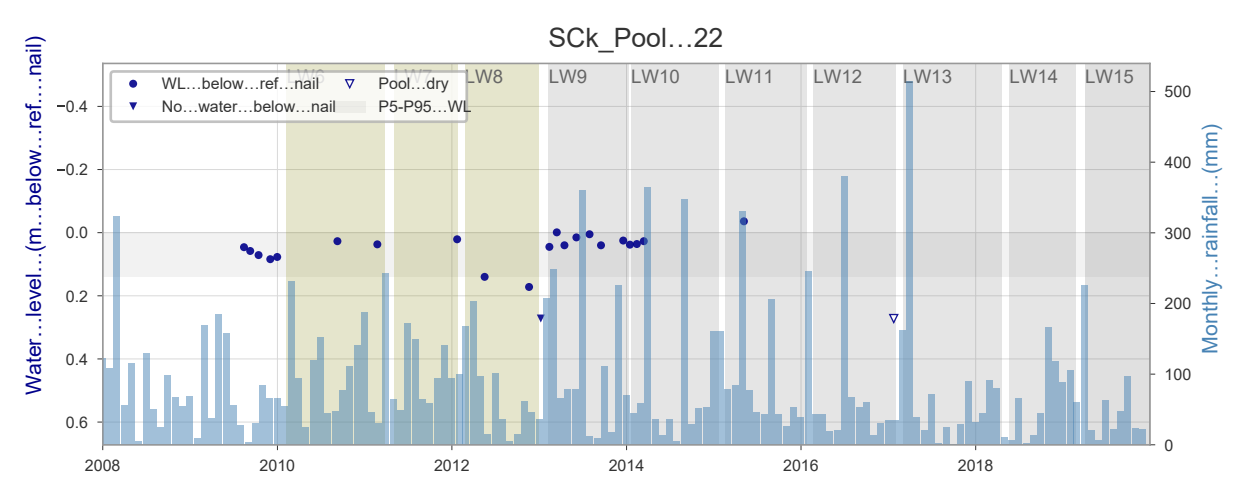

SCk_Pool…20
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018
SCk_Pool…20
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
SCk_Pool…20
pH
P5-P95…pH
Median…(baseline)
pH…units
Monthly…rainfall…(mm)
SCk_Pool…20
DO…(%)
P5-P95…DO
Median…(baseline)
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)

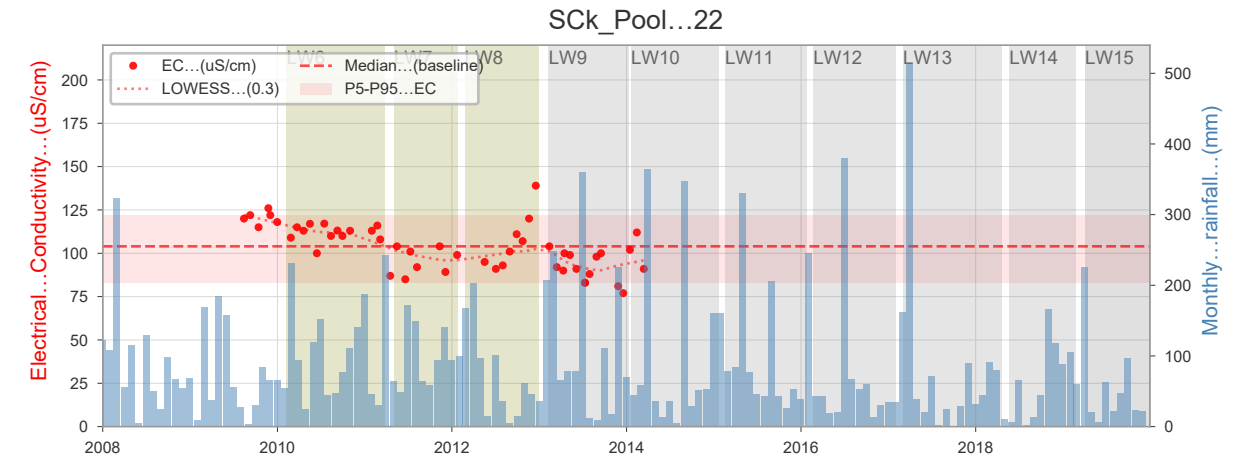

SCk_Pool…21
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

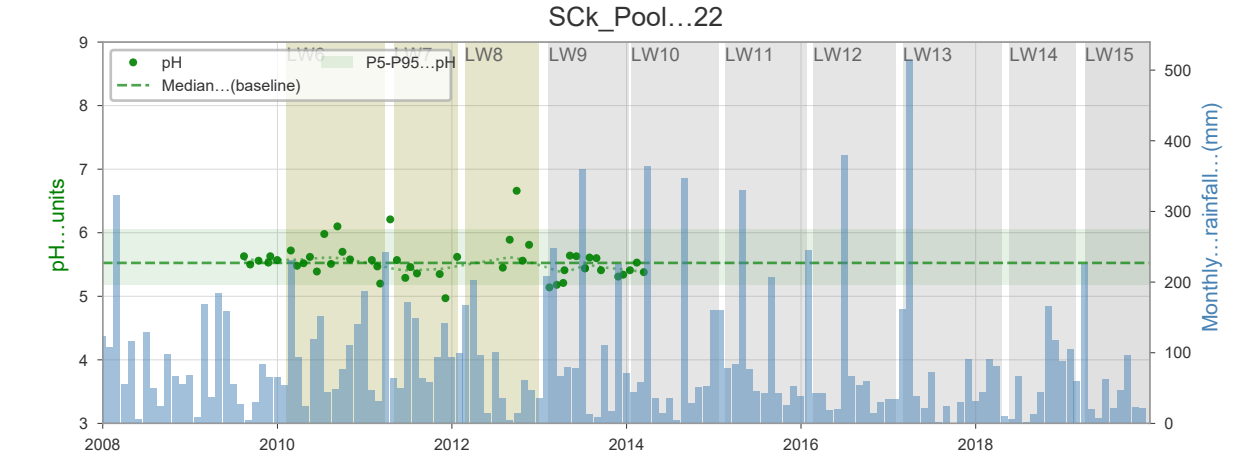

SCk_Pool…21
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

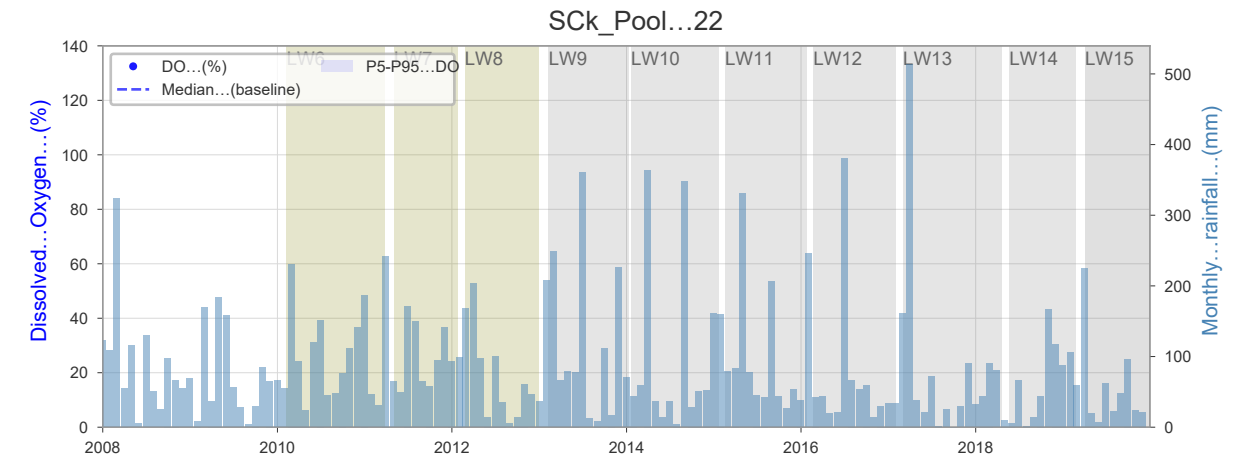

SCk_Pool…21
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

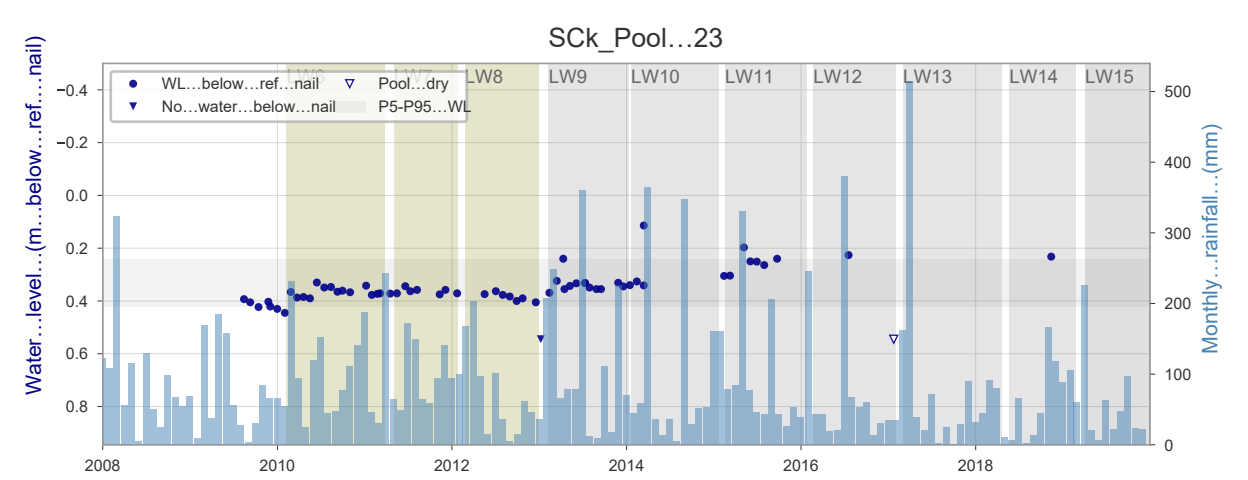

SCk_Pool…21
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

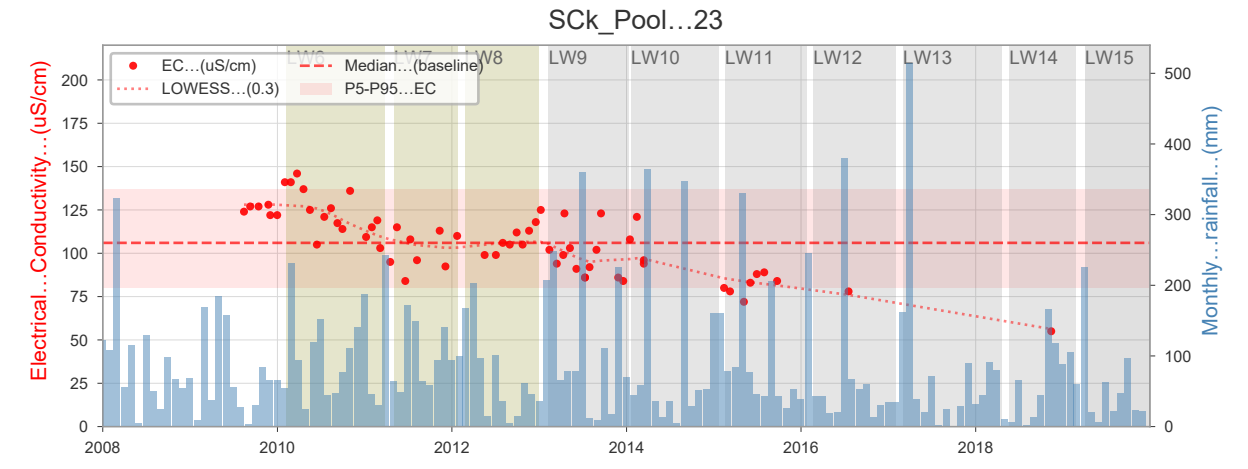

SCk_Pool…22
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref.…nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

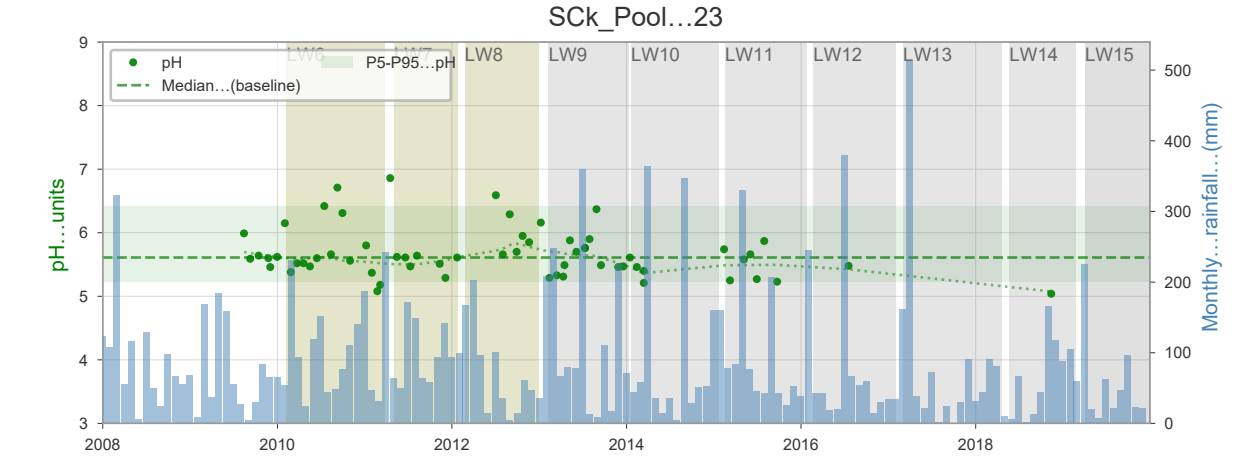

SCk_Pool…22
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

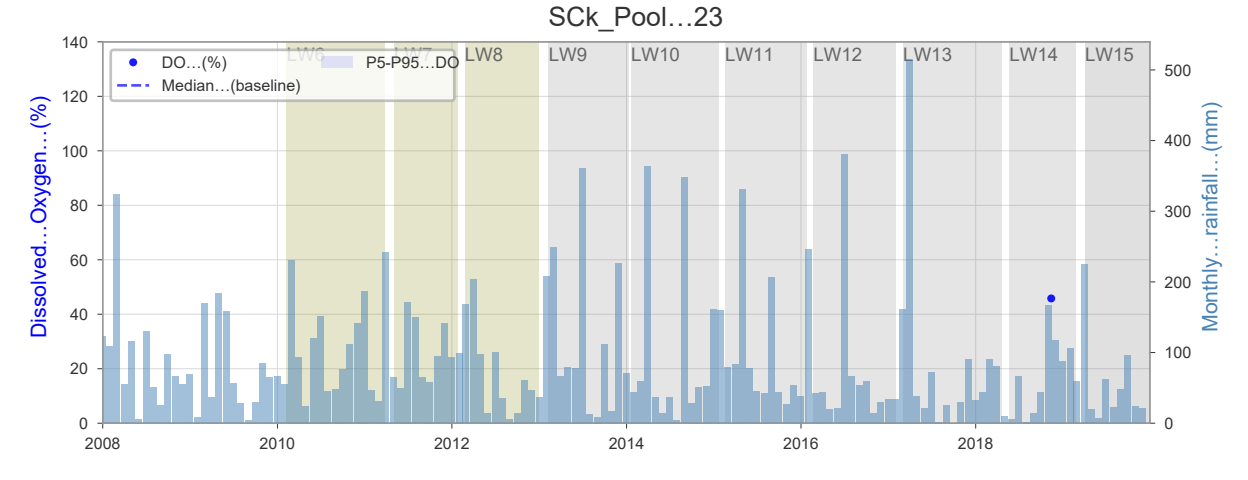

SCk_Pool…22
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

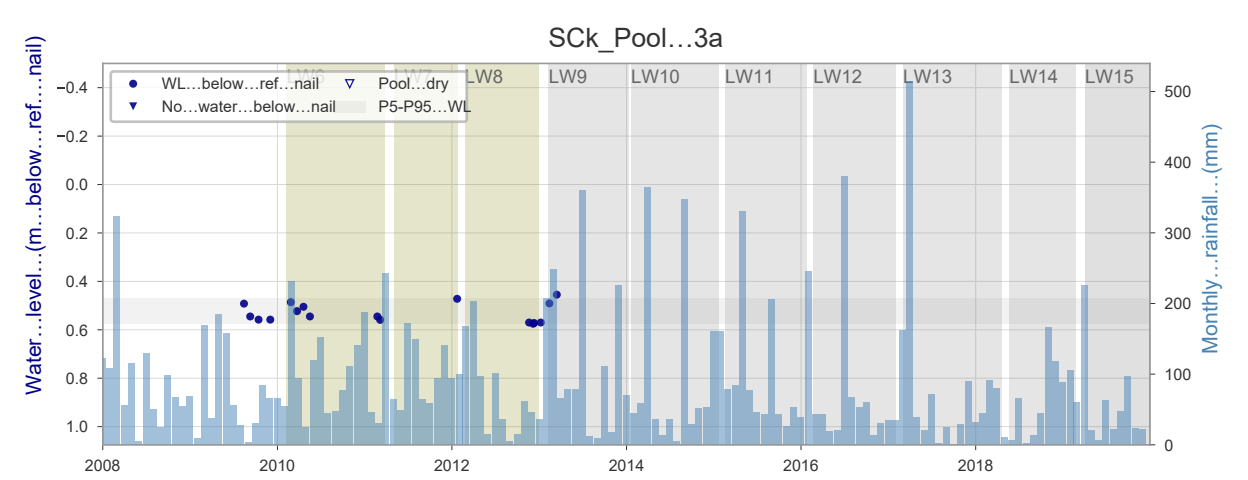

SCk_Pool…22
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

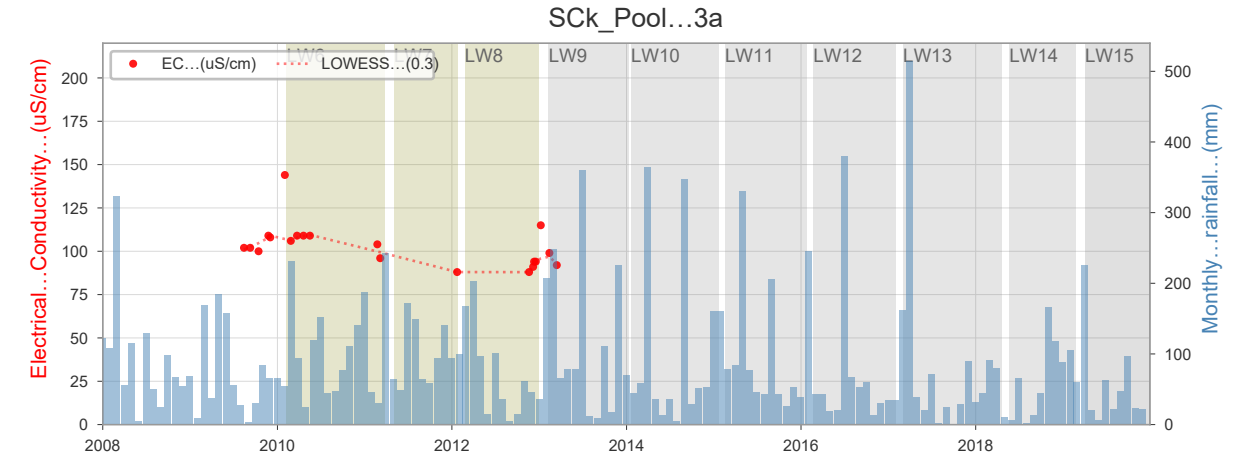

SCk_Pool…23
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

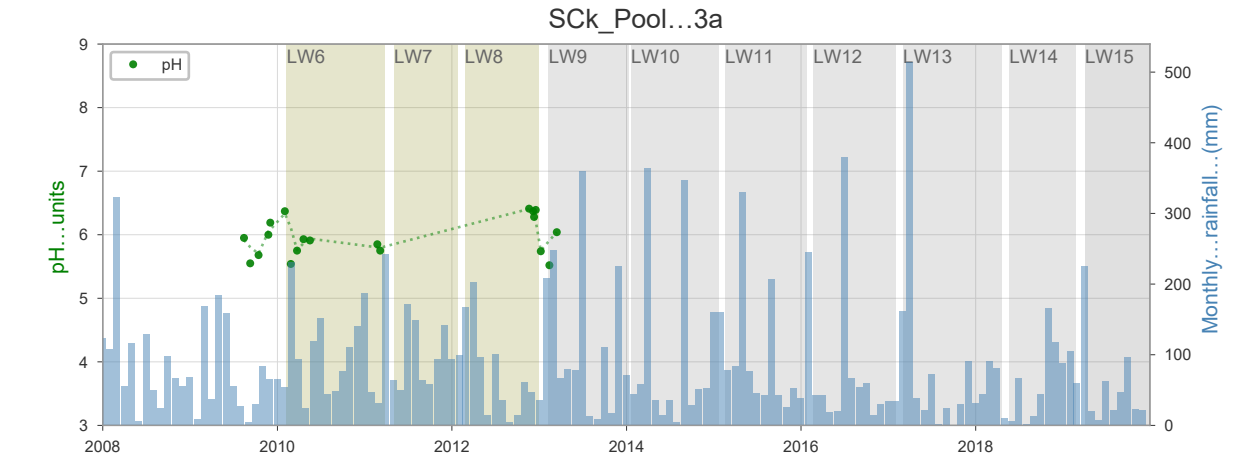

SCk_Pool…23
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

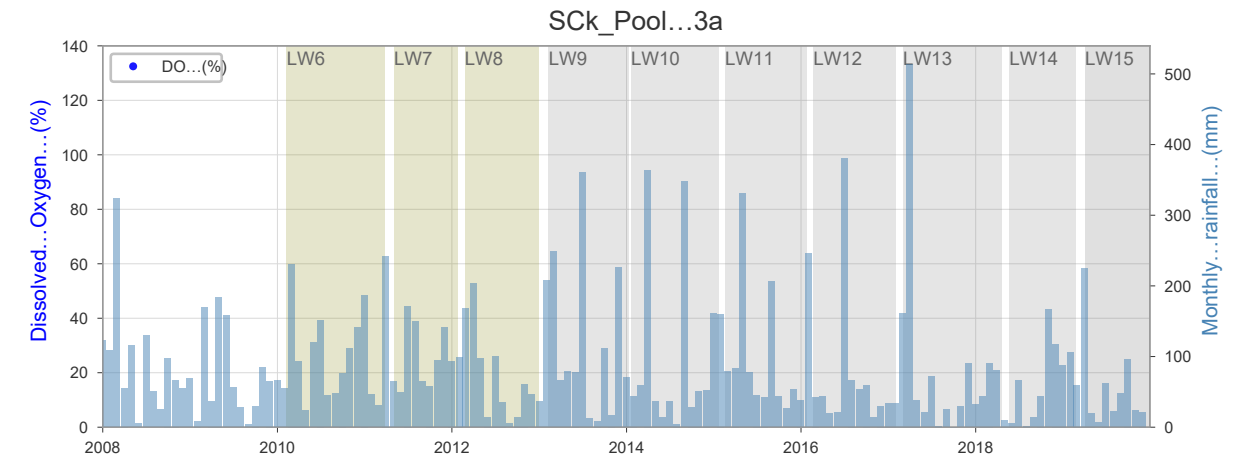

SCk_Pool…23
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

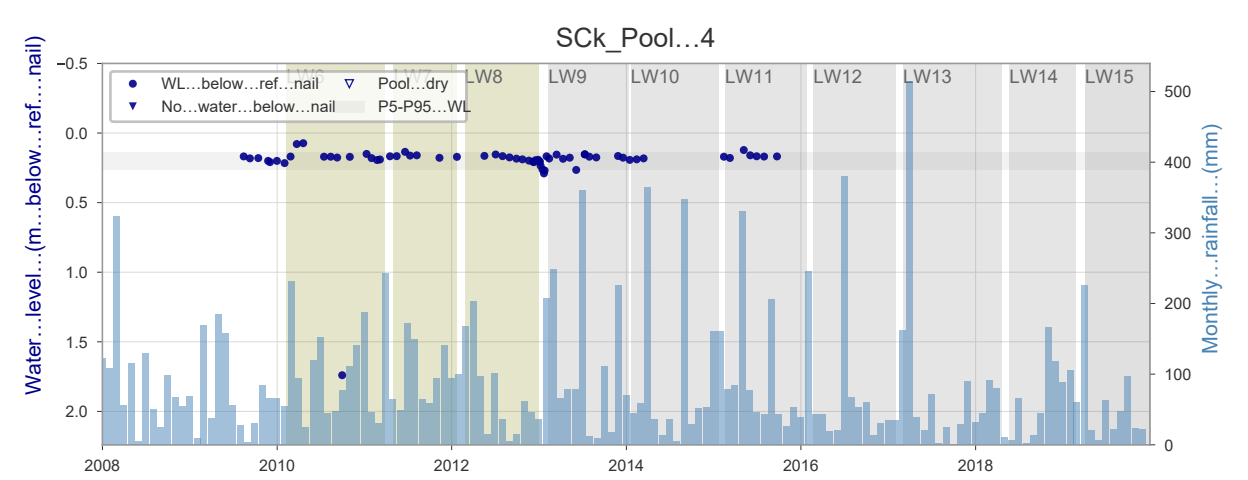

SCk_Pool…23
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

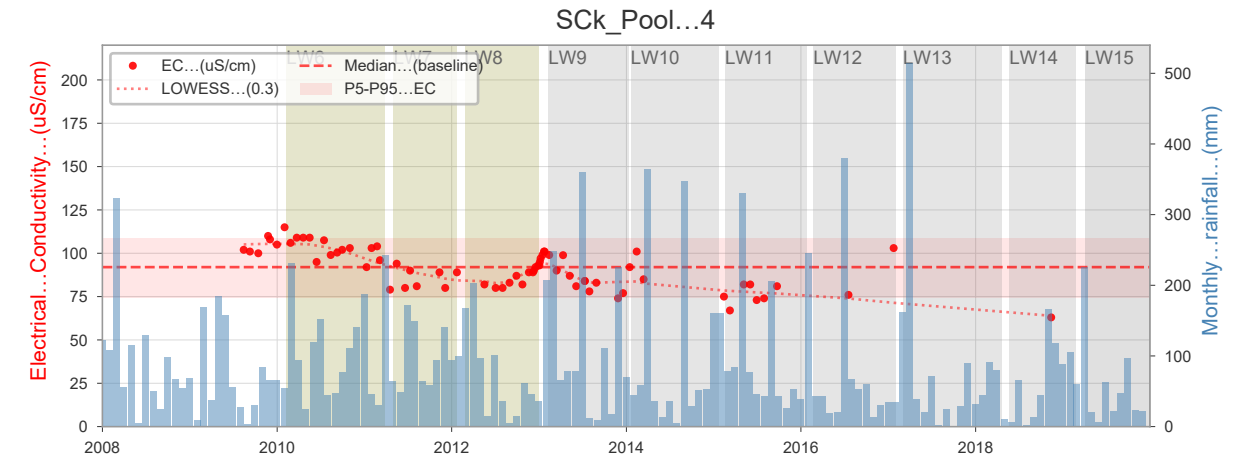

SCk_Pool…3a
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

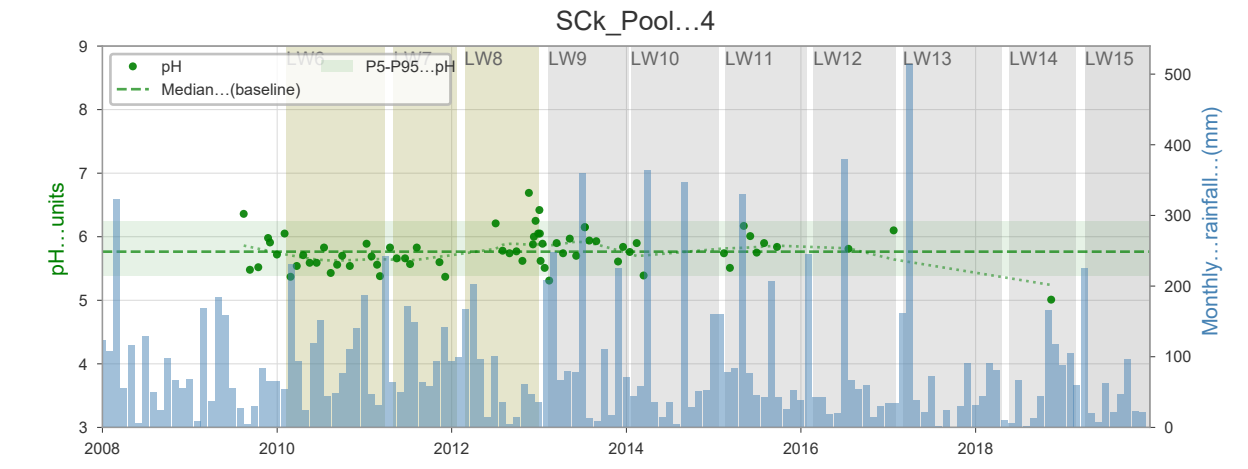

SCk_Pool…3a
EC…(uS/cm)
LOWESS…(0.3)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

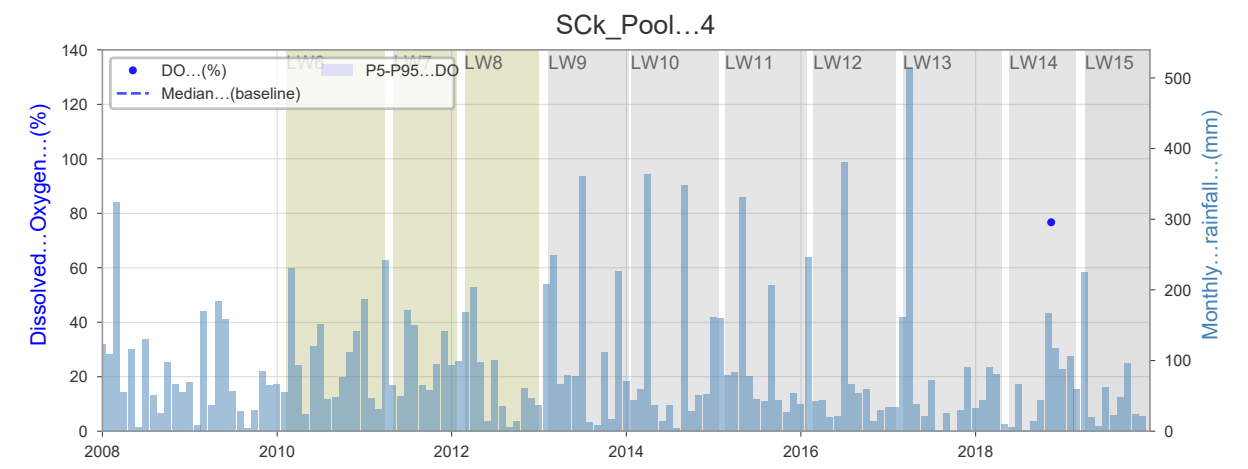

SCk_Pool…3a
pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

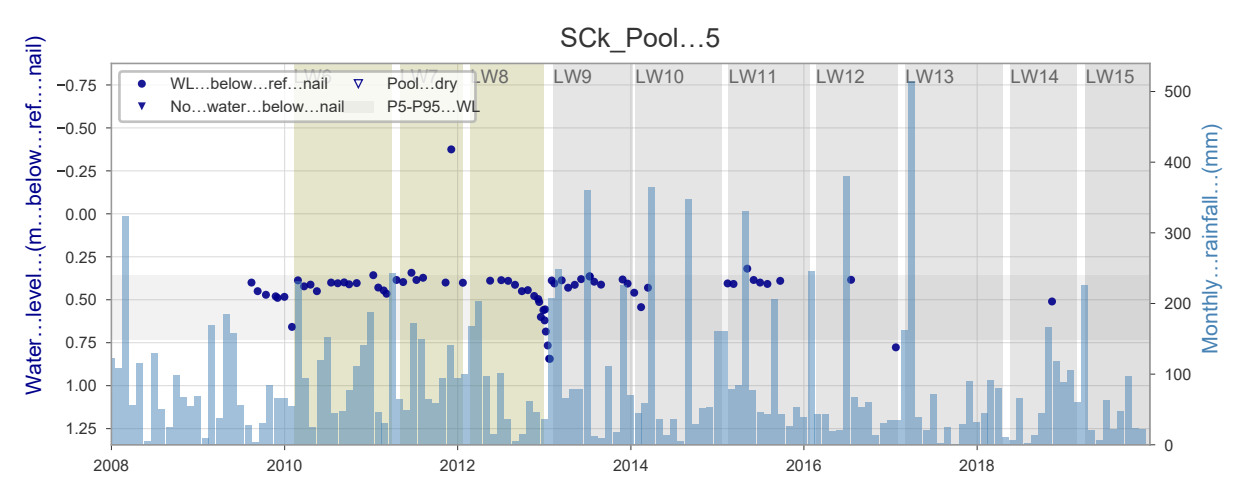

SCk_Pool…3a
DO…(%)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

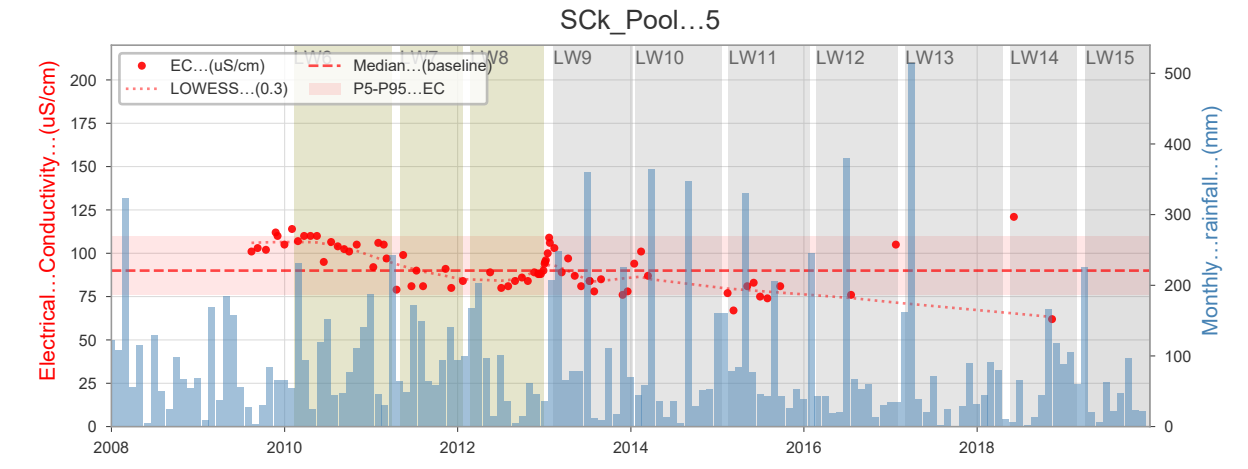

SCk_Pool…4
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

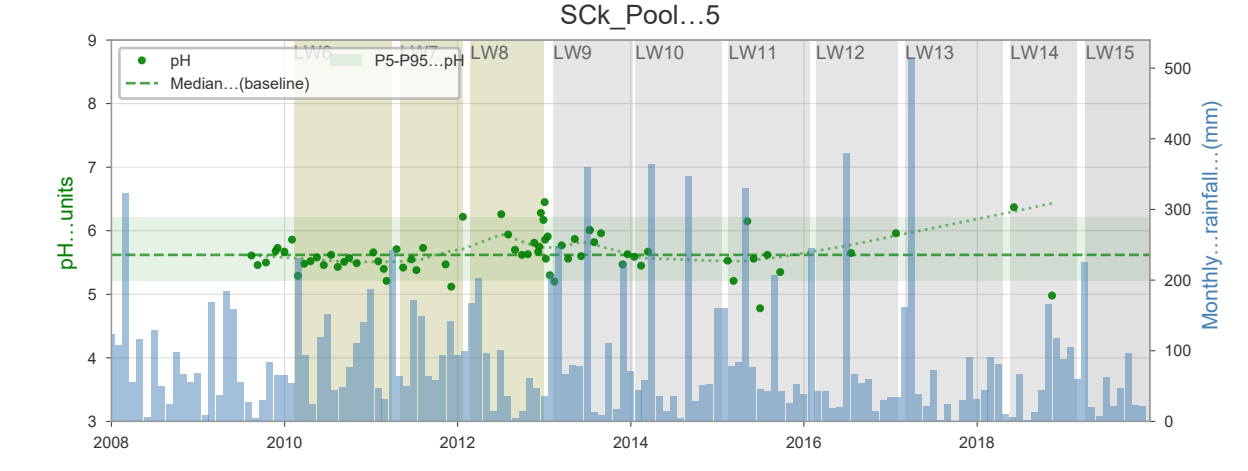

SCk_Pool…4
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

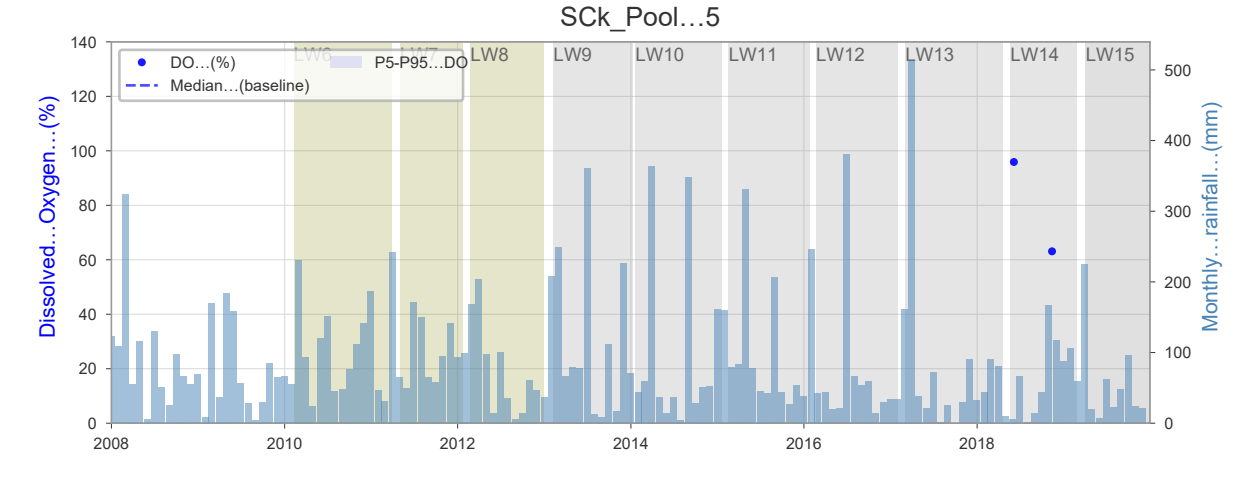

SCk_Pool…4
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

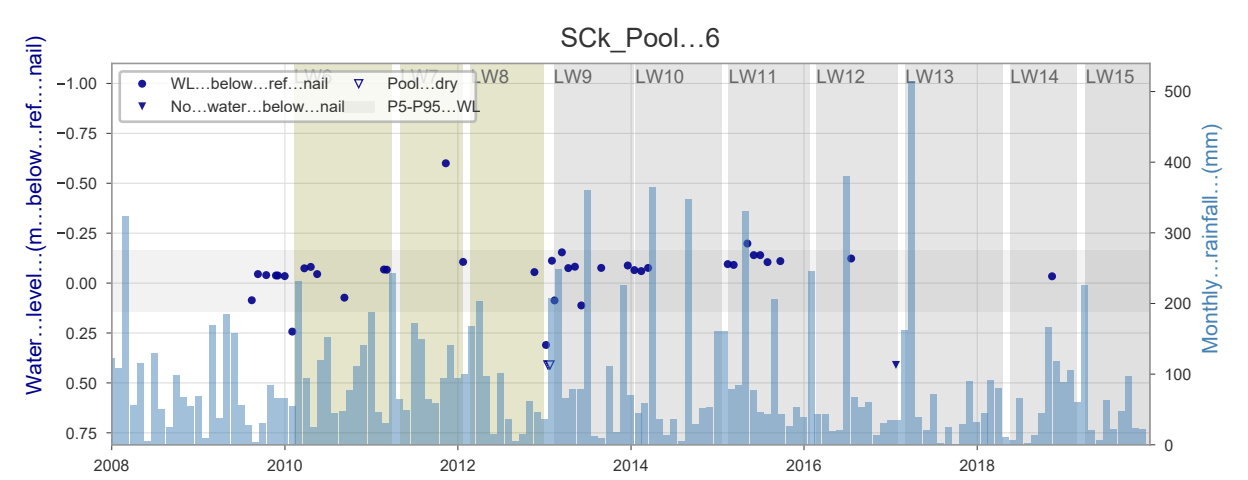

SCk_Pool…4
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

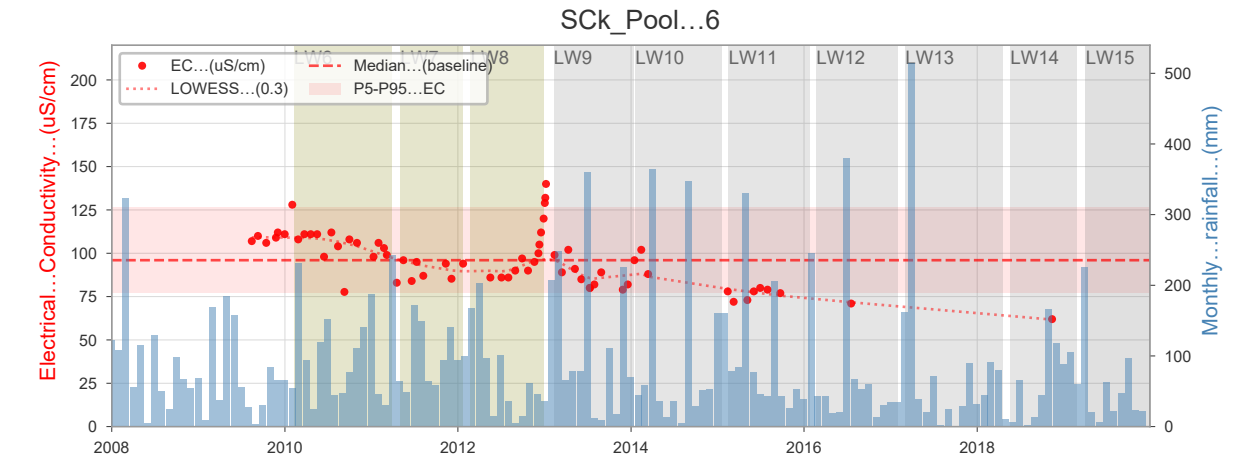

SCk_Pool…5
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

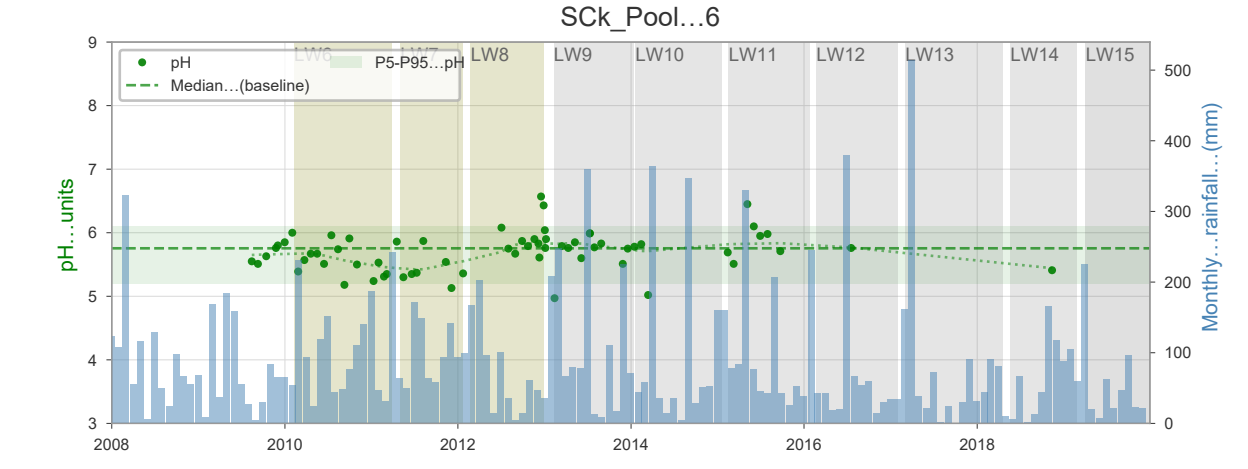

SCk_Pool…5
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

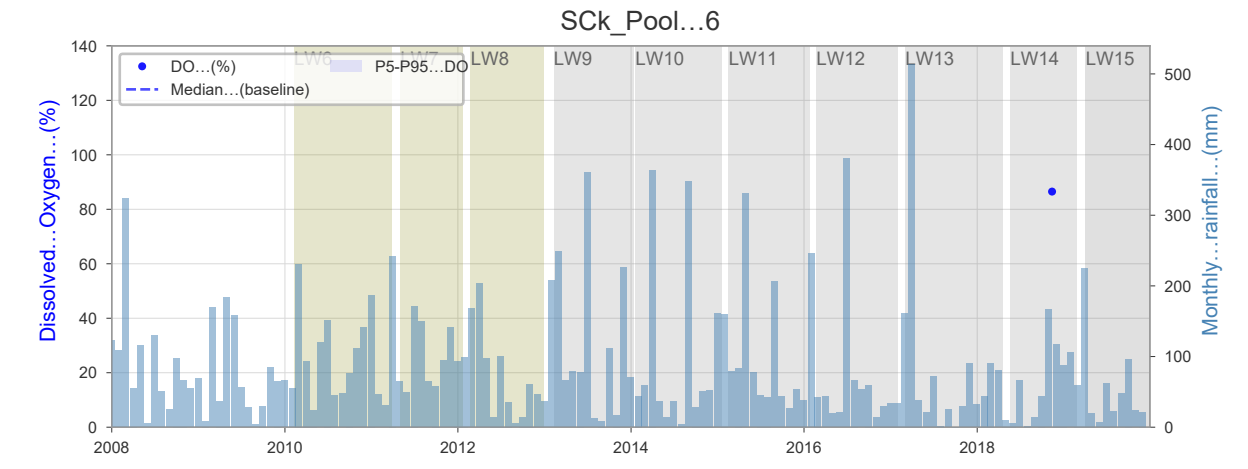

SCk_Pool…5
pH…units
Monthly…rainfall…(mm)
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

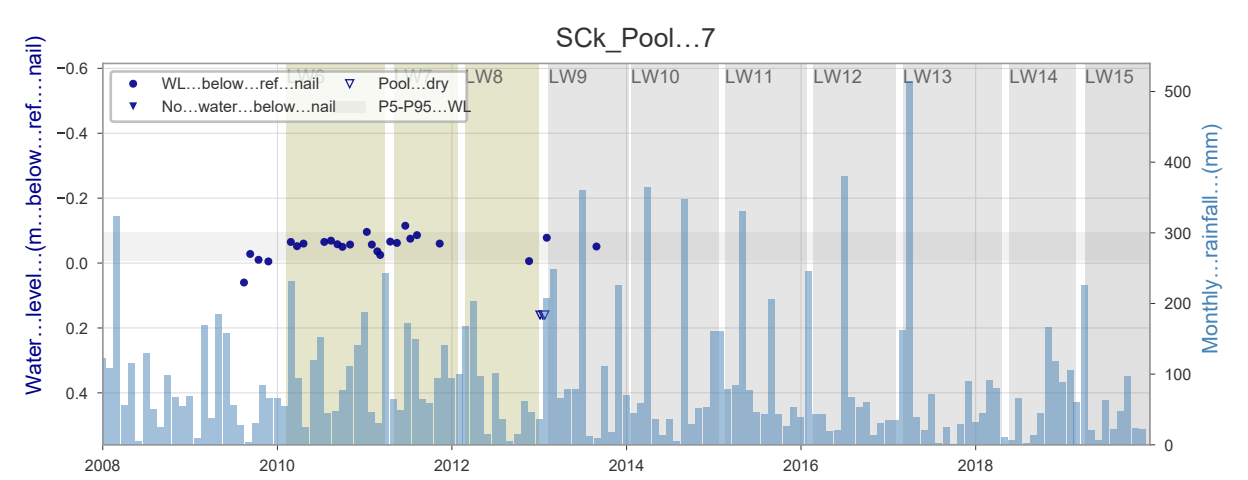

SCk_Pool…5
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

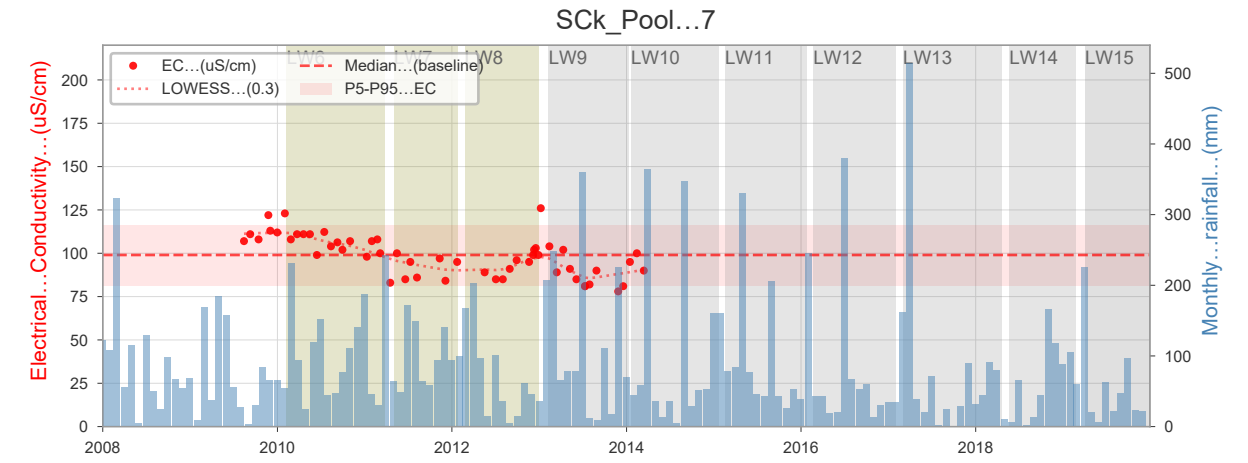

SCk_Pool…6
WL…below…ref…nail
No…water…below…nail
Pool…dry
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

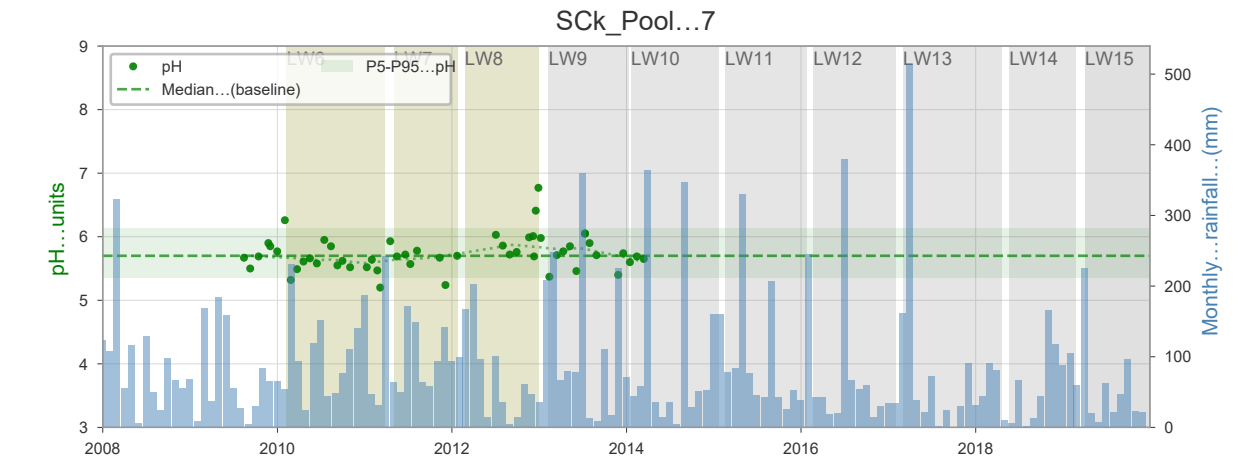

SCk_Pool…6
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

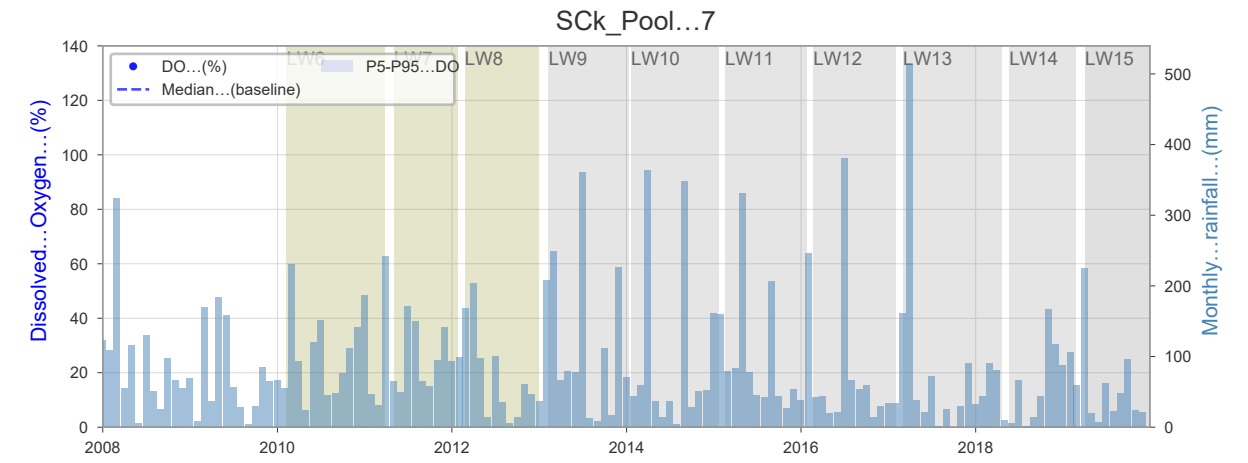

SCk_Pool…6
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

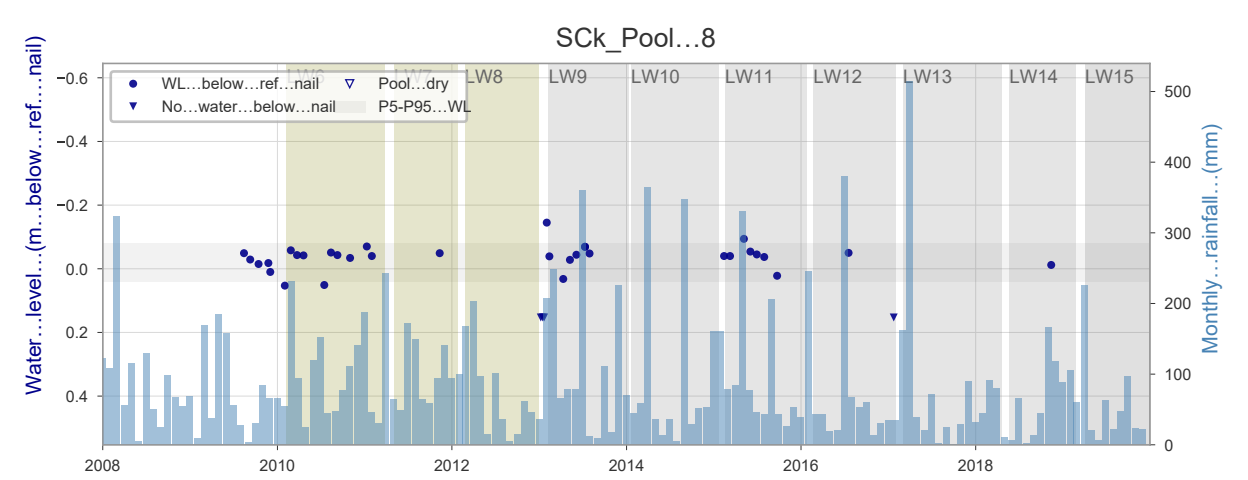

SCk_Pool…6
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

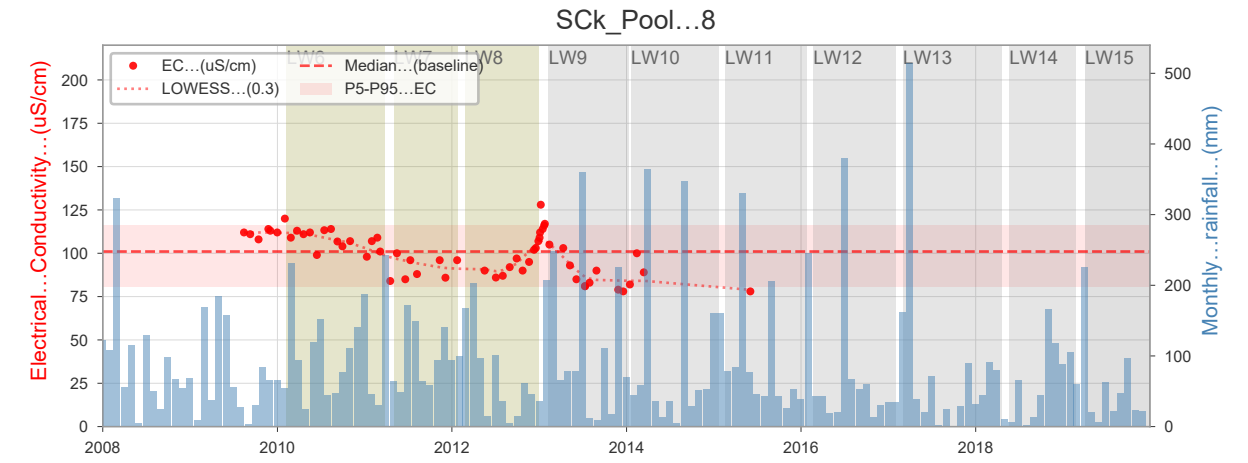

SCk_Pool…7
Water…level…(m…below…ref….…nail)
Monthly…rainfall…(mm)
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

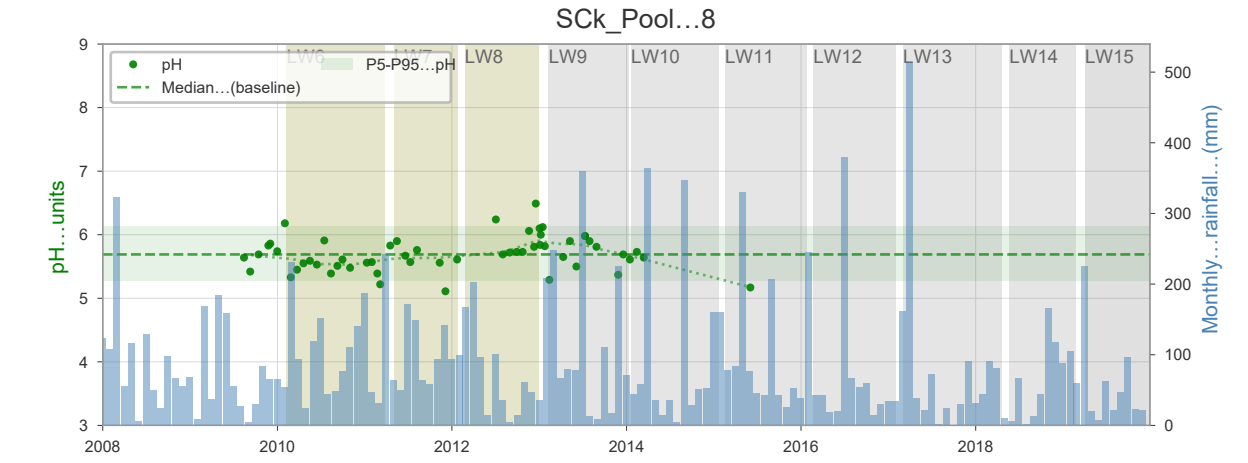

SCk_Pool…7
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

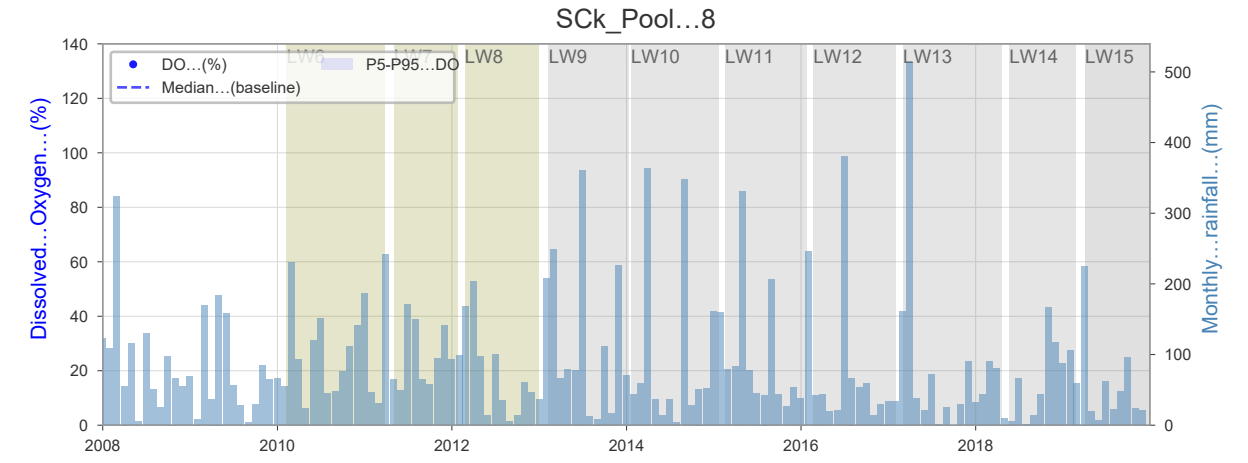

SCk_Pool…7
pH…units
Monthly…rainfall…(mm)
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

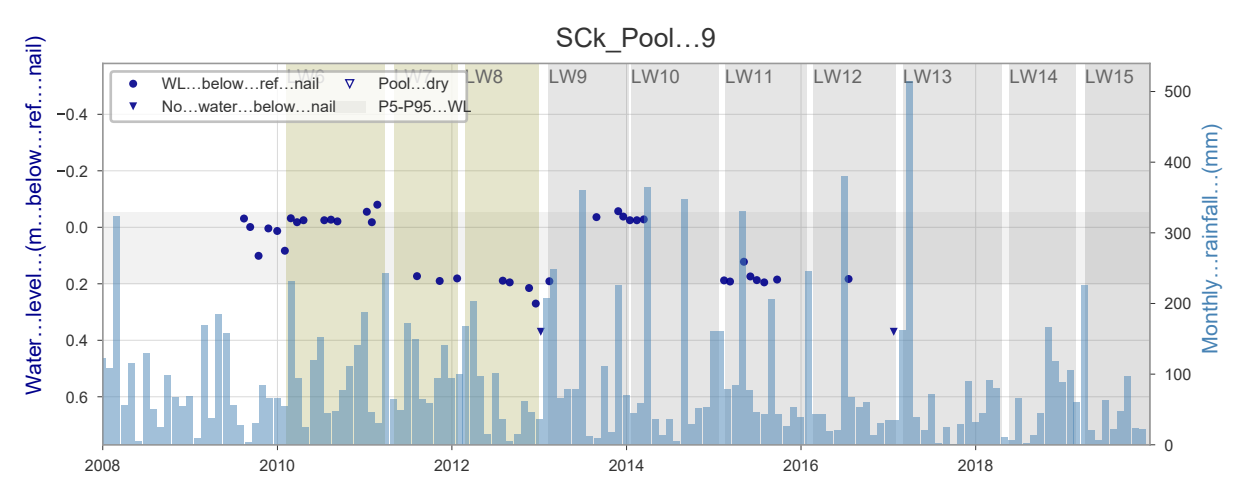

SCk_Pool…7
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

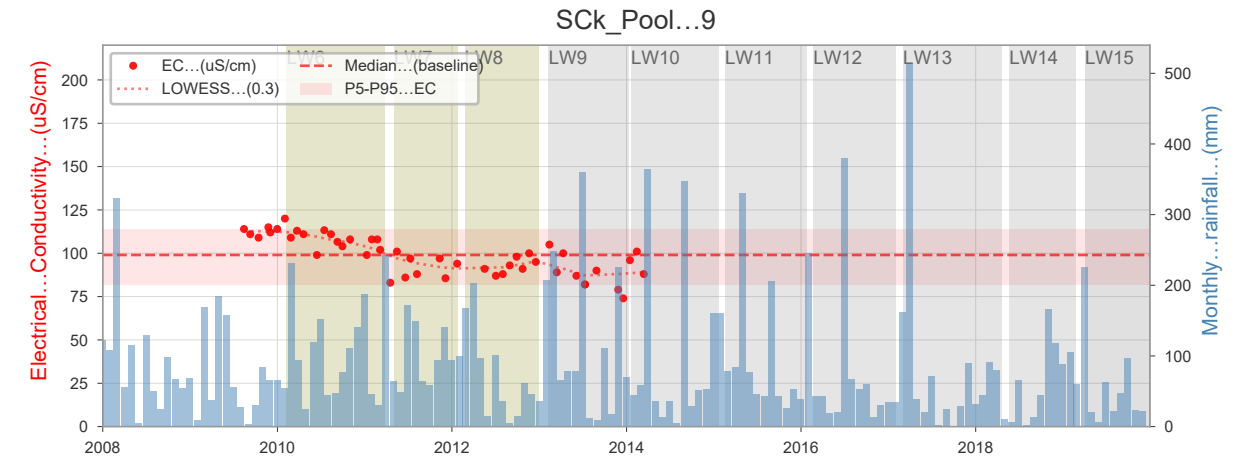

SCk_Pool…8
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

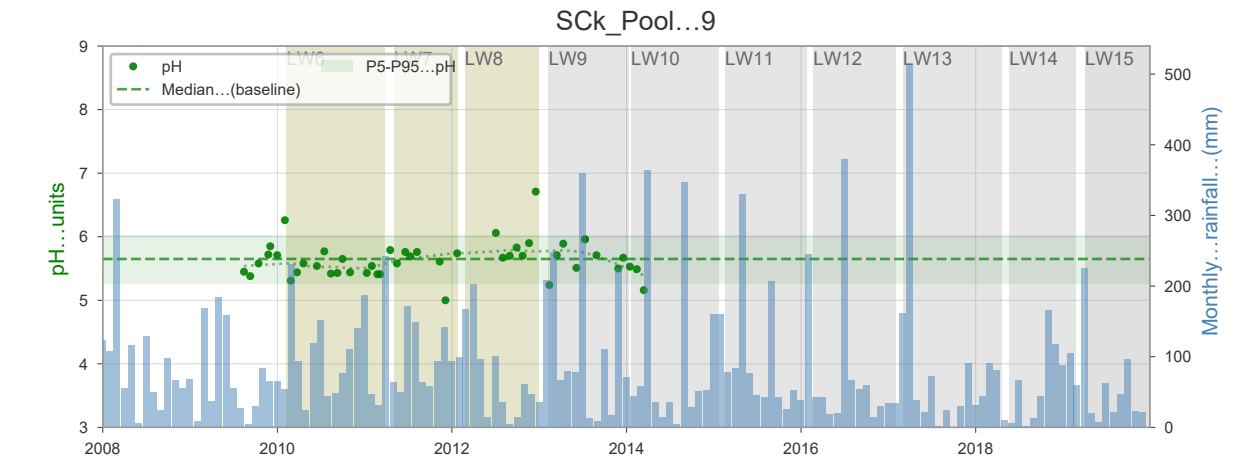

SCk_Pool…8
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

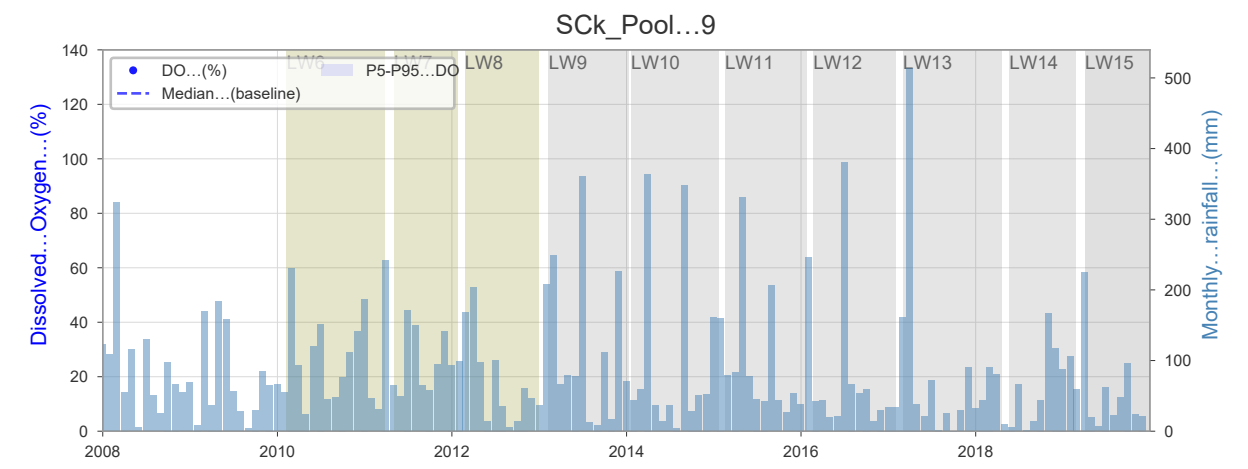

SCk_Pool…8
pH…units
Monthly…rainfall…(mm)
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

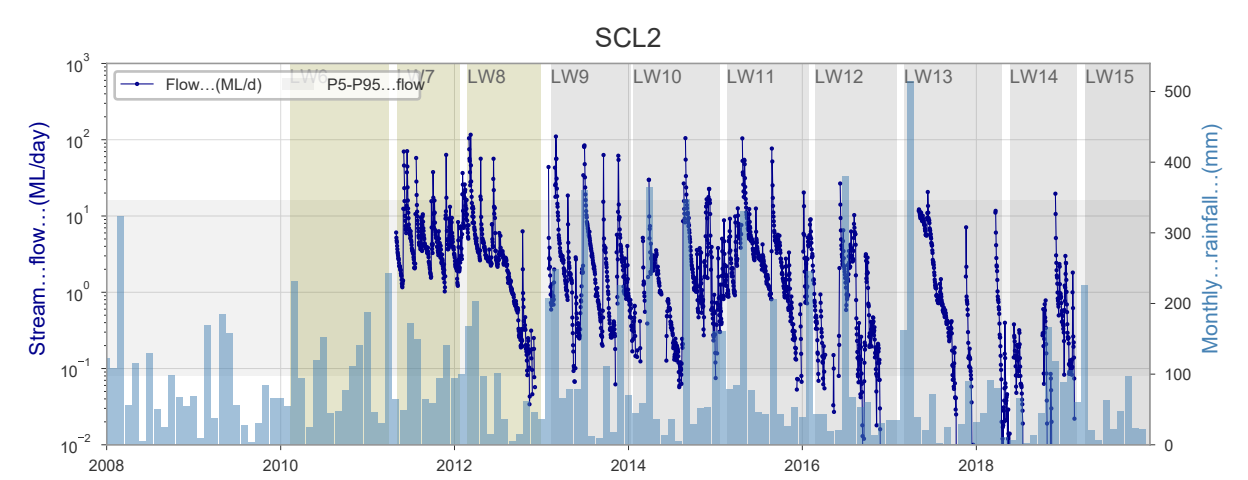

SCk_Pool…8
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

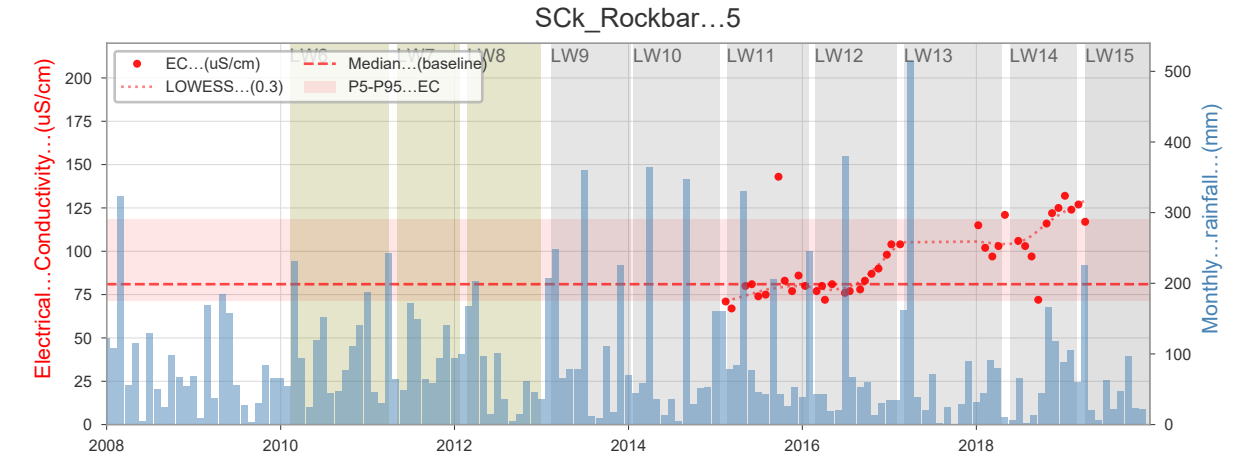

SCk_Pool…9
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….…nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

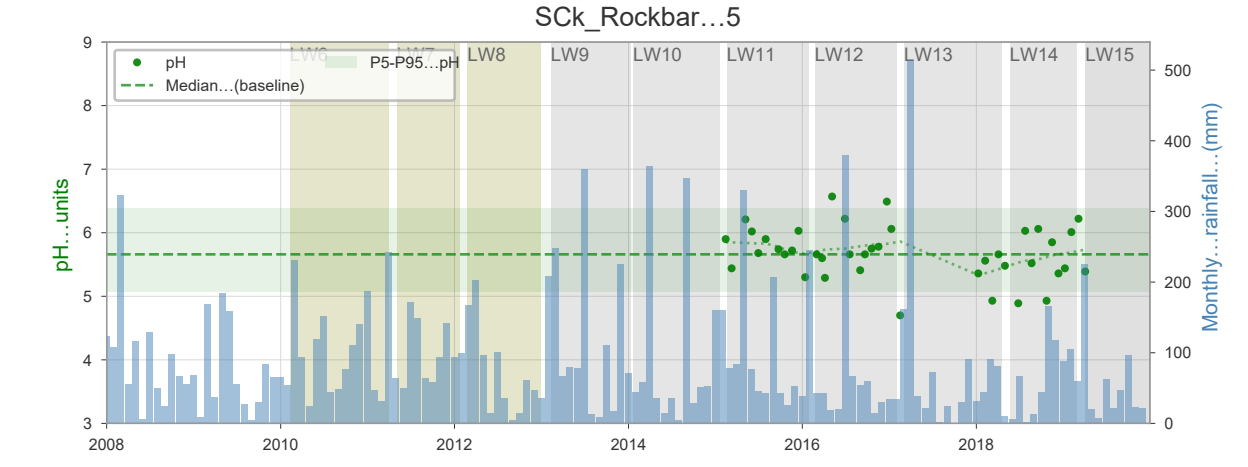

SCk_Pool…9
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

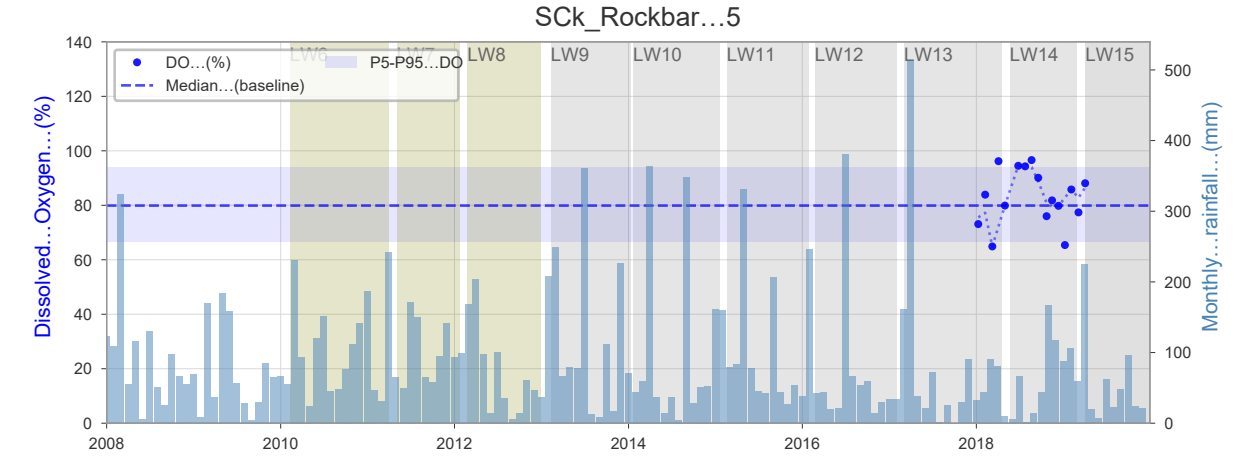

SCk_Pool…9
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

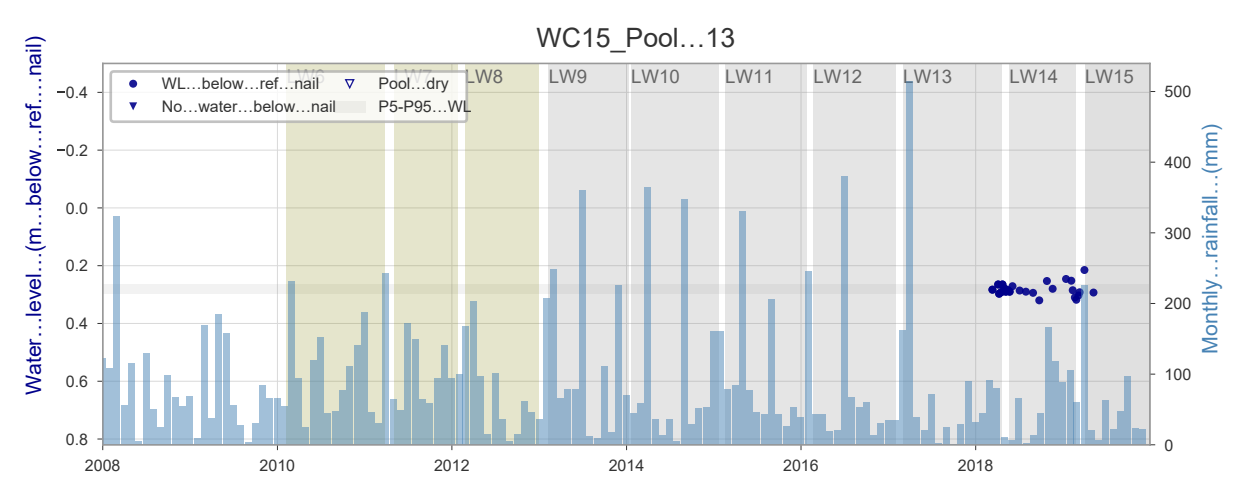

SCk_Pool…9
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

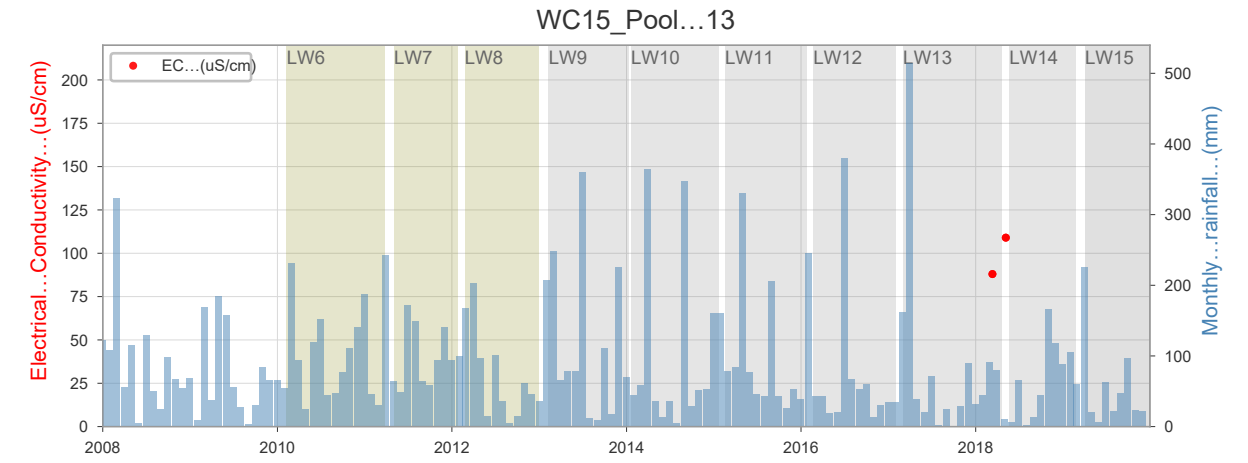

SCL2
Flow…(ML/d)
P5-P95…flow
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Stream…flow…(ML/day)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

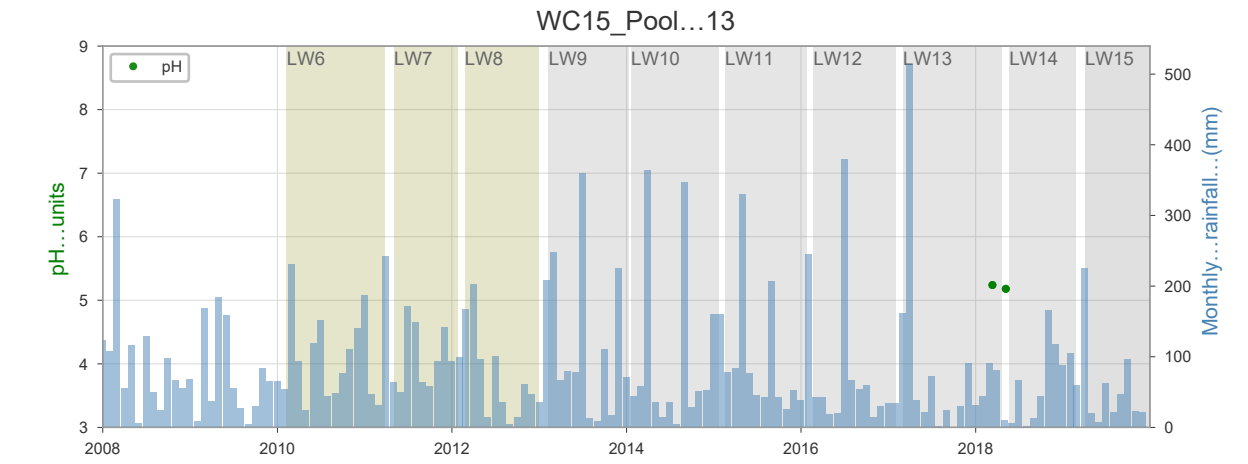

SCk_Rockbar…5
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

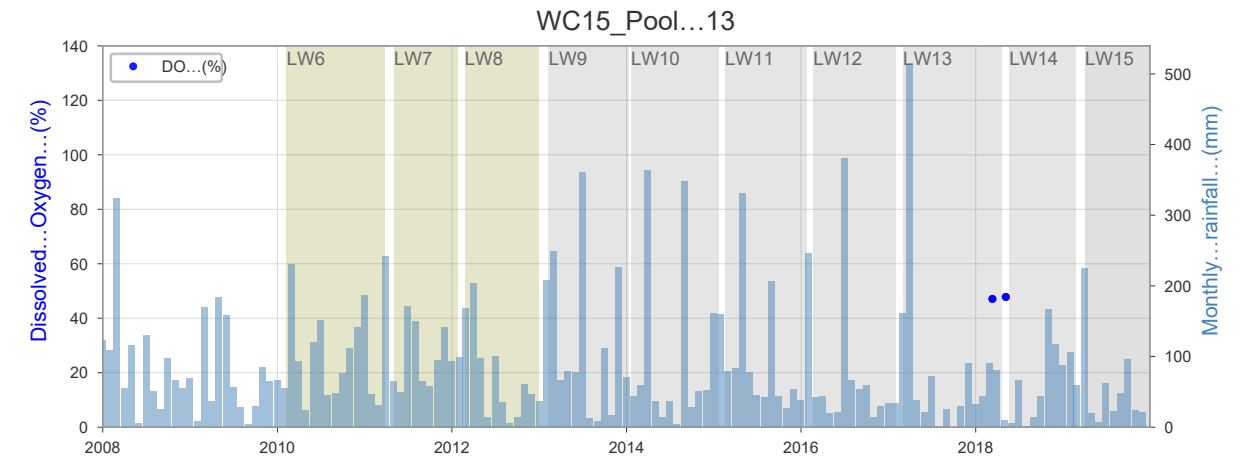

SCk_Rockbar…5
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

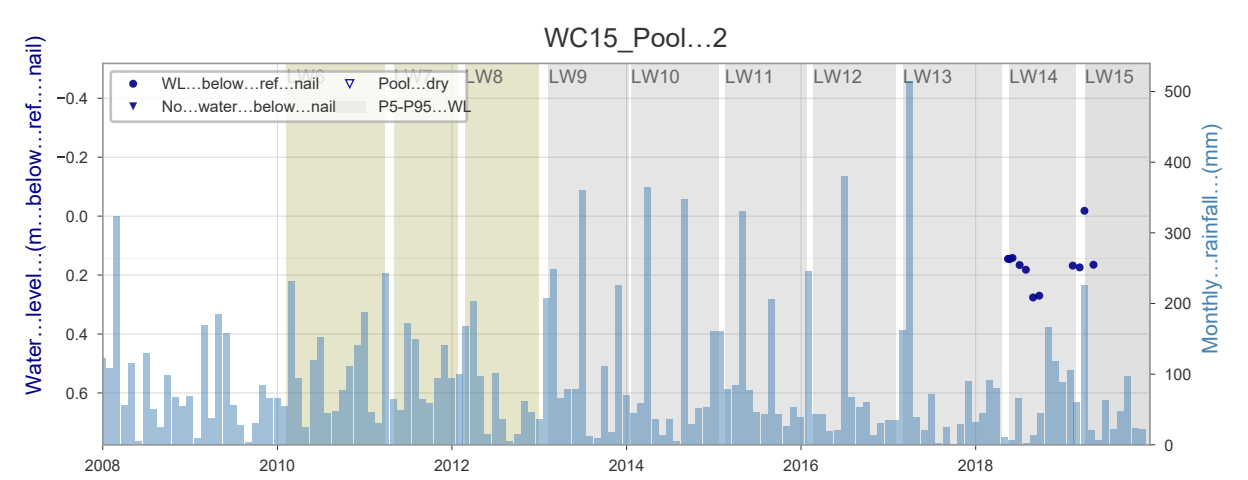

SCk_Rockbar…5
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

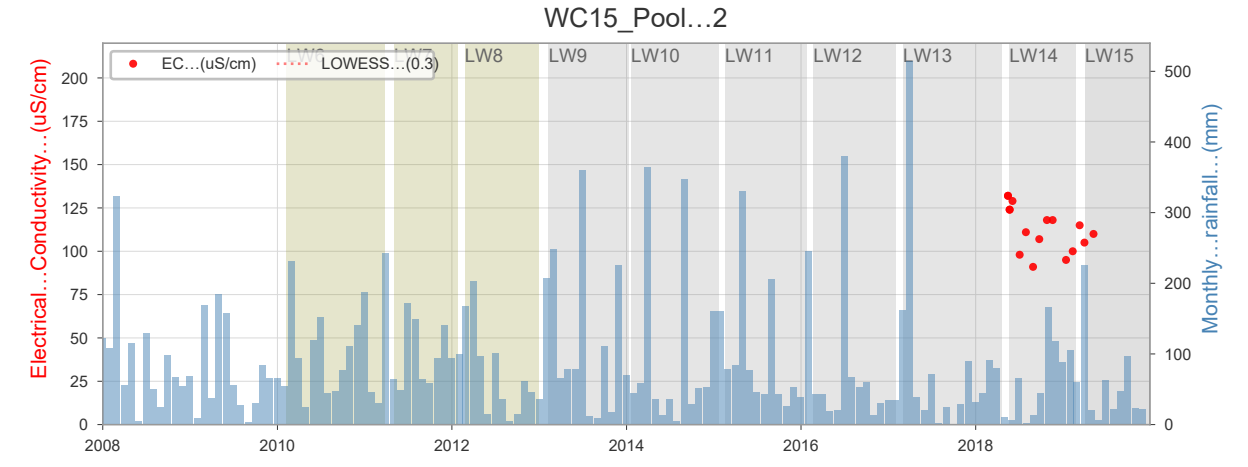

WC15_Pool…13
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

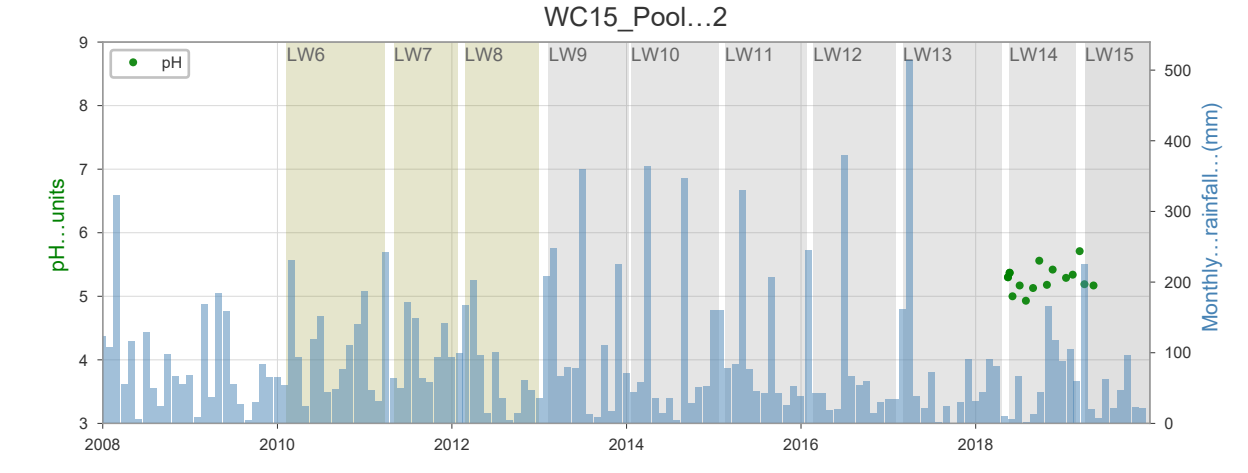

WC15_Pool…13
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
EC…(uS/cm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

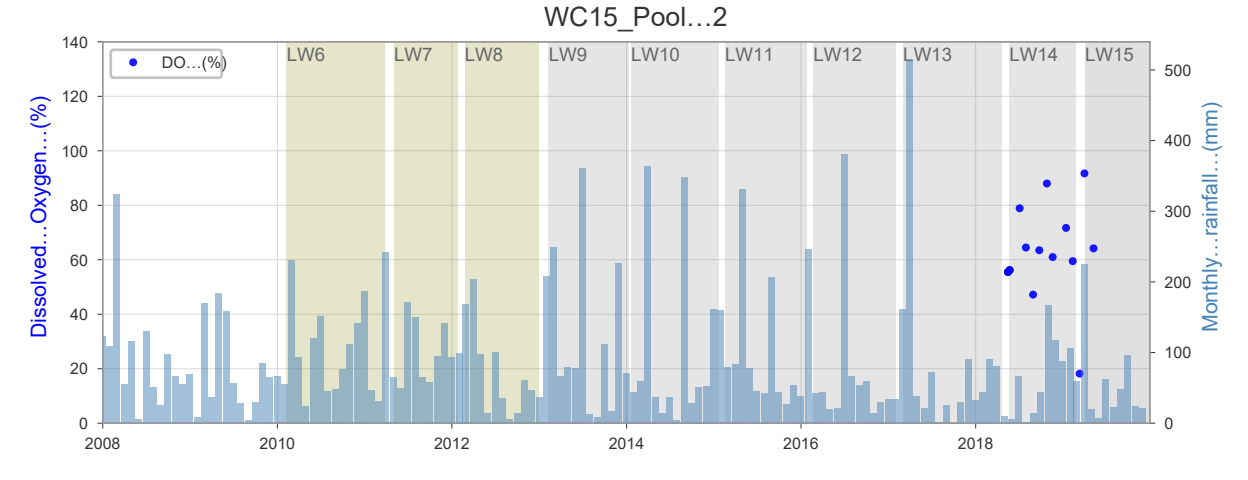

WC15_Pool…13
pH…units
Monthly…rainfall…(mm)
pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

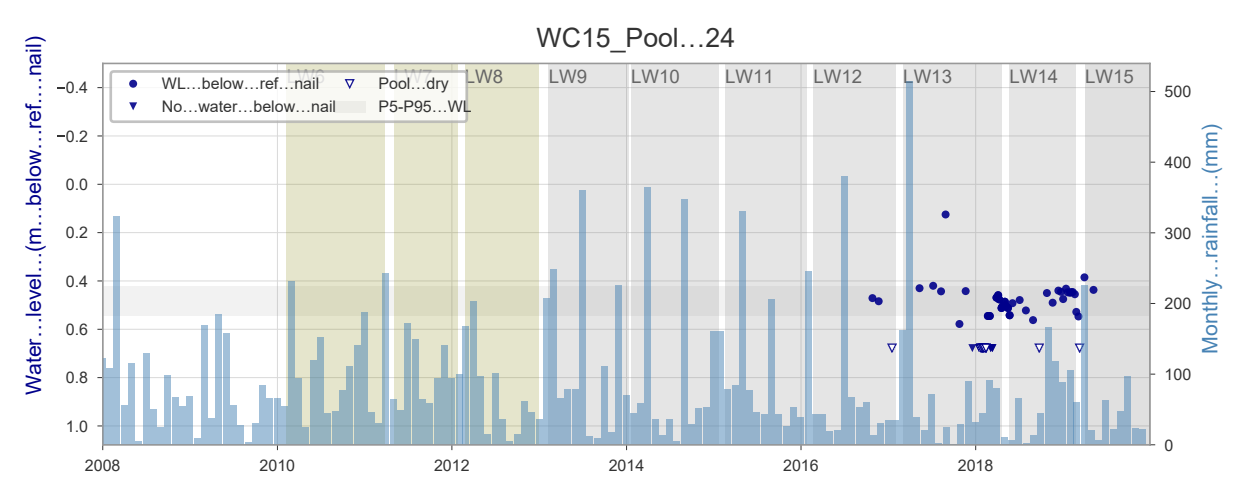

WC15_Pool…13
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
DO…(%)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

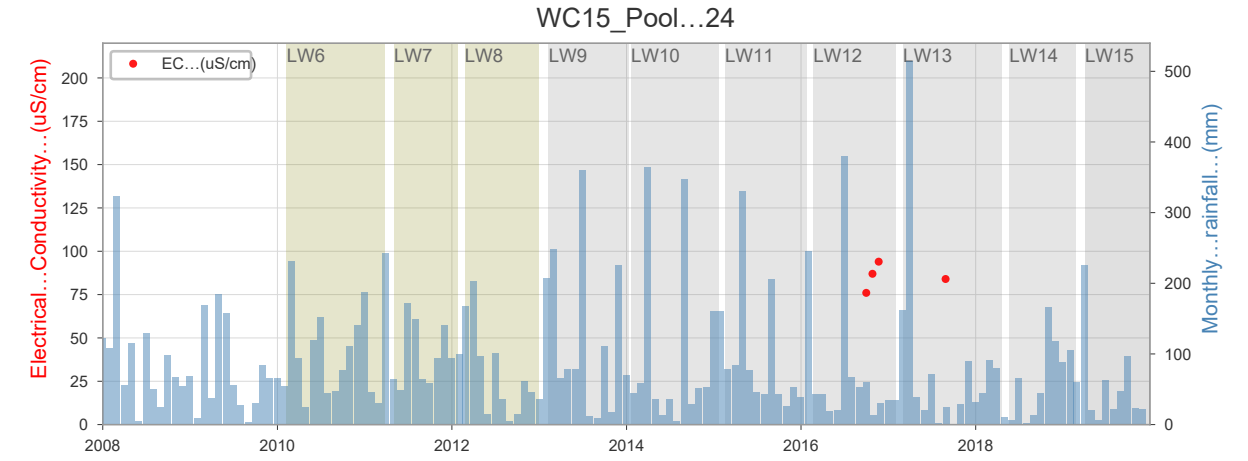

WC15_Pool…2
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

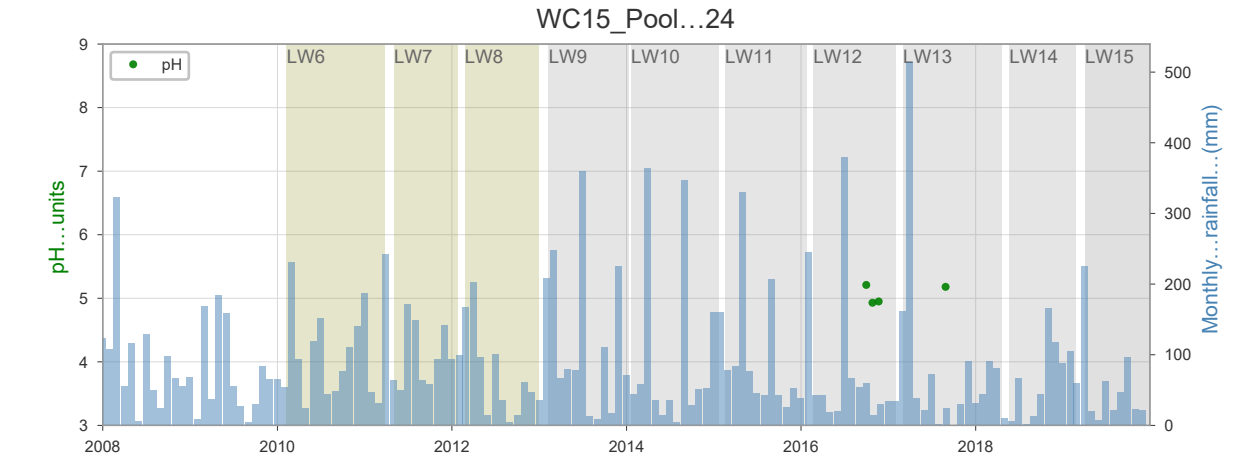

WC15_Pool…2
EC…(uS/cm)
LOWESS…(0.3)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

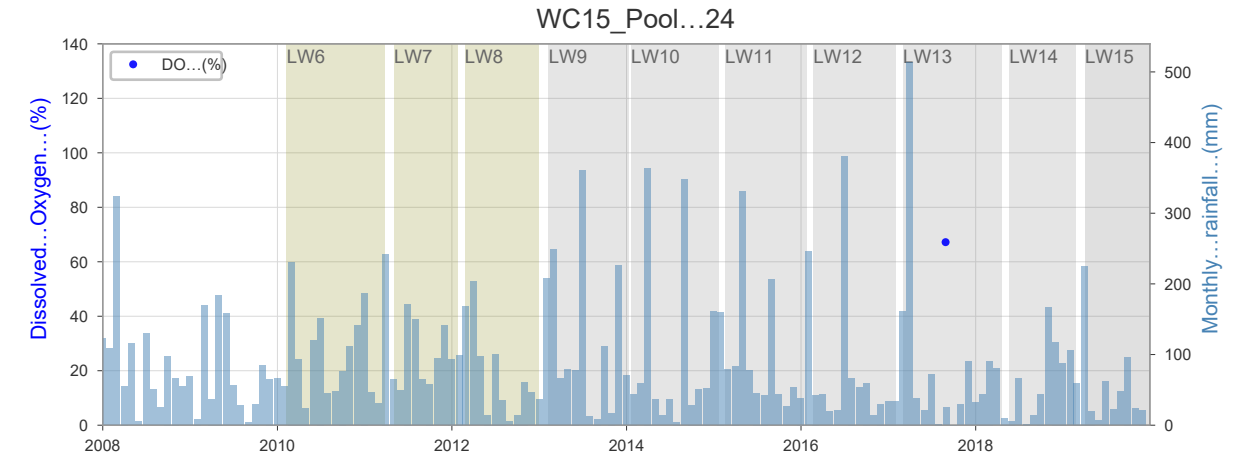

WC15_Pool…2
pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

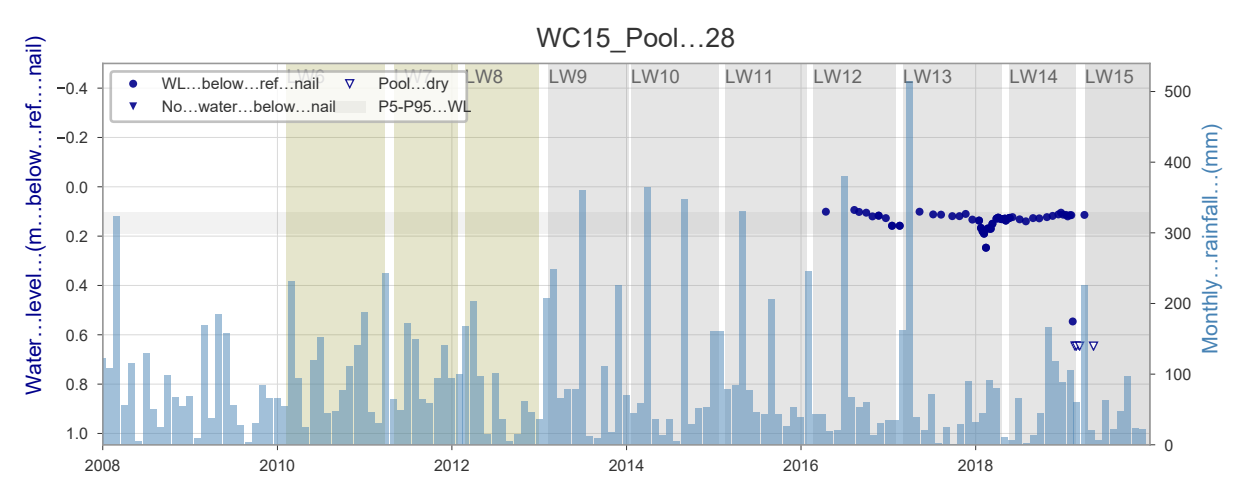

WC15_Pool…2
DO…(%)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

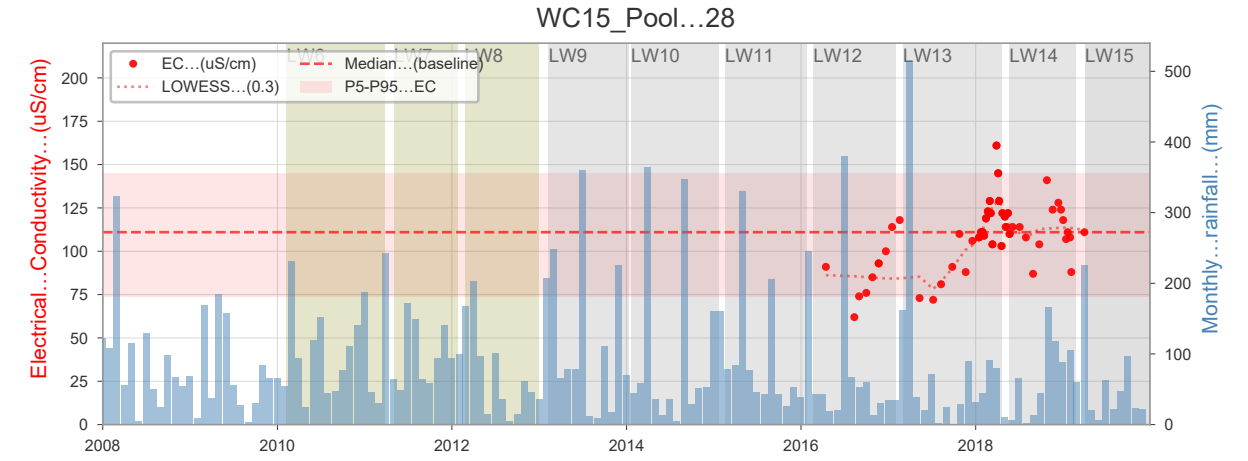

WC15_Pool…24
WL…below…ref…nail
No…water…below…nail
Pool…dry
P5-P95…WL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

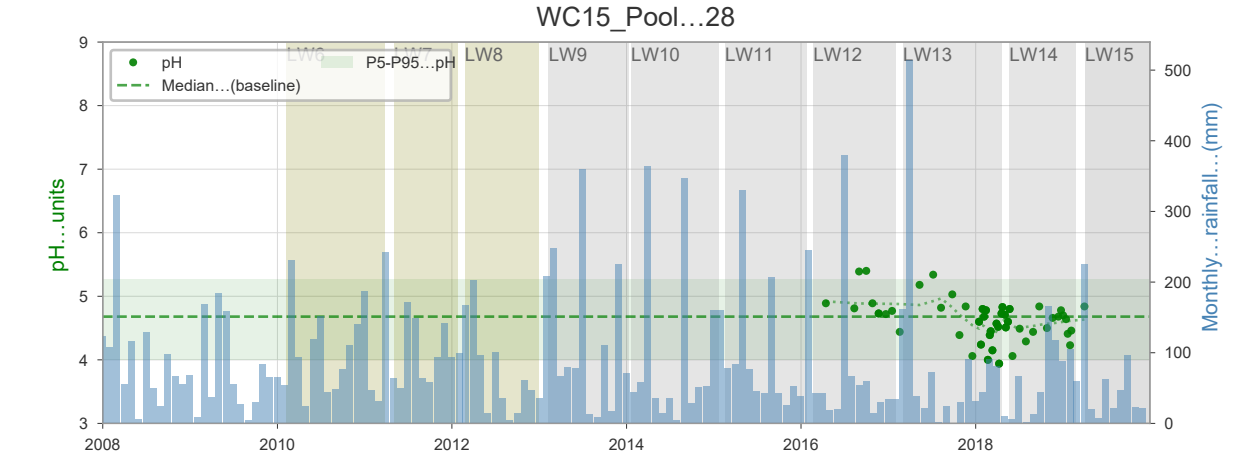

WC15_Pool…24
EC…(uS/cm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

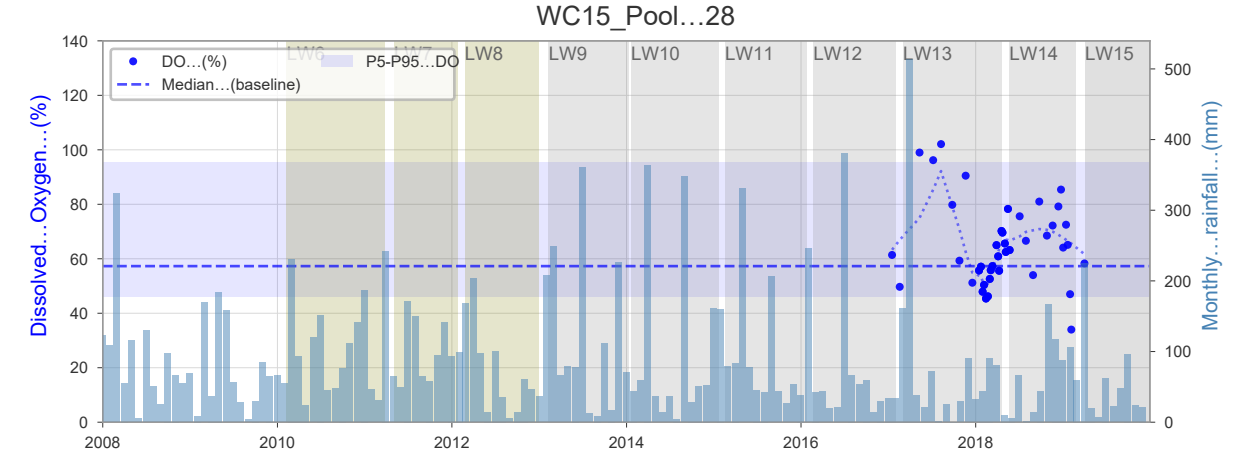

WC15_Pool…24
pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

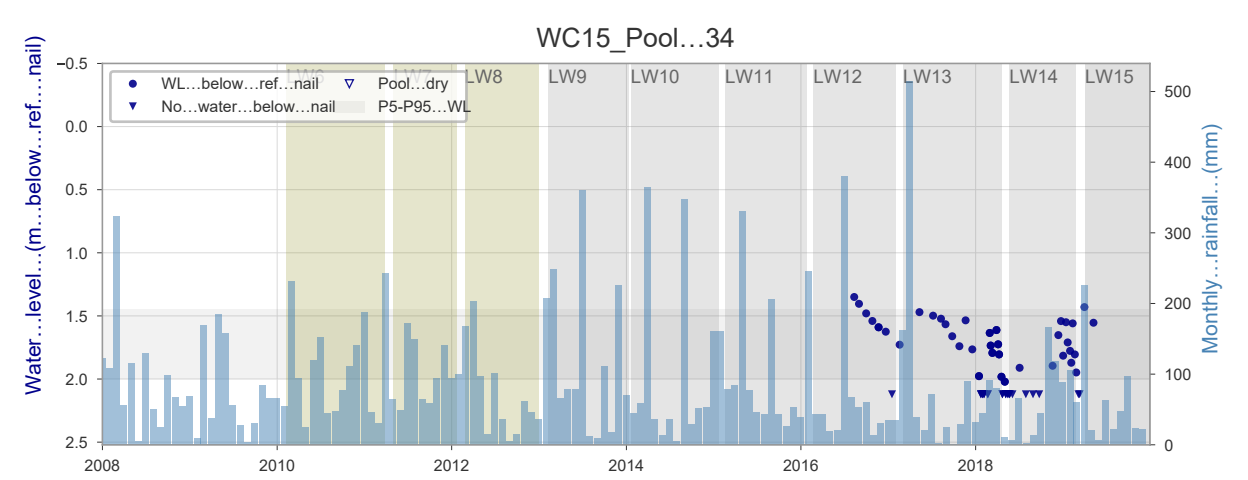

WC15_Pool…24
DO…(%)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

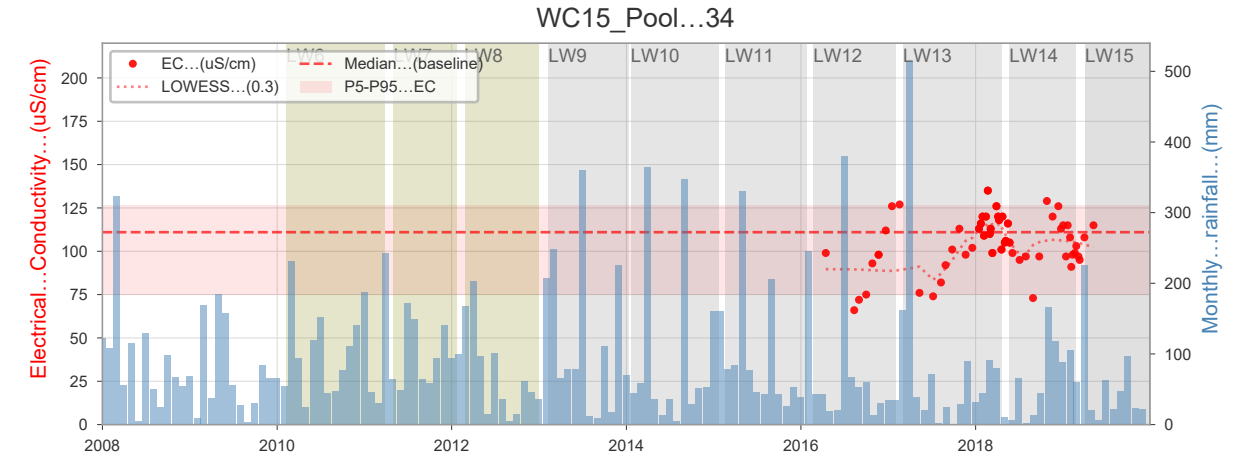

WC15_Pool…28
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

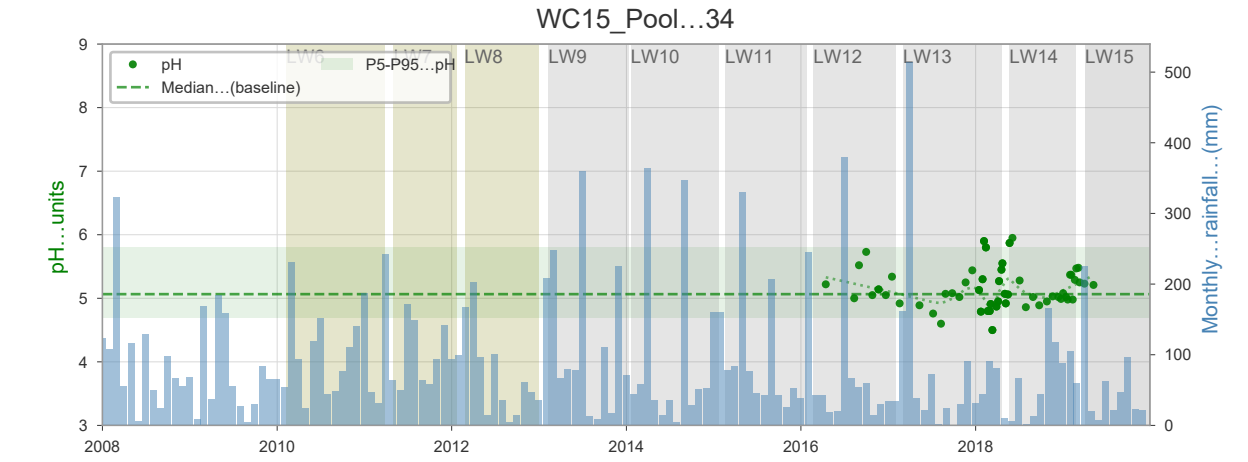

WC15_Pool…28
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

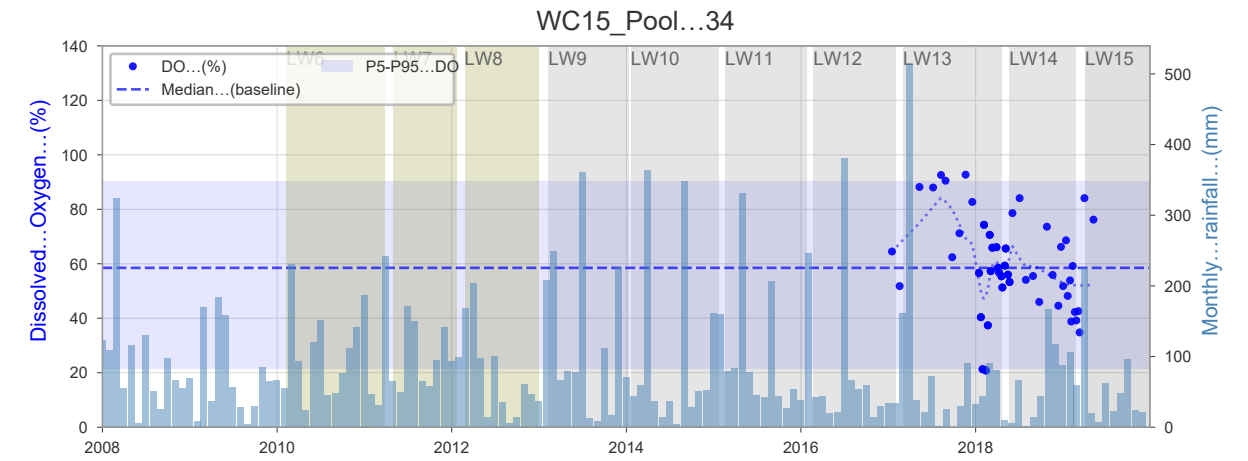

WC15_Pool…28
pH…units
Monthly…rainfall…(mm)
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

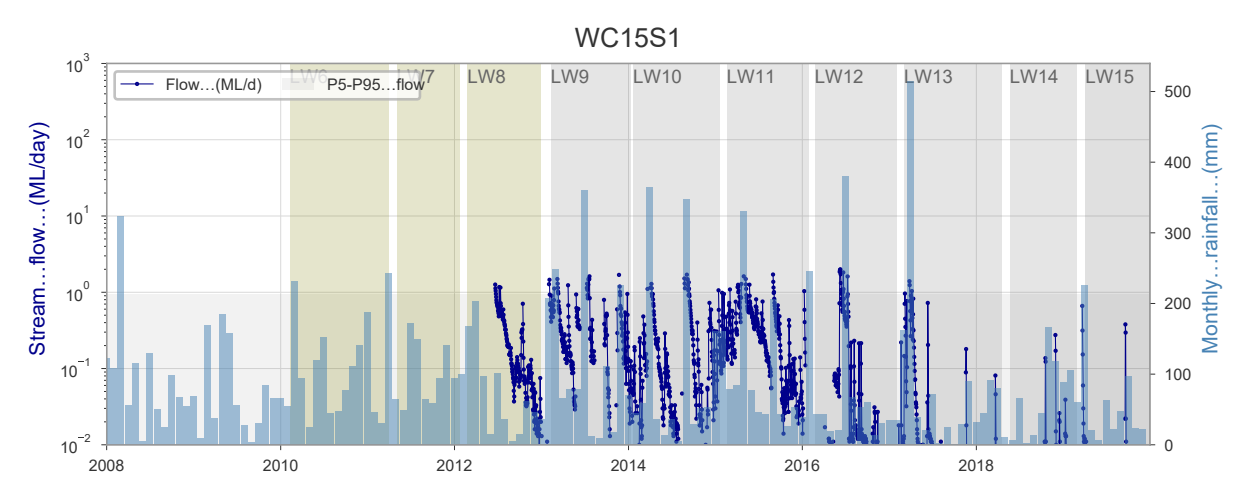

WC15_Pool…28
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

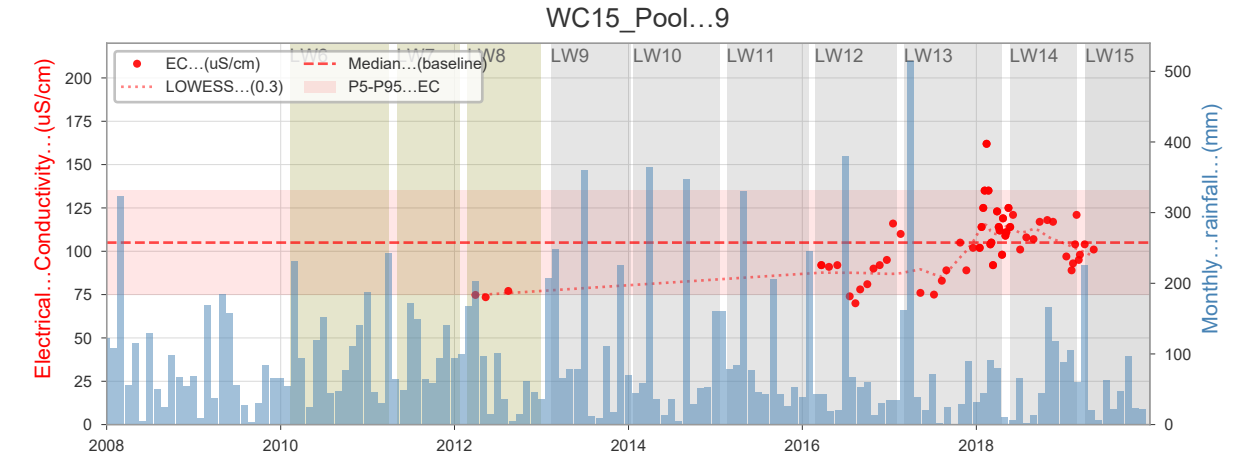

WC15_Pool…34
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

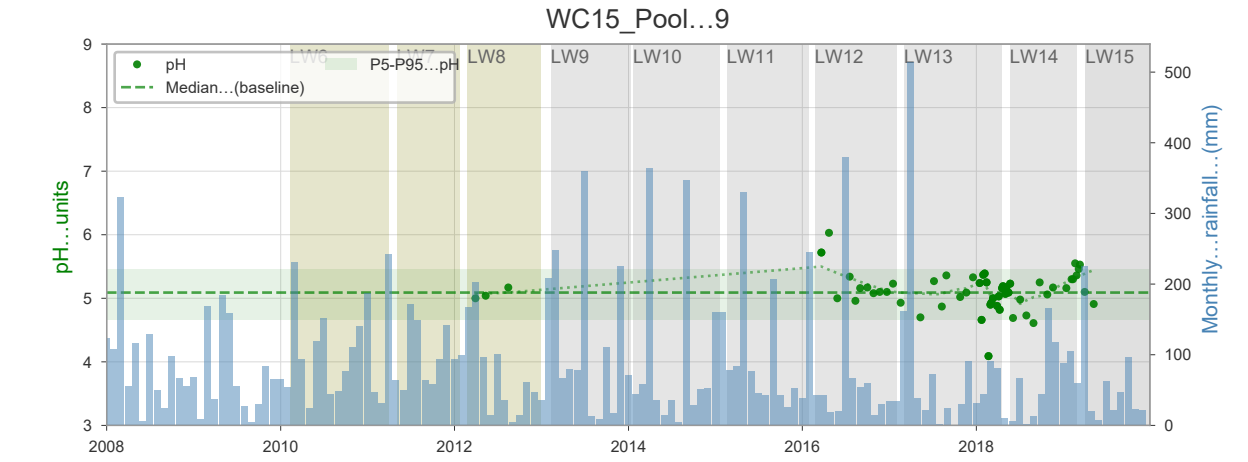

WC15_Pool…34
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

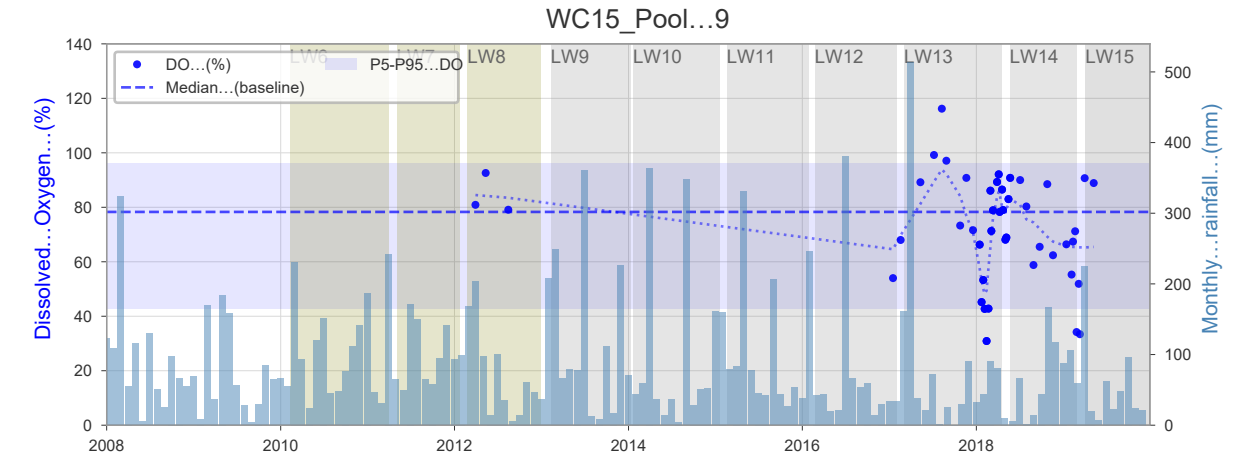

WC15_Pool…34
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

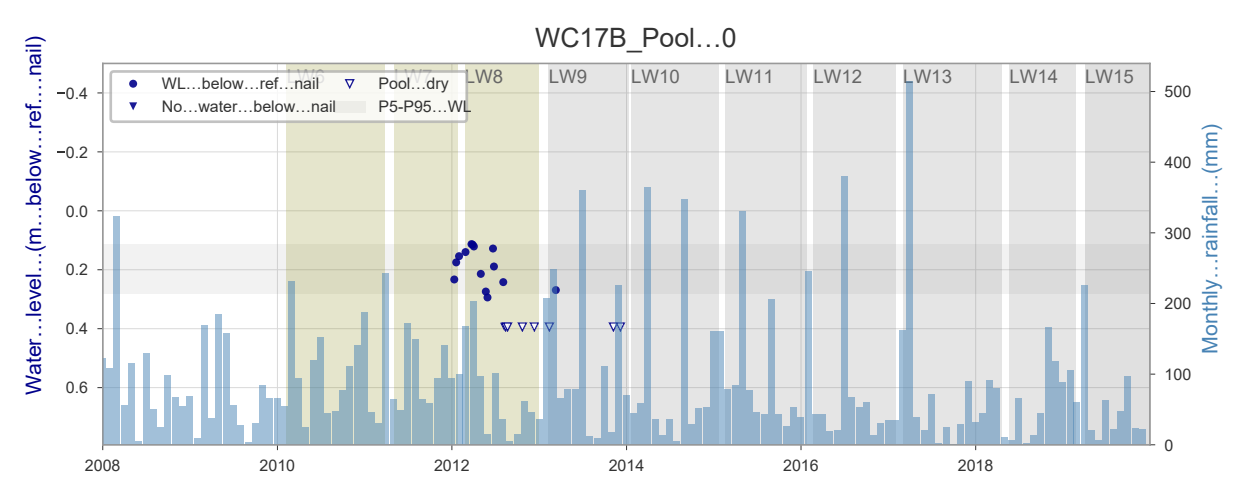

WC15_Pool…34
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

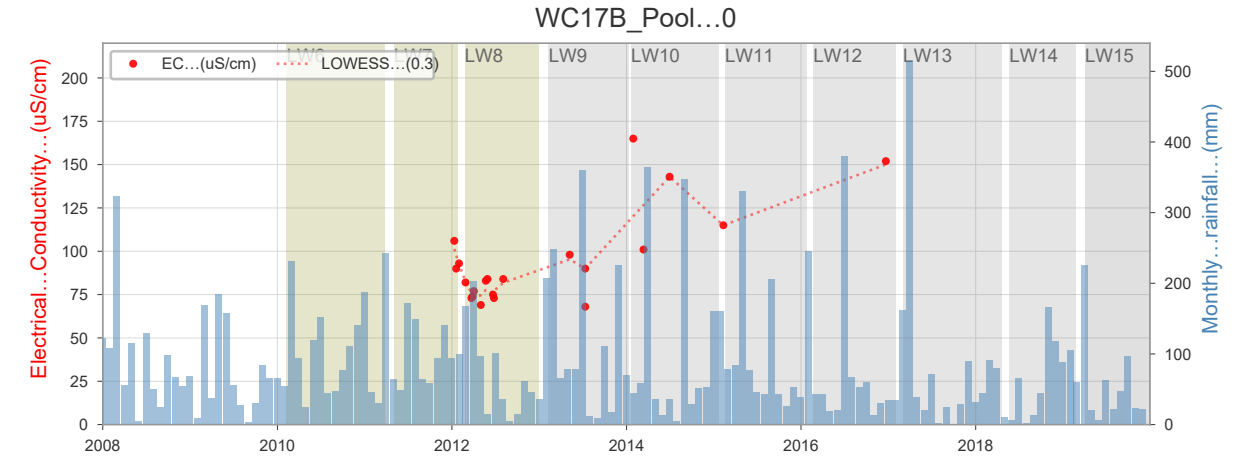

WC15S1
Flow…(ML/d)
P5-P95…flow
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Stream…flow…(ML/day)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

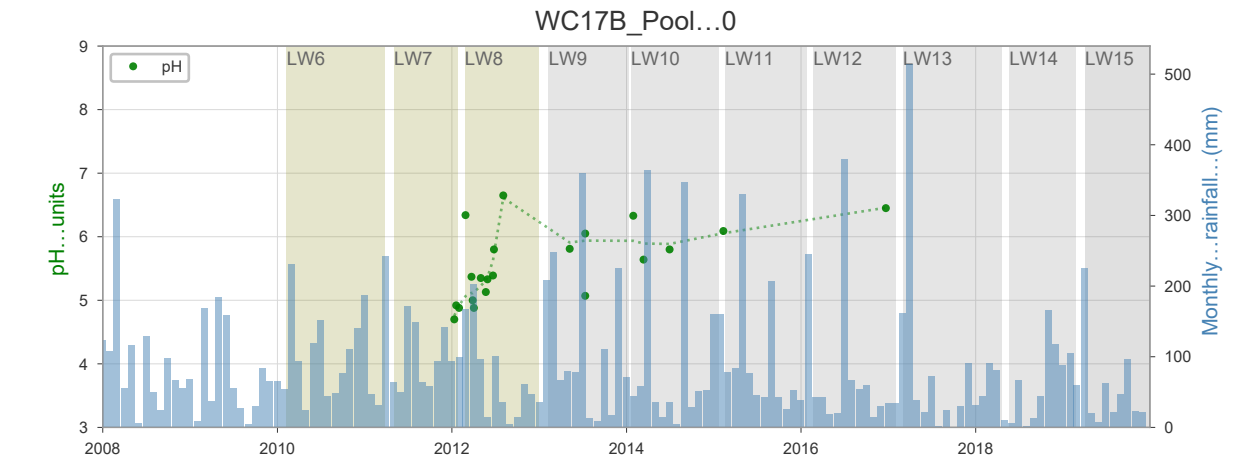

WC15_Pool…9
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

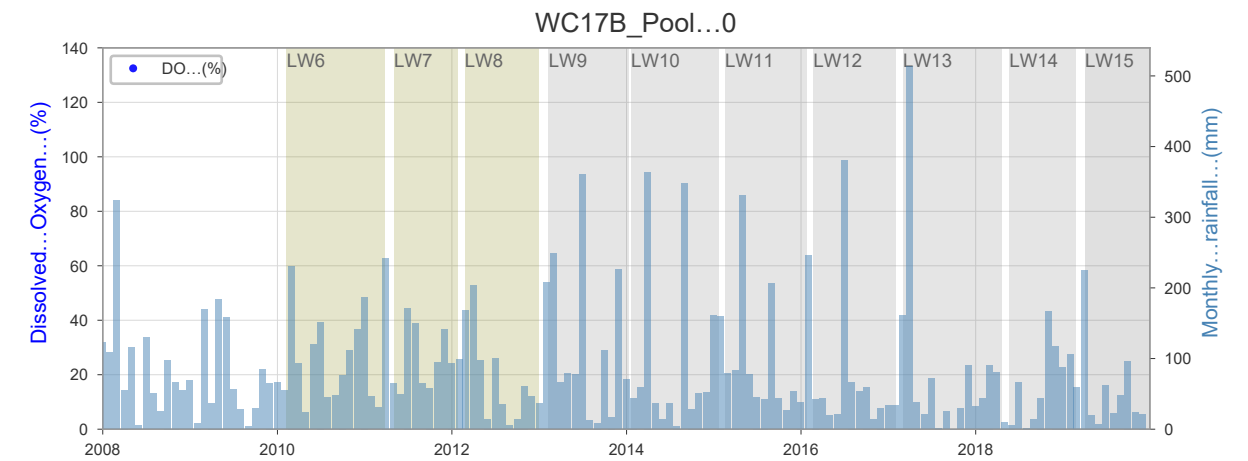

WC15_Pool…9
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

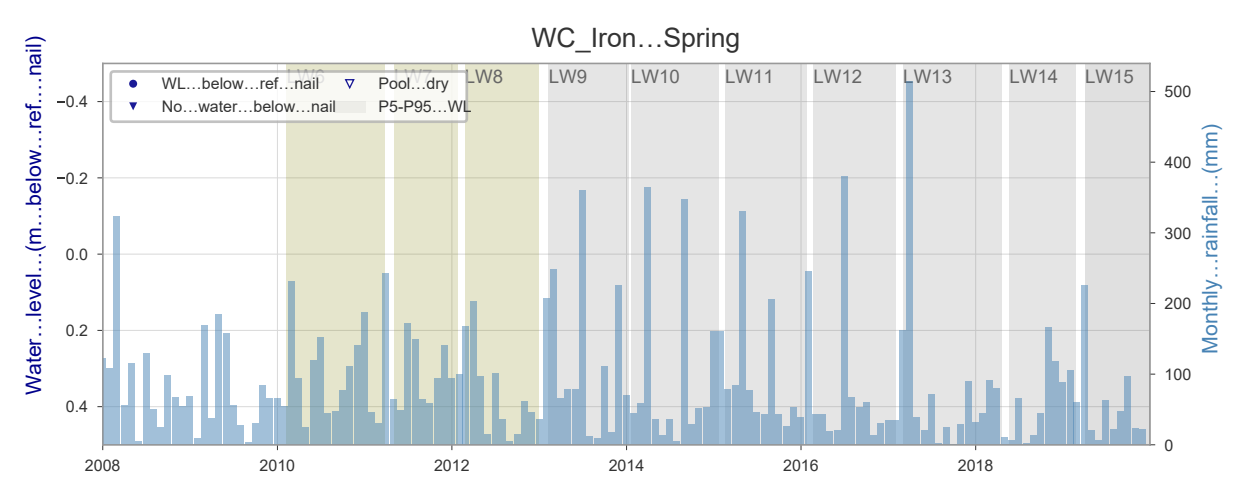

WC15_Pool…9
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

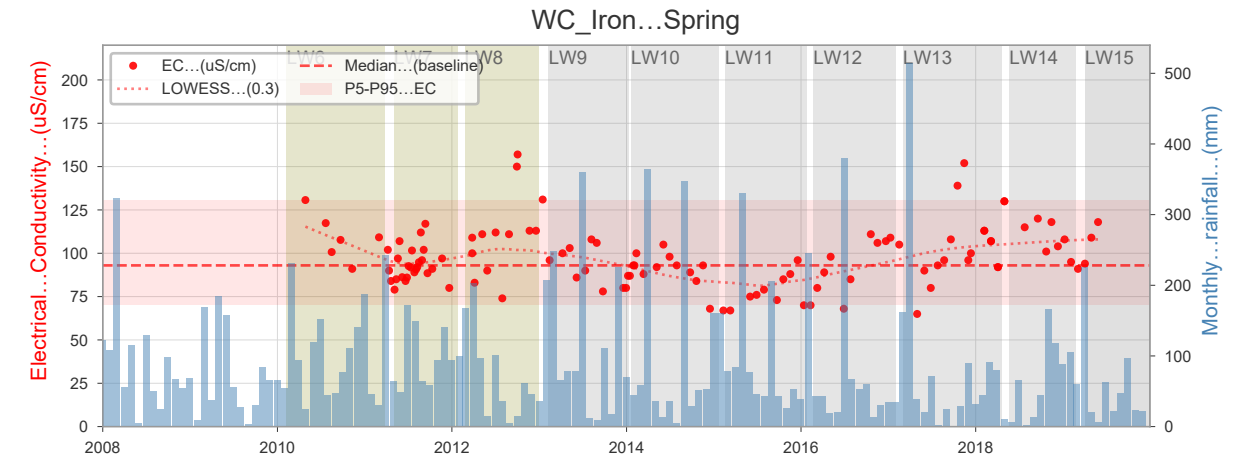

WC17B_Pool…0
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

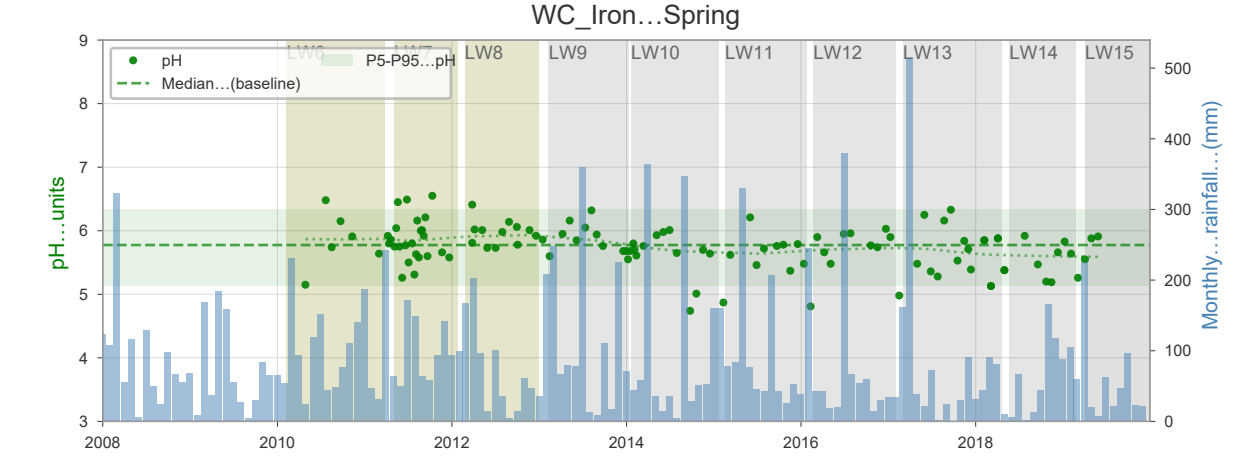

WC17B_Pool…0
EC…(uS/cm)
LOWESS…(0.3)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

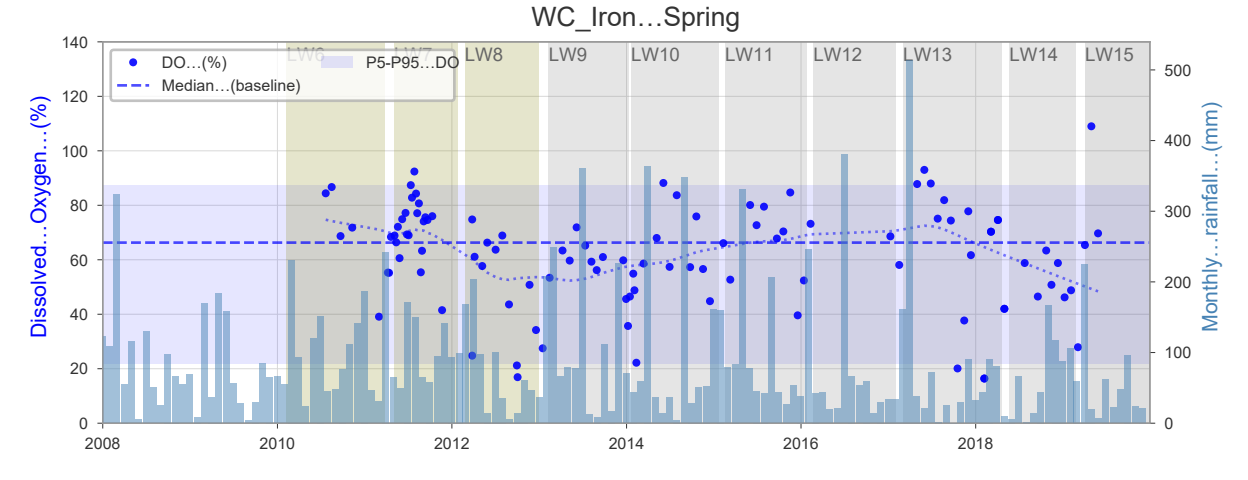

WC17B_Pool…0
pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

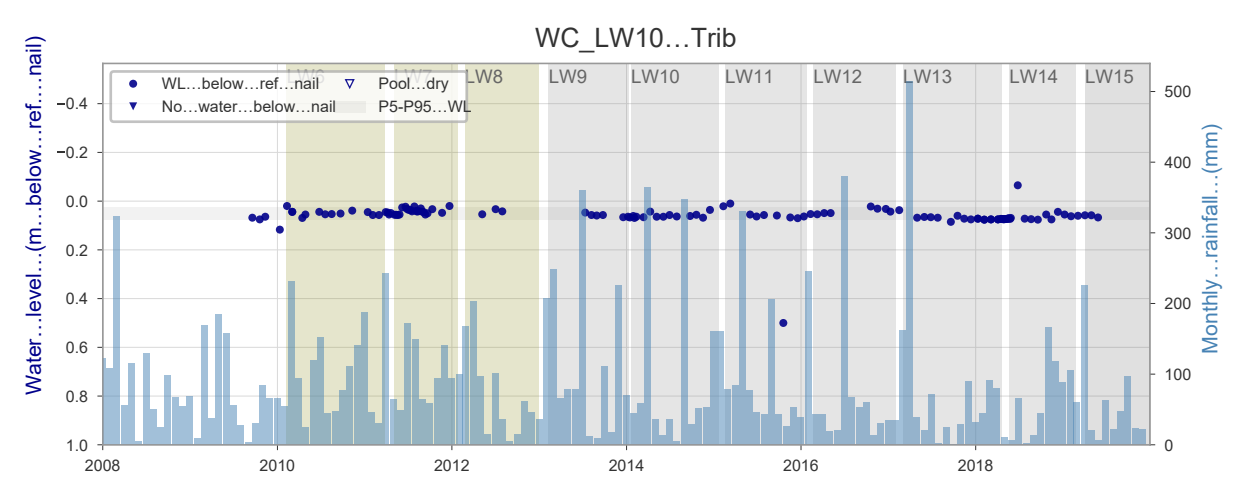

WC17B_Pool…0
DO…(%)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

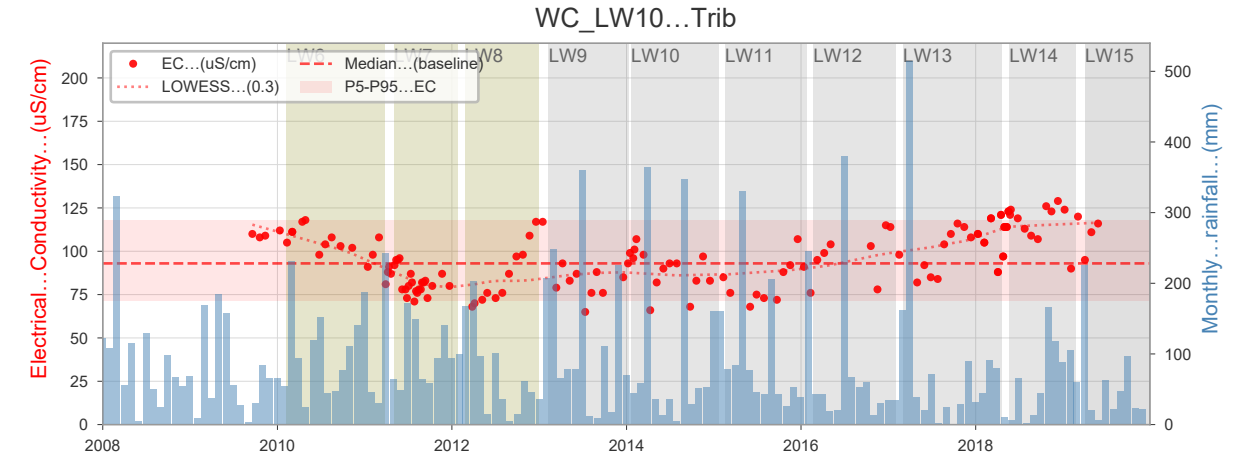

WC_Iron…Spring
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

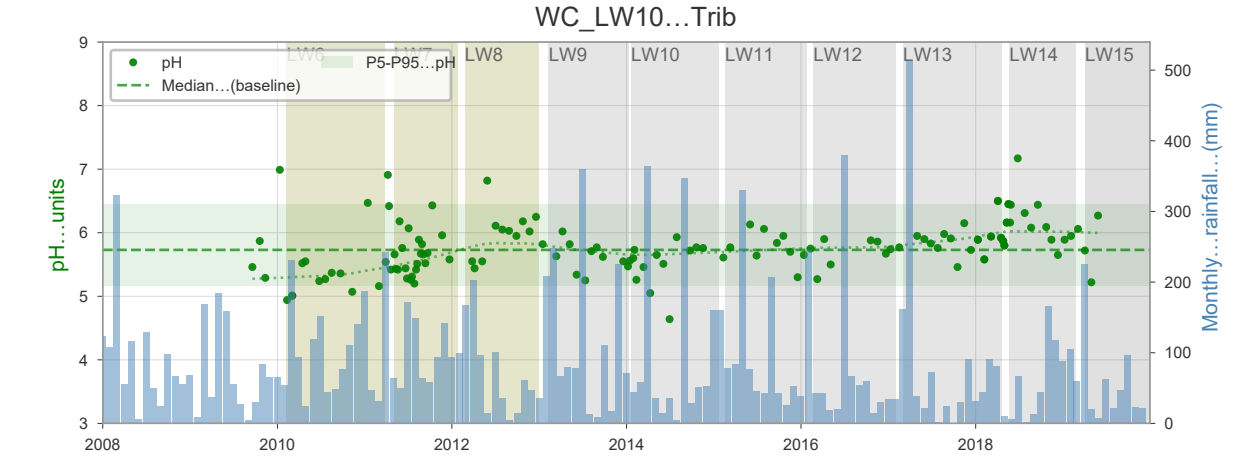

WC_Iron…Spring
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

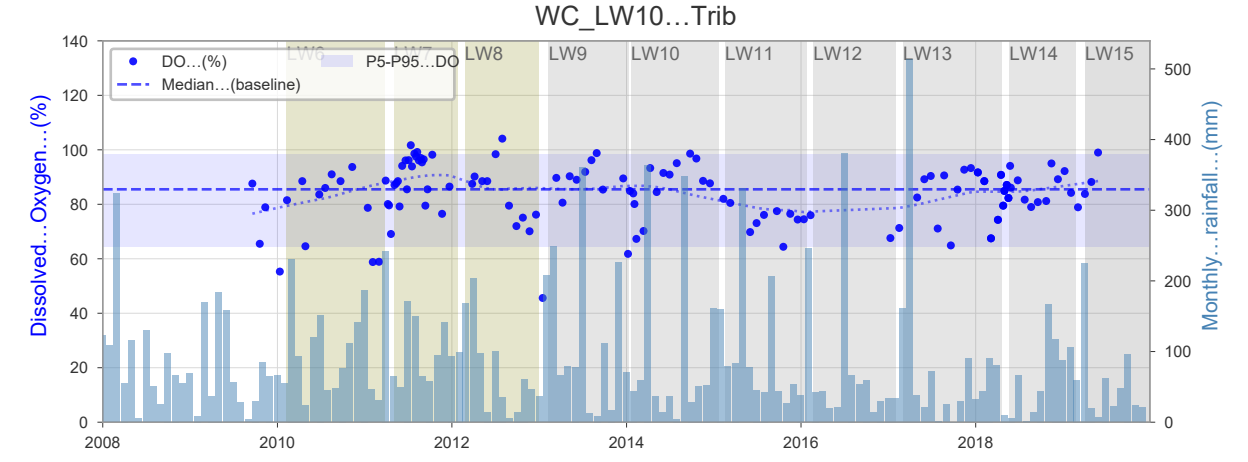

WC_Iron…Spring
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

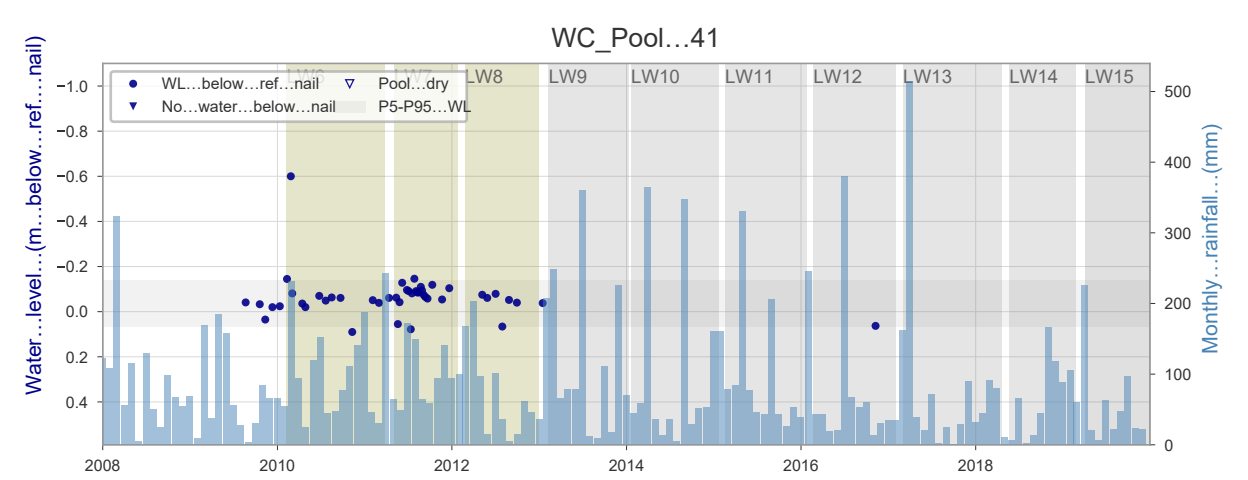

WC_Iron…Spring
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

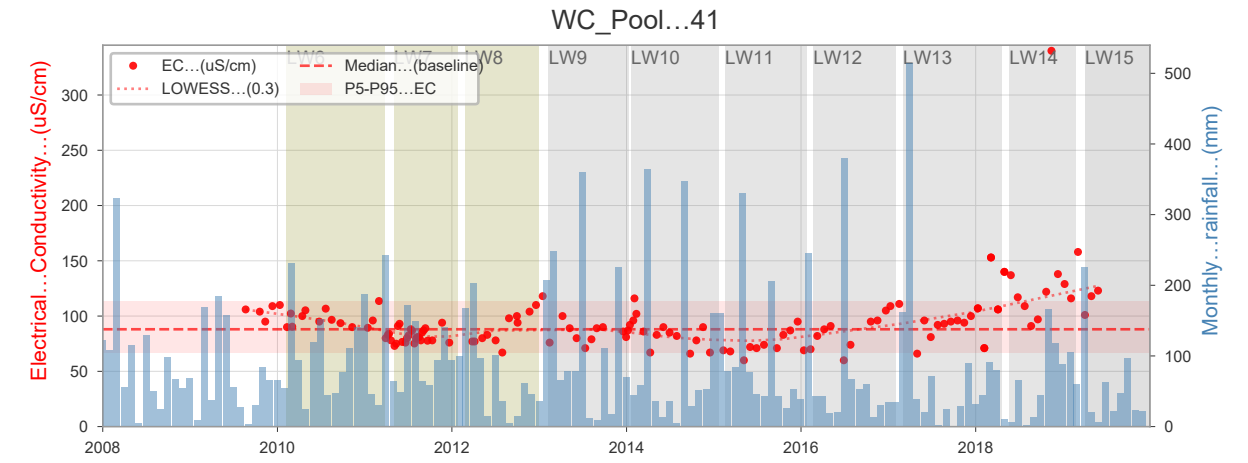

WC_LW10…Trib
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

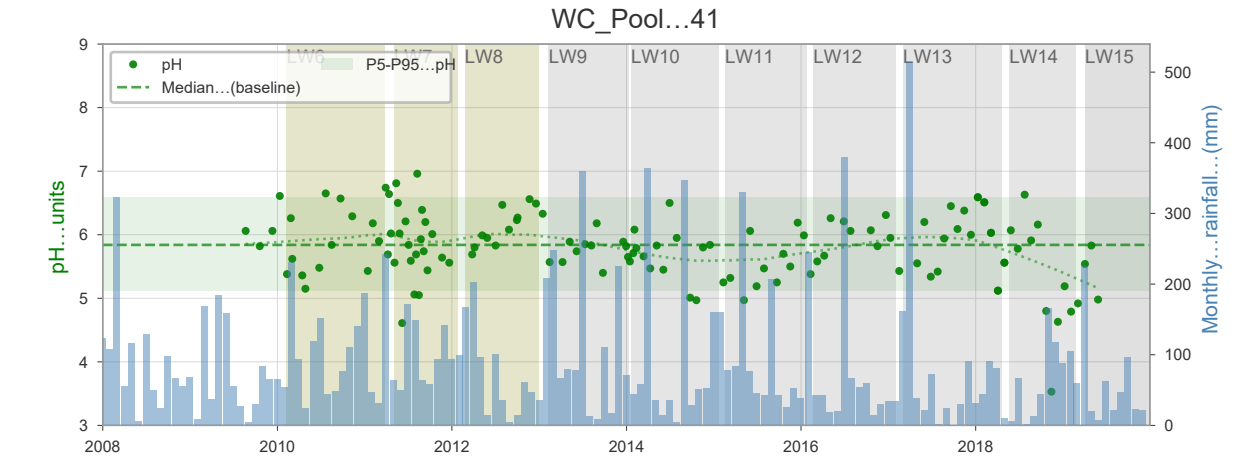

WC_LW10…Trib
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

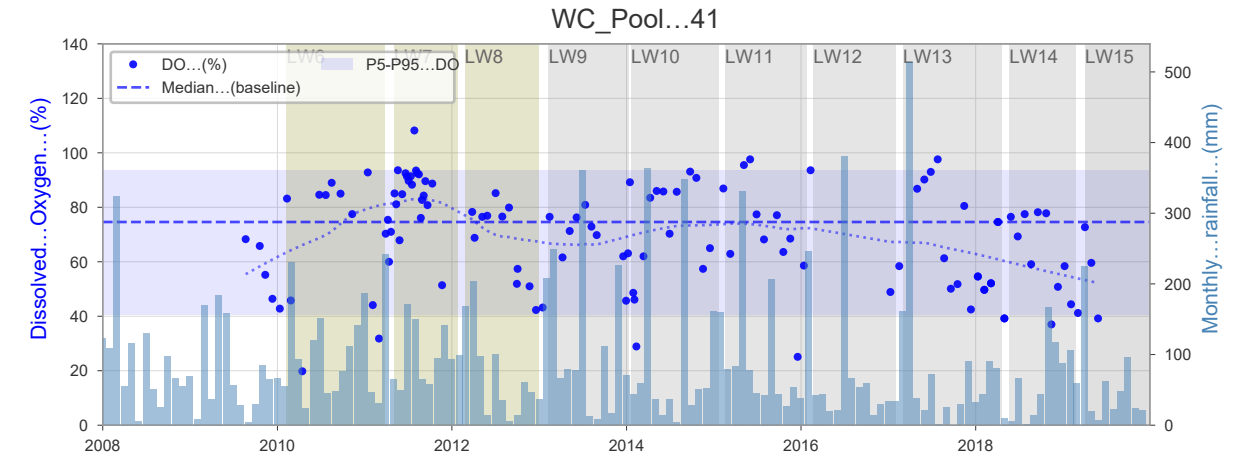

WC_LW10…Trib
pH…units
Monthly…rainfall…(mm)
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

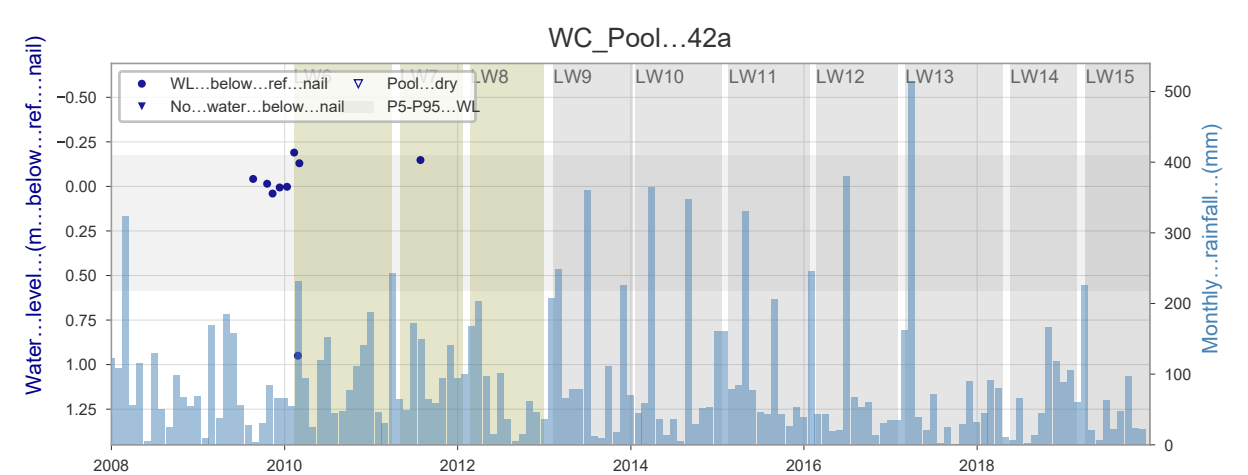

WC_LW10…Trib
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

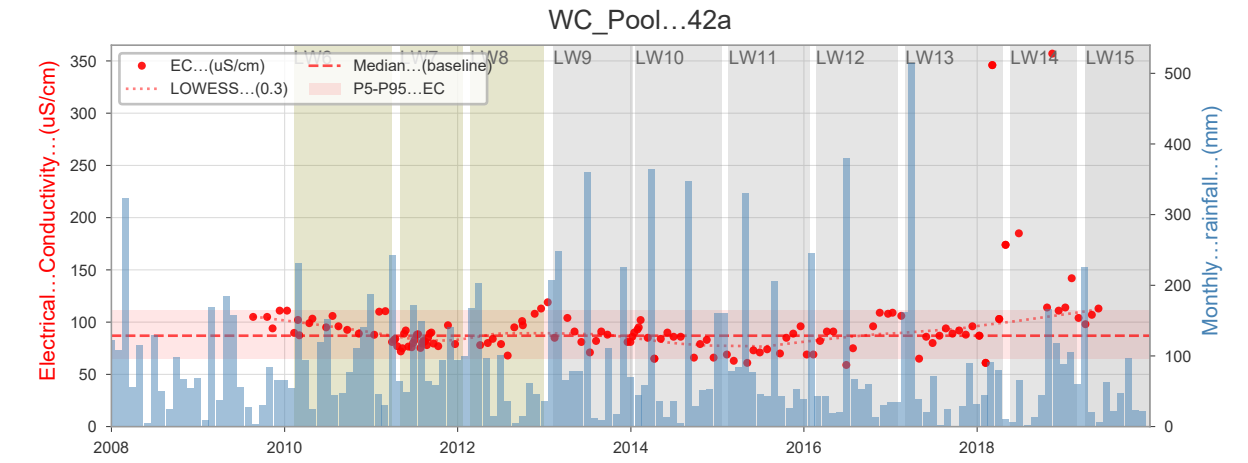

WC_Pool…41
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

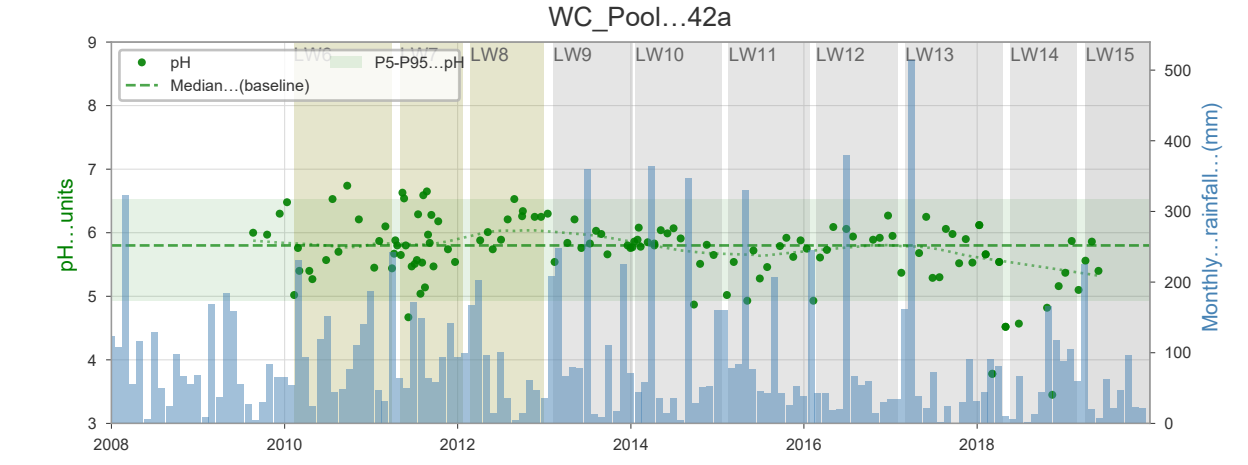

WC_Pool…41
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

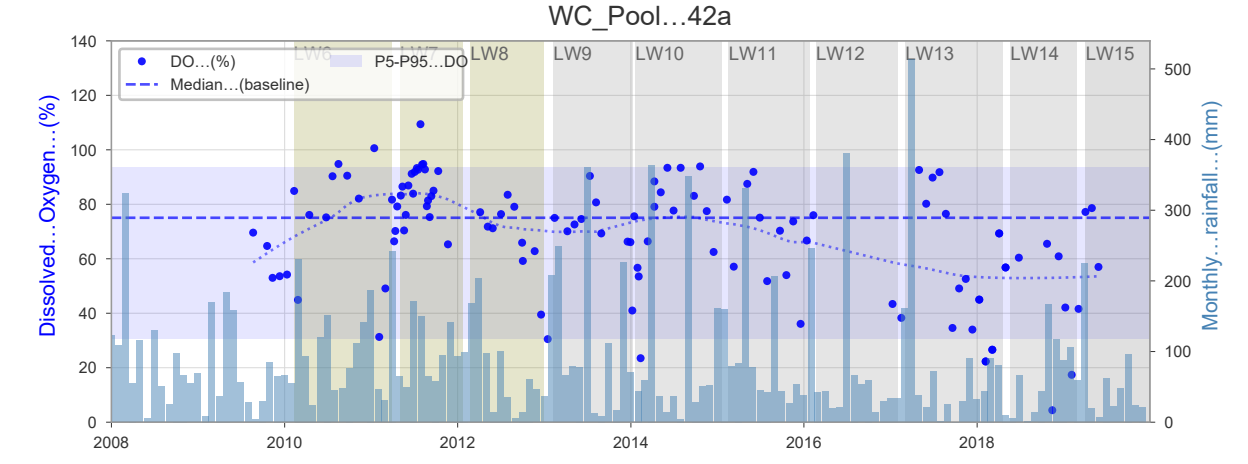

WC_Pool…41
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

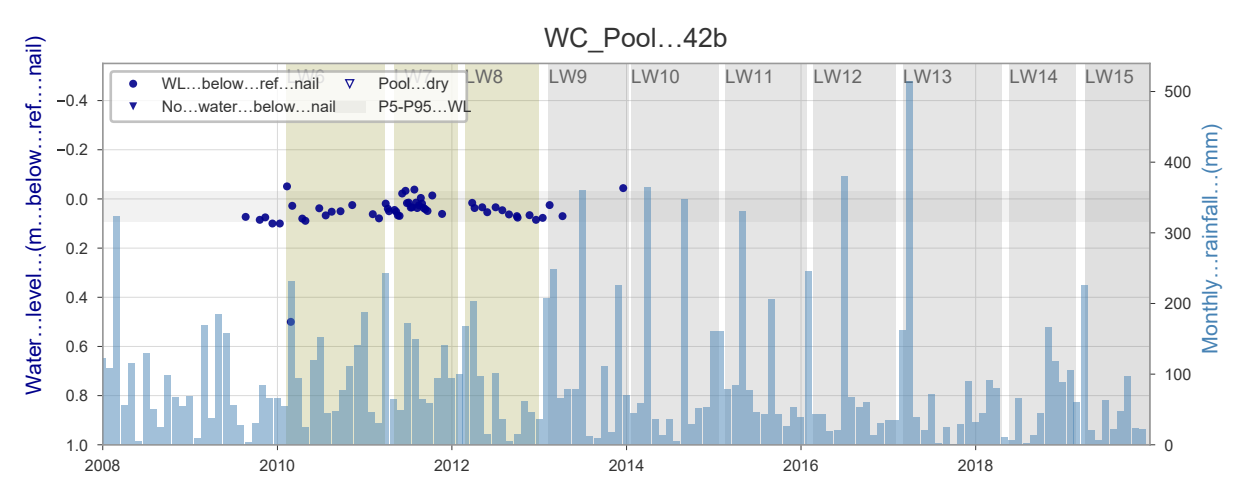

WC_Pool…41
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

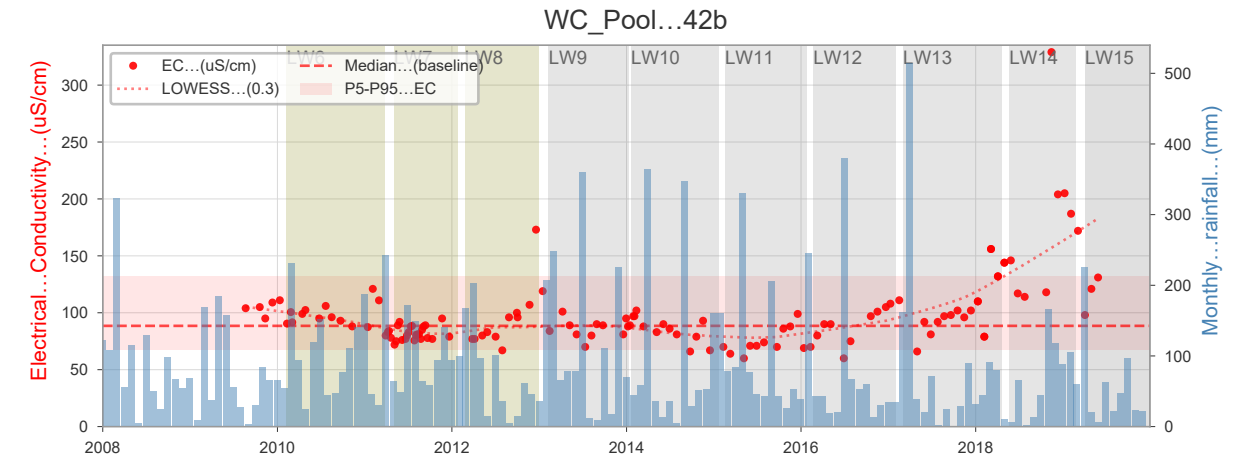

WC_Pool…42a
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….…nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

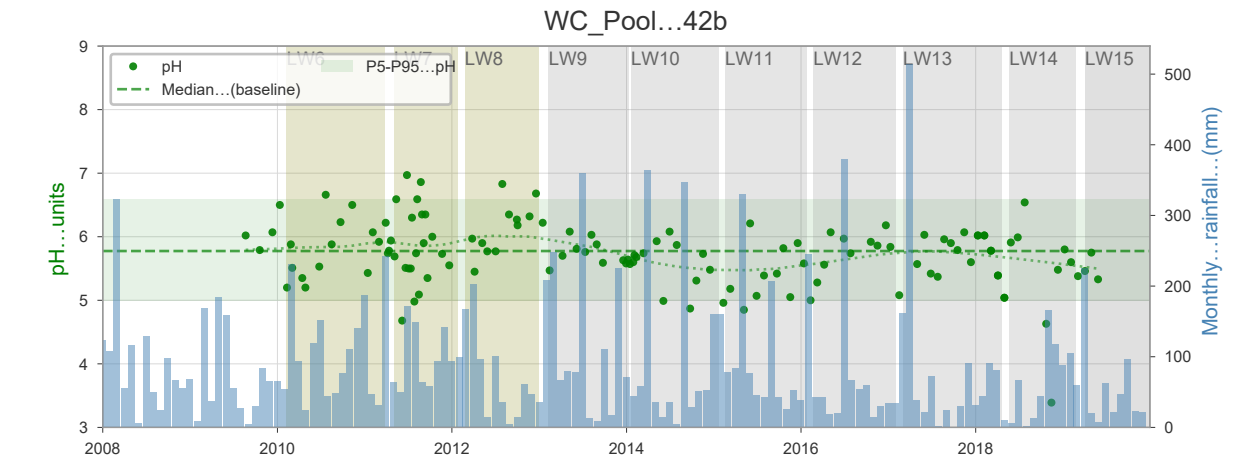

WC_Pool…42a
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

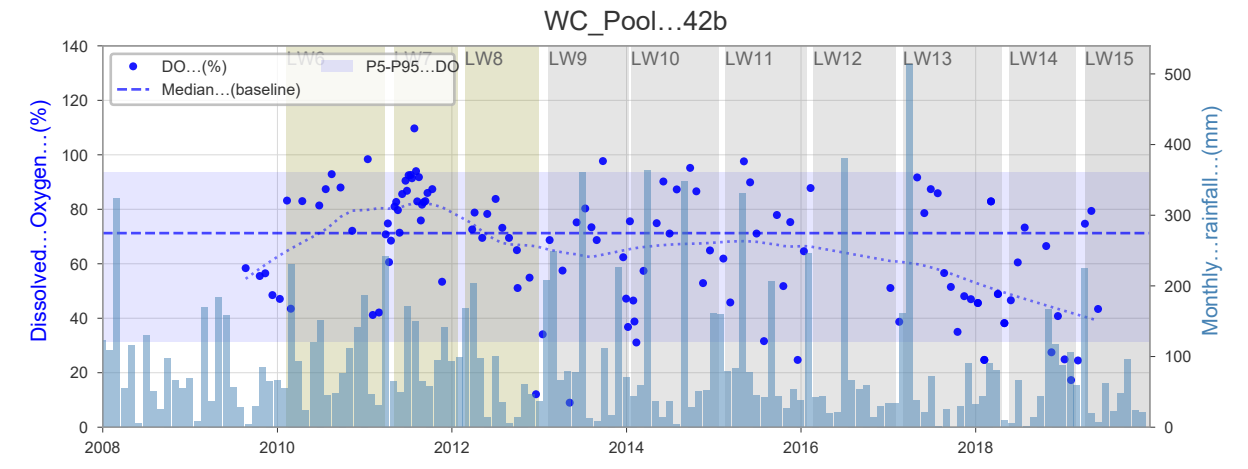

WC_Pool…42a
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

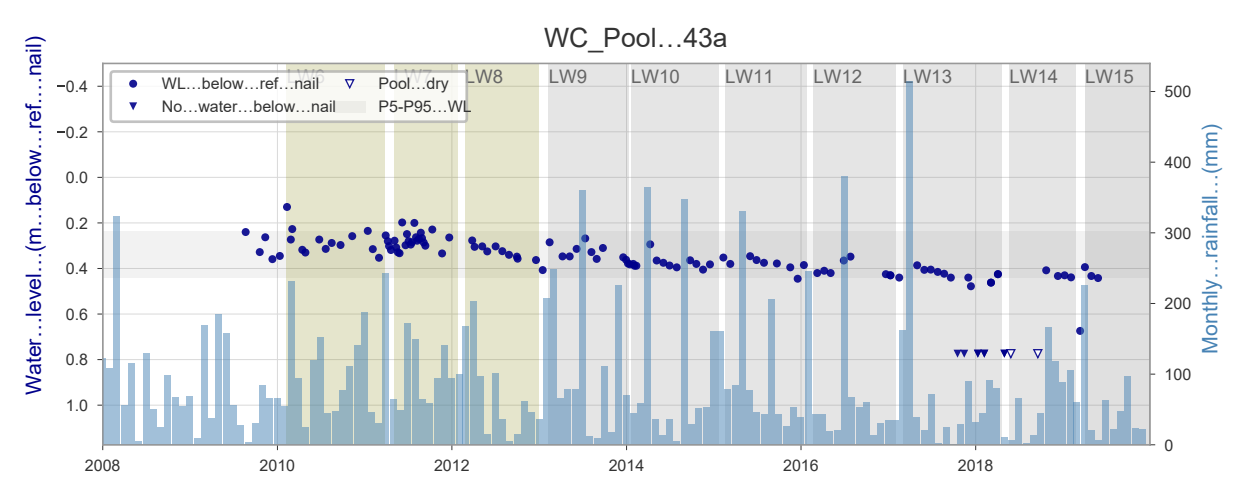

WC_Pool…42a
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

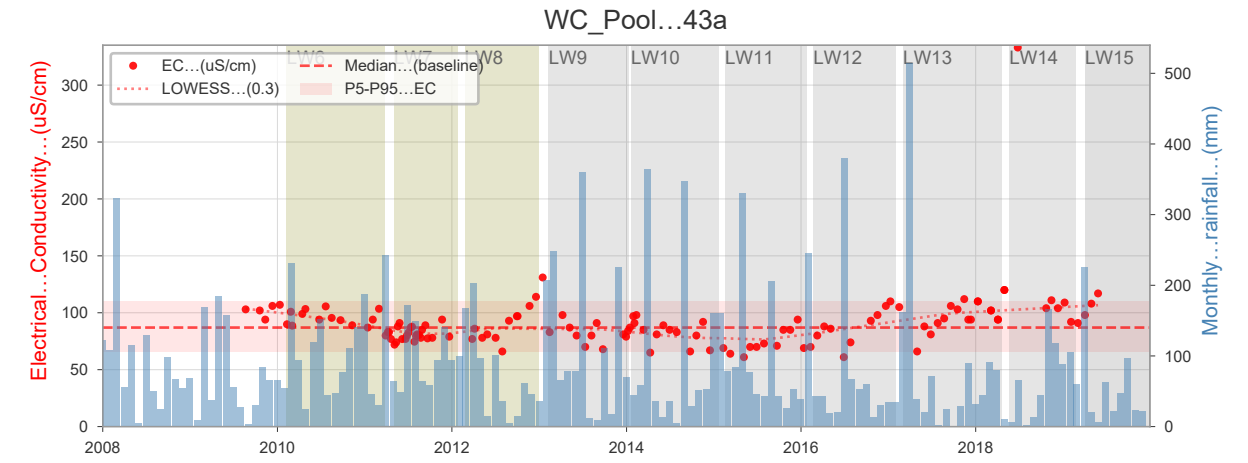

WC_Pool…42b
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….…nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

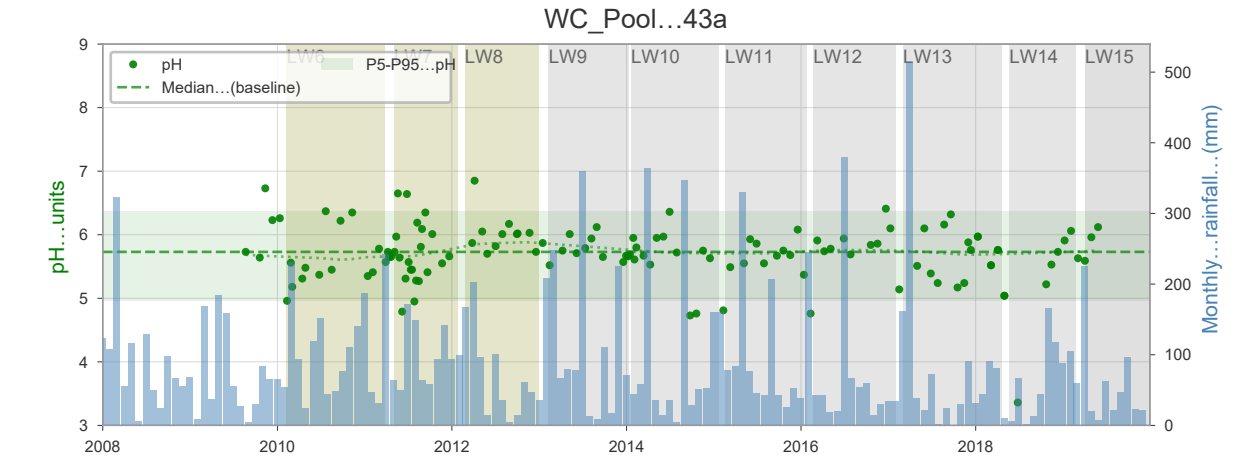

WC_Pool…42b
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

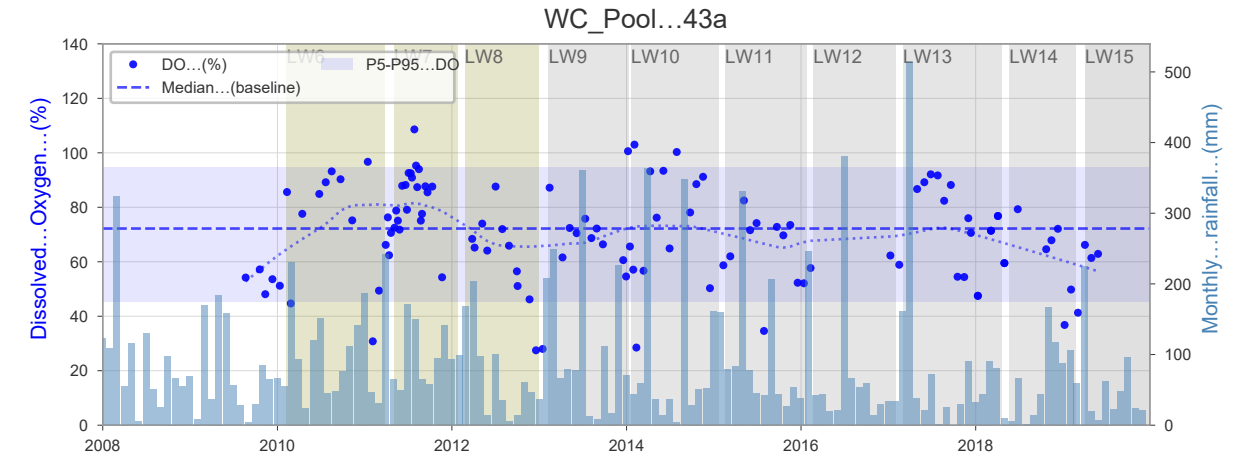

WC_Pool…42b
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

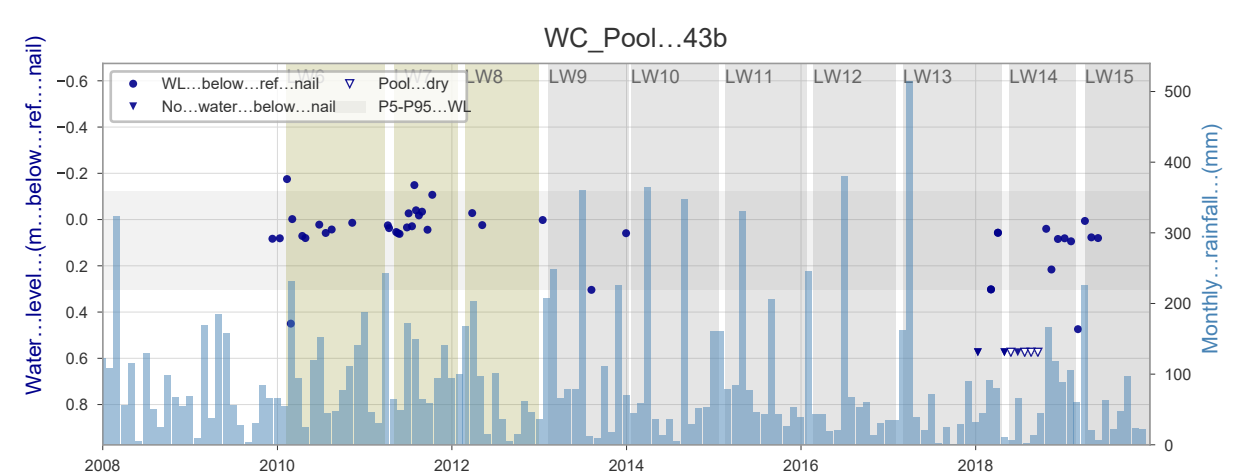

WC_Pool…42b
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

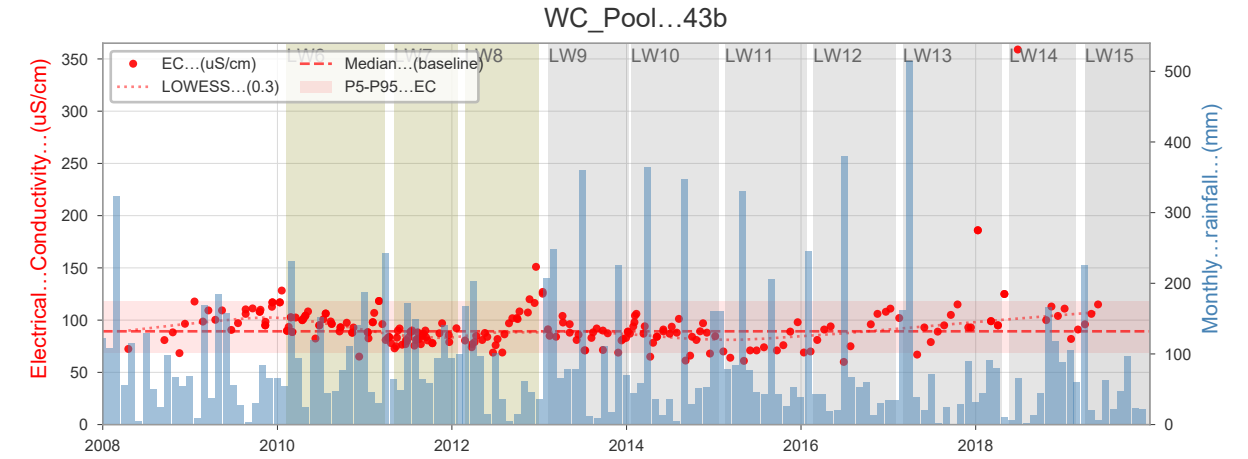

WC_Pool…43a
WL…below…ref…nail
No…water…below…nail
Pool…dry
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

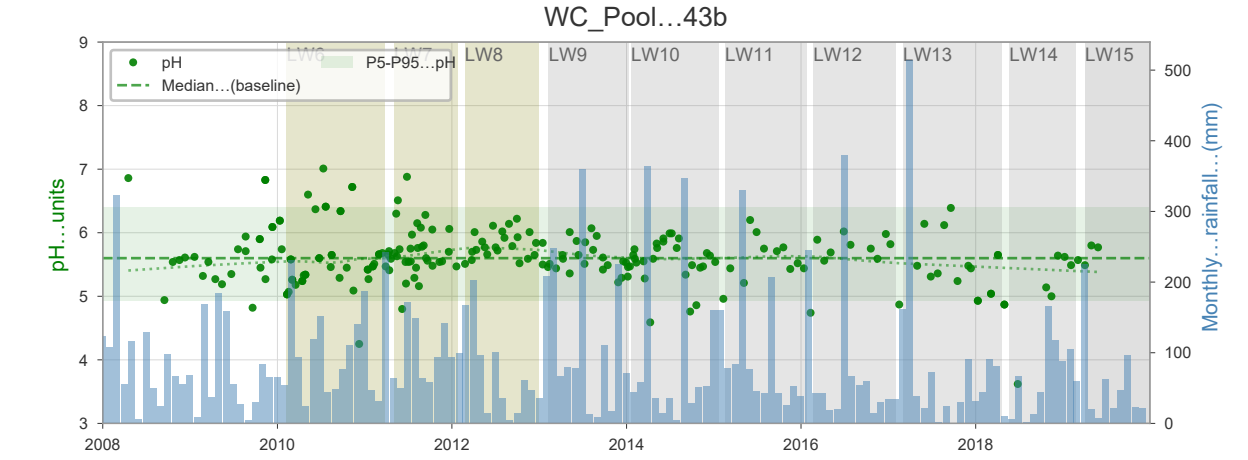

WC_Pool…43a
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

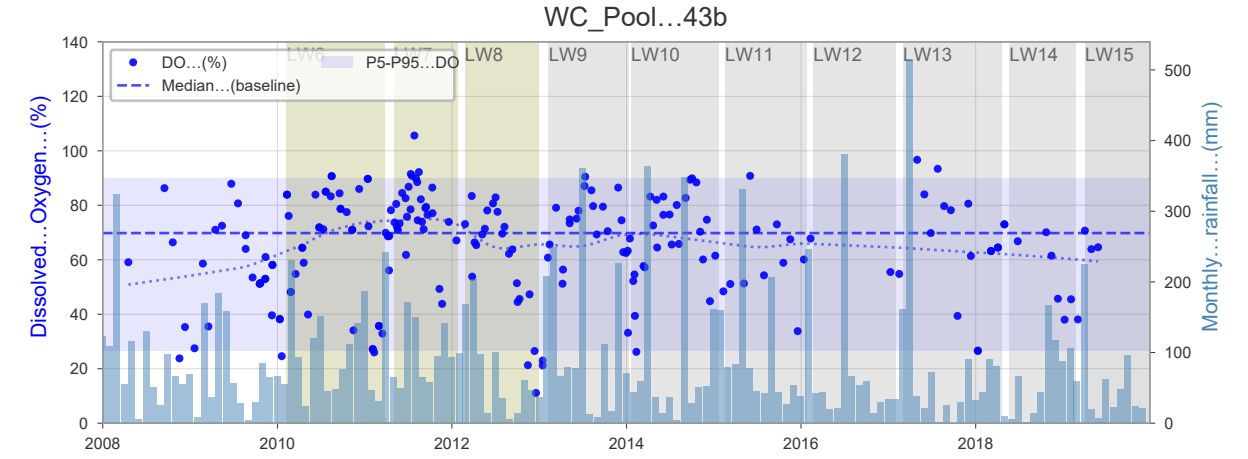

WC_Pool…43a
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

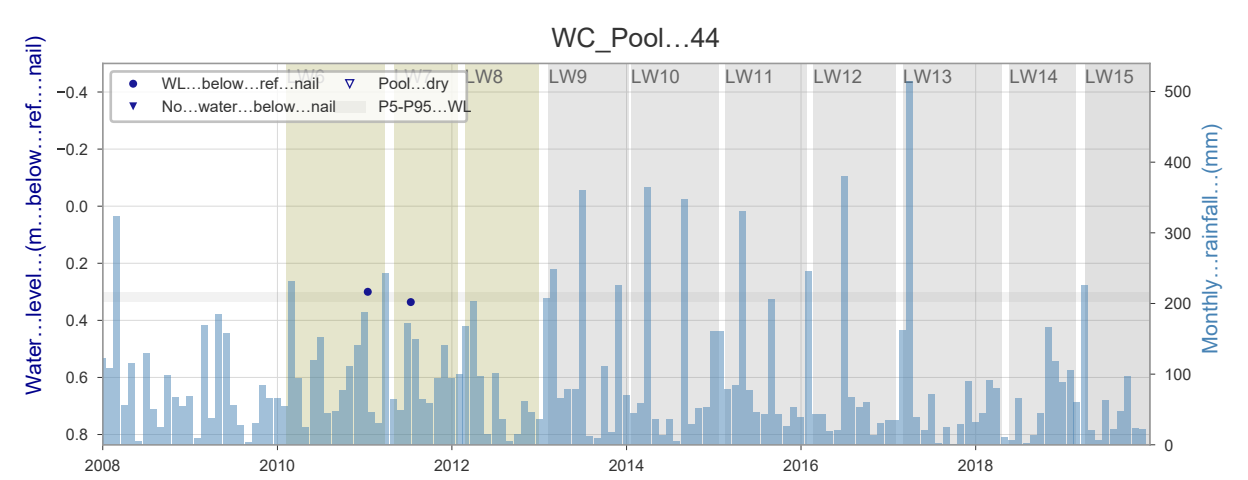

WC_Pool…43a
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

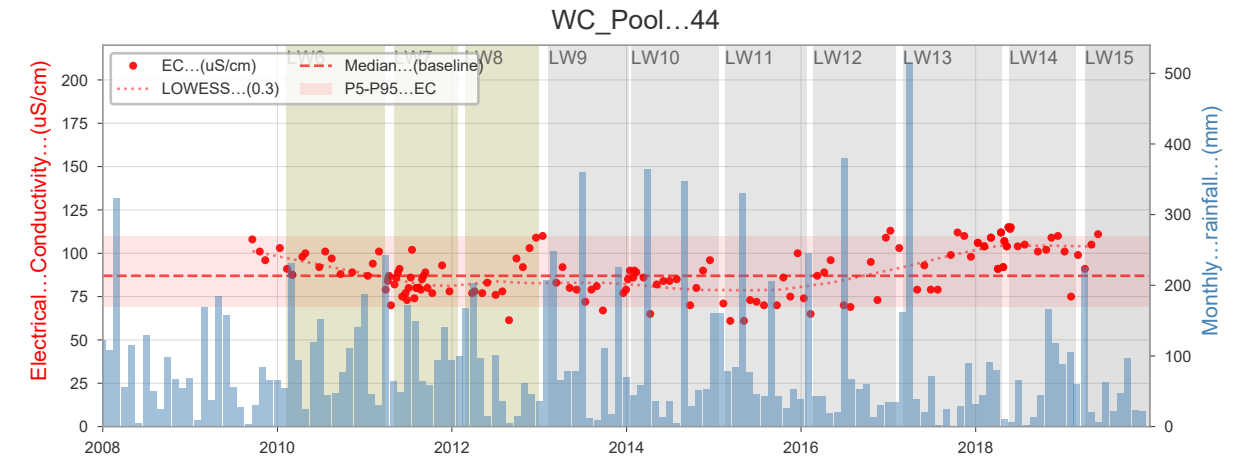

WC_Pool…43b
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

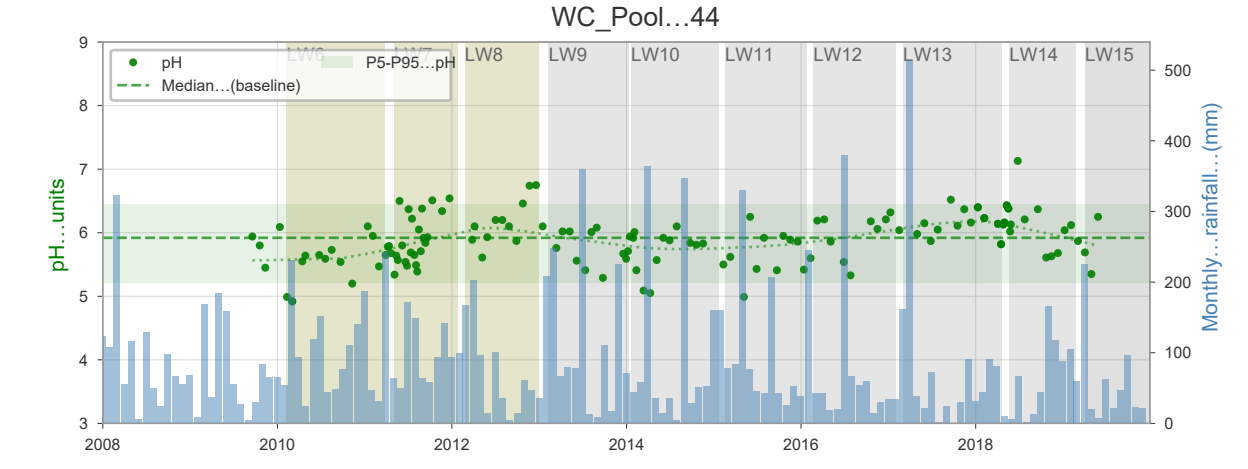

WC_Pool…43b
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

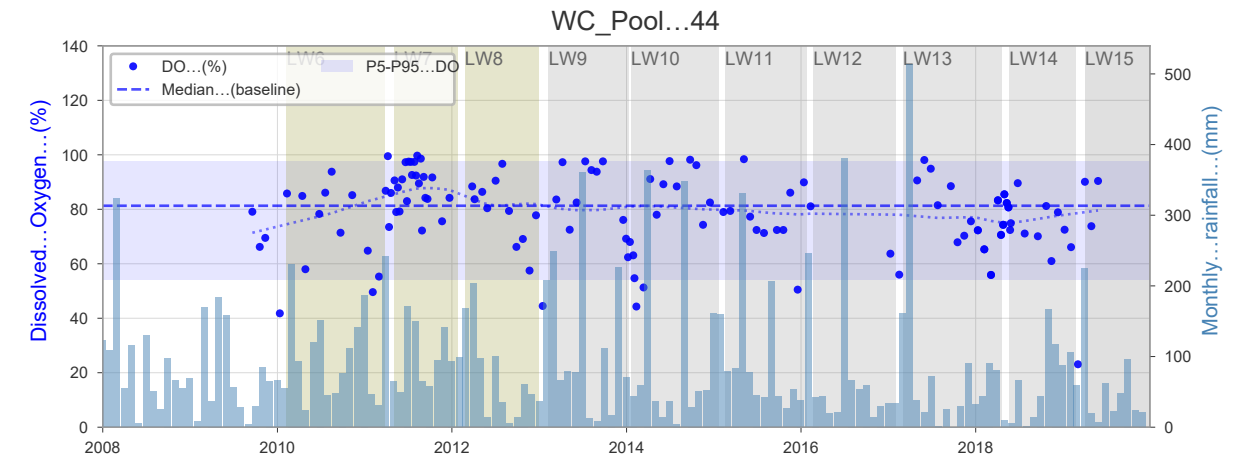

WC_Pool…43b
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

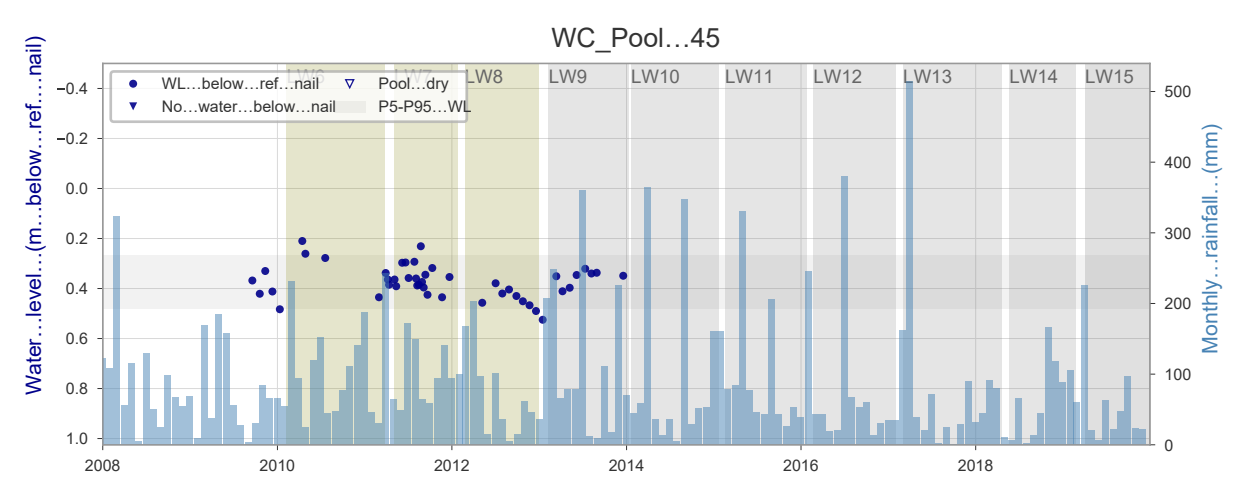

WC_Pool…43b
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

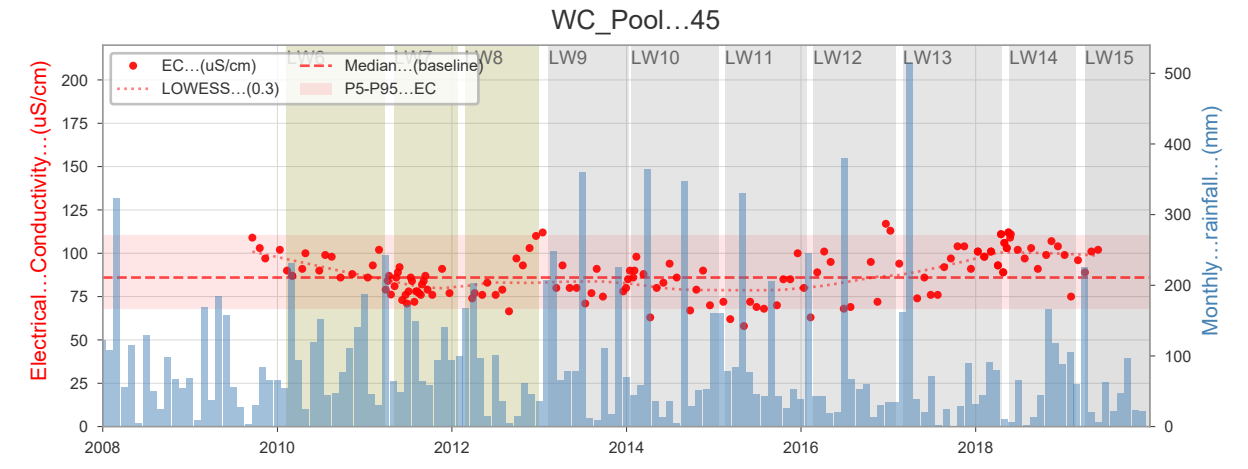

WC_Pool…44
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

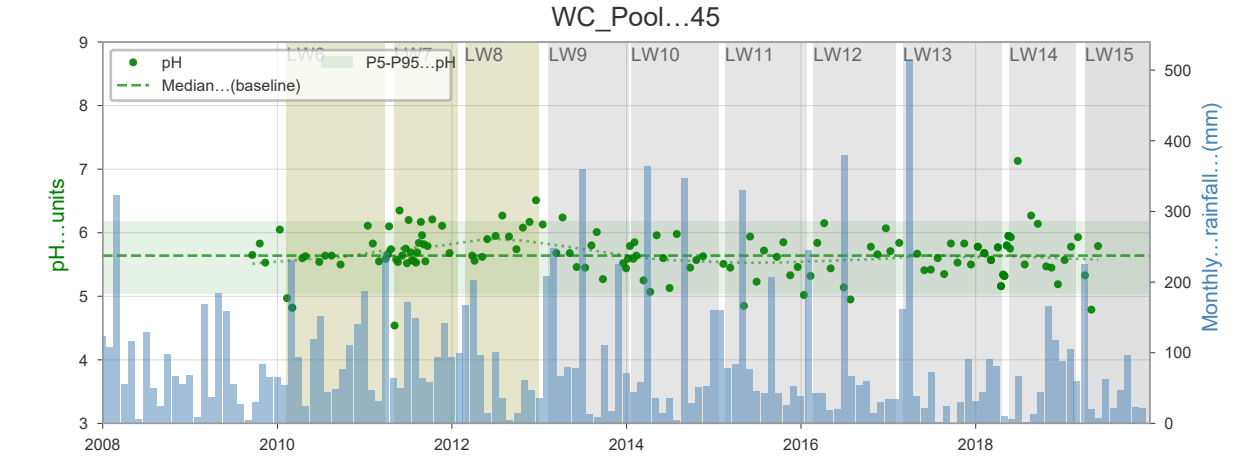

WC_Pool…44
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

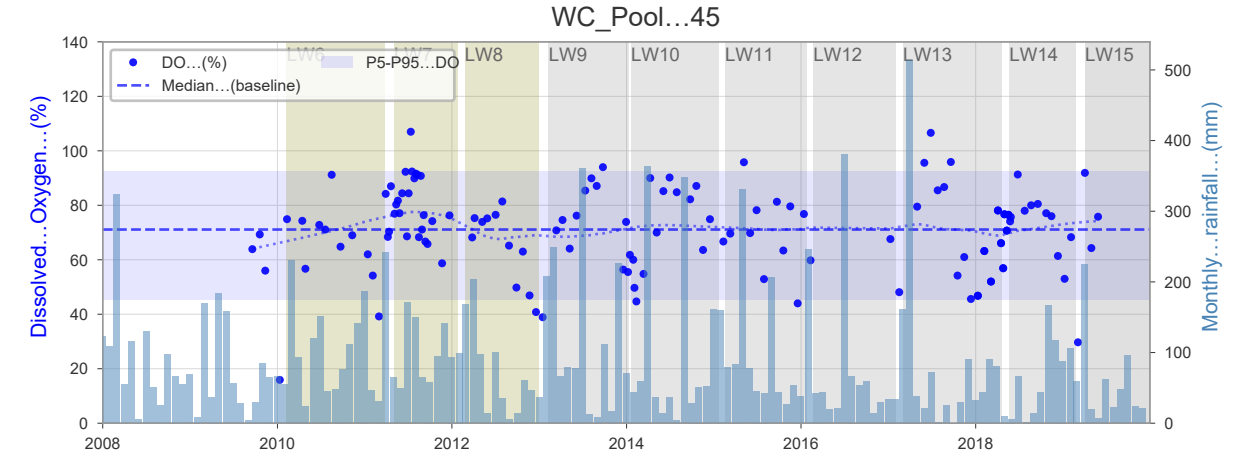

WC_Pool…44
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

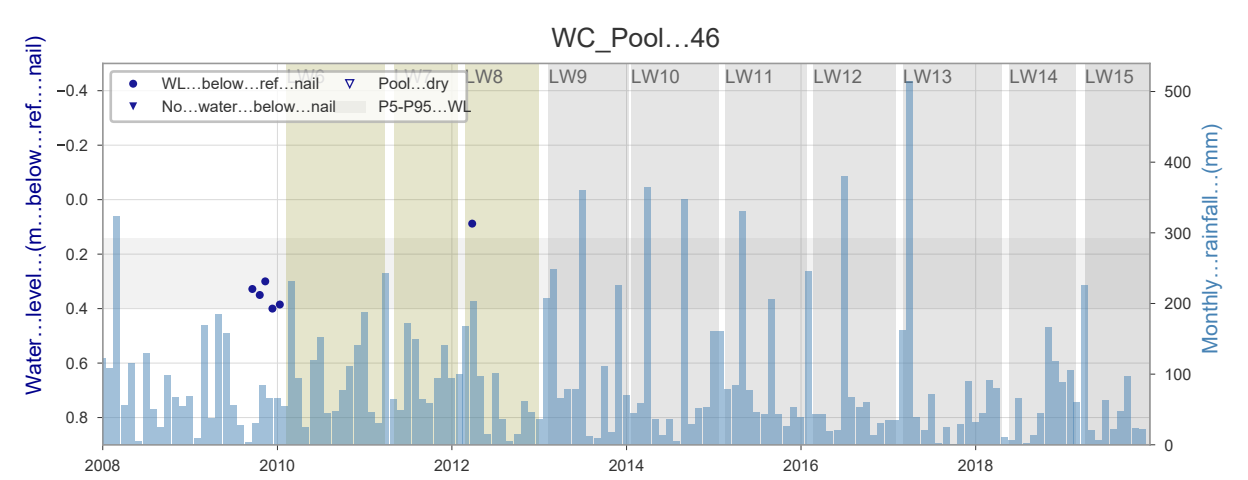

WC_Pool…44
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

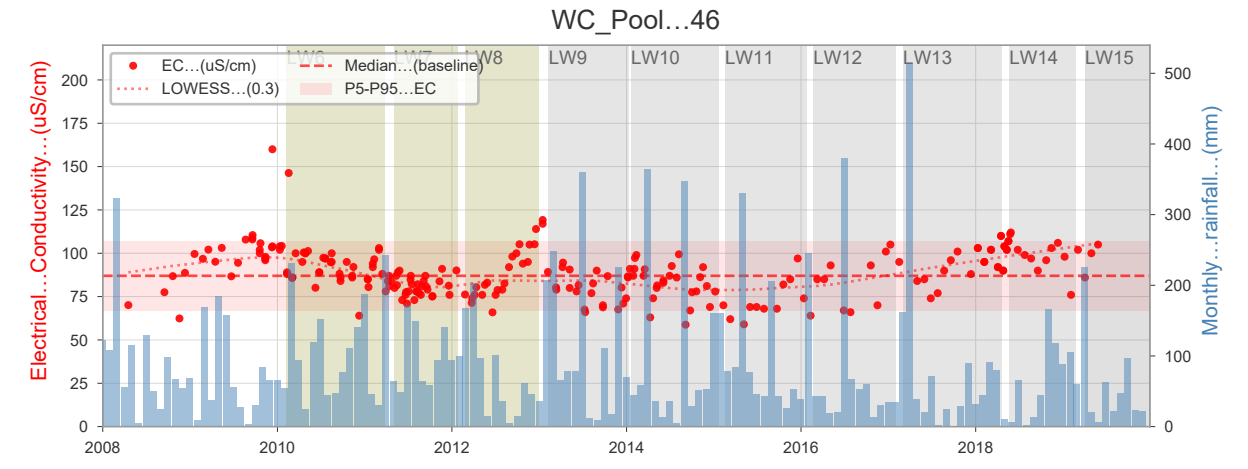

WC_Pool…45
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

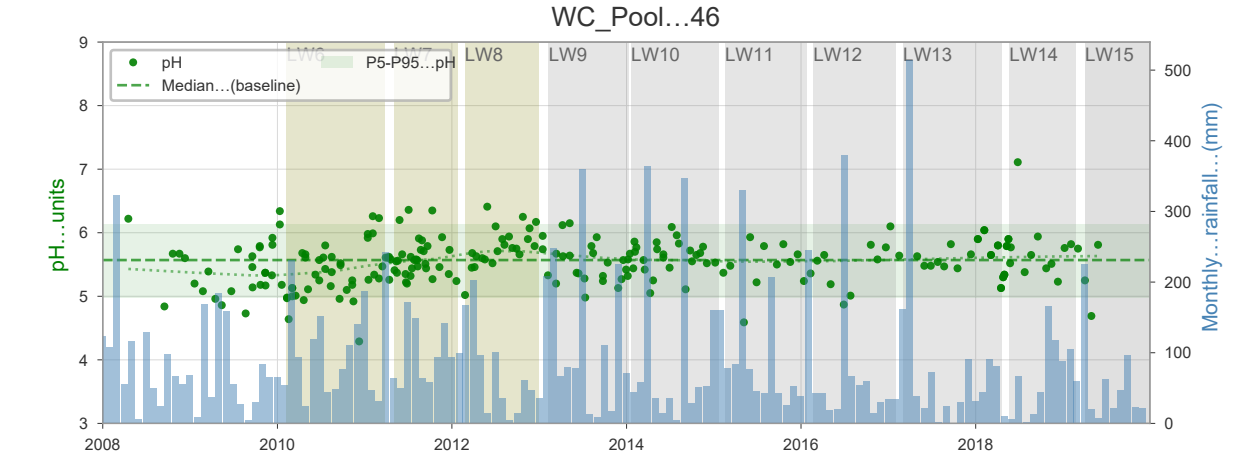

WC_Pool…45
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

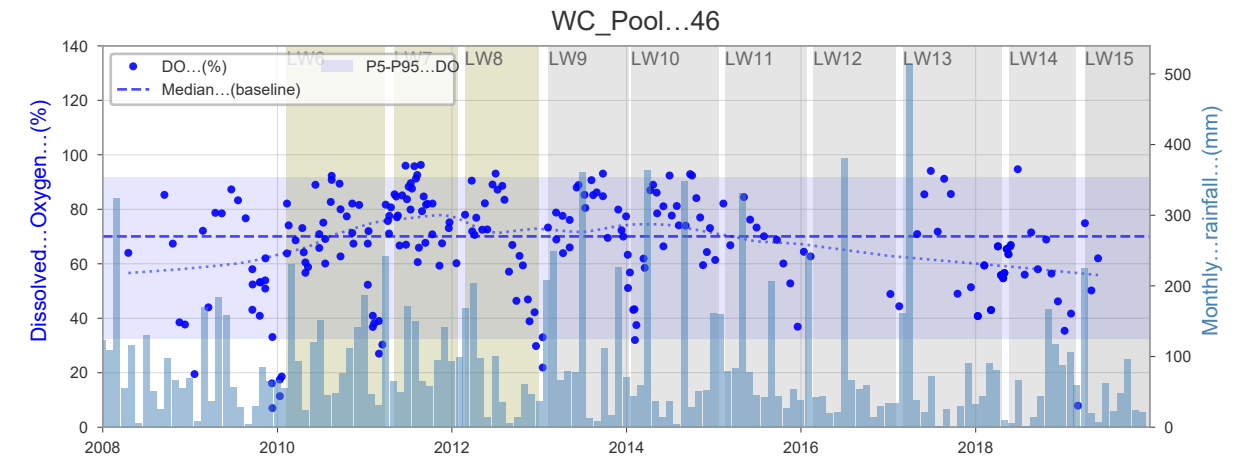

WC_Pool…45
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

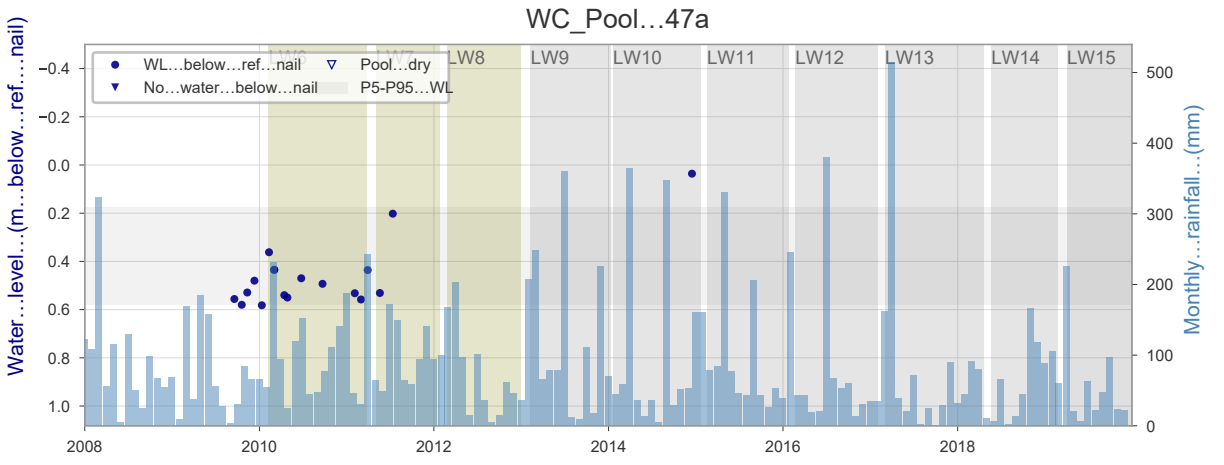

WC_Pool…45
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

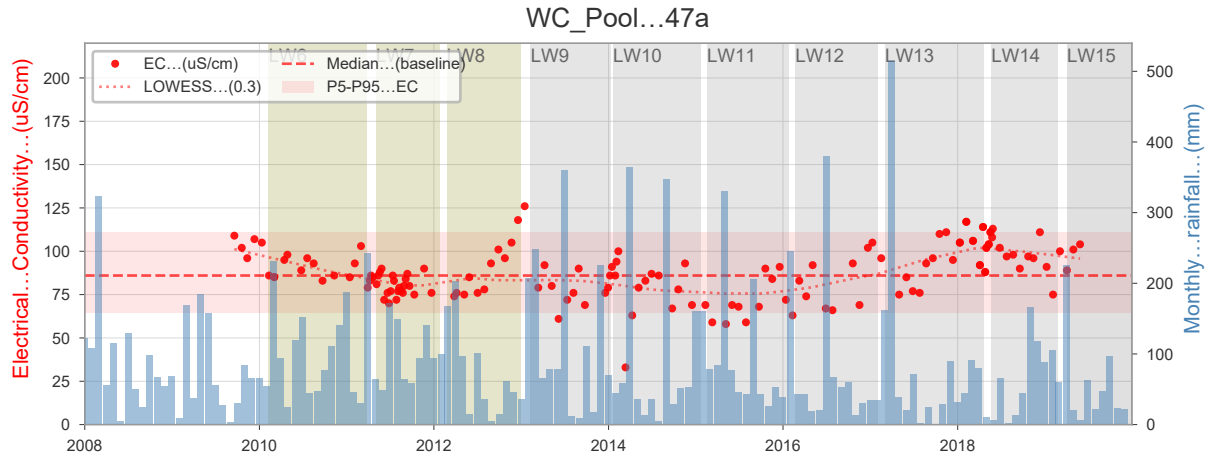

WC_Pool…46
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

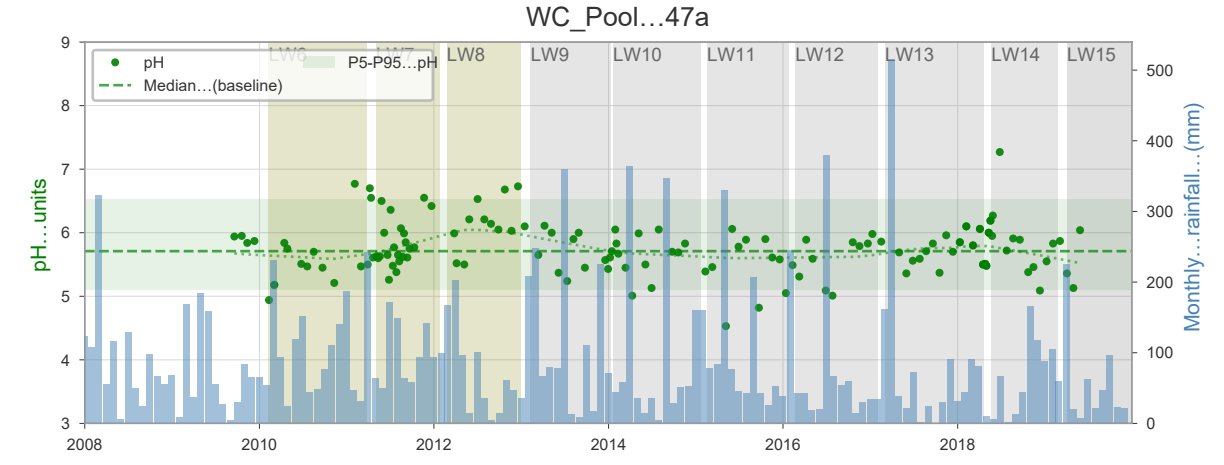

WC_Pool…46
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

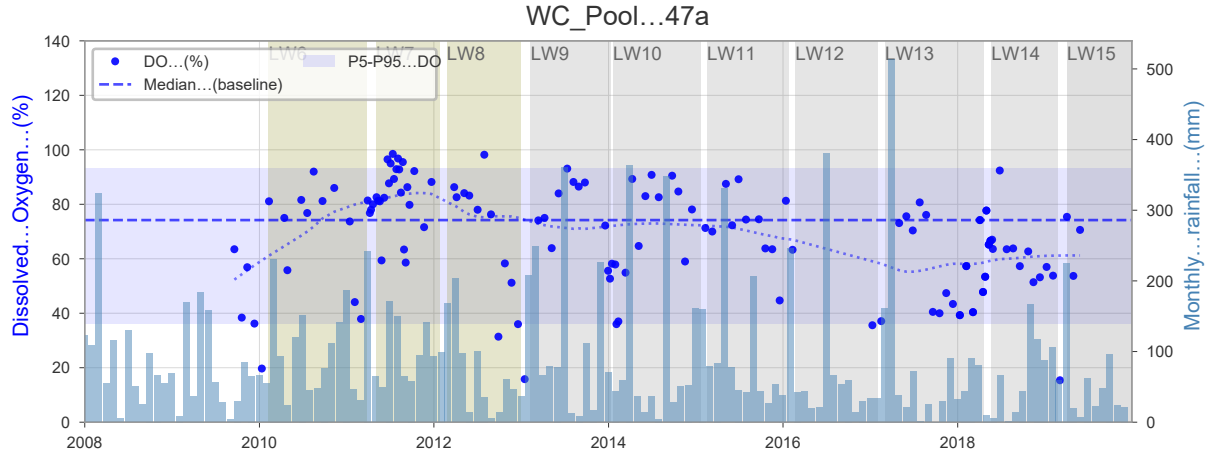

WC_Pool…46
pH…units
Monthly…rainfall…(mm)
pH
Median…(baseline)
P5-P95…pH
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

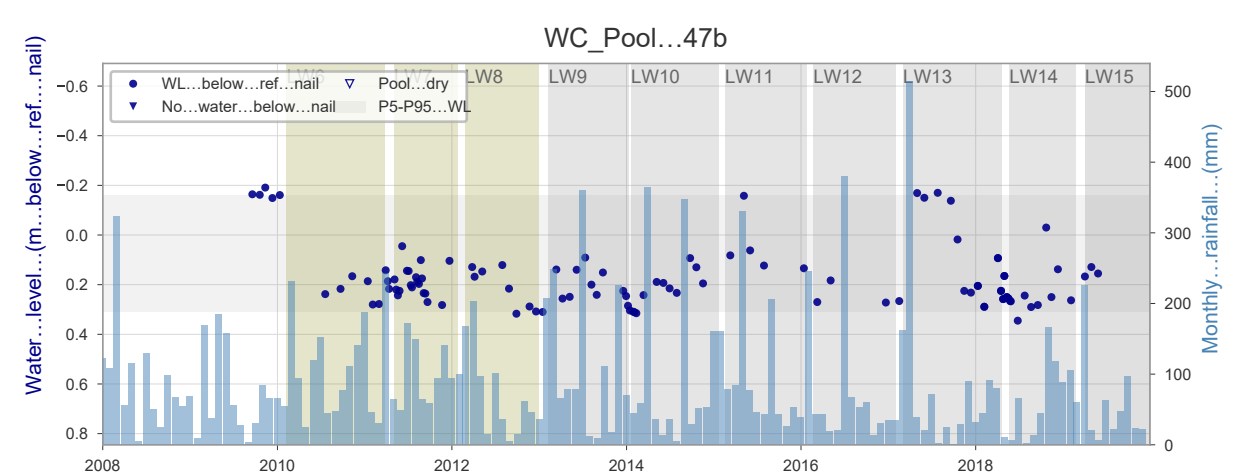

WC_Pool…46
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

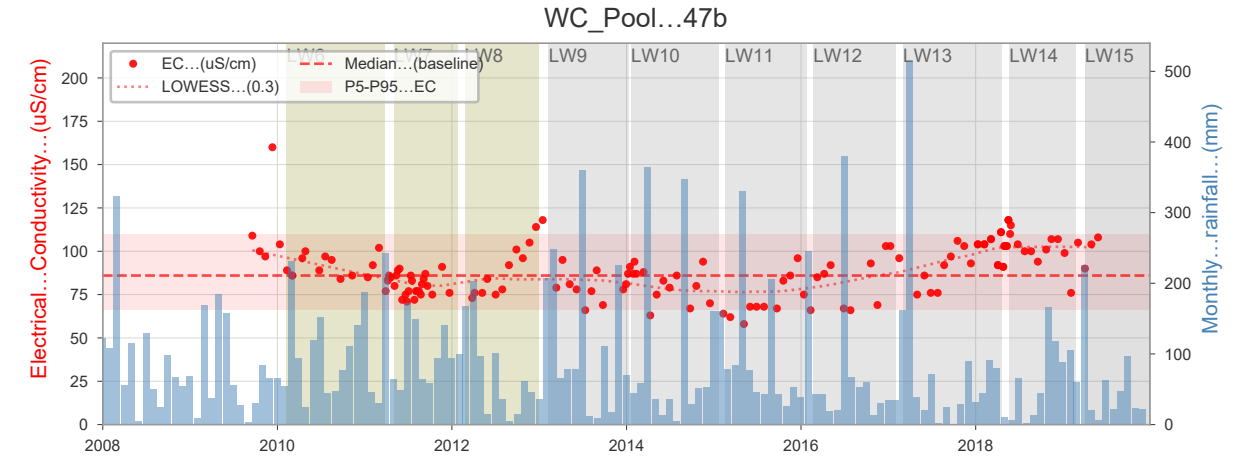

WC_Pool…47a
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

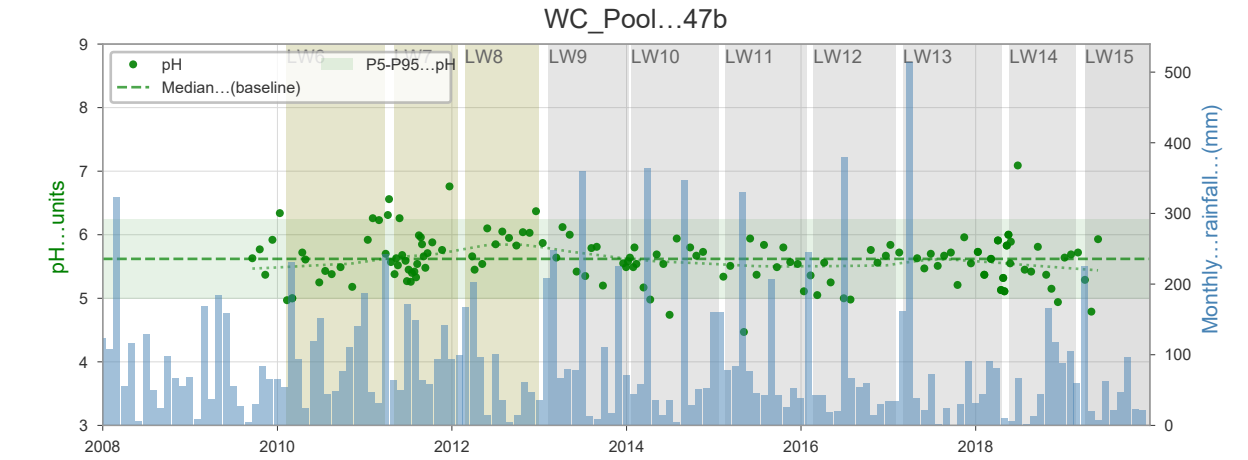

WC_Pool…47a
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

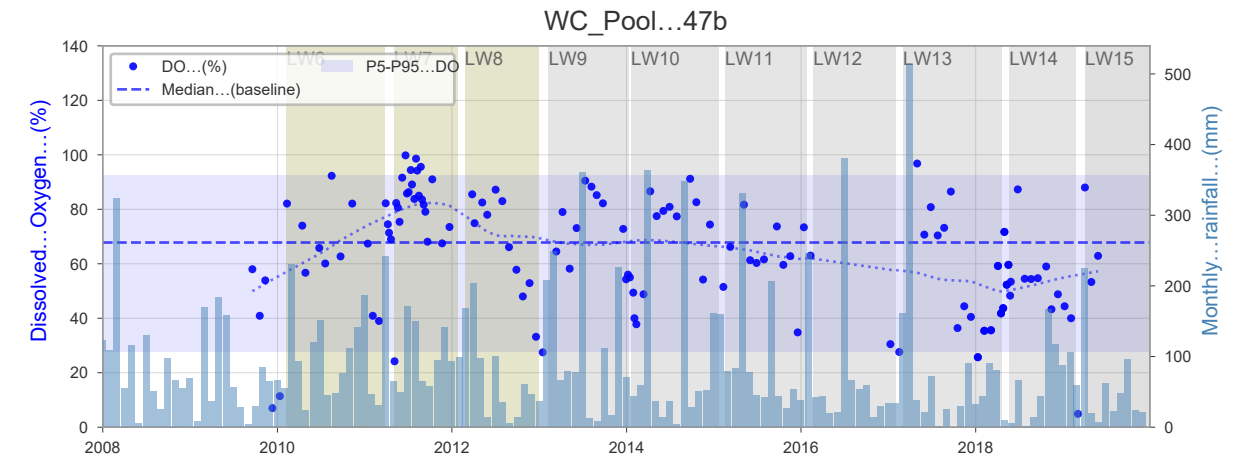

WC_Pool…47a
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

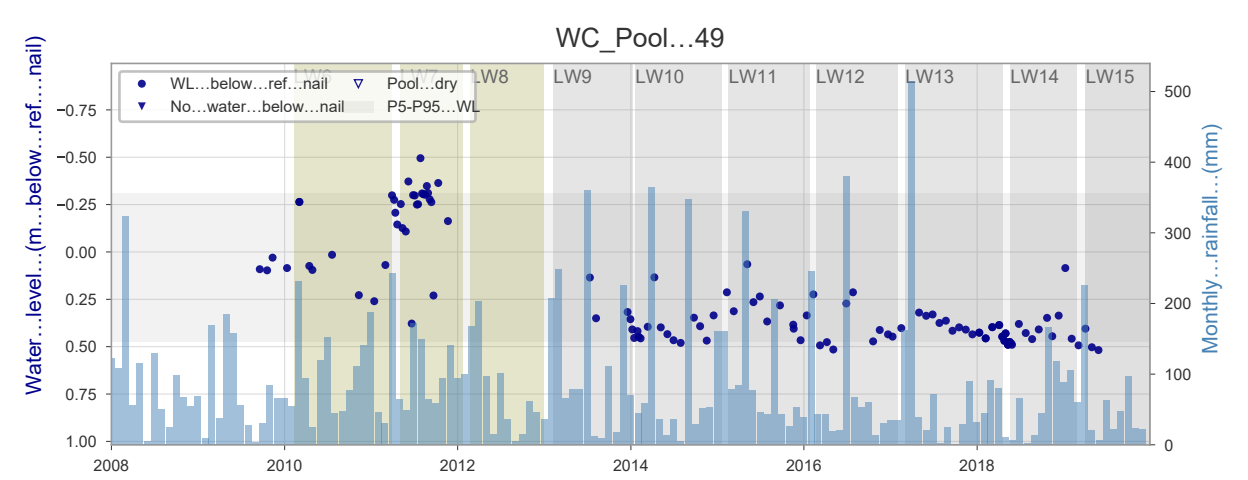

WC_Pool…47a
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

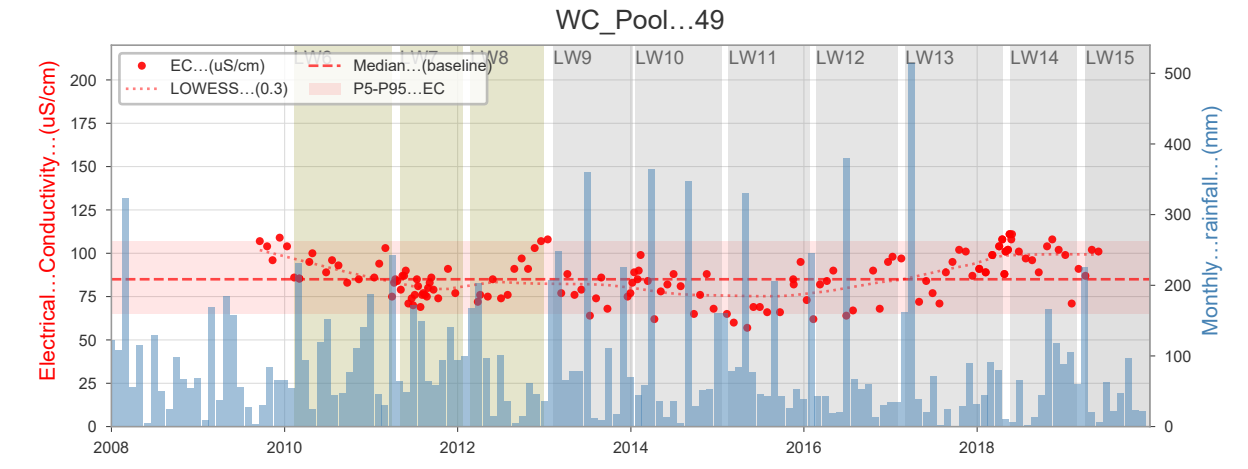

WC_Pool…47b
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

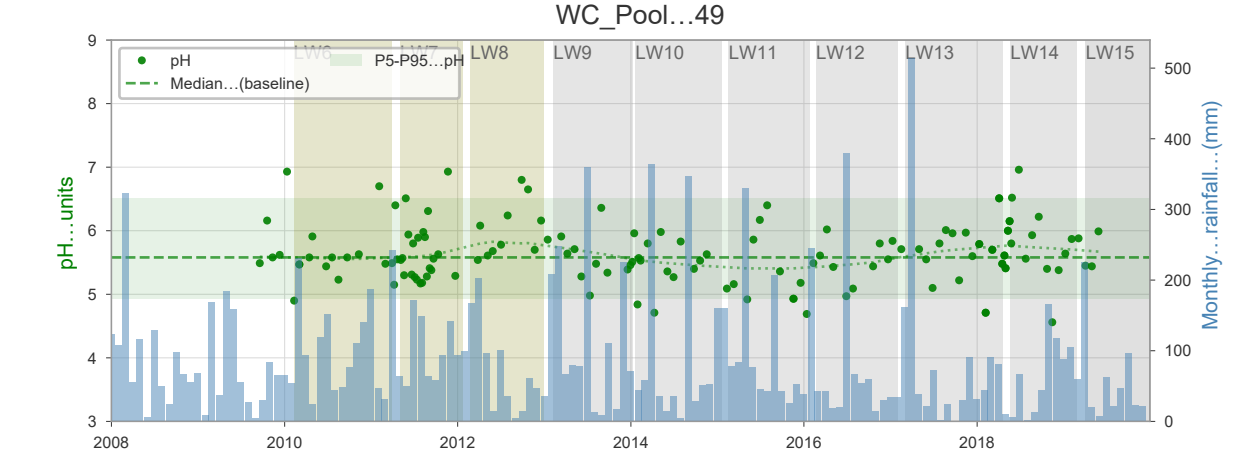

WC_Pool…47b
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

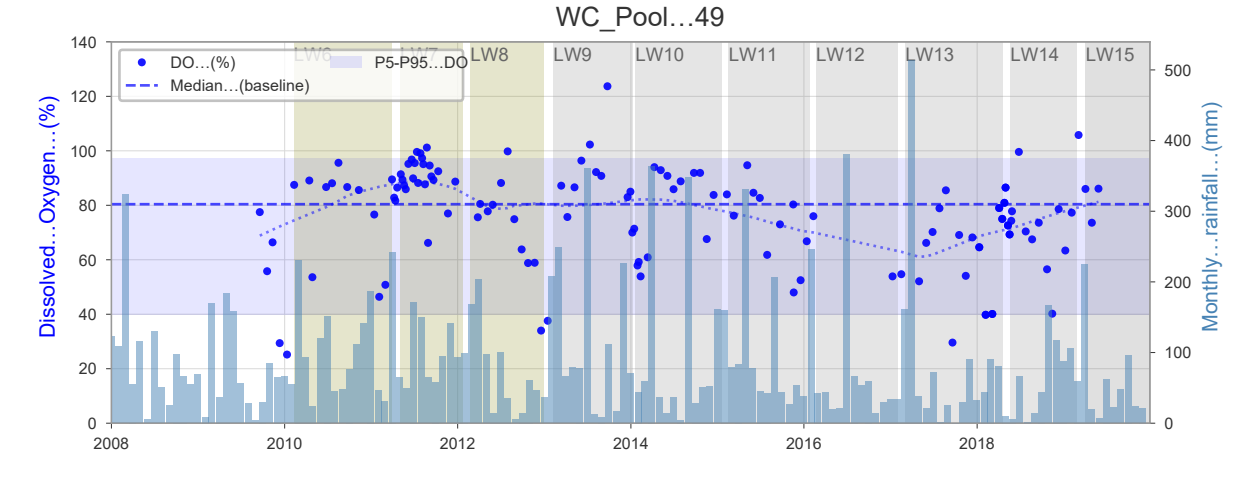

WC_Pool…47b
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

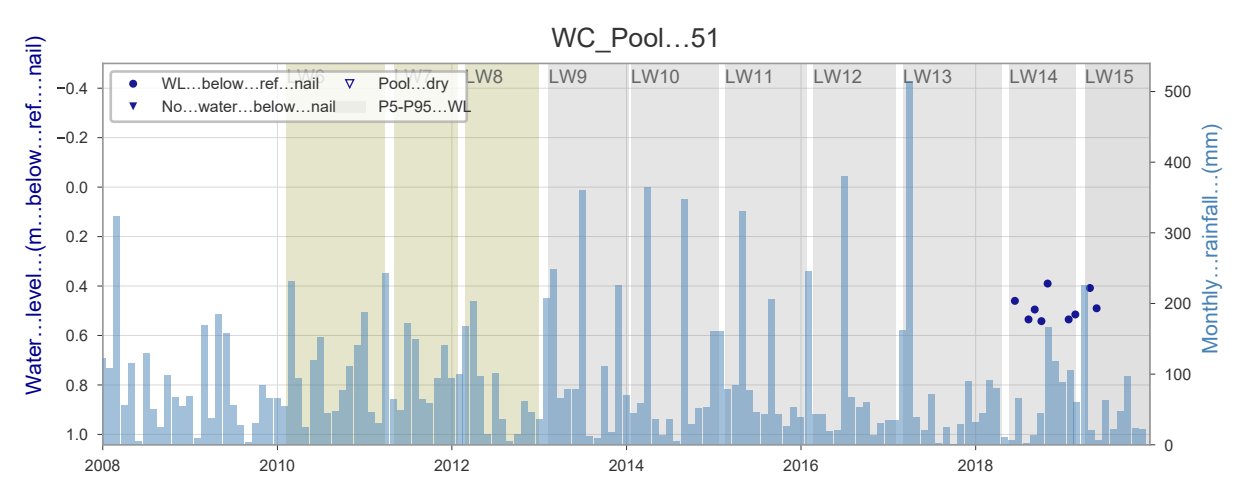

WC_Pool…47b
DO…(%)
P5-P95…DO
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

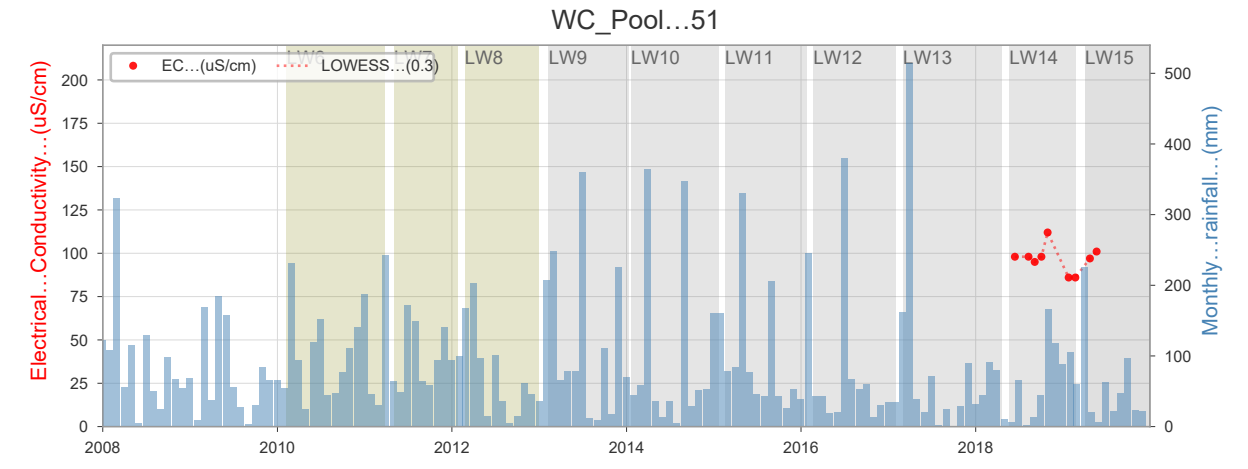

WC_Pool…49
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref.…nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

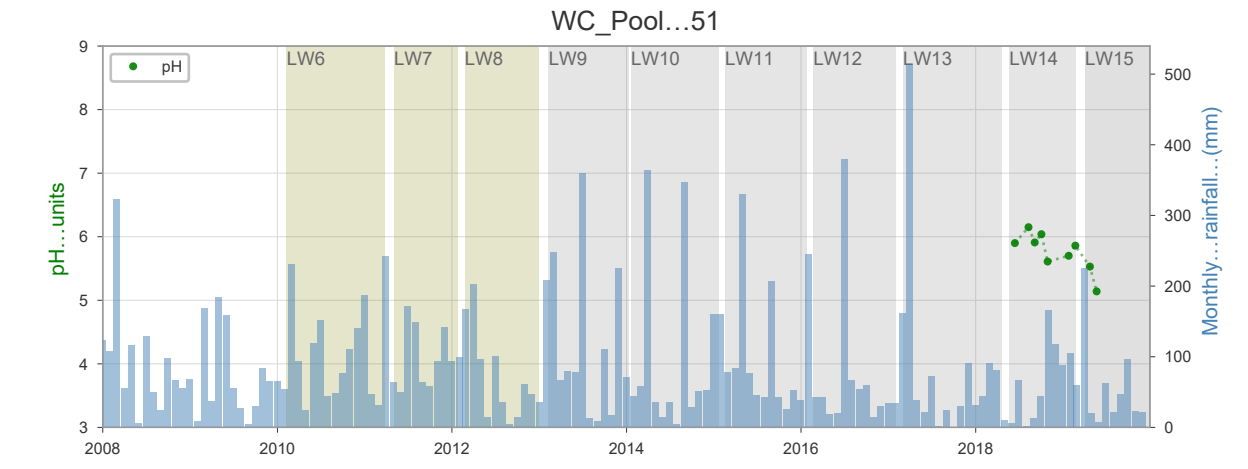

WC_Pool…49
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

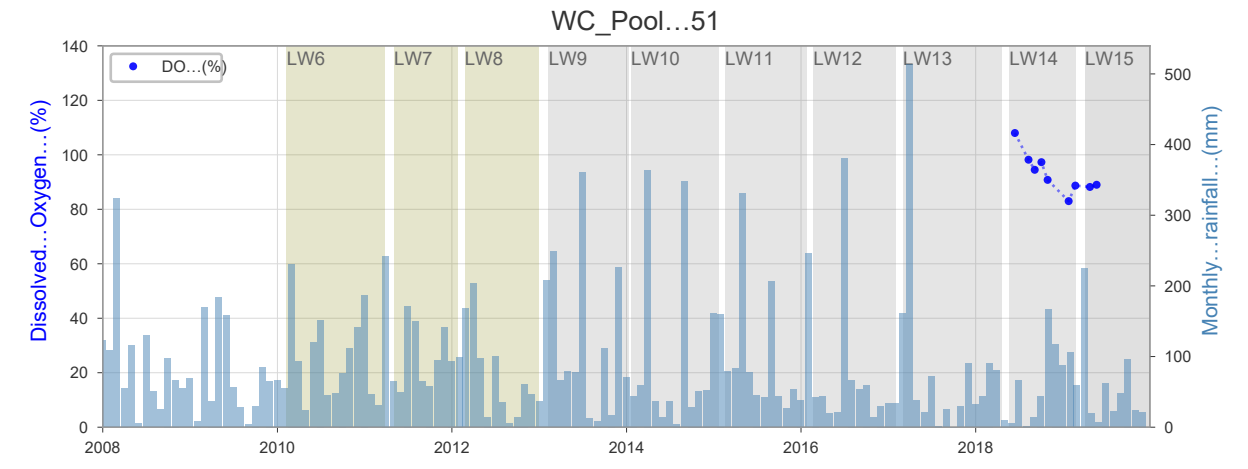

WC_Pool…49
pH
P5-P95…pH
Median…(baseline)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

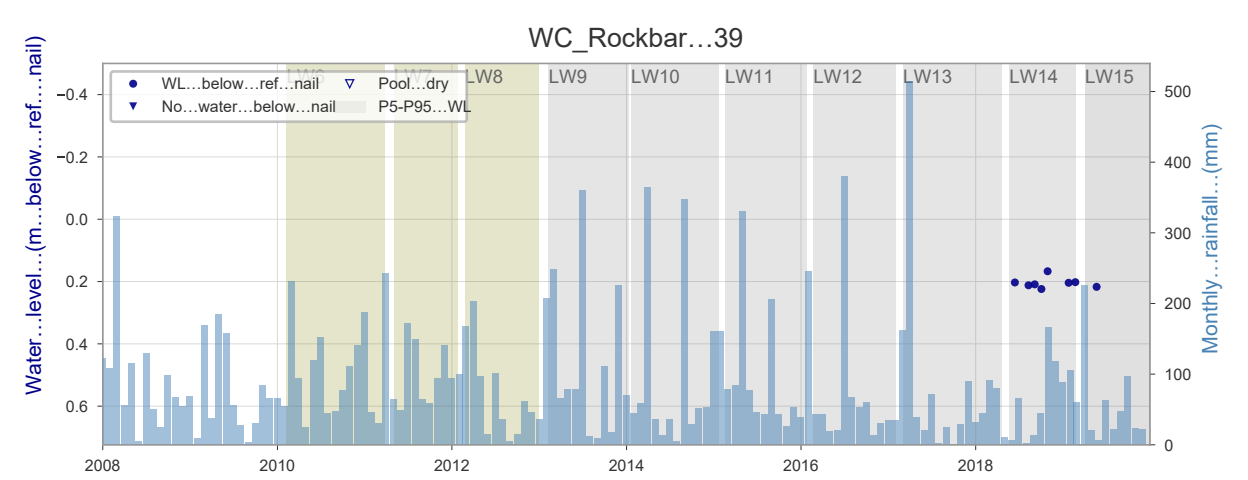

WC_Pool…49
DO…(%)
Median…(baseline)
P5-P95…DO
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

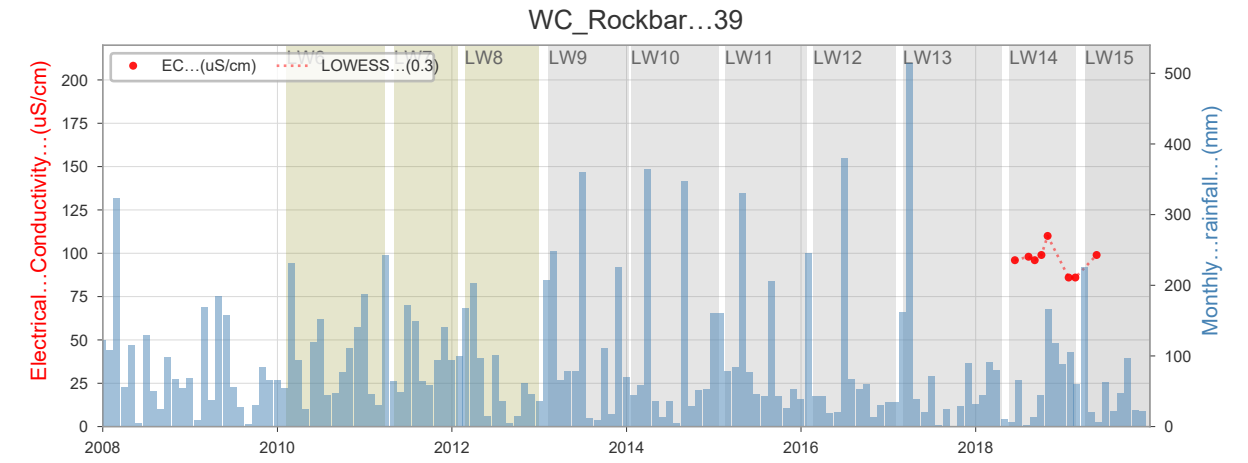

WC_Pool…51
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

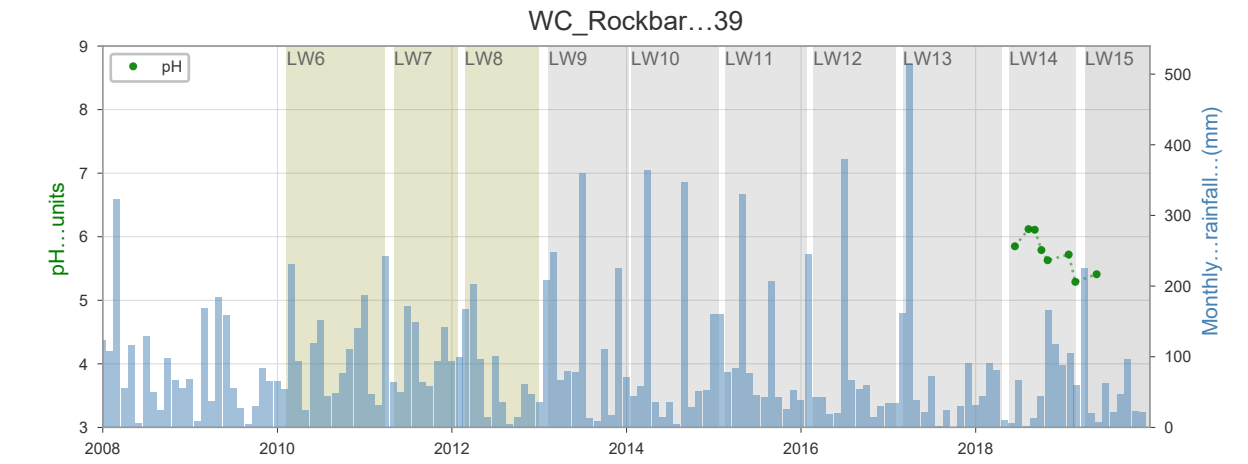

WC_Pool…51
EC…(uS/cm)
LOWESS…(0.3)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

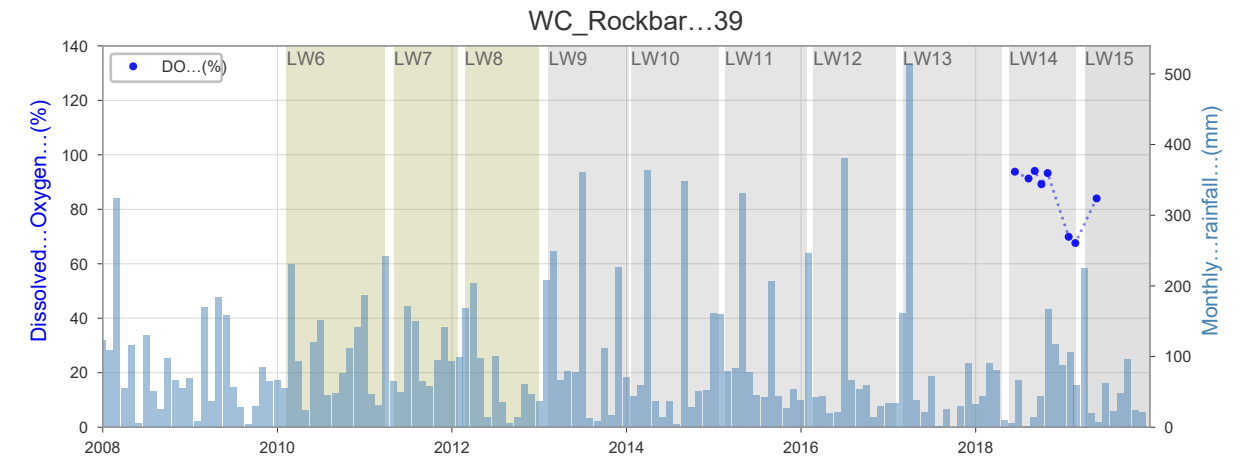

WC_Pool…51
pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

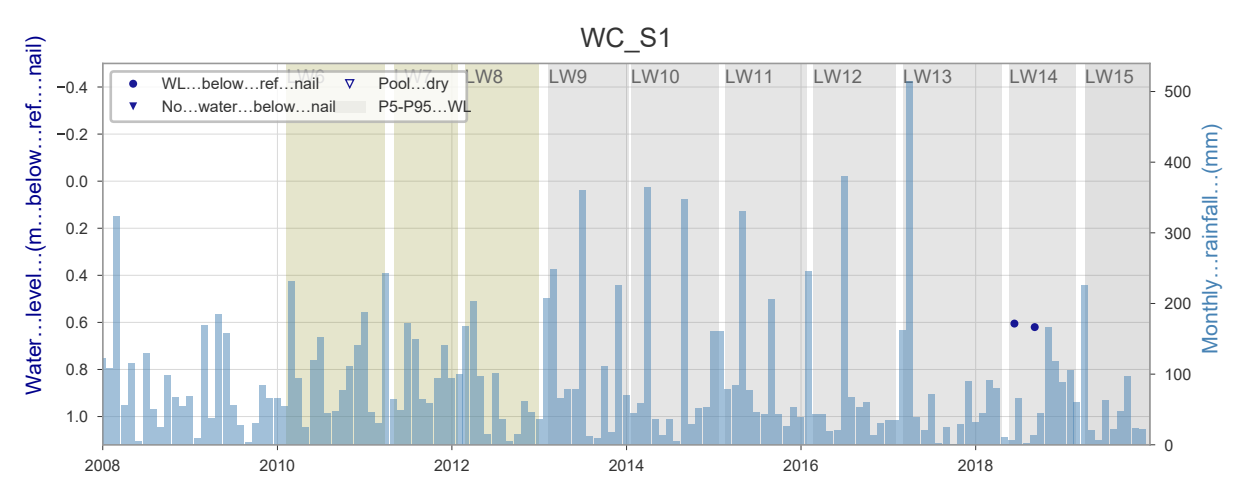

WC_Pool…51
DO…(%)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

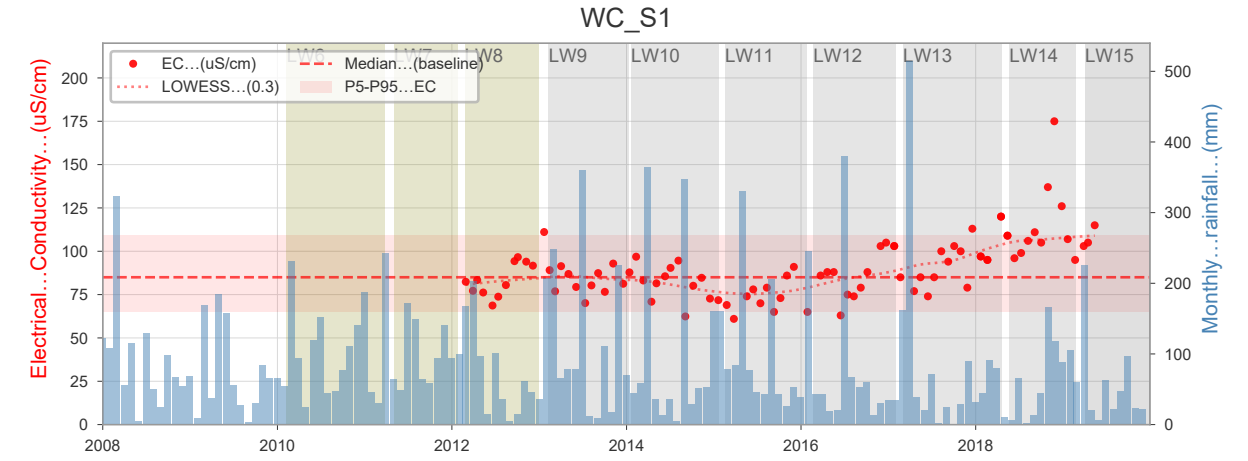

WC_Rockbar…39
WL…below…ref…nail
No…water…below…nail
Pool…dry
P5-P95…WL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

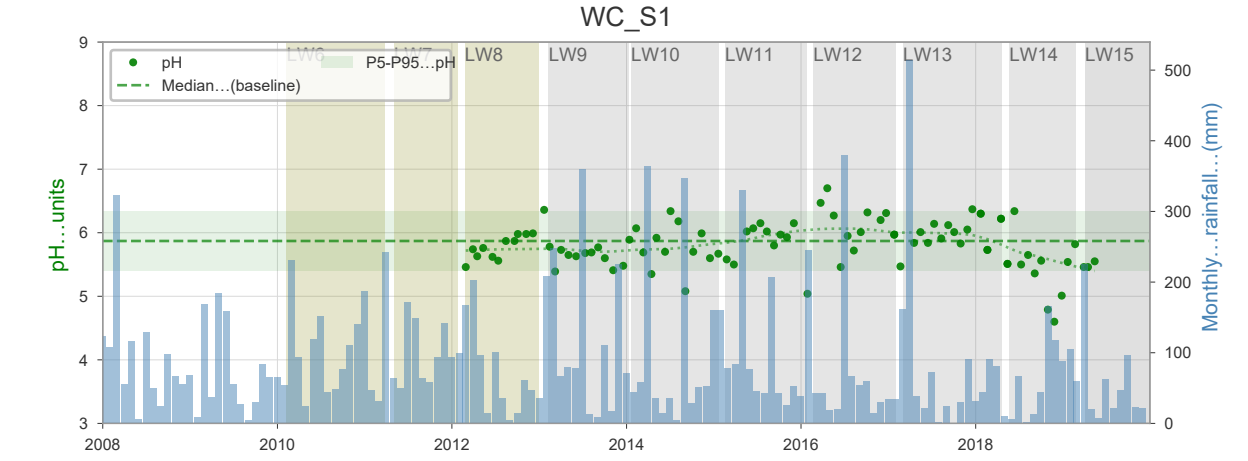

WC_Rockbar…39
EC…(uS/cm)
LOWESS…(0.3)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

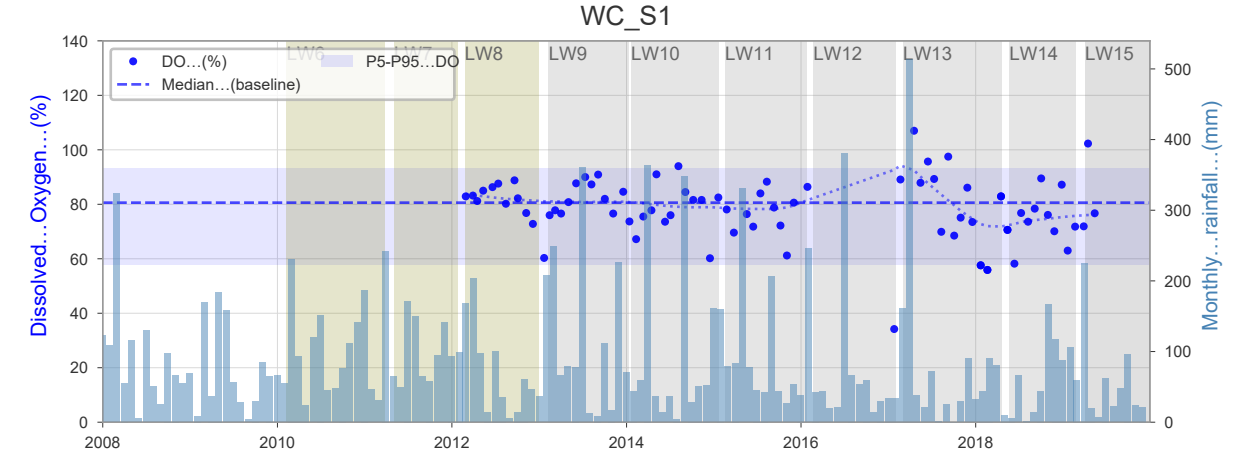

WC_Rockbar…39
pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

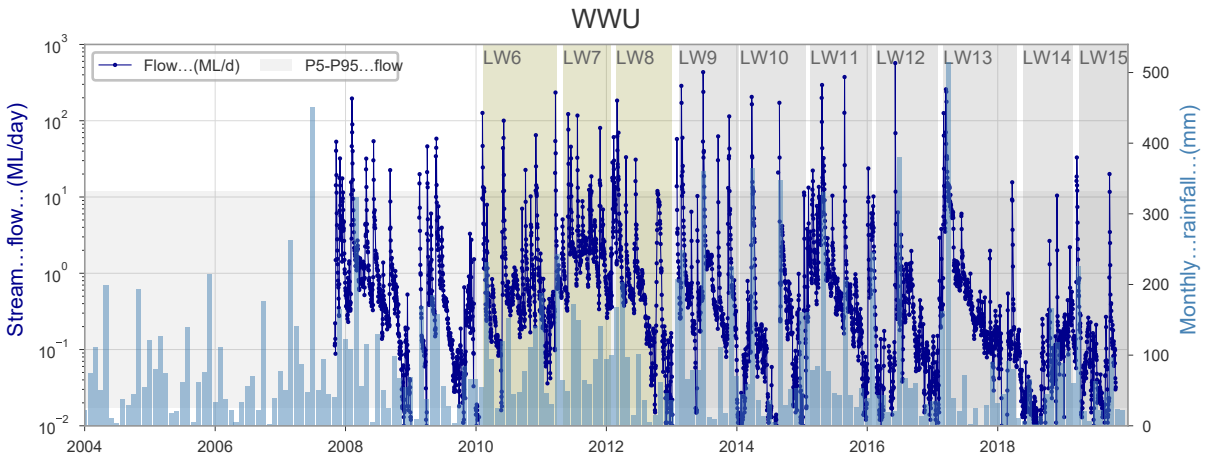

WC_Rockbar…39
DO…(%)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

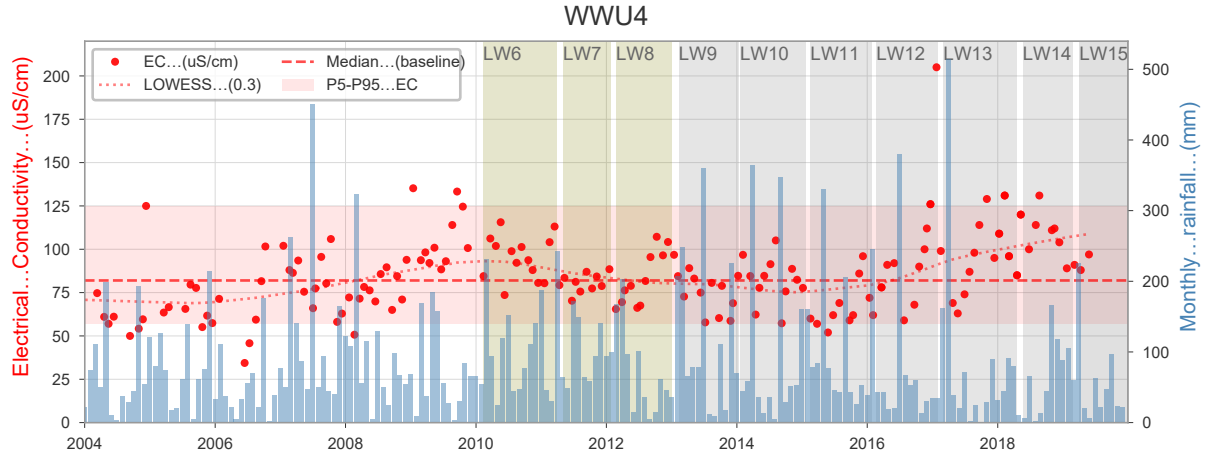

WC_S1
WL…below…ref…nail
Pool…dry
No…water…below…nail
P5-P95…WL
Water…level…(m…below…ref….nail)
Monthly…rainfall…(mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

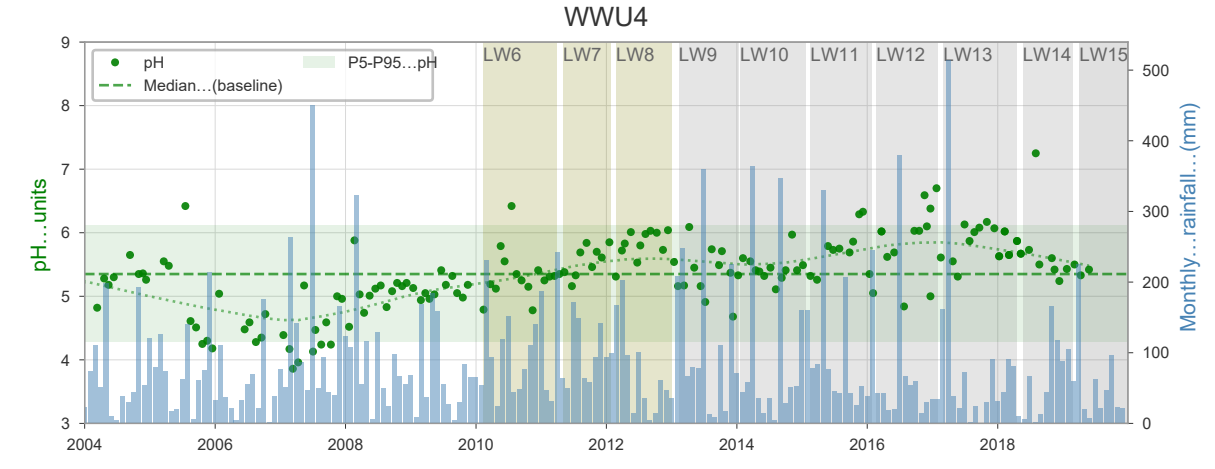

WC_S1
EC…(uS/cm)
Median…(baseline)
LOWESS…(0.3)
P5-P95…EC
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

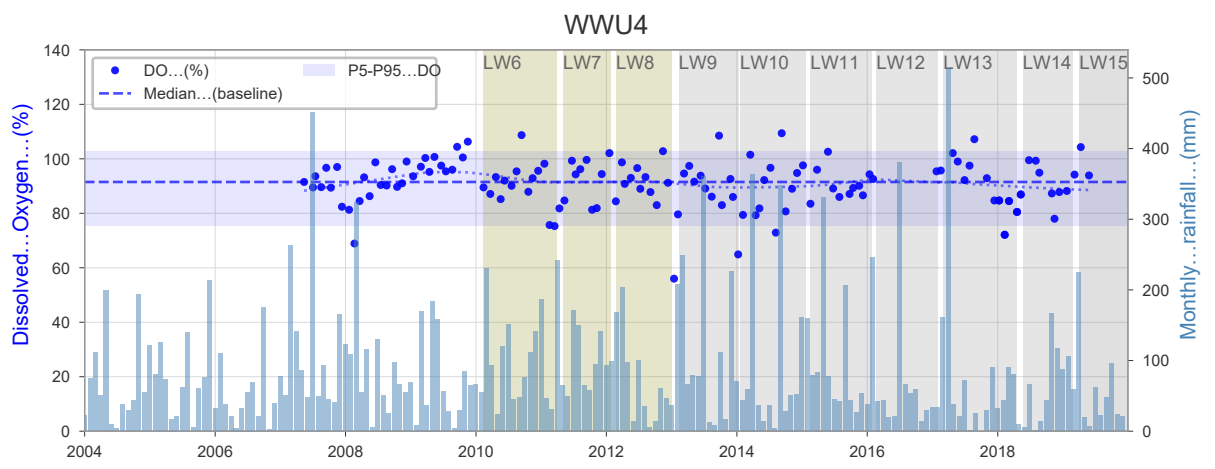

WC_S1
pH
Median…(baseline)
P5-P95…pH
pH…units
Monthly…rainfall…(mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

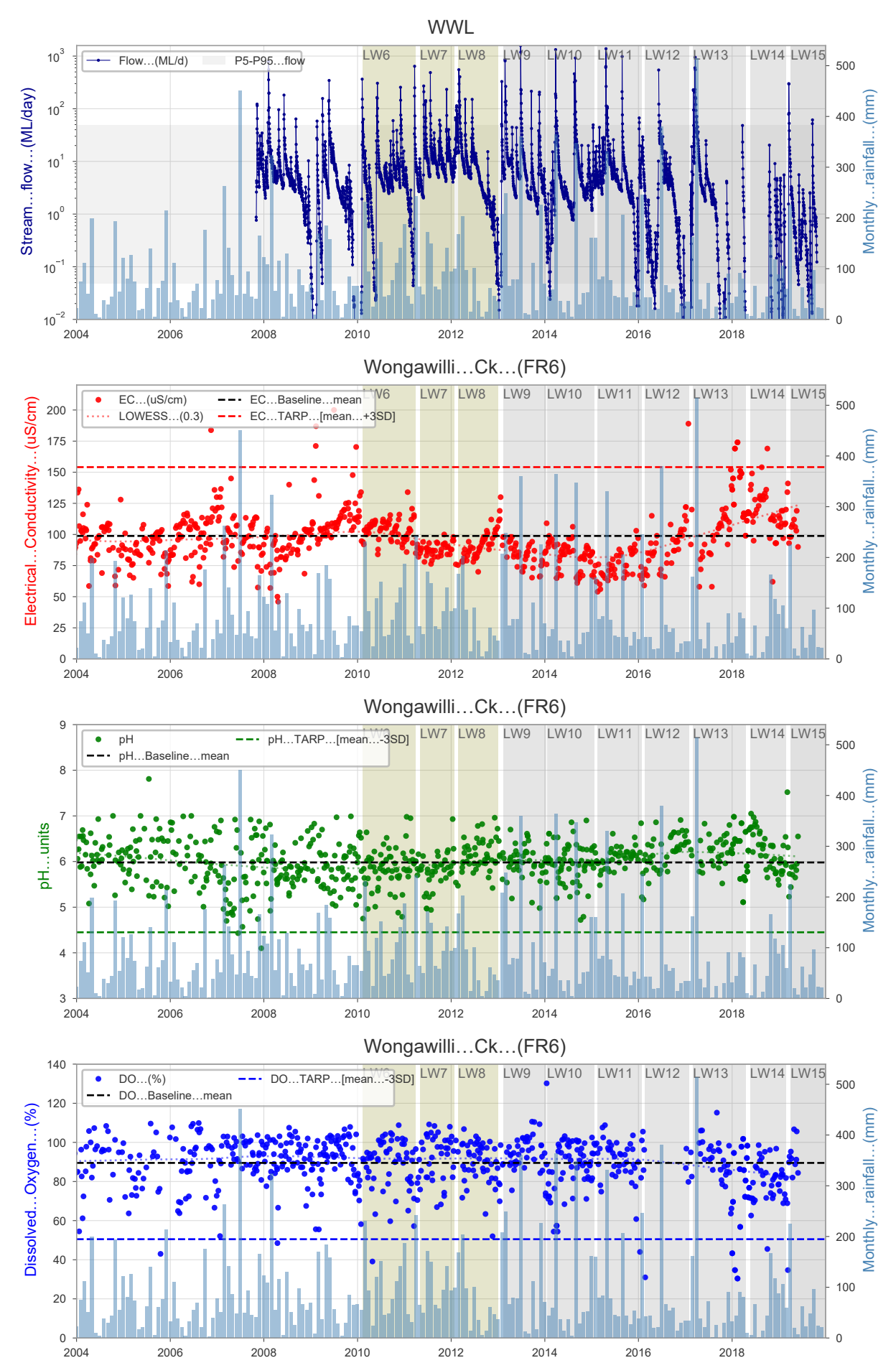

WC_S1
DO…(%)
Median…(baseline)
P5-P95…DO
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

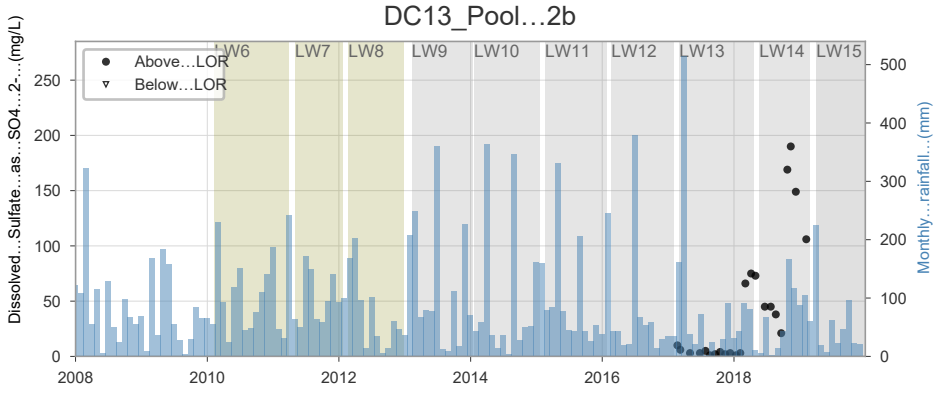

WWU
Flow…(ML/d)
P5-P95…flow
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Stream…flow…(ML/day)
Monthly…rainfall…(mm)
2004
2006
2008
2010
2012
2014
2016
2018

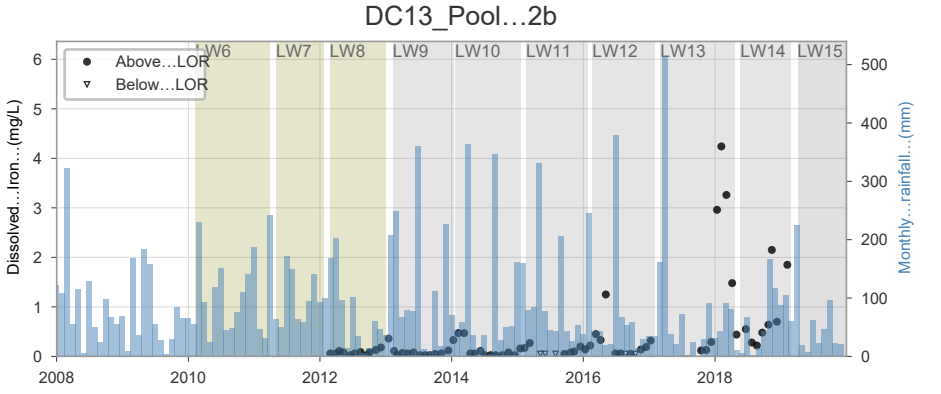

WWU4
EC…(uS/cm)
LOWESS…(0.3)
Median…(baseline)
P5-P95…EC
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Electrical…Conductivity…(uS/cm)
Monthly…rainfall…(mm)
2004
2006
2008
2010
2012
2014
2016
2018

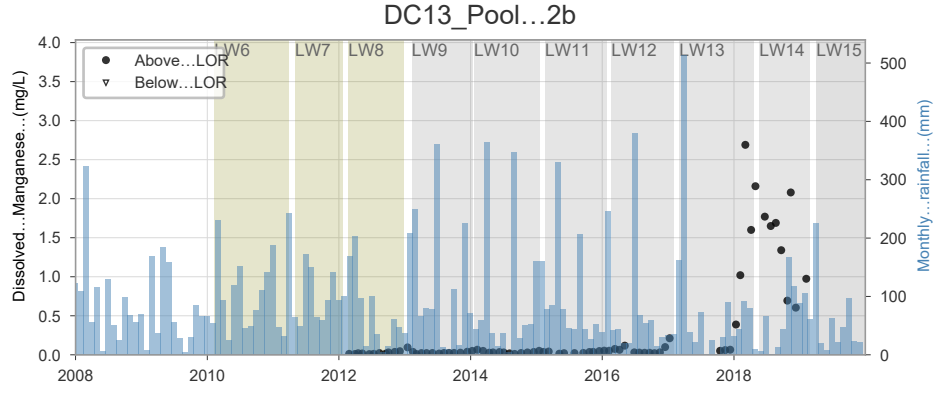

WWU4
pH
Median…(baseline)
P5-P95…pH
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
pH…units
Monthly…rainfall…(mm)
2004
2006
2008
2010
2012
2014
2016
2018

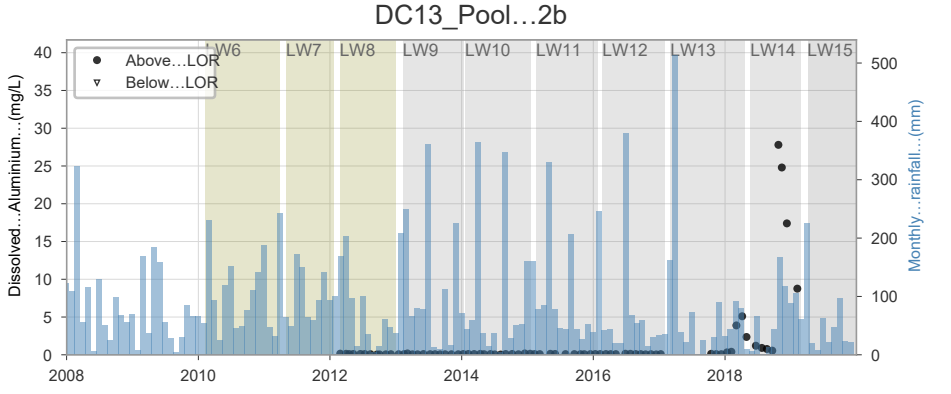

WWU4
DO…(%)
Median…(baseline)
P5-P95…DO
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Oxygen…(%)
Monthly…rainfall…(mm)
2004
2006
2008
2010
2012
2014
2016
2018

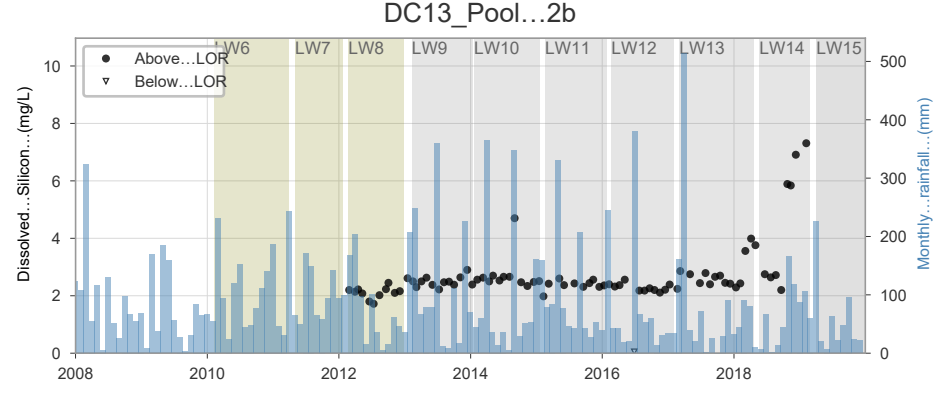

WWL
Flow…(ML/d)
P5-P95…flow
Stream…flow…(ML/day)
Monthly…rainfall…(mm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Wongawilli…Ck…(FR6)
EC…(uS/cm)
LOWESS…(0.3)
EC…Baseline…mean
EC…TARP…[mean…+3SD]
Electrical…Conductivity…(uS/cm)
pH
pH…Baseline…mean
pH…TARP…[mean…-3SD]
pH…units
DO…(%)
DO…Baseline…mean
DO…TARP…[mean…-3SD]
Dissolved…Oxygen…(%)

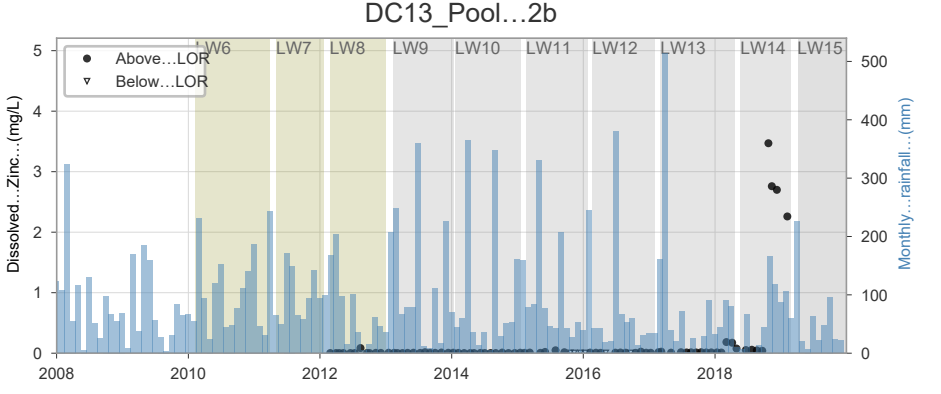

DC13_Pool…2b
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

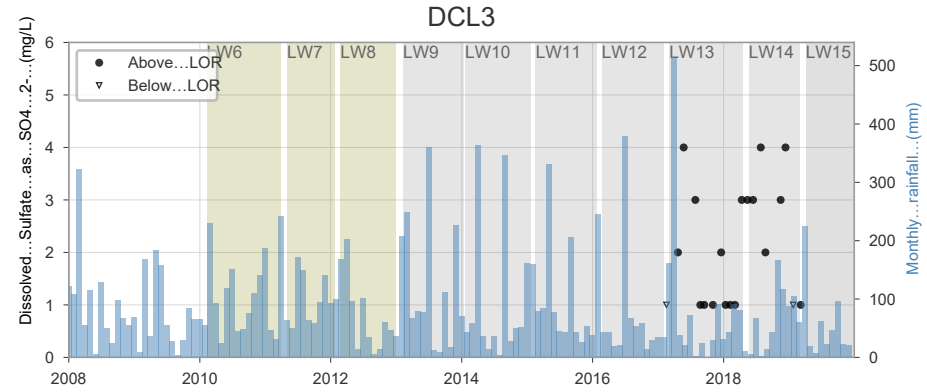

DC13_Pool…2b
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

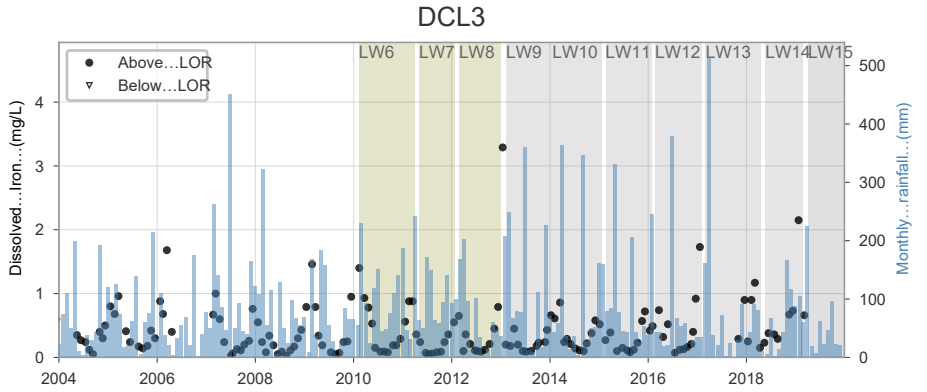

DC13_Pool…2b
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

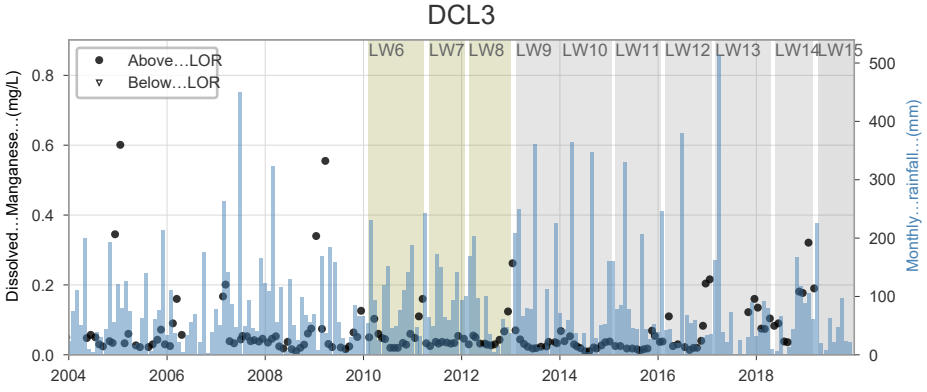

DC13_Pool…2b
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

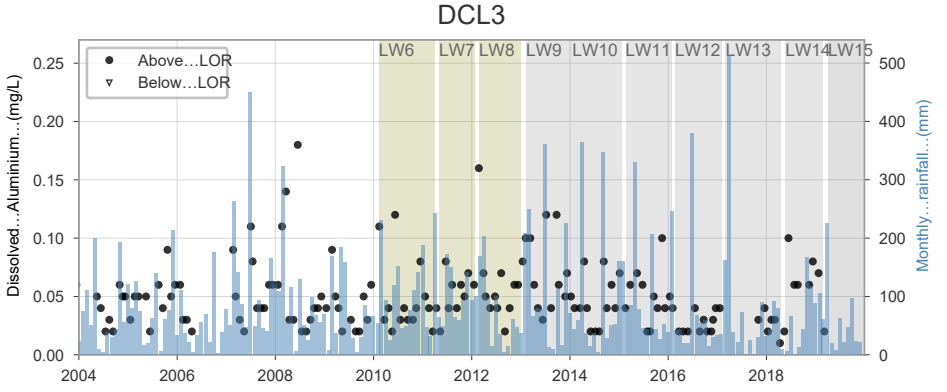

DC13_Pool…2b
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

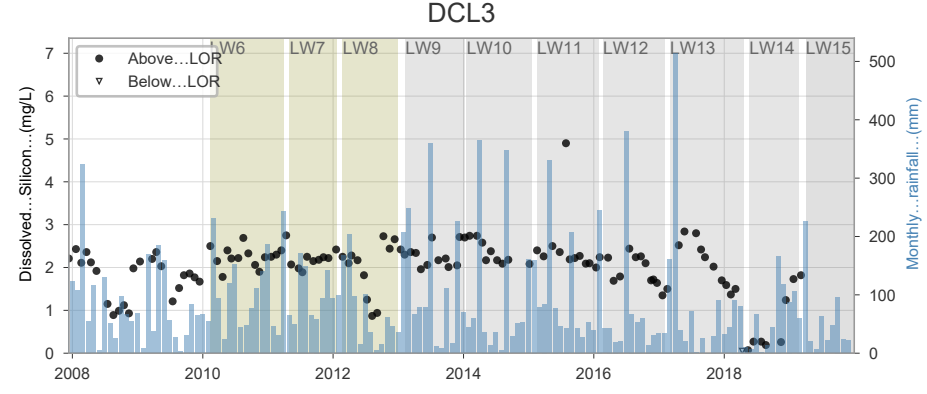

DC13_Pool…2b
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

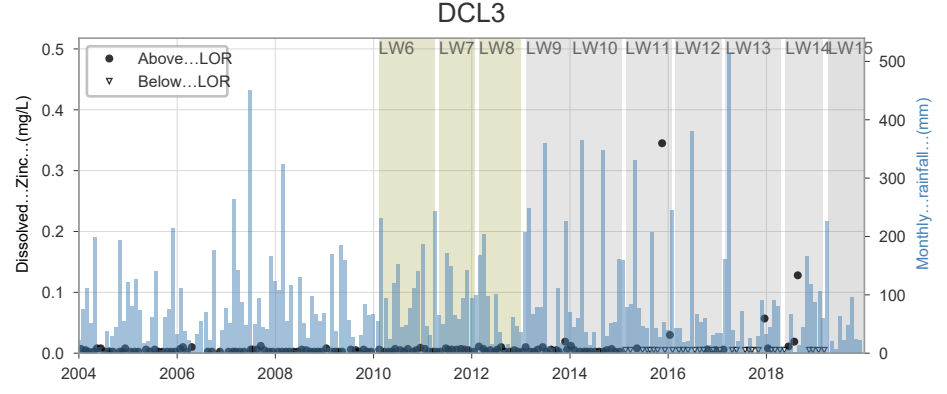

DCL3
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)

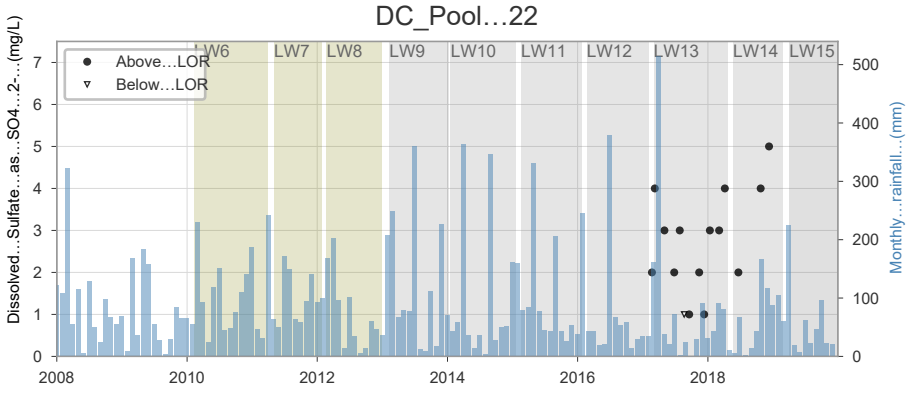

DCL3
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)

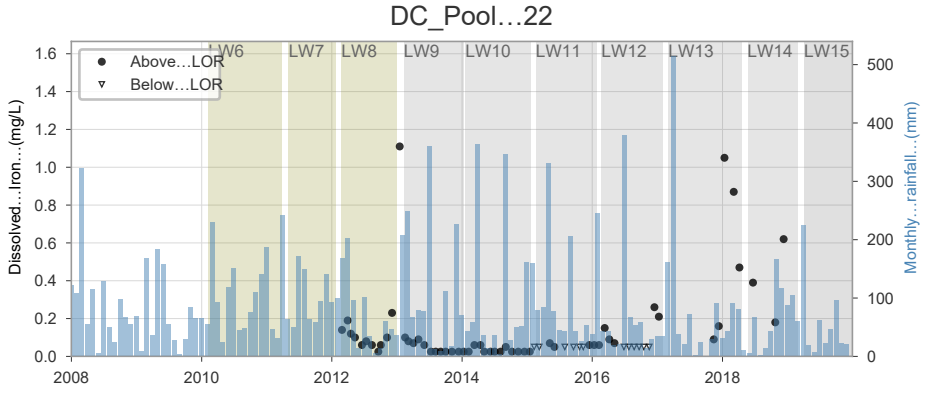

DCL3
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)

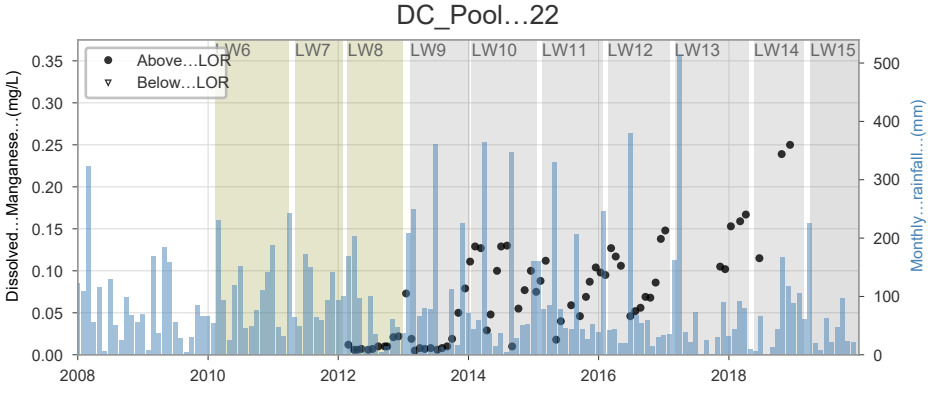

DCL3
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)

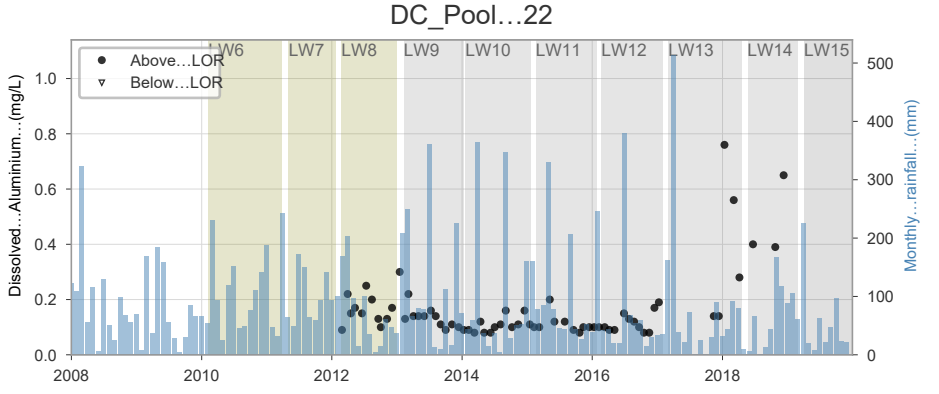

DCL3
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)

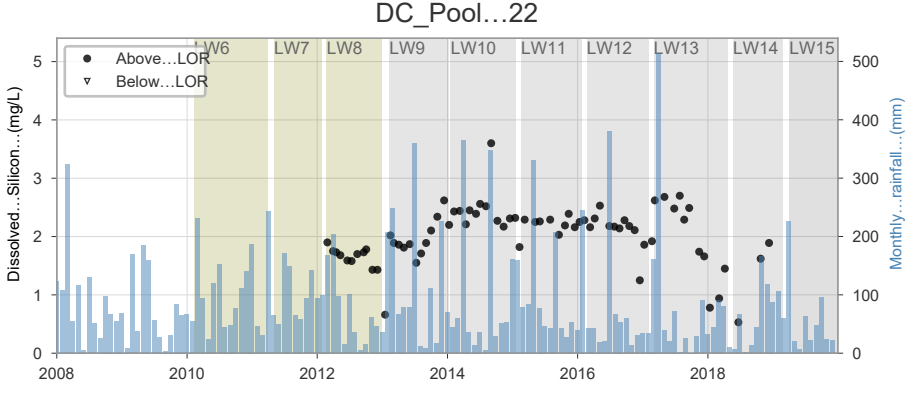

DCL3
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)

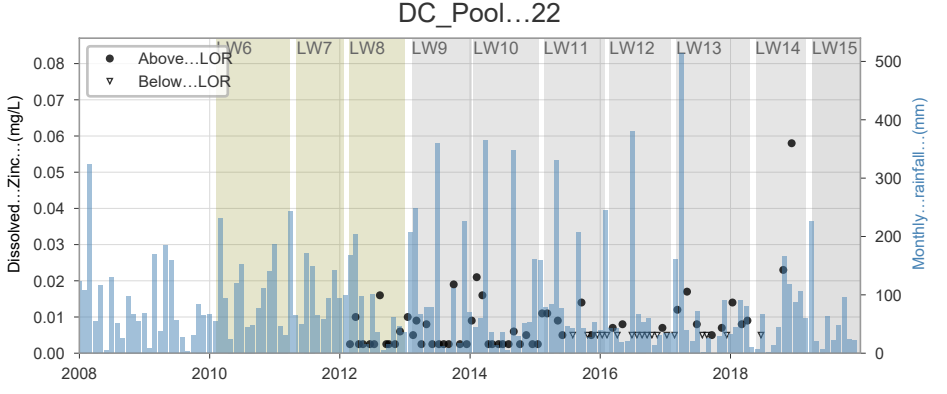

DC_Pool…22
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

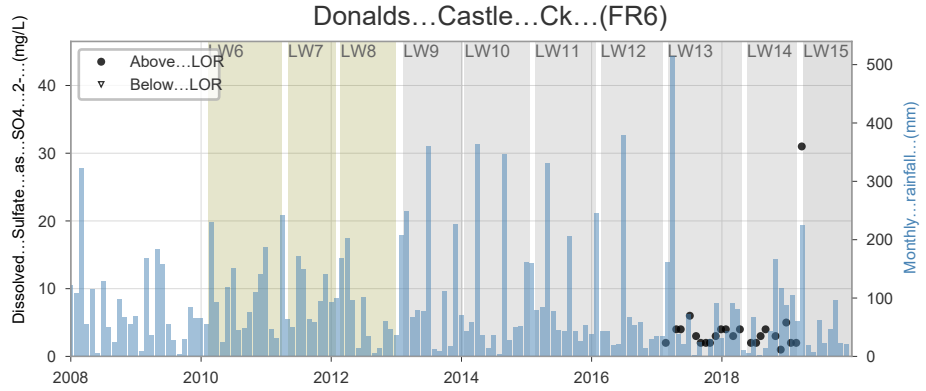

DC_Pool…22
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

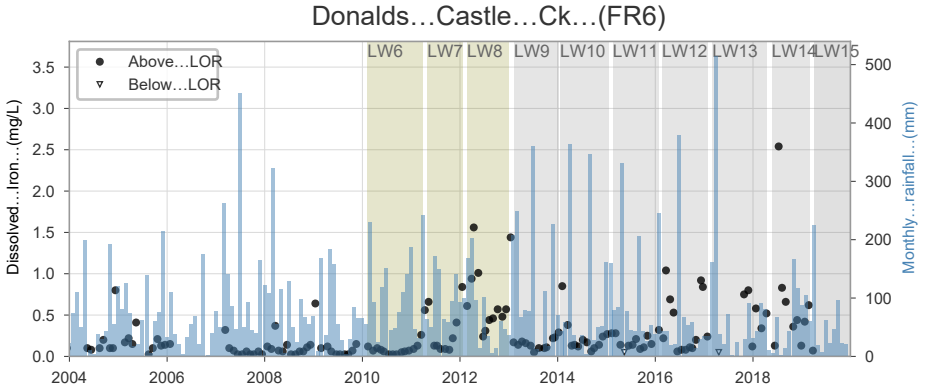

DC_Pool…22
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

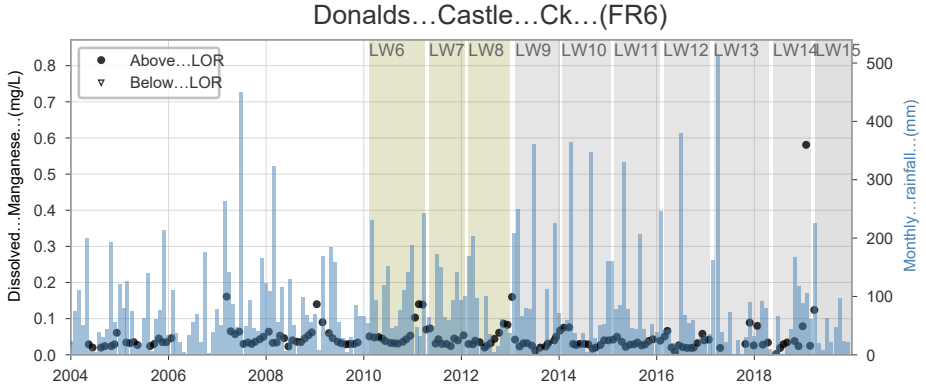

DC_Pool…22
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

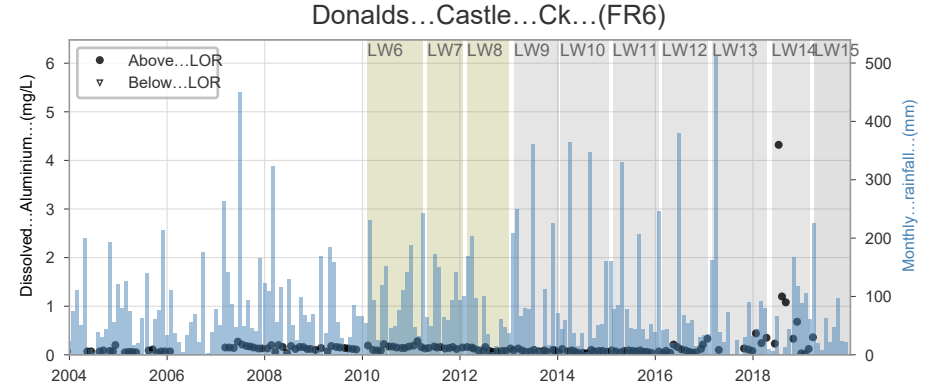

DC_Pool…22
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

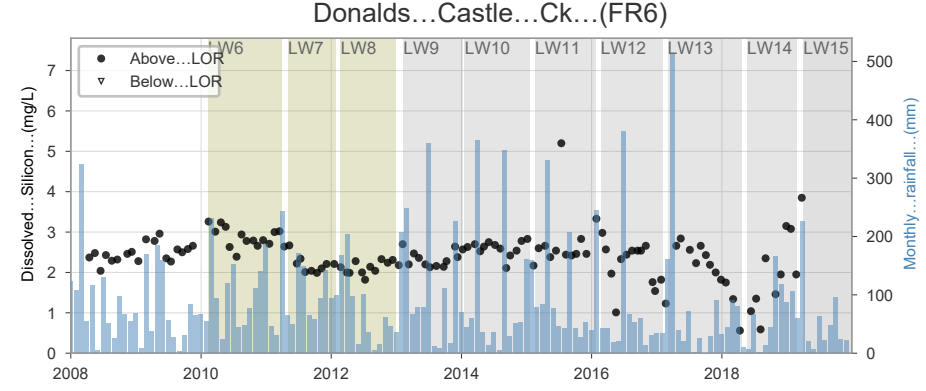

DC_Pool…22
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

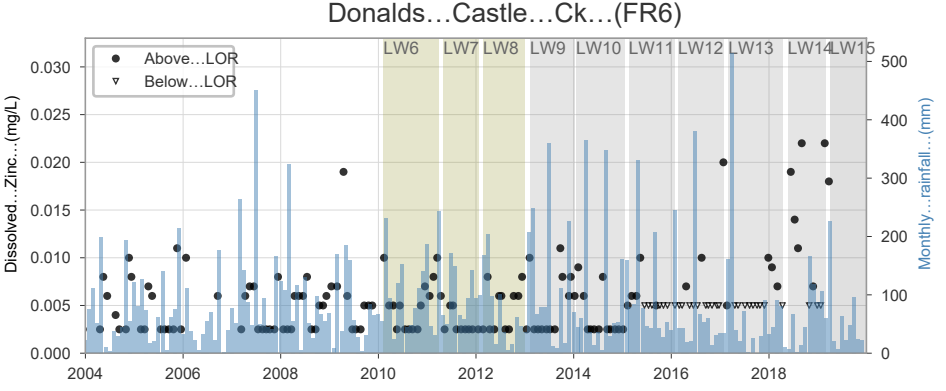

Donalds…Castle…Ck…(FR6)
Above…LOR
Below…LOR
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
0 10 20 30 40
0 100 200 300 400 500
2008 2010 2012 2014 2016 2018

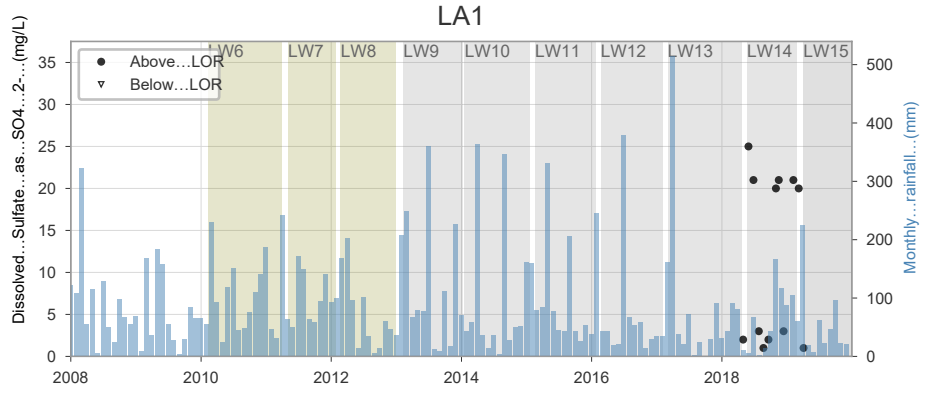

Donalds…Castle…Ck…(FR6)
Above…LOR
Below…LOR
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
0 100 200 300 400 500
2004 2006 2008 2010 2012 2014 2016 2018

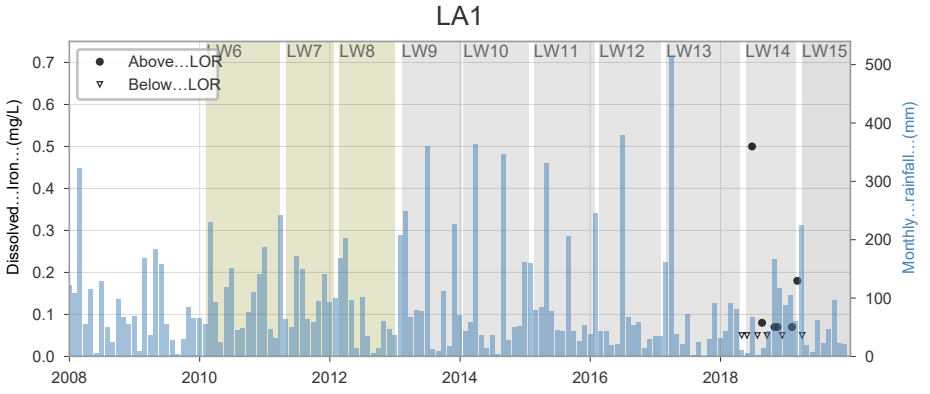

Donalds…Castle…Ck…(FR6)
Above…LOR
Below…LOR
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
0 100 200 300 400 500
2004 2006 2008 2010 2012 2014 2016 2018

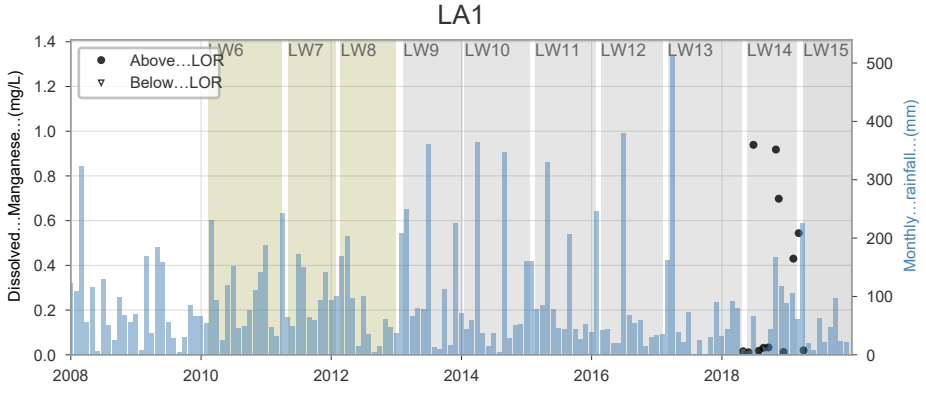

Donalds…Castle…Ck…(FR6)
Above…LOR
Below…LOR
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
0 1 2 3 4 5 6
0 100 200 300 400 500
2004 2006 2008 2010 2012 2014 2016 2018

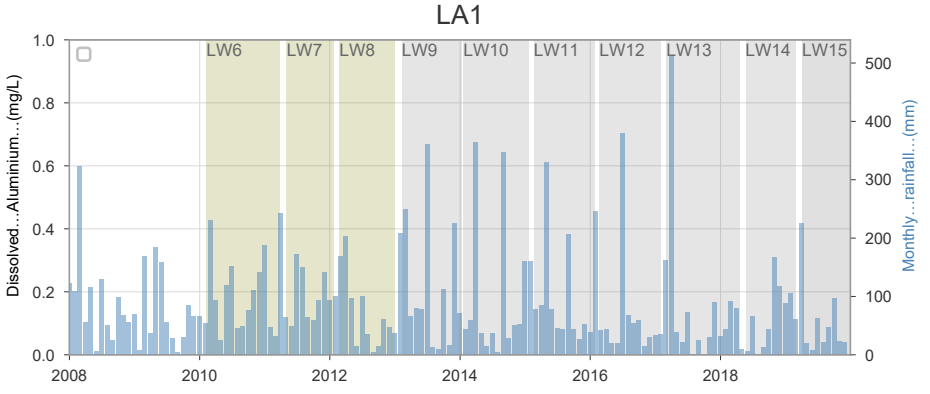

Donalds…Castle…Ck…(FR6)
Above…LOR
Below…LOR
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
0 1 2 3 4 5 6 7
0 100 200 300 400 500
2008 2010 2012 2014 2016 2018

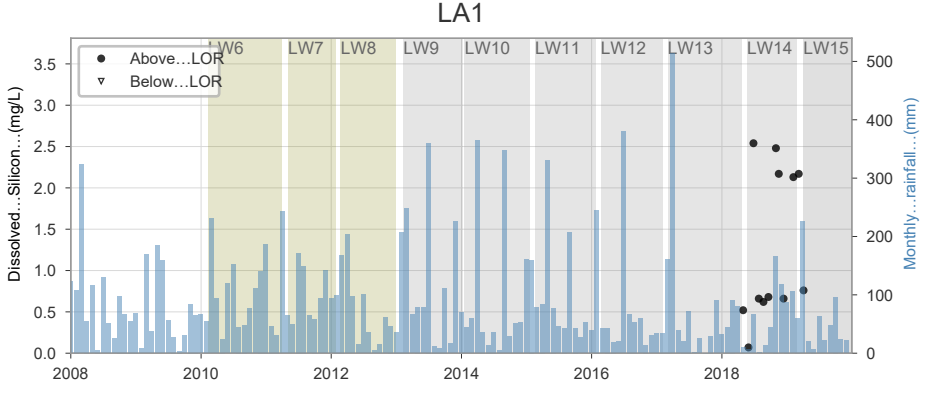

Donalds…Castle…Ck…(FR6)
Above…LOR
Below…LOR
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)
0.000 0.005 0.010 0.015 0.020 0.025 0.030
0 100 200 300 400 500
2004 2006 2008 2010 2012 2014 2016 2018

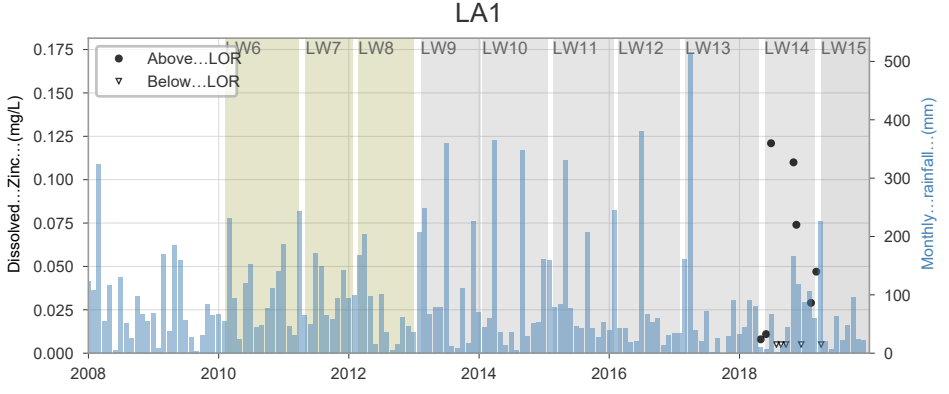

LA1
Dissolved...Sulfate...as...SO4...2-...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

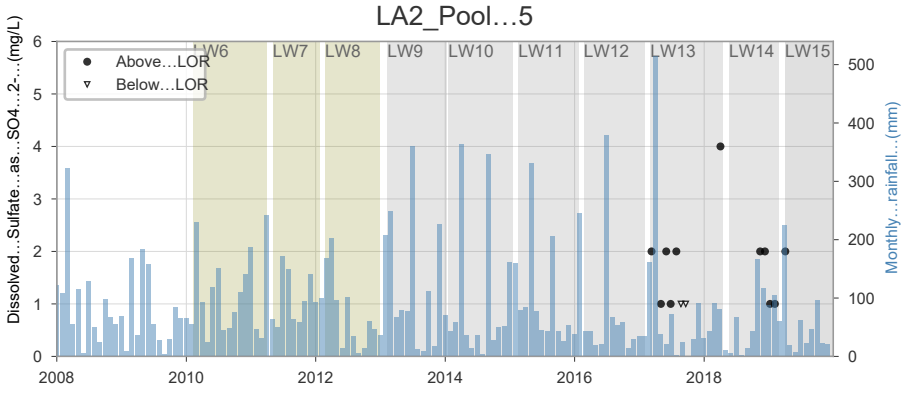

LA1
Dissolved...Iron...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

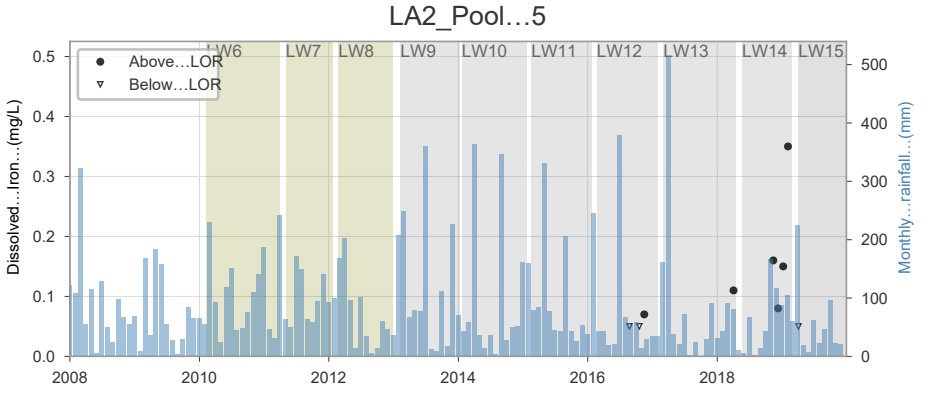

LA1
Dissolved...Manganese...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

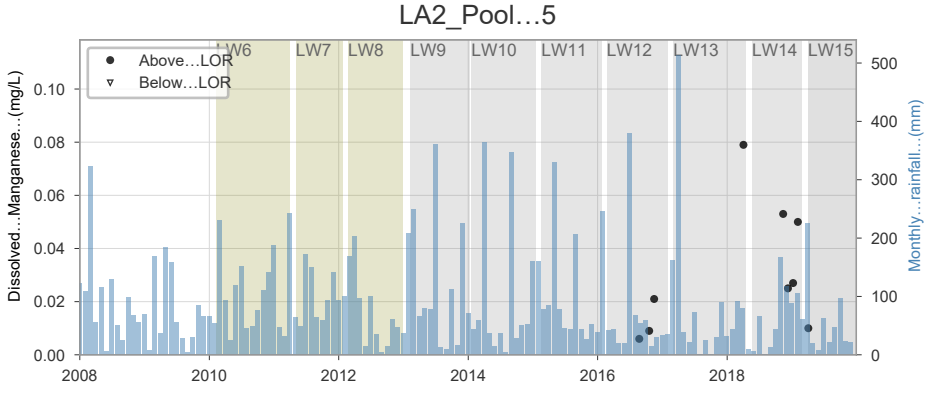

LA1
Dissolved...Aluminium...(mg/L)
Monthly...rainfall...(mm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

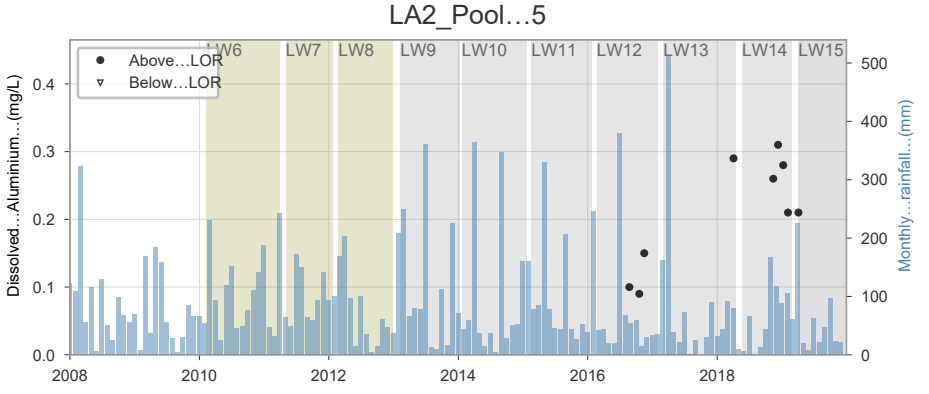

LA1
Dissolved...Silicon...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

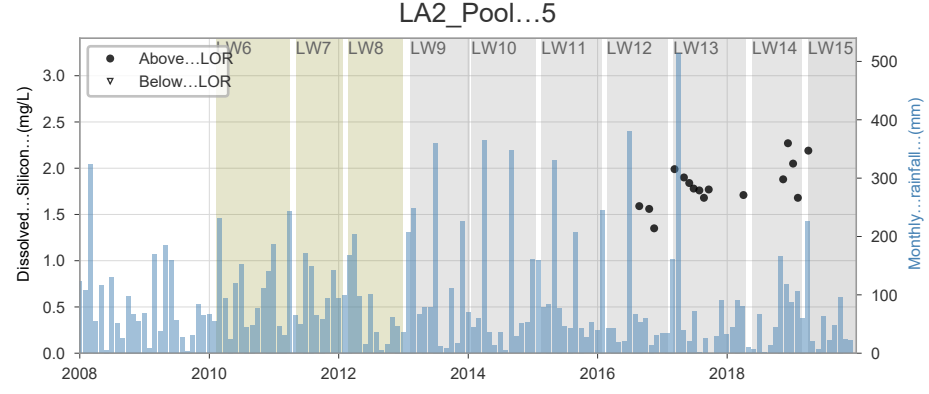

LA1
Dissolved...Zinc...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

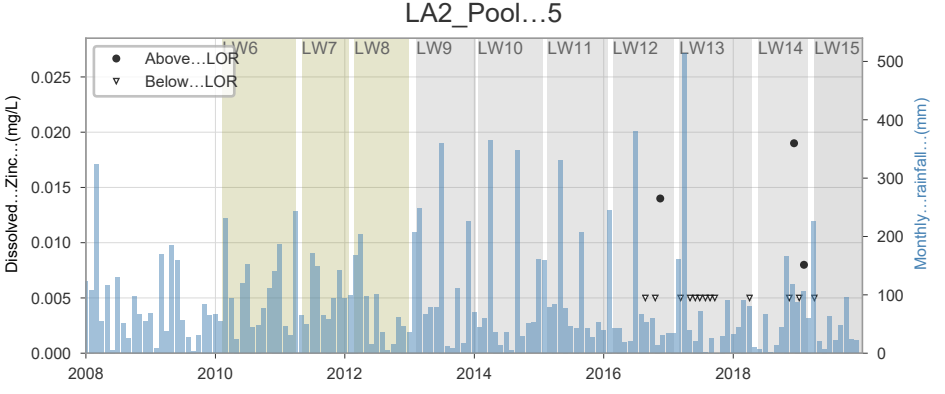

LA2_Pool…5
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

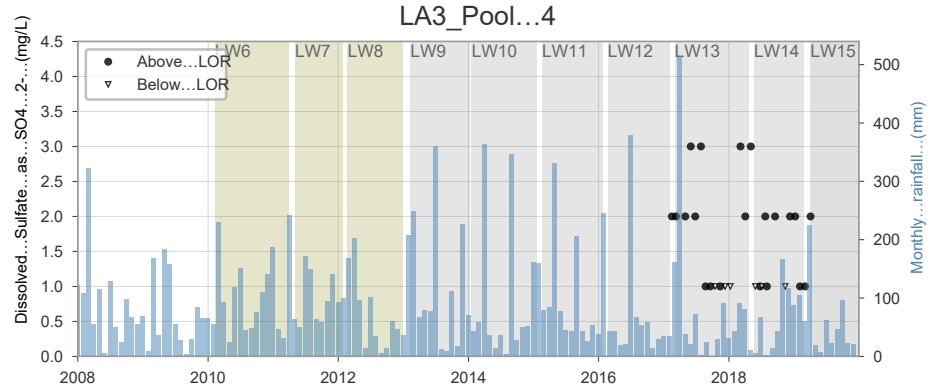

LA2_Pool…5
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

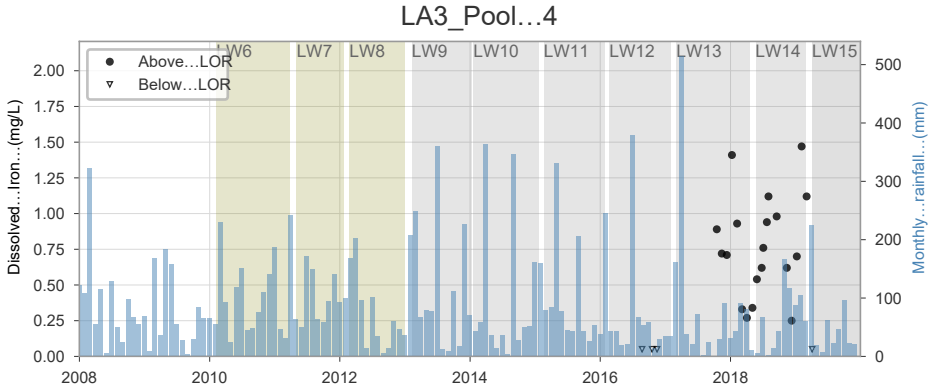

LA2_Pool…5
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

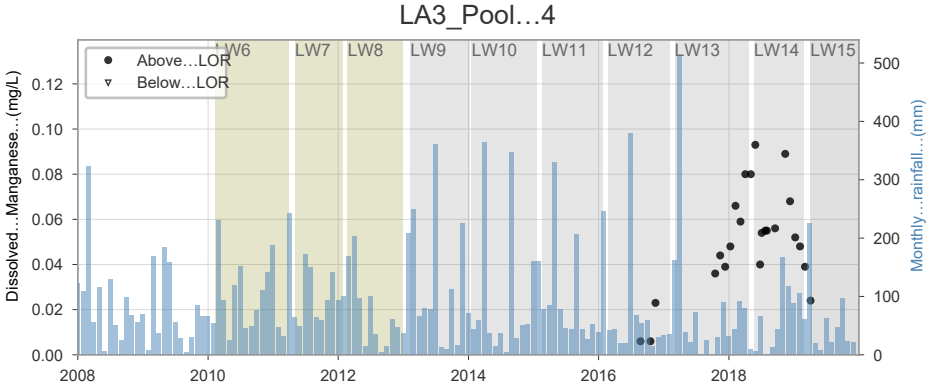

LA2_Pool…5
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

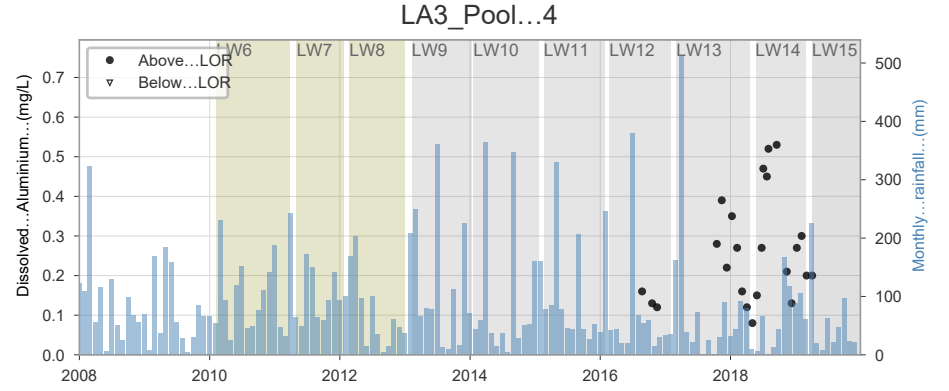

LA2_Pool…5
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

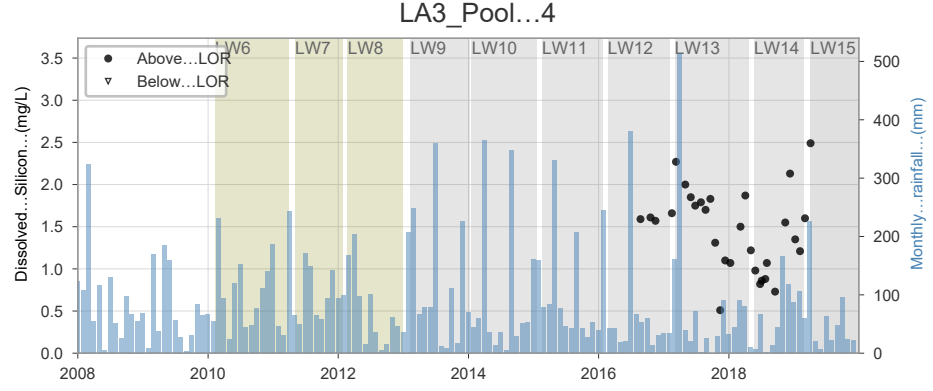

LA2_Pool…5
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

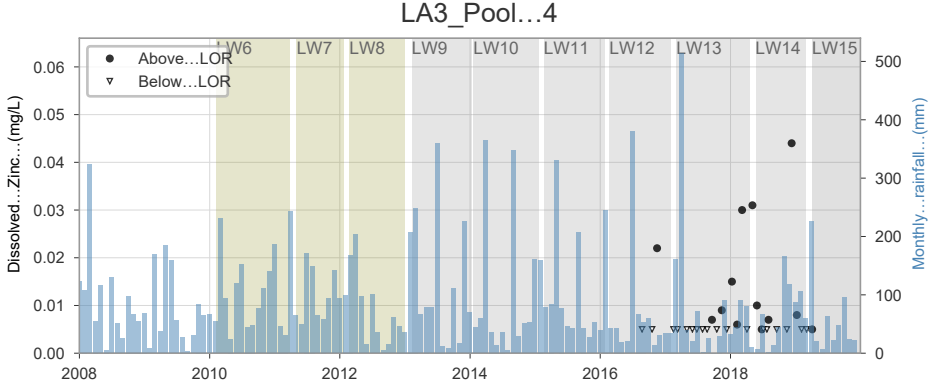

LA3_Pool…4
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

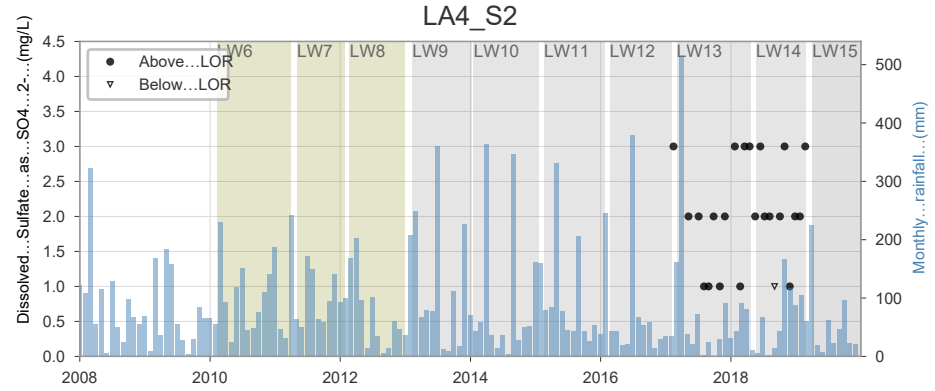

LA3_Pool…4
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

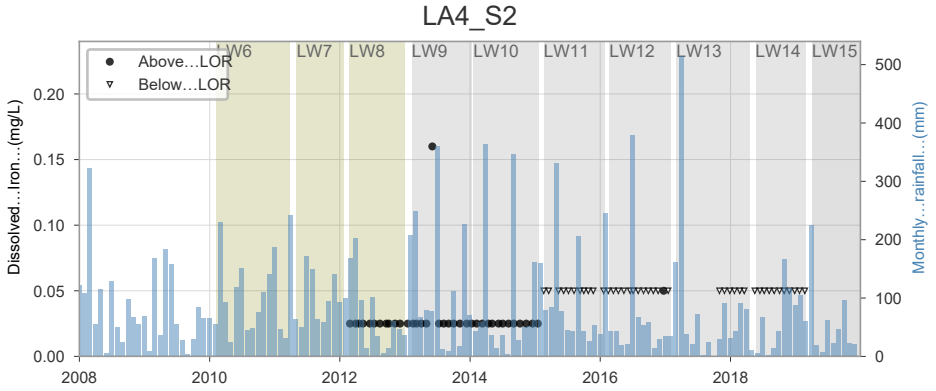

LA3_Pool…4
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

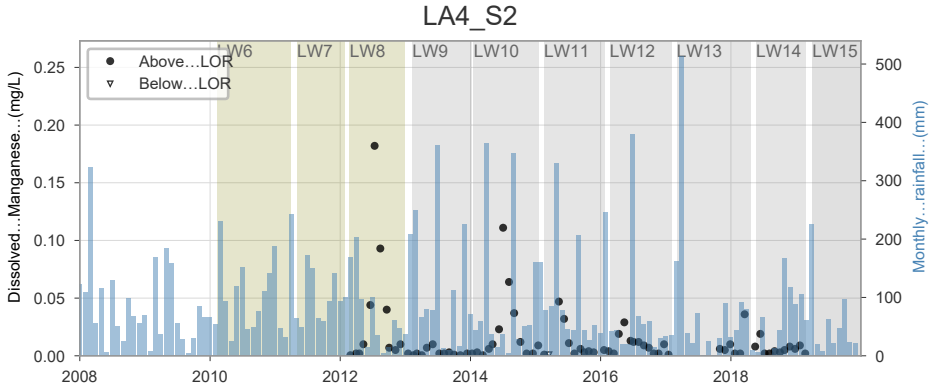

LA3_Pool…4
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

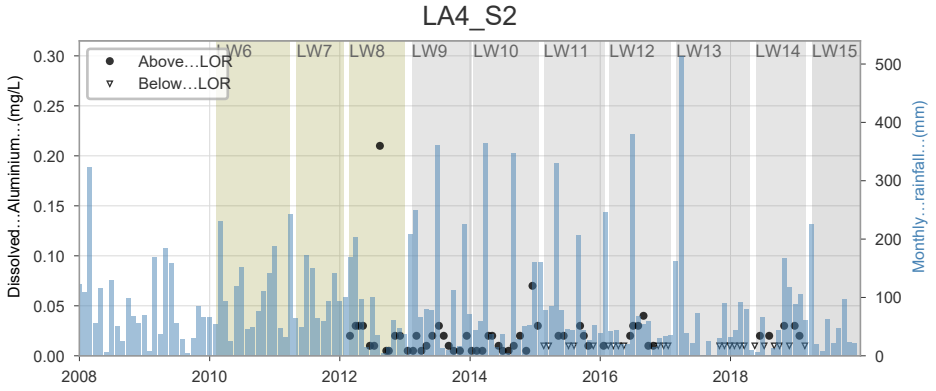

LA3_Pool…4
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

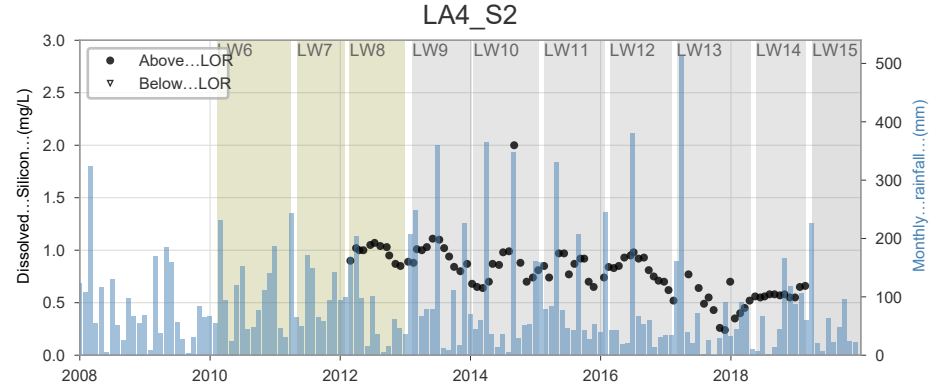

LA3_Pool…4
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

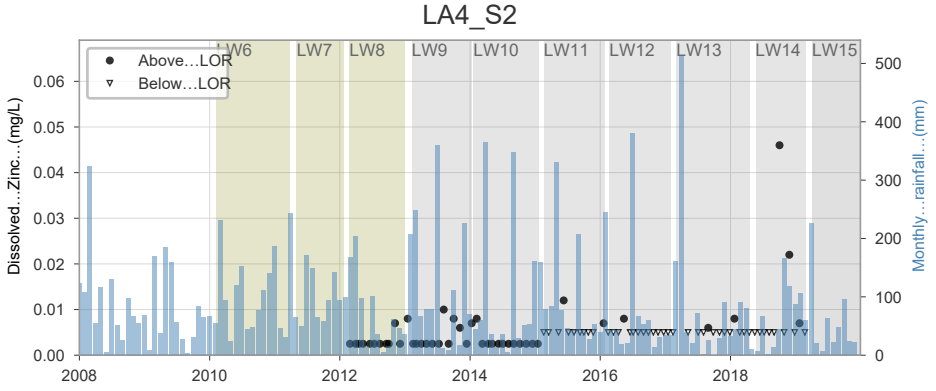

LA4_S2
Dissolved...Sulfate...as...SO4...2-...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

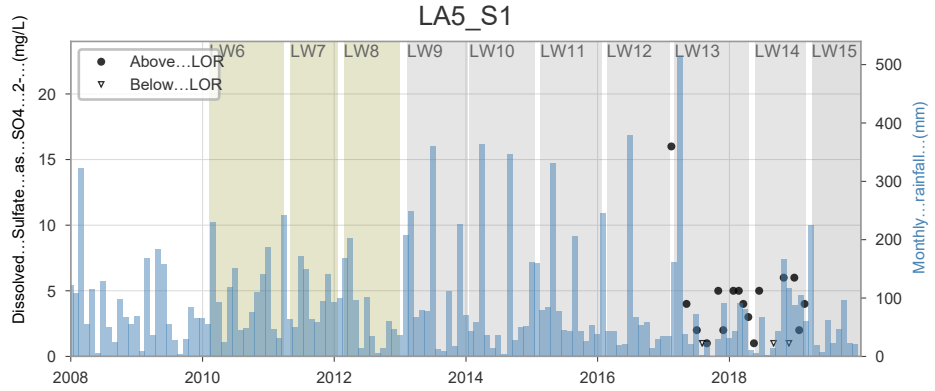

LA4_S2
Dissolved...Iron...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

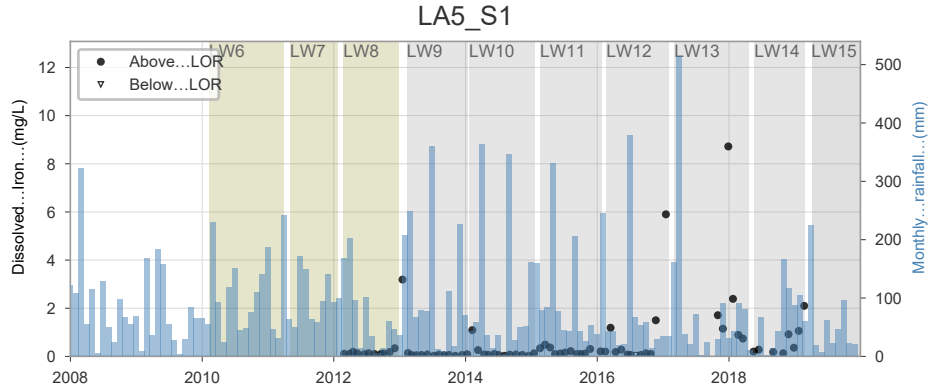

LA4_S2
Dissolved...Manganese...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

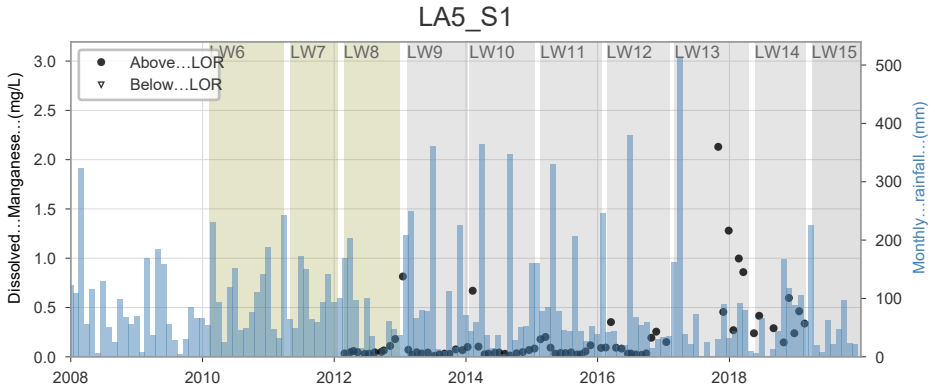

LA4_S2
Dissolved...Aluminium...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

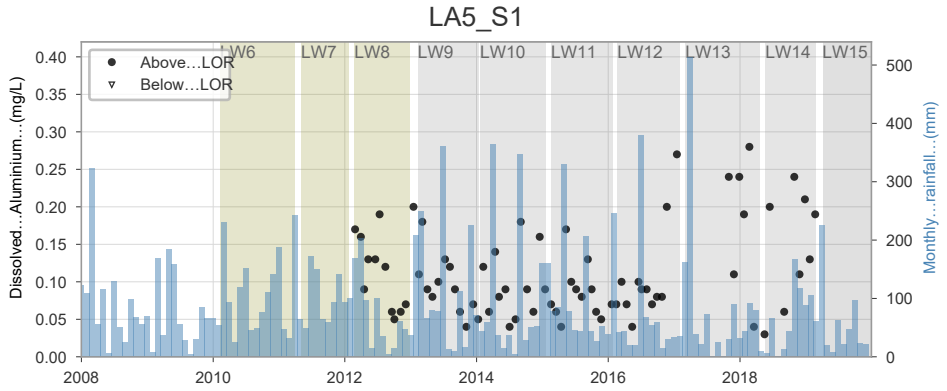

LA4_S2
Dissolved...Silicon...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

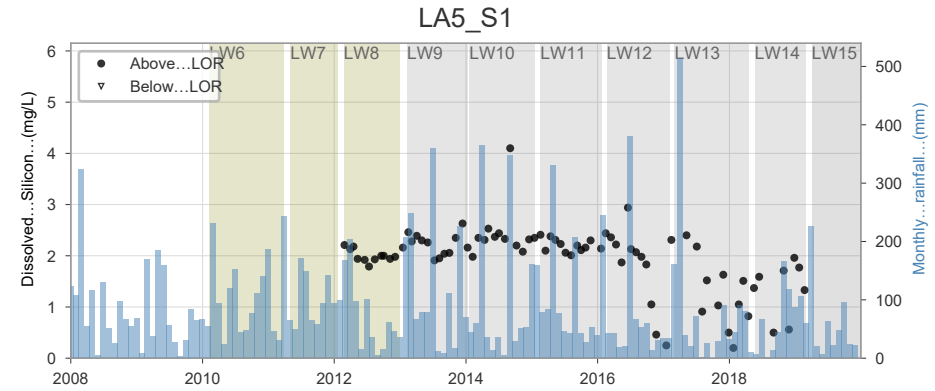

LA4_S2
Dissolved...Zinc...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

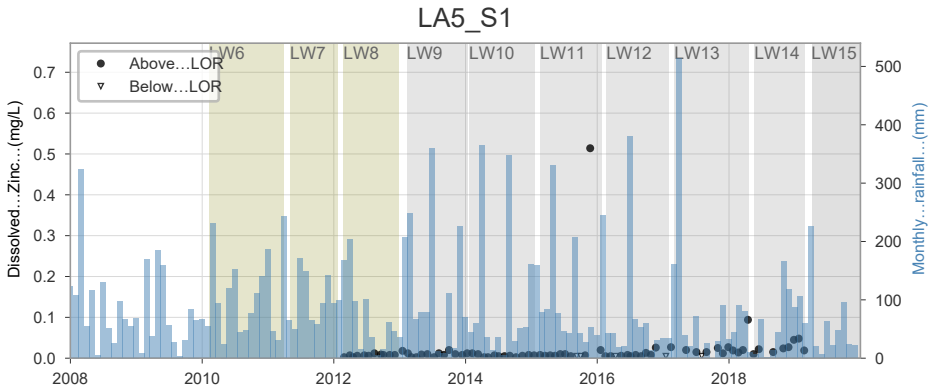

LA5_S1
Dissolved...Sulfate...as...SO4...2-...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

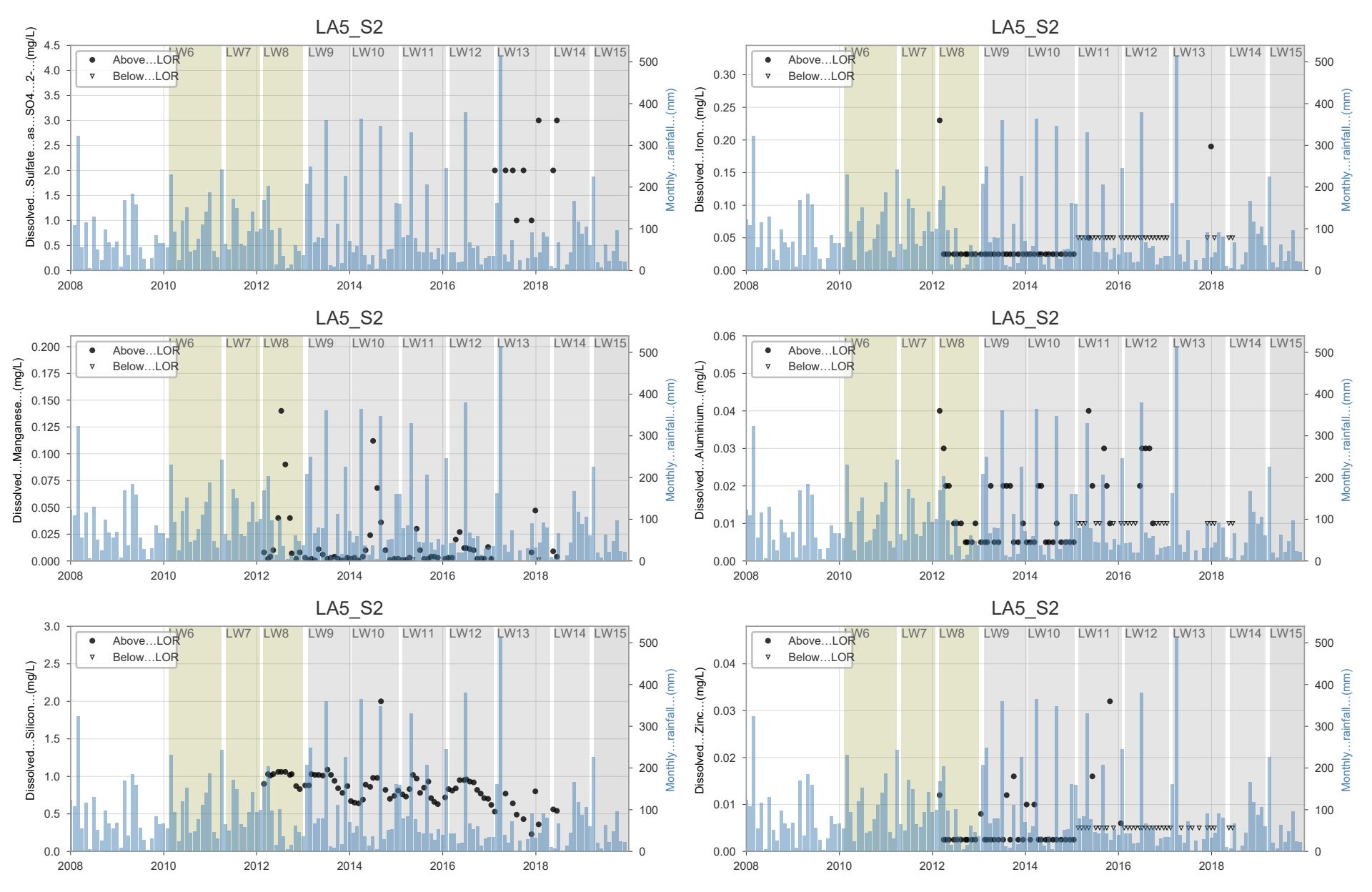

LA5_S1
Dissolved...Iron...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

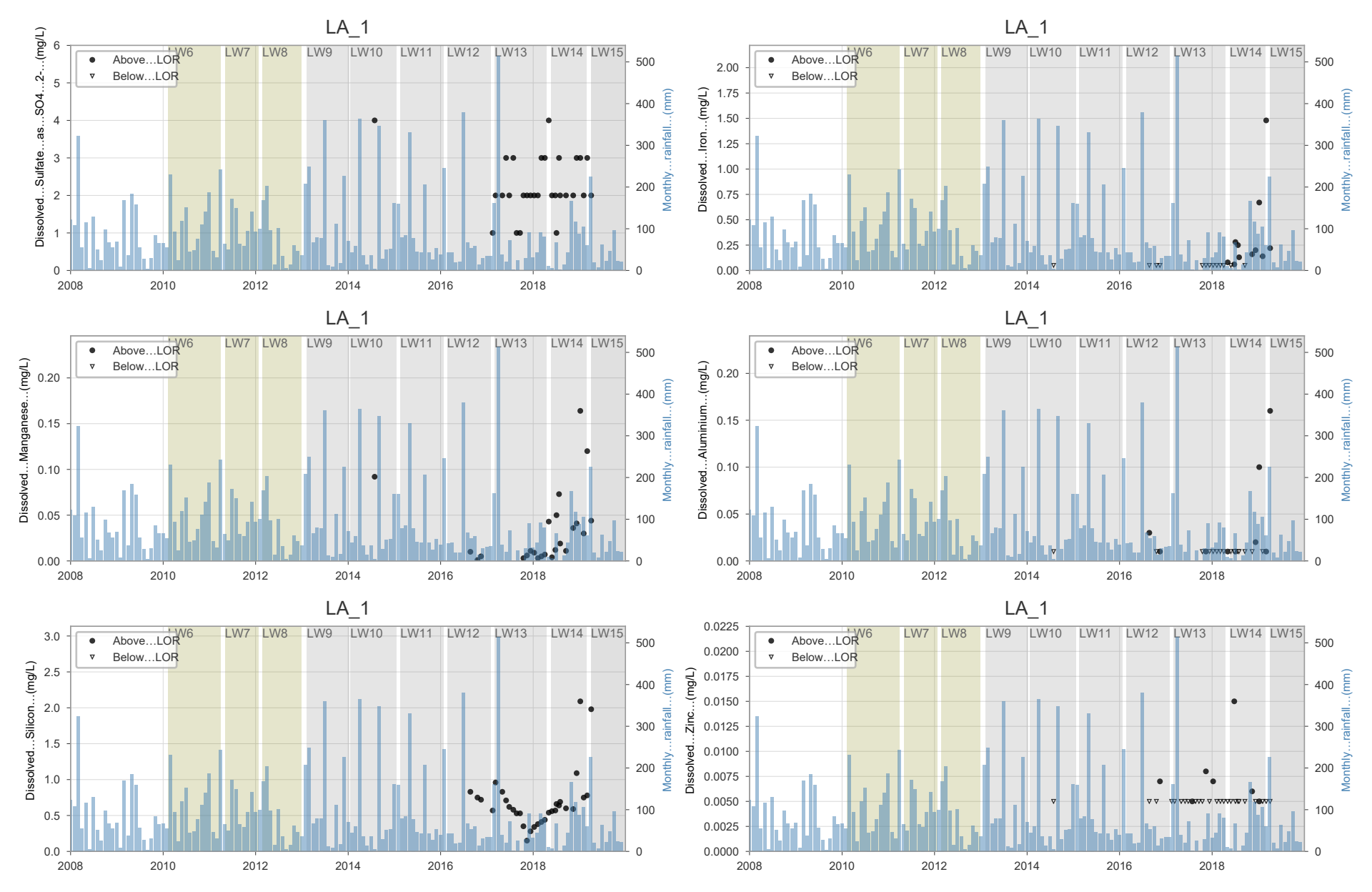

LA5_S1
Dissolved...Manganese...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

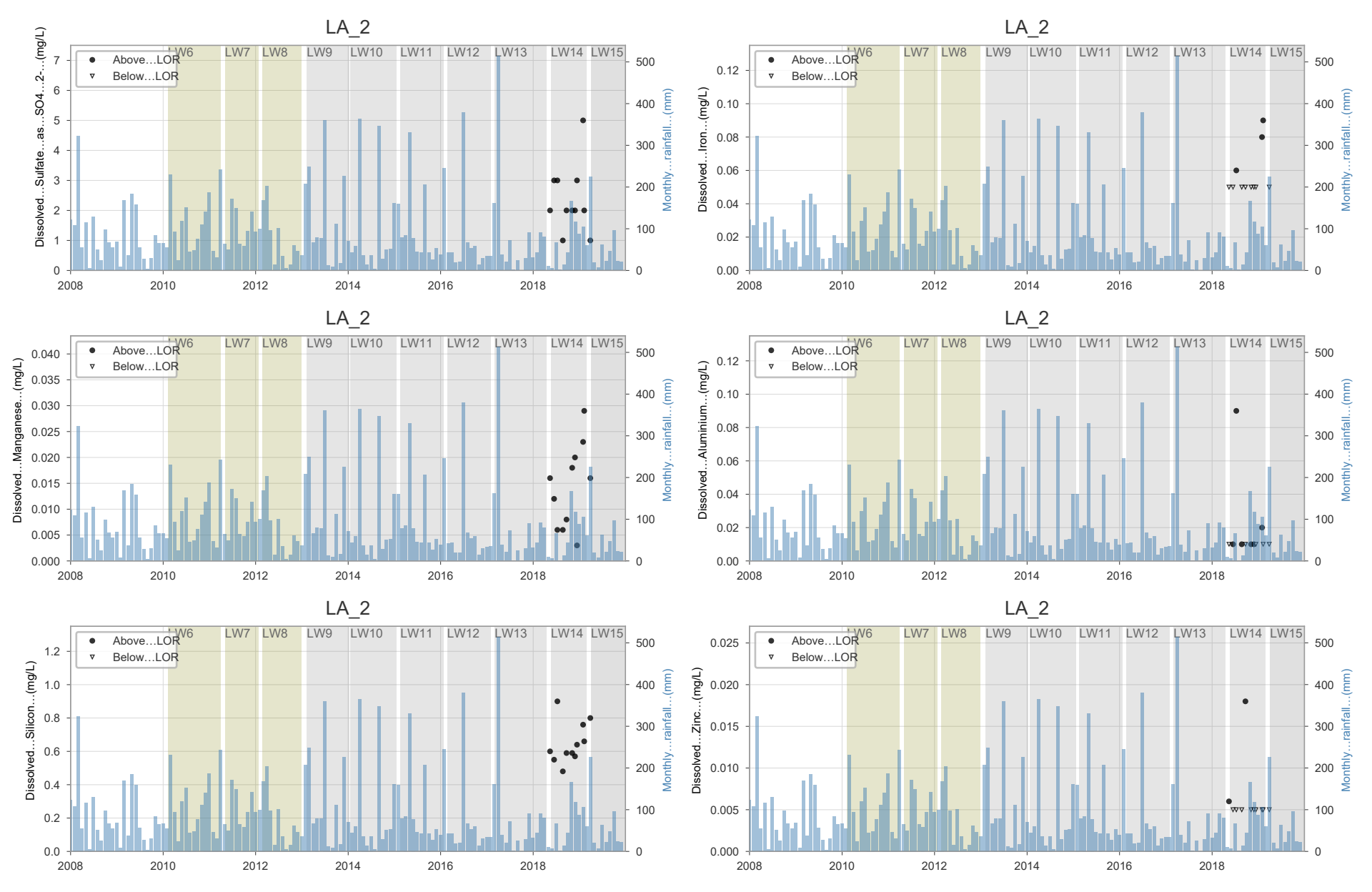

LA5_S1
Dissolved...Aluminium...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

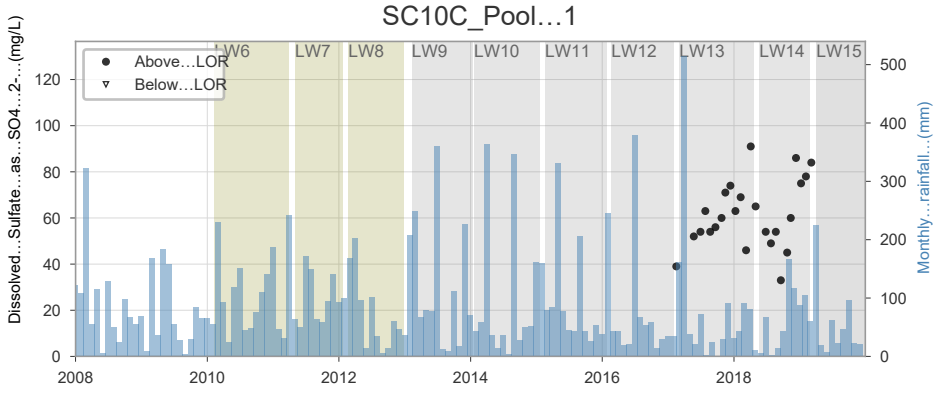

LA5_S1
Dissolved...Silicon...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

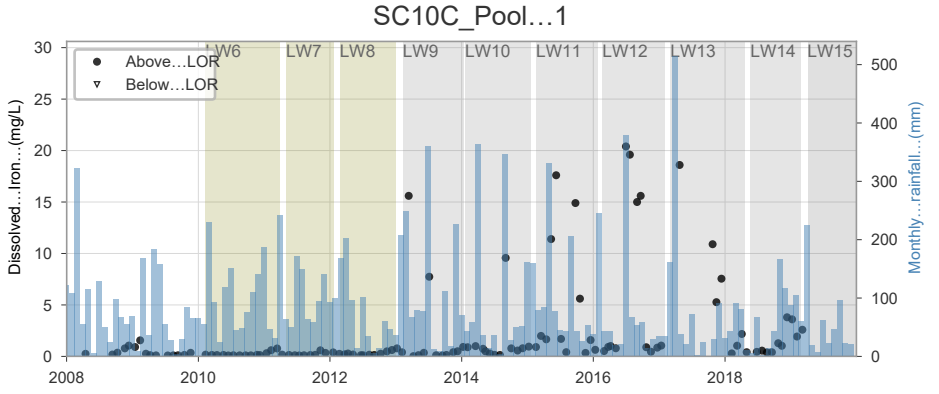

LA5_S1
Dissolved...Zinc...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

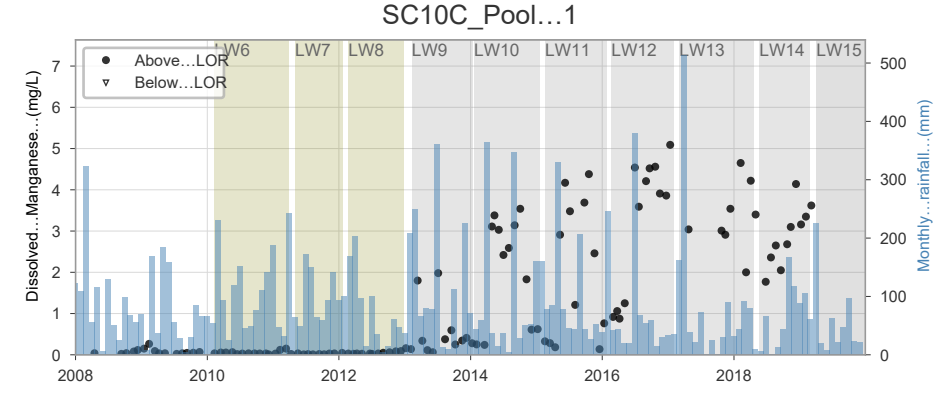

LA5_S2
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
LA5_S2
Above…LOR
Below…LOR
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
LA5_S2
Above…LOR
Below…LOR
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
LA5_S2
Above…LOR
Below…LOR
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
LA5_S2
Above…LOR
Below…LOR
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
LA5_S2
Above…LOR
Below…LOR
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)

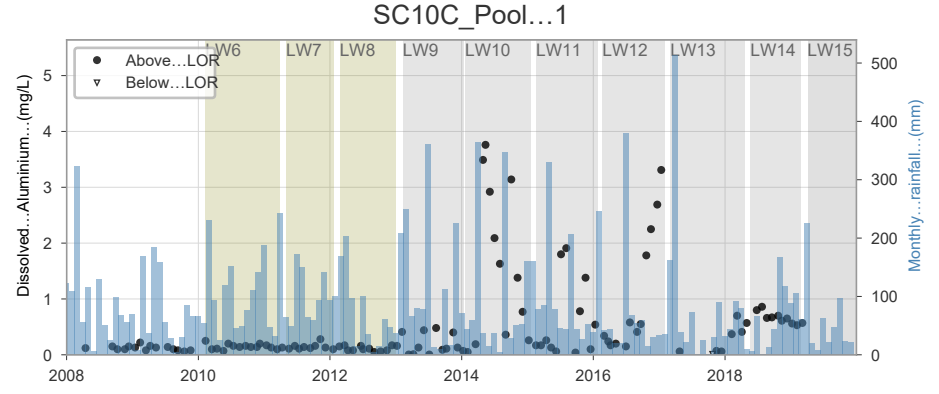

LA_1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
LA_1
Above…LOR
Below…LOR
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
LA_1
Above…LOR
Below…LOR
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
LA_1
Above…LOR
Below…LOR
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
LA_1
Above…LOR
Below…LOR
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
LA_1
Above…LOR
Below…LOR
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)

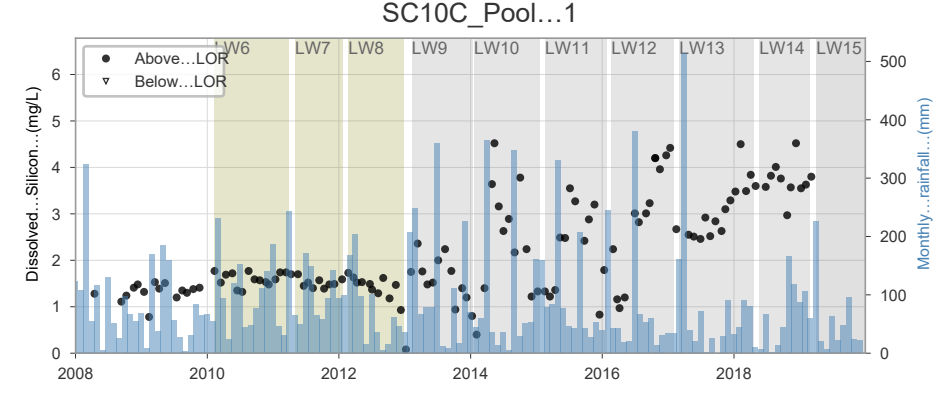

LA_2
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
LA_2
Above…LOR
Below…LOR
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
LA_2
Above…LOR
Below…LOR
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
LA_2
Above…LOR
Below…LOR
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
LA_2
Above…LOR
Below…LOR
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
LA_2
Above…LOR
Below…LOR
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)

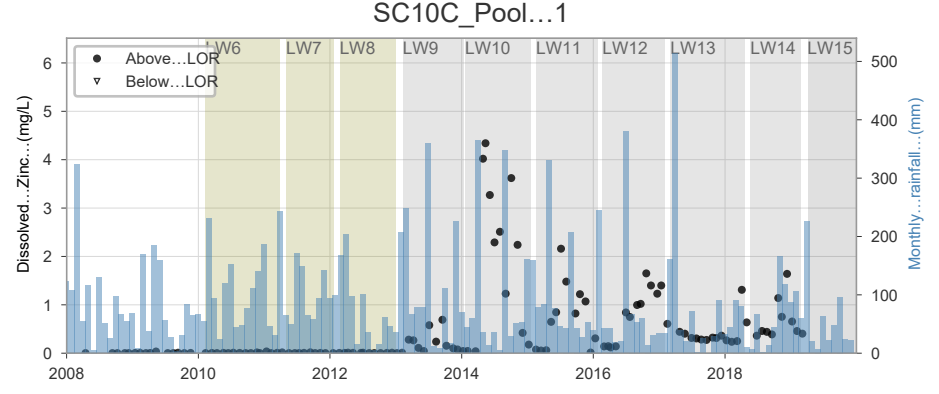

SC10C_Pool…1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

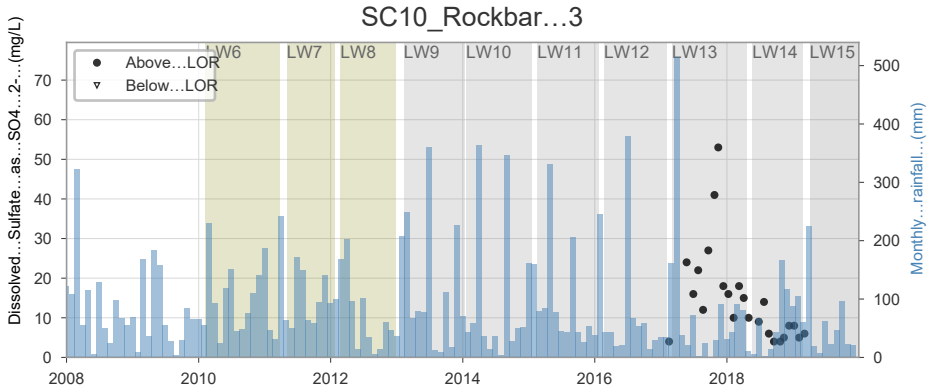

SC10C_Pool…1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

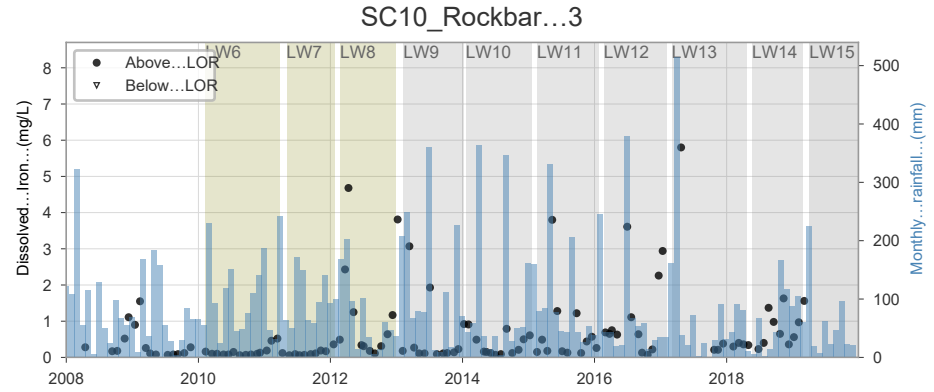

SC10C_Pool…1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

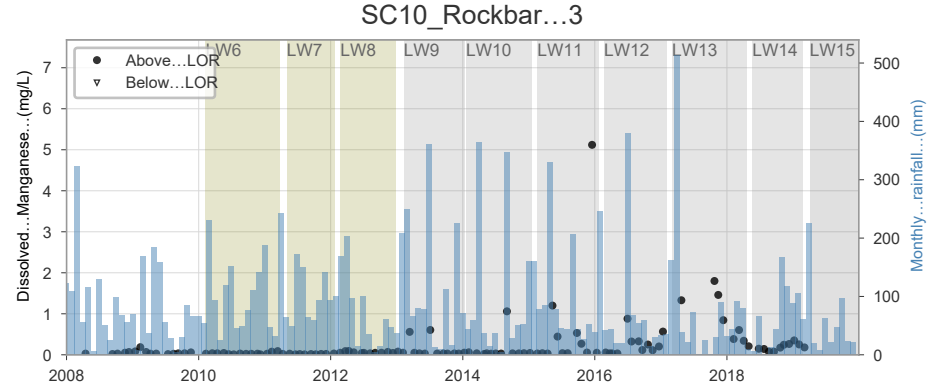

SC10C_Pool…1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

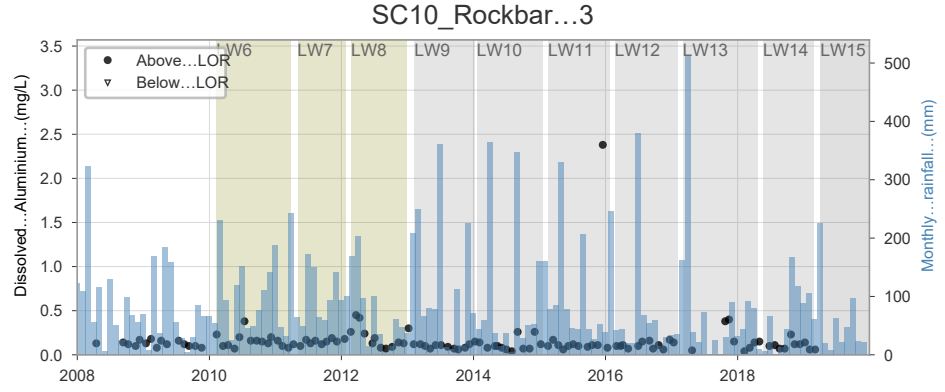

SC10C_Pool…1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

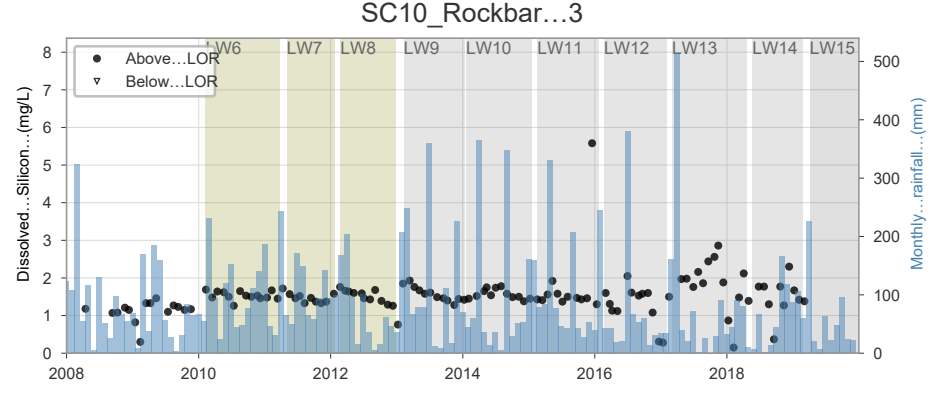

SC10C_Pool…1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

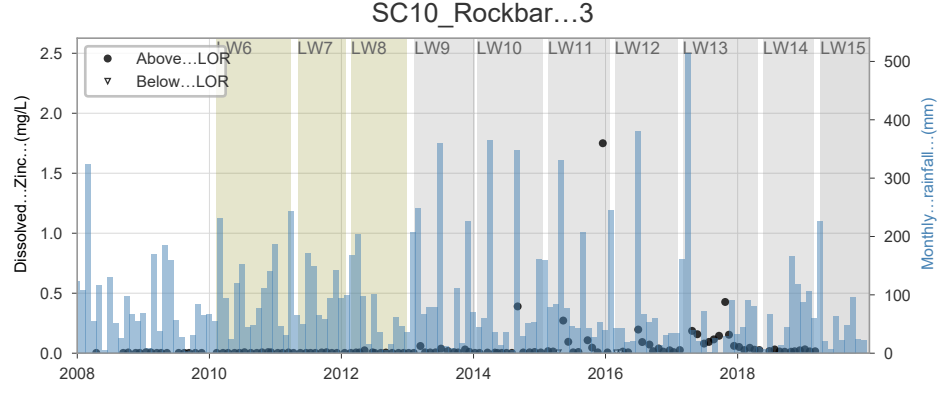

SC10_Rockbar…3
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

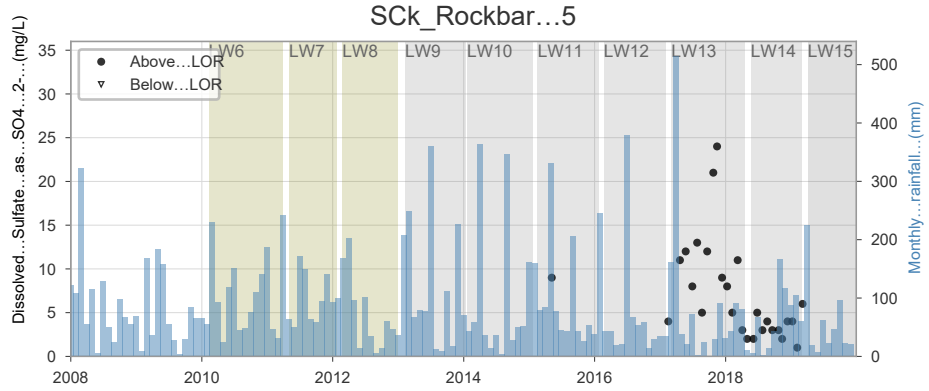

SC10_Rockbar…3
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

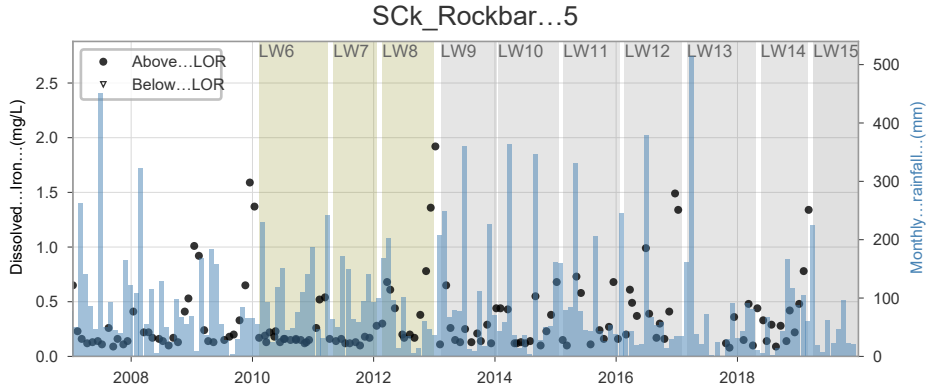

SC10_Rockbar…3
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

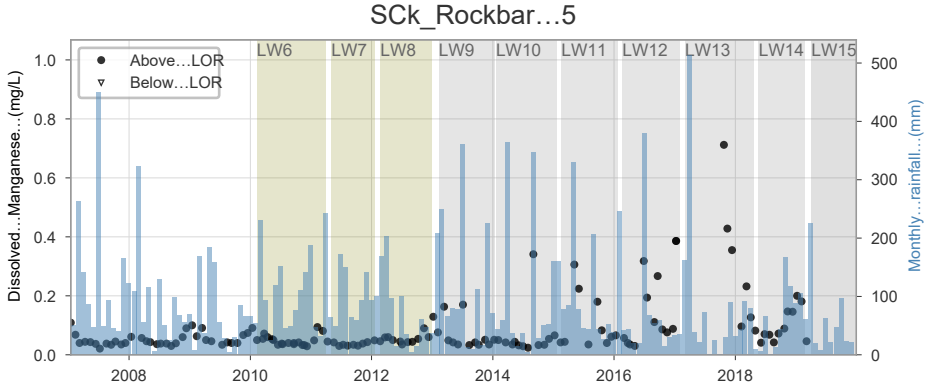

SC10_Rockbar…3
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

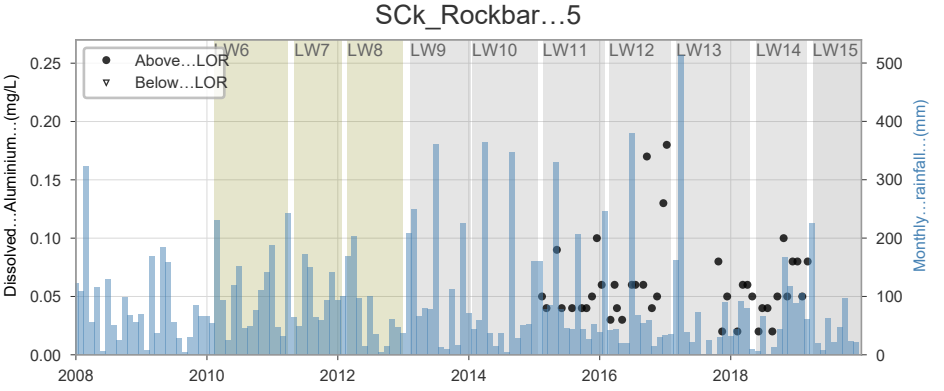

SC10_Rockbar…3
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

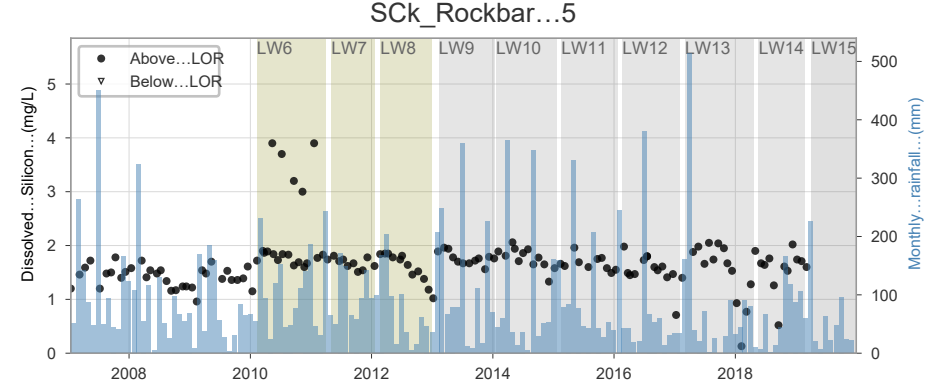

SC10_Rockbar…3
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018

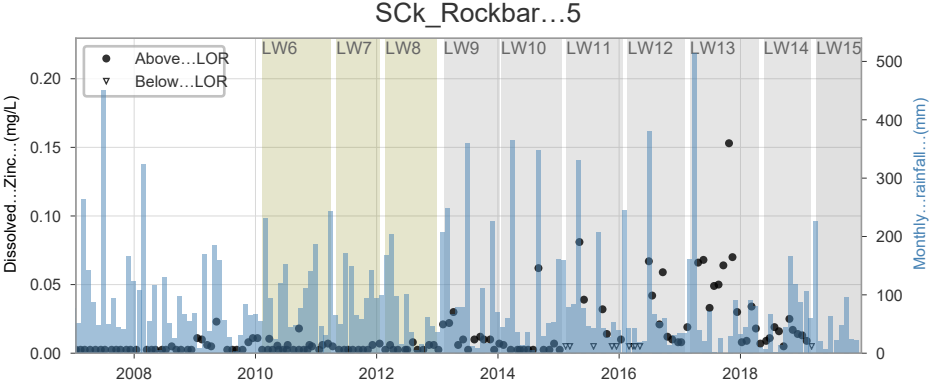

SCk_Rockbar…5
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

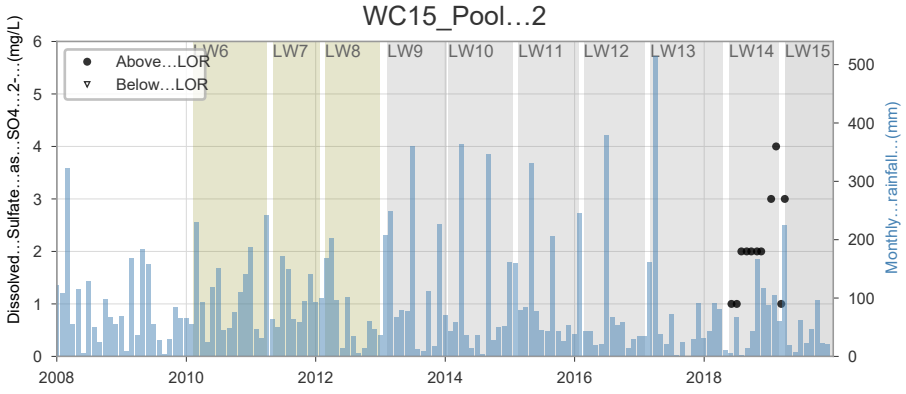

SCk_Rockbar…5
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

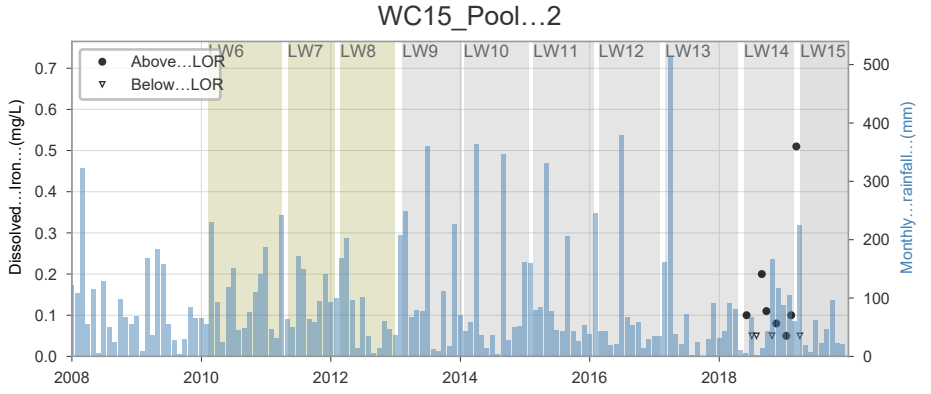

SCk_Rockbar…5
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

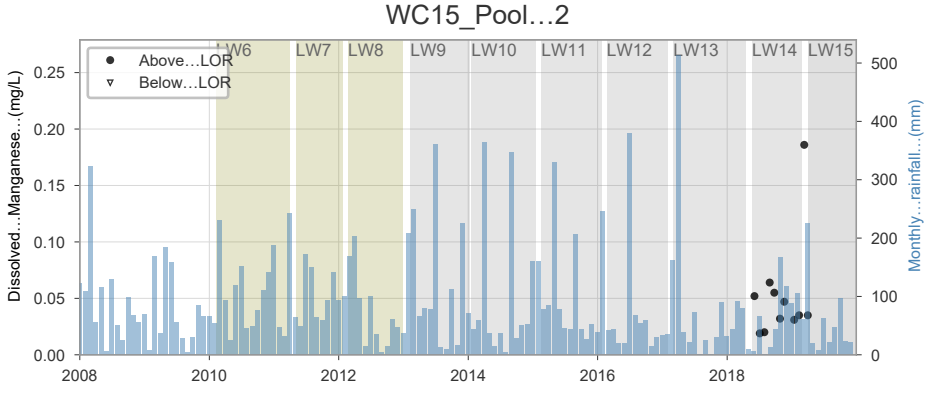

SCk_Rockbar…5
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

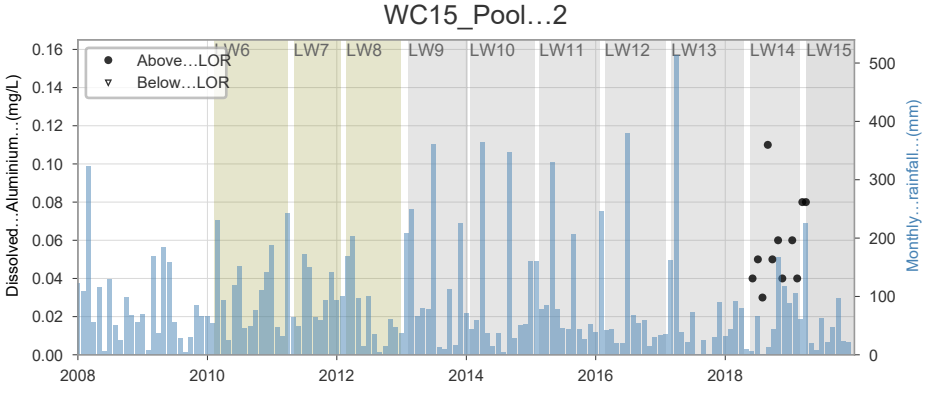

SCk_Rockbar…5
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

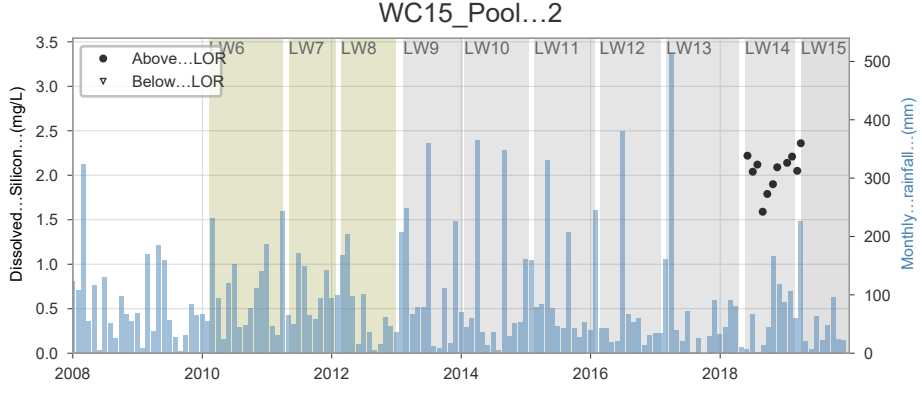

SCk_Rockbar…5
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

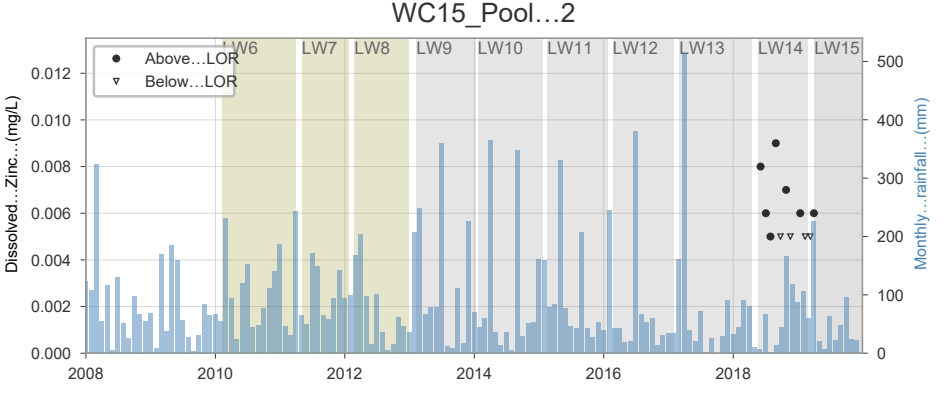

WC15_Pool…2
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

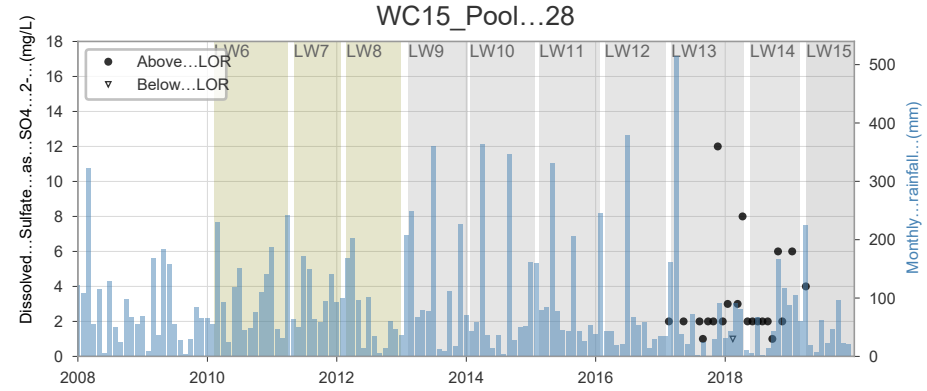

WC15_Pool…2
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

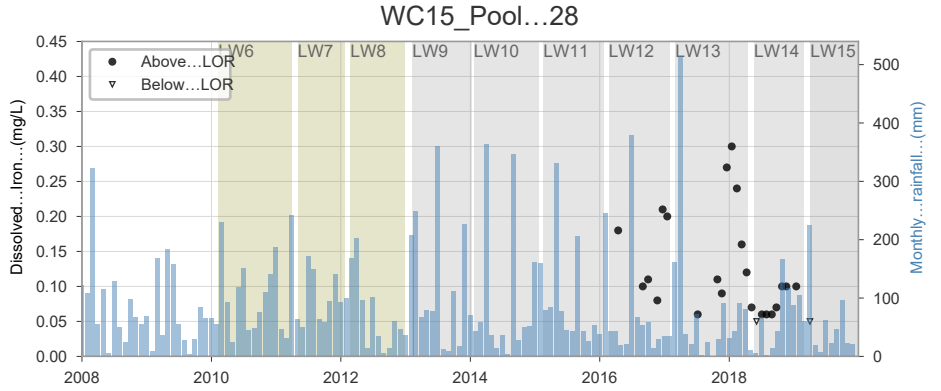

WC15_Pool…2
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

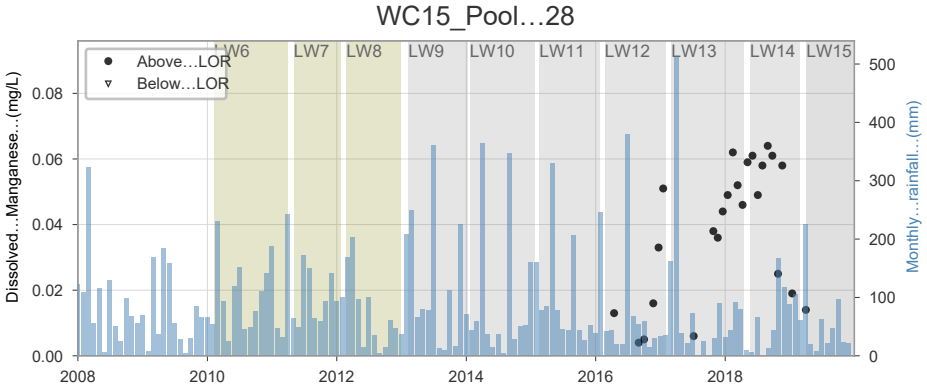

WC15_Pool…2
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

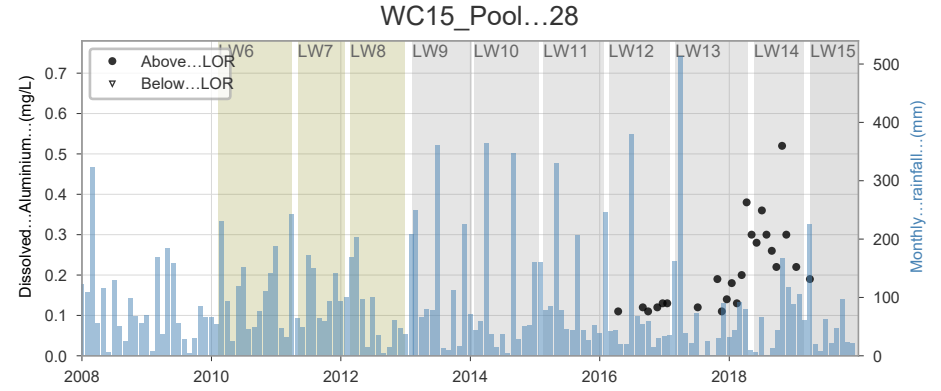

WC15_Pool…2
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

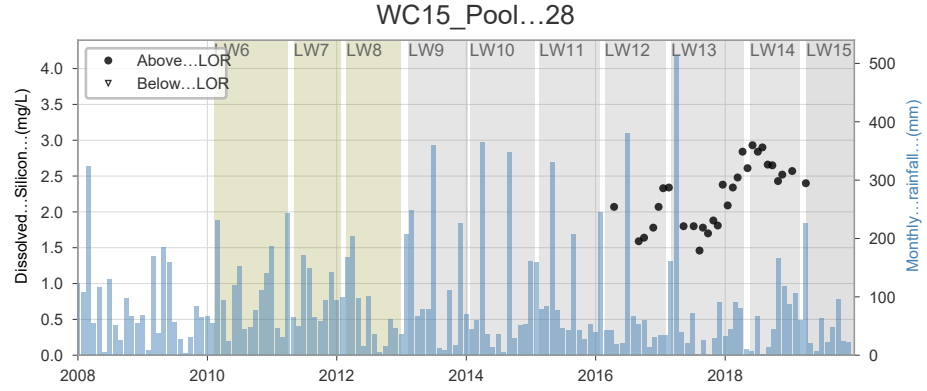

WC15_Pool…2
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

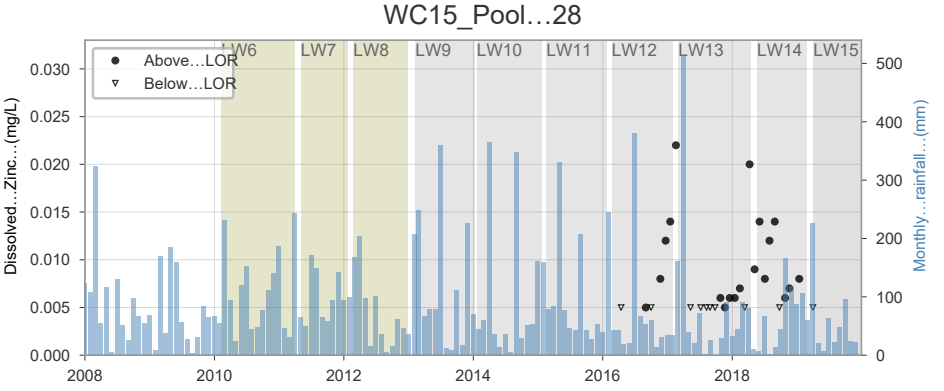

WC15_Pool…28
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

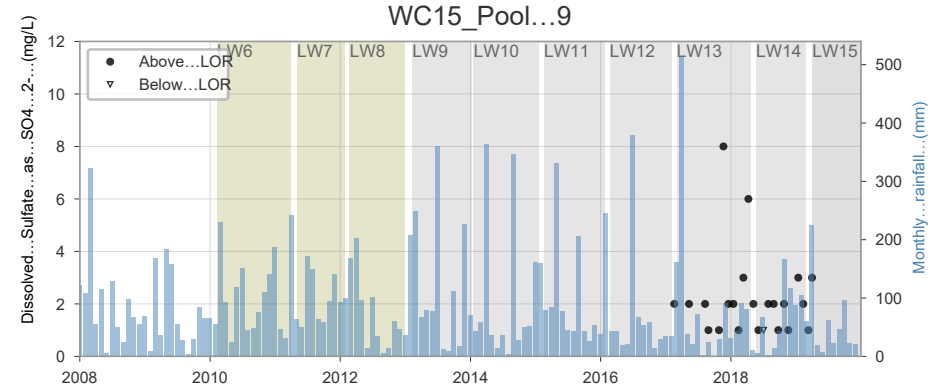

WC15_Pool…28
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

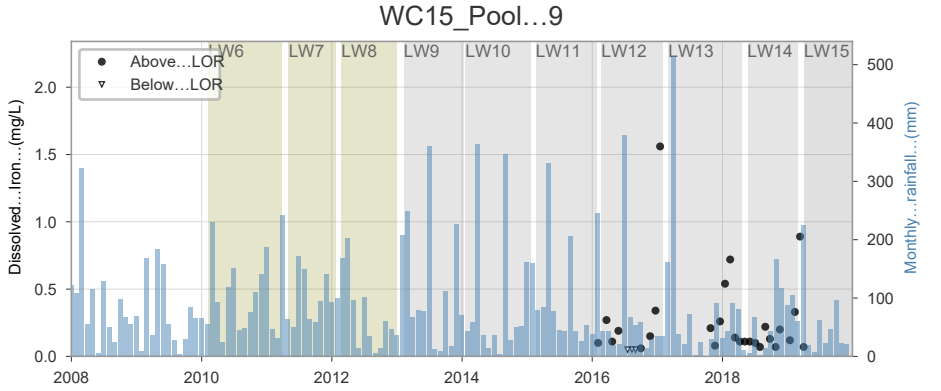

WC15_Pool…28
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

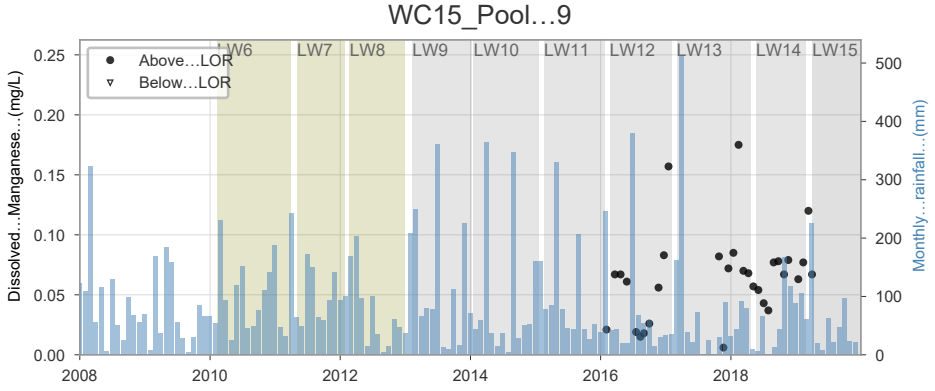

WC15_Pool…28
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

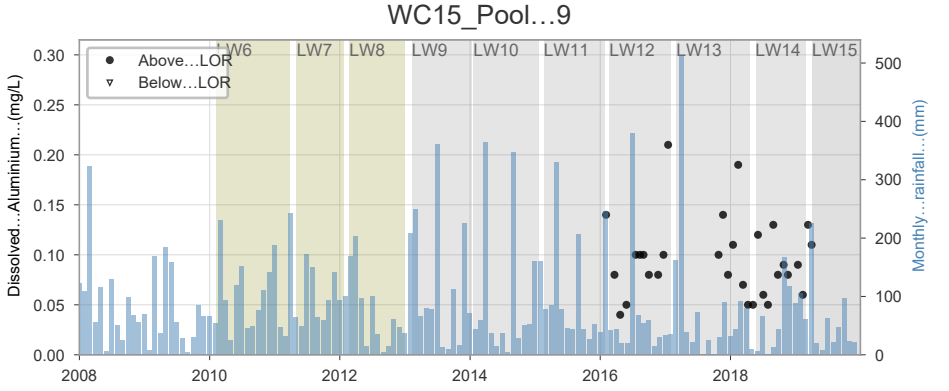

WC15_Pool…28
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

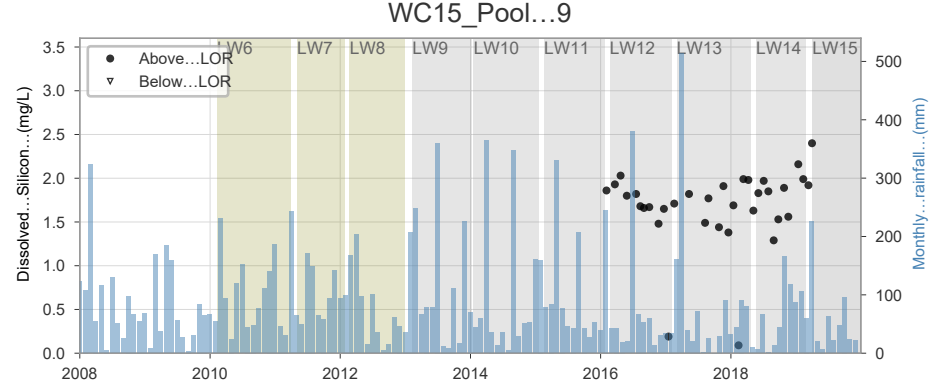

WC15_Pool…28
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

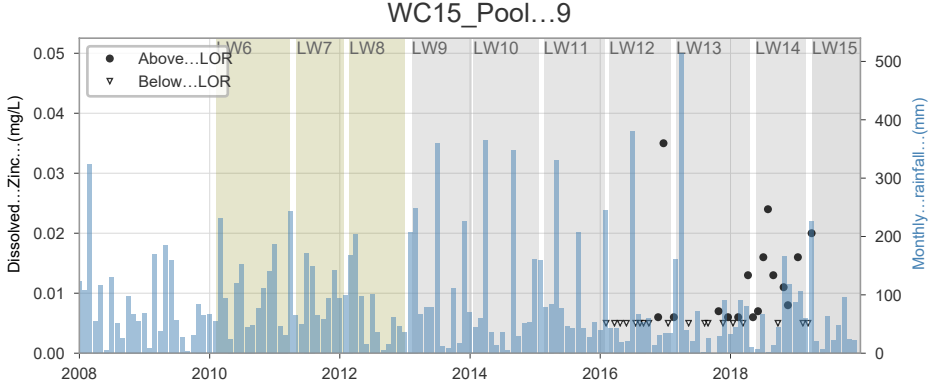

WC15_Pool…9
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

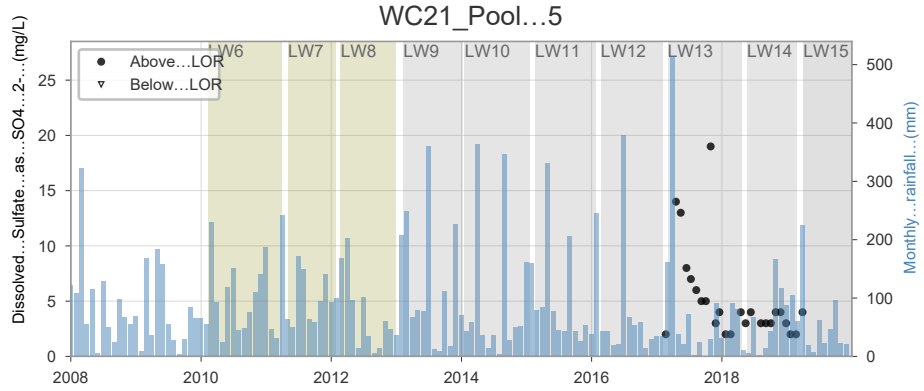

WC15_Pool…9
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

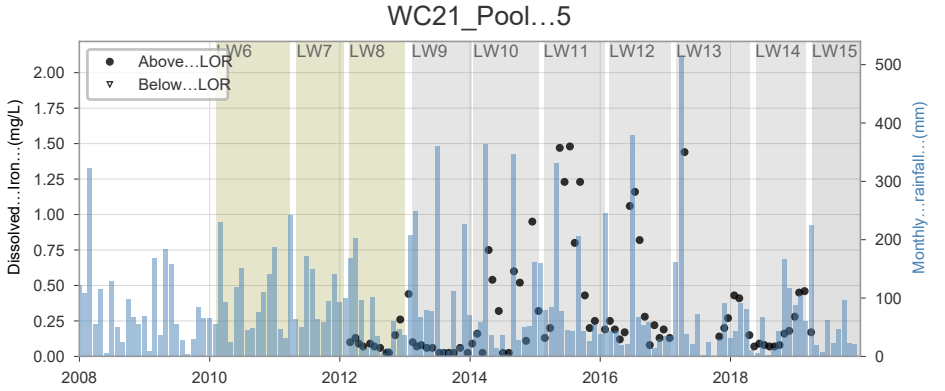

WC15_Pool…9
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

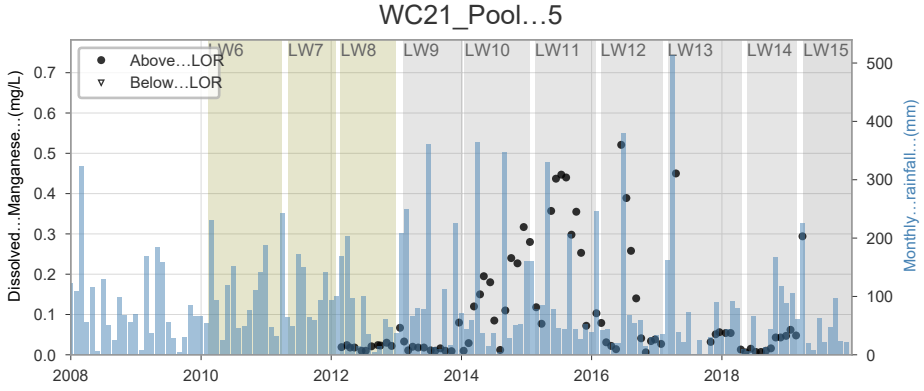

WC15_Pool…9
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

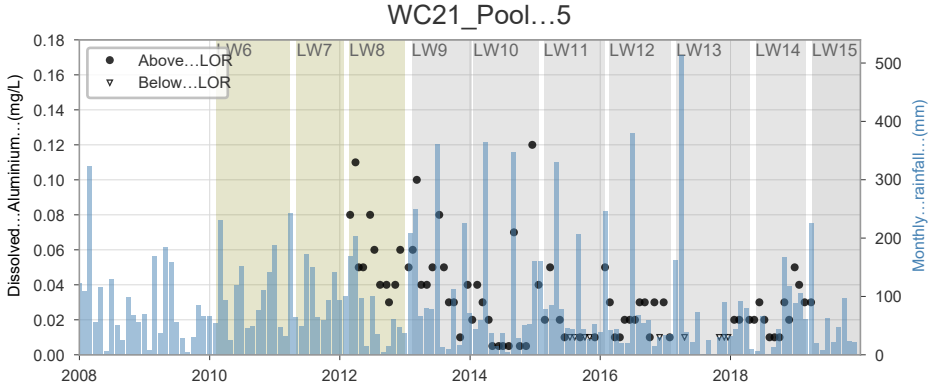

WC15_Pool…9
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

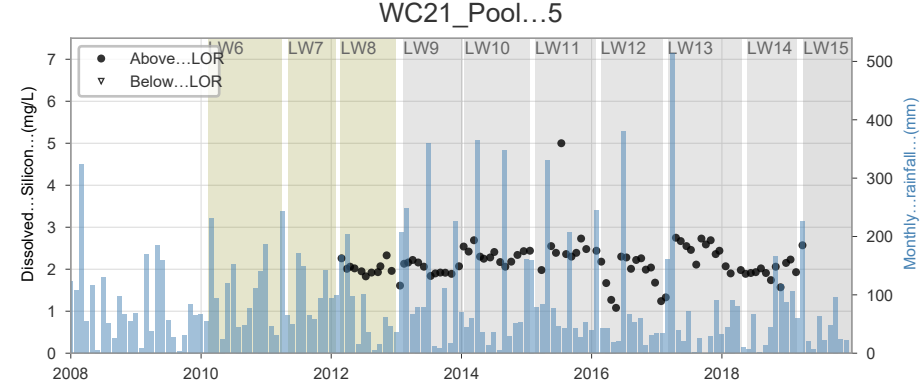

WC15_Pool…9
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

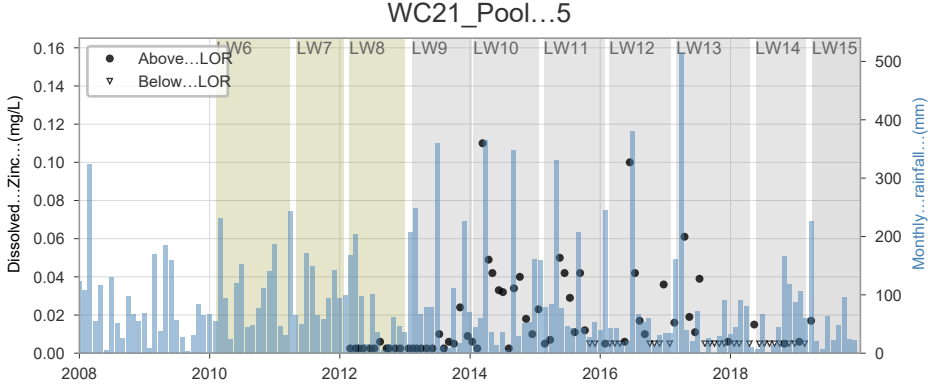

WC21_Pool…5
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

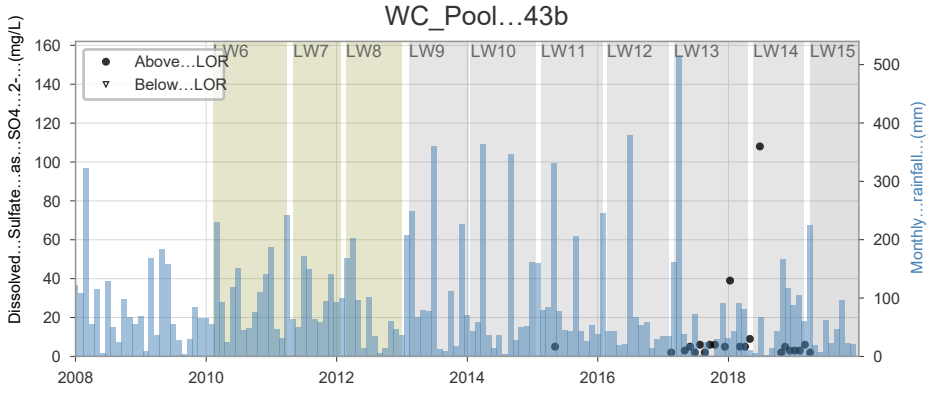

WC21_Pool…5
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

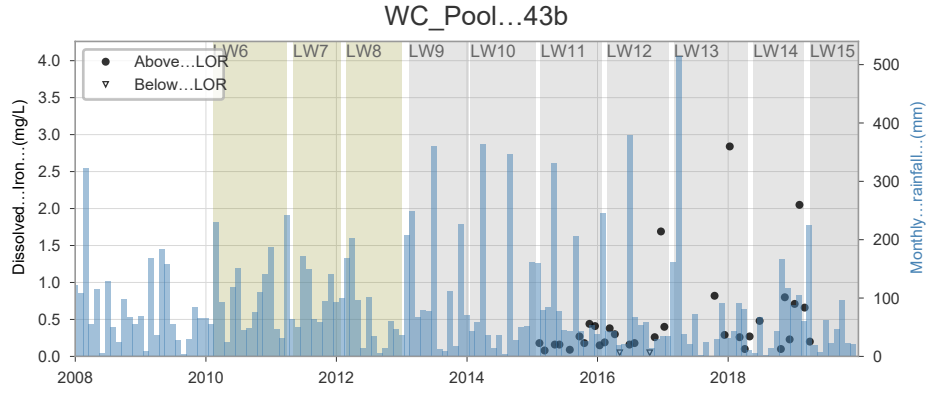

WC21_Pool…5
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

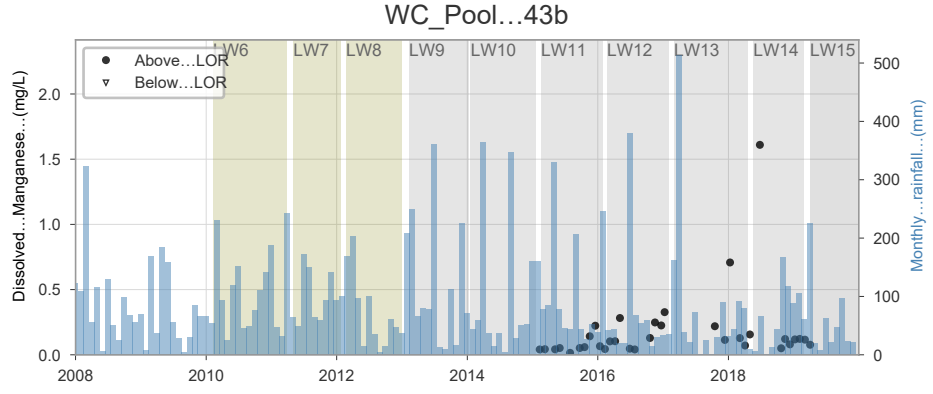

WC21_Pool…5
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

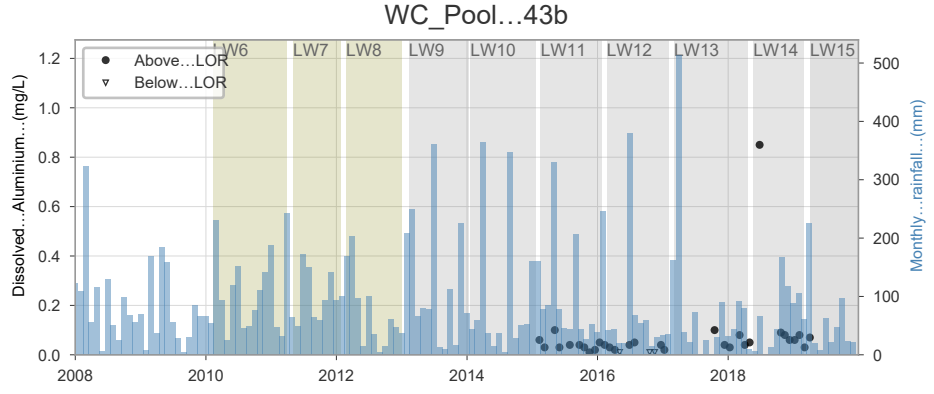

WC21_Pool…5
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

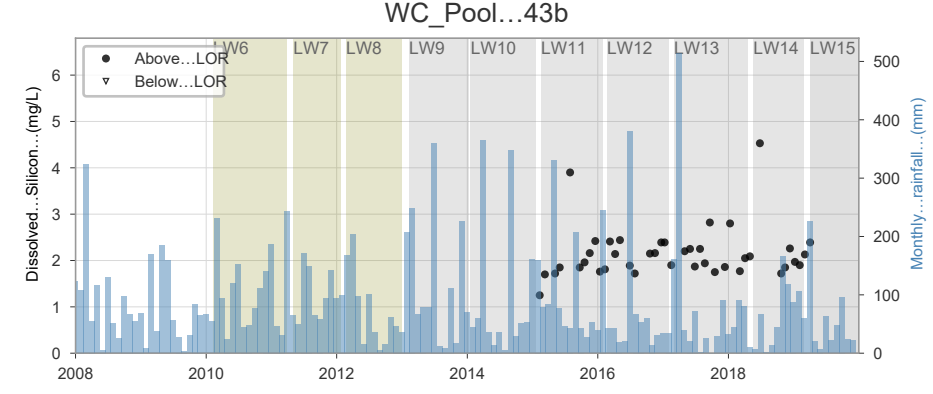

WC21_Pool…5
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

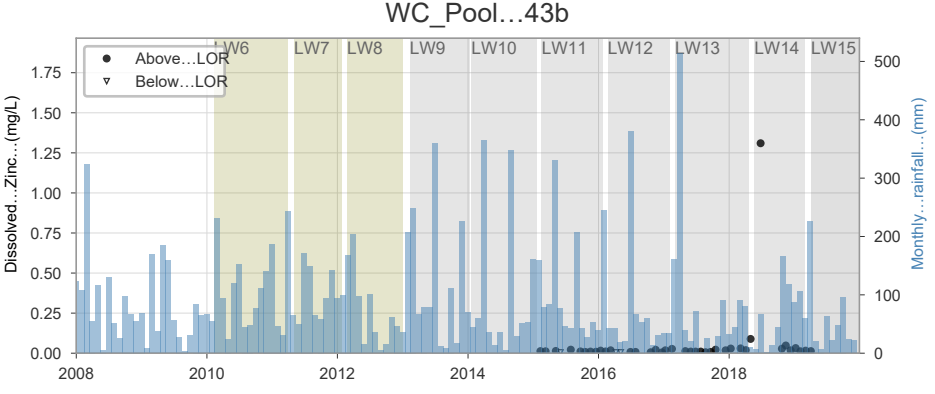

WC_Pool…43b
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

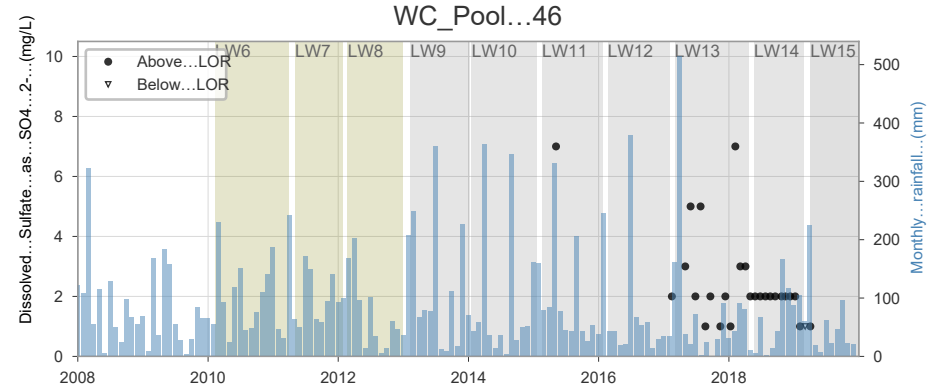

WC_Pool…43b
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

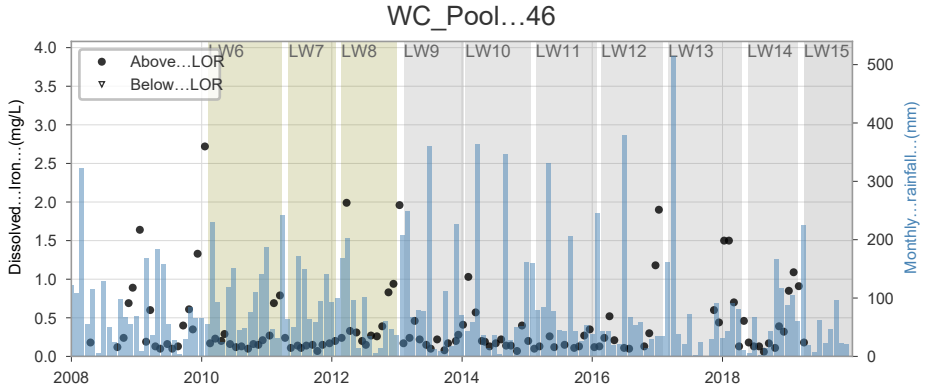

WC_Pool…43b
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

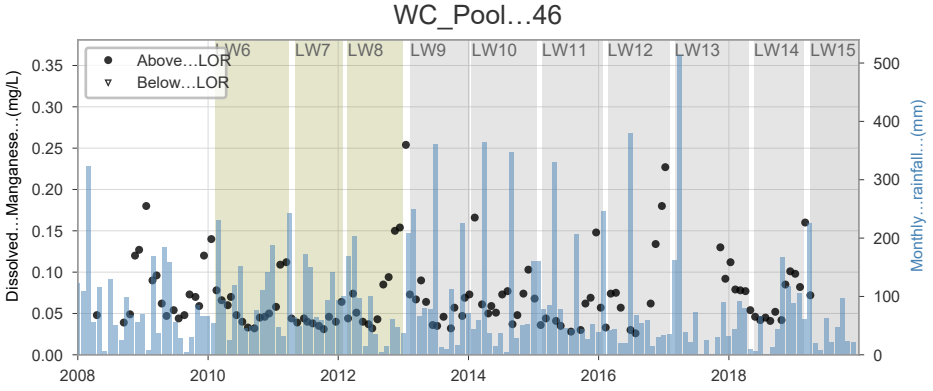

WC_Pool…43b
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

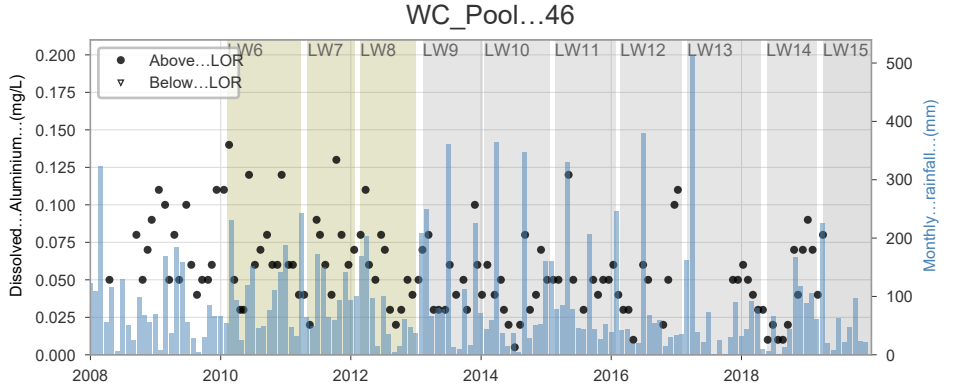

WC_Pool…43b
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

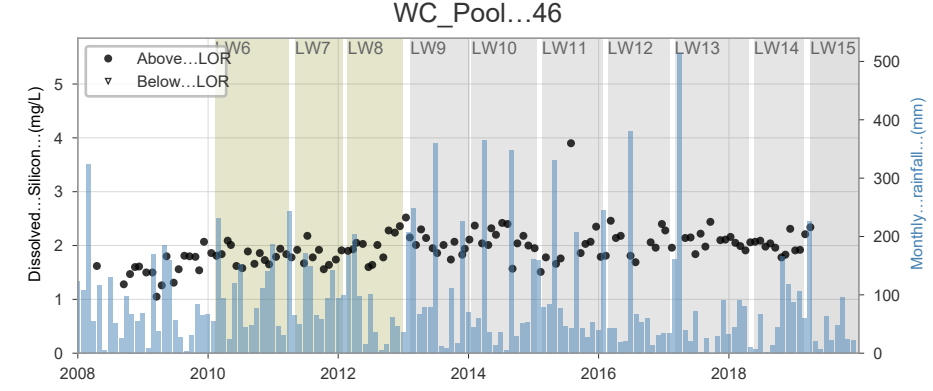

WC_Pool…43b
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

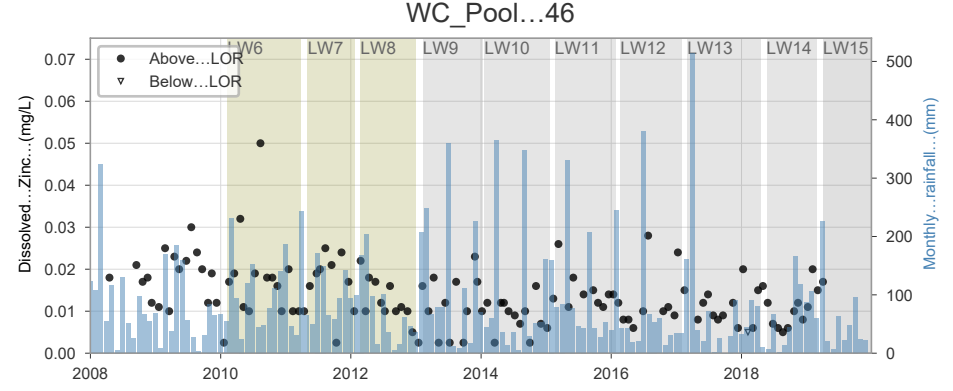

WC_Pool…46
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
2008 2010 2012 2014 2016 2018

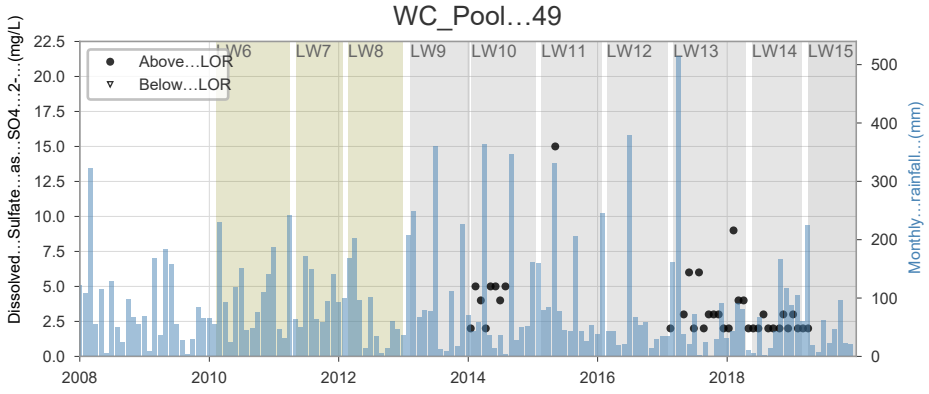

WC_Pool…46
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
2008 2010 2012 2014 2016 2018

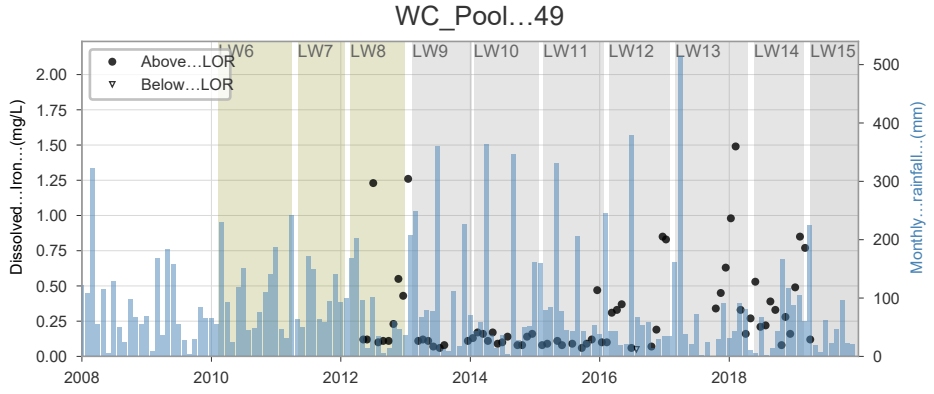

WC_Pool…46
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
2008 2010 2012 2014 2016 2018

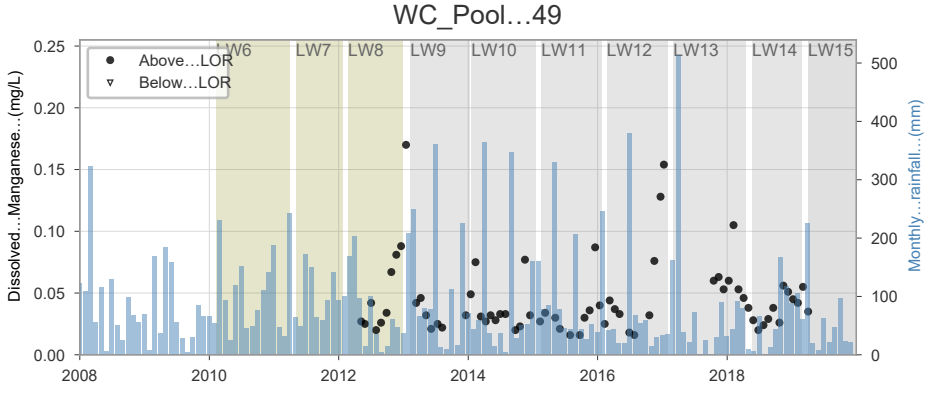

WC_Pool…46
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
2008 2010 2012 2014 2016 2018

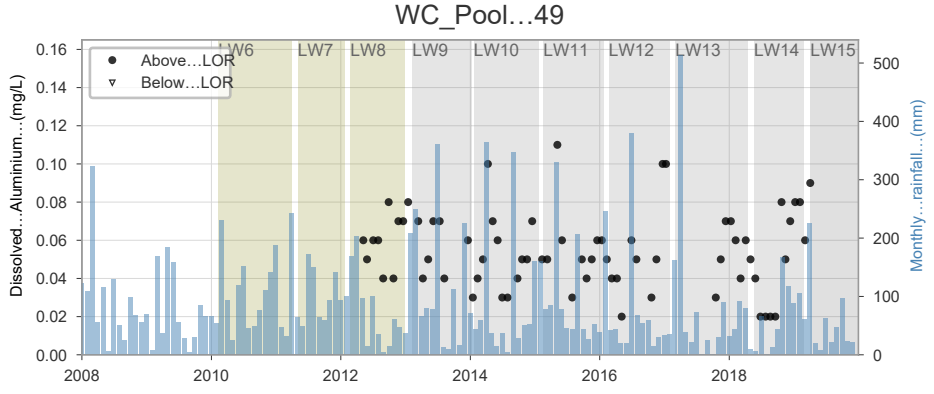

WC_Pool…46
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
2008 2010 2012 2014 2016 2018

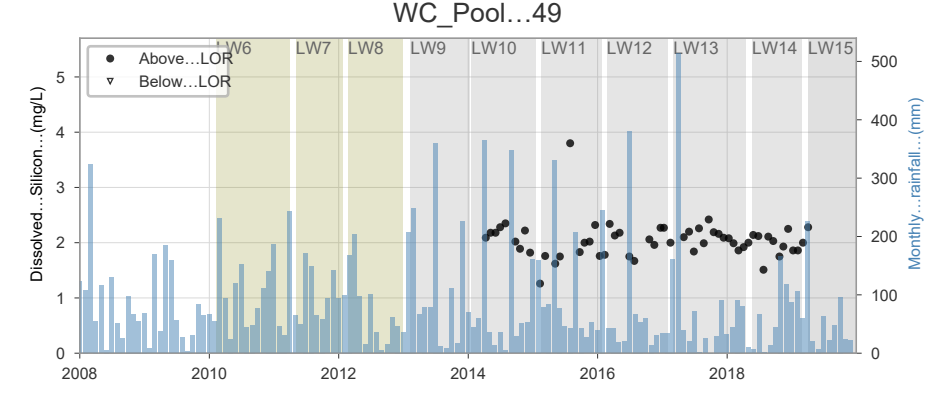

WC_Pool…46
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
2008 2010 2012 2014 2016 2018

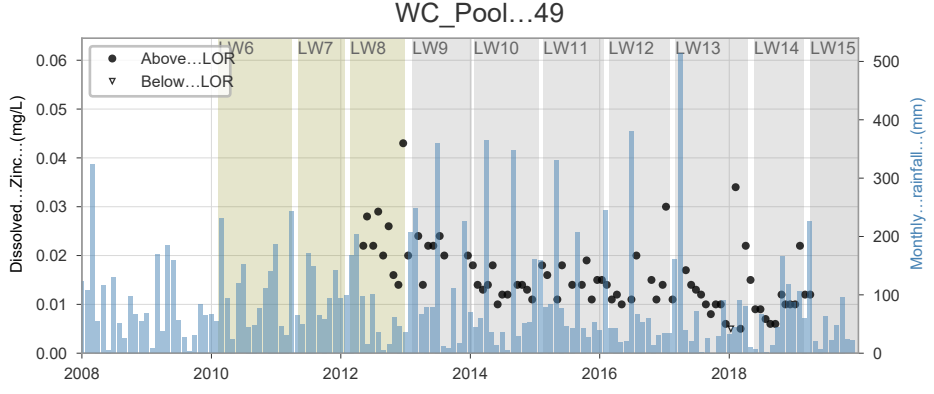

WC_Pool…49
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

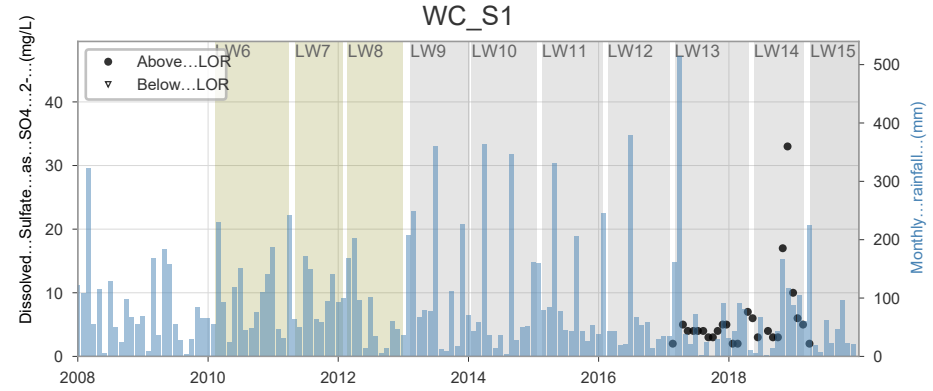

WC_Pool…49
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

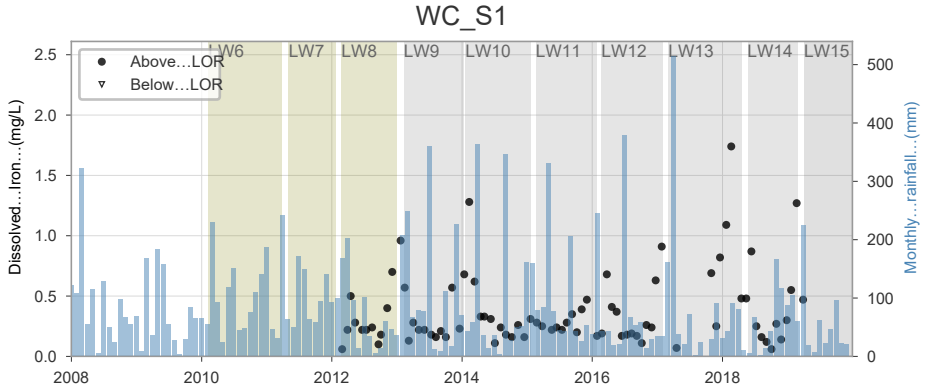

WC_Pool…49
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

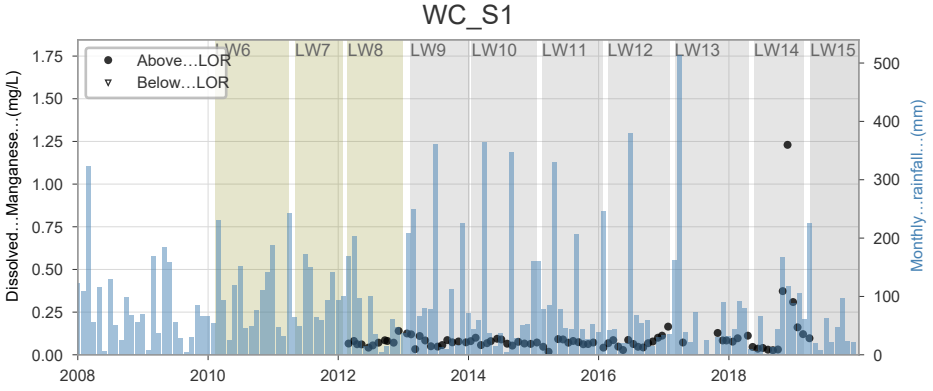

WC_Pool…49
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

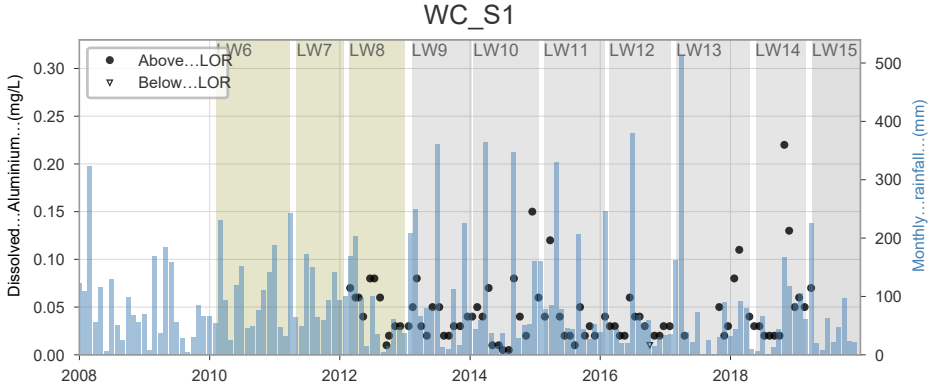

WC_Pool…49
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

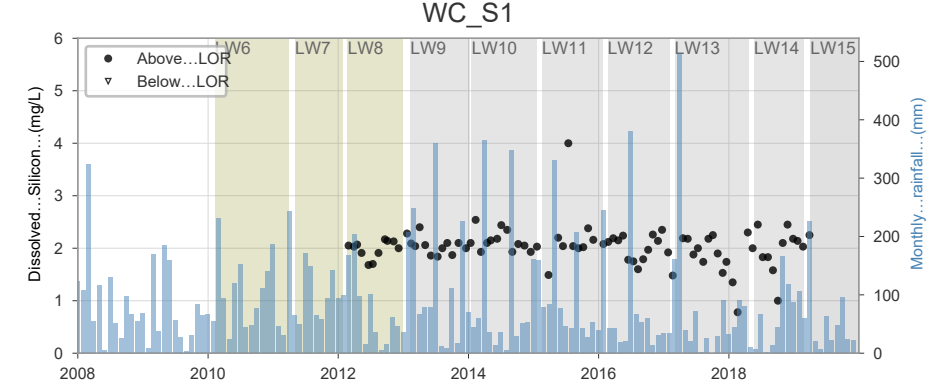

WC_Pool…49
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15

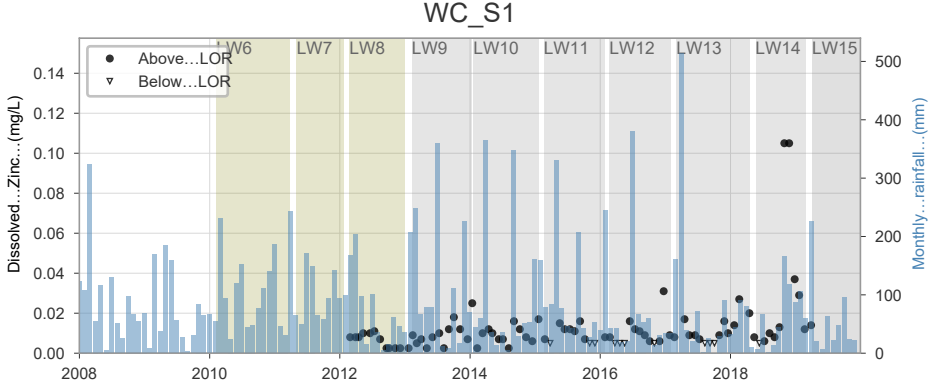

WC_S1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

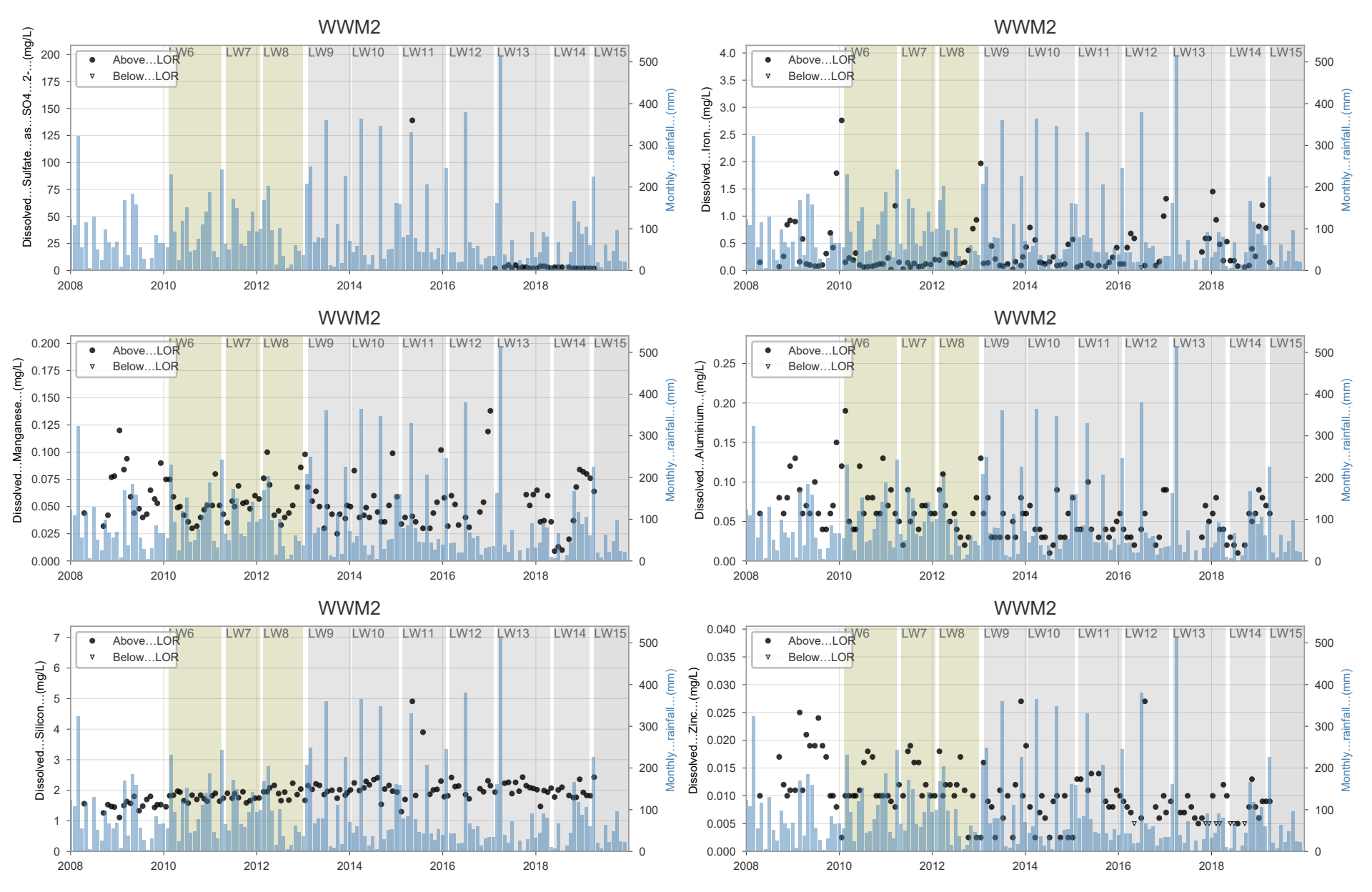

WC_S1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

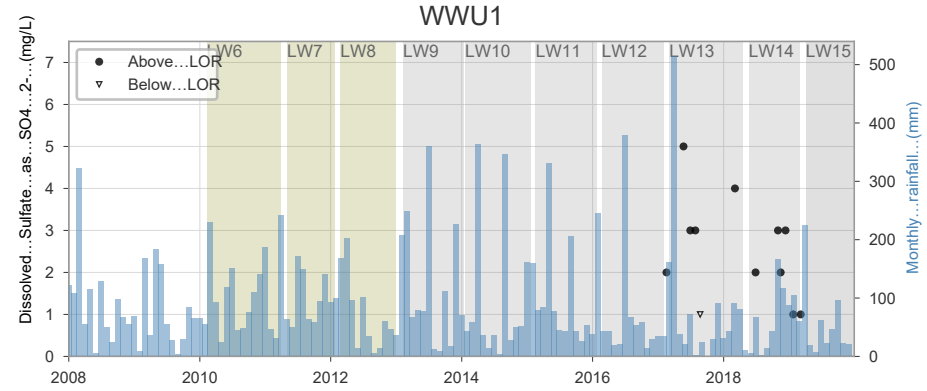

WC_S1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

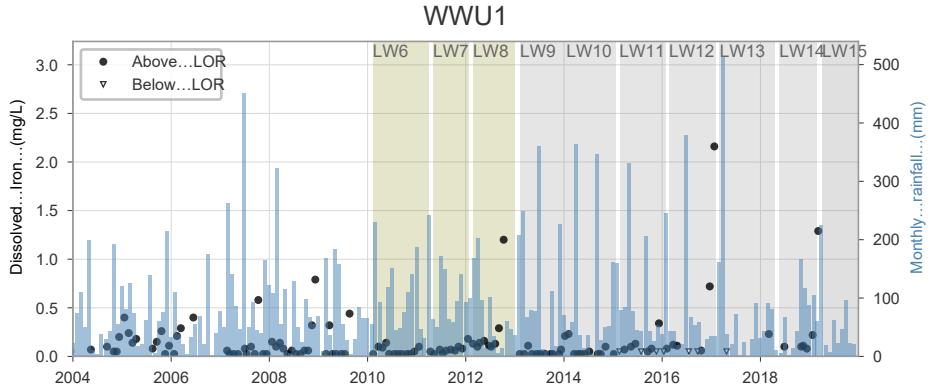

WC_S1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

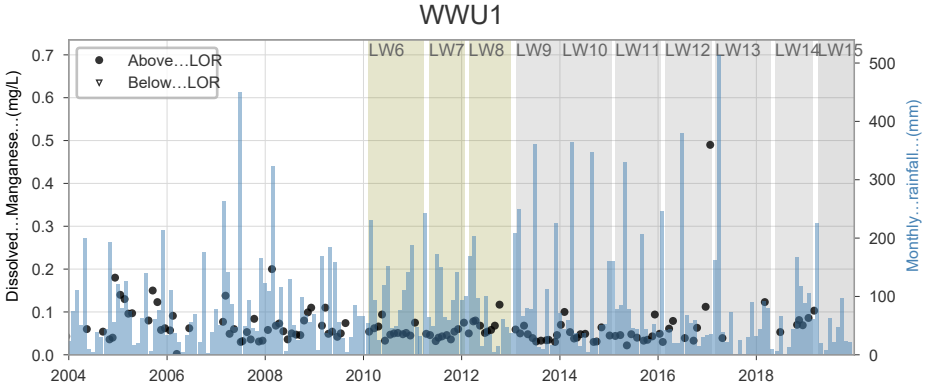

WC_S1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

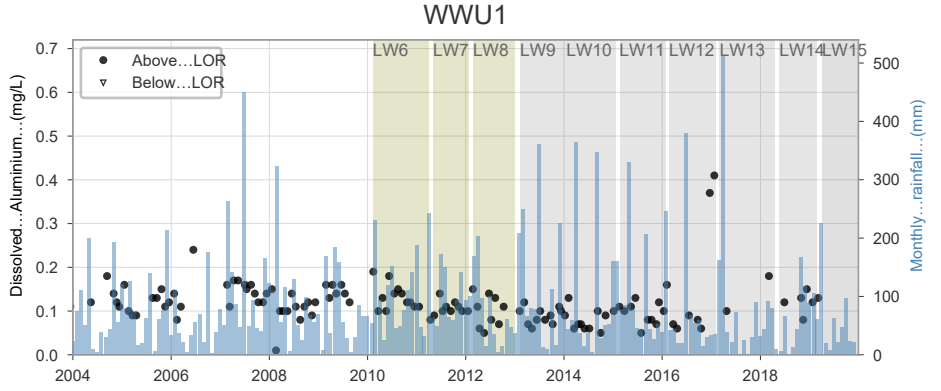

WC_S1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)
2008
2010
2012
2014
2016
2018

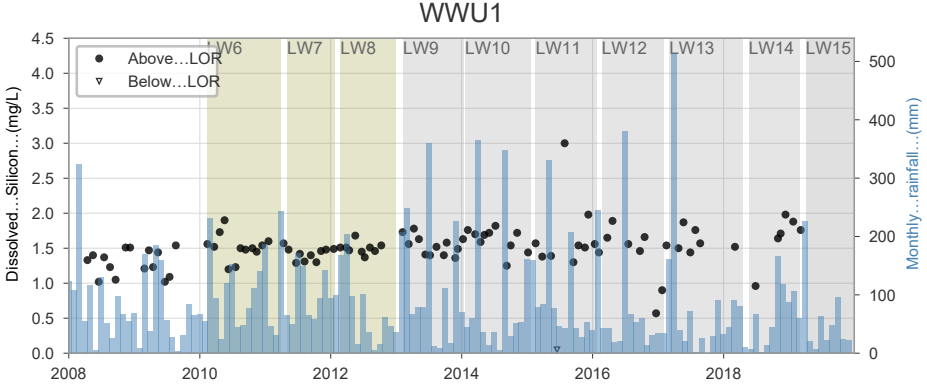

WWM2
Dissolved...Sulfate...as...SO4...2-...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
2008
2010
2012
2014
2016
2018
WWM2
Dissolved...Iron...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
WWM2
Dissolved...Manganese...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
WWM2
Dissolved...Aluminium...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
WWM2
Dissolved...Silicon...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR
WWM2
Dissolved...Zinc...(mg/L)
Monthly...rainfall...(mm)
Above...LOR
Below...LOR

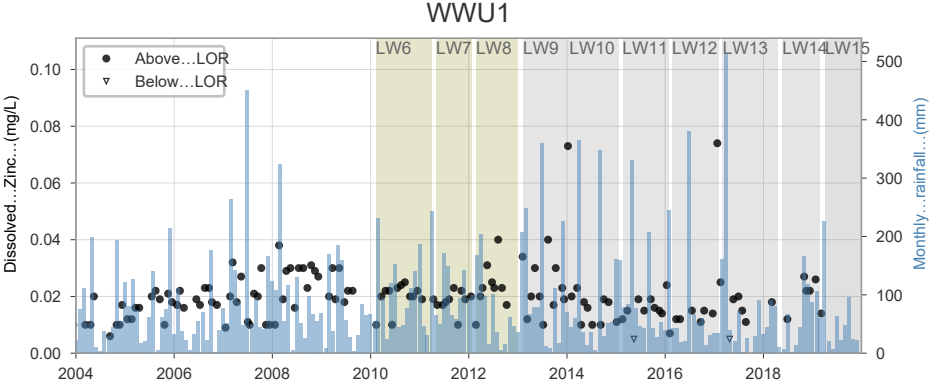

WWU1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)

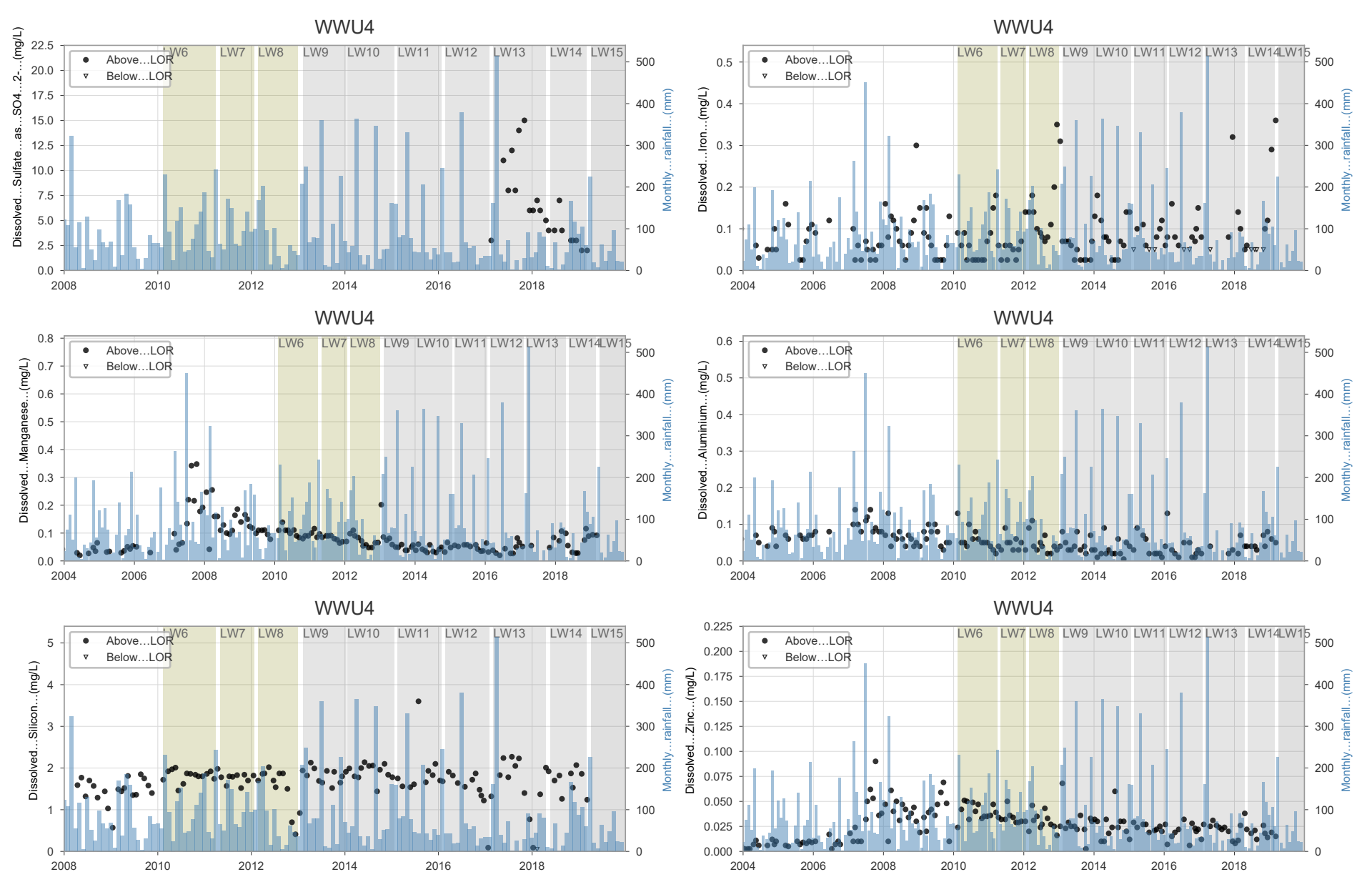

WWU1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)

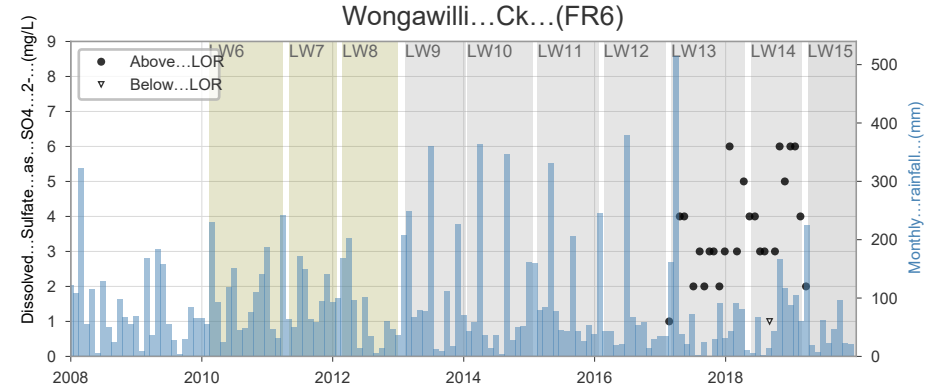

WWU1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)

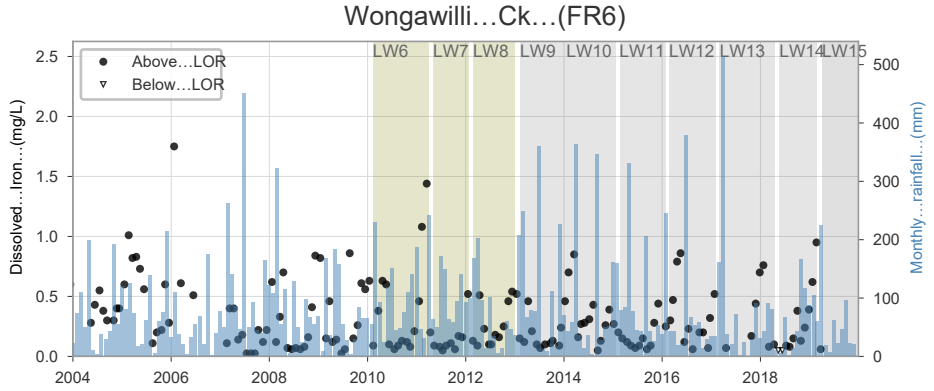

WWU1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)

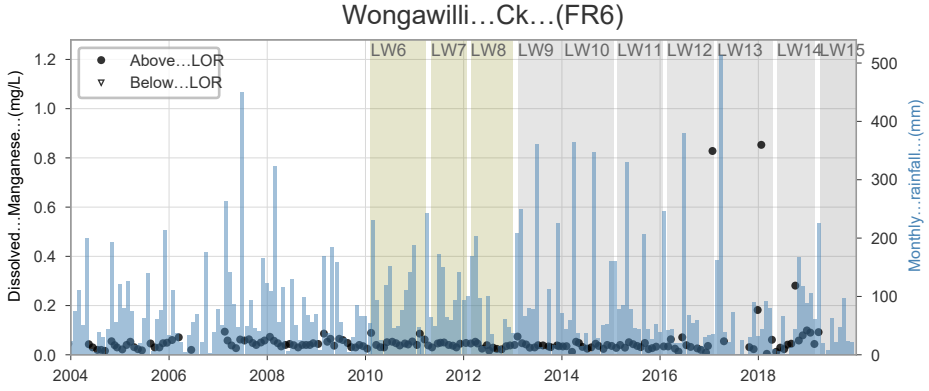

WWU1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)

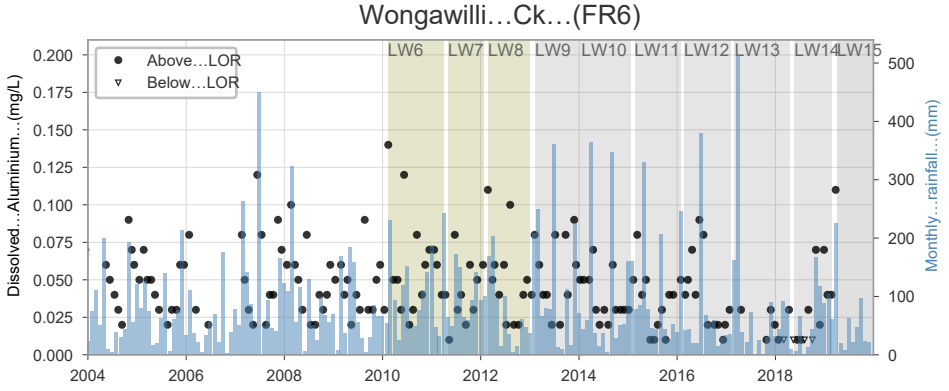

WWU1
Above…LOR
Below…LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)

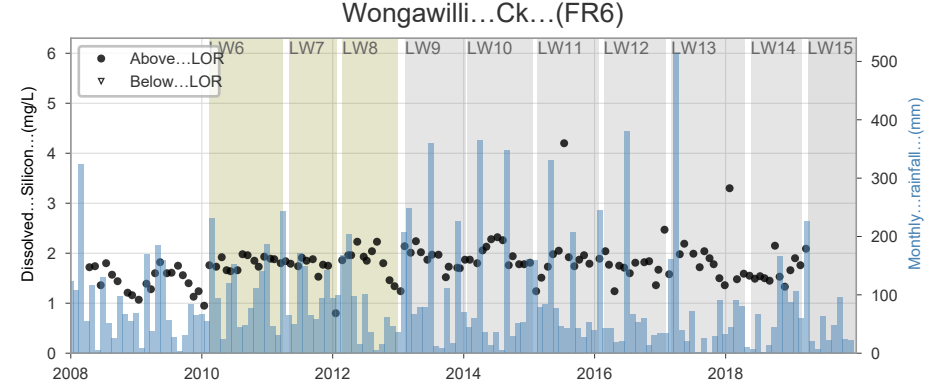

WWU4
Above...LOR
Below...LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
Dissolved...Sulfate...as...SO4...2-...(mg/L)
Monthly...rainfall...(mm)
WWU4
Above...LOR
Below...LOR
Dissolved...Iron...(mg/L)
Monthly...rainfall...(mm)
WWU4
Above...LOR
Below...LOR
Dissolved...Manganese...(mg/L)
Monthly...rainfall...(mm)
WWU4
Above...LOR
Below...LOR
Dissolved...Aluminium...(mg/L)
Monthly...rainfall...(mm)
WWU4
Above...LOR
Below...LOR
Dissolved...Silicon...(mg/L)
Monthly...rainfall...(mm)
WWU4
Above...LOR
Below...LOR
Dissolved...Zinc...(mg/L)
Monthly...rainfall...(mm)

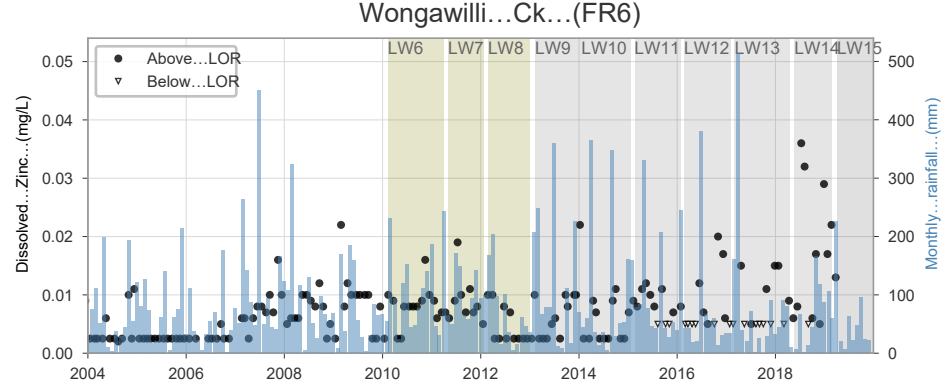

Wongawilli…Ck…(FR6)
Above…LOR
Below…LOR
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
Dissolved…Sulfate…as…SO4…2-…(mg/L)
Monthly…rainfall…(mm)
0 1 2 3 4 5 6 7 8 9
0 100 200 300 400 500
2008 2010 2012 2014 2016 2018


Wongawilli…Ck…(FR6)
Above…LOR
Below…LOR
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
Dissolved…Iron…(mg/L)
Monthly…rainfall…(mm)
0.0 0.5 1.0 1.5 2.0 2.5
0 100 200 300 400 500
2004 2006 2008 2010 2012 2014 2016 2018


Wongawilli…Ck…(FR6)
Above…LOR
Below…LOR
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
Dissolved…Manganese…(mg/L)
Monthly…rainfall…(mm)
0.0 0.2 0.4 0.6 0.8 1.0 1.2
0 100 200 300 400 500
2004 2006 2008 2010 2012 2014 2016 2018


Wongawilli…Ck…(FR6)
Above…LOR
Below…LOR
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
Dissolved…Aluminium…(mg/L)
Monthly…rainfall…(mm)
0.000 0.025 0.050 0.075 0.100 0.125 0.150 0.175 0.200
0 100 200 300 400 500
2004 2006 2008 2010 2012 2014 2016 2018


Wongawilli…Ck…(FR6)
Above…LOR
Below…LOR
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
Dissolved…Silicon…(mg/L)
Monthly…rainfall…(mm)
0 1 2 3 4 5 6
0 100 200 300 400 500
2008 2010 2012 2014 2016 2018


Wongawilli…Ck…(FR6)
Above…LOR
Below…LOR
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
Dissolved…Zinc…(mg/L)
Monthly…rainfall…(mm)
0.00 0.01 0.02 0.03 0.04 0.05
0 100 200 300 400 500
2004 2006 2008 2010 2012 2014 2016 2018

# APPENDIX 2 – Surface flow observations on Wongawilli Ck

**Figure A2-1**

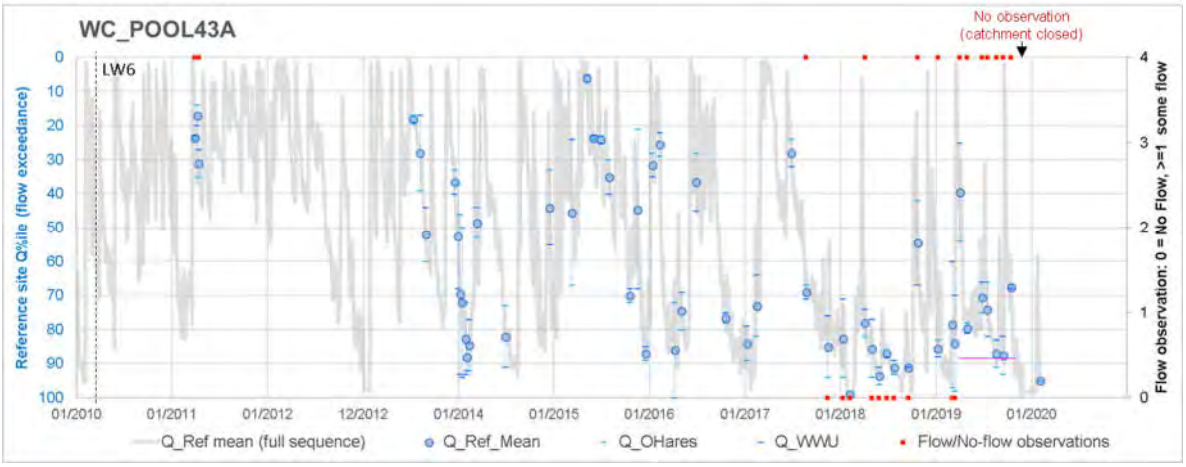



**Figure A2-2**

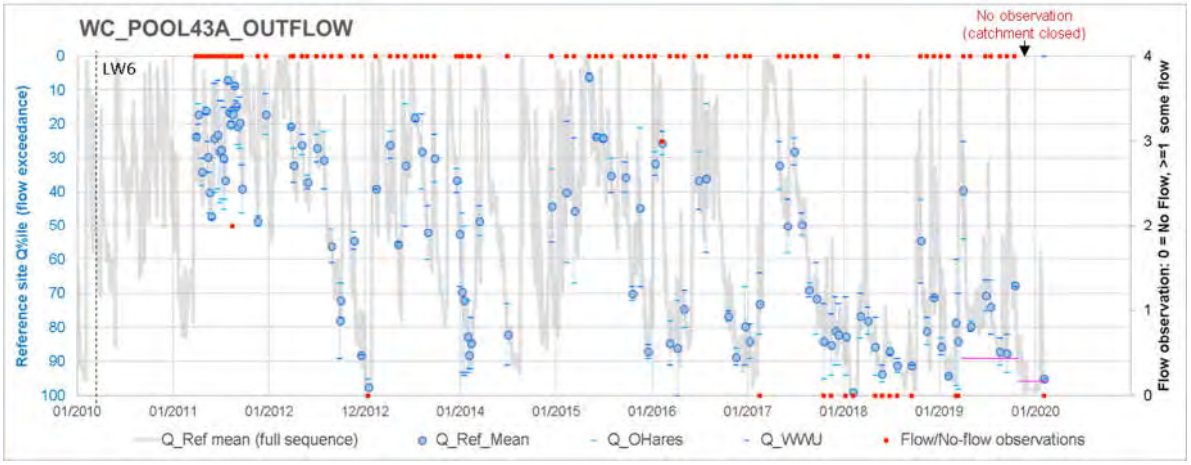
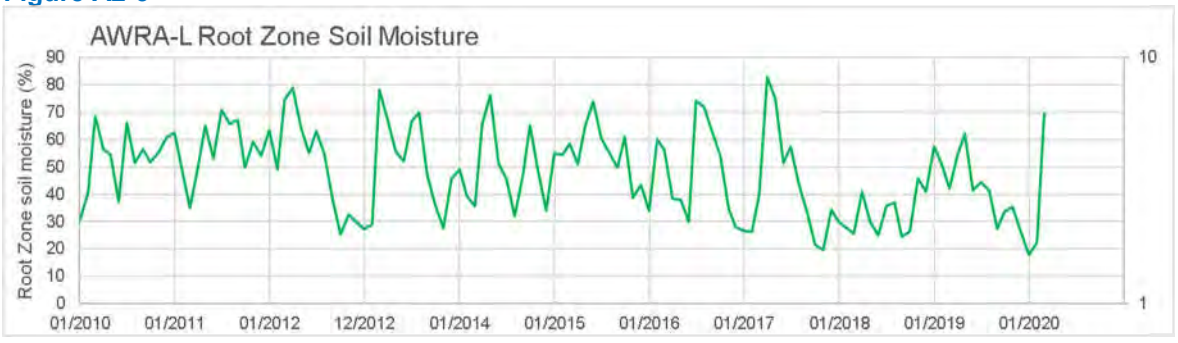



**Figure A2-3**




These inflow and outflow sites at Pool 43A, which is near to Longwalls 6 and 9, have relatively long post-mining records but no pre-mining baseline records.

E:\DENDROBIUM\Reports\HGE009\WongaCk_MiddleReach_v3.pptx

E:\DENDROBIUM\Tech\SurfaceWater\Observations\DA3A_DA3B_Inflow&Outflow_Obs.xlsx

**Figure A2-4**

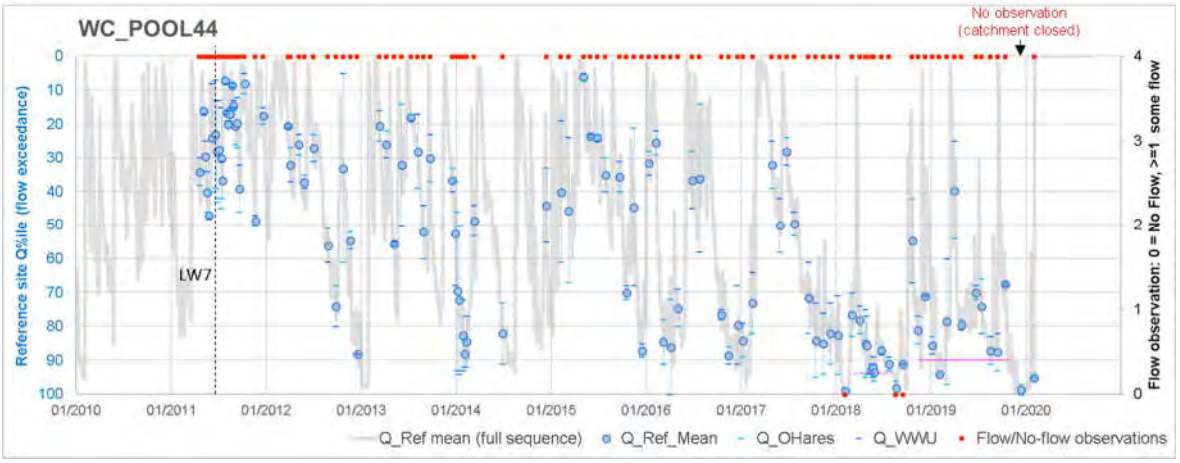



**Figure A2-5**

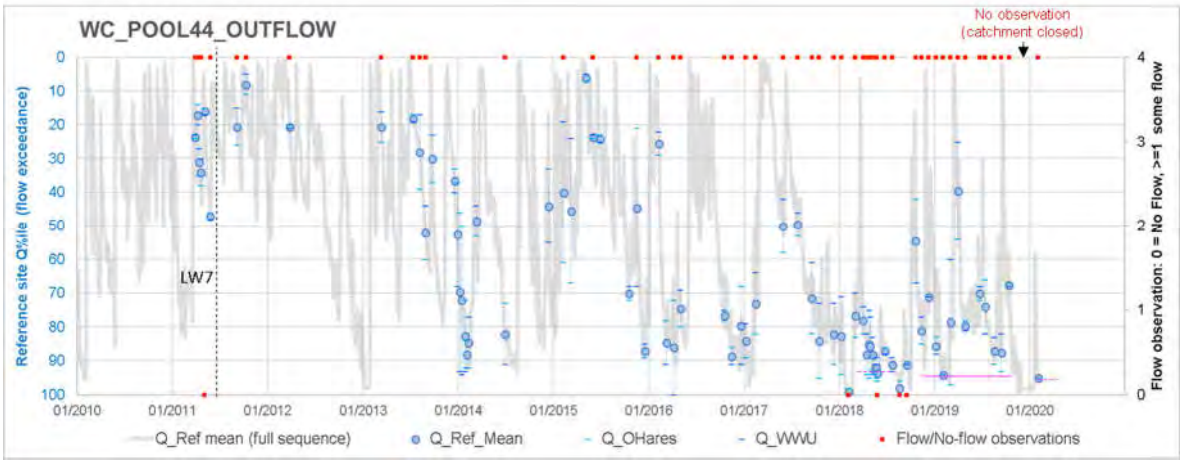
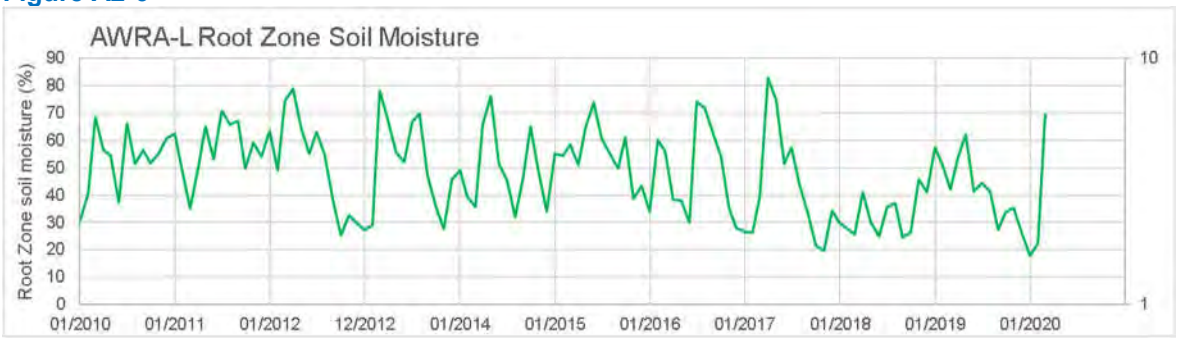



**Figure A2-6**




These inflow and outflow sites at Pool 44, which is near to Longwalls 7 and 10, have relatively long post-mining records but limited pre-mining baseline records.

**Figure A2-7**

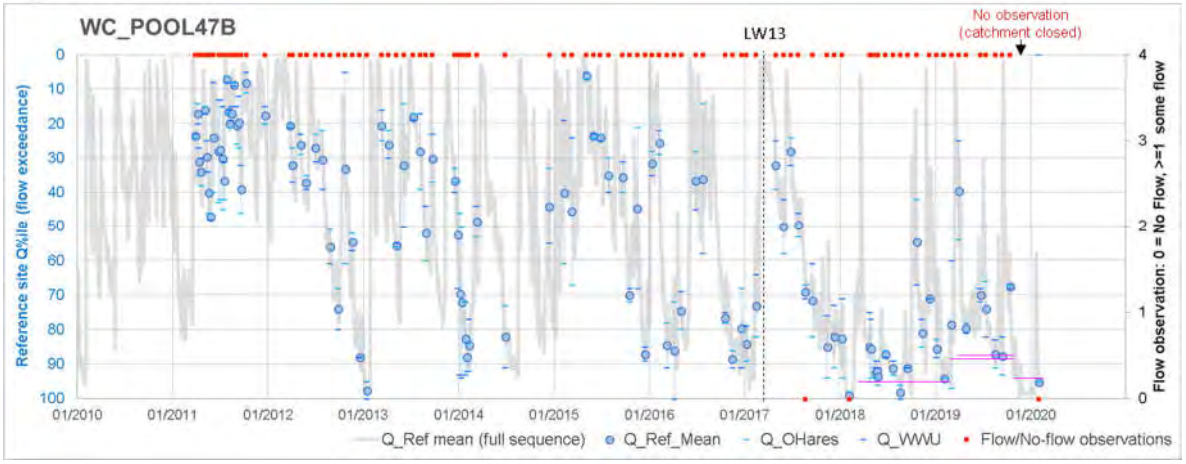



**Figure A2-8**

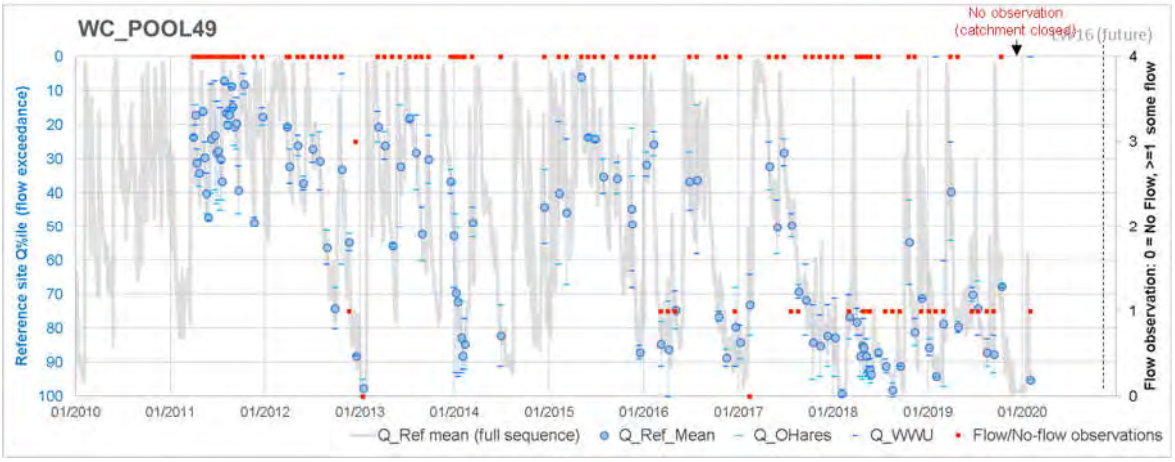
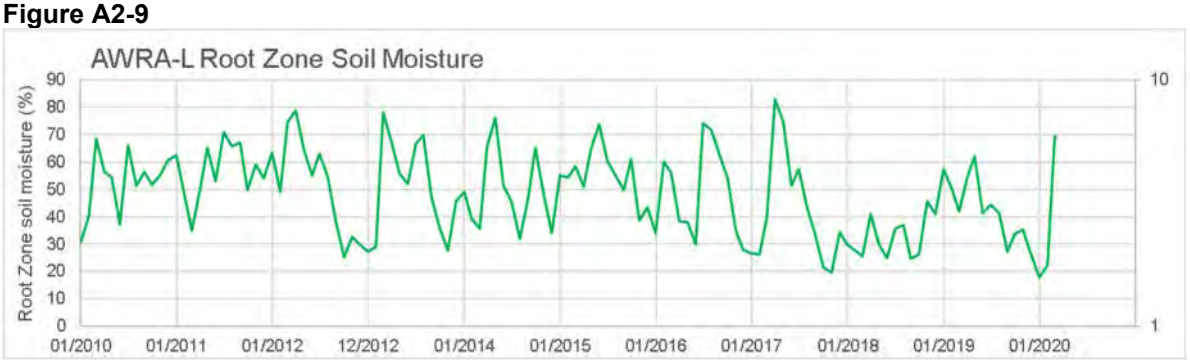
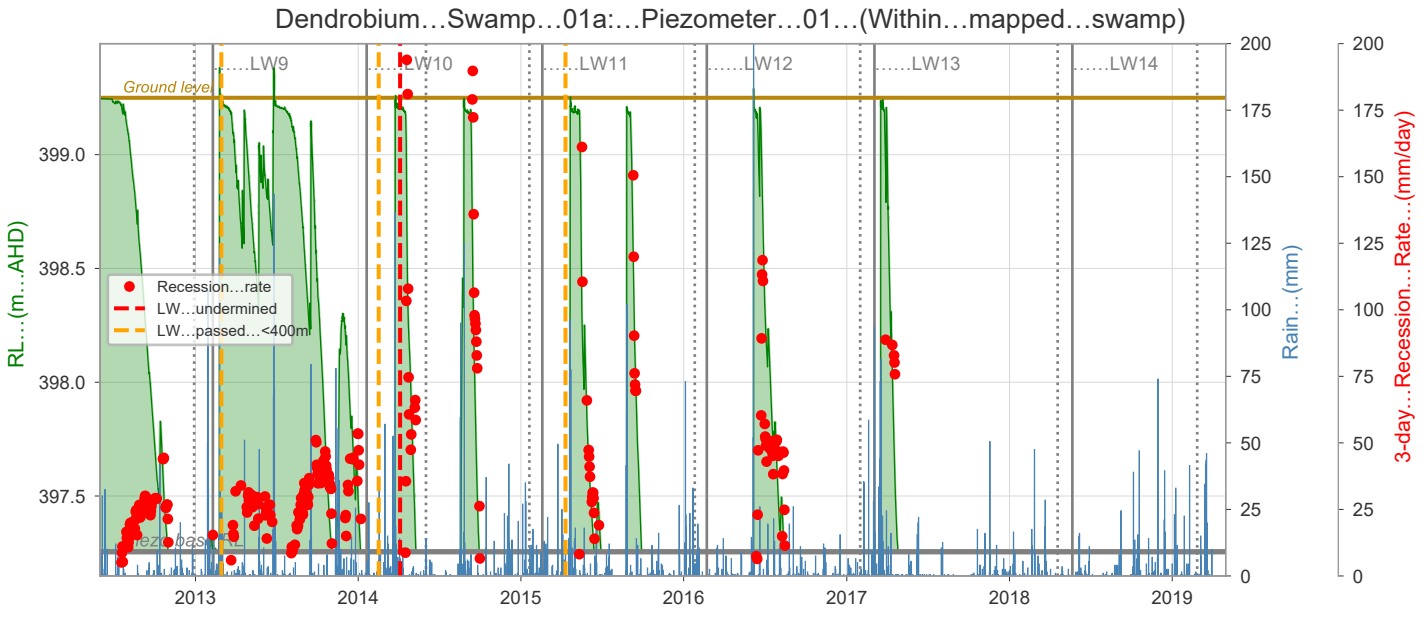


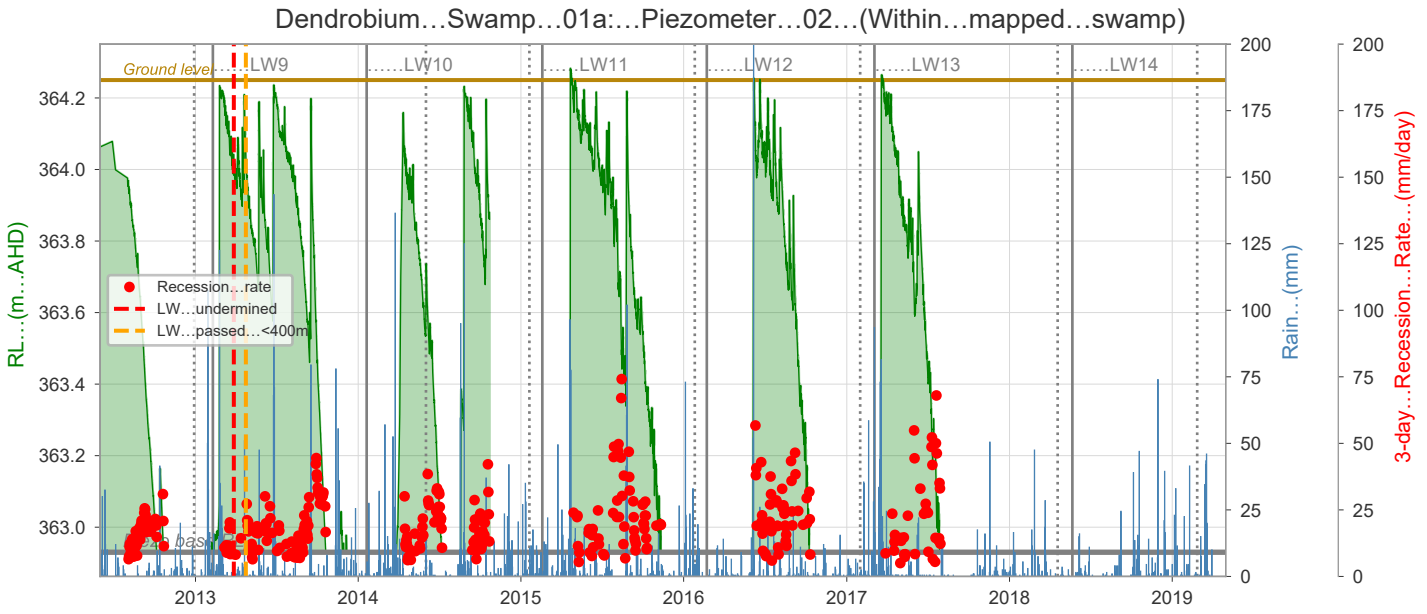

**Figure A2-9**

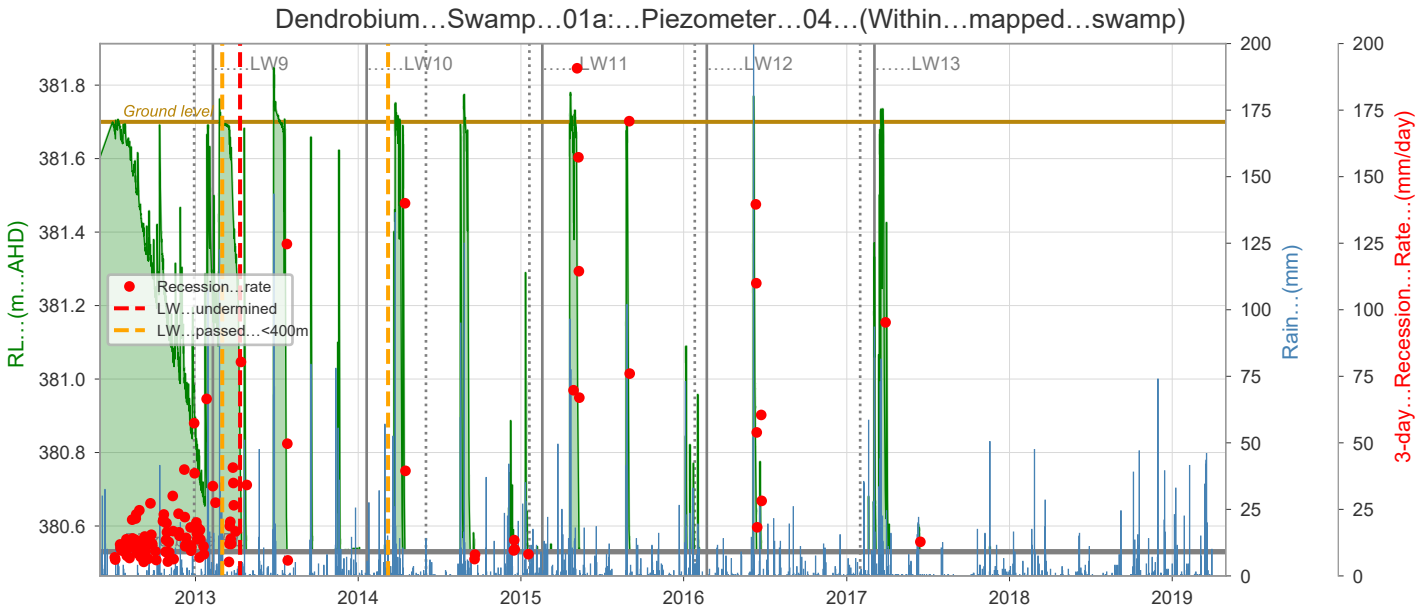


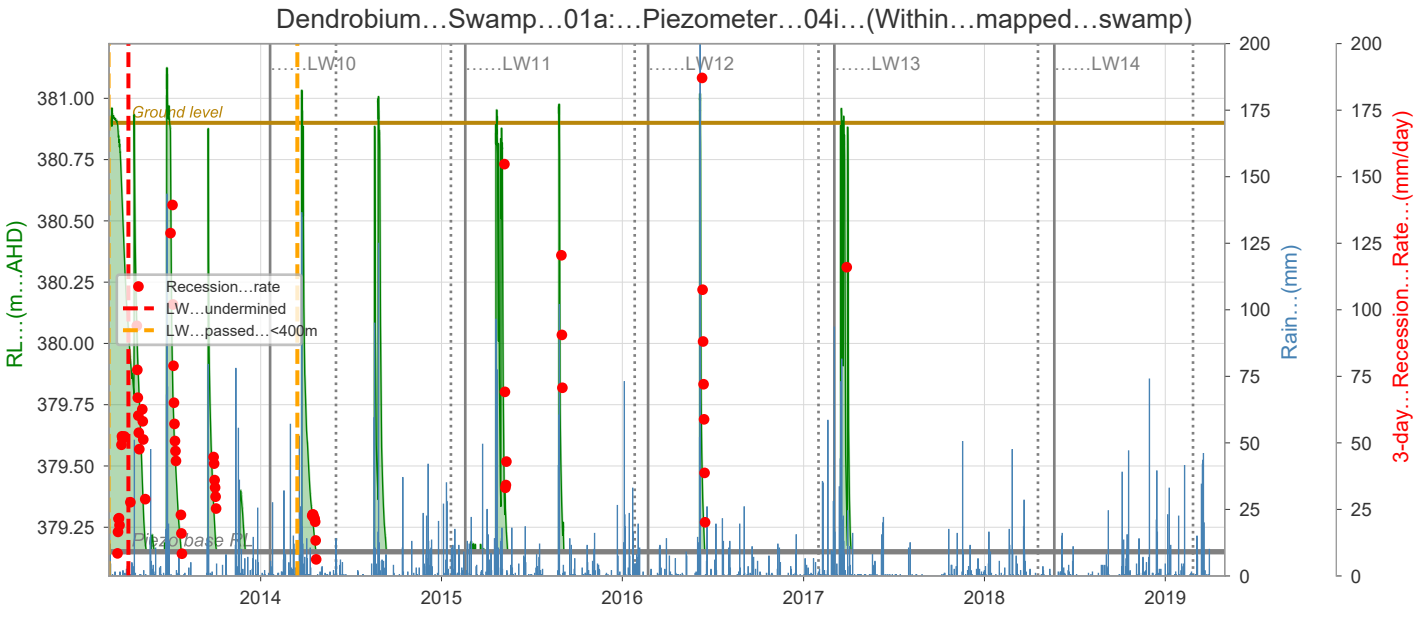

These two sites (Pool 47B and Pool 49) are further upgradient along Wongawilli Creek, near to Longwalls 13 and 16 (which is yet to be extracted). They have relatively longer pre-mining records than the other sites (Pools 43A and 44).

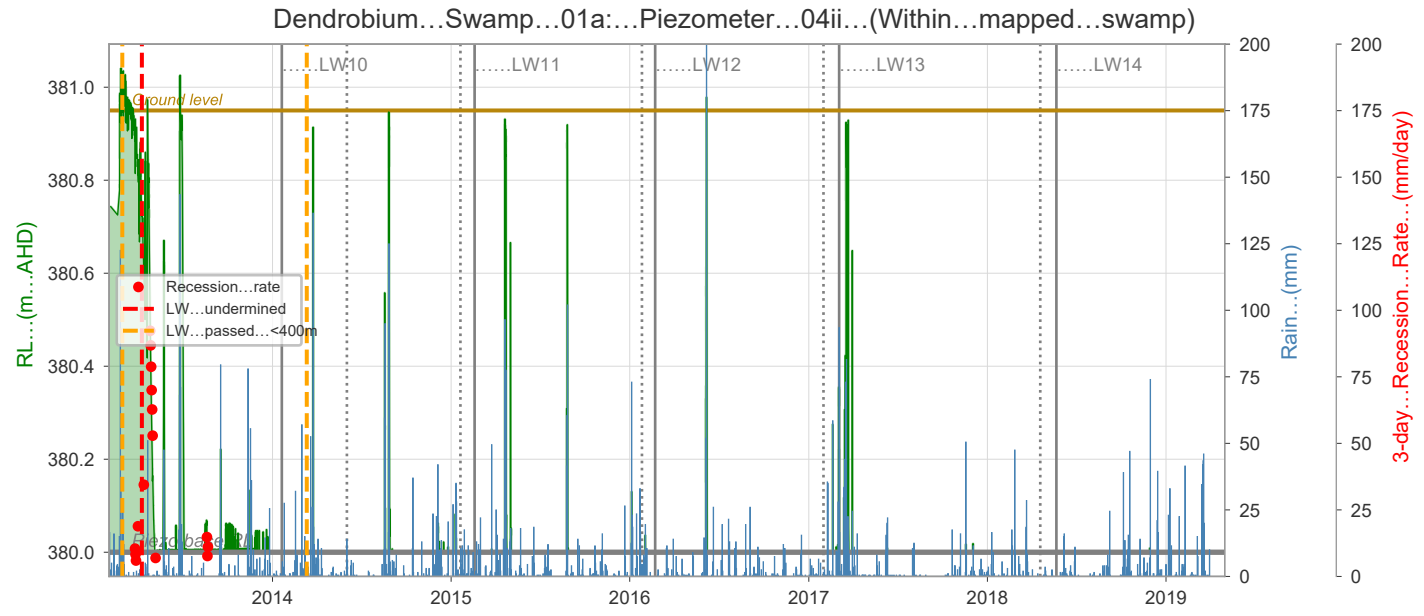
# APPENDIX 3 – Swamp shallow groundwater hydrographs

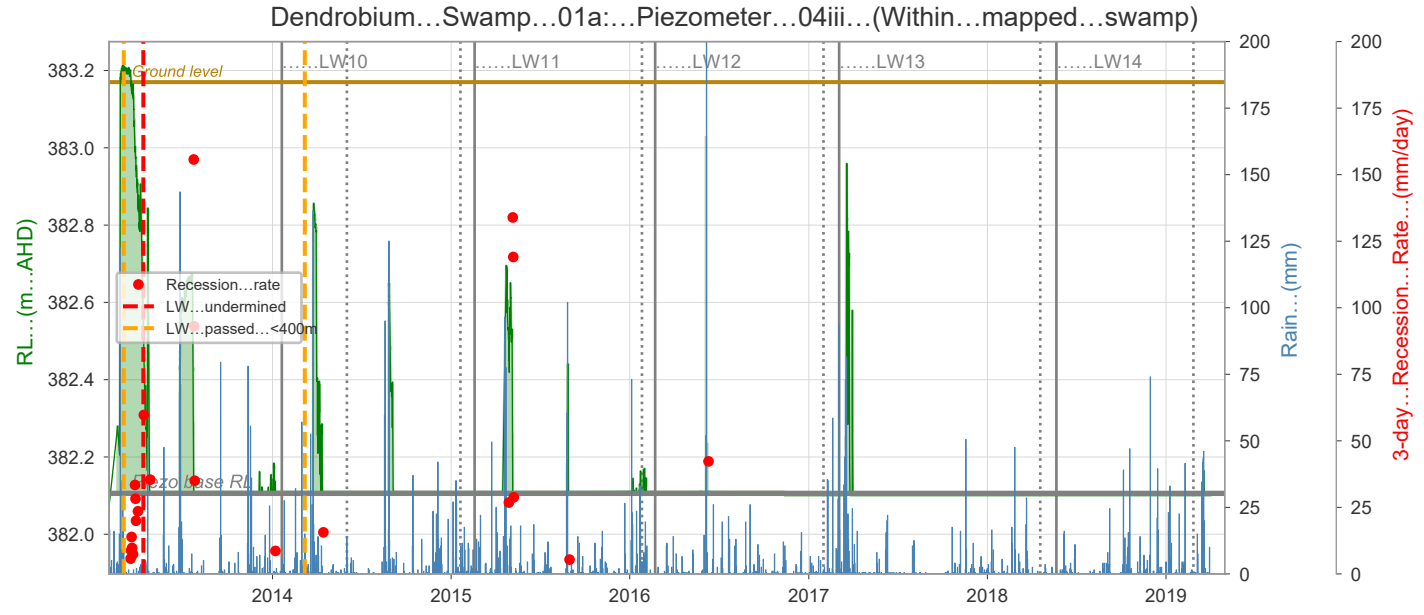

Dendrobium…Swamp…01a:…Piezometer…01…(Within…mapped…swamp)
LW9
LW10
LW11
LW12
LW13
LW14
Ground level
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
399.0
398.5
398.0
397.5
2013
2014
2015
2016
2017
2018
2019

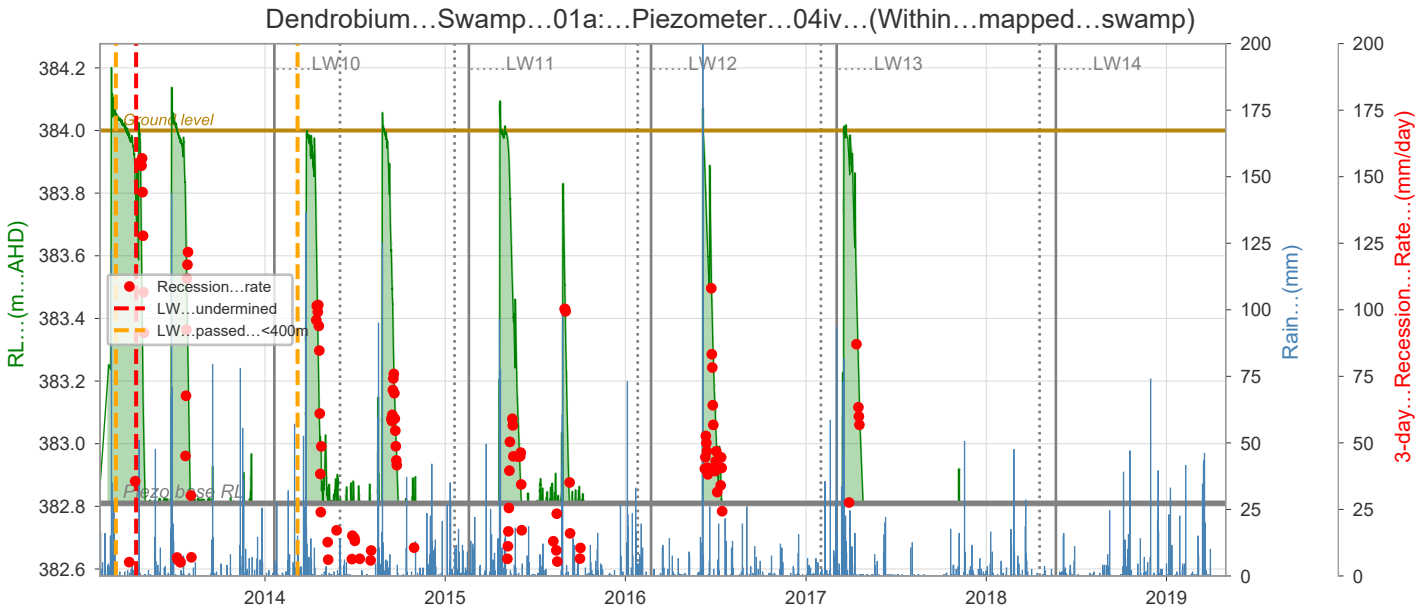

Dendrobium…Swamp…01a:…Piezometer…02…(Within…mapped…swamp)
LW9
LW10
LW11
LW12
LW13
LW14
Ground level
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
364.2
364.0
363.8
363.6
363.4
363.2
363.0
2013
2014
2015
2016
2017
2018
2019

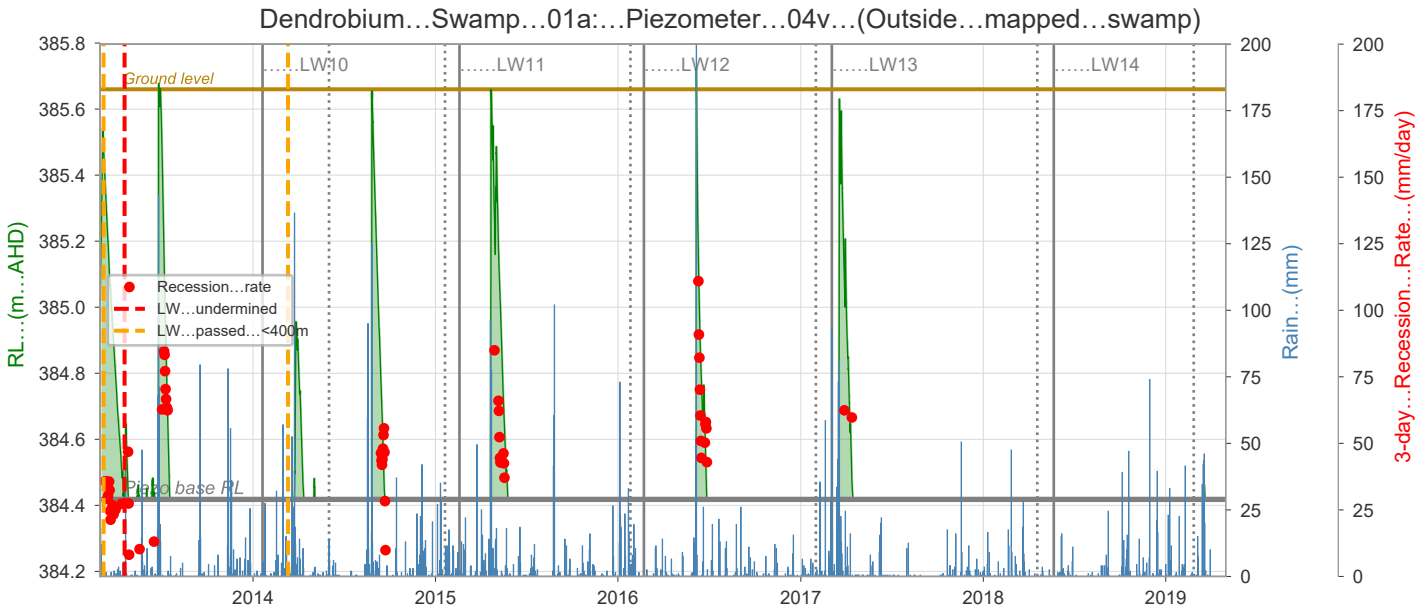

Dendrobium…Swamp…01a:…Piezometer…04…(Within…mapped…swamp)
LW9
LW10
LW11
LW12
LW13
Ground level
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
381.8
381.6
381.4
381.2
381.0
380.8
380.6
2013
2014
2015
2016
2017
2018
2019

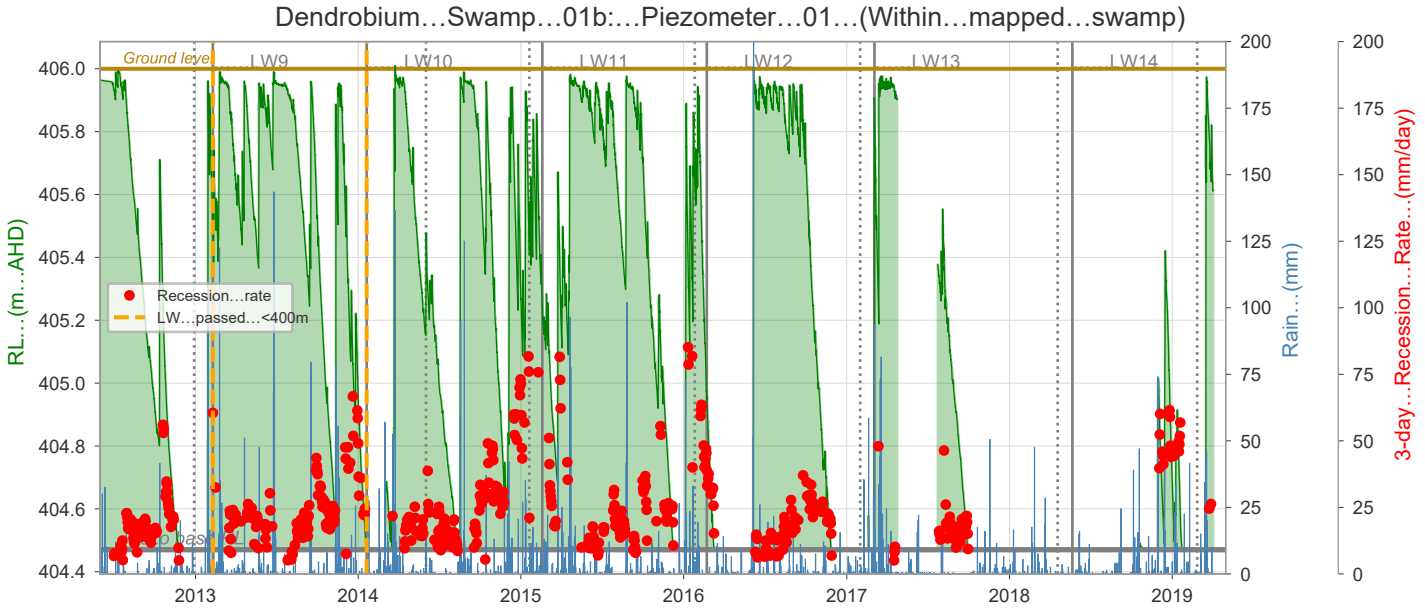

Dendrobium…Swamp…01a:…Piezometer…04i…(Within…mapped…swamp)
LW10
LW11
LW12
LW13
LW14
Ground level
Piezo base RL
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)

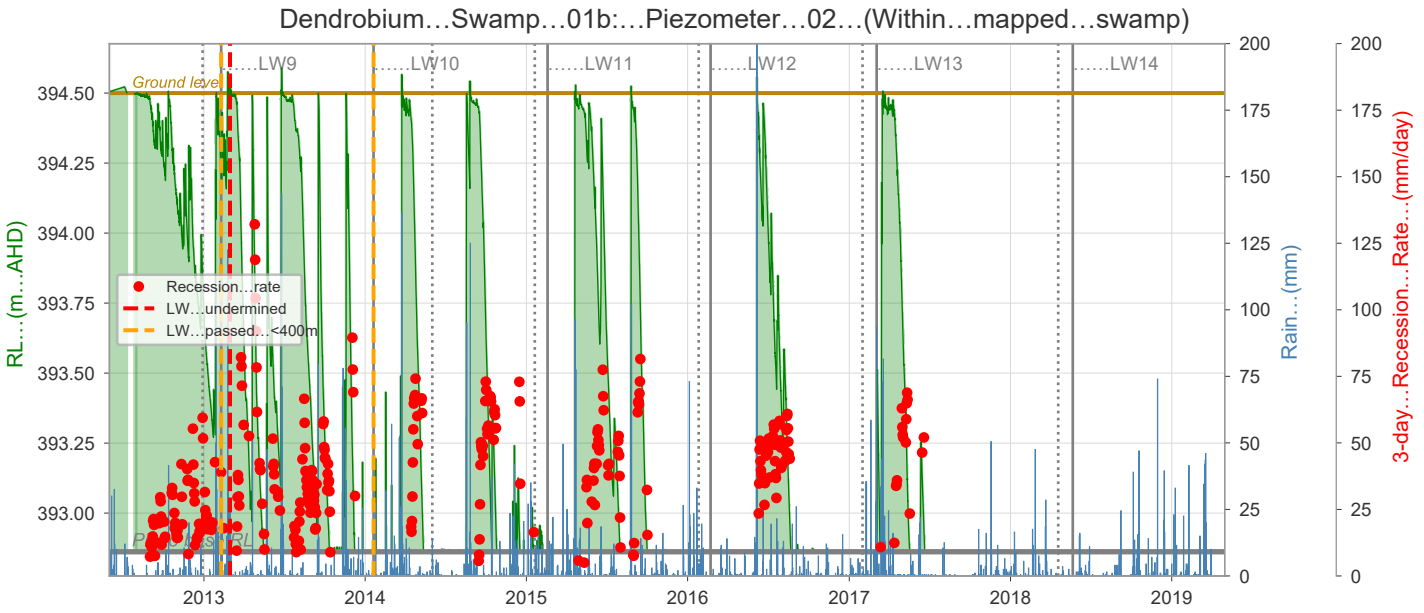

Dendrobium…Swamp…01a:…Piezometer…04ii…(Within…mapped…swamp)
LW10
LW11
LW12
LW13
LW14
Ground level
Piezo base RL
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)

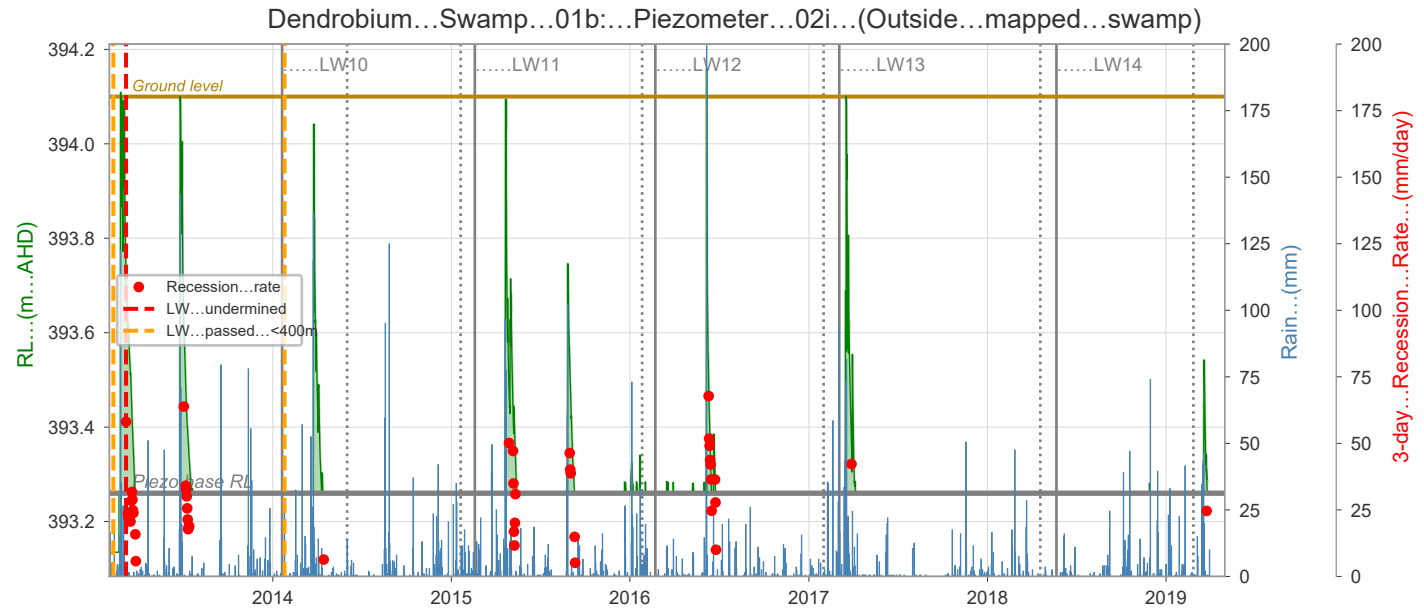

Dendrobium…Swamp…01a:…Piezometer…04iii…(Within…mapped…swamp)
LW10
LW11
LW12
LW13
LW14
Ground level
Piezo base RL
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)

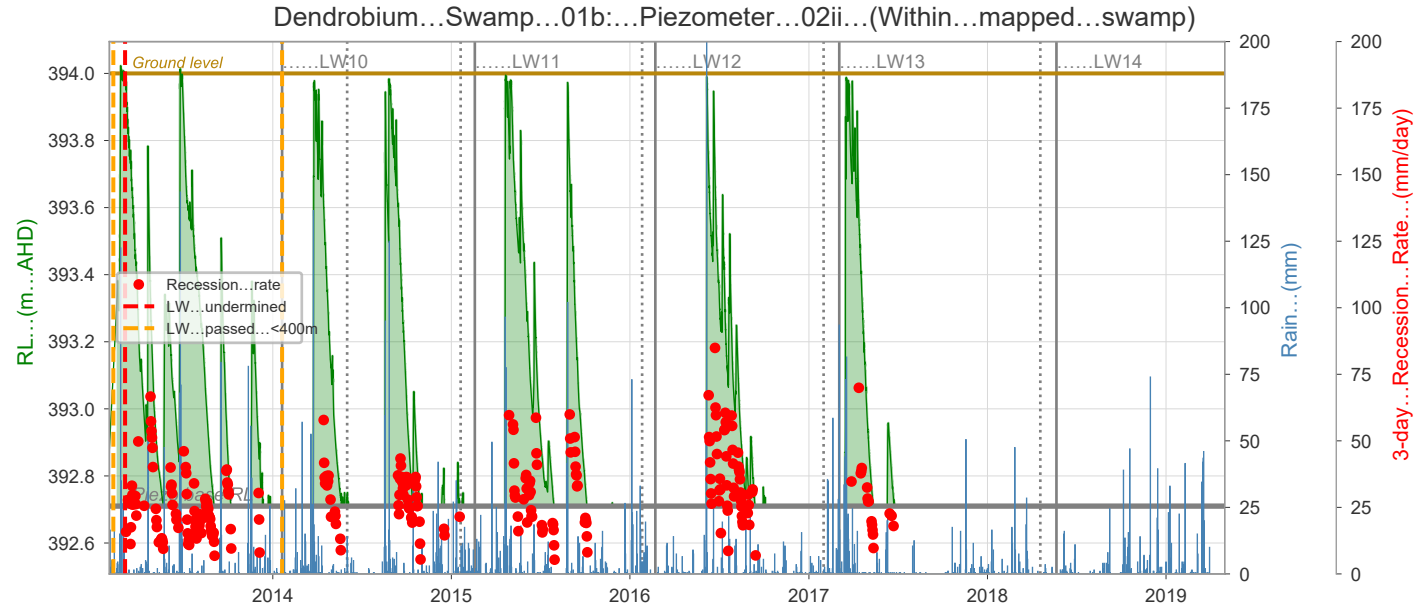

Dendrobium…Swamp…01a:…Piezometer…04iv…(Within…mapped…swamp)
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
Ground level
Piezo base RL
LW10
LW11
LW12
LW13
LW14
Recession…rate
LW…undermined
LW…passed…<400m
384.2
384.0
383.8
383.6
383.4
383.2
383.0
382.8
382.6
200
175
150
125
100
75
50
25
0
2014
2015
2016
2017
2018
2019

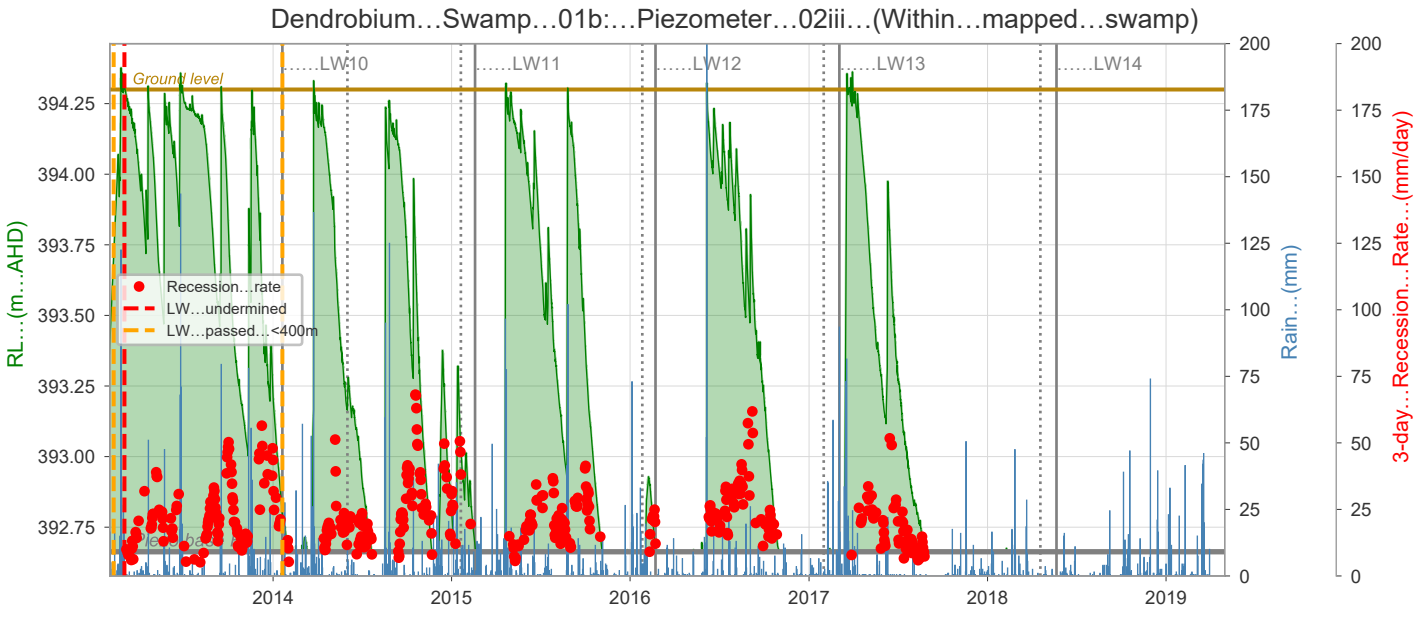

Dendrobium…Swamp…01a:…Piezometer…04v…(Outside…mapped…swamp)
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
Ground level
Piezo base RL
LW10
LW11
LW12
LW13
LW14
Recession…rate
LW…undermined
LW…passed…<400m
385.8
385.6
385.4
385.2
385.0
384.8
384.6
384.4
384.2
200
175
150
125
100
75
50
25
0
2014
2015
2016
2017
2018
2019

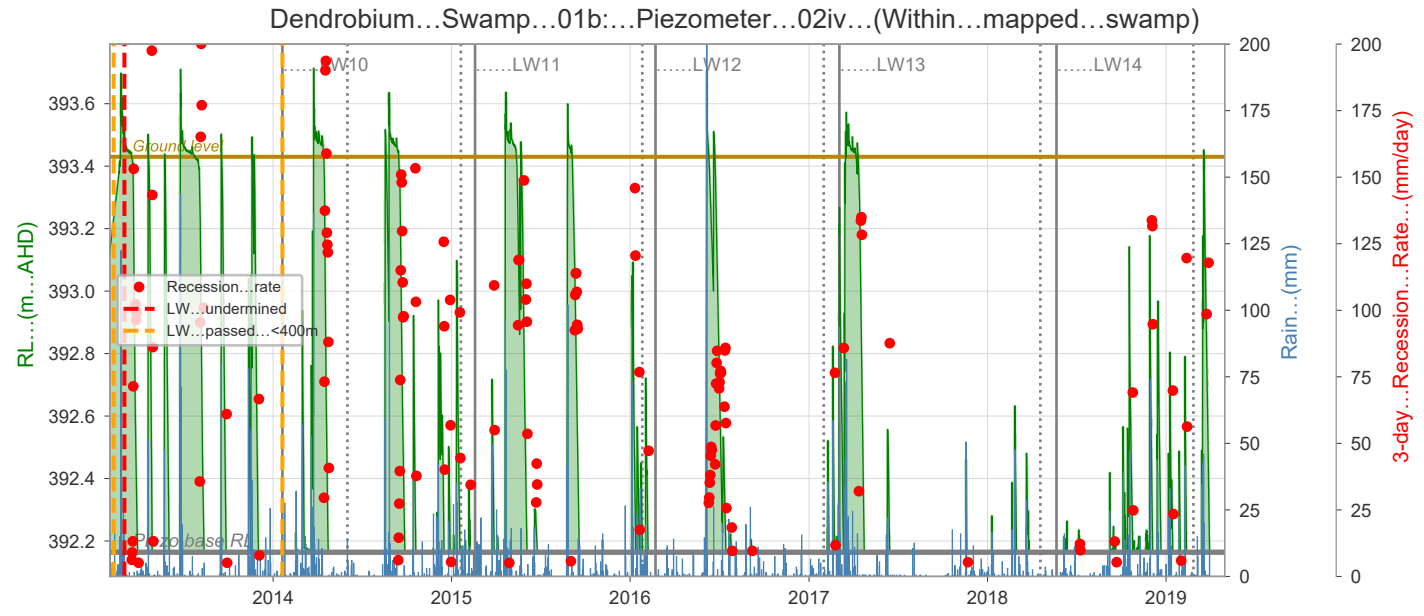

Dendrobium…Swamp…01b:…Piezometer…01…(Within…mapped…swamp)
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
Ground level
LW9
LW10
LW11
LW12
LW13
LW14
Recession…rate
LW…passed…<400m
406.0
405.8
405.6
405.4
405.2
405.0
404.8
404.6
404.4
200
175
150
125
100
75
50
25
0
2013
2014
2015
2016
2017
2018
2019

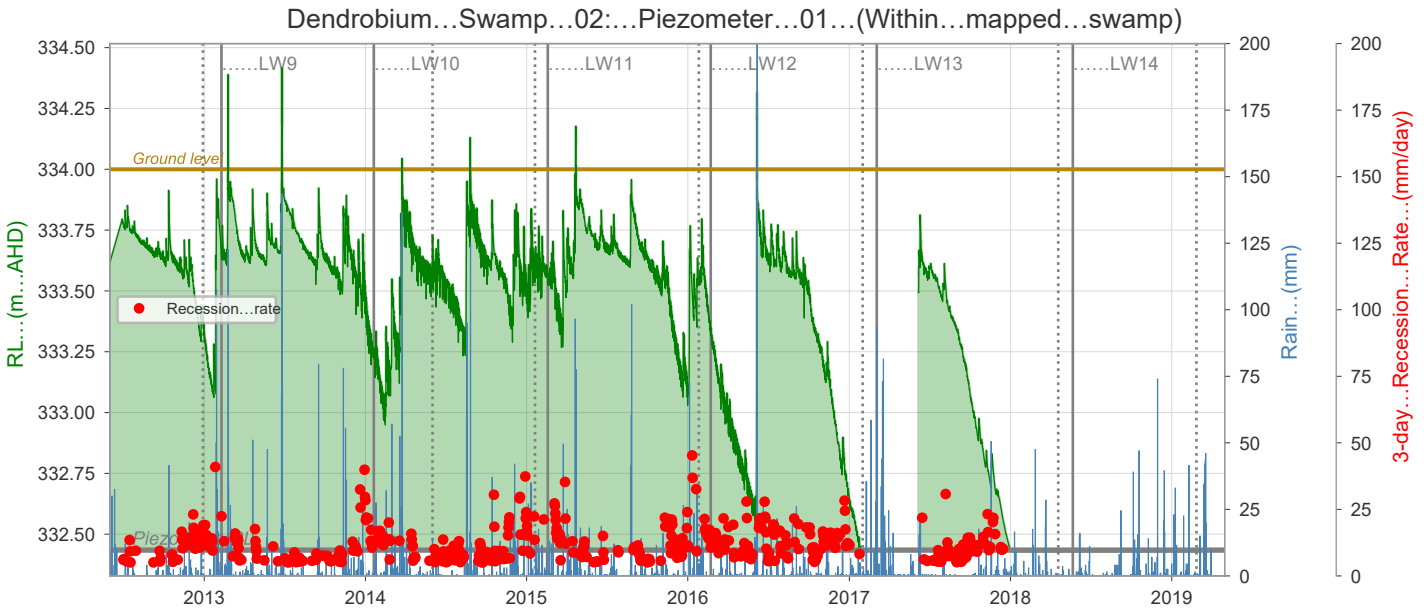

Dendrobium…Swamp…01b:…Piezometer…02…(Within…mapped…swamp)
Ground level
LW9
LW10
LW11
LW12
LW13
LW14
Recession…rate
LW…undermined
LW…passed…<400m
Piezo base RL
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
394.50
394.25
394.00
393.75
393.50
393.25
393.00
200
175
150
125
100
75
50
25
0
2013
2014
2015
2016
2017
2018
2019

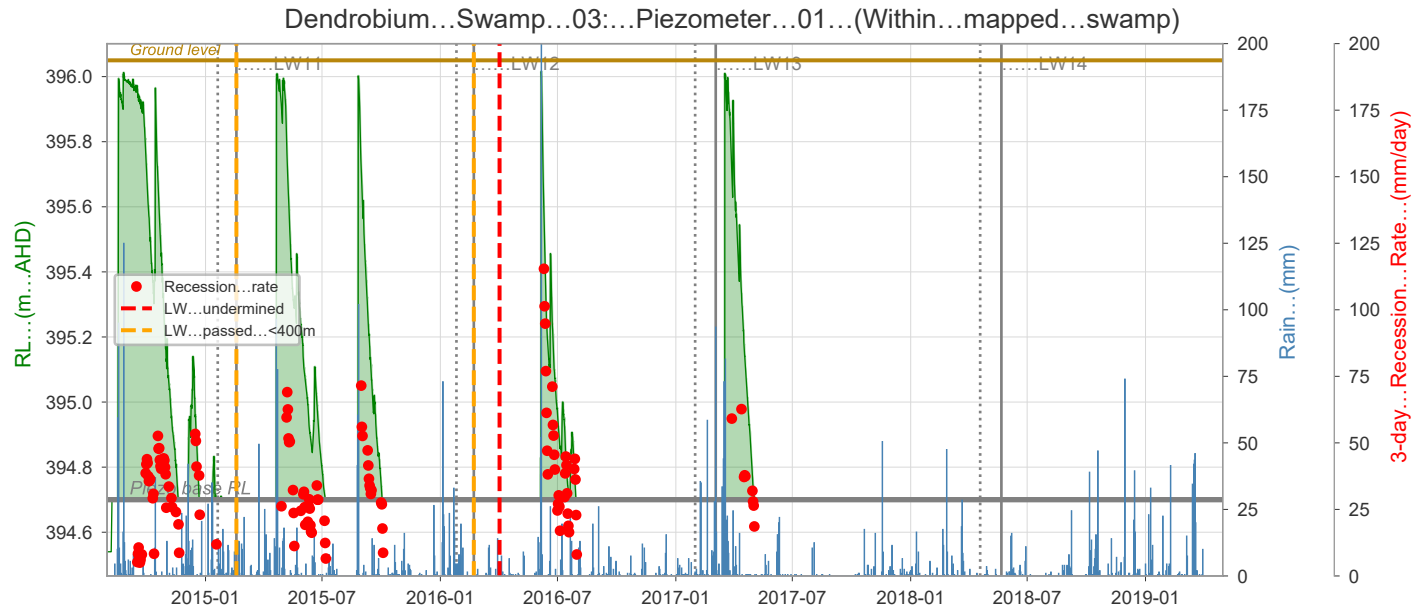

Dendrobium…Swamp…01b:…Piezometer…02i…(Outside…mapped…swamp)
Ground level
LW10
LW11
LW12
LW13
LW14
Recession…rate
LW…undermined
LW…passed…<400m
Piezo base RL
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
394.2
394.0
393.8
393.6
393.4
393.2
200
175
150
125
100
75
50
25
0
2014
2015
2016
2017
2018
2019

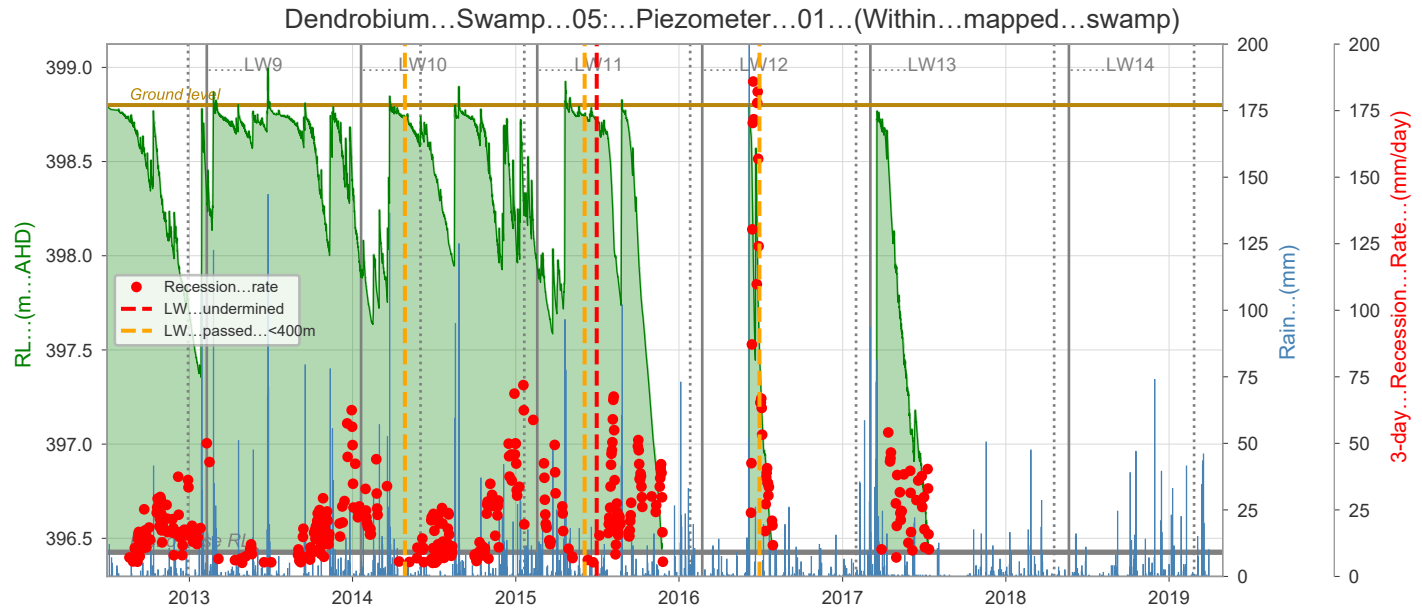

Dendrobium…Swamp…01b:…Piezometer…02ii…(Within…mapped…swamp)
Ground level
LW10
LW11
LW12
LW13
LW14
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
394.0
393.8
393.6
393.4
393.2
393.0
392.8
392.6
200
175
150
125
100
75
50
25
0
2014
2015
2016
2017
2018
2019

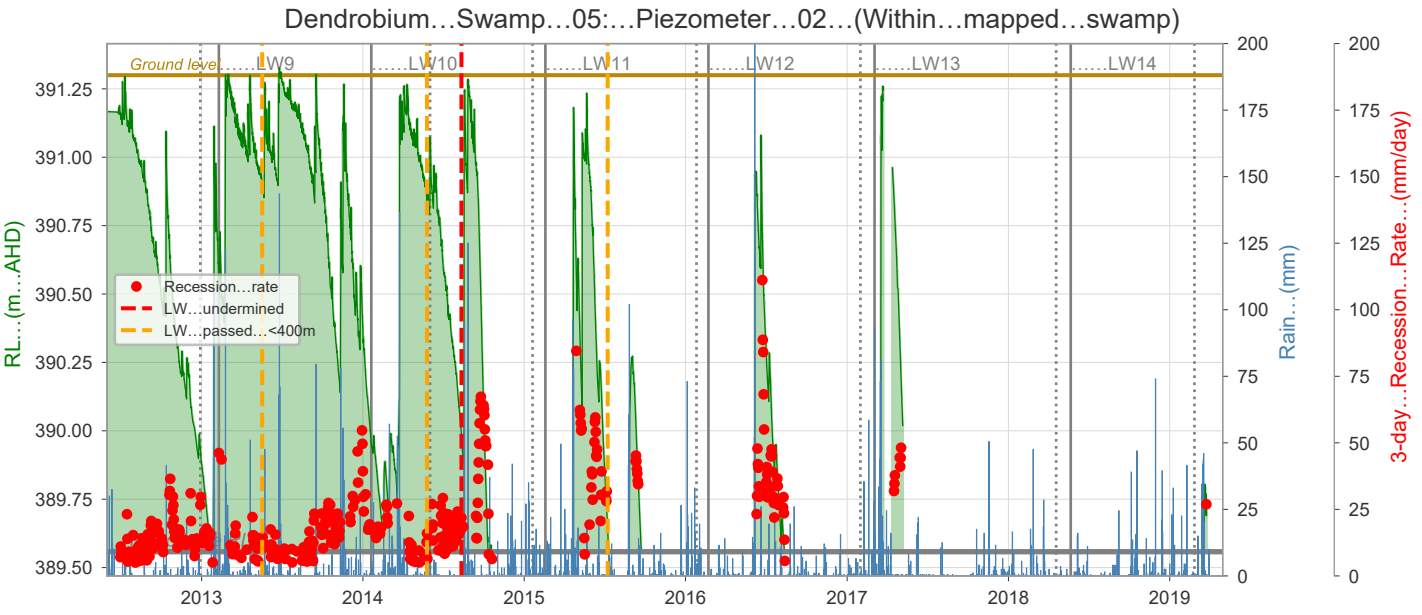

Dendrobium…Swamp…01b:…Piezometer…02iii…(Within…mapped…swamp)
Ground level
LW10
LW11
LW12
LW13
LW14
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)

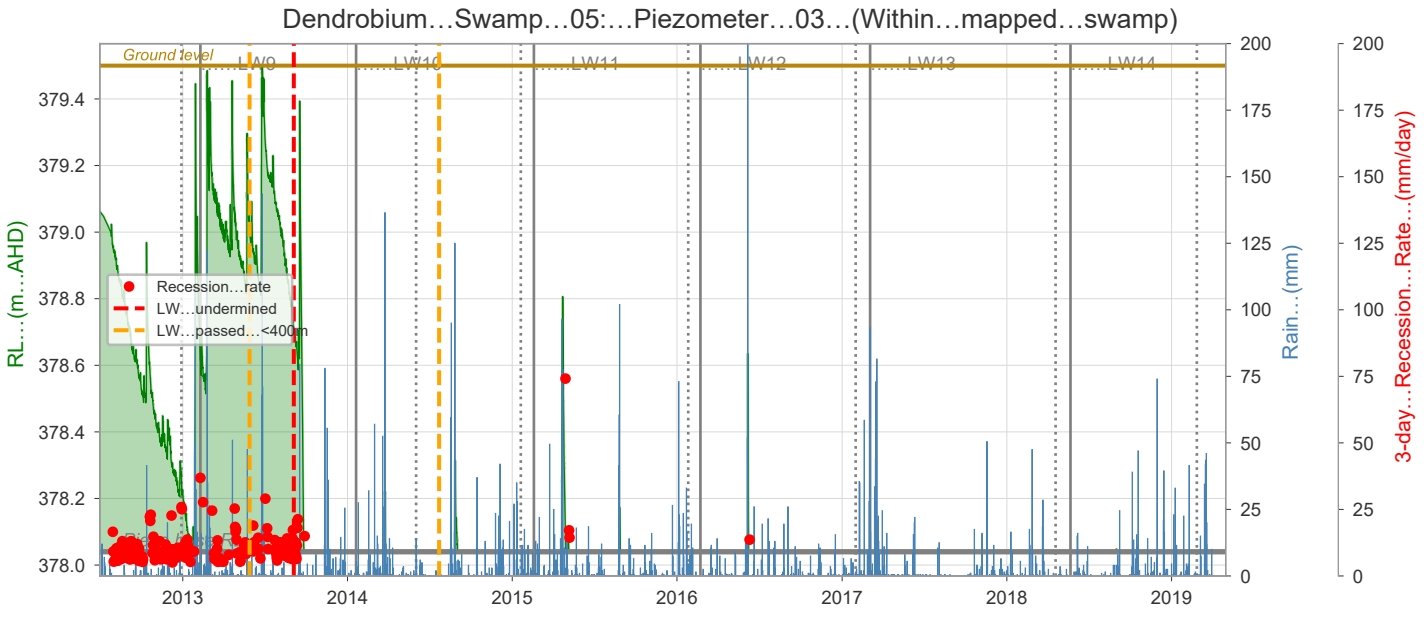

Dendrobium…Swamp…01b:…Piezometer…02iv…(Within…mapped…swamp)
Ground level
LW10
LW11
LW12
LW13
LW14
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)

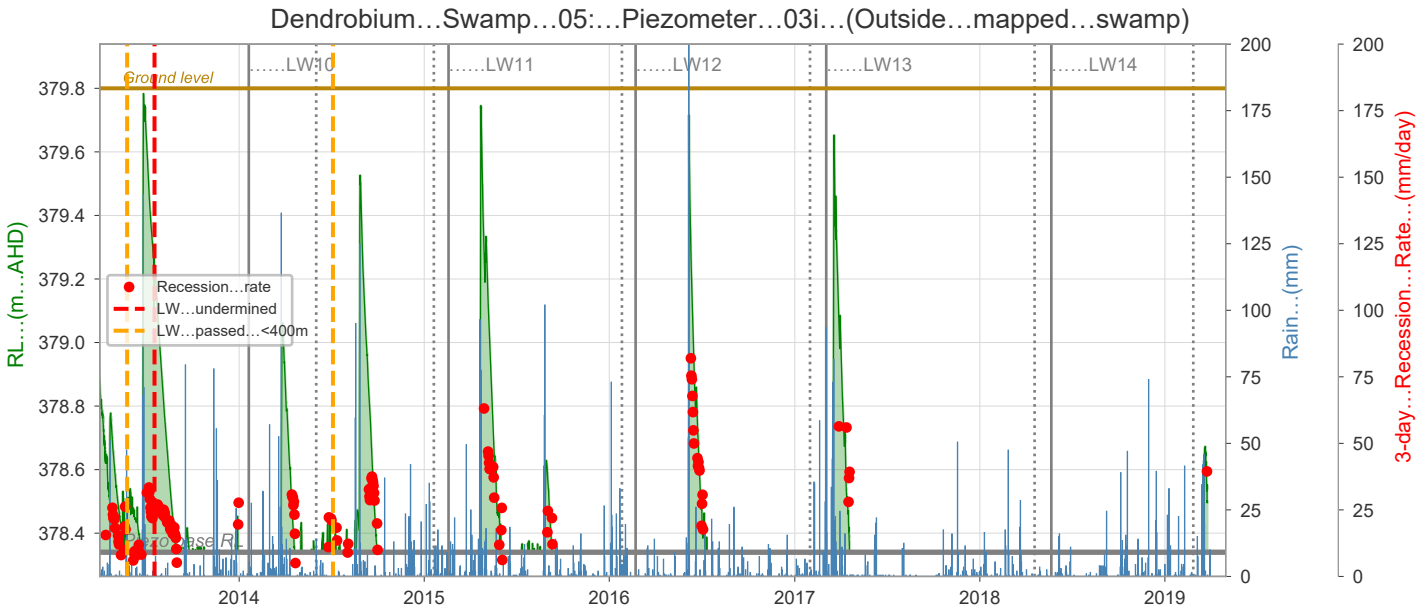

Dendrobium…Swamp…02:…Piezometer…01…(Within…mapped…swamp)
Ground level
LW9
LW10
LW11
LW12
LW13
LW14
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)

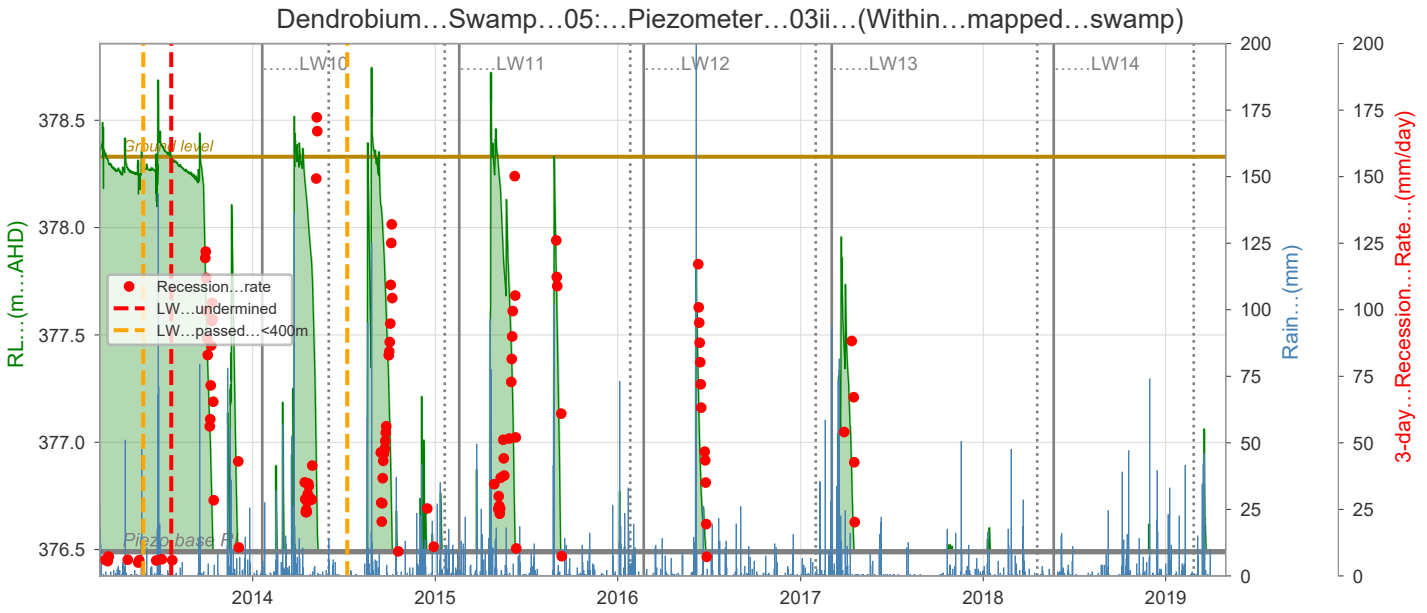

Dendrobium…Swamp…03:…Piezometer…01…(Within…mapped…swamp)
Ground level
LW11
LW12
LW13
LW14
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)

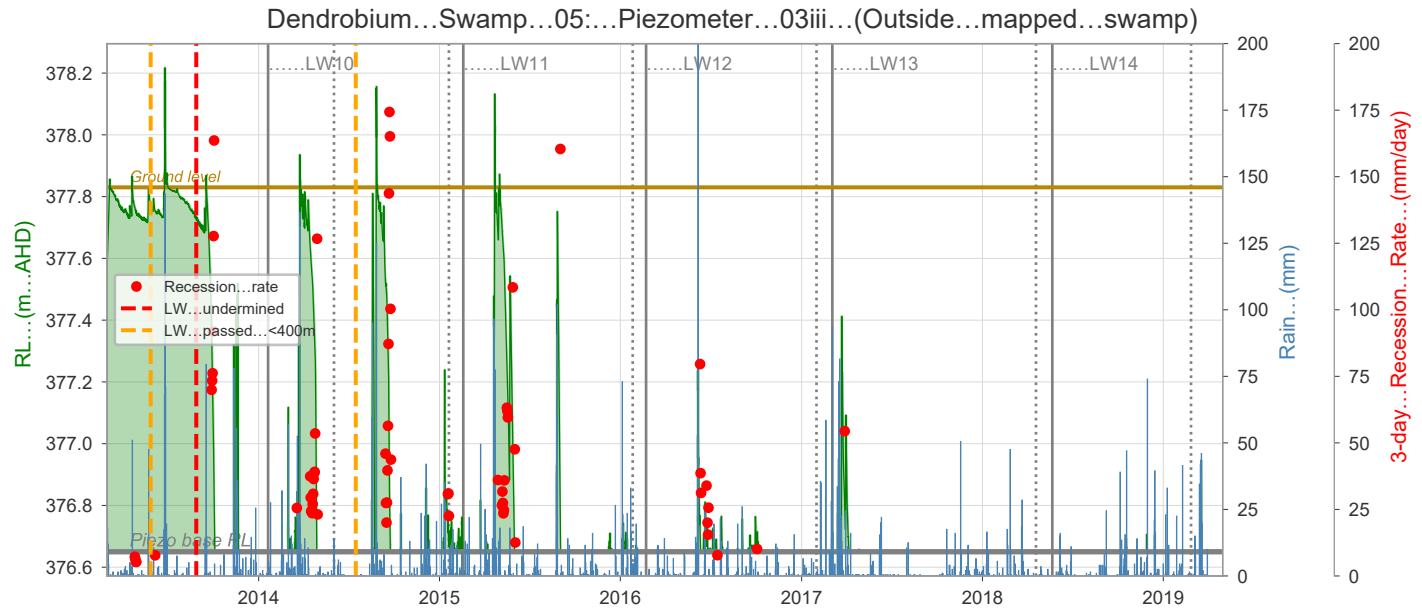

Dendrobium…Swamp…05:…Piezometer…01…(Within…mapped…swamp)
LW9
LW10
LW11
LW12
LW13
LW14
Ground level
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)

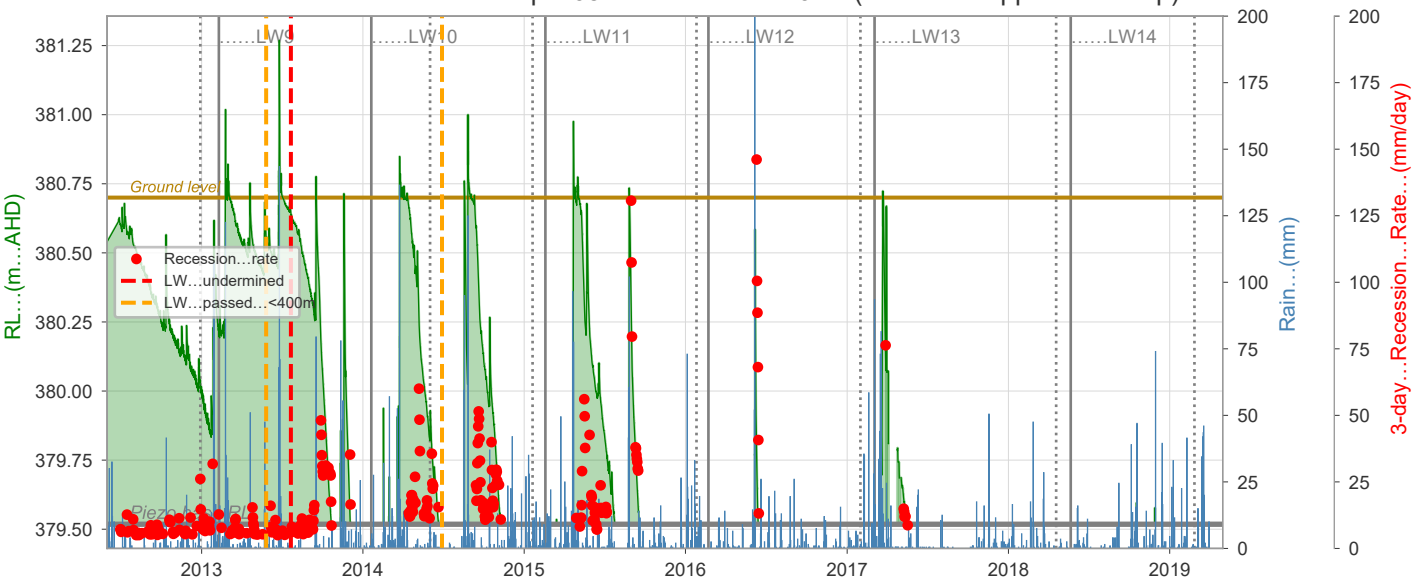

Dendrobium…Swamp…05:…Piezometer…02…(Within…mapped…swamp)
Ground level
LW9
LW10
LW11
LW12
LW13
LW14
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)

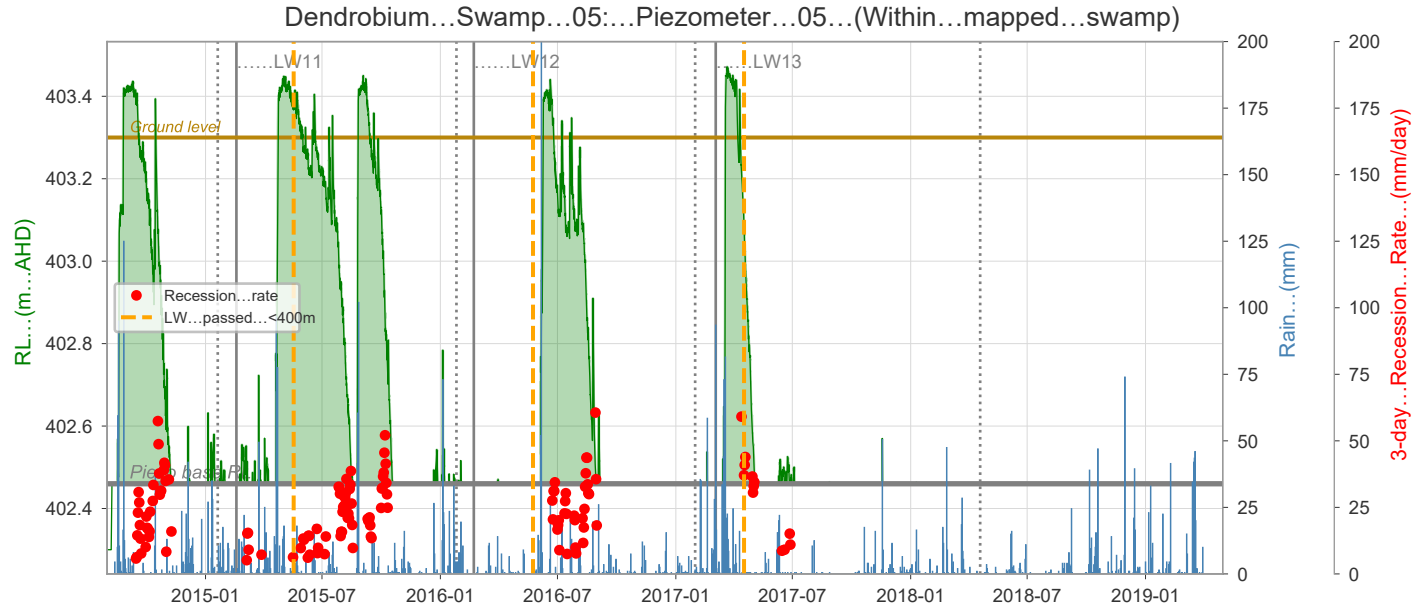

Dendrobium…Swamp…05:…Piezometer…03…(Within…mapped…swamp)
Ground level
LW9
LW10
LW11
LW12
LW13
LW14
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)

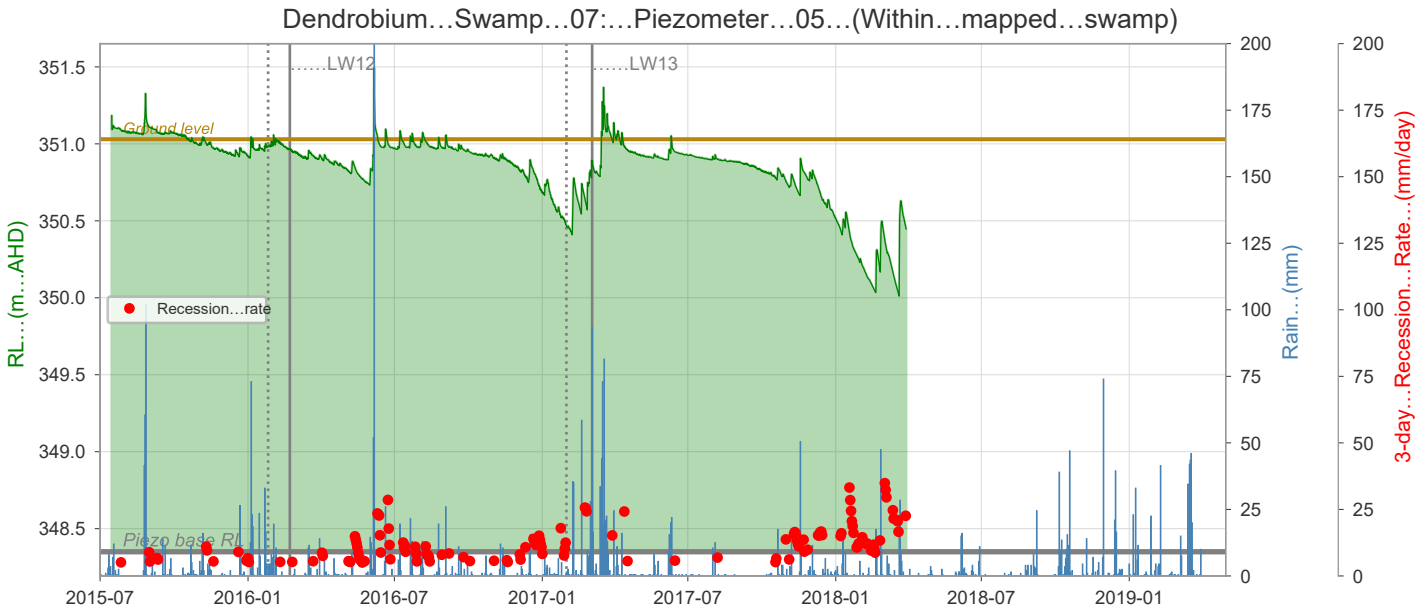

Dendrobium…Swamp…05:…Piezometer…03i…(Outside…mapped…swamp)
Ground level
LW10
LW11
LW12
LW13
LW14
Recession…rate
LW…undermined
LW…passed…<400m
Piezo base RL
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)

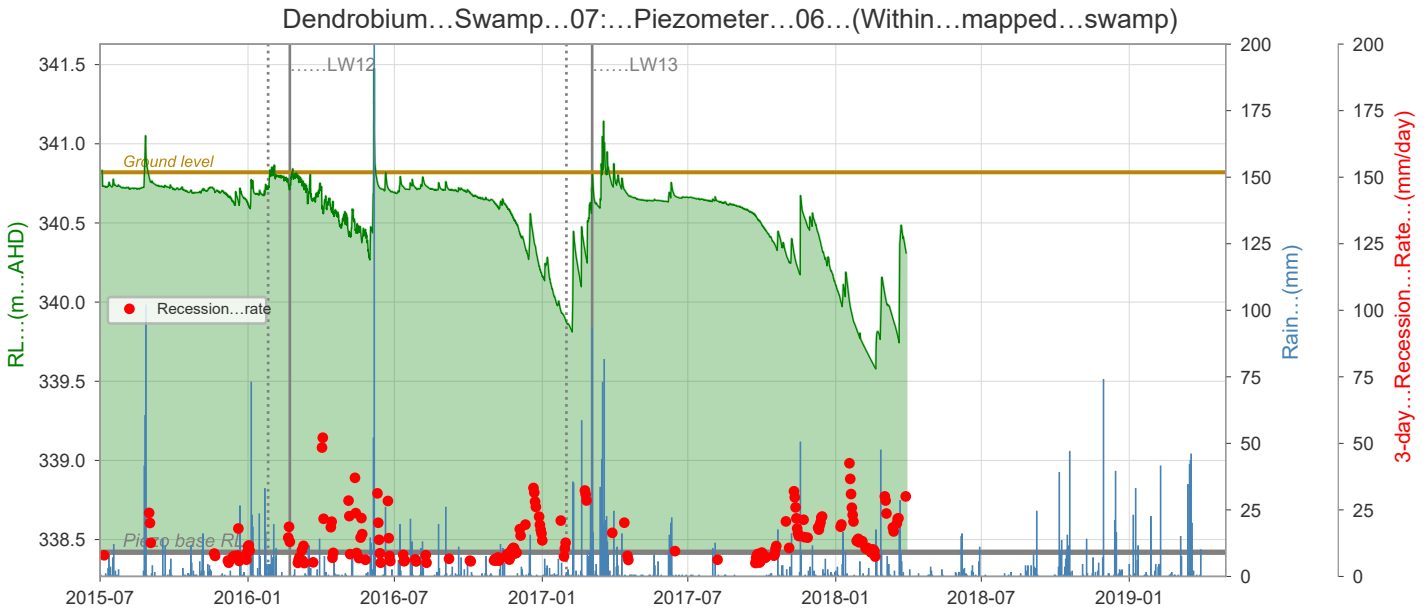

Dendrobium…Swamp…05:…Piezometer…03ii…(Within…mapped…swamp)
Ground level
LW10
LW11
LW12
LW13
LW14
Recession…rate
LW…undermined
LW…passed…<400m
Piezo base RL
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)

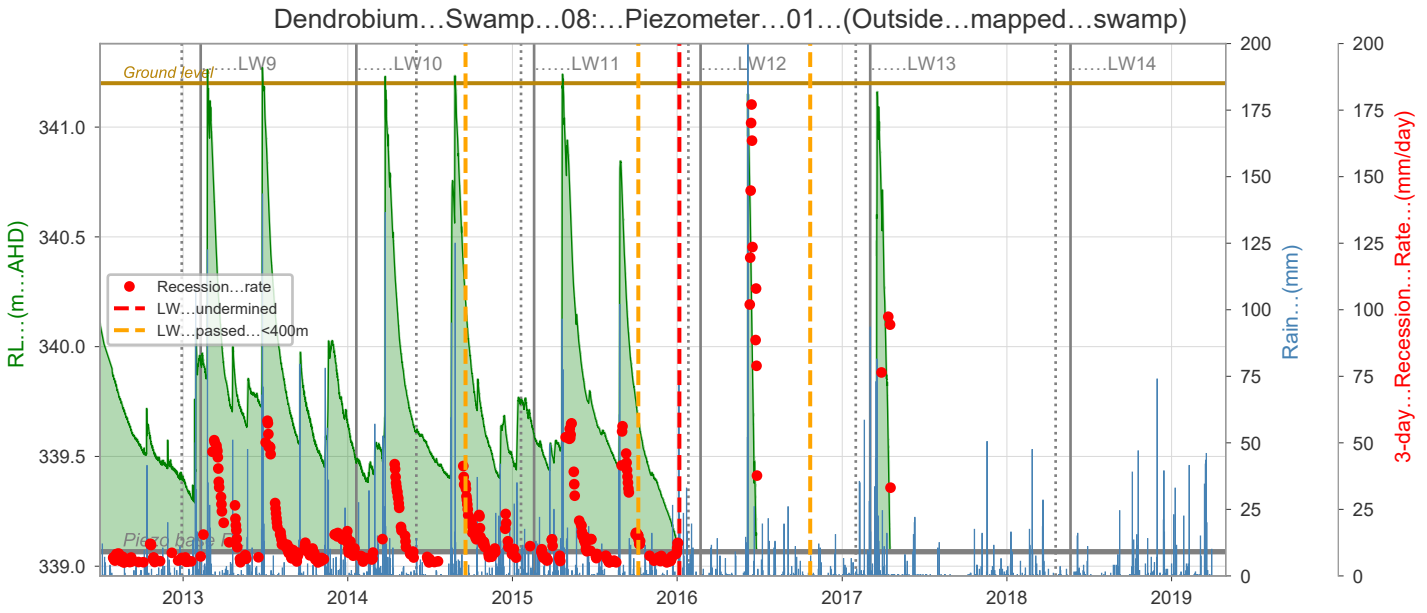

Dendrobium…Swamp…05:…Piezometer…03iii…(Outside…mapped…swamp)
LW10
LW11
LW12
LW13
LW14
Ground level
Piezo base RL
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
2014
2015
2016
2017
2018
2019

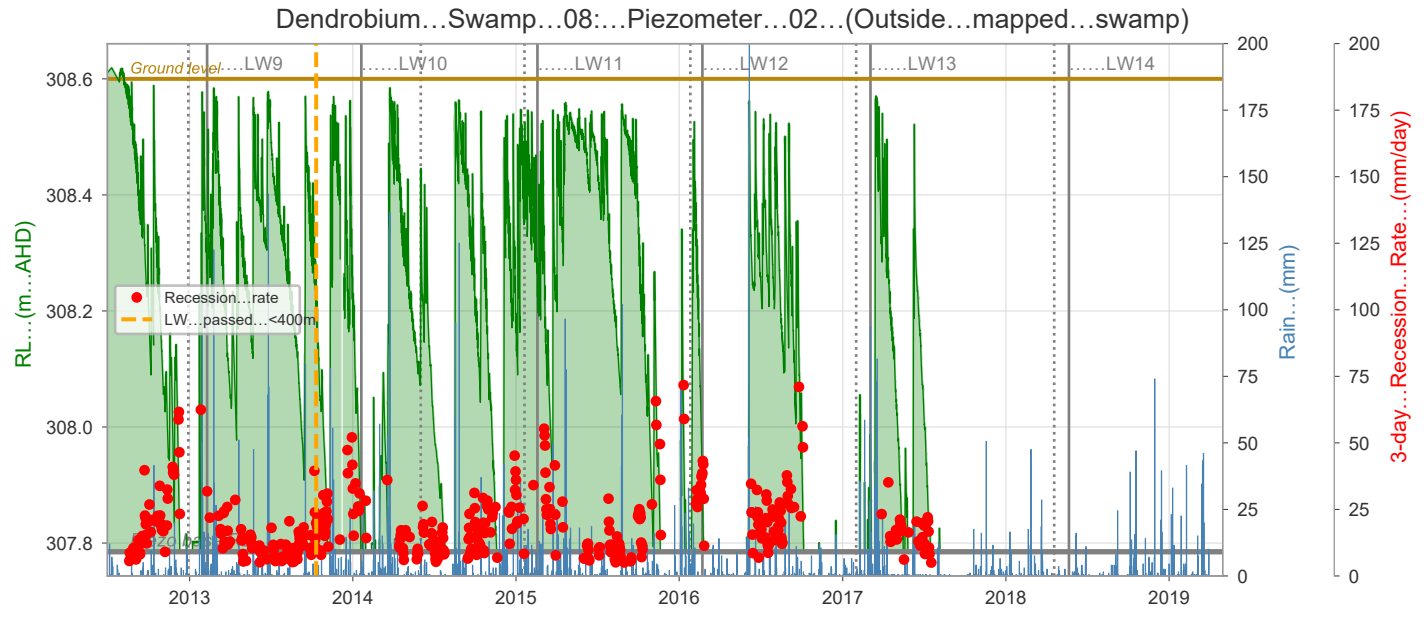

Dendrobium…Swamp…05:…Piezometer…04…(Within…mapped…swamp)
LW9
LW10
LW11
LW12
LW13
LW14
Ground level
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
2013
2014
2015
2016
2017
2018
2019

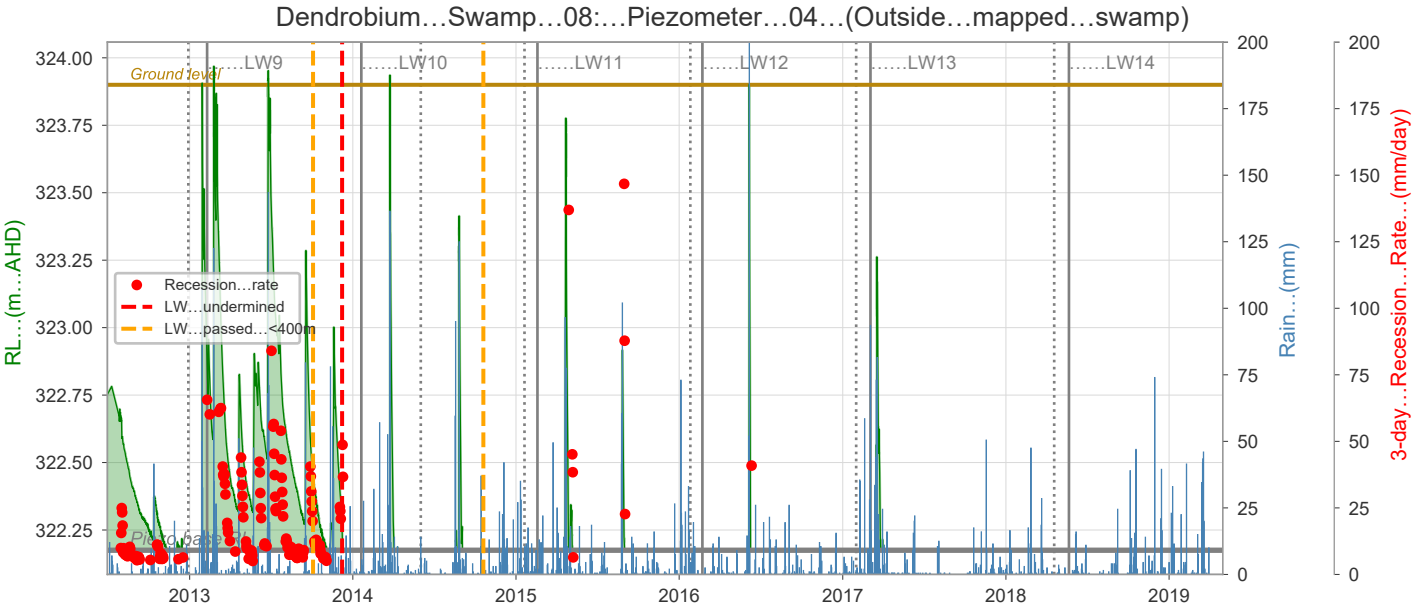

Dendrobium…Swamp…05:…Piezometer…05…(Within…mapped…swamp)
LW11
LW12
LW13
Ground level
Recession…rate
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
2015-01
2015-07
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01

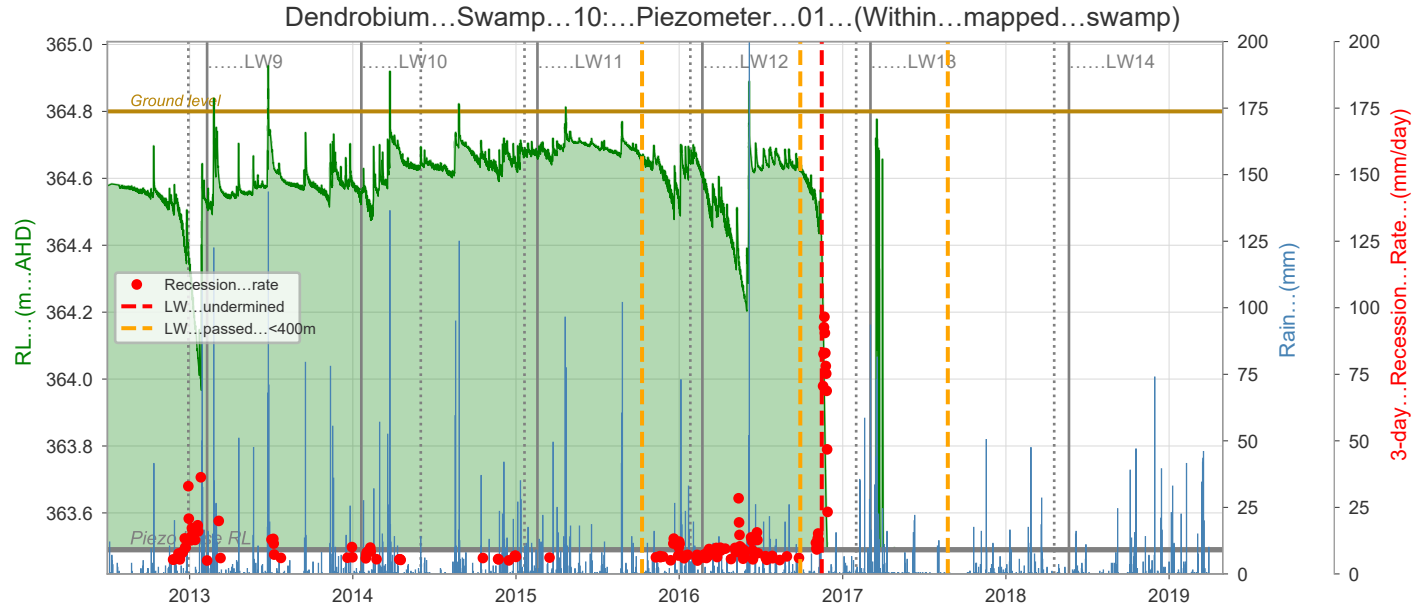

Dendrobium…Swamp…07:…Piezometer…05…(Within…mapped…swamp)
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
Ground level
Piezo base RL
Recession…rate
LW12
LW13
2015-07
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01

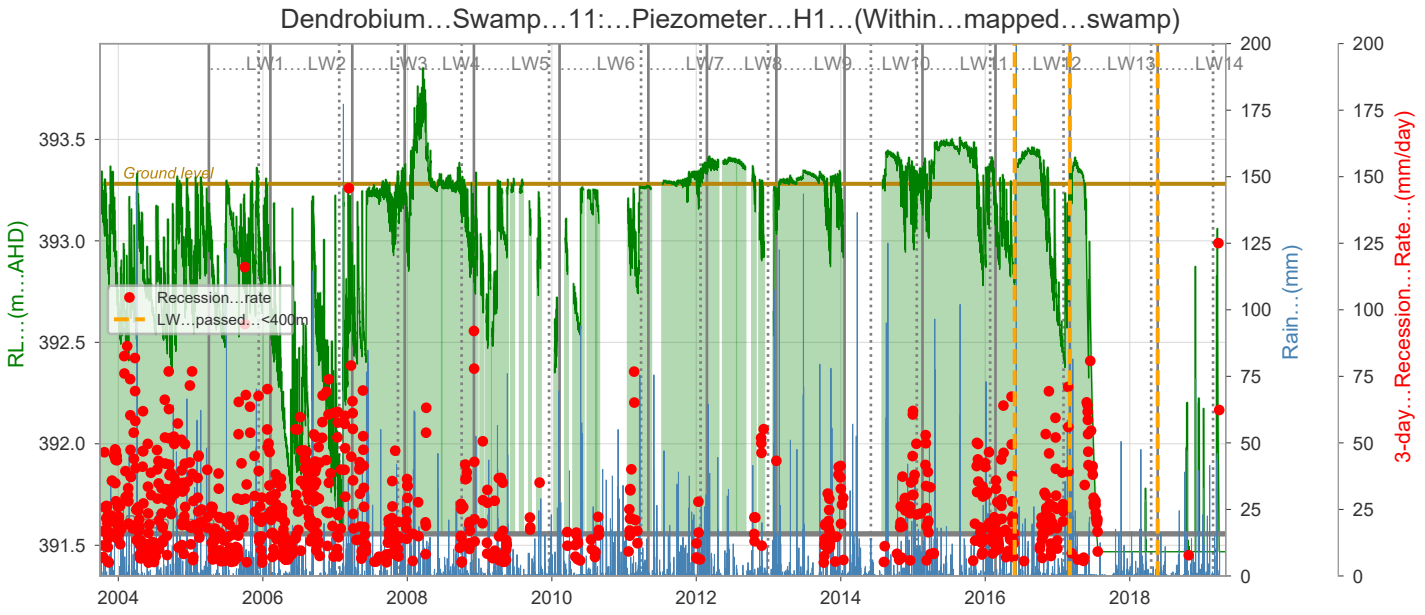

Dendrobium…Swamp…07:…Piezometer…06…(Within…mapped…swamp)
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
Ground level
Piezo base RL
Recession…rate
LW12
LW13
2015-07
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01

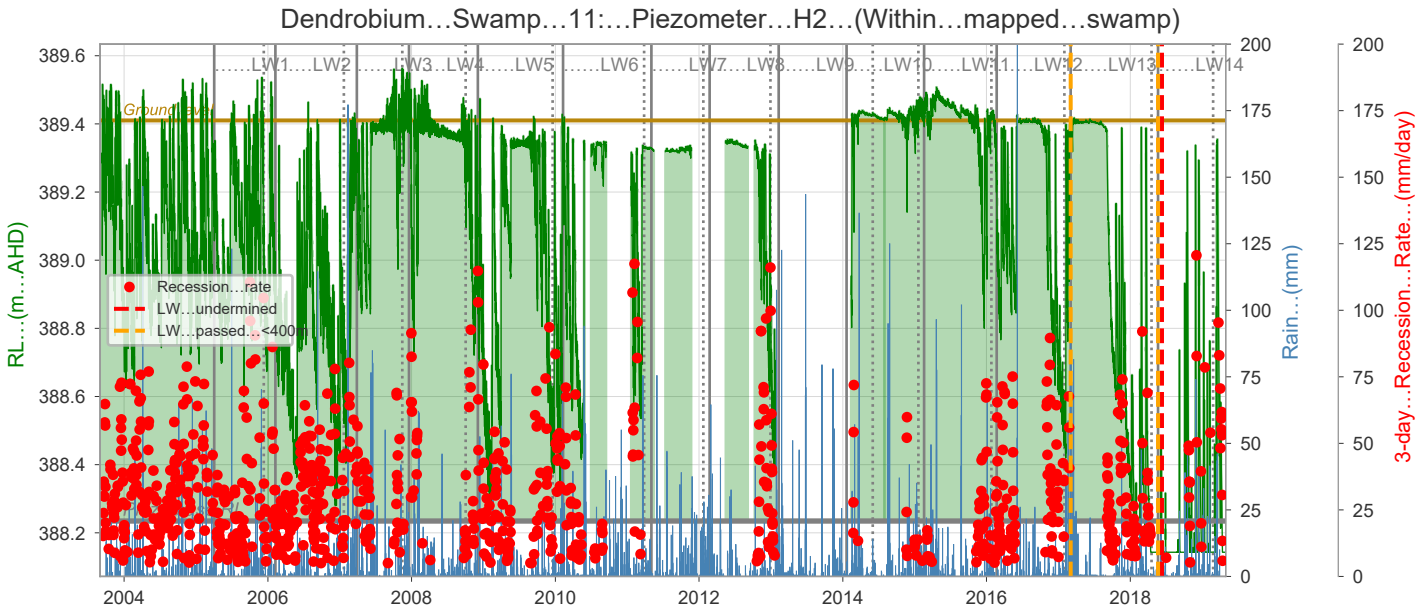

Dendrobium…Swamp…08:…Piezometer…01…(Outside…mapped…swamp)
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
Ground level
Piezo base RL
Recession…rate
LW…undermined
LW…passed…<400m
LW9
LW10
LW11
LW12
LW13
LW14
2013
2014
2015
2016
2017
2018
2019

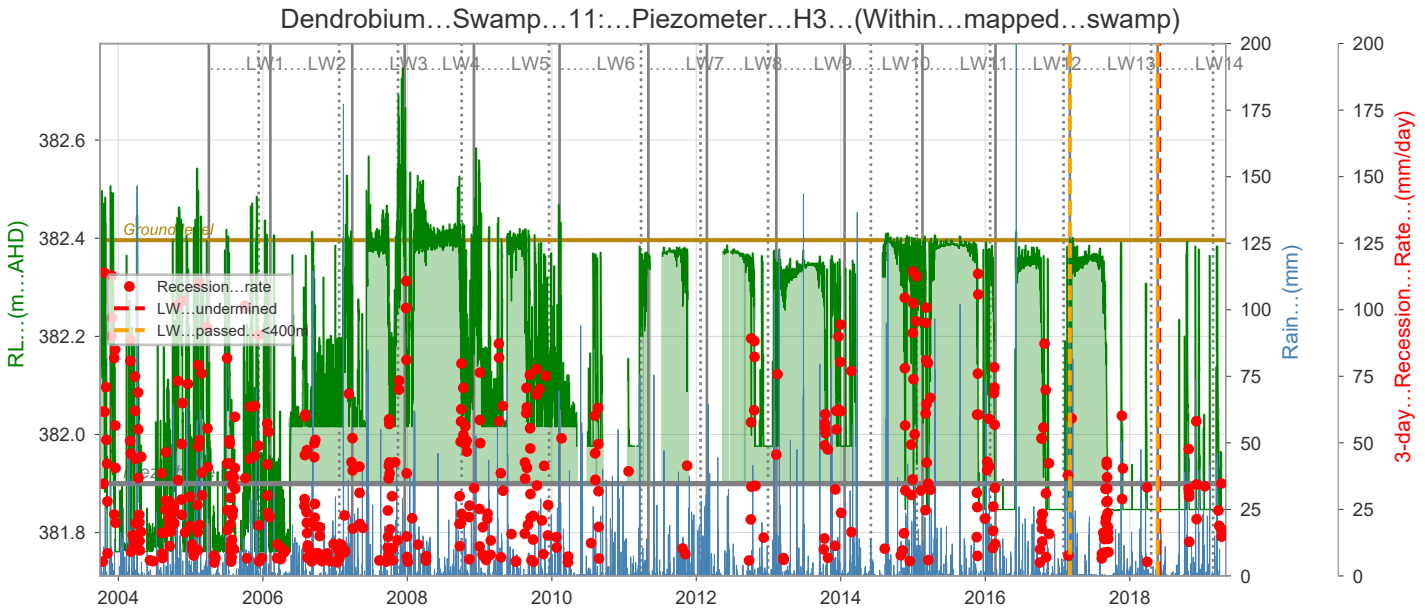

Dendrobium…Swamp…08:…Piezometer…02…(Outside…mapped…swamp)
Ground level
LW9
LW10
LW11
LW12
LW13
LW14
Recession…rate
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
Piezo base RL
308.6
308.4
308.2
308.0
307.8
2013
2014
2015
2016
2017
2018
2019

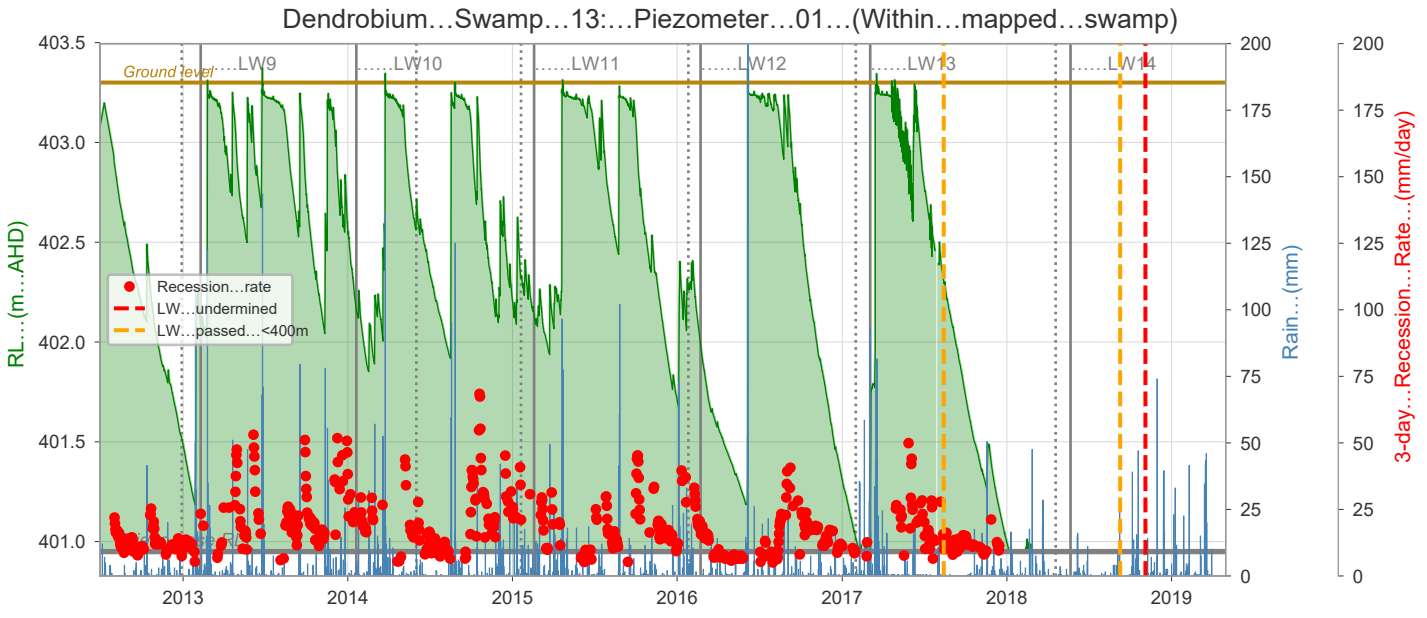

Dendrobium…Swamp…08:…Piezometer…04…(Outside…mapped…swamp)
Ground level
LW9
LW10
LW11
LW12
LW13
LW14
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
Piezo base RL
324.00
323.75
323.50
323.25
323.00
322.75
322.50
322.25
2013
2014
2015
2016
2017
2018
2019

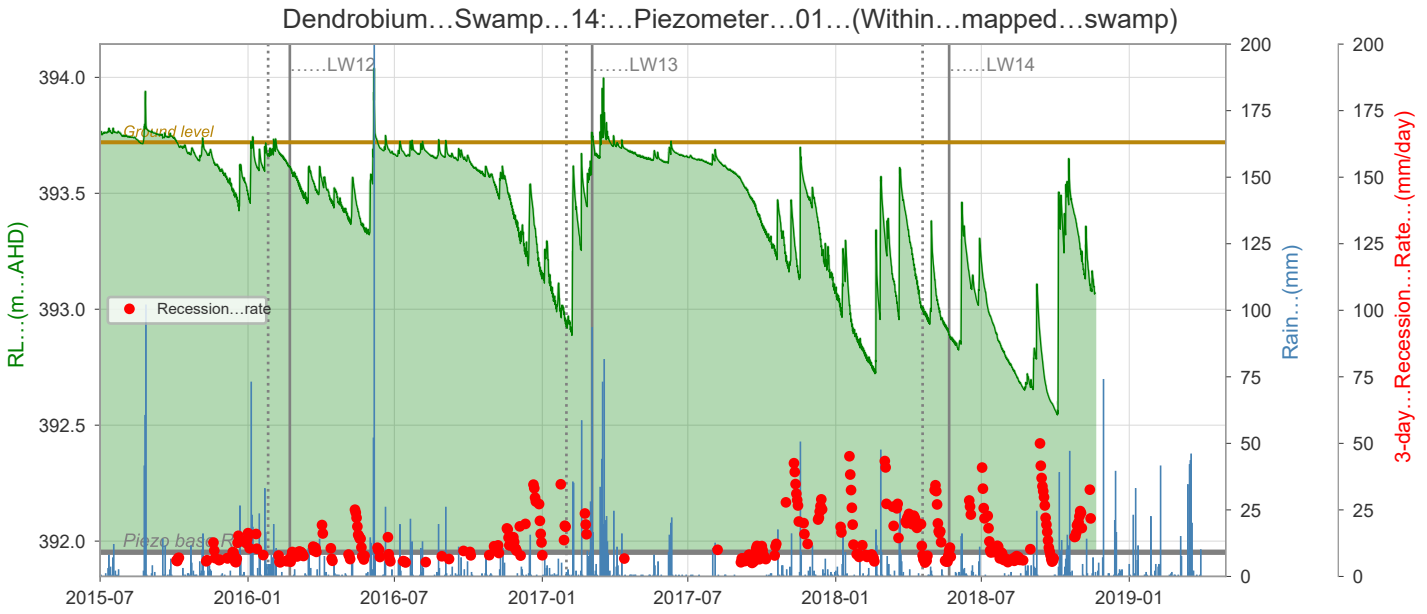

Dendrobium…Swamp…10:…Piezometer…01…(Within…mapped…swamp)
Ground level
LW9
LW10
LW11
LW12
LW13
LW14
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
Piezo base RL
365.0
364.8
364.6
364.4
364.2
364.0
363.8
363.6
2013
2014
2015
2016
2017
2018
2019

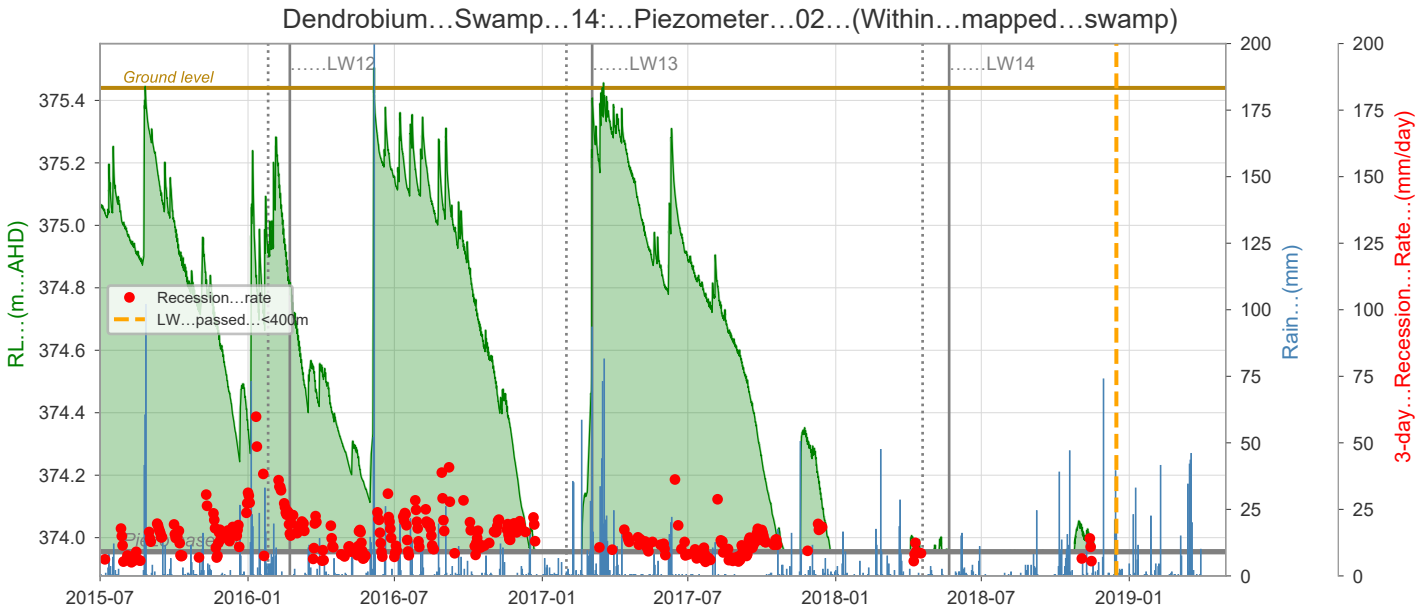

Dendrobium…Swamp…11:…Piezometer…H1…(Within…mapped…swamp)
LW1
LW2
LW3
LW4
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
Ground level
Recession…rate
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
393.5
393.0
392.5
392.0
391.5
200
175
150
125
100
75
50
25
0
2004
2006
2008
2010
2012
2014
2016
2018

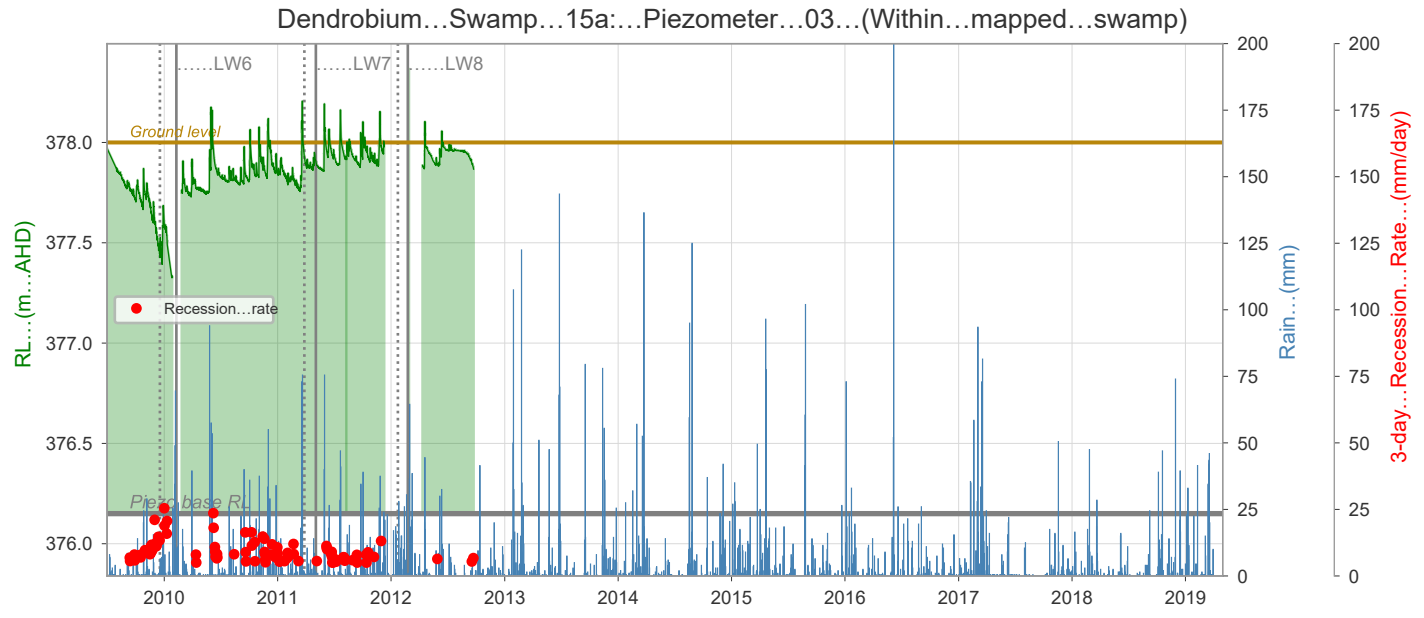

Dendrobium…Swamp…11:…Piezometer…H2…(Within…mapped…swamp)
LW1
LW2
LW3
LW4
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
Ground level
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
389.6
389.4
389.2
389.0
388.8
388.6
388.4
388.2
200
175
150
125
100
75
50
25
0
2004
2006
2008
2010
2012
2014
2016
2018

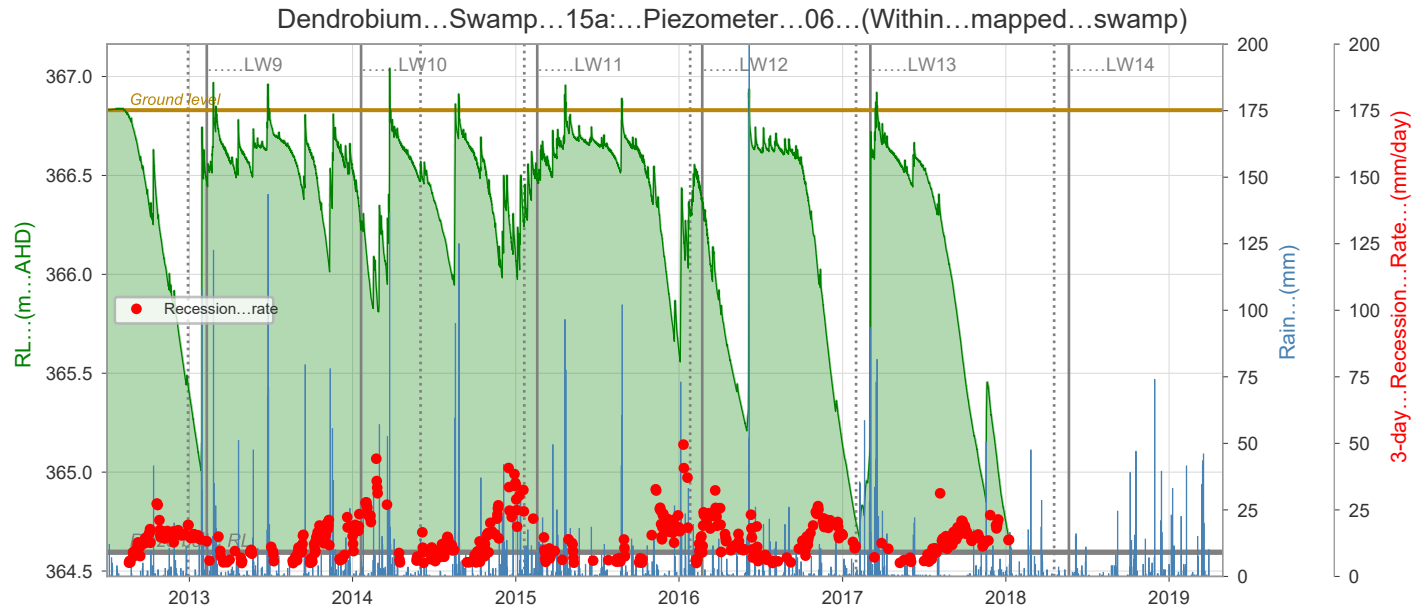

Dendrobium…Swamp…11:…Piezometer…H3…(Within…mapped…swamp)
LW1
LW2
LW3
LW4
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
Ground level
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
382.6
382.4
382.2
382.0
381.8
200
175
150
125
100
75
50
25
0
2004
2006
2008
2010
2012
2014
2016
2018

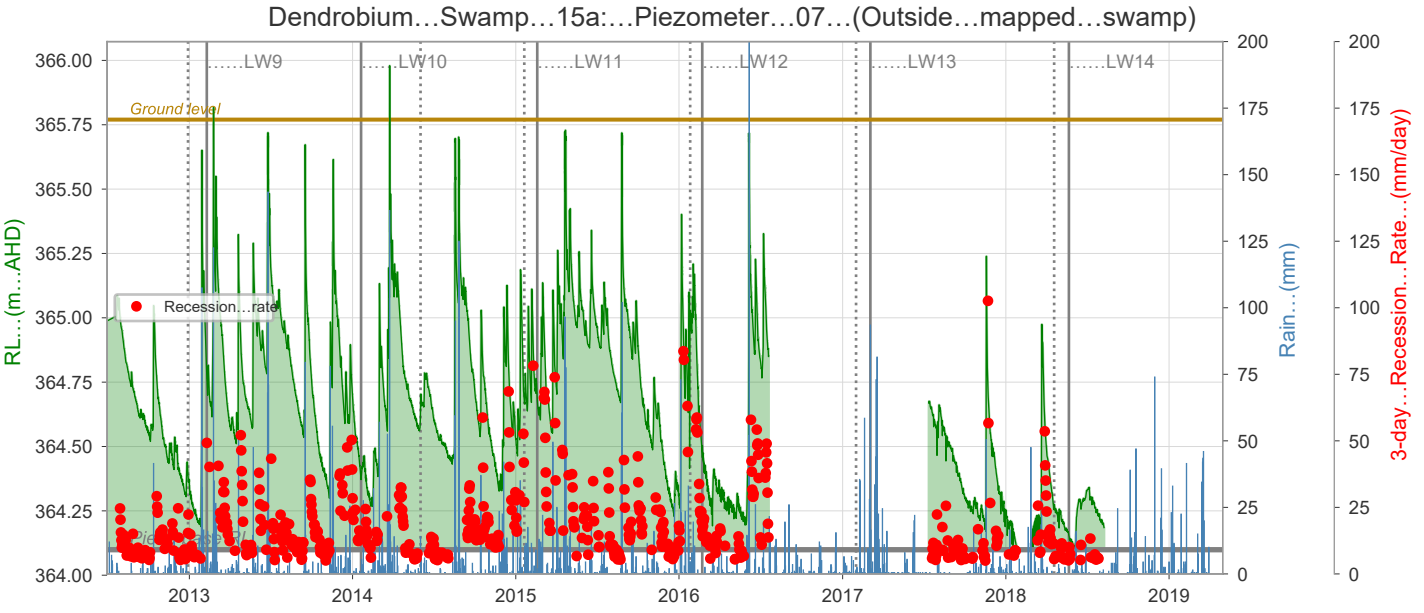

Dendrobium…Swamp…13:…Piezometer…01…(Within…mapped…swamp)
Ground level
LW9
LW10
LW11
LW12
LW13
LW14
Recession…rate
LW…undermined
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)

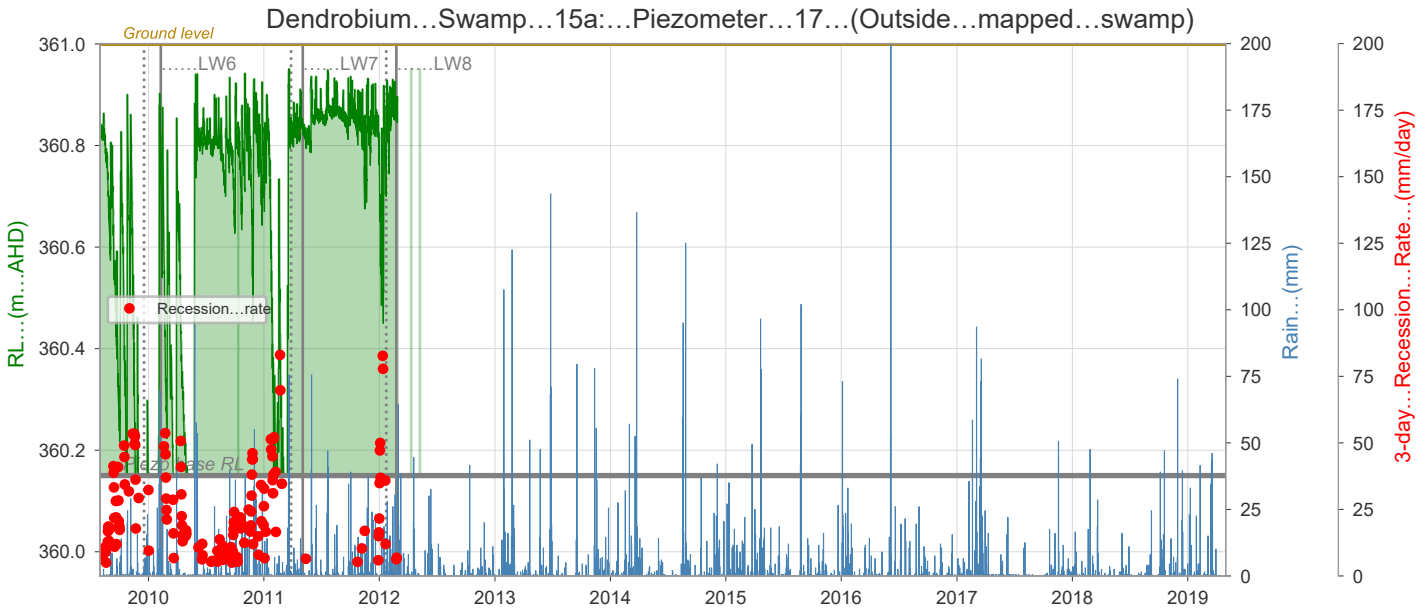

Dendrobium…Swamp…14:…Piezometer…01…(Within…mapped…swamp)
Ground level
LW12
LW13
LW14
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)

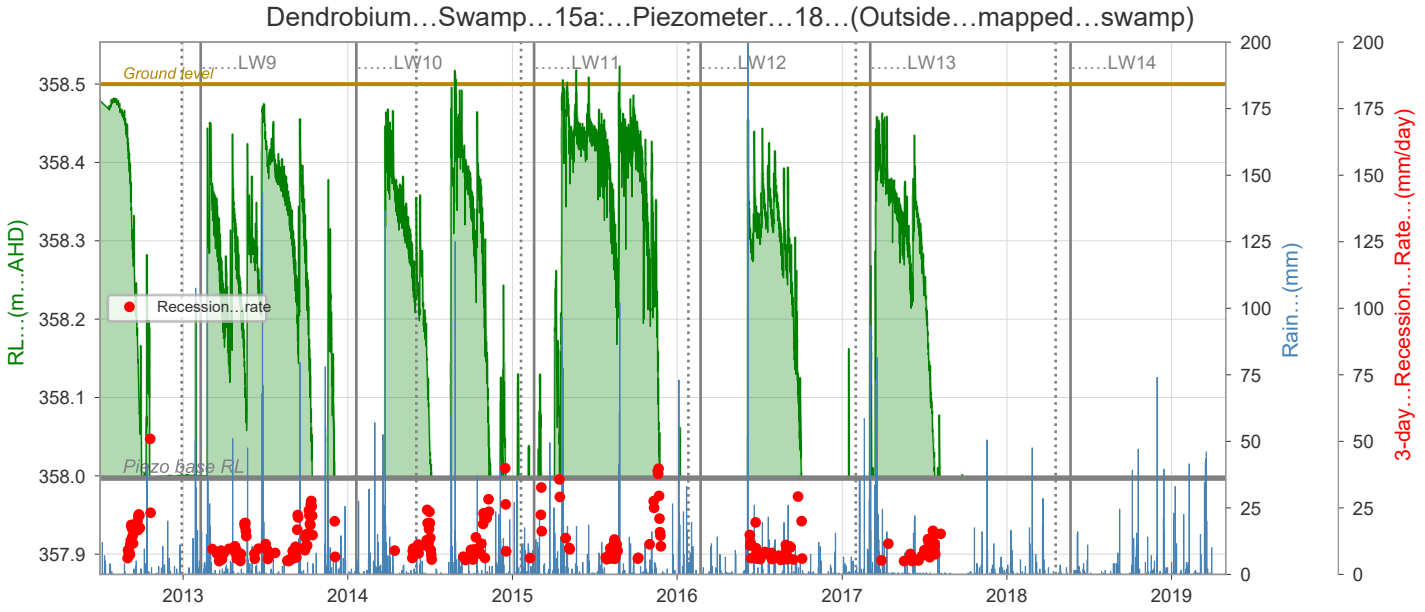

Dendrobium…Swamp…14:…Piezometer…02…(Within…mapped…swamp)
Ground level
LW12
LW13
LW14
Recession…rate
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)

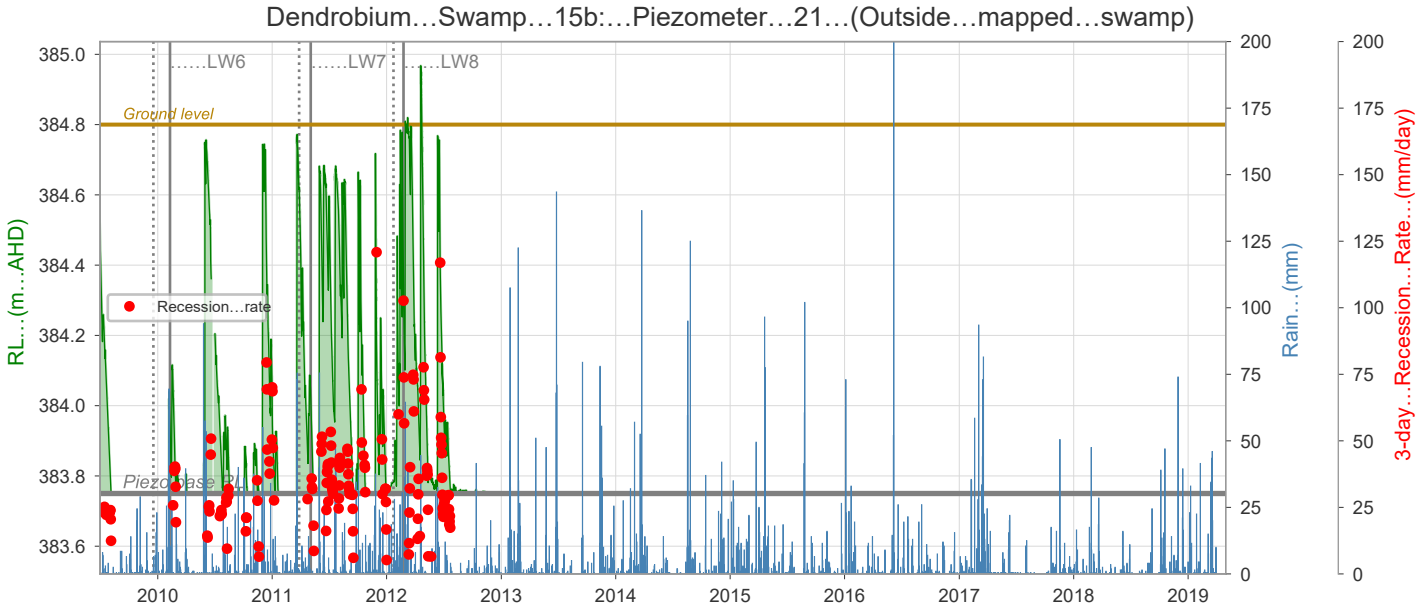

Dendrobium…Swamp…15a:…Piezometer…03…(Within…mapped…swamp)
LW6
LW7
LW8
Ground level
Piezo base RL
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
378.0
377.5
377.0
376.5
376.0
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
200
175
150
125
100
75
50
25
0

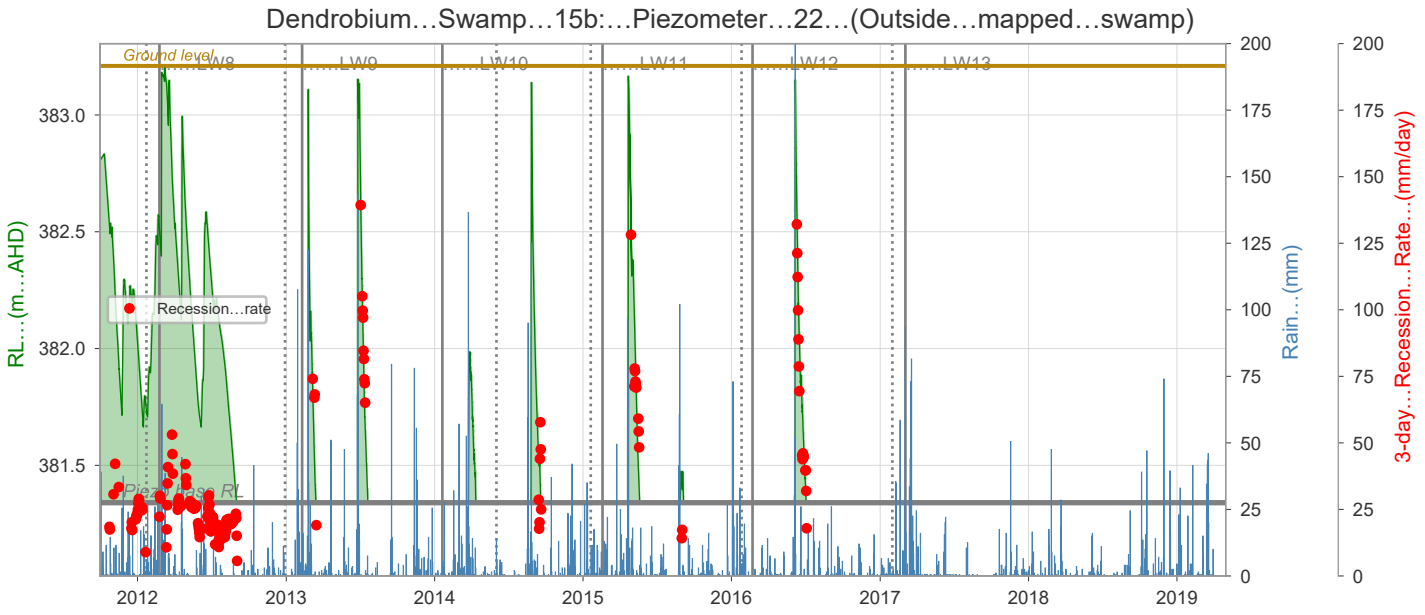

Dendrobium…Swamp…15a:…Piezometer…06…(Within…mapped…swamp)
LW9
LW10
LW11
LW12
LW13
LW14
Ground level
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
367.0
366.5
366.0
365.5
365.0
364.5
2013
2014
2015
2016
2017
2018
2019
200
175
150
125
100
75
50
25
0

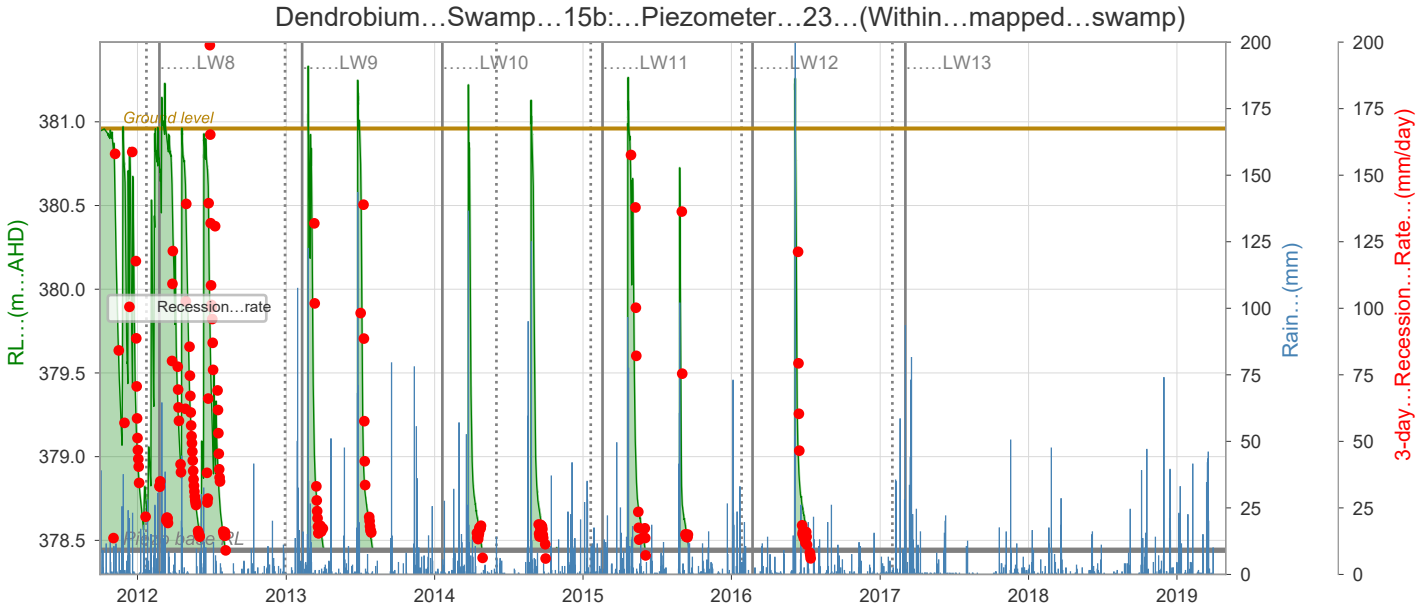

Dendrobium…Swamp…15a:…Piezometer…07…(Outside…mapped…swamp)
LW9
LW10
LW11
LW12
LW13
LW14
Ground level
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
366.00
365.75
365.50
365.25
365.00
364.75
364.50
364.25
364.00
2013
2014
2015
2016
2017
2018
2019
200
175
150
125
100
75
50
25
0

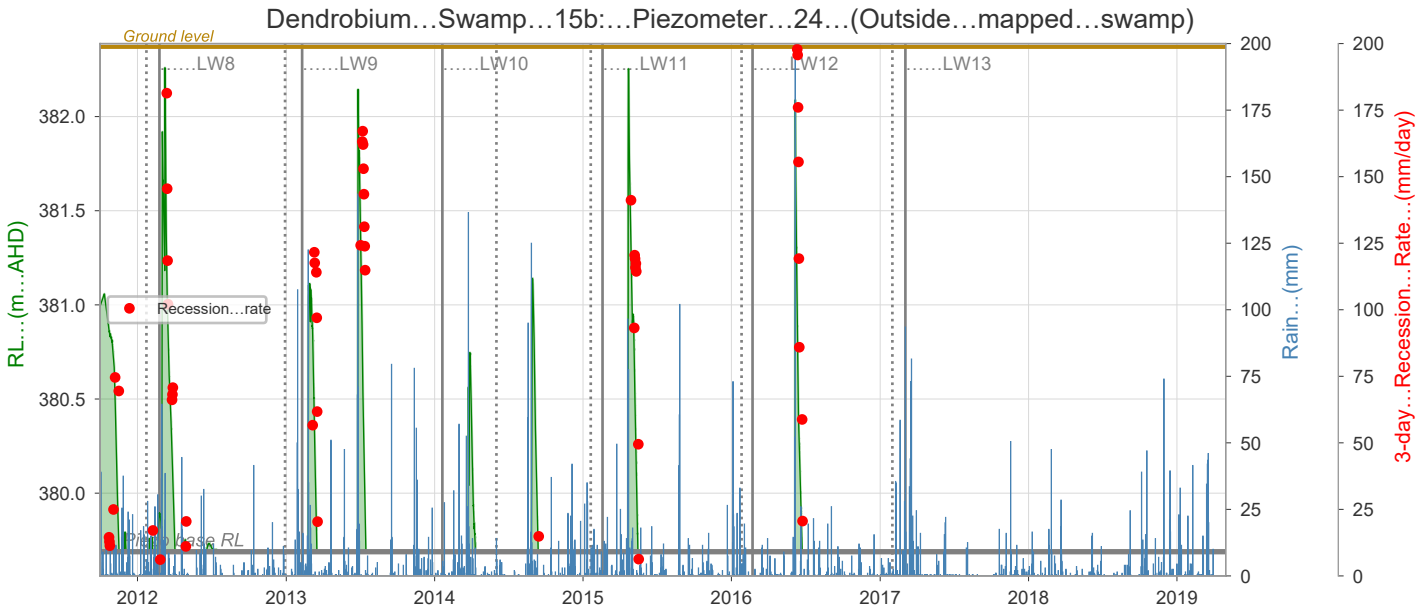

Dendrobium…Swamp…15a:…Piezometer…17…(Outside…mapped…swamp)
Ground level
LW6
LW7
LW8
Recession…rate
Piezo base RL
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)

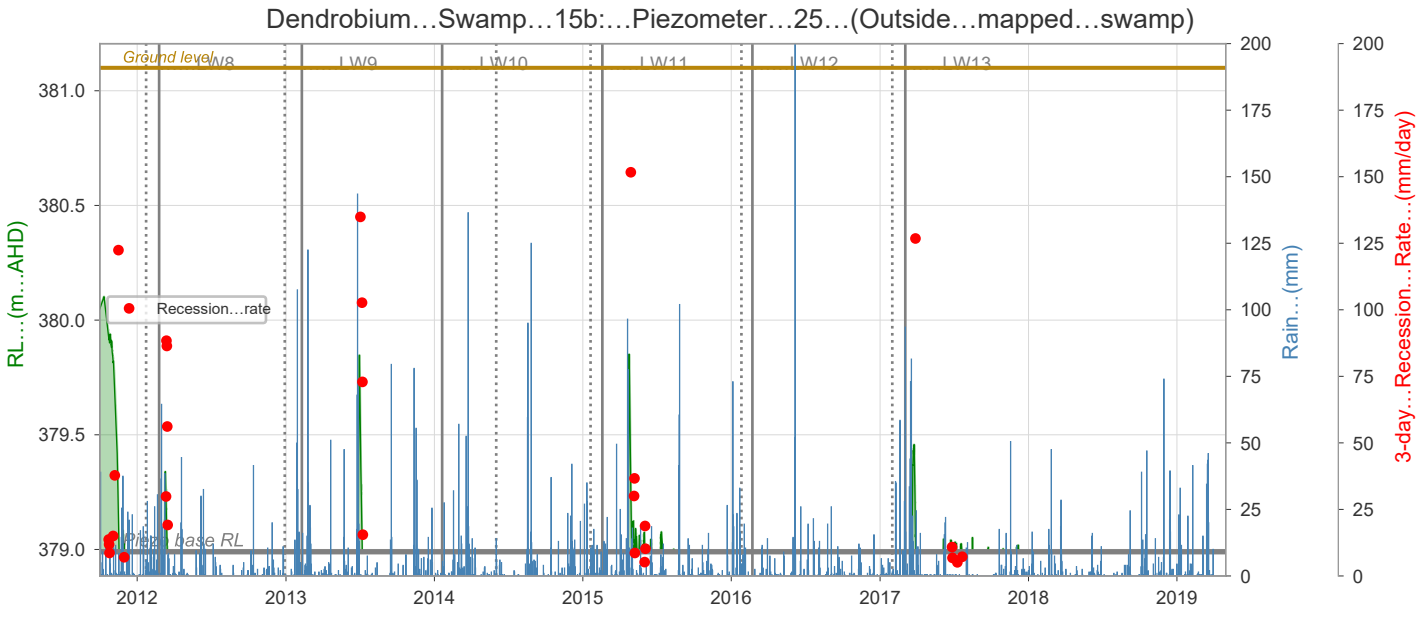

Dendrobium…Swamp…15a:…Piezometer…18…(Outside…mapped…swamp)
Ground level
LW9
LW10
LW11
LW12
LW13
LW14
Recession…rate
Piezo base RL
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)

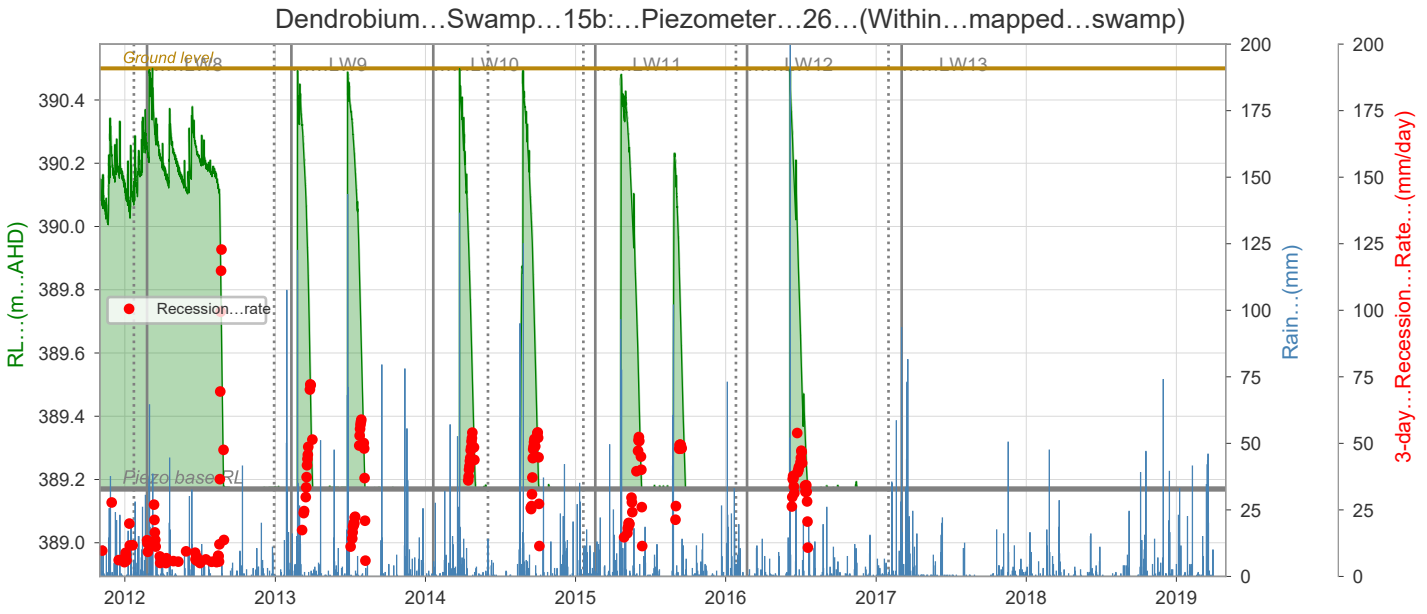

Dendrobium…Swamp…15b:…Piezometer…21…(Outside…mapped…swamp)
Ground level
LW6
LW7
LW8
Recession…rate
Piezo base RL
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)

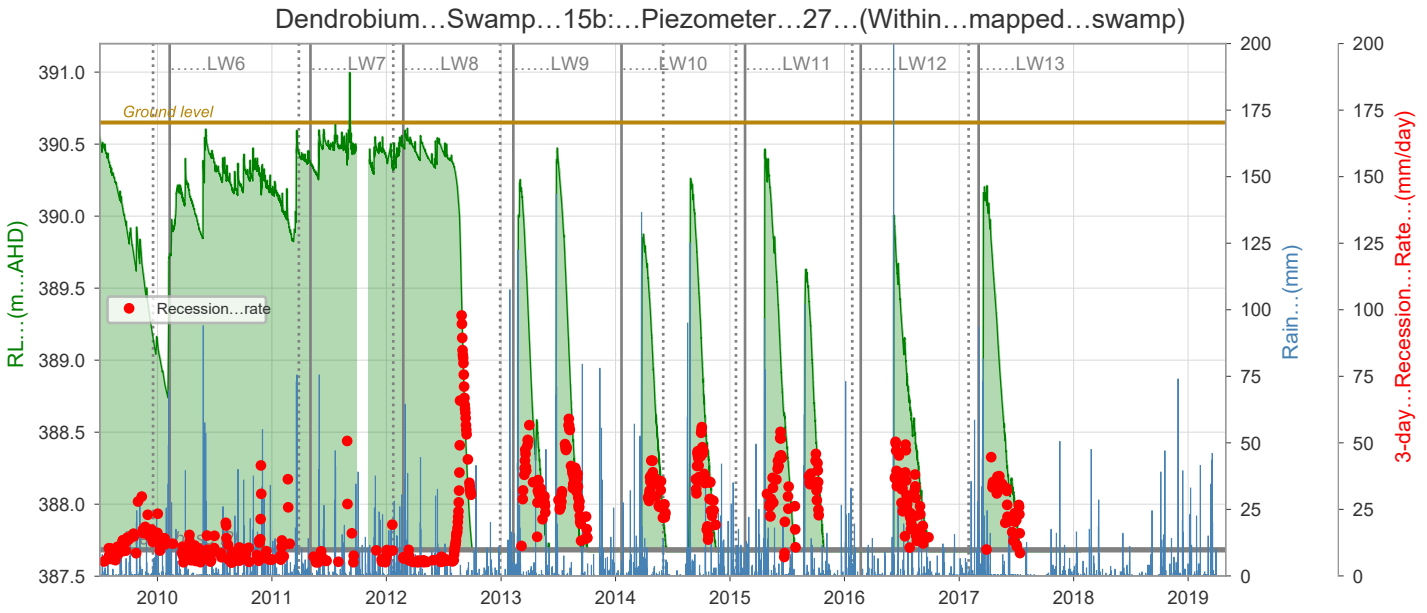

Dendrobium…Swamp…15b:…Piezometer…22…(Outside…mapped…swamp)
Ground level
LW8
LW9
LW10
LW11
LW12
LW13
Recession…rate
Piezo base RL
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
383.0
382.5
382.0
381.5
2012
2013
2014
2015
2016
2017
2018
2019

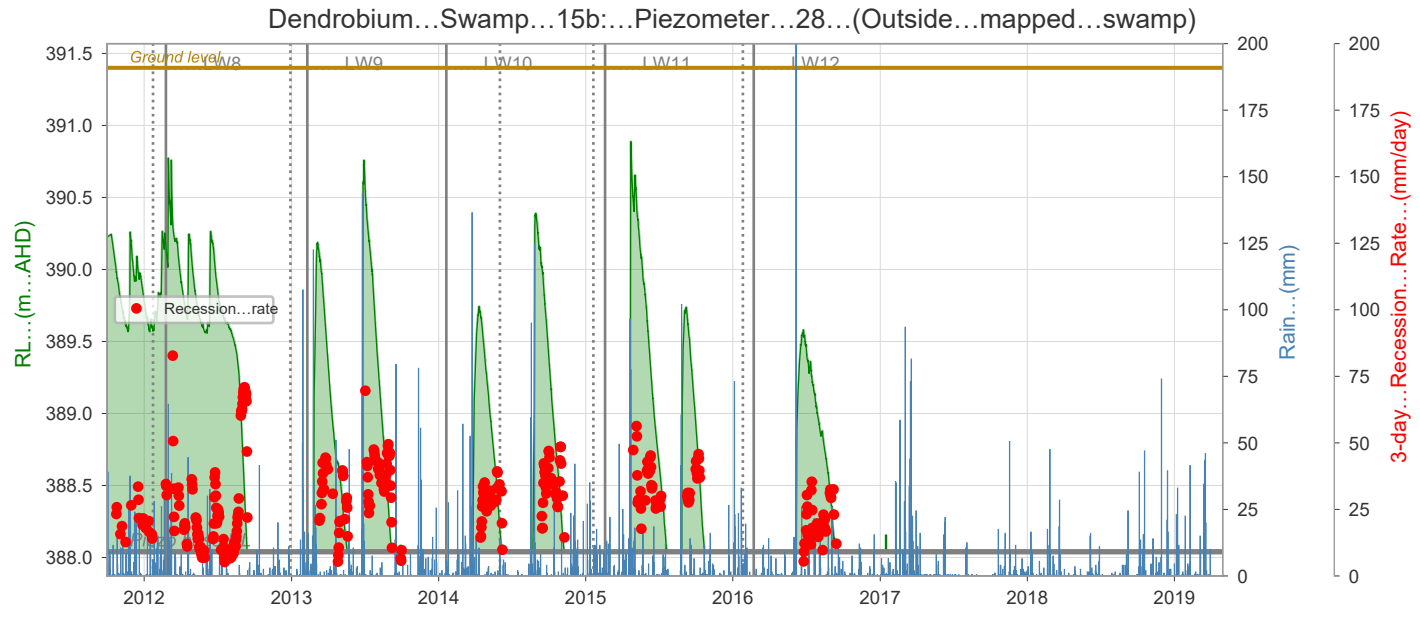

Dendrobium…Swamp…15b:…Piezometer…23…(Within…mapped…swamp)
LW8
LW9
LW10
LW11
LW12
LW13
Ground level
Recession…rate
Piezo base RL
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
381.0
380.5
380.0
379.5
379.0
378.5
2012
2013
2014
2015
2016
2017
2018
2019

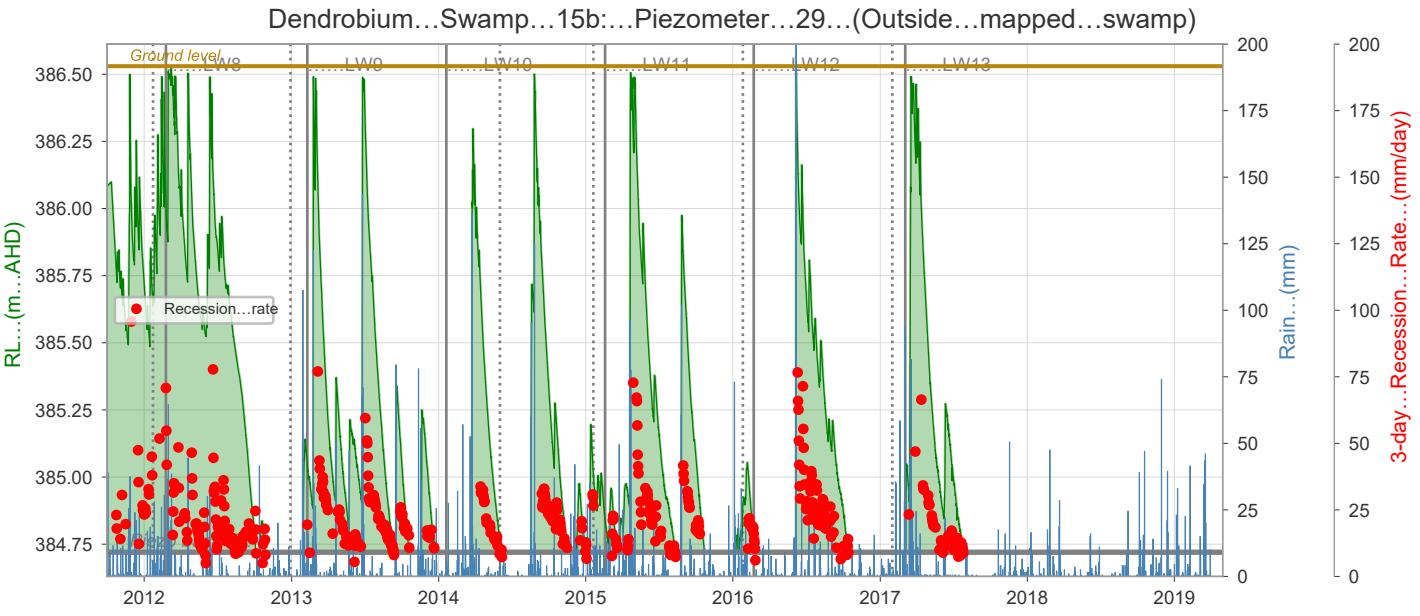

Dendrobium…Swamp…15b:…Piezometer…24…(Outside…mapped…swamp)
Ground level
LW8
LW9
LW10
LW11
LW12
LW13
Recession…rate
Piezo base RL
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
382.0
381.5
381.0
380.5
380.0
2012
2013
2014
2015
2016
2017
2018
2019

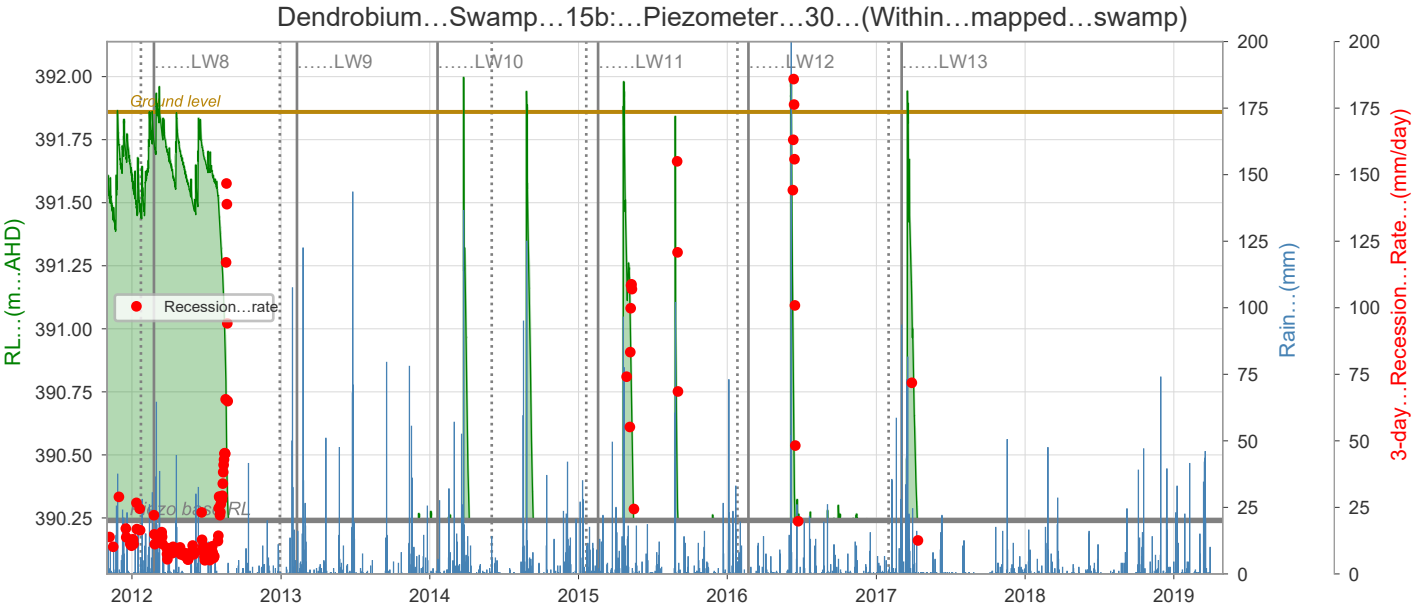

Dendrobium…Swamp…15b:…Piezometer…25…(Outside…mapped…swamp)
Ground level
LW8
LW9
LW10
LW11
LW12
LW13
Recession…rate
Piezo base RL
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
381.0
380.5
380.0
379.5
379.0
200
175
150
125
100
75
50
25
0
2012
2013
2014
2015
2016
2017
2018
2019

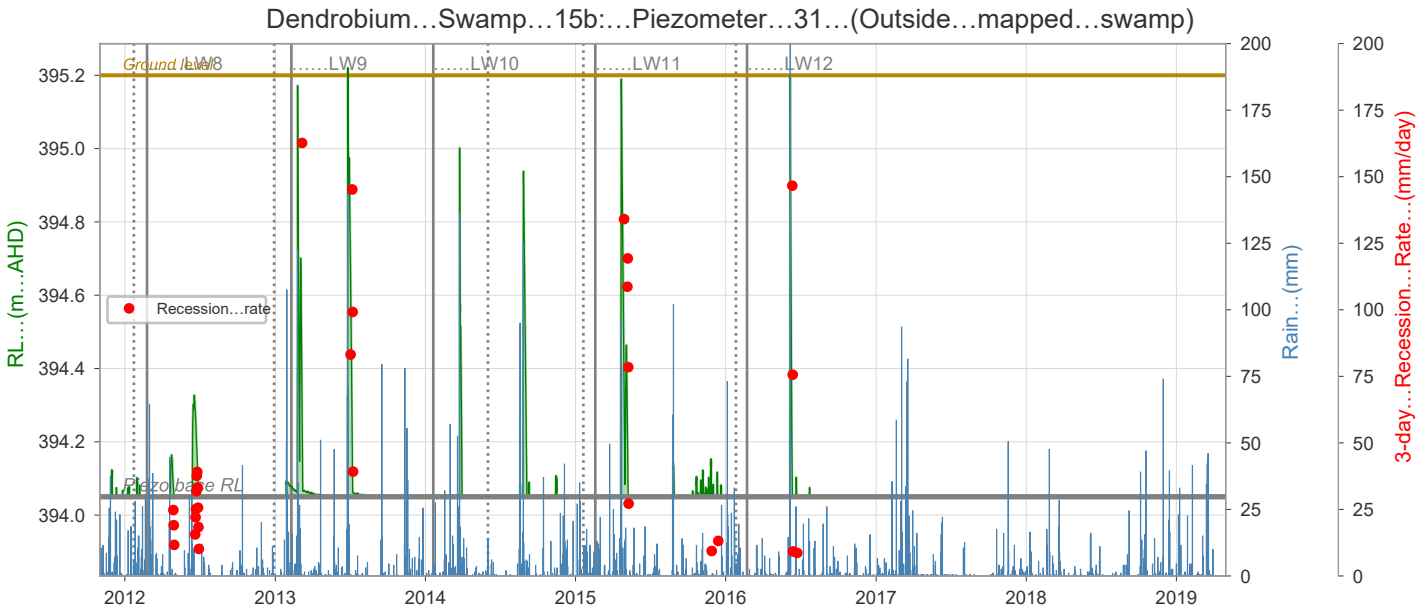

Dendrobium…Swamp…15b:…Piezometer…26…(Within…mapped…swamp)
Ground level
LW8
LW9
LW10
LW11
LW12
LW13
Recession…rate
Piezo base RL
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
390.4
390.2
390.0
389.8
389.6
389.4
389.2
389.0
200
175
150
125
100
75
50
25
0
2012
2013
2014
2015
2016
2017
2018
2019

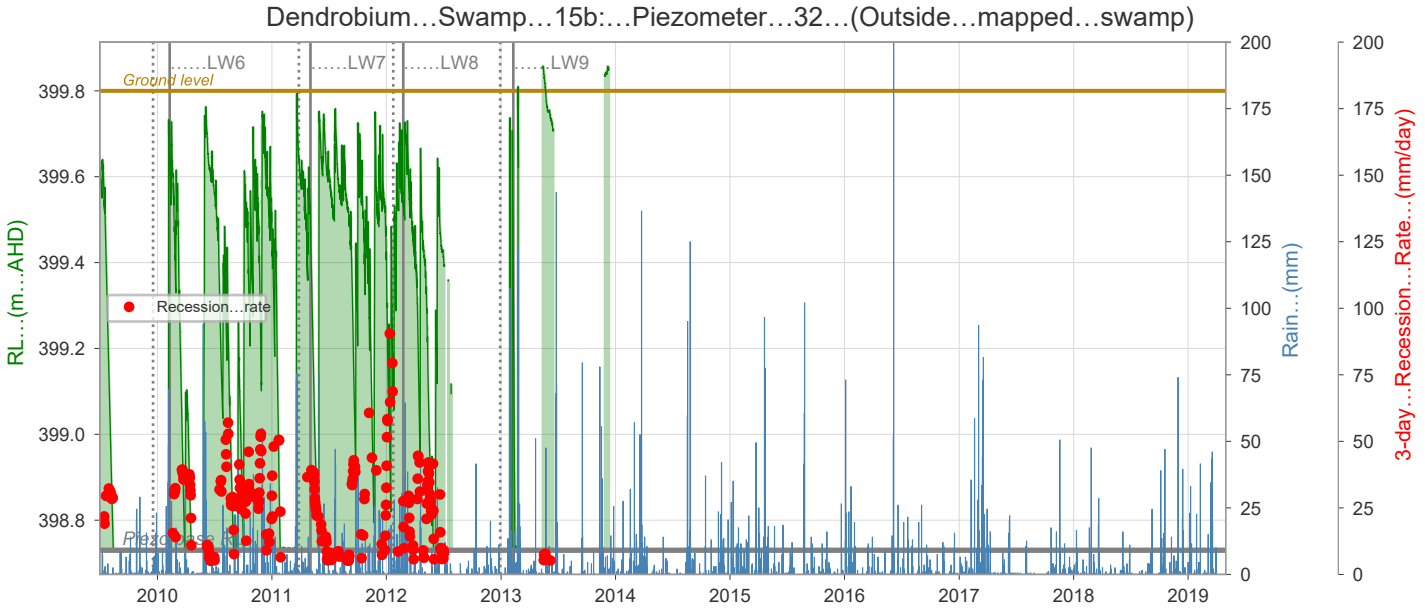

Dendrobium…Swamp…15b:…Piezometer…27…(Within…mapped…swamp)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
Ground level
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
391.0
390.5
390.0
389.5
389.0
388.5
388.0
387.5
200
175
150
125
100
75
50
25
0
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

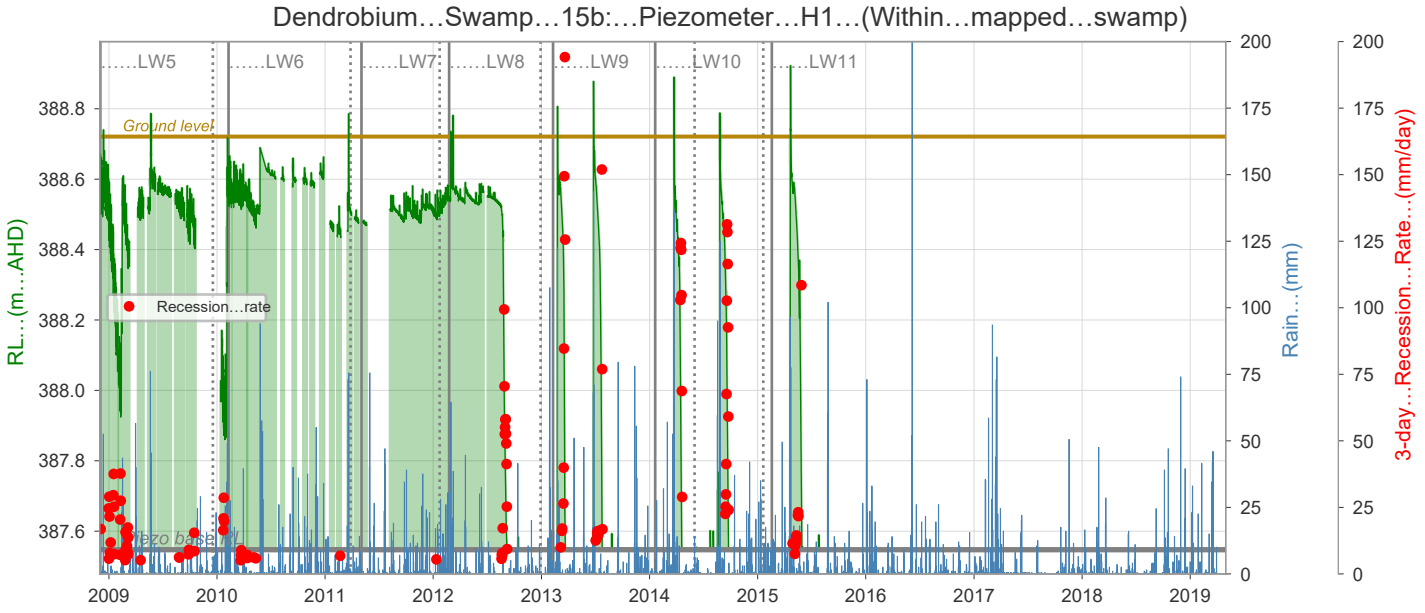

Dendrobium…Swamp…15b:…Piezometer…28…(Outside…mapped…swamp)
Ground level
LW8
LW9
LW10
LW11
LW12
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
391.5
391.0
390.5
390.0
389.5
389.0
388.5
388.0
200
175
150
125
100
75
50
25
0
2012
2013
2014
2015
2016
2017
2018
2019

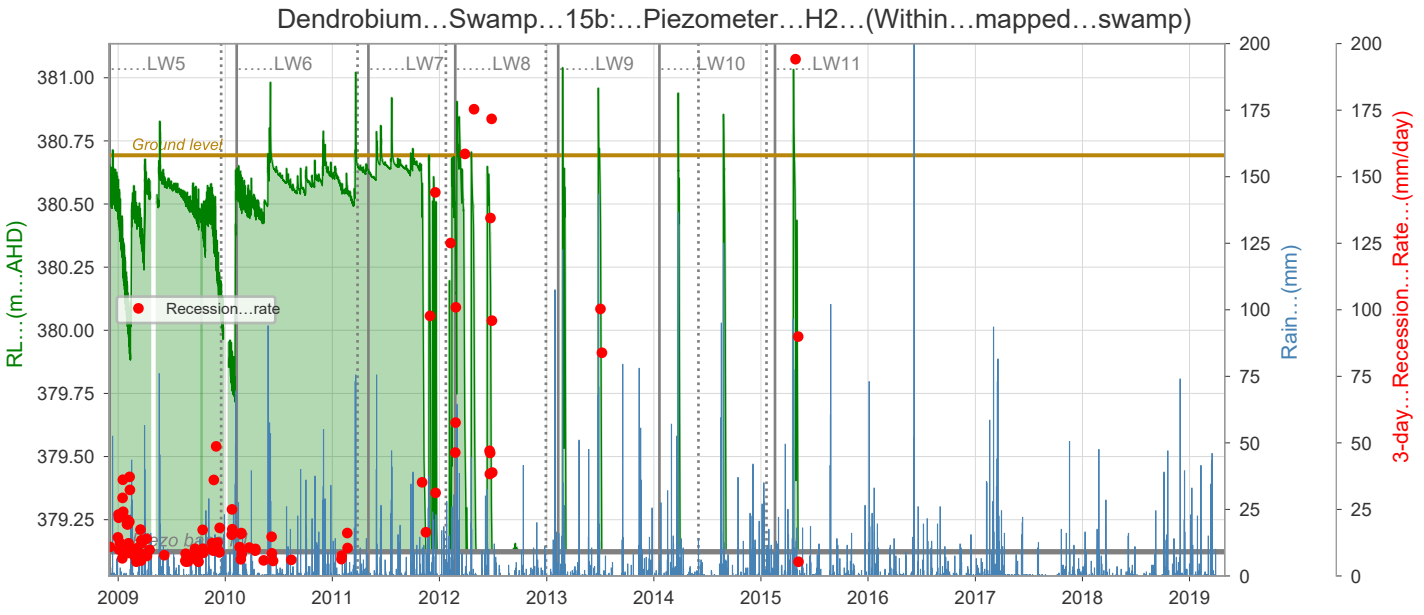

Dendrobium…Swamp…15b:…Piezometer…29…(Outside…mapped…swamp)
Ground level
LW8
LW9
LW10
LW11
LW12
LW13
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
386.50
386.25
386.00
385.75
385.50
385.25
385.00
384.75
200
175
150
125
100
75
50
25
0
2012
2013
2014
2015
2016
2017
2018
2019

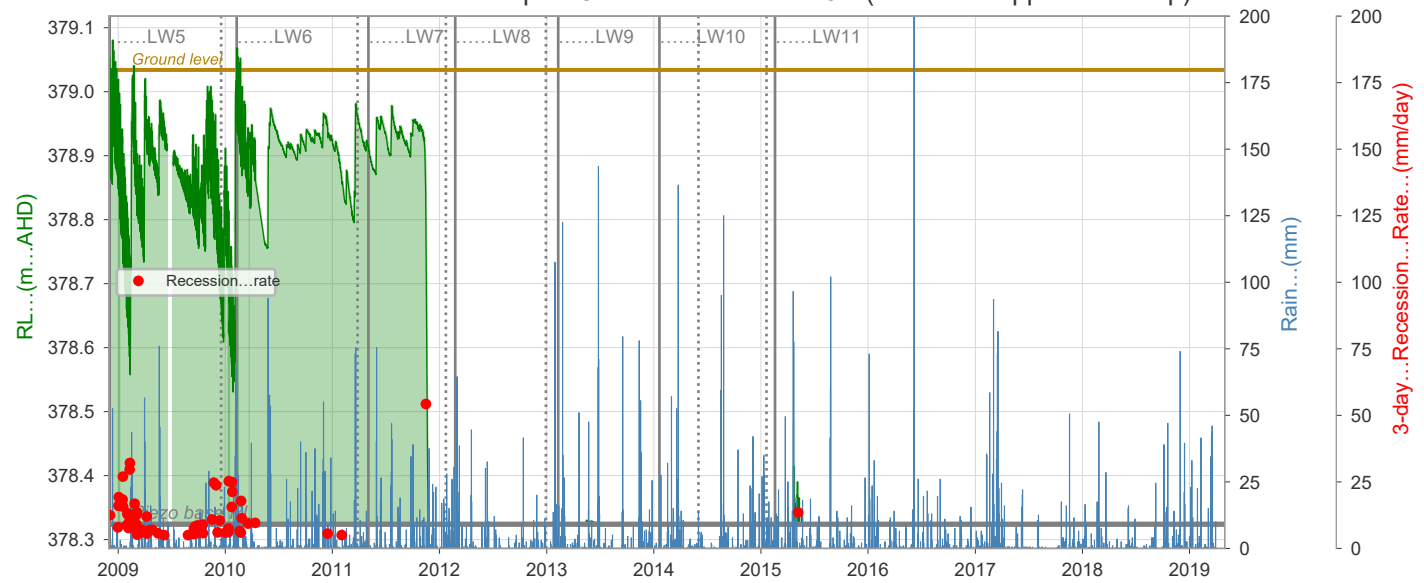

Dendrobium…Swamp…15b:…Piezometer…30…(Within…mapped…swamp)
LW8
LW9
LW10
LW11
LW12
LW13
Ground level
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
392.00
391.75
391.50
391.25
391.00
390.75
390.50
390.25
200
175
150
125
100
75
50
25
0
2012
2013
2014
2015
2016
2017
2018
2019

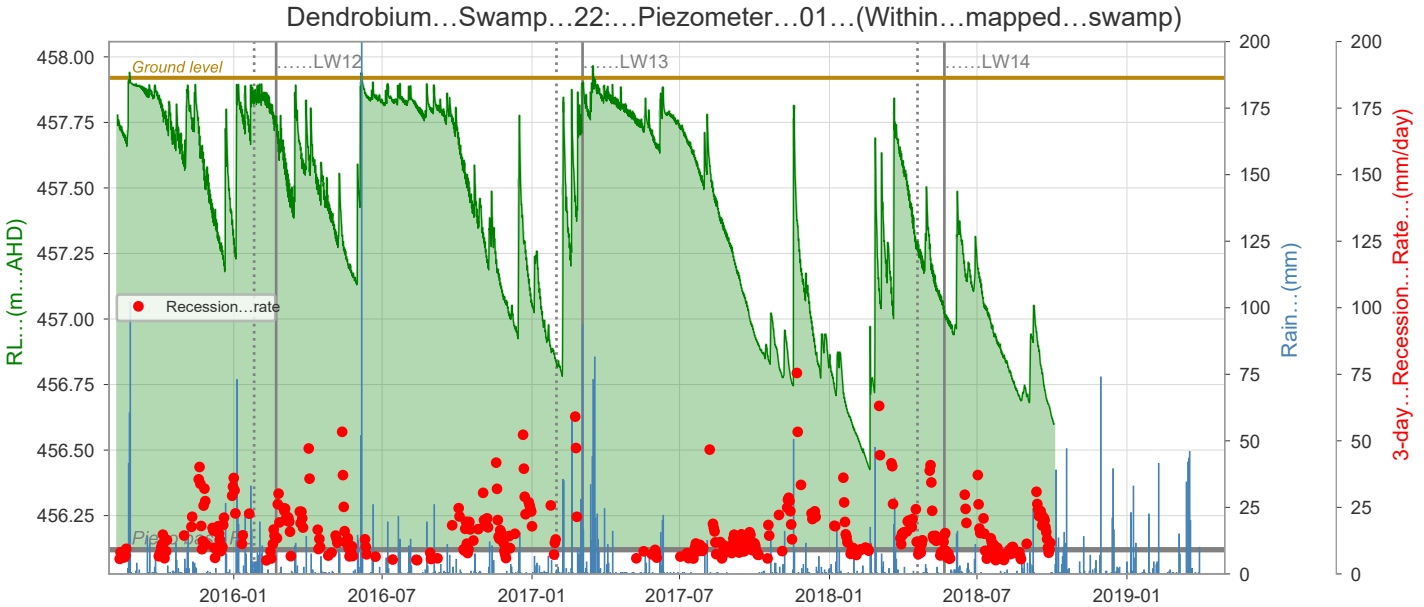

Dendrobium…Swamp…15b:…Piezometer…31…(Outside…mapped…swamp)
Ground level
LW8
LW9
LW10
LW11
LW12
Recession…rate
Piezo base RL
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
395.2
395.0
394.8
394.6
394.4
394.2
394.0
200
175
150
125
100
75
50
25
0
2012
2013
2014
2015
2016
2017
2018
2019

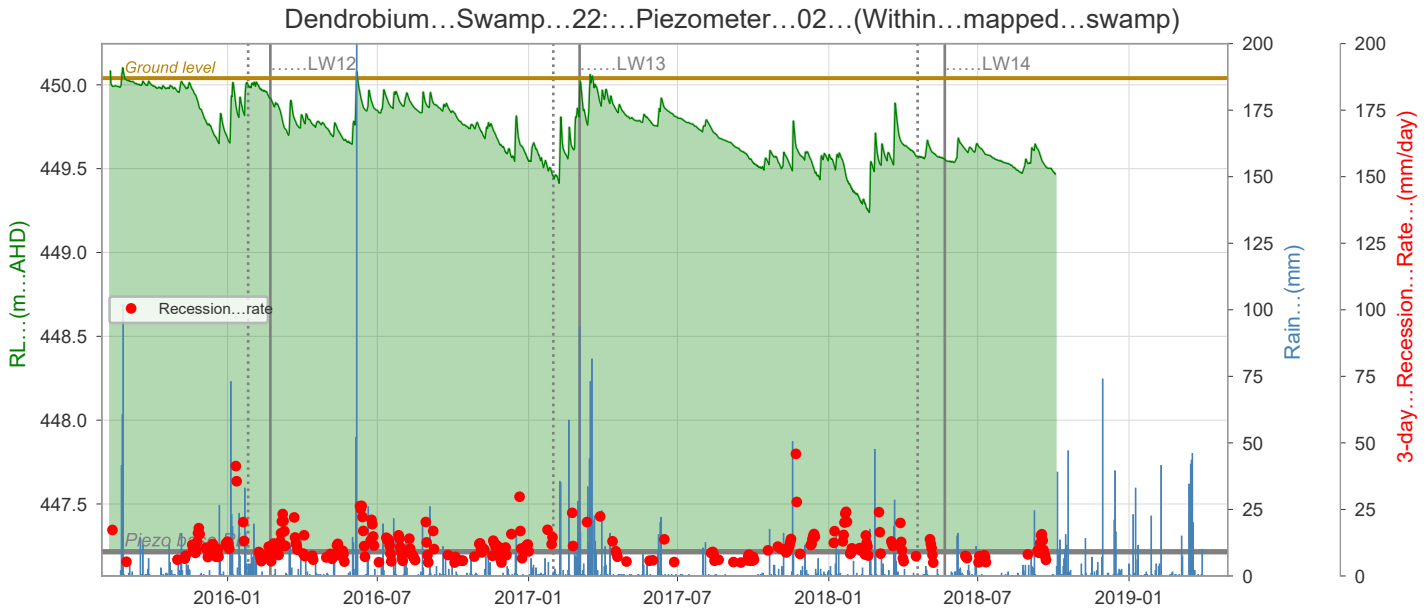

Dendrobium…Swamp…15b:…Piezometer…32…(Outside…mapped…swamp)
LW6
LW7
LW8
LW9
Ground level
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
399.8
399.6
399.4
399.2
399.0
398.8
200
175
150
125
100
75
50
25
0
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

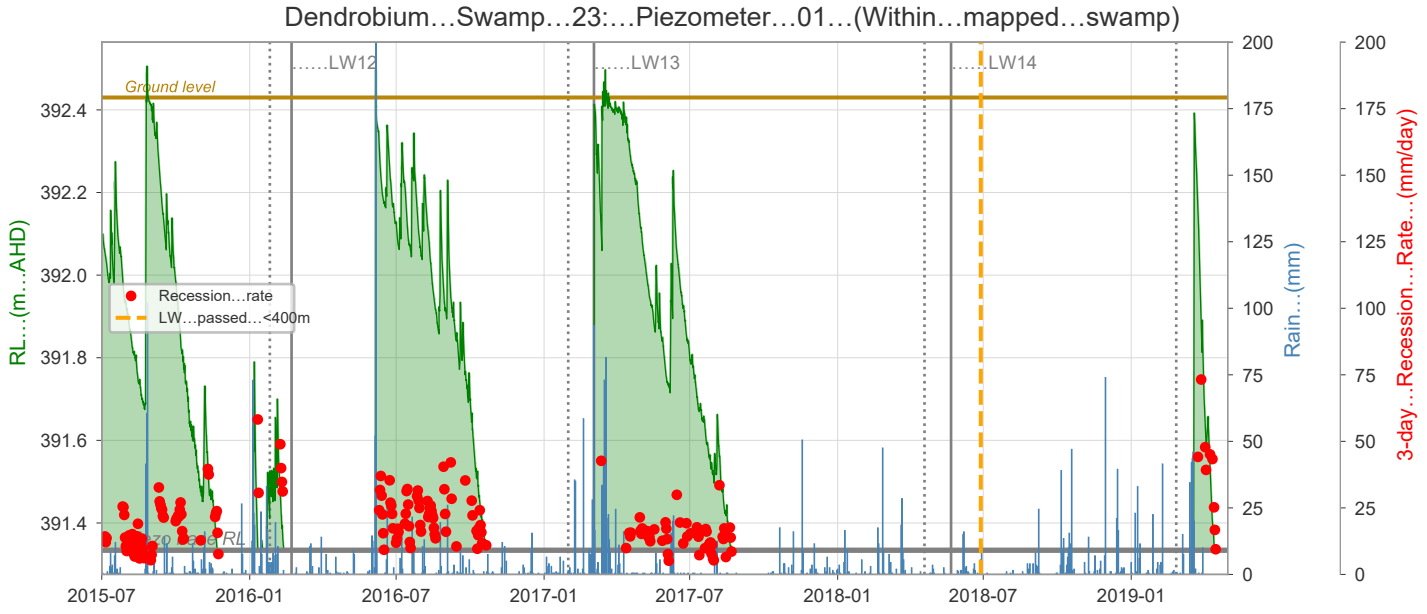

Dendrobium…Swamp…15b:…Piezometer…H1…(Within…mapped…swamp)
LW5
LW6
LW7
LW8
LW9
LW10
LW11
Ground level
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
388.8
388.6
388.4
388.2
388.0
387.8
387.6
200
175
150
125
100
75
50
25
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

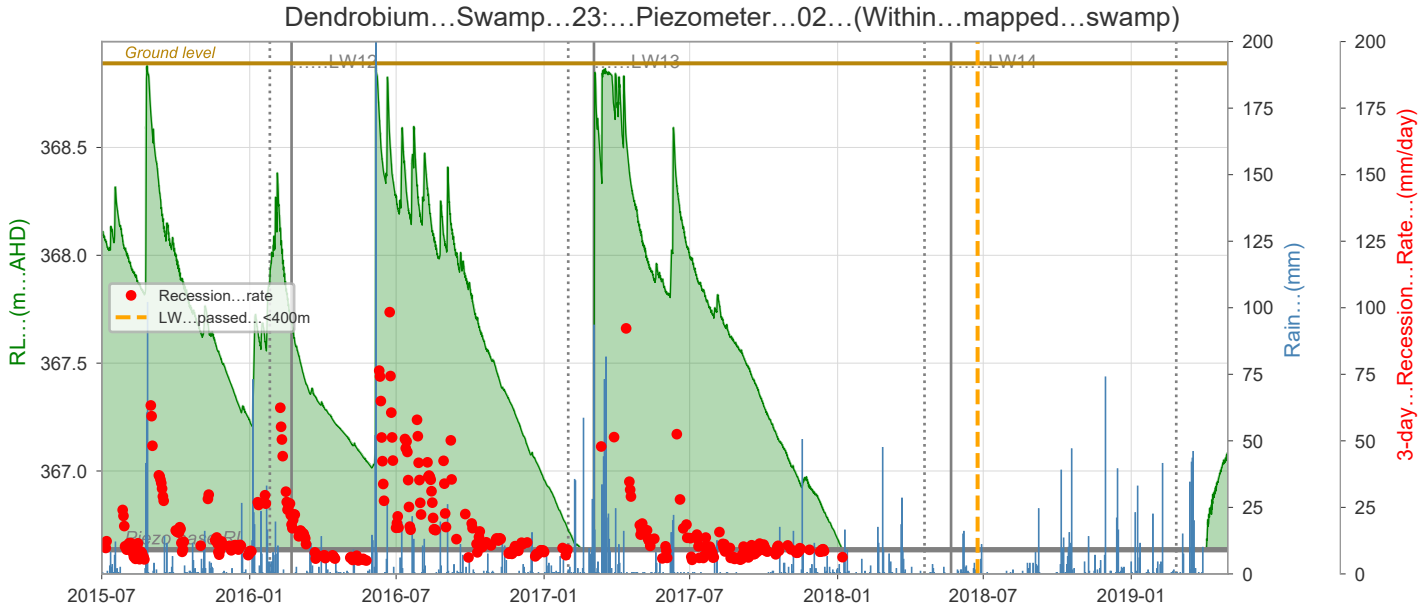

Dendrobium…Swamp…15b:…Piezometer…H2…(Within…mapped…swamp)
LW5
LW6
LW7
LW8
LW9
LW10
LW11
Ground level
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

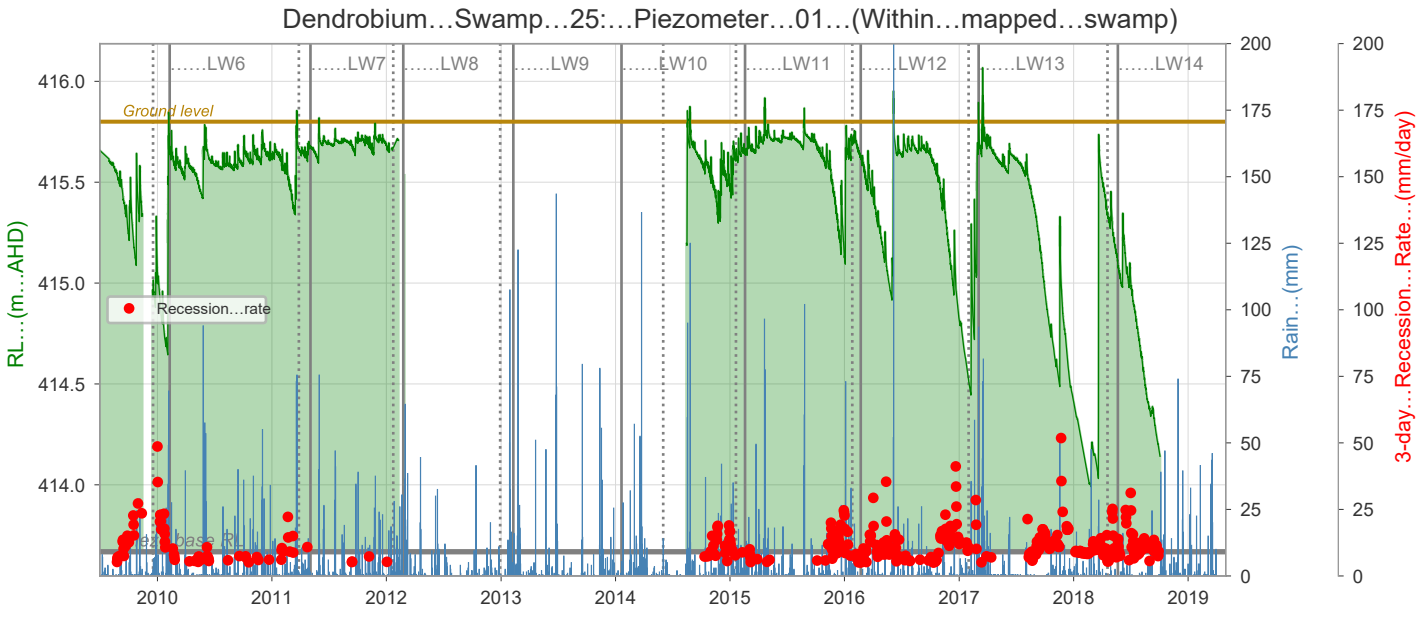

Dendrobium…Swamp…15b:…Piezometer…H3…(Within…mapped…swamp)
LW5
LW6
LW7
LW8
LW9
LW10
LW11
Ground level
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

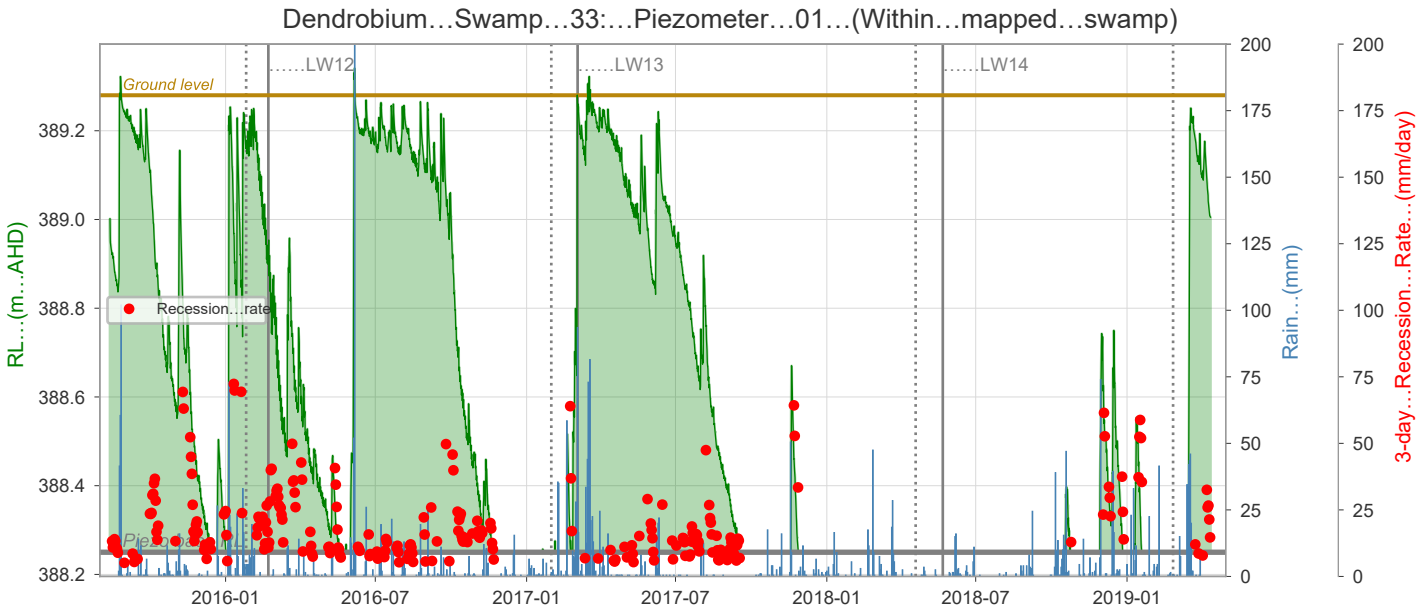

Dendrobium…Swamp…22:…Piezometer…01…(Within…mapped…swamp)
Ground level
LW12
LW13
LW14
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01

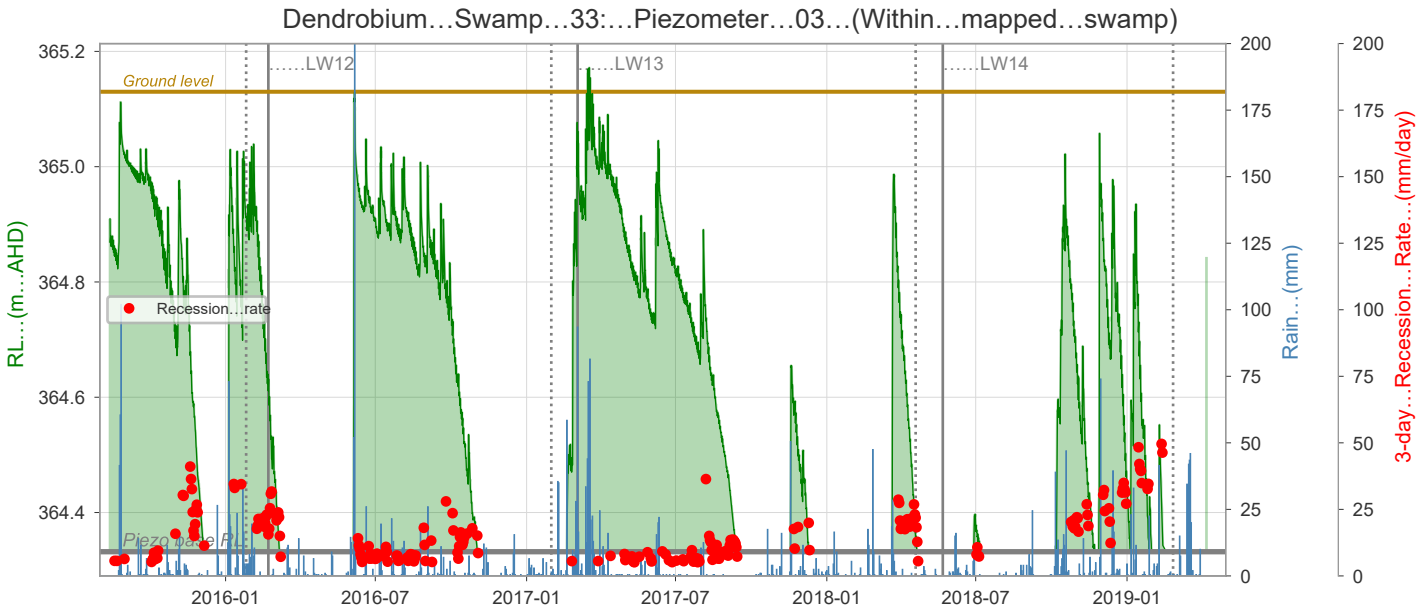

Dendrobium…Swamp…22:…Piezometer…02…(Within…mapped…swamp)
Ground level
LW12
LW13
LW14
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
450.0
449.5
449.0
448.5
448.0
447.5
200
175
150
125
100
75
50
25
0
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01

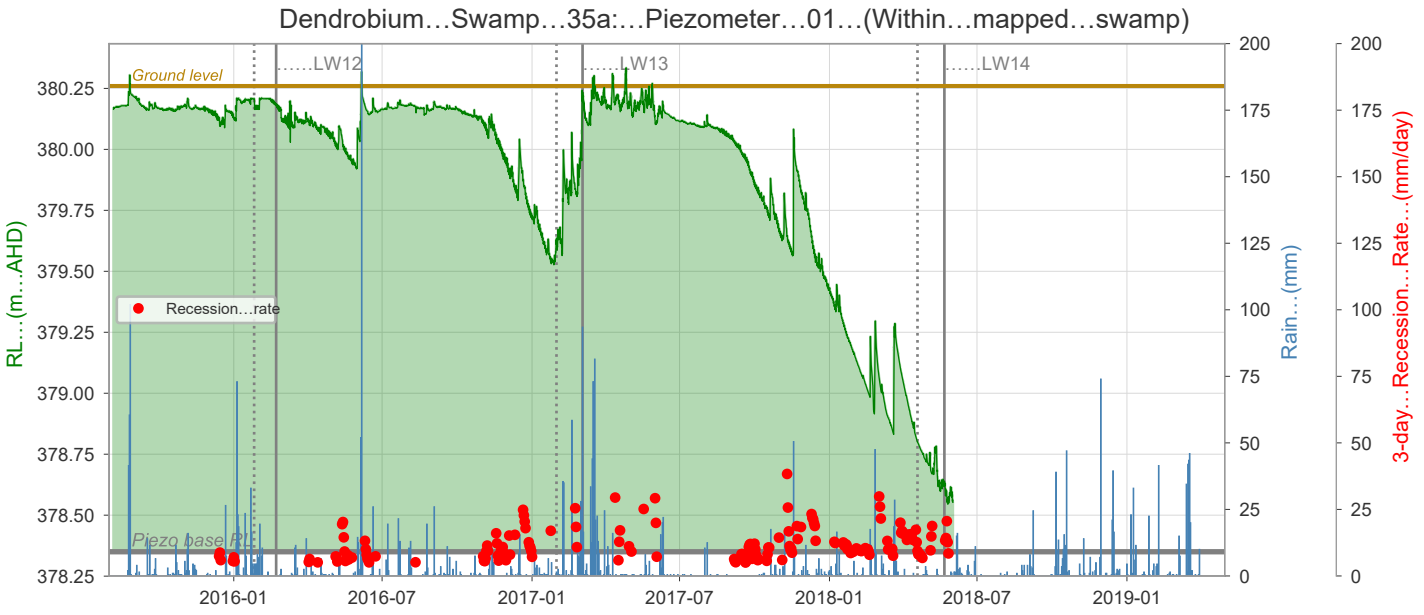

Dendrobium…Swamp…23:…Piezometer…01…(Within…mapped…swamp)
Ground level
LW12
LW13
LW14
Recession…rate
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
392.4
392.2
392.0
391.8
391.6
391.4
200
175
150
125
100
75
50
25
0
2015-07
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01

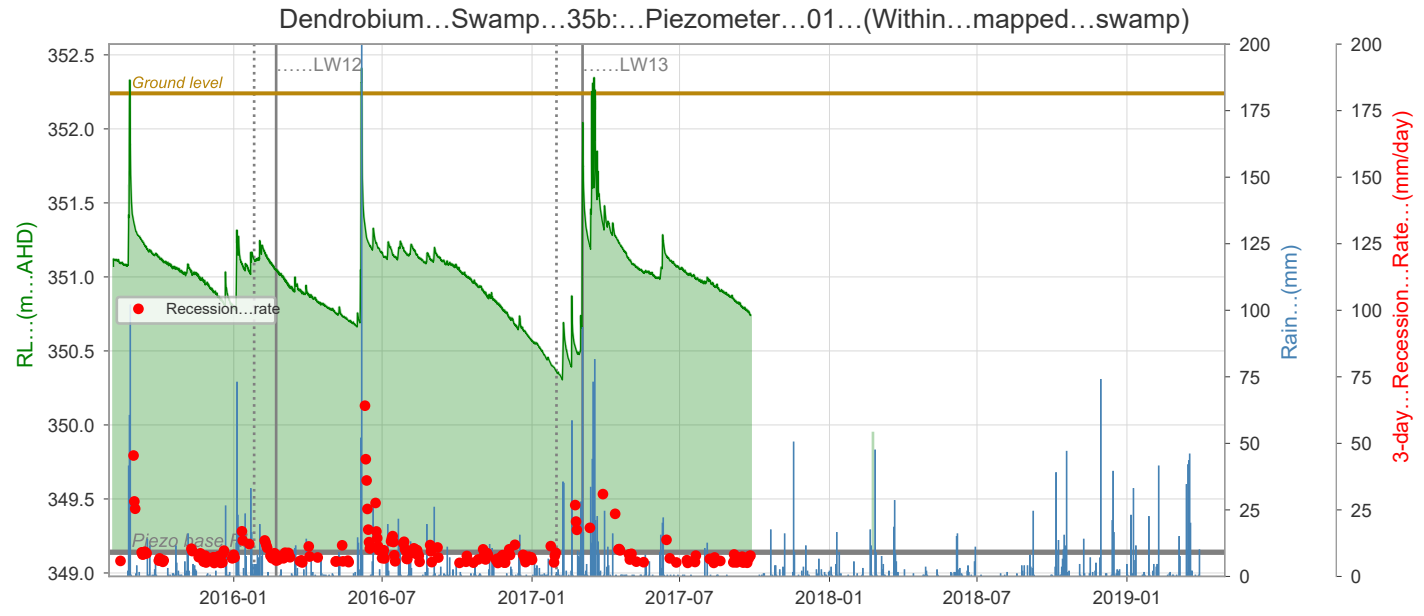

Dendrobium…Swamp…23:…Piezometer…02…(Within…mapped…swamp)
Ground level
LW12
LW13
LW14
Recession…rate
LW…passed…<400m
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
368.5
368.0
367.5
367.0
200
175
150
125
100
75
50
25
0
2015-07
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01

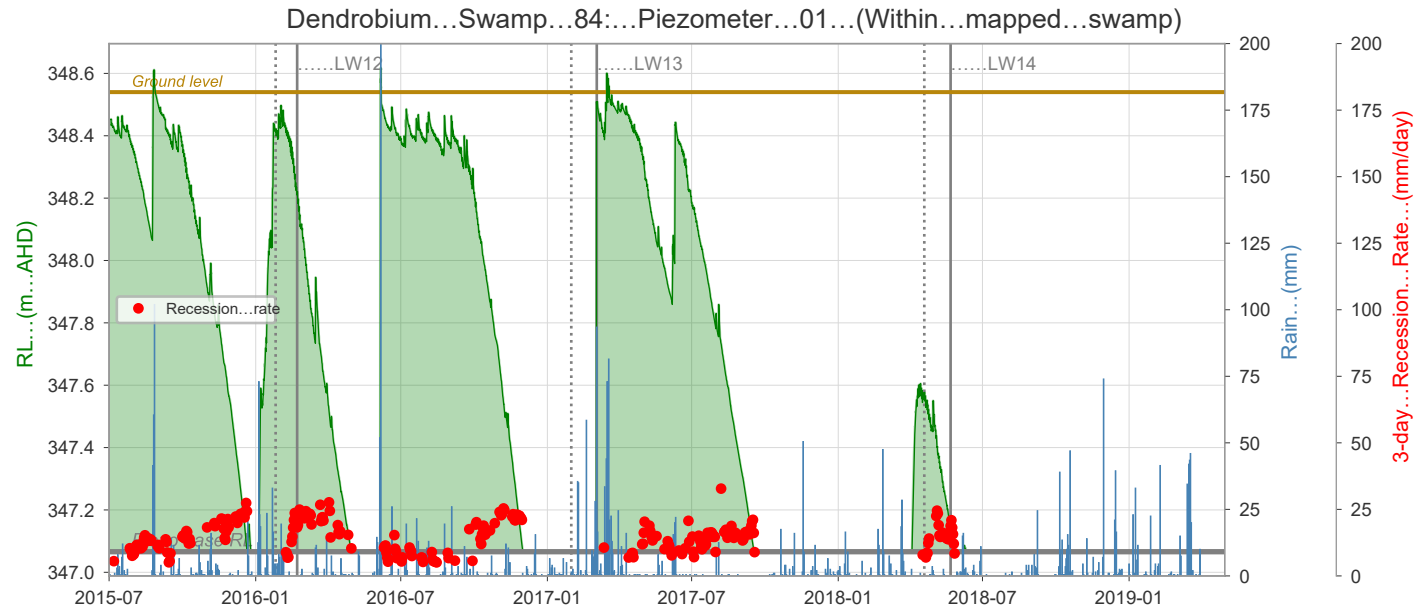

Dendrobium…Swamp…25:…Piezometer…01…(Within…mapped…swamp)
.....LW6
.....LW7
.....LW8
.....LW9
.....LW10
.....LW11
.....LW12
.....LW13
.....LW14
Ground level
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
416.0
415.5
415.0
414.5
414.0
200
175
150
125
100
75
50
25
0
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

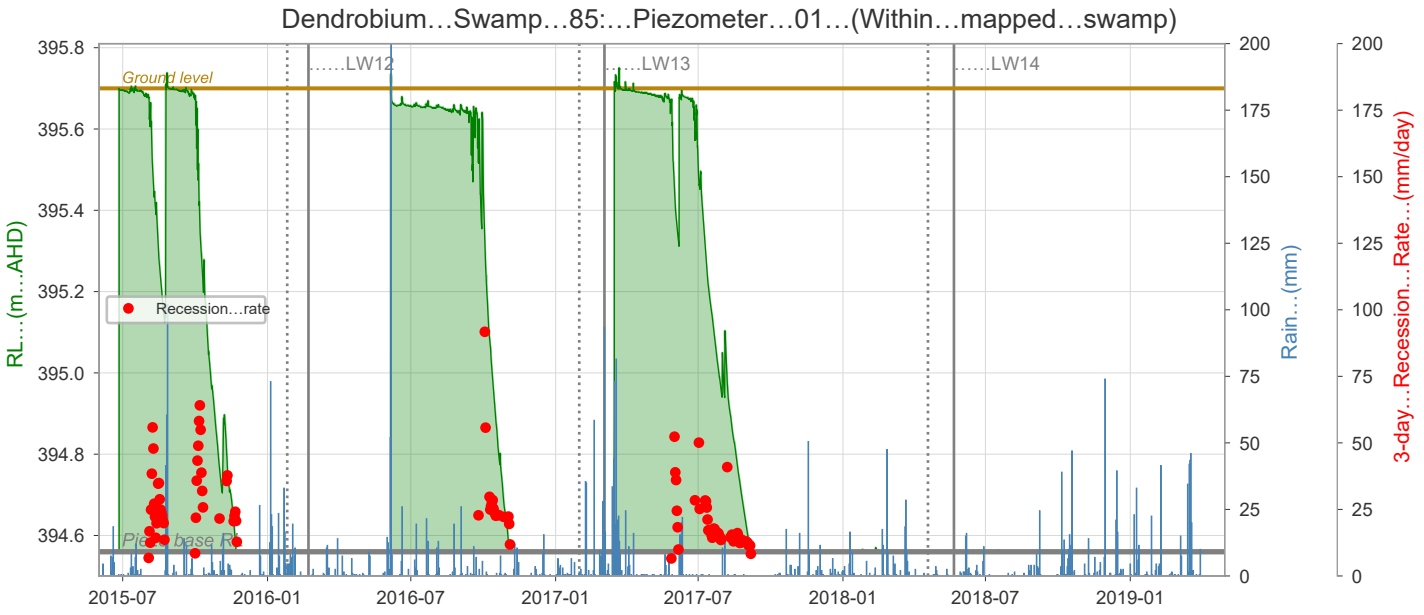

Dendrobium…Swamp…33:…Piezometer…01…(Within…mapped…swamp)
.....LW12
.....LW13
.....LW14
Ground level
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
389.2
389.0
388.8
388.6
388.4
388.2
200
175
150
125
100
75
50
25
0
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01

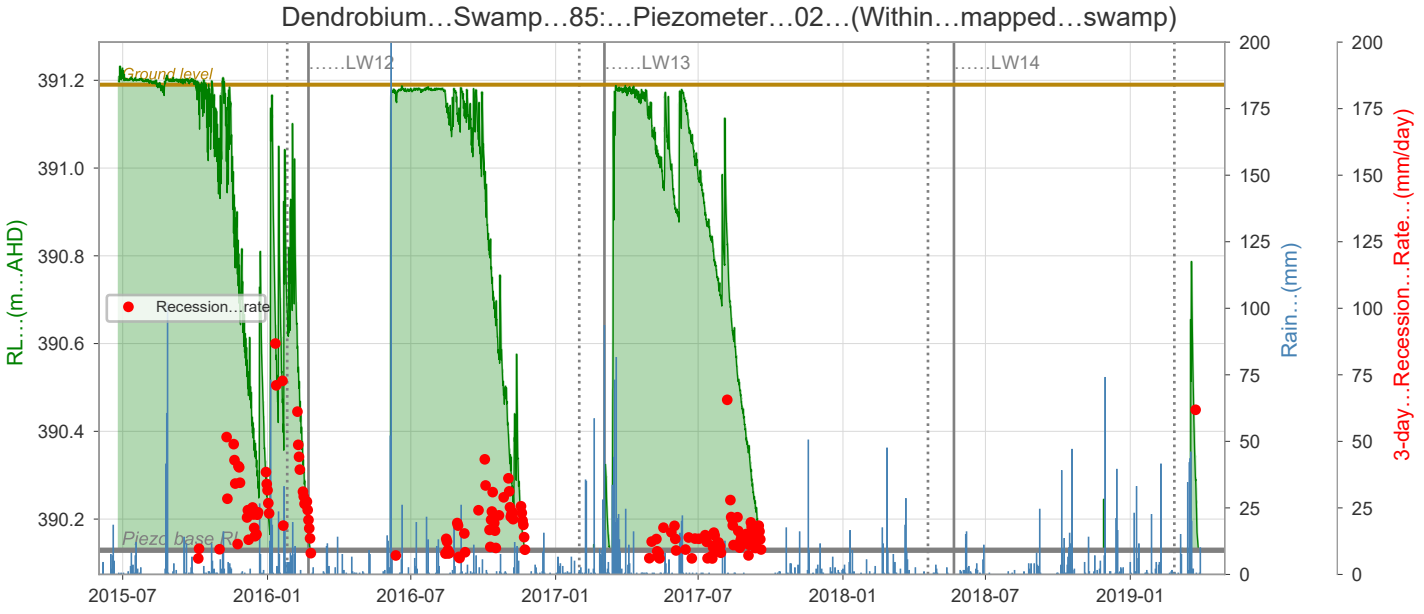

Dendrobium…Swamp…33:…Piezometer…03…(Within…mapped…swamp)
.....LW12
.....LW13
.....LW14
Ground level
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
365.2
365.0
364.8
364.6
364.4
200
175
150
125
100
75
50
25
0
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01

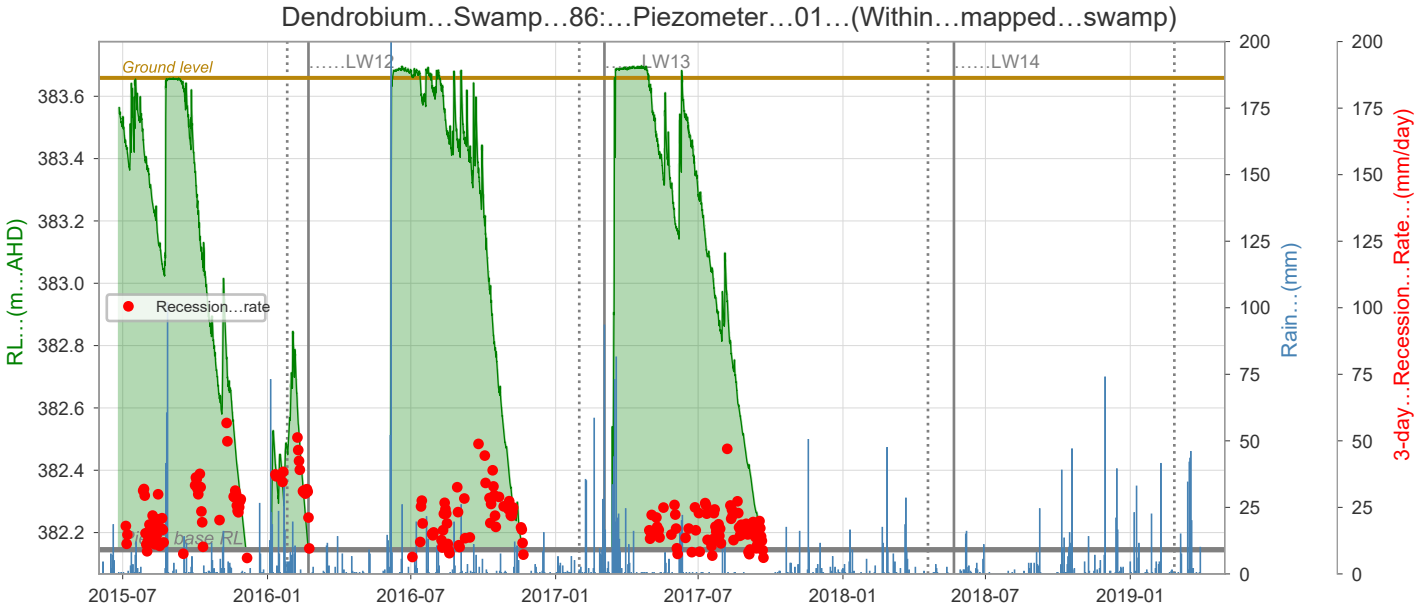

Dendrobium…Swamp…35a:…Piezometer…01…(Within…mapped…swamp)
Ground level
LW12
LW13
LW14
Recession…rate
Piezo base RL
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
380.25
380.00
379.75
379.50
379.25
379.00
378.75
378.50
378.25
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01

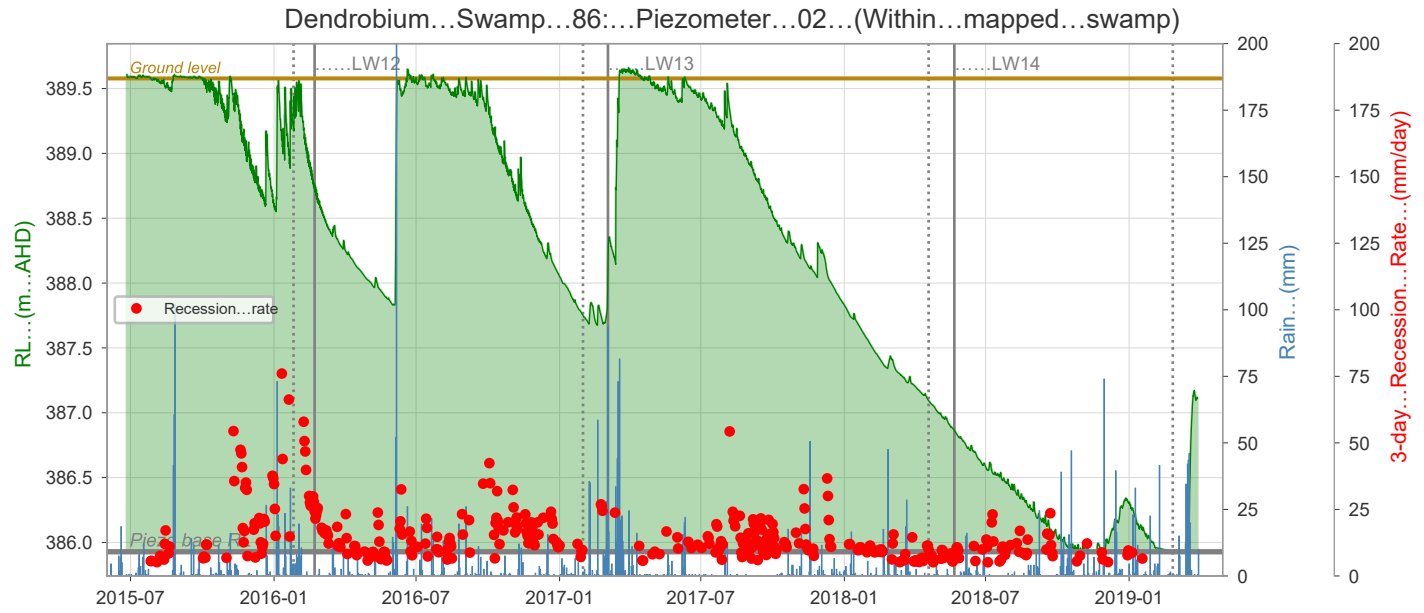

Dendrobium…Swamp…35b:…Piezometer…01…(Within…mapped…swamp)
Ground level
LW12
LW13
Recession…rate
Piezo base RL
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
352.5
352.0
351.5
351.0
350.5
350.0
349.5
349.0
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01

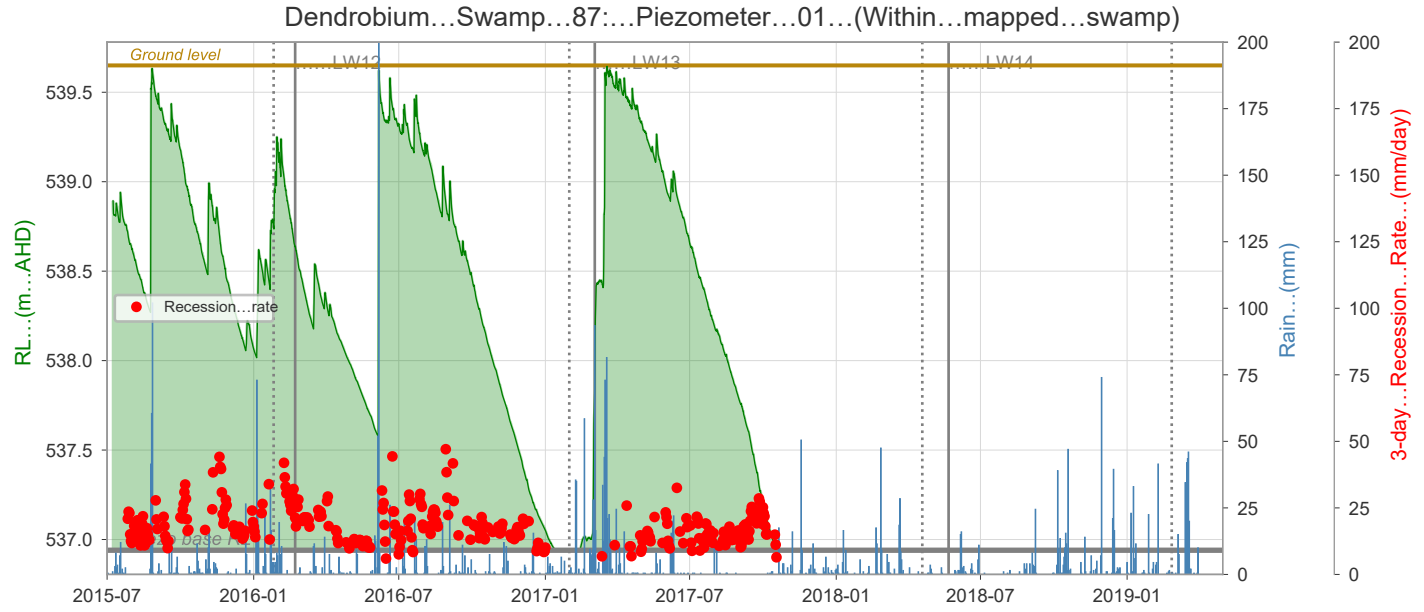

Dendrobium…Swamp…84:…Piezometer…01…(Within…mapped…swamp)
Ground level
LW12
LW13
LW14
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
348.6
348.4
348.2
348.0
347.8
347.6
347.4
347.2
347.0
2015-07
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01

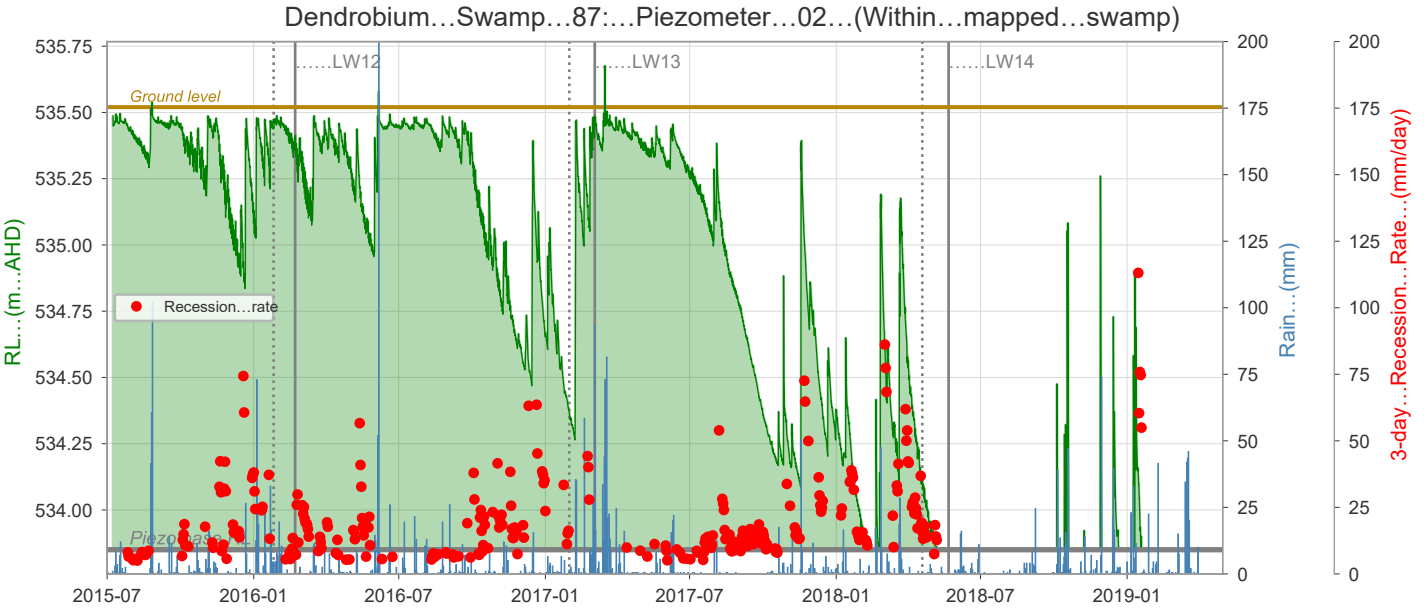

Dendrobium…Swamp…85:…Piezometer…01…(Within…mapped…swamp)
Ground level
LW12
LW13
LW14
Recession…rate
Piezo base RL
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
2015-07
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01

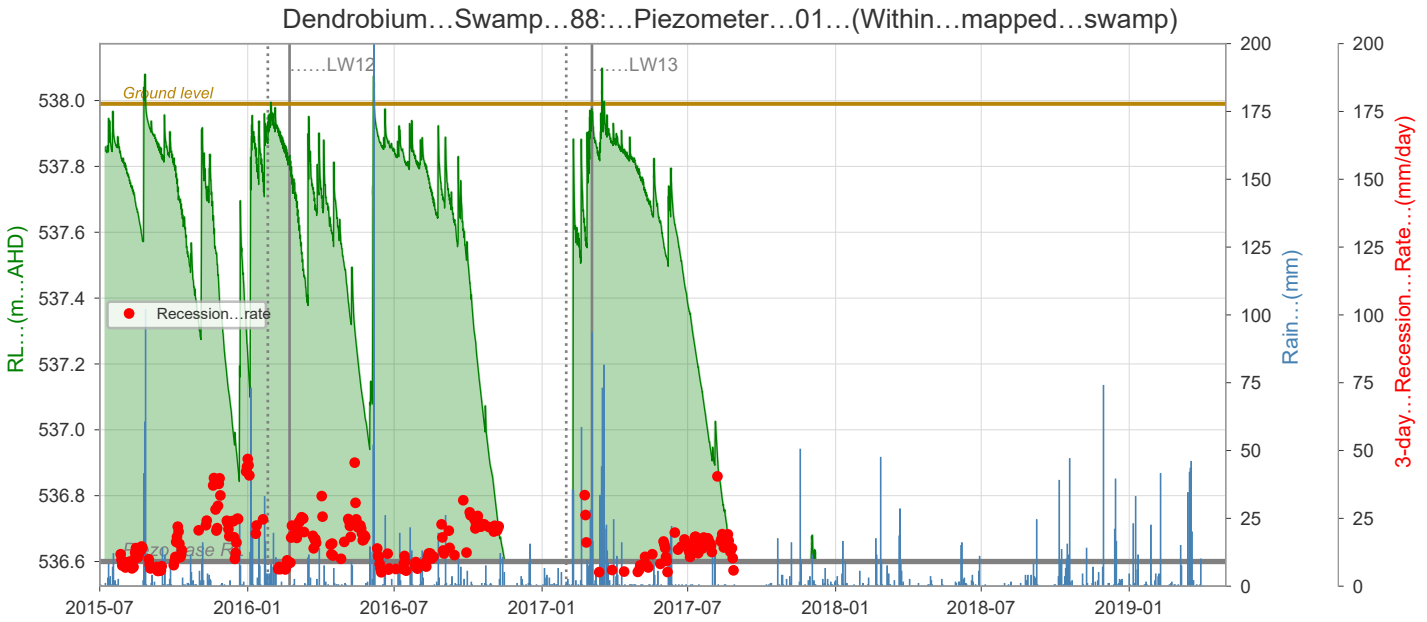

Dendrobium…Swamp…85:…Piezometer…02…(Within…mapped…swamp)
Ground level
LW12
LW13
LW14
Recession…rate
Piezo base RL
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
2015-07
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01

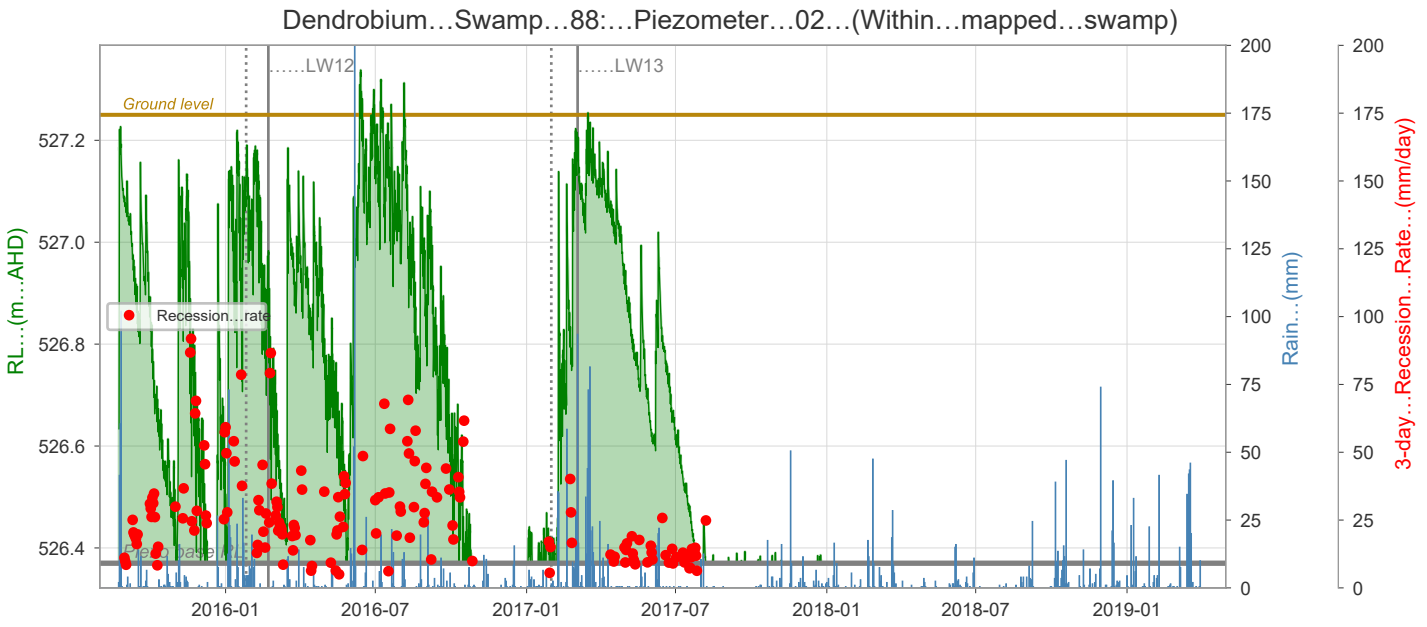

Dendrobium…Swamp…86:…Piezometer…01…(Within…mapped…swamp)
Ground level
LW12
LW13
LW14
Recession…rate
Piezo base RL
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
2015-07
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01


Dendrobium…Swamp…86:…Piezometer…02…(Within…mapped…swamp)
Ground level
LW12
LW13
LW14
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
389.5
389.0
388.5
388.0
387.5
387.0
386.5
386.0
200
175
150
125
100
75
50
25
0
2015-07
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01


Dendrobium…Swamp…87:…Piezometer…01…(Within…mapped…swamp)
Ground level
LW12
LW13
LW14
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
539.5
539.0
538.5
538.0
537.5
537.0
200
175
150
125
100
75
50
25
0
2015-07
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01


Dendrobium…Swamp…87:…Piezometer…02…(Within…mapped…swamp)
Ground level
LW12
LW13
LW14
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
535.75
535.50
535.25
535.00
534.75
534.50
534.25
534.00
200
175
150
125
100
75
50
25
0
2015-07
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01


Dendrobium…Swamp…88:…Piezometer…01…(Within…mapped…swamp)
LW12
LW13
Ground level
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
538.0
537.8
537.6
537.4
537.2
537.0
536.8
536.6
200
175
150
125
100
75
50
25
0
2015-07
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01


Dendrobium…Swamp…88:…Piezometer…02…(Within…mapped…swamp)
LW12
LW13
Ground level
Recession…rate
RL…(m…AHD)
Rain…(mm)
3-day…Recession…Rate…(mm/day)
527.2
527.0
526.8
526.6
526.4
200
175
150
125
100
75
50
25
0
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01

# APPENDIX 4 – Trigger Action Response Plan (Area 3A)

**Table 1.2 – Dendrobium Area 3A Watercourse Impacts, Triggers and Response**

| OBSERVATIONAL MONITORING | | |
|---|---|---|
| **Sandy Creek, Wongawilli Creek and SC-WF1**<br><br>**Relevant Performance Measure(s):**<br>• Wongawilli Creek - minor environmental consequences<br>• Sandy Creek - minor environmental consequences<br>• Sandy Creek Waterfall<br>- no rock fall occurs at Sandy Creek Waterfall or from its overhang;<br>- the structural integrity of the waterfall, its overhang and its pool are not impacted;<br>- cracking in Sandy Creek within 30 m of the waterfall is of negligible environmental and hydrological consequence; and<br>- negligible diversion of water occurs from the lip of the waterfall<br><br>General observation of streams in active mining areas when longwall is within 400m | ***Level 1***<br>• Crack or fracture up to 100mm width at its widest point with no observable loss of surface water or erosion<br>• Crack or fracture up to 10m length with no observable loss of surface water or erosion<br>• Erosion in a localised area (not associated with cracking or fracturing) which would be expected to naturally stabilise without CMA and within the period of monitoring<br>• Observable release of strata gas at the surface<br>• Observable increase in iron staining within the mining area<br>• Observation that a pool on a subject Creek is dry<br>• Observation that the subject Creek has ceased to flow | • Continue monitoring program<br>• Submit an Impact Report to BCD, DPIE, DRG, Water NSW<br>• Report in the End of Panel Report<br>• Summarise actions and monitoring in AEMR |
| | ***Level 2***<br>• Observation that a single pool on a subject Creek is dry in consecutive monitoring events<br>• Observation that two or more pools on a subject Creek are dry in a single monitoring event<br>• Observation that the subject Creek has ceased to flow in consecutive monitoring event | • *Actions as stated for Level 1*<br>• Carry out Water Flow Assessment Method D<br>• Review monitoring frequency<br>• Submit letter report to DPIE, DRG and Water NSW and seek advice on any CMA required<br>• Implement agreed CMAs as approved (subject to agency feedback) |
| | • Crack or fracture between 100 and 300mm width at its widest point or any fracture which results in observable loss of surface water or erosion<br>• Crack or fracture between 10 and 50m length<br>• Soil surface crack that causes erosion that is likely to stabilise within the monitoring period without intervention<br>• Observable increase in iron staining within the mining area continues to outside the mining area i.e. 400m from the longwall | • *Actions as stated for Level 1*<br>• Review monitoring frequency<br>• Submit letter report to DPIE, DRG and Water NSW and seek advice on any CMA required<br>• Implement agreed CMAs as approved (subject to agency feedback) |
| | ***Level 3***<br>• Crack or fracture over 300mm width at its widest point<br>• Crack or fracture over 50m length<br>• Fracturing observed in the bedrock base of any significant permanent pool which results in observable loss of surface water<br>• Soil surface crack that causes erosion that is unlikely to stabilise within the monitoring period without intervention | • *Actions as stated for Level 2*<br>• Offer site visit with BCD, DPIE, DRG, Water NSW<br>• Implement additional monitoring or increase frequency if required<br>• Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BCD, DPIE, DRG, Water NSW<br>• Completion of works following approvals and at a time agreed between S32, DPIE, DRG and Water NSW (i.e. may be after mining induced |

| | | |
|---|---|---|
| | • Gas release results in vegetation dieback, mortality or loss of aquatic habitat<br>• Observable increase in iron staining within the mining area continues more than 600m from the longwall | movements and impacts are complete), including monitoring and reporting on success<br>• Review relevant TARP and Management Plan in consultation with key agencies |
| | ***Exceeding Prediction***<br>• Structural integrity of the bedrock base of any significant permanent pool or controlling rockbar cannot be restored i.e. pool water level within the pool after CMAs continues to be lower than baseline period<br>• Gas release results in vegetation dieback that does not revegetate<br>• Gas release results in mortality of threatened species or ongoing loss of aquatic habitat<br>• Iron staining and associated increases in dissolved iron resulting from the mining is observed in water at Wongawilli Creek downstream monitoring site Wongawilli Creek (FR6)<br>• Iron staining and associated increases in dissolved iron resulting from the mining is observed in water at the Sandy Creek downstream monitoring site Sandy Creek SCk_Rockbar 5<br>• Rock fall at SC-WF1 or its overhang<br>• Impacts on the structural integrity of SC-WF1, its overhang or its pool<br>• Cracking in Sandy Creek within 30 m of the waterfall is of greater than negligible environmental and hydrological consequence<br>• Greater than negligible diversion of water occurs from the lip of the waterfall | • *Actions as stated for Level 3*<br>• Investigate reasons for the exceedance<br>• Update future predictions based on the outcomes of the investigation<br>• Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent |
| **WC13, WC14, WC15, WC16, WC17, WC17A, WC17B, SC7, SC10 and SC10C**<br><br>General observation of streams in active mining areas when longwall is within 400m | ***Level 1***<br>• Crack or fracture up to 100mm width at its widest point with no observable loss of surface water or erosion<br>• Crack or fracture up to 10m length with no observable loss of surface water or erosion<br>• Erosion in a localised area (not associated with cracking or fracturing) which would be expected to naturally stabilise without CMA and within the period of monitoring<br>• Observable release of strata gas at the surface<br>• Observable increase in iron staining within the mining area | • Continue monitoring program<br>• Submit an Impact Report to BCD, DPIE, DRG, Water NSW<br>• Report in the End of Panel Report<br>• Summarise actions and monitoring in AEMR |

| | | |
|---|---|---|
| | ***Level 2***<br>• Crack or fracture between 100 and 300mm width at its widest point or any fracture which results in observable loss of surface water or erosion<br>• Crack or fracture between 10 and 50m length<br>• Soil surface crack that causes erosion that is likely to stabilise within the monitoring period without intervention<br>• Observable increase in iron staining within the mining area continues to outside the mining area i.e. 400m from the longwall | • *Actions as stated for Level 1*<br>• Review monitoring frequency<br>• Submit letter report to DPIE, DRG and Water NSW and seek advice on any CMA required<br>• Implement agreed CMAs as approved (subject to agency feedback) |
| | ***Level 3***<br>• Crack or fracture over 300mm width at its widest point<br>• Crack or fracture over 50m length<br>• Fracturing observed in the bedrock base of any significant permanent pool which results in observable loss of surface water<br>• Soil surface crack that causes erosion that is unlikely to stabilise within the monitoring period without intervention<br>• Gas release results in vegetation dieback, mortality or loss of aquatic habitat<br>• Observable increase in iron staining within the mining area continues more than 600m from the longwall | • *Actions as stated for Level 2*<br>• Offer site visit with BCD, DPIE, DRG, Water NSW<br>• Implement additional monitoring or increase frequency if required<br>• Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BCD, DPIE, DRG, Water NSW<br>• Completion of works following approvals and at a time agreed between S32, DPIE, DRG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success<br>• Review relevant TARP and Management Plan in consultation with key agencies |
| **WATER QUALITY** | | |
| **Wongawilli Creek**<br><br>**Relevant Performance Measure(s):**<br>• Wongawilli Creek - minor environmental consequences<br><br>Wongawilli Creek (FR6)<br>Baseline means:<br>• pH 5.98<br>• EC 98.8 uS/cm<br>• DO 89.5% | ***Level 1***<br>• One exceedance of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months:<br>– pH 4.45<br>– EC 154.1 uS/cm<br>– DO 50.5% | • Continue monitoring program<br>• Submit an Impact Report to BCD, DPIE, DRG, Water NSW<br>• Report in the End of Panel Report<br>• Summarise actions and monitoring in AEMR |
| | ***Level 2***<br>• Two non-consecutive exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months:<br>– pH 4.45<br>– EC 154.1 uS/cm<br>– DO 50.5% | • *Actions as stated for Level 1*<br>• Review monitoring frequency<br>• Submit letter report to DPIE, DRG and Water NSW and seek advice on any CMA required<br>• Implement agreed CMAs as approved (subject to agency feedback) |

| | | |
|---|---|---|
| | ***Level 3***<br>• Three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months:<br>– pH 4.45<br>– EC 154.1 uS/cm<br>– DO 50.5% | • *Actions as stated for Level 2*<br>• Offer site visit with BCD, DPIE, DRG, Water NSW<br>• Implement additional monitoring or increase frequency if required<br>• Review relevant TARP and Management Plan in consultation with key agencies<br>• Develop site CMA (subject to agency feedback). This may include:<br>– Limestone emplacement to raise pH where it is appropriate to do so<br>• Completion of works following approvals and at a time agreed between S32, DPIE, DRG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success |
| | ***Exceeding Prediction***<br>• Mining results in two consecutive exceedances or three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months:<br>– pH 4.45<br>– EC 154.1 uS/cm<br>– DO 50.5% | • *Actions as stated for Level 3*<br>• Investigate reasons for the exceedance<br>• Update future predictions based on the outcomes of the investigation<br>• Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent |
| **Sandy Creek**<br><br>**Relevant Performance Measure(s):**<br>• Sandy Creek - minor environmental consequences<br><br>SCk_Rockbar 5 Site<br>Baseline means:<br>• pH x<br>• EC x uS/cm<br>• DO x% | ***Level 1***<br>• One exceedance of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months:<br>– pH x<br>– EC x uS/cm<br>– DO x% | • Continue monitoring program<br>• Submit an Impact Report to BCD, DPIE, DRG Water NSW<br>• Report in the End of Panel Report<br>• Summarise actions and monitoring in AEMR |
| | ***Level 2***<br>• Two non-consecutive exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months:<br>– pH x<br>– EC x uS/cm<br>– DO x% | • *Actions as stated for Level 1*<br>• Review monitoring frequency<br>• Submit letter report to DPIE, DRG and Water NSW and seek advice on any CMA required<br>• Implement agreed CMAs as approved (subject to agency feedback) |
| | ***Level 3*** | • *Actions as stated for Level 2*<br>• Offer site visit with BCD, DPIE, DRG, Water NSW<br>• Implement additional monitoring or increase frequency if required |

| | | |
|---|---|---|
| | • Three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months:<br>– pH x<br>– EC x uS/cm<br>– DO x% | • Review relevant TARP and Management Plan in consultation with key agencies<br>• Collect laboratory samples and analyse for:<br>– pH, EC, major cations, major anions, Total Fe, Mn & Al<br>– Filterable suite of metals<br>• Develop site CMA (subject to agency feedback). This may include:<br>– Limestone emplacement to raise pH where it is appropriate to do so<br>• Completion of works following approvals and at a time agreed between S32, DPIE, DRG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success |
| | ***Exceeding Prediction***<br>• Mining results in two consecutive exceedances or three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months:<br>– pH x<br>– EC x uS/cm<br>– DO x% | • *Actions as stated for Level 3*<br>• Investigate reasons for the exceedance<br>• Update future predictions based on the outcomes of the investigation<br>• Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent |
| **Lake Cordeaux**<br><br>**Relevant Performance Measure(s):**<br>• Lake Cordeaux - negligible reduction in the quality of surface water inflows to Lake Cordeaux<br><br>Sandy Creek Arm Site<br>Baseline means:<br>• pH x<br>• EC x uS/cm<br>• DO x% | ***Level 1***<br>• One exceedance of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months:<br>– pH x<br>– EC x uS/cm<br>– DO x% | • Continue monitoring program<br>• Submit an Impact Report to BCD, DPIE, DRG, Water NSW<br>• Report in the End of Panel Report<br>• Summarise actions and monitoring in AEMR |
| | ***Level 2***<br>• Two non-consecutive exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months:<br>– pH x<br>– EC x uS/cm<br>– DO x% | • *Actions as stated for Level 1*<br>• Review monitoring frequency<br>• Submit letter report to DPIE, DRG and Water NSW and seek advice on any CMA required<br>• Implement agreed CMAs as approved (subject to agency feedback) |
| | ***Level 3*** | • *Actions as stated for Level 2*<br>• Offer site visit with BCD, DPIE, DRG, Water NSW<br>• Implement additional monitoring or increase frequency if required |

| | | |
|---|---|---|
| | • Three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months:<br>– pH x<br>– EC x uS/cm<br>– DO x% | • Review relevant TARP and Management Plan in consultation with key agencies<br>• Collect laboratory samples and analyse for:<br>– pH, EC, major cations, major anions, Total Fe, Mn & Al<br>– Filterable suite of metals<br>• Develop site CMA (subject to agency feedback). This may include:<br>– Limestone emplacement to raise pH where it is appropriate to do so<br>– Grouting of fractures in rockbar and bedrock base of any significant pool where flow diversion results in pool water level lower than baseline period<br>• Completion of works following approvals and at a time agreed between S32, DPIE, DRG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success |
| | ***Exceeding Prediction***<br>• Mining results in two consecutive exceedances or three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months:<br>– pH x<br>– EC x uS/cm<br>– DO x% | • *Actions as stated for Level 3*<br>• Investigate reasons for the exceedance<br>• Update future predictions based on the outcomes of the investigation<br>• Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent |
| **POOL WATER LEVEL** | | |
| **Wongawilli Creek and Sandy Creek**<br><br>**Relevant Performance Measure(s):**<br>• Wongawilli Creek - minor environmental consequences<br>• Sandy Creek - minor environmental consequences | ***Level 1***<br>• Single pool on a subject Creek is observed as dry | • Continue monitoring program<br>• Carry out Water Flow Assessment Method D.<br>• Submit letter report to DPIE, DRG and Water NSW<br>• Report in the End of Panel Report<br>• Summarise actions and monitoring in AEMR |
| | ***Level 2***<br>• Single pool on a subject Creek is observed as dry in consecutive monitoring events<br>• Two or more pools on a subject Creek are observed as dry in a single monitoring event | • *Actions as stated for Level 1*<br>• Review monitoring frequency<br>• Submit letter report to DPIE, DRG and Water NSW and seek advice on any CMA required<br>• Implement agreed CMAs as approved (subject to agency feedback) |

| | | |
|---|---|---|
| | ***Level 3***<br>• Fracturing resulting in diversion of flow such that <10% of the pools have water levels lower than baseline period | • *Actions as stated for Level 2*<br>• Offer site visit with BCD, DPIE, DRG, Water NSW<br>• Implement additional monitoring or increase frequency if required<br>• Review relevant TARP and Management Plan in consultation with key agencies<br>• Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BD, DPIE, DRG, Water NSW<br>• Completion of works following approvals and at a time agreed between S32, DPIE, DRG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success |
| | ***Exceeding Prediction***<br>• Fracturing resulting in diversion of flow such that >10% of the pools have water levels lower than baseline period | • *Actions as stated for Level 3*<br>• Investigate reasons for the exceedance<br>• Update future predictions based on the outcomes of the investigation<br>• Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent |
| **Waterfall WC-WF54**<br><br>**Relevant Performance Measure(s):**<br>• Waterfall WC-WF54 – negligible environmental consequences | ***Exceeding Prediction***<br>• Fracturing in Wongawilli Creek within 30m of the waterfall which results in observable flow diversion<br>• Fracturing in Wongawilli Creek which results in observable flow diversion from the lip of the waterfall | • *Actions as stated for Level 3*<br>• Investigate reasons for the exceedance<br>• Update future predictions based on the outcomes of the investigation<br>• Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent |

| Monitoring | Trigger | Action |
|---|---|---|
| **SURFACE WATER FLOW** | | |
| **Wongawilli Creek and Sandy Creek**<br>**Lake Cordeaux and Cordeaux River**<br><br>**Relevant Performance Measure(s):** | ***Level 1***<br>• A) Lower flow than expected (additional 10-15% of days where Q% lower than Reference Q%)<br>• B) 5-10% increase in cease-to-flow frequency beyond natural)<br>• C) Reduction in Q50 (10-15% beyond natural) | • Continue monitoring program.<br>• Submit an Impact Report to BCD, DPIE, DRG, WaterNSW.<br>• Report in the End of Panel Report.<br>• Summarise actions and monitoring in AEMR. |

| | | |
|---|---|---|
| • Wongawilli Creek - minor environmental consequences<br>• Sandy Creek - minor environmental consequences<br>• Lake Cordeaux - negligible reduction in the quantity of surface water inflows to Lake Cordeaux[1]<br>• Cordeaux River - negligible reduction in the quantity of surface water inflow to the Cordeaux River at its confluence with Wongawilli Creek[2]<br><br>**Surface water flow Reference sites** (as in Table 1.1)**:**<br>• Wongawilli Creek - WWU (Wongawilli Creek upstream);<br>• O'Hares Creek at Wedderburn (213200);<br>• (other such sites, if necessary, include Woronora River 2132101 and Bomaderry Creek 215016)<br><br>NB. This section of the TARP contains four Water Flow Assessment Methods, labelled A, B, C and D, which are specified in detail in Watershed HydroGeo (2019).<br><br>Hydrological changes are assessed by comparing pre- and post-mining observed flows from impact or assessment sites to flow data from the reference sites.<br>*Natural variability ('NV') will be defined as the 'average' change at the selected reference sites. Triggers may occur when the apparent impact at a site (NV + x% change) could be less than maximum observed variability at one of the reference sites.* | ***Level 2***<br>• A) Lower flow than expected (additional 15-20% of days where Q% lower than Reference Q%).<br>• B) 10-20% increase in cease-to-flow frequency (beyond natural)<br>• C) 15-20% reduction in Q50 (beyond natural)<br>• D) Observation that the subject Creek has ceased to flow at spatially consecutive monitoring sites. | • *Actions as stated for Level 1*<br>• Review monitoring frequency.<br>• D) → carry out Water Flow Assessment Method D.<br>• Submit letter report to DPIE, DRG and WaterNSW and seek advice on any CMA required.<br>• Implement agreed CMAs as approved (subject to agency feedback). |
| | ***Level 3***<br>• A) Lower flow than expected (additional >20% of days where Q% lower than Reference Q%)<br>• B) >20% increase in cease-to-flow frequency (beyond natural)<br>• C) >20% reduction in Q50 (beyond natural) | • *Actions as stated for Level 2*<br>• Offer site visit with BCD, DPIE, DRG, WaterNSW.<br>• Implement additional monitoring or increase frequency if required.<br>• Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BCD, DPIE, DRG, WaterNSW.<br>• Completion of works following approvals and at a time agreed between S32, DPIE, DRG and WaterNSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success.<br>• Review relevant TARP and Management Plan in consultation with key agencies. |
| | ***Exceeding Prediction***<br>Measured surface water flow reduction, based on Assessment Methods C, D, to be compared against predictions made in contemporary groundwater modelling conducted to the satisfaction of the Secretary to assess whether effects that cannot be explained by natural variability "exceed prediction". | • *Actions as stated for Level 3*<br>• Investigate reasons for the exceedance.<br>• Update future predictions based on the outcomes of the investigation.<br>• Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent. |

[1] Surface water inflows calculation = [Impacts at gauged catchments (SCL2) + LC5 + estimated impacts at ungauged but undermined catchments] / [total estimated inflow to LC].
[2] Flow reduction as determined from measured at flow gauging station WWL_A.

| | | |
|---|---|---|
| **Tributaries of Wongawilli Creek and Sandy Creek and other affected watercourses not subject to performance measures**<br><br>**Surface water flow Reference sites** (as in Table 1.1)**:**<br>• Wongawilli Creek - WWU (Wongawilli Creek upstream);<br>• O'Hares Creek and Wedderburn (213200);<br>• (other such sites, if necessary, include Woronora River 2132101 and Bomaderry Creek 215016)<br>NB. This section of the TARP contains four Water Flow Assessment Methods, labelled A, B, C and D, which are specified in detail in Watershed HydroGeo (2019).<br><br>Hydrological changes are assessed by comparing pre- and post-mining observed flows from impact or assessment sites to flow data from the reference sites.<br>*Natural variability ('NV') will be defined as the 'average' change at the selected reference sites. Triggers may occur when the apparent impact at a site (NV + x% change) could be less than maximum observed variability at one of the reference sites.* | ***Level 1***<br>• A) Lower flow than expected (additional 10-20% of days where Q% lower than Reference Q%)<br>• B) 5-10% increase in cease-to-flow frequency (beyond natural)<br>• C) 10-20% reduction in Q50 (beyond natural) | • Continue monitoring program.<br>• Submit an Impact Report to BCD, DPIE, DRG, WaterNSW.<br>• Report in the End of Panel Report.<br>• Summarise actions and monitoring in AEMR. |
| | ***Level 2***<br>• A) Lower flow than expected (additional 20-30% of days where Q% lower than Reference Q%)<br>• B) 10-20% increase in cease-to-flow frequency (beyond natural)<br>• C) 20-30% reduction in Q50 (beyond natural) | • *Actions as stated for Level 1*<br>• Review monitoring frequency.<br>• Submit letter report to DPIE, DRG and WaterNSW and seek advice on any CMA required.<br>• Implement agreed CMAs as approved (subject to agency feedback). |
| | ***Level 3***<br>• A) Lower flow than expected (additional >30% of days where Q% lower than Reference Q%)<br>• B) >20% increase in cease-to-flow frequency (beyond natural)<br>• C) >30% reduction in Q50 (beyond natural) | • *Actions as stated for Level 2*<br>• Offer site visit with BCD, DPIE, DRG, WaterNSW.<br>• Implement additional monitoring or increase frequency if required<br>• Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BCD, DPIE, DRG, WaterNSW.<br>• Completion of works following approvals and at a time agreed between S32, DPIE, DRG and WaterNSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success.<br>• Review relevant TARP and Management Plan in consultation with key agencies. |
| **AQUATIC ECOLOGY** | | |
| **Pool water level, interconnectivity between pools and loss of connectivity, noticeable alteration of habitat**<br>• Wongawilli Creek catchment – 8 sites<br>• Sandy Creek catchment – 2 sites | ***Level 1***<br>• Reduction in aquatic habitat for 1 year | • Continue monitoring program<br>• Submit an Impact Report to BCD, DPIE, DRG, Water NSW<br>• Report in the End of Panel Report<br>• Summarise actions and monitoring in AEMR |
| | ***Level 2*** | • *Actions as stated for Level 1* |

| | | |
|---|---|---|
| **Relevant Performance Measure(s):**<br>• Wongawilli Creek - minor environmental consequences<br>• Sandy Creek - minor environmental consequences | • Reduction in aquatic habitat for 2 years following the active subsidence period | • Review monitoring frequency<br>• Submit letter report to DPIE, BCD, DRG and Water NSW and seek advice on any CMA required<br>• Implement agreed CMAs as approved (subject to agency feedback) |
| | ***Level 3***<br>• Reduction in aquatic habitat for >2 years following the active subsidence period | • *Actions as stated for Level 2*<br>• Offer site visit with BCD, DPIE, DRG, Water NSW<br>• Implement additional monitoring or increase frequency if required<br>• Review relevant TARP and Management Plan in consultation with key agencies<br>• Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BCD, DPIE, DRG, Water NSW<br>• Completion of works following approvals and at a time agreed between S32, DPIE, DRG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success |
| **TERRESTRIAL FAUNA – THREATENED FROG SPECIES** | | |
| **Pool water level, interconnectivity between pools and loss of connectivity, noticeable alteration of habitat**<br>• Wongawilli Creek catchment – 2 sites<br>• Sandy Creek catchment – 5 sites<br>**Relevant Performance Measure(s):**<br>• Wongawilli Creek - minor environmental consequences<br>• Sandy Creek - minor environmental consequences | ***Level 1***<br>• Reduction in habitat for 1 year | • Continue monitoring program<br>• Submit an Impact Report to BCD, DPIE, DRG, Water NSW<br>• Report in the End of Panel Report<br>• Summarise actions and monitoring in AEMR |
| | ***Level 2***<br>• Reduction in habitat for 2 years following the active subsidence period | • *Actions as stated for Level 1*<br>• Review monitoring frequency<br>• Submit letter report to DPIE, BCD, DRG and Water NSW and seek advice on any CMA required<br>• Implement agreed CMAs as approved (subject to agency feedback) |
| | ***Level 3***<br>• Reduction in habitat for > 2 years following the active subsidence period | • *Actions as stated for Level 2*<br>• Offer site visit with BCD, DPIE, DRG, Water NSW<br>• Implement additional monitoring or increase frequency if required<br>• Review relevant TARP and Management Plan in consultation with key agencies<br>• Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BCD, DPIE, DRG, Water NSW<br>• Completion of works following approvals and at a time agreed between S32, DPIE, DRG and Water NSW (i.e. may be after mining induced |

| | | |
|---|---|---|
| | | movements and impacts are complete), including monitoring and reporting on success |

Department of Planning, Industry and Environment (DPIE)

Biodiversity and Conservation Division (BCD) within DPIE

Division of Resources and Geoscience within the Department (DRG) within DPIE

WaterNSW

## Attachment F – Terrestrial Ecology Assessment

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# DENDROBIUM LONGWALL 19 TERRESTRIAL ECOLOGICAL ASSESSMENT

## ACCOMPANYING DOCUMENT TO DENDROBIUM LONGWALL 19 SUBSIDENCE MANAGEMENT PLAN

Prepared for SOUTH32 ILLAWARRA METALLURGICAL COAL | 11 March 2020



## Document control

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# Executive Summary

## Project outline

Niche Environment and Heritage Pty Ltd (Niche) was commissioned by South32 Illawarra Metallurgical Coal (IMC) to prepare a Terrestrial Ecological Assessment for the extraction of Longwall 19 within Dendrobium Area 3A (DA3A). Initial approval to mine Dendrobium Area 3 was granted in 2001 (DA 60-03-2001) and a modification to the consent was granted in 2008. Development consent was granted following the completion of a number of assessments specific to DA3 including a Species Impact Statement (SIS), which was completed in 2007 (Biosis 2007) as part of the modification.

Further to the 2008 approval, a Subsidence Management Plan (SMP), specific to Longwall 19 within DA3A is required to be approved by the New South Wales Department of Planning, Industry and Environment (DPIE) prior to any mining of the proposed Longwall 19. The SMP must be accompanied by a revised terrestrial ecological assessment to address any recent legislative changes, guidelines and research regarding subsidence associated with longwall mining. This report constitutes the revised terrestrial ecological assessment and is specific to Longwall 19 having regard to the proposed mine design and longwall layout as defined by the Mine Subsidence Engineering Consultants (MSEC) subsidence impact assessment (MSEC 2020).

The SMP involved flora and fauna surveys within DA3A and focused on landscape features and associated biodiversity which may be sensitive to the impacts of subsidence from longwall extraction. The study area was defined by the limit of subsidence associated with proposed Longwall 19.

Natural areas and features sensitive to subsidence within the DA3A study area include: Wongawilli Creek, watercourses, cliffs, rock outcrops, steep slopes and Upland Swamps. Significant conclusions from the MSEC (2020) report, relevant to this study include the following:

- The likelihood of fracturing resulting in surface water flow diversions along Wongawilli Creek is low. However, minor fracturing could still occur along the creek, at distances up to approximately 400 m from the proposed longwall.
- It is unlikely that there would be adverse changes in the potential for ponding, flooding or scouring of the banks along the Wongawilli Creek due to the mining-induced tilt. It is possible, however, that there could be some localised changes in the levels of ponding or flooding where the maximum changes in grade coincide with existing pools, steps or cascades along the creek. It is not anticipated that these changes would result in adverse impacts on the creek.
- It is unlikely that adverse impacts would occur along Sandy Creek or Sandy Creek waterfall due to the mining of Longwall 19.
- The potential impacts of increased ponding and scouring of the drainage lines due to tilt are expected to be minor and localised.
- It is expected that fracturing of the bedrock would occur along the sections of the drainage lines that are located directly above Longwall 19 and the adjacent existing Longwalls 7 and 8. Fracturing can also occur outside the extents of the longwall, with minor and isolated fracturing occurring at distances up to approximately 400 m. Surface water flow diversions are likely to occur along the sections of drainage lines that are located directly above and adjacent to the longwalls.
- Cliffs could be impacted due to the extraction of Longwall 19 directly beneath them. The impacts are predicted to represent approximately 7 % to 10 % of the total plan length of the cliffs located directly above Longwall 19. Isolated rock falls could occur at some of the cliffs located outside the extents of

the proposed longwall and within the angle of draw. It is unlikely that other cliffs located outside the 35° angle of draw would experience adverse impacts due to their distances outside of the mining area.

- It is likely that fracturing and cracking would occur where rock outcrops and steep slopes are located directly above the proposed longwalls.
- Fracturing of the bedrock could occur beneath swamps within the study area. Fracturing could occur beneath swamp Den15a near the valley base and where it is located closest to the proposed longwall. The dilated strata beneath the drainage lines could result in the diversion of some surface water flows beneath parts of the swamps where they are located above or adjacent to the proposed longwall (including swamp Den15a). Where there is no connective fracturing to any deeper storage, it is likely that surface water flows will re-emerge at the limits of fracturing and dilation.
- Baseflow components of Wongawilli Creek and Sandy Creek are predicted to decline following longwall extraction. These reductions in base flow can result in an increased number of cease to flow days.
- Water quality influences due to mining is expected to be minor in stream reaches within subsidence affected areas. Effects are likely to include temporary changes in water salinity, pH and iron content with local impacts to streambeds and rock faces by iron hydroxide.

### Literature Review

The findings from the MSEC (2020) report form the basis to which the impact assessments for threatened flora, fauna and ecological communities have been assessed in this report.

A significant body of other work relating to previous approvals and monitoring for underground mining within DA3A and DA3B was reviewed as part of this report with major reports listed below:

- SIS completed for the 2008 modification (Biosis 2007);
- Dendrobium Area 3C Terrestrial Ecology Assessment (Niche 2019);
- Dendrobium Area 3B Terrestrial Ecology Assessment (Niche 2012);
- Monitoring as part of previous SMPs for longwalls within Areas 3A and 3B including annual and end of panel reporting (e.g. Biosis 2019; HGeo 2017);
- Statutory reviews and policy guidelines including;
    - Southern Coalfields Inquiry (DOP 2008);
    - Upland Swamps Environmental Assessment Guidelines – Draft (OEH 2012); and
    - Independent Expert Panel for Mining in the Catchment Report: Part 2. Coal Mining Impacts in the Special Areas of the Greater Sydney Water Catchment (IEPMC 2019).

### Summary of Methods

Literature review was supplemented with field survey concentrating on landscape features and associated biodiversity which may be sensitive to impacts of subsidence from longwall extraction such as swamps, watercourses and rocky areas. Survey was conducted in between December 2019 and January 2020.

Survey activities included vegetation validation of Upland Swamps; and diurnal and nocturnal frog and tadpole searches. A likelihood of occurrence and impact analysis was conducted for threatened species after considering the literature review and survey results.

### Summary of Results and Impact Assessment

Ground-truthing of upland swamp community mapping resulted in changes to upland swamp sub-community patterns, swamp boundaries and changes in vegetation communities. Nine Upland Swamps occur within the wider study area with complexity of swamps generally increasing with overall size. Two of

the complex larger swamps are within the predicted area of subsidence impacts (35 degree angle of draw study area). Based on previous subsidence monitoring, a maximum impact area for swamps was calculated at 18.12 hectares constituting the Upland Swamps within or along the 35 degree angle of draw study area.

Habitats such as pools, primarily located on Wongawilli Creek of which 1.4 km crosses the 600 m study area for Longwall 19, are likely to experience some level of subsidence impacts (comprising both direct and indirect impacts). Subsidence impacts to features such as cliffs, overhangs and rocky outcrops have the potential to occur but are likely to have limited impacts on threatened biodiversity within the study area due to the small area of predicted impacts.

Four threatened plant species (*Epacris purpurascens var. purpurascens, Pultenaea aristata, Cryptostylis hunteriana* and *Leucopogon exolasius)* were deemed to have habitat in the study area that may be potentially impacted by subsidence, however impacts for these species are likely to be minimal.

Nine threatened fauna species are considered to be potentially impacted by subsidence impacts resulting from the proposal comprising:

- Frogs: Littlejohn's Tree Frog, Giant Burrowing Frog, Red-crowned Toadlet.
- Reptiles: Broad-headed Snake, Rosenberg's Goanna.
- Mammals: Eastern Bentwing Bat, Little Bentwing Bat, Southern Myotis.
- Invertebrates: Giant Dragonfly.

From the above species, it is considered that potentially significant impacts could occur for the three frog species and the Giant Dragonfly.

Ongoing monitoring requirements for biodiversity are provided within the recommendations section of the report. Recommendations are focussed around swamp and frog monitoring along watercourses in concert with established programs for measuring physical impacts of subsidence.

# Glossary and list of abbreviations

| Term or abbreviation | Definition |
|---|---|
| BC Act | NSW *Biodiversity Conservation Act 2016* |
| BCD | Biodiversity Conservation Division of DPIE |
| DA3A | Dendrobium Area 3A |
| DEE | Commonwealth Department of Environment and Energy |
| DPE | NSW Department of Planning and Environment |
| DPIE | Department of Planning, Industry and Environment (formerly OEH) |
| EEC | Endangered Ecological Community |
| EP&A Act | NSW *Environmental Planning and Assessment Act 1979* |
| EPBC Act | Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* |
| ESSGW | Exposed Sandstone Scribbly Gum Woodland |
| ha | Hectares |
| KTP | Key Threatening Process |
| IMC | South32 Illawarra Metallurgical Coal |
| Locality | The area within a 10 kilometre radius of the study area |
| LW | Longwall |
| MNES | Matters of National Environmental Significance listed on the EPBC Act |
| NPWS | National Parks and Wildlife Service |
| OEH | NSW Office of Environment and Heritage (now DPIE) |
| Proposal | the development, activity or proposed action, LW19 |
| SGPF | Sandstone Gully Peppermint Forest |
| SIS | Species Impact Statement |
| SMP | Subsidence Management Plan |
| Study area | Area potentially directly or indirectly impacted by the proposal |
| TARP | Trigger Action Response Plan |
| THPS | Temperate Highland Peat Swamps |
| TSC Act | NSW *Threatened Species Conservation Act 1995* (repealed by the *BC Act*) |
| USBT | Upland Swamp: Banksia Thicket |
| USTTT | Upland Swamp: Tea Tree Thicket |
| USSHC | Upland Swamp: Sedgeland Heath Complex |
| USFEW | Upland Swamp: Fringing Eucalypt Woodland |

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# 1 Introduction

## 1.1 Background and need for the project

Niche Environment and Heritage Pty Ltd (Niche) was commissioned by South32 Illawarra Metallurgical Coal (IMC) to prepare a Terrestrial Ecological Assessment for the extraction of Longwall (LW) 19 within Dendrobium Area 3A (DA3A) (Figure 1). Initial approval to mine Dendrobium Area 3 was granted in 2001 (DA 60-03-2001) and a modification to the consent was granted in 2008 (Figure 2). Development consent was granted following the completion of a number of assessments specific to DA3 including a Species Impact Statement (SIS), which was completed in 2007 (Biosis 2007) as part of the modification.

Further to the 2008 approval, a Subsidence Management Plan (SMP) for LW19 within DA3A (Figure 1 and Figure 2) is required to be approved by the New South Wales (NSW) Department of Planning, Industry and Environment (DPIE) prior to any mining of the proposed LW19. The SMP must be accompanied by a revised terrestrial ecological assessment to address any recent legislative changes, guidelines and research regarding subsidence associated with longwall mining. This report constitutes the revised terrestrial ecological assessment and is specific to the proposed LW19 in DA3A having regard to the proposed mine design as defined by Mine Subsidence Engineering Consultants (MSEC) subsidence impact assessment (MSEC 2020).

This ecological report has been prepared to meet the relevant sections of the *NSW Department of Primary Industries Guideline for Applications for Subsidence Management Approvals December 2003*.

## 1.2 Statutory and other approvals

### 1.2.1 Landscape approval

Approval to mine Dendrobium Area 3 was granted by the Department of Planning in 2001. In 2007, IMC applied to modify the approval for Dendrobium Mine pursuant to section 75W of the *Environmental Planning and Assessment Act 1979* (EP&A Act). A SIS was conducted, and an environmental assessment completed to support the proposal to modify the footprint of Area 3.

Since the Dendrobium mine was approved by the Commonwealth of Australia as a controlled action under the *Environmental Protection and Biodiversity Act 1999* (EPBC Act) in December 2001, approval within this assessment is not required under the EPBC Act. Threatened species and threatened ecological communities (TECs) listed under the EPBC Act have been considered within this report, however revised impact assessments for species listed under the EPBC Act are not required.

## 1.3 Timeline and project justification

LW19 is scheduled to be extracted between February 2023 – September 2023.

Mine layouts for DA3A have been developed using IMC's Integrated Mine Planning Process (IMPP). This process considers mining and surface impacts when designing mine layouts. IMC has assessed mining layout options for DA3A against the following criteria:

- Extent, duration and nature of any community, social and environmental impacts;
- Coal customer requirements;
- Roadway development and longwall continuity;
- Mine services such as ventilation;
- Recovery of the resource for the business and the State; and

- Gas drainage, geological and geotechnical issues.

Several layout alternatives for DA3A were assessed by IMC using a multi-disciplinary team including environment, community, mining and exploration expertise. These included variations in the number of longwalls and orientations, lengths, and setbacks of the longwalls from key surface features. These options were reviewed, analysed and modified until an optimised longwall layout in DA3A was achieved. DA3A is part of the overall mining schedule for Dendrobium Mine and has been designed to flow on from (and return to) Areas 1, 2 3A, 3B and 3C to provide a continuous mining operation. There are a number of surface and subsurface constraints within the vicinity of DA3A including major surface water features such as Lake Cordeaux and Wongawilli Creek; and a number of geological constraints such as dykes, faults, and particularly the Dendrobium Nepheline Syenite Intrusion. The process of developing the layout for DA3A has considered predicted impacts on major natural features and aimed to minimise these impacts within geological and other mining constraints. The layouts at Dendrobium Mine have been modified to reduce the potential for impacts to surface features. The process adopted in designing the DA3A mine layout incorporated the hierarchy of avoid/minimise/mitigate as requested by the DPIE and its incorporated Biodiversity Conservation Division (BCD).

## 1.4 Consultation

IMC have consulted with key Government Agencies (e.g. DPIE and WaterNSW) during the development of the SMP.

# 2 Description of the study area and subsidence predictions

## 2.1 Study area

One longwall (LW19) (hereafter referred to as the proposal) has been proposed in the study area. The study area considered within this report (Figure 2) is consistent with the area described in MSEC 2020 as the surface area that could be affected by the mining of the proposed LW19 (area of longwall approximately 54 hectares [ha]) consisting of:

- The 35° angle of draw line from the extents of the proposed LW19;
- The predicted limit of vertical subsidence, taken as the 20 millimetres (mm) subsidence contour, resulting from the extraction of the proposed longwalls; and
- The natural features located within 600 metres (m) of the extent of the longwall mining area, in accordance with Condition 8(d) of the Development Consent DA 60-03-2001.

The study area at its largest (Figure 2) constitutes approximately 415 ha of largely undisturbed bushland and watercourses of the Cordeaux River Catchment inside the WaterNSW Metropolitan Special Area. The Cordeaux River is part of the Hawkesbury-Nepean Catchment.

Fire roads, easements and active and rehabilitating trails as well as exploration drilling sites occur within the study area and are the primary sources of disturbance. The study area is in WaterNSW controlled land and is contiguous with a large reserve system which includes the Upper Nepean State Conservation Area to the west and the Illawarra Escarpment Area to the east (Figure 1).

### 2.1.1 Creeks and waterways

The major permanent waterway within the study area, Wongawilli Creek, flows northwards through the western section of the study area and joins the Cordeaux River approximately 11.5 kilometres (km) to the north (Figure 2, Figure 3). Pools and riffle zones in Wongawilli Creek are permanent and naturally develop upstream of rockbars and at areas of sediment and debris accumulations (Figure 3).

Sandy Creek runs parallel to Wongawilli Creek to its east, to the east of the study area (Figure 3). Smaller tributary streams traverse the study area flowing into Wongawilli Creek, Sandy Creek and Lake Cordeaux to the east (outside of the study area). Lake Cordeaux or Cordeaux Dam is one of several large artificial waterbodies in the locality used for drinking water catchment.

A number of waterways throughout the study area have Upland Swamps at their headwaters or along other sections. Swamps within the study area act as a buffer for surface flow allowing for more continuous and even water flows along streams after rain events.

## 2.2 Predicted mine subsidence for natural features

Subsidence predictions for LW19 within DA3A were investigated and reported by MSEC (2020). Subsidence impacts for natural features prone to subsidence impacts were examined including:

- Major creeks and associated drainage features;
- Swamps; and
- Cliffs, rock outcrops and steep slopes.

These natural features may provide important habitat for threatened species or constitute TECs and are the focus of this assessment. A summary of the predicted impacts that the proposal will have on these features is described below (Table 1), as documented in MSEC (2020).

**Table 1: Predicted subsidence impacts to natural features and potential biodiversity impacts for Longwall 19 (MSEC 2020; HGeo 2020)**

| Feature | Description of natural feature | Predicted subsidence or surface water impact LW19 | Previously observed impacts in other areas |
|---|---|---|---|
| Wongawilli Creek | Wongawilli Creek is a third order perennial stream with a small base flow and increased flows for short periods of time after each significant rain event. The creek generally flows in a northerly direction and drains into the Cordeaux River more than 5 km north of LW19. Pools in the creek are permanent (based on monitoring to date) and naturally develop behind the rockbars and at sediment and debris accumulations.<br>Wongawilli Creek is situated on the western side of the existing LW6 to LW8 and proposed LW19 in DA3A. The currently active longwalls in Area 3B are being mined on the western side of the creek. The longwalls in both Areas 3A and 3B have been set back from Wongawilli Creek so that they do not directly mine beneath it.<br>Wongawilli Creek is located at a minimum distance of 175 m south-west of the finishing end of LW19, at its closest point. The minimum distances between the thalweg of the creek and the completed longwalls are 110 m for LW6 in DA3A and 290 m for LW9 in Area 3B.<br>The total length of Wongawilli Creek located within the study area based on the 35° angle of draw line and predicted 20 mm subsidence contour is approximately 0.1 km. The length of the creek located within the study area based on the 600 m boundary is approximately 1.4 km. | Wongawilli Creek is predicted to experience less than 20 mm vertical subsidence, 150 mm upsidence and 210mm closure due to the extraction of the proposed longwall.<br>It is unlikely that there would be adverse changes in the potential for ponding, flooding or scouring of the banks along the creek due to the mining-induced tilt. It is possible, however, that there could be some localised changes in the levels of ponding or flooding where the maximum changes in grade coincide with existing pools, steps or cascades along the creek. It is not anticipated that these changes would result in adverse impacts on the creek.<br>It has been assessed that the likelihood of fracturing resulting in surface water flow diversions along Wongawilli Creek, due to the extraction of the proposed LW19, is low, i.e. affecting less than 10 % of rockbars located within the study area. However, minor fracturing could still occur along the creek, at distances up to approximately 400 m from the proposed longwalls. | Wongawilli Creek was predicted to experience less than 20 mm vertical subsidence, 150 mm upsidence and 210mm closure due to the extraction of the proposed LW6 to LW18 and LW20-LW21.<br>The extraction of LW6 to LW14 resulted in one Type 3 impact along Wongawilli Creek. A Type 3 impact is defined as fracturing in a rockbar or upstream pool resulting in reduction in standing water level based on current rainfall and surface water flow. Fracturing was first observed in the bed of Pool 43a after the completion of LW9. This pool is located at distances of 200 m west of LW6 in DA3A and 410 m east of LW9 in Area 3B. Pool water levels below baseline conditions were observed in this pool during low flow conditions (i.e. Type 3 impact) after the completion of LW13. No other fractures have been observed along Wongawilli Creek due to the longwalls extracted in Areas 3A and 3B. |

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| Sandy Creek and Sandy Creek Waterfall | Sandy Creek is situated on the eastern side of the existing LW6 to LW8 and the proposed LW19 in DA3A.<br>The thalweg of the creek is located 750 m from the commencing end of LW19, at its closest point. Sandy Creek is therefore located outside the study area based on the 600 m boundary.<br>Sandy Creek Waterfall is situated where Sandy Creek flows into the Cordeaux Reservoir. The centreline of the waterfall is located 900 m north-east of the commencing end of LW19. | The maximum predicted incremental vertical subsidence, upsidence and closure for Sandy Creek, due to the mining of LW19, are all less than 20 mm. While the creek could experience very low levels of these subsidence effects, it is not expected to experience measurable tilts, curvatures or strains. It is unlikely, therefore, that adverse impacts would occur along Sandy Creek due to the mining of LW19.<br>Sandy Creek Waterfall is located at a distance from the proposed longwall that the predicted incremental vertical subsidence, upsidence and closure for Sandy Creek Waterfall are negligible. It is unlikely that Sandy Creek Waterfall would experience adverse impacts due to the mining of LW19. | The maximum measured total closure across Sandy Creek Waterfall due to the mining of LW6 to LW8 was 14 mm. The greatest closure was measured downstream of the waterfall and across the valley of Lake Cordeaux. |
| Drainage Lines | SC10 and WC14 are partially located above the proposed LW19. Other drainage lines are partially located above the existing LW6 to LW8. The drainage lines in the western part of the study area flow into Wongawilli Creek and the drainage lines in the eastern part of the study area flow into Sandy Creek.<br>The drainage lines are first and second order streams. The beds generally comprise exposed bedrock containing rockbars with some standing pools. There are also steps and cascades along the steeper sections. Debris accumulations have formed along the flatter sections that include loose rocks and tree branches.<br>A waterfall (SC10-WC15) is located 160 m east of the proposed LW19, at its closest point. | The drainage lines are located across the Study Area and, therefore, could experience the full range of predicted subsidence movements.<br>The potential impacts of increased ponding and scouring of the drainage lines due to tilt are expected to be minor and localised. Impacts resulting from changes in surface water flows due to tilt are expected to be small in comparison with those which occur during natural flooding conditions.<br>It is expected that fracturing of the bedrock would occur along the sections of the drainage lines that are located directly above the proposed LW19 and the adjacent existing LW7 and LW8. Fracturing can also occur outside the extents of the longwalls, with minor and isolated fracturing occurring at distances up to approximately 400 m.<br>The mining-induced compression due to valley closure effects can also result in dilation and the | Impacts have been observed along the drainage lines above and adjacent to the previously extracted LW9 to LW14 in Area 3B, including fracturing in the rockbars and exposed bedrock, dilation and uplift of the bedrock, iron staining, surface water flow diversions and reduction in pool water levels. These impacts predominately occurred directly above the extracted longwalls. However, fracturing was also observed up to 300 m from the extracted longwalls in Area 3B. |

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| | | development of bed separation in the topmost bedrock, as it is less confined. This valley closure related dilation is expected to develop predominately within the top 10 m to 20 m of the bedrock. Compression can also result in buckling of the topmost bedrock resulting in heaving in the overlying surface soils.<br>Surface water flow diversions are likely to occur along the sections of drainage lines that are located directly above and adjacent to the longwalls.<br>The likelihood of an instability at the waterfall SC10-WF15 is considered to be very low. It is possible, however, that isolated rockfalls could occur at or near the waterfall due to mining, due to natural processes, or both. | |
| Cliffs<br>**"**Continuous rock face, including overhangs, having a minimum length of 20 m, a minimum height of 10 m and a minimum slope of 2 to 1 (>63.4º)" | There are five cliffs that have been identified within the study area based on the 35° angle of draw line and predicted 20 mm subsidence contour. There are also seven additional cliffs located within the study area based on the 600 m boundary.<br>The cliffs have formed predominantly from Hawkesbury Sandstone, with the faces being at various stages of weathering and erosion. The cliffs have many overhangs and undercuts that are generally less than 6 m.<br>The minor cliffs within the study area are located within the valleys of Wongawilli Creek and the drainage lines. The lengths of each of the minor cliffs typically range between 20 m and 50 m and have heights up to 10 m. | Cliffs DA3-CF7, DA3-CF8 and DA3-CF17 (refer to Drawing No. MSEC1802-08 Rev. B, of MSEC 2020) could be impacted due to the extraction of LW19 directly beneath them. The impacts are predicted to represent approximately 7 % to 10 % of the total plan length of the cliffs located directly above LW19.<br>Cliffs DA3-CF16 and DA3-CF18 are located outside the mining area and are predicted to experience less than 20 mm vertical subsidence. These cliffs are predicted to experience only low levels of tilt, curvature and strain. Isolated rock falls could occur at some of the cliffs located outside the extents of the proposed longwall and within the angle of draw.<br>It is unlikely that other cliffs located outside the 35° angle of draw would experience adverse impacts due to their distances outside of the mining area. This is based on the extensive experience of mining near to but not directly beneath cliffs in the NSW coalfields, where no large cliff falls have occurred | LW1 and LW2 in Area 1 at Dendrobium were extracted directly beneath a ridgeline and rock falls were observed in eight locations directly above mining. The total length of disturbance resulting from the extraction of LW1 and LW2 was approximately 135 m to 175 m. The total plan length of ridgeline located directly above the longwalls was between approximately 1800 m to 2000 m. It should be noted that there are two levels of cliffs in some locations and, therefore, the total length of cliffline is greater than the total plan length of the ridgeline.<br>The length of ridgeline disturbed due to the extraction of LW1 and LW2 was, therefore, estimated to be between 7 % and 10 % of the total plan length of ridgeline directly above the longwalls. The length of rockfalls that occurred due to the extraction of LW1 and |

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| | | when the cliffs are located completely outside the angle of draw from mining. It is still possible, but unlikely, that isolated rock falls could occur due to mining, natural processes, or both. | LW2 was, however, less than the length of disturbed ridgeline. |
| Rock outcrops/ steep slopes | There are rock outcrops located across the study area, primarily within the valleys of Wongawilli Creek and its tributaries.<br>The steep slopes within the study area have been identified within the valleys of Wongawilli Creek and its tributaries. | The rock outcrops and steep slopes are located across the study area and, therefore, are expected to experience the full range of predicted subsidence movements.<br>It is likely that fracturing and cracking would occur where these features are located directly above the proposed longwalls. The crack widths could be similar to those previously observed in LW1 and LW2. | Within Dendrobium Area 1, cracks up to approximately 400 mm in width were observed along the top of the ridgeline, with other surface cracks, typically in the order of 100 mm to 150 mm in width, observed further down the ridgeline and the steep slopes. |
| Swamps, wetlands and water related ecosystems | Within the study area, there have been four swamps identified wholly or partially within the study area based on the 35 degree angle of draw (swamps Den12, Den15a and Den15b, Den148).<br>MSEC (2020) and Niche (based on field survey results) have added five additional swamps located wholly or partially within the study area based on the 600 m boundary (Den34, Den95, Den96, Den146 and Den147).<br>Small parts of Swamps Den15a and Den15b are located above the eastern end of the proposed LW19. The remaining swamps are located outside the extents of the proposed longwall.<br>See Figure 3 for upland swamp mapping. | Fracturing of the bedrock could occur beneath Swamps Den12 and Den15b and where Swamps Den15a and Den148 are located above and adjacent to the proposed longwall. It is possible that a series of smaller fractures, rather than one single fracture, could develop in the bedrock.<br>The downstream controlling feature for Swamp Den15a is SC10-15A. This rockbar is located 190 m east of the proposed LW19 and 110 m south of the existing LW8. The predicted subsidence effects for rockbar SC10-15A are less than 20 mm vertical subsidence, 90 mm upsidence and 125 mm closure.<br>The potential for Type 3 impacts (i.e. fracturing in a rockbar or upstream pool resulting in reduction in standing water level based on current rainfall and surface water flow) at rockbar SC10-15A due to the mining of the proposed LW19 is in the order of 13 %.<br>It is unlikely that fracturing would occur in the bedrock beneath swamps Den34, Den95, Den96, Den146 and Den147 as they are located outside the mining area. | The mining of LW9 in Area 3B, located directly above Swamp Den05, resulted in multiple fractures and uplifting at its basal step. Reduction in groundwater levels were also noted.<br>The groundwater levels were lower than baseline and recession rates greater than baseline for Swamps Den03, Den05, Den10, Den11, Den13 and Den14. Soil moisture levels below baseline were also reported in Swamps Den05, Den11 and Den23.<br>LW4 and LW5 in Area 2 were extracted directly beneath Swamp Den01, which is both a headwater and valley infill swamp located along Drainage Line A2-14. Cracking was observed within the extent of the swamp in three locations and fracturing was observed in the downstream rockbar.<br>LW7 in DA3A was extracted directly beneath Swamp Den12, which is a headwater swamp located on the valley side of Drainage Line |

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| | | Swamps Den12 and Den15b are located directly above the mining area and are predicted to experience upsidence of 275 mm to 350 mm. The sections of Swamps Den15a and Den148 located above the proposed LW19 are predicted to experience upsidence of 125 mm to 150 mm. These valley related effects could result in the dilation of the strata beneath these swamps. The dilated strata beneath the drainage lines could result in the diversion of some surface water flows beneath parts of the swamps where they are located above or adjacent to the proposed longwall (including swamp Den15a). Where there is no connective fracturing to any deeper storage, it is likely that surface water flows will re-emerge at the limits of fracturing and dilation.<br>The potential impacts on Swamps Den12 and Den15b are predominately due to the mining of LW7 and LW8 of which they are located directly above, rather than the proposed LW19.<br>Swamps Den12, Den15a, Den15b and Den148 are located near the bases of drainage lines WC17, SC10, SC10C and WC14, respectively. These swamps could experience valley related effects due to the extraction of the longwalls in DA3A. The remaining swamps within the study area are located further up the valley side and, therefore, it is unlikely to experience upsidence or compressive strain due to valley closure effects. | WC17. One fracture was identified in a rock outcrop after mining beneath this swamp. Piezometer data (one of four monitoring station) shows a reduction in groundwater levels. |
| Water quality and surface water | • Sandy Creek<br>• Wongawilli Creek<br>• Tributaries | Baseflow components of Wongawilli Creek and Sandy Creek may decline by up to 1.27 and 1.15 megalitres per day (ML/day) (cumulative / whole mine) and up to 0.01 ML/day and 0.06 ML/day (due to LW19 incrementally) following longwall | Watercourses that have been affected by subsidence (including WC21, LA4 and DC13 in Area 3B) have shown temporary increases in dissolved Fe and Mn, and an increase in pH to near neutral (pH 7) at sampling locations |

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| | • Water quality<br>• Swamps | extraction. This equates to approximately 8% and 29% of the mean flow at the downstream gauges (0.1% and 1.5% incremental).<br>Water quality influence due to mining is expected to be minor in stream reaches within subsidence affected areas. Effects are likely to include temporary changes in water salinity, pH and iron content with local discolouration of streambeds and rock faces by iron hydroxide.<br>It is likely that shallow groundwater levels will be affected in approximately 7% of the area of Swamp Den15a and most of Swamp Den148. Other swamps within 400 m of LW19 were previously impacted by subsidence at DA3A and may experience further effects due to LW19. The remaining swamps are unlikely to be impacted since they are located more than 400 m from the proposed goaf and/or are predicted to experience negligible ground movement related to valley closure. | immediately down-gradient of the affected area. The overall salinity of stream waters (as estimated from EC) is controlled largely by rainfall patterns, with EC tending to increase during periods of low rainfall. This reflects evaporative concentration of salts and the relative increase in contribution from groundwater discharge (baseflow). In most cases, there is no discernible change in EC and other water quality parameters at monitoring sites down-gradient of noted effects or impacts. One possible exception is at Donalds Castle Creek (the upper reaches of which cross Longwalls 9 and 10) in which EC has been elevated for the last two years at the downstream site (DCL3 and at FR6). The anomalous EC trend coincides with the recent drought period and will continue to be assessed. Based on previous observations, it is expected that water quality influence due to mining would be minor in stream reaches within subsidence affected areas (SC10 and SC10C; upper reaches of WC14). Local discolouration of streambeds and rock faces by iron hydroxide precipitation can continue for a number of years but is a temporary impact. |

## 2.3 Approach

The approach to this assessment has been informed by previous ecological survey work and impact assessment for the study area and surrounds, field survey of the study area, current knowledge of subsidence impacts on the landscape, legislative guidelines and consultation.

While impact assessment for the entire DA3 study area has already been completed in the form of a SIS (Biosis 2007), the current assessment is required to ensure that the findings of the SIS remain relevant to LW19 within DA3A, given the following:

- Updates to schedules of relevant legislation concerning threatened species (which may confer a different conservation status for certain species or community).
- New information regarding predicted subsidence impacts, the accuracy of previous subsidence predictions and results from monitoring of impacts to ecological features and threatened species.
- Requirement to examine the proposal against the relevant conditions of consent (Condition 5) relating to impacts to Swamp Den15a.

The SIS for Dendrobium Area 3, which incorporated the current study area, was completed in 2007 (Biosis 2007). Some data gaps within the SIS have been identified in this study, and appropriate surveys completed to fill these gaps.

The target of the current survey and assessment has been to focus on the ecological values sensitive to the effects of subsidence, as identified in MSEC (2020) and Section 2.2.

# 3 Literature review

A significant body of work has been conducted within the DA3 study area for previous approvals for underground mining and to satisfy consent conditions in regard to monitoring. The main relevant documentation as listed below was reviewed as part of this SMP with details provided in proceeding sections of this report:

- SIS completed for the 2008 modification (Biosis 2007);
- Dendrobium Area 3B Terrestrial Ecology Assessment (Niche 2012);
- Dendrobium Area 3C Terrestrial Ecology Assessment (Niche 2019);
- Monitoring as part of previous SMPs for longwalls within areas 3A and 3B (Figure 2), including annual and end of panel reporting;
- Statutory reviews and policy guidelines including;
    - Southern Coalfields Inquiry;
    - Upland Swamps Environmental Assessment Guidelines (Draft); and
    - Independent Expert Panel for Mining in the Catchment Report: Part 2. Coal Mining Impacts in the Special Areas of the Greater Sydney Water Catchment.

## 3.1 Dendrobium Area 3 Species Impact Statement

Biosis prepared a SIS in 2007, to support the application to modify the Dendrobium Mine consent (DA-60-03-2001) to incorporate a revised Area 3 footprint and longwall layout. The SIS involved an extensive survey and impact assessment of Areas 3A, 3B and 3C.

To assess the impacts of mining in Dendrobium Area 3, the maximum subsidence parameters determined from MSEC (2007) for DA3A were extrapolated to the entire Dendrobium Area 3 footprint.

As such, the consent required that once the mine plans for these areas were finalised any impacts in areas DA3B and DA3C greater than those specified in the SIS, would require a review of the SIS outcomes. The SIS therefore provides the basis against which the proposal should be assessed.

A comparison of the relevant DA3 subsidence parameters used in the SIS (MSEC, 2007), against the current MSEC (2020) report is provided below in Table 2. Both MSEC reports concluded similar potential subsidence impacts. The impact assessments for threatened species in the SIS are similar to those within this report.

**Table 2: Subsidence predictions from the Area 3 SIS (2007) compared to MSEC (2020) report for current study area**

| Subsidence Parameters | MSEC (2007) report for Dendrobium Area 3 used in the SIS | MSEC (2020) report for DA3A |
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| Wongawilli Creek | Longwalls set back from Wongawilli Creek.<br>Wongawilli Creek is unlikely to incur any significant impacts as a result of the extraction of the proposed longwalls. Some minor fracturing could occur. Localised ponding changes may occur due to subsidence induced tilt. | Longwalls set back from Wongawilli Creek.<br>It is possible that there could be some localised changes in the levels of ponding or flooding where the maximum changes in grade due to subsidence induced tilt coincide with existing pools, steps or cascades along the creek. It is not anticipated that these changes would result in adverse impacts on the creek.<br>It has been assessed that the likelihood of fracturing resulting in surface water flow diversions along Wongawilli Creek, due to the extraction of the proposed LW19, is low, i.e. affecting less than 10 % of rockbars located within the study area. However, minor fracturing could still occur along the creek, at distances up to approximately 400 m from the proposed longwalls. |
| Sandy Creek and Sandy Creek Waterfall | It is unlikely that there would be any significant increases in levels of ponding, flooding or scouring of the creek banks. However, it is possible that there could be some very localised increased level of ponding or flooding where the maximum predicted tilts coincide with existing pools, steps or cascades along the creek.<br>It is possible that there could be minor fracturing in the beds of Wongawilli and Sandy Creeks as a result of the extraction of the proposed longwalls. Any fracturing that does occur in the beds of these creeks would be expected to be isolated and of a minor nature and not result in any significant surface water flow diversions. | It is unlikely that adverse impacts would occur along Sandy Creek due to the mining of LW19. |
| Cliffs | Predicted to be some impact to between 7% and 10% of the cliff lines that will be directly mined beneath. Cliff lines that will not | Cliffs DA3-CF7, DA3-CF8 and DA3-CF17 could be impacted due to the extraction of LW19 directly beneath them. The impacts are |

| Subsidence Parameters | MSEC (2007) report for Dendrobium Area 3 used in the SIS | MSEC (2020) report for DA3A |
|---|---|---|
| | be directly mined beneath are unlikely to exhibit any significant impacts. | predicted to represent approximately 7 % to 10 % of the total plan length of the cliffs located directly above LW19.<br>Cliffs DA3-CF16 and DA3-CF18 are located outside the mining area and are predicted to experience less than 20 mm vertical subsidence. These cliffs are predicted to experience only low levels of tilt, curvature and strain. Isolated rock falls could occur at some of the cliffs located outside the extents of the proposed longwall and within the angle of draw.<br>It is unlikely that other cliffs located outside the 35° angle of draw would experience adverse impacts due to their distances outside of the mining area. It is still possible, but unlikely, that isolated rock falls could occur due to mining, natural processes, or both. |
| Rock outcrops | Percentage of rock outcrops that are likely to be impacted by mining is small – much less than 7% to 10% of the total length of rock outcrops directly mined beneath. | It is likely that fracturing and cracking would occur where rock outcrops are located directly above the proposed longwalls. |
| Steep slopes | Potential DA3 steep slopes are expected to result in cracking of the surface soils and possible downhill movements, similar to Dendrobium Areas 1 and 2. The greatest surface cracking and downhill movements are expected to occur along the steep slopes directly mined beneath and adjacent to ridgelines. | It is likely that fracturing and cracking would occur where steep slopes are located directly above the proposed longwall. |
| Upland Swamps | Swamps directly mined beneath are expected to experience the full range of predicted subsidence and valley related movements.<br>It is unlikely that mine subsidence induced scour effects would affect the swamps in Area 3.<br>It is possible that the changes in water level within the swamps could impact on the distribution of local vegetation within the swamps. The surfaces of the swamps are free draining, and it is | Fracturing of the bedrock could occur beneath Swamps Den12, Den15b. Fracturing could occur beneath swamp Den15a and Den148 where they are located above and adjacent to the proposed longwall.<br>It is unlikely that fracturing would occur in the bedrock beneath swamps Den34, Den95, Den96, Den147, Den146 as they are located outside the mining area. |

| Subsidence Parameters | MSEC (2007) report for Dendrobium Area 3 used in the SIS | MSEC (2020) report for DA3A |
|---|---|---|
| | not anticipated that significant changes in water levels would occur as a result of subsidence induced tilt. | Swamps Den12, Den15b and Dend15a (where it is located above the corner of the proposed longwall) are predicted to experience upsidence that could result in the dilation of the strata beneath these swamps.<br>The dilated strata beneath the drainage lines could result in the diversion of some surface water flows beneath parts of the swamps where they are located above or adjacent to the proposed longwall (including swamp Den15a). Where there is no connective fracturing to any deeper storage, it is likely that surface water flows will re-emerge at the limits of fracturing and dilation.<br>Swamps Den12, Den15a, Den15b and Den34 could experience valley related effects due to the extraction of the longwalls in DA3A. The remaining swamps within the study area are located further up the valley side and, therefore, it is unlikely to experience upsidence or compressive strain due to valley closure effects. |

The results of the SIS in regard to ecological impacts, specifically threatened species, included the following:

- Fourteen threatened flora species were considered in the SIS. Two threatened flora species, *Acacia bynoeana* and *Pultenaea aristata* were recorded within Area 3. A further nine species were regarded as having potential habitat. Seven-part tests under the *Threatened Species Conservation Act 1995* (TSC Act) (equivalent to the current five-part test under the *Biodiversity Conservation Act 2016* [BC Act]) concluded that the proposed longwall mining activities in Area 3 were unlikely to have a significant impact on any threatened flora within the study area.
- Sixty three threatened fauna were considered in the SIS. Sixteen species were recorded in the Area 3 study area including:
    - Littlejohn's Tree Frog (*Litoria Littlejohni*);
    - Giant burrowing Frog (*Heleioporus australiacus*);
    - Red-crowned Toadlet (*Pseudophryne australis*);
    - Gang-gang cockatoo (*Callocephalon fimbriatum*);
    - Glossy black cockatoo (*Calyptorhynchus lathami*);
    - Olive Whistler (*Pachycephala olivacea*);
    - Barking Owl (*Ninox connivens*);
    - Powerful Owl (*Ninox strenua*);
    - Eastern Pygmy-possum (*Cercartetus nanus*);
    - Eastern Freetail Bat (*Mormopterus norfolkensis*);
    - Koala (*Phascolarctos cinereus*);
    - Grey-headed Flying-fox (*Pteropus poliocephalus*);
    - Eastern Bentwing-bat (*Miniopterus schreibersii*);
    - Large-eared Pied bat (*Chalinolobus dwyeri*);
    - Southern Myotis (*Myotis macropus*); and
    - Rosenberg's Goanna (*Varanus rosenbergi*).
- Seven-part tests concluded that the Area 3 mining operations would likely cause a significant impact to local populations of Littlejohn's Tree Frog, Giant Burrowing Frog, Red-crowned Toadlet, Stuttering Frog (*Mixophyes balbus*) and Giant Dragonfly (*Petalura gigantea*). The possible mechanisms of subsidence and physical effects of subsidence were determined to have a direct impact on known and potential habitat for the threatened fauna, which included waterways, Upland Swamps, riparian vegetation, ridge lines and rock overhangs.
- One Endangered Ecological Community (EEC): Shale Sandstone Transition Forest, which was listed on the TSC Act (now the BC Act) and EPBC Acts was recorded within the study area. However, was considered unlikely to be significantly impacted by the proposal. Shale Sandstone Transition Forest (SSTF) is now listed as a Critically Endangered Ecological Community (CEEC).

It is noted that Upland Swamps within the study area were not a listed TEC at the time of the SIS under either the TSC Act (gazetted in 2012) or EPBC Act (gazetted in 2014), the community has since been added to the relevant schedules as an endangered ecological community.

The survey effort and outcomes of the SIS have been summarised in Section 4.1.

## 3.2 Dendrobium Longwalls 20-21 Terrestrial Ecological Assessment

Niche was commissioned by IMC to prepare a Terrestrial Ecological Assessment for proposed LW20-21 within Dendrobium Area 3C (DA3C) (Niche 2019).

The assessment involved flora and fauna survey within DA3C which focused on landscape features and threatened species sensitive to the impacts of subsidence from extraction of proposed LW20 - 21. Natural areas sensitive to subsidence within the DA3C study area included: Wongawilli Creek, Donalds Castle Creek, drainage lines, cliffs, rock outcrops, steep slopes, and Upland Swamps.

Four threatened plant species (*Epacris purpurascens* var. *purpurascens, Pultenaea aristata, Cryptostylis hunteriana* and *Leucopogon exolasius*) were considered to have habitat in the study area. Impacts on these species were assessed within the project's SIS (Biosis 2007) and are likely to be minimal as a result of DA3C.

Nine threatened fauna species were considered to be potentially impacted by subsidence impacts resulting from the proposal comprising:

- Frogs: Littlejohn's Tree Frog, Giant Burrowing Frog, Red-crowned Toadlet.
- Reptiles: Broad-headed Snake, Rosenberg's Goanna.
- Mammals: Eastern Bentwing Bat, Little Bentwing Bat, Southern Myotis.
- Invertebrates: Giant Dragonfly.

The findings of the SIS were determined to be accurate in relation to LW20-21 impact on local populations of the three frog species and the Giant Dragonfly. Subsidence impacts were determined as likely for known and potential habitat for these species, as they are reliant upon drainage lines, Upland Swamps, ridgelines and rock outcrops. The same conclusion was reached in the SIS impact assessments for these species, however the Stuttering Frog was considered to be significantly impacted within the initial SIS whereas it was considered unlikely to occur within the Area 3B Terrestrial Ecological Assessment.

Ten Upland Swamps were recorded within the LW20-21 study area within DA3C. The Upland Swamps in the study area fit the description of Coastal Upland Swamps in the Sydney Basin Bioregion, which has been listed as an EEC under the BC Act and EPBC Act since the 2007 SIS.

A number of recommendations were proposed in relation to terrestrial ecological values, and included the following:

- On-going monitoring which is currently being undertaken within Dendrobium Area 3 should continue. Monitoring of impacts due to LW20-21 to follow pre-existing methodology. Monitoring to continue targeted surveys for Littlejohn's Tree Frog and Red-crowned Toadlet. Upland swamp monitoring transects should continue. If monitoring reveals impacts greater than predicted or authorised by the approval, modifications to the project and mitigation measures should be considered to minimise impacts.
- Visual comparison of photo point monitoring undertaken at each upland swamp site should also continue from marked monitoring points.
- Mapping of microhabitats such as pools along streams, as currently performed by IMC for DA3B, should be extended to DA3C prior to baseline frog surveys.

- All remediation works should include appropriate measures to minimise environmental impacts. This includes avoiding the spread of Chytrid Fungus following the NPWS guidelines (Department of Environment and Climate Change [DECC] 2008).
- The implementation of any mitigation measures should include monitoring to confirm the success of any implemented measures.
- Surface cracking within woodland or forested areas where significant fauna entrapment is likely should be mitigated in order to minimise fauna entrapment.

## 3.3 Dendrobium Area 3B Terrestrial Ecology Assessment

Niche was commissioned by IMC in 2011 to prepare a Terrestrial Ecological Assessment for Dendrobium Area 3B (DA3B) (Niche 2012).

The assessment involved a flora and fauna survey within DA3B which focused on landscape features sensitive to the impacts of subsidence from extraction of proposed Longwalls 9 to 18. Natural areas sensitive to subsidence within the DA3B study area included: Wongawilli Creek, Donalds Castle Creek, drainage lines, cliffs, rock outcrops, steep slopes, and Upland Swamps.

One threatened flora population of *Pultenaea aristata* was recorded in an upland swamp in the DA3B study area. The population estimate was greater than a thousand individuals. The SIS also identified a population of *Acacia bynoeana* consisting of approximately 30 individuals within the DA3B study area.

Four threatened plant species (*Epacris purpurascens* var*. purpurascens, Pultenaea aristata, Cryptostylis hunteriana* and *Leucopogon exolasius*) were considered to have habitat in the study area that may be potentially impacted by subsidence. Seven-Part Tests were carried out for each of these species which concluded that a significant impact was unlikely. The same conclusion was reached in the 2007 SIS (Biosis 2007).

Threatened fauna recorded during the DA3B survey included Red-crowned Toadlet, Littlejohn's Tree Frog, Gang-gang Cockatoo, and Grey-headed Flying Fox. Fauna impact assessments were conducted for 31 threatened fauna, including:

- Amphibians: Littlejohn's Tree Frog, Giant Burrowing Frog and Red-crowned Toadlet;
- Birds: Barking Owl, Black Bittern (*Ixobrychus flavicollis*), Eastern Bristle Bird (*Dasyornis brachypterus*), Eastern Ground Parrot (*Pezoporus wallicus wallicus*), Grass Owl (*Tyto longimembris*), Gang-gang Cockatoo, Glossy Black Cockatoo, Masked Owl (*Tyto novaehollandiae*), Sooty Owl (*Tyto tenebricosa*), and Powerful Owl;
- Mammals: Brush-tailed Rock Wallaby (*Petrogale penicillata*), Eastern Pygmy Possum, Long nosed Potoroo (*Potorous tridactylus tridactylus*), Southern Brown Bandicoot (*Isoodon obesulus*), Spotted tail Quoll (*Dasyurus maculatus*), Squirrel Glider (*Petaurus norfolcensis*), Eastern Bentwing-bat, Little Bentwing-bat (*Miniopterus australis*), Large-eared Pied Bat, Eastern Cave Bat (*Vespadelus troughtoni*), Eastern False Pipistrelle (*Falsistrellus tasmaniensis*), Golden-tipped Bat (*Kerivoula papuensis*), Southern Myotis, Greater Broad-nosed Bat (*Scoteanax rueppellii*) and Yellow-bellied Sheathtail-bat (*Saccolaimus flaviventris*).
- Reptiles: Broad-headed Snake (*Hoplocephalus bungaroides*) and Rosenberg's Goanna; and
- Giant Dragonfly.

Seven-Part Tests concluded that the proposed longwalls were likely to have a significant impact on local populations of Littlejohn's Tree Frog, Giant Burrowing Frog, Red-crowned Toadlet, and Giant Dragonfly. Subsidence impacts were determined as likely for known and potential habitat for these species, as they are reliant upon Donalds Castle Creek and drainage lines, Upland Swamps, ridgelines and rock outcrops. The same conclusion was reached in the SIS impact assessments for these species, however the Stuttering Frog was considered to be significantly impacted within the initial SIS whereas it was considered unlikely to occur within the Area 3B Terrestrial Ecological Assessment.

SSTF which was listed as a CEEC under the EPBC Act and TSC Act (repealed and replaced by the BC Act), occurs within the DA3B study area. Mining in DA3B was considered unlikely to result in any physical landscape changes which may impact this community. The assessment concluded that SSTF is unlikely to be significantly impacted by the Proposal.

Thirteen large Upland Swamps were recorded within the DA3B study area. The Upland Swamps in the study area fit the description of Coastal Upland Swamps in the Sydney Basin Bioregion, which has been listed as an EEC under the BC Act and EPBC Act since the 2007 SIS. The potential for DA3B to impact Upland Swamps was considered to be low. A Seven-Part Test for Coastal Upland Swamps in the Sydney Basin Bioregion was conducted and concluded that a significant impact on this community was unlikely, primarily due to the proportion of swamps likely to be impacted compared with swamps within the locality and the severity of impacts predicted.

A number of recommendations were proposed in relation to terrestrial ecological values, and included the following:

- On-going monitoring which is currently being undertaken within Dendrobium Area 3 should continue. Monitoring of DA3B to follow pre-existing methodology. Monitoring to continue targeted surveys for Littlejohn's Tree Frog, Red-crowned Toadlet and Giant Dragonfly. Upland swamp monitoring transects should continue. Transect and photo point monitoring to be included within upland Swamp 35A as this swamp contains a population of *Pultenaea aristata*. In the event that monitoring reveals impacts greater than predicted or authorised by the approval, modifications to the project and mitigation measures should be considered to minimise impacts.
- The implementation of any mitigation measures should include monitoring to confirm the success of any implemented measures.
- All remediation works should include appropriate measures to minimise environmental impacts. This includes avoiding the spread of Chytrid Fungus following the NPWS guidelines (DECC 2008).
- Surface cracking within woodland or forested areas where significant fauna entrapment is likely should be mitigated in order to minimise fauna entrapment.

## 3.4 Dendrobium Terrestrial Ecology Monitoring Program

Annual Reporting (Biosis 2016, Biosis 2017 and Biosis 2018) documents the ecological monitoring program undertaken within Dendrobium Areas 2 (11 years), 3A (8-14 years) and 3B (4 years). Subsidence related impacts following mining in these areas include lowering of shallow groundwater in Upland Swamps and loss or alteration in the quality of pool water for first and second order streams.

The following ecological features are monitored as part of the terrestrial ecology program:

- Vegetation within Upland Swamps in Dendrobium Area 2, Area 3A and Area 3B;
- Vegetation along one stream in DA3A; and
- Littlejohn's Tree Frog along streams in DA3A and Area 3B.

As part of the monitoring program, Biosis (2018) also undertake LIDAR mapping of the upland swamp extents. This detailed mapping of the upland swamp boundaries was used in the current assessment.

The following summarises the findings of the vegetation monitoring program to date (Biosis 2019, 2016):

- Swamp size and the extent of groundwater dependent swamp sub-communities showed a global decrease across control and impacted swamps in 2014 and 2015 when compared to 2012 data. The decrease was found to be greater at impacted sites when compared to control sites suggesting some effect of mining-related impacts. However, ground-truthing of modelled results at several swamps in March 2016 found that, in many cases, the modelled contraction in swamp size was not a true and accurate reflection of swamp vegetation on the ground and the model tended towards over-estimation of the reduction in swamp size and extent of groundwater dependent sub-communities.
- The change in extent of vegetation communities within upland swamp from the baseline is most notable at impact sites. A similar pattern has been observed across the control swamps, although the degree of change is not as great as that recorded at the impact swamps. Swamp den15b recorded a reduction in Banksia Thicket (MU42), Tea-tree Thicket (MU43) and Swamp: Sedgeland-Heath Complex (Cyperoid Heath) (MU44a) that exceeded the degree of change observed within the control group.
- All Upland Swamps continue to show a trending decline in total species richness, indicating broader landscape scale driven changes.
- Regardless of treatment (impact and control), species composition is changing every year and this change is statistically significant at most sites. This change is within the expected range, as some natural turnover of species occurs at sites each season and across the years monitored.
- A statistically significant change in species composition post-mining was found at Swamp Den15b and Swamp Den15a. These changes were observed immediately following undermining and have continued at Swamp Den15b and Swamp Den15a for at least four years post-mining. Species composition is changing within Swamps Den15a and Den15b, an increase in species that prefer drier soils as opposed to species preferring water-logged substrate.
- Changes in species composition in Swamp 15(A)2 are likely to be linked to or facilitated by incremental changes in vegetation driven by post fire succession of Heath-leaved Banksia (*Banksia ericifolia*) which occurred during 2001 which is within expected transitions within the upland swamp sub-communities. Therefore a change in the species composition doesn't indicate that the swamp is transitioning into a woodland and it is more likely a result of climatic and landscape influences.
- There is one post-mining creek site (SC10) within DA3A where monitoring is conducted. There has been no significant change in the total species richness when comparing pre-mining data and post-mining data for the one post-mining creek being monitored in DA3A (SC10).

The Littlejohn's Tree Frog monitoring (Biosis 2018) detailed the following results within the LW19 study area:

- No significant changes in Littlejohn's Tree Frog populations, an increase in tadpoles at SC10(1), and an increase in egg mass at SC10(2) may be due to displacement of breeding adults from impacted areas such as SC10C.

- Subsidence related impacts including cracking of bedrock, lowering of water levels and build-up of iron flocculant have been recorded at sites SC10C, SC10(1), with each of these sites triggering either Level 1 (SC10(1) or Level 3 (SC10C) of the Dendrobium Area 3 Watercourse TARP (Illawarra Coal 2015a).

## 3.5 Previous surveys and ongoing monitoring

The DA3 study area has been included within ecological assessments commissioned by IMC for over 15 years which have been used to support development applications and exploration activities within the area. The results of select key relevant assessments have been referred to or summarised in this report. Threatened species previously recorded in previous assessments have generally been supplied to BCD (and its predecessors) for inclusion in the Bionet Atlas of NSW Wildlife threatened species database which has been consulted for this assessment. Relevant assessments conducted within the Dendrobium area include:

- Dendrobium Coal Project SIS (Biosis 2001a);
- Dendrobium Coal Project: Terrestrial and Aquatic Habitat Assessment (Biosis 2001b);
- Dendrobium Coal Project: Likely Impacts of Subsidence on Terrestrial Ecology (Biosis 2001c);
- Terrestrial Flora and Fauna Habitat Assessments accompanying coal exploration activities within DA3B (various companies approximately 1996 – 2011);
- Dendrobium Coal Mine and Elouera Colliery Flora and Fauna Environmental Management Program, Annual Monitoring Report – Spring 2003 to Winter 2006 (Biosis 2007a);
- Dendrobium Area 2 Longwalls 3-5a Impacts of Subsidence on Terrestrial Flora and Fauna (Biosis 2007b);
- Dendrobium Area 3B: Terrestrial Ecological Assessment (Niche 2012);
- Dendrobium Area 3C: Terrestrial Ecological Assessment (Niche 2019);
- Geographic review of mining effects on Upland Swamps at Dendrobium Mine (Watershed HydroGeo 2019); and
- Dendrobium Next Domain - Biodiversity Assessment Report and Biodiversity Offset Strategy (Niche 2019a).

Long-term monitoring of vegetation and fauna populations has been undertaken in Dendrobium Areas 1, 2 and 3, which began in 2003. Ecological monitoring has targeted both flora and fauna, and has involved vegetation quadrats and transects, and bird, frog and reptile surveys. Five years of data and records from the monitoring locations were utilised in the SIS (Biosis 2007).

A review of piezometer data used for detection of impacts to swamps throughout the Dendrobium area has been conducted (Watershed HydroGeo 2019) which concluded: "*Based on assessments of water levels and recession rates around past mining in Areas 2, 3A and 3B, hydrographs from swamp piezometers within 60 m are likely to exhibit a mining effect and almost certain to exhibit a mining effect when directly mined under, be that through a reduction in the water table to below pre-mining levels and/or increased recession (drainage) rate. Effects on swamp water tables have not been observed at distances greater than 60 m from a longwall panel.*

*When considering piezometers that are lithologically similar, but lying outside of mapped swamp communities, impacts have been observed at 95 and 125 m in two piezometers in Area 3B. Some piezometers within that distance (125 m) have recorded no mining effects."*

The above findings are important with regard to assessing the likely extent of impacts to swamp communities.

## 3.6 Relevant reviews considered in this report

The following reviews have been considered in the current study:

- Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield (Southern Coalfield Inquiry) (DOP 2008);
- The Draft Upland Swamp Environmental Assessment Guidelines, Guidance for the Underground Mining Industry Operating in the Southern and Western Coalfields (DECCW 2011); and
- Independent Expert Panel for Mining in the Catchment Report: Part 2. Coal Mining Impacts in the Special Areas of the Greater Sydney Water Catchment (IEPMC 2019).

Key findings of the above reviews (as relevant to this assessment) are shown in Table 3.

**Table 3: Key findings of relevant reviews**

| **Southern Coalfield Inquiry** |
|---|
| Environmental assessments should include a minimum of 2 years of baseline data, collected at an appropriate frequency and scale provided for significant natural features. |
| Development of improved regional and cumulative data sets for the natural features of the Southern Coalfield. |
| Before After Control Impact (BACI) study is considered the most appropriate design for many impact studies. Appropriate replication in both impact (directly above the mine) and control (outside direct impact zone) sites is required in monitoring programs so natural variability can be determined. |
| Environmental assessments should include identification and assessment of significance for all natural features located within 600 m of the edge of secondary extraction. |
| Risk Management Zones should be identified for all significant natural features, which are sensitive to valley closure and upsidence, including rivers, significant streams (3rd order or above in the Strahler stream classification), significant cliff lines, significant overhangs and valley infill swamps. |
| Approved mining within identified Risk Management Zones (and particularly in proximity to highly-significant natural features) should be subject to increased monitoring and assessment requirements which address subsidence effects, subsidence impacts and environmental consequences. |
| The requirements should also address reporting procedures for back analysis and comparison of actual versus predicted effects and impacts, in order to review the accuracy and confidence levels of the prediction techniques used. |
| **Upland Swamps Environmental Assessment Guidelines (Draft)** |
| All underground mining proposals and operations that have the potential to impact on Upland Swamps demonstrate how they have applied the Upland Swamp Environmental Assessment Guideline. |
| Impacts to swamps of 'special significance status' are avoided. |
| Impacts on Upland Swamps (not of special significance status) are minimised as far as possible. |

Monitoring undertaken by the underground mining industry to understand subsidence effects, impacts and environmental consequences is greatly improved.

Adaptive management should be implemented to provide a systematic process for continually detecting impacts, validating predictions and improving mining operations to prevent further impacts. Active adaptive management usually involves a comparison of management options and a conscious investment in learning by experimentation.

Effective and rigorous monitoring, evaluation, and reporting on management performance and ecological and hydrological impacts are required to inform the adaptive management process and should be integrated into core management systems in a consistent way across industry.

Management measures are to include contingency plans that allow for any unforeseen circumstances, particularly given the uncertainty inherent in the assessment of subsidence impacts, such as non-systematic subsidence (valley closure and upsidence).

Prior to underground mining proponents preparing an environmental assessment there is a need to gather baseline data. Initial steps in the collection of baseline data on Upland Swamps may include desktop studies to identify the location of the Upland Swamps (e.g. through vegetation mapping) and the identification of key threatening processes and Upland Swamps listed under national and state legislation.

**Independent Expert Panel for Mining in the Catchment Report: Part 2. Coal Mining Impacts in the Special Areas of the Greater Sydney Water Catchment (IEPMC 2019)**

Longwall mining directly under swamps in the Southern Coalfield can result in significant changes to swamp hydrology and redirection of surface runoff, which the Panel considers are very likely irreversible.

Despite decades of monitoring, mining-induced changes to upland swamp vegetation communities are still not able to be clearly differentiated from natural changes. Vegetation change assessment to date does not provide a clear and timely measure of possible changes in ecosystem functionality of the Upland Swamps. This means that it has been of limited value as a performance indicator. This may be resolved in part by changes in methodology. Quantitative monitoring data should be supplemented by an overview of the whole swamp and assessment of changes in biomass. Use of targeted obligate swamp-dependent species (either plants or animals) may be a more reliable and timely indicator of ecological consequences than measures such as total species richness of vegetation. However, the decadal nature of many changes still remains a barrier to distinguishing between mining induced variations and natural variations.

Existing TARPs define ecosystem functionality predominantly by consequences (vegetation change and erosion) that may take years or decades to be measurable and clearly separable from natural variation. Swamps are groundwater-dependent ecosystems. Therefore, a change in piezometric levels should be the primary gauge of impacts on the ecosystem. If maintenance of ecosystem functionality is to be mandated for any swamp, then piezometric variation must be used not only in TARPs but also in performance measures.

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.
- Link any changes in swamp vegetation to changes in water table position, soil moisture content and soil organic carbon content.
- Identify the presence of and any changes in obligate swamp fauna such as the Giant Dragonfly (*Petalura gigantea*).

Annual performance reports, end-of-panel reports and reports on studies required by development consent conditions, should:

- integrate hydrological and ecological impact and consequence assessments;

| |
|---|
| • include discussion of the inter-related changes in hydrological and ecological consequences for swamps, rather than having only discrete chapters on each;<br>• include results for the entire period of monitoring, rather than just the previous year, that should be assessed, not only for the current mining area but for previous mining domains. |
| Remediation should not be relied upon for features, including watercourses and swamps, that are highly significant or of special significance (as per the guidance provided by the Planning Assessment Commission Panels for the Metropolitan Coal Project and the Bulli Seam Operations Project). |
| Consent conditions for Dendrobium Mine issued in 2008 in relation to offsetting impacts on swamps do not appear to have foreseen the scale of impacts occurring today but have been subsequently addressed by a Strategic Biodiversity Offset approved in 2016. |
| There is very limited, if any, scope for remediating fracture networks beneath swamps. Therefore, in circumstances where it is difficult, if not impossible, to design a viable mining layout that avoids impacting swamps and mining is to proceed, there is little option other than to consider offsets as compensation for the consequences of negative environmental impacts on swamps. |
| All future mine approvals in the Special Areas should include performance measures related to measured changes in groundwater pressure and/or pressure gradients where these have the potential to impact on surface water diversions or losses. |

The proposal is consistent with the recommendations of these reports due to the following proposed actions:

- Subsidence prediction reports and environmental studies have been used to determine potential impacts for DA3A;
- Potential impacts to Upland Swamps have been determined;
- Long-term monitoring of natural features in Dendrobium Area 3 is currently undertaken including Upland Swamps, piezometric variation and targeted surveys of Littlejohns Tree Frog and giant dragonfly. It is recommended these programs continue and are expanded to DA3A; and
- Additional management and mitigation measures have been recommended in this report and the SIS.

## 3.7 Databases

Databases used in the preparation of this report include:

- DPIE Bionet Atlas of NSW Wildlife (DPIE 2019) (accessed December 2019); and
- EPBC Act Protected Matters Search Tool (Department of the Environment and Energy (DoEE) 2019) (accessed December 2019).

Further records of threatened species were obtained from the SIS (Biosis 2007), and from the previous studies listed in Section 3.5.

# 4 Field survey

## 4.1 Previous survey effort

This section identifies the extensive surveys which have been conducted within Dendrobium Area 3 and surrounds. The survey effort from the SIS (Biosis 2007) and previous surveys within Dendrobium Area 3 has been summarised in Table 4.

**Table 4: Approximate total hours of SIS survey effort and other previous surveys in Area 3**

| Survey method | Total hours |
|---|---|
| Vegetation quadrats and transects | 44 person hours in SIS, and 373.5 person hours in previous surveys |
| Vegetation validation and Targeted surveys for threatened plant species | 244.5 person hours in SIS and 95 hours in previous surveys |
| Plot based surveys for *Pultenaea aristata* population count | 14 person hours in SIS |
| Diurnal bird survey | 288.5 person hours in previous survey |
| Nocturnal frog survey | 274.8 person hours in previous survey |
| Bat Detection | 68 Trap nights in previous survey |
| Harp Trap | 24 Trap nights in previous survey |
| Arboreal Elliot Traps (Small) | 72 Trap nights in previous survey |
| Arboreal Elliot Traps (Large) | 72 Trap nights in previous survey |
| Arboreal hair tubes | 303 Trap nights in previous survey |
| Cage traps | 360 Trap nights in previous survey |
| Diurnal bird surveys | 13.88 person hours in previous survey |
| Diurnal herpetofauna Search | 44.03 person hours |
| Diurnal call playback | 2.05 person hours in previous survey |
| Frog habitat search | 23.9 person hours |
| Nocturnal watercourse search | 49 person hours in previous survey |
| Spotlighting | 64 person hours in previous survey |
| Nocturnal call playback | 52 person hours in previous survey |
| Frog call/Song Meter | 225 trap nights |

Areas previously surveyed within the current study area as part of the SIS (Biosis 2007) and ongoing monitoring (Biosis 2018), have been identified in Table 5 and 6.

**Table 5: Previous Survey Effort of Swamps in study area**

| Site | Swamp characteristics | Position of highest impact area | Previous vegetation survey | Previous fauna survey |
|---|---|---|---|---|
| Den12 | Small simple swamp | Angle of draw. Previously mined beneath by LW7 and | 1 x vegetation surveys sites (vegetation | - |

| Site | Swamp characteristics | Position of highest impact area | Previous vegetation survey | Previous fauna survey |
|---|---|---|---|---|
| | | LW8. Feeding tributary (WC17) within angle of draw. | validation and dominant species observations). | |
| Den 15a | Large complex swamp | Small section of swamp beneath longwall, remained within Angle of draw. Feeding tributary (SC10) within Angle of draw. | Fixed swamp monitoring transects (Biosis 2019). Monitoring undertaken for 8-14 years. | Fixed frog and bird monitoring sites (Biosis 2019). Monitoring undertaken for 8-14 years. Nocturnal frog habitat search. Spotlighting on foot (mammals, birds reptiles). Arboreal Elliots/Hair Tubes. |
| Den 15b | Large complex swamp | Within Angle of draw. Previously mined beneath by LW8. | Fixed swamp monitoring transects (Biosis 2019). Monitoring undertaken for 8-14 years. | Fixed frog, bird and invertebrate monitoring sites (Biosis 2019). Monitoring undertaken for 8-14 years. Nocturnal frog habitat search. Spotlighting on foot (mammals, birds reptiles). Nocturnal call playback frogs. |
| Den34 | Small simple swamp | Within 600 m boundary. Feeding tributary (WC13) within 600 m boundary. | - | - |
| Den95 | Small simple swamp | Within 600 m boundary. Feeding tributary (SC10) within Angle of draw. | - | - |
| Den96 | Small simple swamp | Within 600 m boundary. | - | - |
| Den146 | Small simple swamp | Within 600 m boundary. Previously mined beneath by LW7. | - | - |
| Den147 | Small simple swamp | Within 600 m boundary. | - | - |
| Den148 | Small simple swamps | Swamps to be mined beneath or within Angle of draw. | - | - |

**Table 6: Previous Survey Effort of Natural Features in study area**

| Stream | Stream order | Position of highest impact area | Previous vegetation survey | Previous fauna survey |
|---|---|---|---|---|
| SC10 | 2 | Angle of draw. Partially located above LW19. | Fixed vegetation monitoring quadrat (Biosis 2018). Monitoring undertaken for 8-14 years. | Fixed frog and bird monitoring sites (Biosis 2019). Monitoring undertaken for 8-14 years. |
| SC10C | 1 | Angle of draw | - | Fixed frog, bird and invertebrate monitoring sites (Biosis 2019). Monitoring undertaken for 8-14 years. |
| WC13 | 2 | 600 m boundary | - | - |
| WC14 | 1 | Partially located above LW19. | - | - |
| WC17 | 2 | Angle of draw | - | - |
| Wongawilli Creek | 3 | Angle of draw | 1 x vegetation surveys sites (vegetation validation and dominant species observations) and 3 x 20 x 20 m quadrats (Q1, Q7 and Q8). | Frog surveys and call play back, bird survey, frog searches, habitat assessments, diurnal herpetofauna search, anabat, spotlighting, nocturnal call play back for owls, various other surveys. |

## 4.2 Current survey

### 4.2.1 Survey timing

The current project involved flora and fauna surveys within the study area and focused on landscape features and associated biodiversity which may be sensitive to the impacts of subsidence from longwall extraction such as swamps, waterways and rocky areas. Survey effort focussed on areas within the study area which had not been subject to previous survey or had limited survey coverage (Figure 4 and Figure 5).

Survey was conducted throughout the study area over three days (12 and 13 of December 2019, 21 January 2020). Field survey activities are detailed in the following sections.

### 4.2.2 Flora and vegetation survey

Flora survey focused on vegetation validation of Upland Swamps within the study area (Figure 4). A sample of swamps mapped within the Woronora vegetation mapping project (NPWS 2003), Biosis (2018) swamp mapping or identified via aerial photography analysis were visited to confirm the vegetation present and update mapping of swamp boundaries including the swamp unit and sub unit as per NPWS 2003. This process was completed by performing Rapid Data Points to record the following:

- Dominant species present at all strata levels; and

- Total projective foliage cover and height at all strata levels.

Species composition and characteristics were then compared with vegetation descriptions. Boundaries between units and sub units were captured in the field by collecting waypoints and tracks along identified boundaries. Where possible, vegetation patterns within swamps were also observed from surrounding vantage points using binoculars to aid with identifying consistency of vegetation or otherwise across the swamp.

Field GPS data was later overlaid onto aerial imagery and boundary mapping was completed with adjustments made if necessary, according to observable colour and texture patterns of vegetation as well as observations of tree canopies, which were used to define the outer-boundaries of the swamps.

Limitations associated with the selected method include reliance on correct positioning of aerial imagery as well as correct interpretation of canopy shadows. Boundaries between swamp communities and sub-communities are frequently not discrete, rather these communities' grade into one another. Therefore, there is an element of subjectivity regarding the exact positioning of boundaries dependent upon the observer.

The flora survey included targeted threatened plant species search within Upland Swamps in the study area.

### 4.2.3 Fauna survey

Fauna survey effort focused on areas susceptible to subsidence impacts and associated fauna. Areas targeted included Upland Swamps and creek lines (Figure 5). It is noted that most areas of frog habitat have been previously surveyed during annual monitoring of the area.

A summary of the current survey effort is shown in Table 7.

**Table 7: Current Survey Effort**

| Survey Technique | Habitat | Survey Effort (person hours) | Date |
|---|---|---|---|
| Diurnal frog and tadpole searches | Creeks | 6 | 12/12/2019 |
| Nocturnal frog searches | Creek | 6 | 12/12/2019 |

### 4.2.4 Survey conditions and limitations

Survey was conducted during December 2019. There were no significant rainfall events prior to, or during, the December survey period (Appendix 3) and the area was experiencing significant drought which limited breeding habitat for various frogs including target threatened species. This may have limited observations where the Littlejohn's Tree Frog has previously been recorded, however habitat for this species is well known and thus potential habitat has been considered within this report. In addition, given the extensive frog monitoring surveys that have been undertaken in the study area to date by Biosis (2019), this is considered to be a minor limitation given the objectives of this assessment.

## 4.3 Likelihood of occurrence assessment for threatened species

A list of threatened species within the locality was derived from database searches (DPIE Bionet Atlas of NSW Wildlife and EPBC Act Protected Matters Search Tool) (Appendix 1). The list of potentially impacted species is determined from consideration of this list. In order to adequately determine the relevant level of assessment for each species, further analysis of the likelihood of those species occurring within the study area was undertaken.

Five categories for 'likelihood of occurrence' (Table 8) were attributed to species after consideration of criteria such as known records, presence or absence of important habitat features on the subject site, results of the field surveys and professional judgement. This process was completed for each individual species.

Species considered further were those in the 'Known' to 'Moderate' categories and where impacts for the species could reasonably occur from the development (Appendix 1).

**Table 8: Likelihood of occurrence methodology**

| Likelihood rating | Threatened Flora/EEC Criteria | Threatened and Migratory Fauna Criteria |
|---|---|---|
| Known | The species/EEC was observed within the study area. | The species was observed within the study area. |
| High | It is likely that a species/EEC inhabits or utilises habitat within the study area. | It is likely that a species inhabits or utilises habitat within the study area. |
| Moderate | Potential habitat for a species/EEC occurs on the site. Adequate field survey would determine if there is a 'high' or 'low' likelihood of occurrence for the species within the study area. | Potential habitat for a species occurs on the site and the species may occasionally utilise that habitat. Species unlikely to be wholly dependent on the habitat present within the study area. |
| Low | It is unlikely that the species/EEC inhabits the study area. | It is unlikely that the species inhabits the study area. If present at the site, the species would likely be a transient visitor. The site contains only very common habitat for this species which the species would not rely on for its on-going local existence. |
| None | The habitat within the study area is unsuitable for the species/EEC. | The habitat within the study area is unsuitable for the species. |

# 5 Results

## 5.1 Vegetation communities

Six vegetation communities or sub-communities have been mapped as occurring within the study area by NPWS (2003) and Niche during the current project, after confirmation of swamp mapping (Table 9).

Ground-truthing of upland swamp community mapping resulted in changes to upland swamp sub-community patterns, swamp boundaries and changes in vegetation communities (Figure 3, Figure 4).

A number of small swamps were added to vegetation mapping after field observations. Conversely, sections of previously mapped swamps were reclassified as other community types. These areas corresponded with woodland or forest communities with thick understories of banksia thicket. These changes are to be expected since the base mapping of the Upland Swamp Banksia Thicket community unit did not attempt to remove areas of banksia thicket that may occur in other communities such as Exposed Sandstone Scribbly Gum Woodland (see page 200 of NPWS 2003).

Banksia thickets occur moderately frequent throughout the study area in the range of communities present. Often these areas share floristic similarities with simpler swamp types such as areas of banksia thicket (typically dominated by *Banksia marginata*). However, the presence of other diagnostic swamp species that are more reliant on frequently waterlogged soils is lacking or poorly represented in these areas.

**Table 9: Area of vegetation communities within the study area (including adjacent swamp areas)**

| Map Unit (NPWS 2003) | Vegetation Community (NPWS 2003) | Area in study area * (ha) |
|---|---|---|
| MU26 | Sandstone Gully Peppermint Forest (SGPF) | 208.53 |
| MU29 | Exposed Sandstone Scribbly Gum Woodland (ESSGW) | 169.25 |
| MU | Rock Plate Heath Mallee | 0.89 |
| MU42 | Upland Swamps: Banksia Thicket (USBT) | 20.26 |
| MU43 | Upland Swamps: Tea-Tree Thicket (USTTT) | 4.3 |
| MU44 | Upland Swamps: Sedgeland-Heath (USSH) Complex | 7.47 |
| MU46 | Upland Swamps: Mallee-Heath | 1.9 |

*note that figures for swamp communities include areas of swamps beyond the study area boundary where any part of the swamp occurs within the boundary. Vegetation calculations are a combination of NPWS (2003) mapped areas and Niche validated mapping for swamp communities. There may be some discrepancies where NPWS (2003) has mapped upland swamp communities and the swamp boundaries have been adjusted as part of the validated swamp mapping undertaken as part of this assessment.

## 5.2 Upland Swamps within the study area

Nine Upland Swamps occur within the study area based on the 600m boundary (Table 10) (Figure 3 and 4). The majority of swamps are smaller swamps with single sub-communities, which tend to be drier swamp types (Banksia Thicket). Complexity of swamps generally increased with overall size of the swamp complex. This is likely due to larger swamps having more variable groundwater conditions across the

swamp from more frequently waterlogged areas with heavy peat development to less frequently waterlogged areas with less peat development.

The two complex large swamps within the study area (Den15a and Den15b) are located within the predicted area of subsidence impacts (35 degree angle of draw study area) (Figure 3 and 4). There are also four swamps occurring within the predicted area of subsidence impacts (35 degree angle of draw study area) (Figure 3).

**Table 10: Upland Swamps within the study area**

| Swamp No. | Swamp Community/sub-community | Area (ha) | | | |
|---|---|---|---|---|---|
| | | Total Swamp[1] | 600 m boundary | Angle of draw | Above proposed longwalls |
| Den12 | Upland Swamps: Banksia Thicket | 5.37 | 5.37 | 5.37 | - |
| Den15a | Upland Swamps: Banksia Thicket | 8.57 | 8.14 | 5.02 | 0.01 |
| | Upland Swamps: Sedgeland-Heath Complex (Cyperoid Heath) | 4.40 | 3.40 | 1.37 | <0.01 |
| | Upland Swamps: Sedgeland-Heath Complex (Restoid Heath) | 2.49 | 2.49 | 0.38 | - |
| | Upland Swamps: Tea-tree Thicket | 2.56 | 0.73 | 0.32 | - |
| Den15b | Upland Swamps: Banksia Thicket | 3.35 | 3.35 | 3.20 | 0.01 |
| | Upland Swamps: Tea-tree Thicket | 1.04 | 1.04 | 1.04 | - |
| | Upland Swamps: Sedgeland-Heath Complex (Cyperoid Heath) | 0.57 | 0.57 | 0.55 | - |
| | Upland Swamps: Sedgeland-Heath Complex (Sedgeland) | 0.01 | 0.01 | 0.01 | - |
| Den34 | Upland Swamps: Mallee-Heath | 1.90 | 1.90 | - | - |
| | Upland Swamps: Banksia Thicket | 0.40 | 0.40 | - | - |
| | Upland Swamps: Tea-tree Thicket | 0.10 | 0.10 | - | - |
| Den95 | Upland Swamps: Banksia Thicket | 1.09 | 0.81 | - | - |
| Den96 | Upland Swamps: Banksia Thicket | 0.17 | 0.17 | - | - |
| Den146 | Upland Swamps: Tea-tree Thicket | 0.60 | 0.08 | - | - |
| Den147 | Upland Swamps: Banksia Thicket | 0.45 | 0.45 | - | - |
| Den148 | Upland Swamps: Banksia Thicket | 0.86 | 0.86 | 0.86 | - |
| **Total** | | **33.93** | **29.87** | **18.12** | **0.02** |

## 5.3 Upland swamp community descriptions

### 5.3.1 MU42: Upland Swamps: Banksia Thicket (BT)

Banksia Thicket occurs as small swamps or on the drier edges of larger more complex swamps within the study area. Within the study area the community typically grades into adjoining areas of the drier MU26: Sandstone Gully Peppermint Forest and MU29 Exposed Sandstone Scribbly Gum Woodland.

[1] Includes all swamps that are located wholly or partially within the 600 m study area boundary.

In some swamps, a sparse canopy layer exists. Where this occurs, the canopy has a low projective foliage cover (e.g. 5%). Trees included *Eucalyptus racemosa* or *E. sieberi* with a canopy height to approximately to 15 m.

The shrub layer reached a height of approximately 4 - 5 m, and a high projective foliage cover of 60 to 90%. The shrub layer primarily consisted of *Banksia ericifolia* with associate species including *Acacia terminalis, Hakea teretifolia, Leptospermum polygalifolium, L. juniperinum, L. squarrosum, Petrophile pulchella.*

Ground layer species include: *Bauera rubioides, Baeckea imbricata, Epacris microphylla, Empodisma minus, Cyathochaeta diandra, Hibbertia riparia, Lepidosperma limicola, Sprengelia incarnata, Schoenus brevifolius* and *Dillwynia floribunda.*

### 5.3.2 MU43: Upland Swamps: Tea Tree Thicket (TTT)

Tea Tree Thicket occurs in areas of impeded drainage within swamps in the study area.

The community has been classified as a closed scrub, with a small tree and shrub layer reaching a height of approximately 5 m and project foliage cover of up to 80%. Canopy trees include *Eucalyptus piperita and E. racemosa.*

The midstorey and shrub layers include: *Acacia rubida, Banksia robur, Melaleuca linearifolia, Leptospermum juniperinum, L polygalifolium, L lanigerum* and *Petrophile pulchella.*

Ground layer species include: *Gahnia sieberi, Baumea teretifolia, Dillwynia floribunda, Empodisma minus, Leptocarpus tenax* and *Lepidosperma limicola*.

### 5.3.3 MU44: Upland Swamps: Sedgeland Heath Complex

**a) Sedgeland**

The sedgeland community was recorded within minor depressions in a number of Upland Swamps in the study area.

The shrub layer reached a height of approximately 1 m with a project foliage cover of up to 30%. Shrubs included: *Baeckea imbricata, Epacris obtusifolia, Sprengelia incarnata, Symphionema paludosum, Boronia parviflora, Hakea teretifolia* and *Banksia ericifolia* subsp*. ericifolia*

The Ground layer has a projected foliage cover of approximately 30 to 60%. Species include: *Leptocarpus tenax, Schoenus brevifolius, Schoenus paludosus, Lepyrodia scariosa, Ptilothrix deusta, Dampiera stricta* and *Stylidium graminifolium.*

**b) Restioid Heath**

The restioid heath, like that of sedgeland, occurs within the minor depressions in a number of Upland Swamps in the study area.

A low shrub layer of *Banksia oblongifolia*, *Hakea teretifolia* and *Epacris obtusifolia* consistently occur with occasional *B. robur*, *Melaleuca thymifolia* and *M. squarrosa*. The project foliage cover is approximately 40% to a height of 1 m.

The ground cover consists of a combination of rushes, herbs and grasses forming a dense ground cover. Species present include *Empodisma minus*, *Lepyrodia scariosa*, *Leptocarpus tenax*, *Lindsaea linearis*, *Xanthorrhoea resinifera*, *Stackhousia nuda*, *Mitrasacme polymorpha* and *Schoenus brevifolius*.

**c) Cyperoid heath**

The cyperoid heath occurs within the minor depressions in a number of Upland Swamps in the study area.

A low shrub layer of *Banksia robur, Melaleuca squarrosa, Hakea teretifolia, Leptospermum juniperinum, Banksia ericifolia* subsp. *ericifolia, Pultenaea divaricata* and *Baeckea linifolia*. The project foliage cover is approximately 35% to a height of 1.5 m.

The ground cover consists of a combination of sedges and rushes up to 1 m in height and 90% projected foliage cover. Species present include *Lepidosperma limicola, Gymnoschoenus sphaerocephalus, Chorizandra sphaerocephala, Baumea rubiginosa, Empodisma minus, Leptocarpus tenax, Mitrasacme polymorpha* and *Xyris operculata*.

### 5.3.4 MU46: Upland Swamps: Mallee-Heath

Mallee-Heath occurs as a small swamps within the study area. Within the study area the community typically grades into adjoining areas of the drier MU26: Sandstone Gully Peppermint Forest and MU29 Exposed Sandstone Scribbly Gum Woodland.

Characterised by an emergent Mallee ash (*Eucalyptus stricta*) above a shrub layer of Banksias, Hakeas and Tea-trees. Shrubs to 1.5 m tall and mean projected canopy cover of 5-35% include *Eucalyptus stricta, Banksia ericifolia subsp. ericifolia, Hakea teretifolia, Banksia paludosa subsp. Paludosa* and *Allocasuarina nana*. Sedges and rushes occur in the groundlayer to 1m tall with a mean projected canopy cover 70-90%, including *Leptocarpus tenax, Lepyrodia scariosa, Empodisma minus* and *Mitrasacme polymorpha.*

## 5.4 Upland swamp – TEC classification

### 5.4.1 BC Act/TSC Act/EPBC Act

The majority of Upland Swamps within the study area are considered to fit the NSW and Commonwealth determination descriptions of Coastal Upland Swamps in the Sydney Basin Bioregion, which is listed as an EEC under the NSW BC Act and the Commonwealth EPBC Act. Point 7 of the Final Determination (NSW Scientific Committee 2005) states Coastal Upland Swamp in the Sydney Basin bioregion includes mapping units: Upland Swamps Banksia Thicket (MU42), Upland Swamps Tea-tree Thicket (MU43) and Upland Swamps Sedgeland-Heath Complex (MU44) of NPWS (2003). All three of these communities occur within the Upland Swamps in the study area (Figure 3). Upland Swamps: Mallee-Heath (MU46) is not included in the definition for the EEC.

The approximate area of EEC Coastal Upland Swamps within the wider study area, which includes the totality of a swamp where any part of the swamp is within 600 m of the proposed longwalls is 32.03 ha (Table 10).

## 5.5 Threatened flora

A total of 27 threatened plant species listed on the EPBC Act and or BC Act have been previously recorded, or have potential habitat within a 5 km radius of the study area (Appendix 1 and Figure 6). Of the 27 threatened species obtained in the database searches, 10 species (*Acacia bynoeana, Cryptostylis hunteriana, Epacris purpurascens* var. *purpurascens, Grevillea parviflora* subsp. *parviflora, Grevillea raybrownii, Leucopogon exolasius, Melaleuca deanei, Persoonia acerosa, Persoonia hirsuta* and *Pultenaea aristata*) were considered to have a Moderate to High likelihood of occurrence in the study area.

*Leucopogon exolasius* were observed at multiple locations within the study area, within areas where the species has previously been observed and mapped. This species predominantly occurs on ridgetops within the study area and is not dependent on groundwater. Therefore, as this species would not be impacted by subsidence the species was not surveyed in detail. No other threatened flora was recorded within the study area.

Potential impacts to threatened flora are discussed in Section 6.3.

## 5.6 Threatened fauna

A total of 56 threatened fauna species listed on the EPBC Act and or BC Act have been previously recorded, or have potential habitat within a 5 km radius of the study area (Appendix 1 and Figure 7).

The previous SIS survey recorded 139 fauna, including 32 threatened fauna within Dendrobium Area 3. Three threatened fauna were recorded during the current survey as detailed in Table 11.

**Table 11: Threatened fauna recorded during current survey**

| Threatened species | Observation details | Date |
|---|---|---|
| Littlejohn's Tree Frog | Observations of tadpoles were made from the following locations:<br>• WC13 (50 individuals observed across 4 pools small and med/large with tadpoles of various stages include close to metamorphic).<br>• Swamp Den15a (approximately 170 individuals observed in three separate pools along edge of swamp. | 12/12/2019 |
| Gang-gang Cockatoo | One individual observed sitting in a tree within Exposed Sandstone Scribbly Gum Woodland, upslope from swamp Den12. | 13/12/2019 |
| Glossy Black-cockatoo | Two individuals observed at WC13 | 12/12/2019 |

## 5.7 Fauna habitat

Fauna habitat within the study area considered prone to subsidence impacts is described in Section 5.7.

### 5.7.1 Upland Swamps

Upland Swamps range in character from relatively dry swamps supporting Banksia Thicket to more permanently inundated swamps with abundant sedges and herbs (see section 5.2). Upland Swamps may provide habitat to a wide variety of birds, mammals, amphibians, reptiles and invertebrate species, with particular species performing strong associations with swamps (e.g. the Giant Dragonfly).

Upland Swamps within the study area also provide an important role in regulating flows along particular watercourses within the study area.

### 5.7.2 Creeks and drainage lines

Major watercourses within and adjoining the DA3A study area include: Wongawilli Creek and Sandy Creek. Various drainage lines and tributaries of these watercourses occur throughout the study area. All creeks and drainage lines within the study area are considered to be generally in good condition, and they provide a range of habitat features including: emergent vegetation, riffles, pools, sandy substrate and rocks.

Creek lines are important to particular frog and reptile species including threatened species, with water facilitating the breeding cycle and other lifecycle components of most frogs. The character of drainage lines depends on their size, slope and catchment area with small ephemeral streams offering important breeding and sheltering habitat for some species while larger permanent streams are preferred by others. Habitat features along the streams include rock pools, riffle zones, gravel beds, woody debris, boulders and aquatic vegetation.

### 5.7.3 Sandstone outcrops, overhangs and caves

Sandstone outcrops, overhangs and caves are typically important to reptile and bat species. Threatened reptiles that may utilise such features include the threatened Broad-headed Snake.

Caves and overhangs within the study area may provide habitat for micro-bats, including threatened species: Eastern Bentwing-bat, Little Bentwing-bat and Southern Myotis. Cave development within the study area is poor however, so roosting is likely to be confined to limited areas. No large breeding colonies of cave dependant bats are expected to occur within the study area.

## 5.8 Key threatening processes

Key-threatening processes (KTP) relevant to the project include:

1. Alteration of habitat following subsidence due to longwall mining; and
2. Alteration of the natural flow regimes of rivers, stream, floodplains and wetlands.

### 5.8.1 Alteration of habitat following subsidence due to Longwall mining

Alteration of habitat following subsidence due to longwall mining is listed as a KTP under Schedule 4 of the NSW BC Act. This is the most relevant KTP associated with the proposal.

Subsidence due to longwall mining has been recognised as causing habitat alteration, with species and ecological communities that depend on aquatic and semi-aquatic habitats being particularly susceptible to the impacts of subsidence. Consequently, alteration of habitat following subsidence due to longwall mining has been determined by the NSW Scientific Committee to constitute a Key Threatening Process (NSW Scientific Committee 2005).

A list of threatened species, populations and TECs potentially impacted by longwall mining is provided in the NSW Scientific Committee Final Determination for this KTP (NSW Scientific Committee 2005). Flora of relevance to this assessment include: *Acacia baueri* subsp*. aspera, Epacris purpurascens* var*. purpurascens, Leucopogon exolasius, Melaleuca deanei, Persoonia acerosa* and *Pultenaea aristata.* Fauna include: Eastern Pygmy Possum, Southern Brown Bandicoot, Giant Burrowing Frog, Black Bittern, Littlejohn's Tree Frog, Stuttering Frog, Southern Myotis, Red-crowned Toadlet, Grey-headed Flying Fox, Giant Dragonfly, Broad-headed Snake and Rosenberg's Goanna.

### 5.8.2 Alteration of the natural flow regimes of rivers, stream, floodplains and wetlands

Alteration of the natural flow regimes of rivers, stream, floodplains and wetlands is listed as a KTP under Schedule 4 of the BC Act. This is a relevant KTP associated with the Proposal, which is caused by subsidence.

Alteration to natural flow regimes can occur through reducing or increasing flows, altering seasonality of flows, changing the frequency, duration, magnitude, timing, predictability and variability of flow events, altering surface and subsurface water levels and changing the rate of rise or fall of water levels.

## 5.9 Critical habitat or Areas of Outstanding Biodiversity Value (AOBV)

Areas of Critical Habitat under the NSW TSC Act have been replaced by AOBVs with the introduction of the NSW BC Act. No AOBVs have been declared for any ecological values within the study area. No AOBVs will be impacted by the proposal.

# 6 Impact assessment

## 6.1 Potential impacts to vegetation

Vegetation communities which are not dependant on groundwater are unlikely to be impacted by subsidence due to underground mining. This accounts for most of the woodland and forest communities in Table 9.

Groundwater dependant and riparian vegetation may experience some floristic changes in response to changed groundwater conditions, as a result of subsidence.

Riparian vegetation is generally not mapped as discrete vegetation communities, rather these areas display structural and floristic variation within their composite community in response to more frequent contact with shallow groundwater. Riparian vegetation may be potentially impacted by subsidence through water diversion or cracking of bedrock.

In the Southern Coalfield, observed impacts to riparian vegetation as a result of subsidence are minor in occurrence. Furthermore, limited impacts to riparian vegetation have been observed in Dendrobium Mine to date (Biosis 2016). Previous examples of impacts include: dieback of riparian vegetation as a result of methane releases which occurred nearby Cataract River during the 1990s (Eco Logical Australia 2004), and small localised changes to riparian vegetation along a section of the Waratah Rivulet.

Impacts to riparian vegetation associated with the Proposal are predicted to be minor in occurrence, being localised if they occurred.

Groundwater dependant ecosystems (typically comprising Upland Swamps within the locality) on the other hand are prone to groundwater changes as a result of subsidence. Potential impacts are discussed below.

## 6.2 Potential impacts to Upland Swamps

The study area contains a mixture of headwater swamps and valley infill swamps. If all nine swamp areas within and adjacent to the 600 m study area boundary are considered, 33.93 ha of Upland Swamps including complex swamps with wetter sub-units have some potential for impact. However, the areas bounded by 600 m (especially if adjacent swamp areas are included) is considered a conservative approach to determining areas of potential impacts.

The majority of impacts to Upland Swamps will take place where they occur above the proposed longwall (0.02 ha of Upland Swamps). The severity and risk of impacts will reduce with distance from longwalls up to the 35° angle of draw study area, which includes the 20 mm subsidence contour (18.12 ha of upland swamp within 35° angle of draw study area). Beyond the 35° angle of draw study area, impacts to features such as swamps and watercourses are expected to be minor or negligible. A recent assessment at Dendrobium Mine concluded that hydrological change in Upland Swamps is not evident in shallow groundwater piezometers located more than 60 m from the extracted longwall margin (Watershed Hydrogeo, 2019). Where streams flowing into swamps are located above or in close proximity to longwalls this may have impacts on swamps downstream of impacted streams.

Den15a is located partially above the south-eastern corner of LW19, a total of 0.01 ha (Figure 3). Den15b is also located partly above the LW19 tailgate, a total of 0.001 ha (Figure 3). Approximately 18.12 ha of

Upland Swamps from Den15a, Den15b and other swamps occur within the 35° angle of draw study area. These areas are likely to experience a range of subsidence impacts (see Table 12). Additional swamps located within the study area based on the 600 m boundary (Figure 3) equate to an additional 11.75 ha of Upland Swamps within the wider study area which may experience some minor or negligible impacts depending on the distance from the proposed longwall.

To assess the potential impacts of subsidence on Upland Swamps, a review of MSEC (2020) subsidence predictions and previous literature on monitoring of swamp subsidence impacts from the locality has been completed, with a summary provided in Table 12.

**Table 12: Impact predictions for Upland Swamps within and adjacent to the study area**

| Site | Swamp characteristics | Position | Subsidence predictions (MSEC 2020) | Conclusion |
|---|---|---|---|---|
| Den12 | Medium sized simple swamp. Northern tip of swamp adjacent to WC17. | Within the angle of draw. Directly above LW7 and LW8, 180 m north of LW19 at closest point | Swamp Den12 is located above the previously extracted LW7 and LW8. There are small reductions in stream grade within or near to Swamp Den12. There is potential for subsidence induced tilt to result in minor and localised increased ponding upstream of these locations. However, these swamps are located above the existing LW7 and LW8 and, therefore, the potential for increased ponding occurs due to these existing longwalls rather than the proposed LW19.<br>Fracturing of the bedrock could occur beneath Swamps Den12. The swamp has layers of organic soil and, in most cases, cracking would not be visible at the surface within these swamps, except where the depths of bedrock are shallow or exposed. The dilated strata beneath the drainage lines could result in the diversion of some surface water flows beneath parts of the swamps where they are located above and adjacent to the proposed longwall. Where there is no connective fracturing to any deeper storage, it is likely that surface water flows will re-emerge at the limits of fracturing and dilation. | Monitoring of the impacts of LW7 in DA3A, which was extracted directly beneath Swamp Den12, revealed one fracture in a rock outcrop after mining beneath this swamp. Regular monitoring has been undertaken and, to date, no erosion or other changes have been observed (MSEC 2020).<br>Unlikely to be measurable additional impacts (after impacts from LW7 and LW8) to this swamp or associated species including threatened species from the current proposal. Monitoring of impacts likely to be confounded from previous direct undermining (LW 7 and 8).<br>A known population of Littlejohn's Tree Frog occurs along WC17 downstream, of swamp Den12. |
| Den15a | Large complex swamp with pools observed within or on edges of swamp. Swamp follows alignment of watercourse SC10. | Partially above the maingate of LW19, within angle of draw. Feeding tributary (SC10) within angle of draw. | Fracturing could occur beneath swamp Den15a near the valley base and where it is located closest to the proposed longwall. It is possible that a series of smaller fractures, rather than one single fracture, could develop in the bedrock.<br>Predicted upsidence could result in the dilation of the strata beneath this swamp (where it | Possible ecological impacts including changes in vegetation and threatened species habitat (predominantly for Littlejohn's Tree Frog) for the area of swamp directly above and adjacent the proposed longwall. A large population of Littlejohn's Tree Frog is known to occur within areas of this swamp and associated drainage lines |

| Site | Swamp characteristics | Position | Subsidence predictions (MSEC 2020) | Conclusion |
|---|---|---|---|---|
| | | | occurs above LW19). The dilated strata beneath the drainage lines could result in the diversion of some surface water flows beneath parts of the swamp where they are located above or adjacent to the proposed longwall. Where there is no connective fracturing to any deeper storage, it is likely that surface water flows will re-emerge at the limits of fracturing and dilation.<br>Swamp Den15a, is located near the base of drainage lines SC10. This swamp could experience valley related effects due to the extraction of the longwalls in DA3A.<br>The potential for fracturing of the downstream controlling rockbar for Swamp Den15a due to the mining of the proposed LW19, resulting in reduction in standing water level based on current rainfall and surface water flow, is in the order of 13 %.<br>Given their proximity to the proposed longwall panel, it is likely that shallow groundwater levels will be affected at Swamp Den15a (7% of the mapped area of Swamp Den15a is within 60 m of the goaf footprint) HGEO (2020). | and pools. Breeding habitat for this population may be impacted through reductions in water retention from pools after fracturing. Areas may trend towards Fringing Eucalypt Forest if changes are long-term. Swamp is large and complex and contributes significantly to biodiversity values given its size, complexity and available pooling habitat, which is known to support a population of Littlejohn's Tree Frog. |
| Den15b | Large complex swamp with pools observed within or on edges of swamp. Swamp follows alignment of watercourse SC10C. | Within angle of draw. Previously mined beneath by LW8. Directly above LW7 and LW8, partially above LW19 tailgate. | Fracturing could occur in the bedrock beneath this swamp where it is located above and adjacent to the proposed longwall.<br>There are no predicted reversals of stream grade along drainage lines nor within the extents of the swamp as a result of subsidence induced tilt.<br>Predicted upsidence could result in the dilation of the strata beneath this swamp. The dilated | Possible ecological impacts including changes in vegetation and threatened species habitat (predominantly for Littlejohn's Tree Frog). A population of Littlejohn's Tree Frog is known to occur within areas of this swamp and associated drainage lines and pools. Breeding habitat for this population may be impacted through reductions in water retention from pools after fracturing. Areas may trend towards Fringing Eucalypt Forest if |

| Site | Swamp characteristics | Position | Subsidence predictions (MSEC 2020) | Conclusion |
|---|---|---|---|---|
| | | | strata beneath the drainage lines could result in the diversion of some surface water flows beneath parts of the swamp where they are located above or adjacent to the proposed longwall. Where there is no connective fracturing to any deeper storage, it is likely that surface water flows will re-emerge at the limits of fracturing and dilation.<br>Swamp Den15b is located near the bases of drainage line SC10C. This swamp could experience valley related effects due to the extraction of the longwalls in DA3A.<br>These impacts may lead to groundwater changes within the swamp. | changes are long-term. Swamp is large and complex and contributes significantly to biodiversity values given its size, complexity and available pooling habitat.<br>Monitoring of impacts from LW19 are likely to be confounded from previous direct undermining (LW 7 to 8). |
| Den34 | Small simple swamp occurring along WC13. | Within 600 m boundary. Feeding tributary (WC13) within 600 m boundary. Outside the mining area, 310 m south of LW19 at closest point. | It is unlikely that fracturing would occur in the bedrock beneath this swamp.<br>Unlikely to experience upsidence or compressive strain due to valley closure effects.<br>Swamp Den34 is located along WC13. There are no predicted reversals of stream grade along the drainage line nor within the extents of the swamp due to subsidence induced tilt.<br>This swamp could experience valley related effects due to the extraction of the longwalls in DA3A. | Unlikely to be measurable impacts to this swamp or associated species, including threatened species.<br>Swamp is small and simple. Observations of Littlejohn's Tree Frog were made approximately 200 m downstream of the swamp and the species may occur within the swamp and downstream pools. |
| Den95 | Small simple swamp along watercourse SC10. | Within 600 m boundary. Feeding tributary (SC10) within angle of draw. Outside the mining area, 230 m | It is unlikely that fracturing would occur in the bedrock beneath this swamp.<br>Unlikely to experience upsidence or compressive strain due to valley closure effects. | Unlikely to be measurable impacts to this swamp or associated species including threatened species. |

| Site | Swamp characteristics | Position | Subsidence predictions (MSEC 2020) | Conclusion |
|---|---|---|---|---|
| | | east of LW19. Located partially above LW8. | | |
| Den96 | Small simple swamp, no mapped pools or watercourses adjacent. | Partially within 600 m boundary. Outside the mining area, 210 m south of LW19. | It is unlikely that fracturing would occur in the bedrock beneath this swamp.<br>Unlikely to experience upsidence or compressive strain due to valley closure effects. | Unlikely to be measurable impacts to this swamp or associated species including threatened species. |
| Den146 | Small simple swamp, no mapped pools or watercourses adjacent. | Partially within 600 m boundary. Directly above LW7, 580 m north of LW19. | It is unlikely that fracturing would occur in the bedrock beneath this swamp as a result of LW19.<br>Unlikely to experience upsidence or compressive strain due to valley closure effects as a result of LW19. | Unlikely to be measurable additional impacts (after impacts from LW7 and LW8) to this swamp or associated species including threatened species from the current proposal. Monitoring of impacts from LW19 likely to be confounded from previous direct undermining (LW 7 and 8). |
| Den147 | Small simple swamp, Adjacent to tributary of Sandy Creek. | Within 600 m boundary. Outside the mining area, 490 m south-east of LW19. | It is unlikely that fracturing would occur in the bedrock beneath this swamp.<br>Unlikely to experience upsidence or compressive strain due to valley closure effects. | Unlikely to be measurable impacts to this swamp or associated species including threatened species. |
| Den148 | Small simple swamp, Adjacent to WC14. | Partially above LW19 | Fracturing of the bedrock could occur beneath Swamp Den148 where it is located above and adjacent to the proposed longwall. The swamp has layers of organic soil and, in most cases, cracking would not be visible at the surface within the swamp, except where the bedrock is shallow or exposed. The dilated strata beneath the drainage lines could result in the diversion of some surface water flows beneath parts of the swamps where they are located above and adjacent to the proposed longwall. Where there is no connective fracturing to any deeper storage, it is likely that surface water flows will re-emerge at the limits of fracturing and dilation. | Possible ecological impacts including changes in vegetation and threatened species habitat. Areas may trend towards Fringing Eucalypt Forest if changes are long-term. |

| Site | Swamp characteristics | Position | Subsidence predictions (MSEC 2020) | Conclusion |
|---|---|---|---|---|
| | | | There are no predicted reversals of stream grade along drainage lines nor within the extent of the swamp due to subsidence induced tilt. | |

The MSEC (2020) report has predicted potential subsidence impacts within swamps located within the 35° angle of draw study area constituting four swamps, with parts of the large complex swamps (Den15a and Den15b) being mined beneath by LW19. It is expected that fracturing of the bedrock beneath four of the swamps within the study area would occur as the result of the proposed longwall (MSEC 2020).

Should changes in groundwater levels within the Upland Swamps occur, this may impact on the distribution of local vegetation within the swamps as well as potential for downstream impacts to associated watercourses.

## 6.3 Potential impacts to threatened flora

Eleven threatened flora species have been determined to have a moderate to high likelihood of occurring within the study area (Appendix 4). However, a limited number have potential habitat likely to be impacted by subsidence.

Threatened flora likely to be impacted by subsidence (Table 13), include those associated with ground water dependent habitats, such as Upland Swamps and riparian vegetation. Ridgeline and woodland dependent threatened flora are unlikely to be significantly impacted by subsidence mechanisms.

Four species (*Epacris purpurascens* var*. purpurascens, Pultenaea aristata, Cryptostylis hunteriana* and *Leucopogon exolasius*) are considered to have habitat within the study area that may be potentially impacted by subsidence. Each of these species has potential habitat within Upland Swamps or creek line vegetation communities, however none of these species are reliant on such habitat and occur throughout a range of other habitats within the study area.

Impacts from the current proposal on threatened flora have been assessed within the project's SIS and are likely to be minimal as a result of the current proposal.

**Table 13: Threatened flora with potential to be impacted within the study area**

| Botanical Name | Potential Habitat in study area | Potential to be Impacted by Subsidence | Seven-Part Test Undertaken in SIS (Biosis 2007) |
|---|---|---|---|
| *Cryptostylis hunteriana* | Not previously recorded in study area.<br>Potential habitat includes Upland Swamps, creek lines and ridge lines. | Yes. Upland Swamps and creek line habitat may be impacted by subsidence mechanisms. | Yes.<br>No significant impact concluded. |
| *Epacris purpurascens* var. *purpurascens* | Not previously recorded in study area.<br>Potential habitat includes Upland Swamps, creek lines and ridge lines. | Yes. Upland Swamps and creek line habitat may be impacted by subsidence. | Yes.<br>No significant impact concluded. |
| *Leucopogon exolasius* | Previously recorded in the study area on ridgetop. Ridgetop habitat not likely to be impacted by subsidence. | Yes. Creek line habitat may be impacted by subsidence mechanisms. | Yes.<br>No significant impact concluded. |

| Botanical Name | Potential Habitat in study area | Potential to be Impacted by Subsidence | Seven-Part Test Undertaken in SIS (Biosis 2007) |
|---|---|---|---|
| | Potential habitat includes creek lines. Vegetation communities include SGPF and SRS. | | |
| *Pultenaea aristata* | Not previously recorded in study area.<br>Potential habitat includes Upland Swamps and creek lines. | Yes. Upland Swamps and creek line habitat may be impacted by subsidence mechanisms. | Yes.<br>No significant impact concluded. |

## 6.4 Potential impacts to fauna

Subsidence may have a direct impact on known and potential habitat for threatened fauna such as watercourses, Upland Swamps, riparian vegetation, rock overhangs, rocky outcrops, cliffs and crevices. Predicted impacts to these habitats are documented in Table 1.

Woodland and forest habitat types make up the majority of the study area. These habitat types which are not dependent on groundwater are unlikely to be impacted by subsidence. Microhabitat features such as tree hollows and exfoliating bark are also unlikely to be impacted.

The proposed longwall layout has been set back from major watercourses within the study area including Wongawilli Creek and Sandy Creek, and as such, subsidence impacts within these areas would be limited (MSEC 2020).

Watercourses that are directly mined beneath and those within the 35° angle of draw, are likely to have bedrock fracturing with associated impacts such as diversion of surface water flows and draining of pooled water. In addition to hydrological impacts, secondary impacts on water quality, such as increased concentrations of iron and manganese precipitates are likely to occur as a result of bedrock fracturing and increased groundwater input to the streams. The iron and manganese precipitates form an organic flocculant which decomposes and decreases dissolved oxygen, which may impact aquatic fauna and insects. Both such impacts (hydrological and water quality) may extend some distance downstream from the zone of fracturing, with the severity of impacts reducing with distance from the zone of fracturing as a result of dilution, particularly in partially ground-water fed systems. Overall, 3.9 km of mapped watercourses occur within the 35 degree angle of draw study area, which are susceptible to subsidence impacts (both direct and indirect), however impacts are likely to be confined to features such as standing pools, which make up a small but important proportion of the overall watercourse. A total of 8.2 km of mapped streams occur within 600m from the proposed LW19.

Within the Dendrobium mining domain, the above-mentioned aquatic impacts are considered the most significant impact to fauna. In regard to terrestrial fauna, such impacts are of particular relevance to frog species including the threatened species Red-crowned Toadlet, Littlejohn's Tree Frog and Giant Burrowing Frog, which are discussed in detail in Section 6.5.

Impacts on cliff lines, rock outcrops and other rocky habitats within the study area are likely to be minor, as observed in previous mining areas. No large-scale cliff collapses or slope failures are predicted. Small

rock outcrops are expected to experience minor impacts. Such impacts, while having some potential to alter available roosting or sheltering habitat for a range of species, have limited potential to harm or cause widespread mortality to species given the minimal occurrence of rock falls and collapses predicted, as well as the limited importance of any given area of such habitat (i.e. there is no one area considered to be particularly important for the survival of species within the study area such as roosting bats).

## 6.5 Potential impacts to threatened fauna

Fifty six threatened fauna were considered during likelihood of occurrence assessment (Appendix 1). Thirty nine of these species were determined to have a moderate or high likelihood of occurrence within the study area. Subsidence impacts from the proposed longwalls are likely to be negligible for the majority of these species. Nine threatened species are considered to be potentially impacted by subsidence impacts resulting from the proposal (Table 14).

Assessments of significance under the TSC Act were carried out for 30 threatened species during the project SIS, with significant impacts considered to potentiality occur for six species comprising:

- Frogs: Littlejohn's Tree Frog, Giant Burrowing Frog, Red-crowned Toadlet and Stuttering Frog;
- Reptiles: Broad-headed Snake; and
- Invertebrates: Giant Dragonfly.

The results of the assessments of significance are considered relevant to the current project considering the DA3, with the exception of the Stuttering Frog. The Stuttering Frog is not likely to be present in the study area as it has not been recorded during the present study or during extensive survey programs targeting threatened frog species conducted in adjacent areas with the same habitats (Biosis 2019). The very few recent records of the Stuttering Frog located from the Sydney Basin and southwards have all been associated with large permanent streams lined by wet sclerophyll or rainforest vegetation that tends to form a dense enclosing canopy over the stream area. This habitat is very limited or absent from the study area and surrounds.

An assessment of potential impacts from the current proposal for each of the identified threatened species likely to be impacted is provided below in Table 14.

**Table 14: Threatened fauna with moderate to high potential for impacts of study area due to the proposal**

| Species | Recent records and habitat in study area | Potential impact to species or potential habitat in study area | Assessment of significance undertaken in SIS and result (Biosis 2007) | Current conservation and impact status |
|---|---|---|---|---|
| **Amphibians** | | | | |
| *Heleioporus australiacus*<br><br>Giant Burrowing Frog | Species has been recorded during SIS and subsequent monitoring surveys in areas 3A and 3B (Biosis 2019; Figure 7).<br>Records are sporadic due to difficulty of detection. Not recorded during current survey but assumed to be present due to difficulty of detection. | Potential impacts include: changes to flow regimes, loss of surface flow and water retention within breeding pools. Changes in Upland Swamps are likely to impact the species via influencing downstream pool availability or permanency or through changes in sheltering habitat within swamps. | Yes.<br>Significant impact determined. | Conservation listing status of species has not changed since original SIS. Habitat has been shown to be impacted during monitoring of subsidence impacts within Areas 3A and 3B as predicted within SIS. Access constraints and detectability make it difficult to judge severity of impacts on population via effective monitoring.<br>Impacts detected for Littlejohn's Tree Frog for permanent pools are likely relevant for Giant Burrowing Frog. |
| *Litoria Littlejohni*<br><br>Littlejohn's Tree Frog | Recorded throughout Areas 3A-3C during SIS. Recorded within current study in several watercourses and downstream of Upland Swamps (Figure 5). Likely to be present in other watercourses throughout study area where appropriate breeding habitat is present.<br>Within the study area, the species relies upon semi-permanent pools for tadpole development. Maturation times for tadpoles | Potential impacts include: changes to flow regimes, loss of surface flow and water retention within breeding pools. Changes in Upland Swamps are likely to impact the species via influencing downstream pool availability or permanency or through changes in sheltering habitat within swamps. | Yes.<br>Significant impact determined. | Conservation listing status of species has not changed since original SIS.<br>Habitat has been shown to be impacted during monitoring of subsidence impacts within Areas 3A and 3B as predicted within SIS. Monitoring within Area 3B indicates that abundance of species is likely to have declined due to subsidence impacts such as reduced water retention in pools (Biosis 2016). In 2016 a declining trend in Littlejohn's Tree Frogs was recorded at post- |

| Species | Recent records and habitat in study area | Potential impact to species or potential habitat in study area | Assessment of significance undertaken in SIS and result (Biosis 2007) | Current conservation and impact status |
|---|---|---|---|---|
| | have been observed to take around four months (Anstis 2002), although this is variable in the field depending on factors such as weather. Pools of sufficient depth and hydroperiod within the catchment area were almost exclusively located along second order or higher streams or else first order streams where headwater swamps are positioned upstream. Larger, faster flowing streams such as Wongawilli Creek are less likely to support breeding. | | | mining site WC17, with no tadpoles or egg masses recorded from 2014 – 2016 (Biosis 2019). However, in 2017 120 tadpoles were recorded at the site, indicating a return to pre-mining recruitment conditions (Biosis 2019). In 2018, no individuals at any life stage were recorded within the breeding pools. This is consistent with the trends observed at the control sites and was attributed to the dry conditions at the time of survey (Biosis 2019). |
| *Pseudophryne australis*<br><br>Red-crowned Toadlet | Recorded during the SIS at five sites in Area 3 including upland Swamp 10, and a drainage line near upland Swamp Den15b.<br>Recorded in area 3B in 2012 surveys (Niche 2012) and during follow-up monitoring (e.g. Biosis 2016).<br>Recorded in Area 3C along WC20. | Yes, potentially impacted.<br>Given its habitat preferences appear to be largely dependent upon surface water runoff and seepage rather than ground water and requirements for semi-permanent pools, it is considered that this species is less sensitive to impacts from subsidence in comparison with other species such as Littlejohn's Tree Frog. Nonetheless, changes in hydrology related to cracking of bedrock underlying streams providing habitat for the Red-crowned | Yes.<br>Significant impact determined. | Conservation listing status of species has not changed since original SIS.<br>There has been limited monitoring to specifically assess impacts to Red-crowned Toadlet due to subsidence within the Dendrobium area. Monitoring has focussed upon the Littlejohn's Tree Frog which is likely to be more prone to subsidence impacts and more effectively monitored due to a conspicuous, relatively lengthy tadpole phase. |

| Species | Recent records and habitat in study area | Potential impact to species or potential habitat in study area | Assessment of significance undertaken in SIS and result (Biosis 2007) | Current conservation and impact status |
|---|---|---|---|---|
| | | Toadlet have the potential to influence moisture levels and retention of moisture within small pools, soaks and leaf litter environments on which Red-crowned Toadlets rely to complete their lifecycle. While some records of the species in the local area are adjacent to swamps, it is not considered that swamps play a particularly important role in providing appropriate breeding or sheltering habitat. | | Impacts detected for Littlejohn's Tree Frog along smaller streams are likely relevant for Red-crowned Toadlet. |
| **Reptiles** | | | | |
| *Hoplocephalus bungaroides*<br><br>Broad-headed Snake | Not previously recorded in study area.<br>Potential habitat includes ridgeline and creek lines. Vegetation communities include SGPF and ESSGW. | Yes, potentially impacted.<br>Impacts to any potential habitat is likely to be limited, based on previous observations of subsidence within adjacent mined areas and predictions of subsidence for the current proposal. That is, predictions of subsidence impacts such as rock-falls are limited in their extent (MSEC 2020). This factor, coupled with the requirement that subsidence would need to be coincident with sheltering habitat for the Broad-headed Snake which is quite limited, and | Yes.<br>No significant impact determined. | Conservation listing status of species has not changed since original SIS.<br>Limited monitoring has been done for this species. The species is difficult to detect and monitoring which includes lifting of preferred rock plates is potentially harmful to the species.<br>It is not known if this species has been impacted by subsidence from mining within the Dendrobium area, however given the limited extent of reported rock-falls, impacts |

| Species | Recent records and habitat in study area | Potential impact to species or potential habitat in study area | Assessment of significance undertaken in SIS and result (Biosis 2007) | Current conservation and impact status |
|---|---|---|---|---|
| | | that deleterious impacts would need to then result, leads to a prediction of minimal impacts for this species. | | are likely to be minimal and difficult to detect. |
| *Varanus rosenbergi*<br><br>Rosenberg's Goanna | Previously recorded by Biosis (2007) within Area 3.<br>Potential habitat includes Upland Swamps, ridgelines and creek lines. Vegetation communities include: SGPF and upland swamp communities. | Yes, potentially impacted.<br>Potential impacts include: death or injury resulting from rock fall or collapse.<br>Impacts to any potential habitat is likely to be limited, based on previous observations of subsidence within adjacent mined areas and subsidence predictions for the current proposal. That is, predictions of subsidence impacts such as rock-falls are limited in their extent (MSEC 2020). This factor, coupled with the requirement that subsidence would need to be coincident with sheltering habitat for the Rosenberg's Goanna and that deleterious impacts would need to then result, leads to a prediction of minimal impacts for this species. | Yes.<br>No significant impact determined. | Conservation listing status of species has not changed since original SIS.<br>Limited monitoring has been done for this species.<br>It is not known if this species has been impacted by subsidence from mining within the Dendrobium area, however given the limited extent of reported rock-falls, impacts are likely to be minimal and difficult to detect. |
| **Mammals** | | | | |
| *Miniopterus schreibersii* | Recorded in study area with probable certainty during the SIS. | Yes, potentially impacted. | Yes. | Conservation listing status of species has not changed since original SIS. |

| Species | Recent records and habitat in study area | Potential impact to species or potential habitat in study area | Assessment of significance undertaken in SIS and result (Biosis 2007) | Current conservation and impact status |
|---|---|---|---|---|
| Eastern Bent-wing Bat | Potential habitat includes the entire study area, however only specific features likely to be impacted. | Potential impacts include: death or injury resulting from rock fall or collapse, possible changes in availability of breeding and roosting habitat.<br>Maternity caves would not occur within the study area. If roosting occurs within the study area, it is unlikely to be widespread or significant. Minimal impacts (from subsidence of features such as cliffs and overhangs) are expected to occur given the limited propensity of roosting within the study area and the limited area of impact predicted to occur for possible roost habitats. | No significant impact determined. | Monitoring has not been undertaken for this species.<br>It is not known if this species has been impacted by subsidence from mining within the Dendrobium area, however given the limited extent of reported rock-falls and cliff failures, impacts are likely to be minimal and difficult to detect. |
| *Minipoterus australis*<br><br>Little Bent-wing Bat | Recorded in study area with probable certainty during the SIS.<br>Potential habitat includes the entire study area, however only specific features likely to be impacted. | Yes, potentially impacted.<br>Potential impacts include: death or injury as result of rock fall or collapse, possible changes in availability of breeding and roosting habitat. | Yes.<br>No significant impact determined. | Conservation listing status of species has not changed since original SIS.<br>Monitoring has not been undertaken for this species.<br>It is not known if this species has been impacted by subsidence from mining within the Dendrobium area, however given the limited extent of reported rock-falls and cliff failures, impacts are likely to be minimal and difficult to detect. |

| Species | Recent records and habitat in study area | Potential impact to species or potential habitat in study area | Assessment of significance undertaken in SIS and result (Biosis 2007) | Current conservation and impact status |
|---|---|---|---|---|
| *Myotis macropus*<br><br>Southern Myotis | Recorded in study area during the SIS.<br>Potential habitat includes larger watercourses with pools and standing water and adjacent vegetation. | Yes, potentially impacted.<br>Potential impacts include: death or injury as result of rock fall or collapse and impacts on prey availability due to drying of pools. | Yes.<br>No significant impact determined. | Conservation listing status of species has not changed since original SIS.<br>Monitoring has not been undertaken for this species.<br>It is not known if this species has been impacted by subsidence from mining within the Dendrobium area, however given the limited extent of reported rock-falls and cliff failures, impacts are likely to be minimal and difficult to detect. Drying of pools may impact on prey availability, but this impact is considered likely to be minimal given that the larger watercourses in the study area (such as Wongawilli Creek and Sandy Creek) are unlikely to be impacted by LW19. |
| **Invertebrates** | | | | |
| *Petalura gigantea*<br><br>Giant Dragonfly | One possible sighting in swamp Den15a (upper section) (Invertebrate Identification Australasia 2019). The lower section of swamp Den15a was determined to be unsuitable habitat (Invertebrate Identification Australasia 2019). No other | Yes, potentially impacted.<br>Potential impacts include: loss of upland swamp habitat as a result of subsidence. The critical factor governing the presence of *P. gigantea* is the permanent shallow groundwater level (Invertebrate Identification Australasia | Yes.<br>Significant impact determined. | Conservation listing status of species has not changed since original SIS.<br>Swamps with preferred breeding habitat for this species, based on the presence of moist swamp subcommunities (Den15a and Den15b) occur within the angle of draw and may be impacted by subsidence as a result |

| Species | Recent records and habitat in study area | Potential impact to species or potential habitat in study area | Assessment of significance undertaken in SIS and result (Biosis 2007) | Current conservation and impact status |
|---|---|---|---|---|
| | swamps within the study area have known sightings of the species.<br>Potential habitat includes Upland Swamps. Swamps that were recorded as being suitable habitat for *P. gigantea* were those swamps that had a high groundwater level with permanent wet areas that could include active soaks/seepage zones, exposed pools and streams evident during the dry periods and a deep peat layer (Invertebrate Identification Australasia 2019). The swamps also usually contained characteristic saturated soil vegetation such as *Banksia robur*, *Melaleuca sp*, *Gahnia sp*. *Lomandra sp* and the pouched Coral Fern (*Gleichenia dicarpa*) (Invertebrate Identification Australasia 2019). | 2019). Once the groundwater level drops below the depth of the larval burrows (> 70cm) and the peat dries the habitat, potentially a population in a specific swamp is lost (Invertebrate Identification Australasia 2019). | | of LW19. Additional swamps with preferred foraging habitat (i.e. within 500 m of a swamp with breeding habitat) for this species occur within the angle of draw study area and the 600 m study area. Minimal impacts are expected to occur for foraging habitat within dryer swamp types. |

## 6.6 Consent conditions specific to the current proposed longwall

Condition 5, schedule 3 of the Dendrobium Consent states:

> *5. The Applicant must ensure that subsidence does not cause erosion of the surface or changes in ecosystem functionality of Swamp 15a and that the structural integrity of its controlling rockbar is maintained or restored, to the satisfaction of the Secretary.*

The terms 'ecosystem functionality' and 'controlling rockbar' are not defined in the condition of consent.

Ecosystem Functionality is defined in the approved Area 3B Swamp Impact Monitoring, Management and Contingency plan (SIMMCP, Section 2.11.1, South32 2019) as:

> *ecosystem function of swamps is measured via the following attribute: the size of the groundwater dependent communities contributing to the swamps. Specifically, any changes in the proportion of Banksia Thicket, Tea-tree Thicket and Sedgeland-heath Complex within the monitored swamps.*

DPE advised the intent of the performance measure relating to ecosystem functionality for swamps was more general in intent; basically, the swamp will remain a swamp (South32 2019). Detailed swamp mapping will be updated as mining approaches each swamp. Mapping of Swamp Den15a as part of the current assessment, prior to the mining of LW19 shows the following areas of each sub community (total swamp area):

- Sedgeland-heath complex (Restioid Heath) 2.49 ha;
- Sedgeland-heath complex (Cyperoid Heath) 4.4 ha;
- Banksia Thicket 8.57 ha; and
- Tea-tree Thicket 2.56 ha.

The Final determination for Coastal Upland Swamp (NSW Scientific Committee 2012) includes a definition of ecological function in stating that:

> *Coastal Upland Swamp in the Sydney Basin Bioregion is eligible to be listed as an Endangered Ecological Community as, in the opinion of the Scientific Committee, it is facing a very high risk of extinction in New South Wales in the near future, as determined in accordance with the following criteria :*
>
> *…*
>
> ***Clause 19 Reduction in ecological function of ecological community***
>
> *The ecological community has undergone, is observed, estimated, inferred or reasonably suspected to have undergone or is likely to undergo within a time span appropriate to the life cycle and habitat characteristics of its component species:*
>
> *(b) a large reduction in ecological function, as indicated by any of the following:*
>
> *(d) change in community structure,*
>
> *(e) change in species composition,*
>
> *(f) disruption of ecological processes,*

*(h) degradation of habitat,*

*(i) fragmentation of habitat.*

Changes in community structure and species composition have been noted in the ongoing monitoring (Biosis 2019) for swamp Den15a and Den15b, with changes in structure being more pronounced in mined sites than control sites. Potential changes to ecosystem functionality to Swamp Den15a from LW19 include changes to groundwater levels from potential fracturing of bedrock (as predicted by MSEC 2020), which may lead to further changes to community structure and species composition.

Disruption of ecological processes (through changes to water table and recession rates) have also been noted historically (Watershed 2019) and have the potential to impact swamp Den15a and Den15b post mining of LW19. Recent historic analysis completed by Watershed (2019) of Dendrobium Coastal Upland Swamps and swamp piezometers following longwall mining was undertaken to determine the distance at which piezometers have indicated an impact[2] to water table and recession rates. Based on assessments of water levels and recession rates around past mining in Areas 2, 3A and 3B, it was concluded by Watershed (2019) that hydrographs from swamp piezometers within 60 m are likely to exhibit a mining effect and almost certain to exhibit a mining effect when directly mined under, be that through a reduction in the water table to below pre-mining levels and/or increased recession (drainage) rate. Effects on swamp water tables were not reported at distances greater than 60 m from a longwall panel. If the Watershed (2019) findings are applied to the proposed LW19, there is potential to cause changes to ecosystem functionality to parts of Swamp Den15a, where the swamp occurs within 60 m of LW19 and potentially areas downstream (Figure 3). Fracturing of bedrock within the swamp is likely to lower the capacity for shallow groundwater retention within a small part of the swamp, located directly above the longwall goaf and within 60 m of LW19. Monitoring of swamps that have been mined under has demonstrated similar levels of groundwater recharge but decreased retention of groundwater (e.g. HGEO 2017). Changes in groundwater retention is likely to disrupt ecological processes.

The controlling rockbar for Swamp Den15a is defined in the approved Area 3 SIMMCP (South 32) as the downstream rockbar where it meets Sandy Creek (SC10-15A), which is located 150 m east of proposed LW19 and 170 m south of the existing LW8 (MSEC 2020) (Figure 3). The controlling rockbar is determined to have a 13% risk of fracturing as a result of LW19 (MSEC 2020). There are number of other rockbars within Swamp Den15a (Figure 3), which are considered to be the high points at the downstream margins of each swamp section. The watercourse mapping included in Figure 3 (provided by IMC) is useful in indicating where the main rockbars might occur with the rockbars extending from the mapped watercourse areas along the downslope margin of the swamp sections. Note there are rockbars within Swamp Den15a (Figure 3) that occur closer to LW19 than 'controlling rockbar' SC10-15A and therefore would presumably be subject to an increased risk of impact from the mining of LW19 (i.e. greater than the 13% predicted for the identified 'controlling rockbar'). MSEC (2020) predict the risk of fracturing increases to up to 56% where rockbars occur at distances of less than 150 m from the mining area. Impacts to these

[2] As discussed in Watershed (2019) "in other studies at Dendrobium, the definition of 'impact' is consistent with the SIMMCP regarding how an impact or environmental consequence of mining is classified:

1) A shallow groundwater level within swamp sediments lower than the baseline level at any monitoring site within a swamp (in comparison to control swamps).
2) A rate of shallow groundwater level reduction post-mining that exceeds the rate of shallow groundwater level reduction during the baseline period at any monitoring site (measured as average mm per day during the recession curve).

In some instances, both the above modes of impact may be observed at a single site, and in others, just one might be identified from the water level record".

rockbars may also impact on the ecosystem functionality of Swamp Den15a, through reductions in water retention within the swamp, potentially leading to changes in community structure and species composition to a drier vegetation community type.

MSEC (2020) includes a discussion on the previous experience of mining beneath swamps at Dendrobium Mine, relating to the reported physical impacts, which include surface cracking and fracturing of bedrock at the swamps (though it should be noted that these swamps were completely mined beneath, which is not the case for LW19 and Swamp Den15a):

- Dendrobium Area 2 - Cracking was observed within the extent of Swamp Den01 in three locations and fracturing was observed in the downstream rockbar after the extraction of LW4 and LW5 directly beneath this swamp. Impacts included reductions in groundwater levels in the soil and the upstream hillslope aquifer, however the groundwater levels respond to significant recharge events. Based on the observations to date, there has been no erosion or other physical changes observed within Swamp Den01 resulting from the mining in Area 2.

- DA3A - One fracture was identified in a rock outcrop in Swamp Den12 after the extraction of LW7 directly beneath the swamp. No erosion or other changes have been observed through regular monitoring. One of four installed piezometers has measured a reduction in the groundwater level within the sediments above the sandstone bedrock.

- Dendrobium Area 3B - Multiple fractures and uplift on the basal step of Swamp 5 and exfoliation from the step after extraction of LW9 directly beneath the swamp. Associated flow diversion was recorded, along with reduction and recession rates in relation to shallow groundwater levels in Swamps 1a, 1b and Swamp 5. Impacts were also observed to the swamps due to the extraction of LW10 to LW14 including groundwater levels lower than baseline and recession rates greater than baseline for Swamps Den03, Den05, Den10, Den11, Den13 and Den14. Soil moisture levels below baseline were also reported in Swamps Den05, Den11 and Den23.

Predicted fracturing of bedrock for the 7% of the mapped area of Swamp Den15a within 60 m of the goaf footprint could potentially lead to change in ecosystem functionality. The likelihood of changes in ecosystem functionality of mapped sections of Swamp Den15a decreases with increasing distance from LW19. MSEC (2020) estimate there is a 13% risk of fracturing and compromising the integrity of the controlling rockbar as a result of extracting LW19. If the controlling rockbar was fractured, this may potentially impact areas of Swamp Den15a upstream of the controlling rockbar.

MSEC (2020) predicted impacts could potentially lead to change in ecosystem functionality and compromise the integrity of the controlling rockbar of Swamp Den15a. It should be noted that Condition 5 required protection **or restoration** of the controlling rockbar and that grouting of discrete rockbars would be undertaken if fracturing and flow diversion occurred, as was undertaken in the Georges River where West Cliff Mine extracted longwalls directly under the Georges River.

The SIMMCP (Section 5.4.1, South32 2019) states:

> *Where the bedrock base of any significant permanent pool or controlling rockbar within Wongawilli Creek or Donalds Castle Creeks are impacted from subsidence and where there is limited ability for these fractures to seal naturally they will be sealed with an appropriate and approved cementitious (or alternative) grout.*

# 7 Monitoring and recommendations

## 7.1 Existing monitoring and requirements

A terrestrial ecology monitoring program within Dendrobium began in 2003. Details of the current monitoring program for DA3B are contained in Biosis (2019) *Dendrobium Terrestrial Ecological Monitoring Program Annual Report for 2018*. Findings from each year of terrestrial ecology monitoring are reported in Annual Environmental Management Reports and End of Panel Reports.

Related monitoring programs include monitoring of abiotic parameters which are key predictors of biodiversity impacts, such as soil moisture, shallow groundwater levels and recharge rates, rainfall and temperature.

Prior to the proposed mining, a SIMMCP and Watercourse Impacts Monitoring Management and Contingency Plan is to be implemented to the satisfaction of the Secretary as per Schedule 3 Condition 6 of the Development Consent. It is to be prepared in consultation with BCD, WaterNSW and DPIE.

## 7.2 Recommendations for future monitoring

Terrestrial ecology monitoring for DA3A should continue to be based on existing methodologies within Biosis (2019) to ensure consistency of data capture to allow for ongoing comparisons with monitoring conducted to date. Improvements and additions to these programs are however recommended.

It is recommended the following be continued or included in the terrestrial ecology monitoring program for DA3A:

- Monitoring of Upland Swamps should continue to follow the methodology outlined in Biosis (2016) which is consistent with Keith *et al.* (2006).
- Visual comparison of photo point monitoring undertaken at each upland swamp site should also continue from marked monitoring points.
- Mapping of upland swamp boundaries within DA3A should be refined prior to baseline surveys. Recent methods including the use of drones is likely to achieve better accuracy and consistency for mapping of swamp boundaries and overcome current identified limitations (see 4.2.2).
- Mapping of microhabitats such as pools along streams, as currently performed by IMC for DA3B and DA3C, should be extended to DA3A prior to baseline frog surveys.
- Frog monitoring in DA3A (and other areas) should include rainfall or hydrometric trigger values for surveys to allow for greater consistency between years which would aid in comparison of results (pre versus post mining and impact versus control).
- A baseline survey focussed on tadpole survey for Littlejohn's Tree Frog and aural detection of Red-crowned Toadlet should be conducted after sufficient rainfall and within the appropriate season.
- Targeted surveys for the giant dragonfly should be included in swamp monitoring.
- Analysis of swamp monitoring data should incorporate any changes in piezometric levels at or near the swamps.
- Monitoring programs should continue to be based on BACI design.

- Swamp and watercourse monitoring should categorise impact sites based on their distance from longwalls, distinguishing between sites above longwalls, sites less than 60 m from longwalls and sites outside the 35° angle of draw.
- All remediation works that are undertaken near waterways, must take appropriate measures to minimise environmental impacts. This includes avoiding the spread of Chytrid Fungus following the NPWS guidelines.
- The implementation of mitigation measures should also be followed by monitoring to confirm the success or otherwise of any implemented measures.
- Methods should seek to identify any significant (e.g. greater than 10 mm) surface cracking within the study area so that monitoring and mitigation measures to minimise fauna entrapment (if identified as occurring) can be undertaken.

# 8 Conclusion

Impacts on features from subsidence caused by longwall mining within the Dendrobium domain are largely predictable given a particular longwall mine layout. This is evidenced through identification of reasonably consistent patterns during monitoring of subsidence impacts undertaken for Dendrobium Areas 2, 3A and 3B (e.g. MSEC 2018; Watershed HydroGeo 2019). Subsidence predictions for the proposed LW19 within DA3A are consistent with previous subsidence predictions for Area 3 in their nature.

Monitoring of impacts to natural features such as swamps, watercourses and cliffs in DA3A and 3B (e.g. Biosis 2016; HGEO 2017) supports past subsidence predictions. Monitoring results have highlighted a high likelihood of impacts to watercourses and swamps through a reduced capacity for water recharge and permanency within the shallow groundwater table and within features such as pools along watercourses. Such impacts can be confidently predicted above and in close proximity to longwalls but become less apparent with distance from longwalls. For example, a recent review of monitoring (Watershed HydroGeo 2019) indicates that hydrographs from swamp piezometers within 60 m of longwalls at Dendrobium are likely to exhibit a mining effect and almost certain to exhibit a mining effect when directly mined under, be that through a reduction in the water table to below pre-mining levels and/or increased recession (drainage) rate. Conversely, effects on swamp groundwater have not been observed at distances greater than 60 m from a longwall panel.

Where subsidence impacts do occur, deleterious effects to particular threatened species such as Littlejohn's Tree Frog have been highlighted as highly likely or definitive in some areas. However, clear patterns regarding the significance and severity of impacts to biodiversity values such as swamps and target threatened species have at times been difficult to illustrate confidently due to other impacts such as drought operating concurrently with subsidence impacts (e.g. Biosis 2016).

Review of the SIS predictions with regard to subsidence impacts on threatened biodiversity along with other relevant studies and surveys conducted as part of the current project support the findings of the *Dendrobium Area 3 Species Impact Statement* (Biosis 2007) with few departures. Since the SIS (2007), Upland Swamps of the study area have been listed as an EEC within NSW under the TSC/BC Acts and nationally under the EPBC Act. In addition, whereas the original SIS highlighted significant impacts for the Stuttering Frog (on a precautionary basis) sufficient data now exists to assess with relatively high confidence that the species does not occur within the study area.

Nine Upland Swamps occur within the 600 m study area boundary and the majority of these are not expected to be impacted by the proposal. A maximum of 18.12 ha of swamps within the study area may be impacted via subsidence from the proposal, as they occur within the 35 degree angle of draw). In addition, habitats such as pools, along a combined length of 3.9 km of watercourses within the 35° angle of draw study area, are likely to experience subsidence impacts (comprising both direct and indirect impacts). Subsidence impacts to features such as cliffs, overhangs and rocky outcrops have the potential to occur but are likely to have limited impacts on threatened biodiversity within the study area due to the small area of predicted impacts.

It is recommended that subsidence monitoring programs including biodiversity monitoring continue. Recommendations in regard to biodiversity monitoring have been included within this report.

# 9 References


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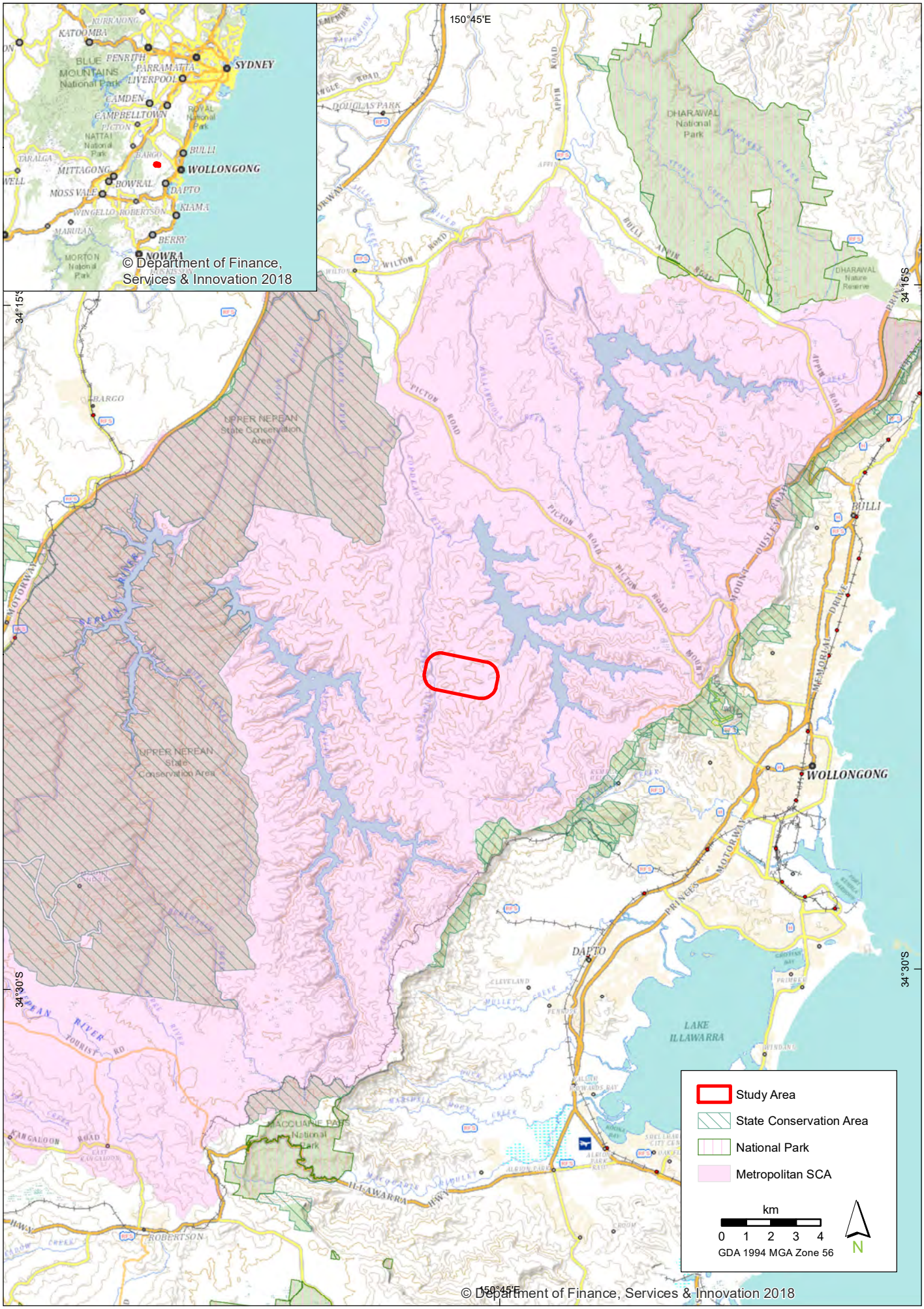
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# Figures



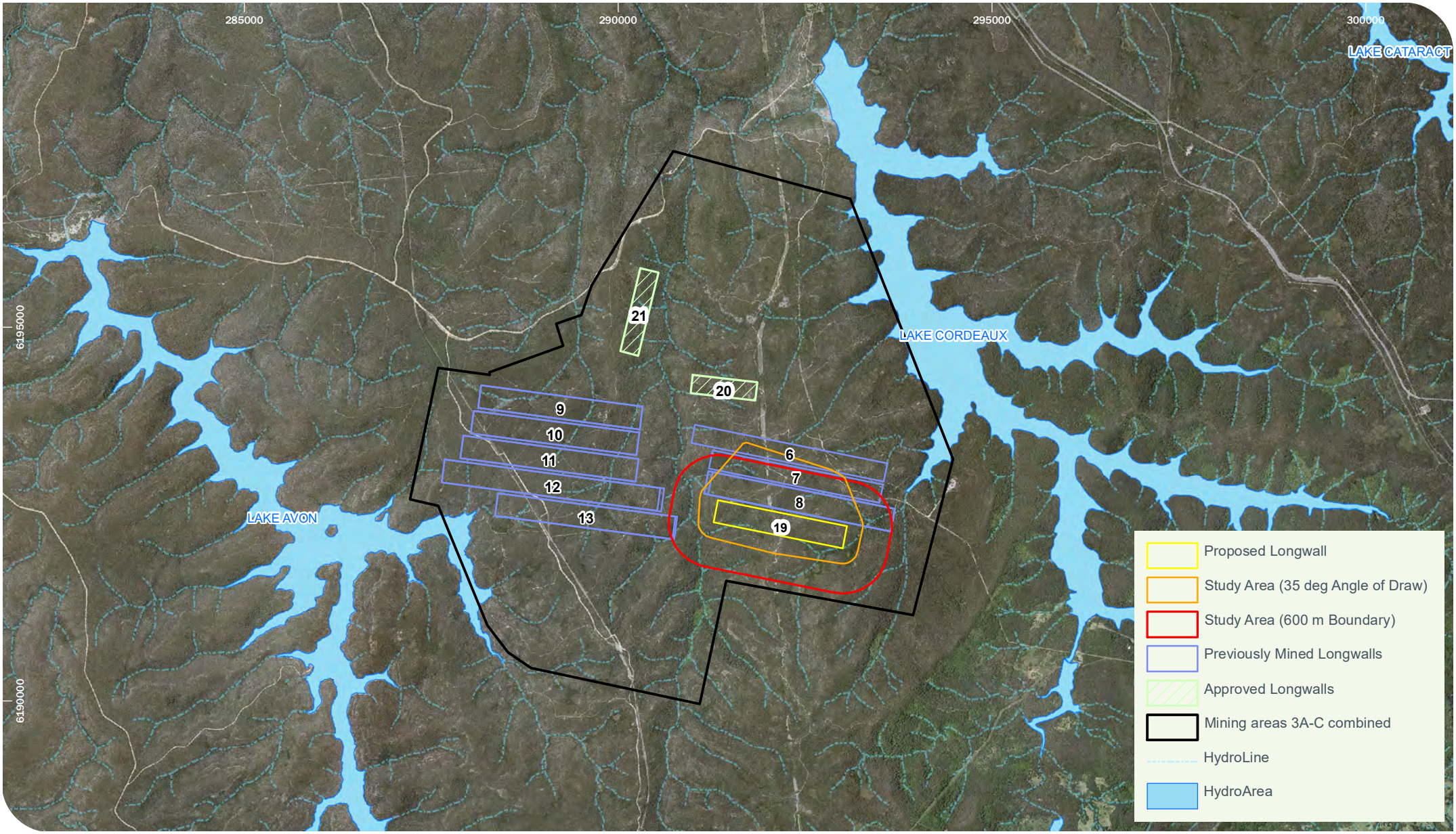

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## Location Map

Dendrobium Area 3A Longwall 19 - Terrestrial Flora and Fauna Assessment

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**FIGURE 1**




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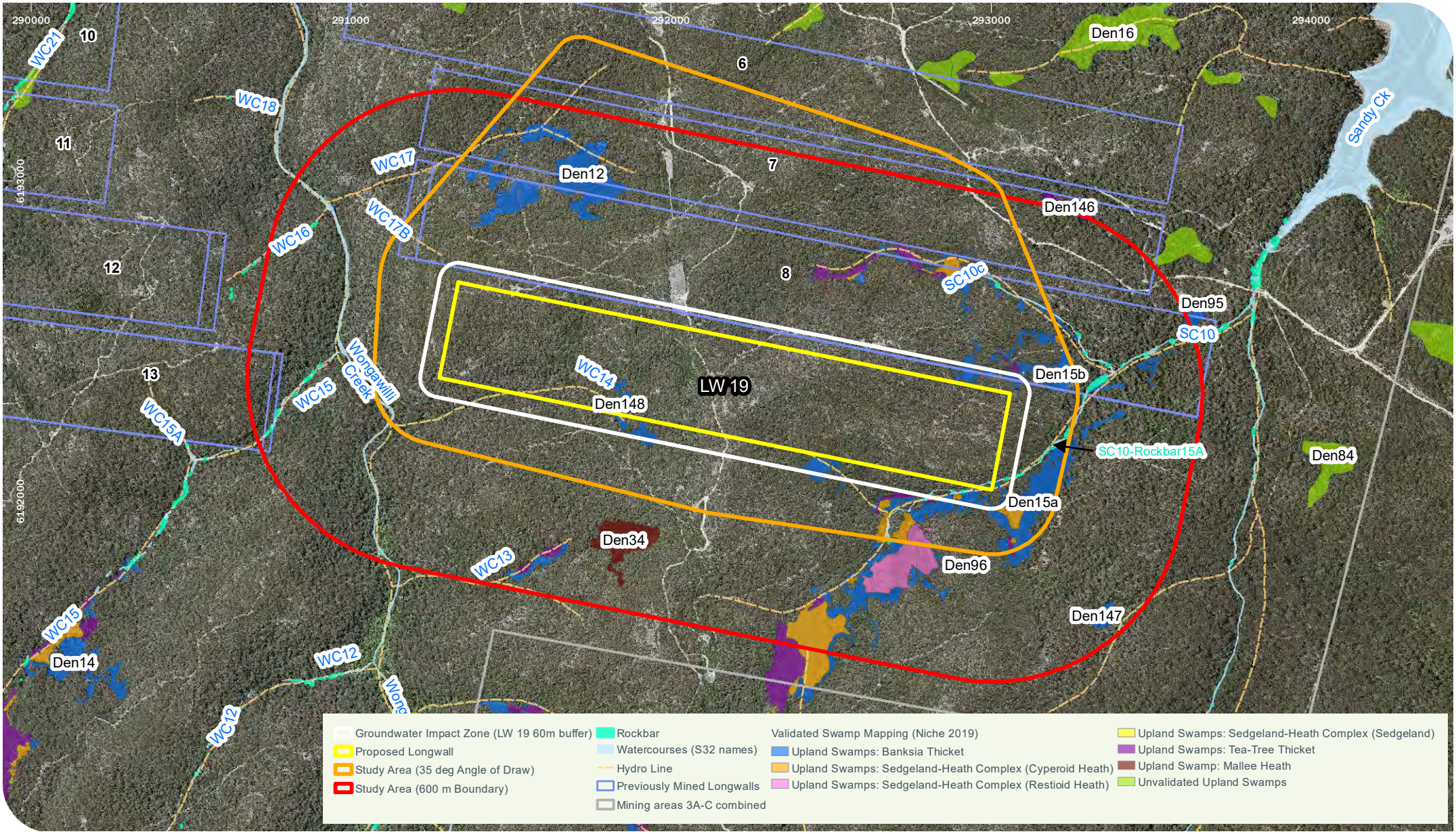
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Niche PM: Sian Griffiths
Niche Proj. #: 5555
Client: South32 Illawarra Metallurgical Coal

# Site map

## Dendrobium Area 3A Longwall 19 - Terrestrial Flora and Fauna Assessment

Figure 2




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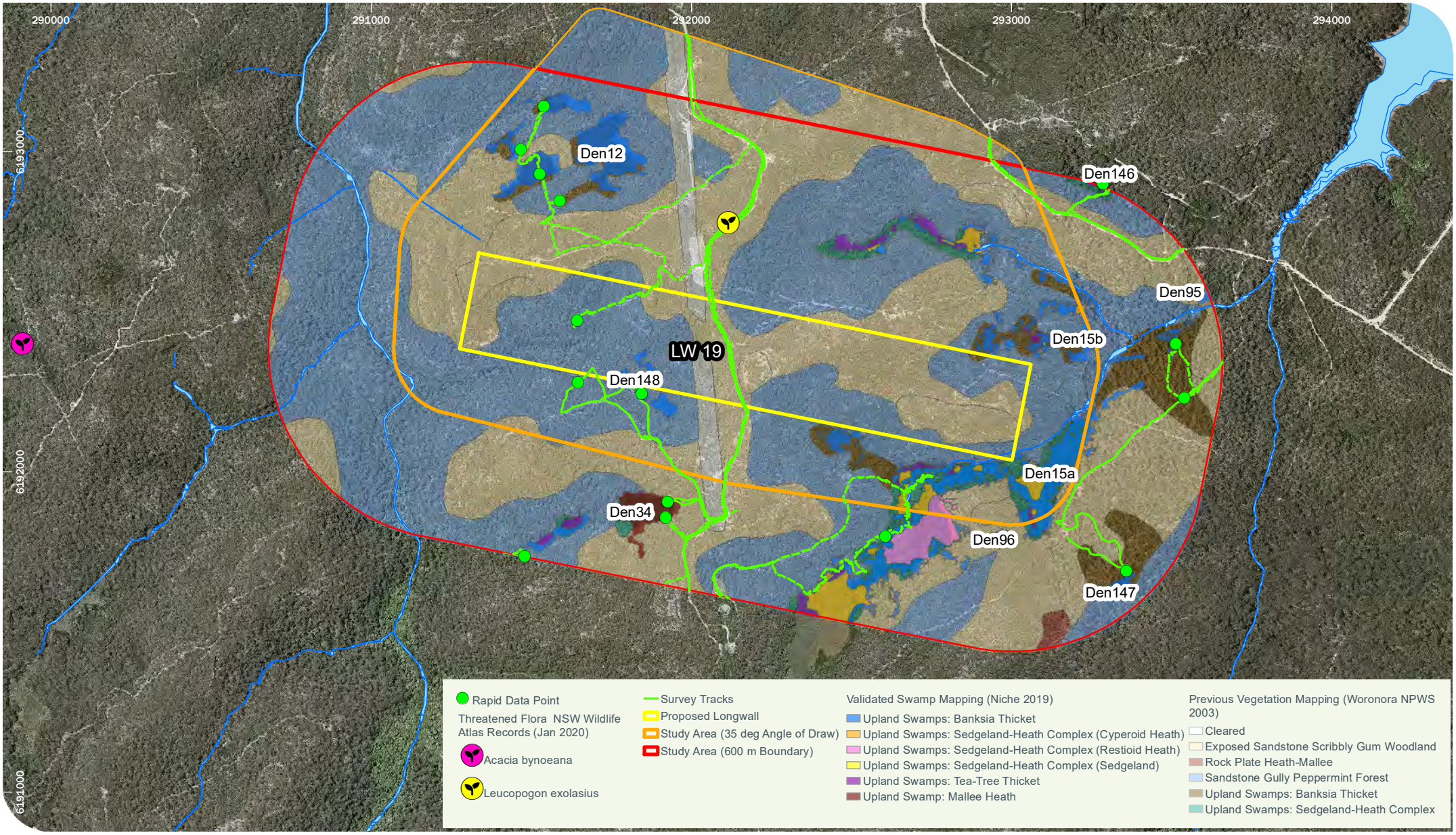
# Watercourses and Confirmed Swamps within the Study Area and Surrounds

## Dendrobium Area 3A Longwall 19 - Terrestrial Flora and Fauna Assessment

Niche PM: Sian Griffith
Niche Proj. #: 5555
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Figure 3

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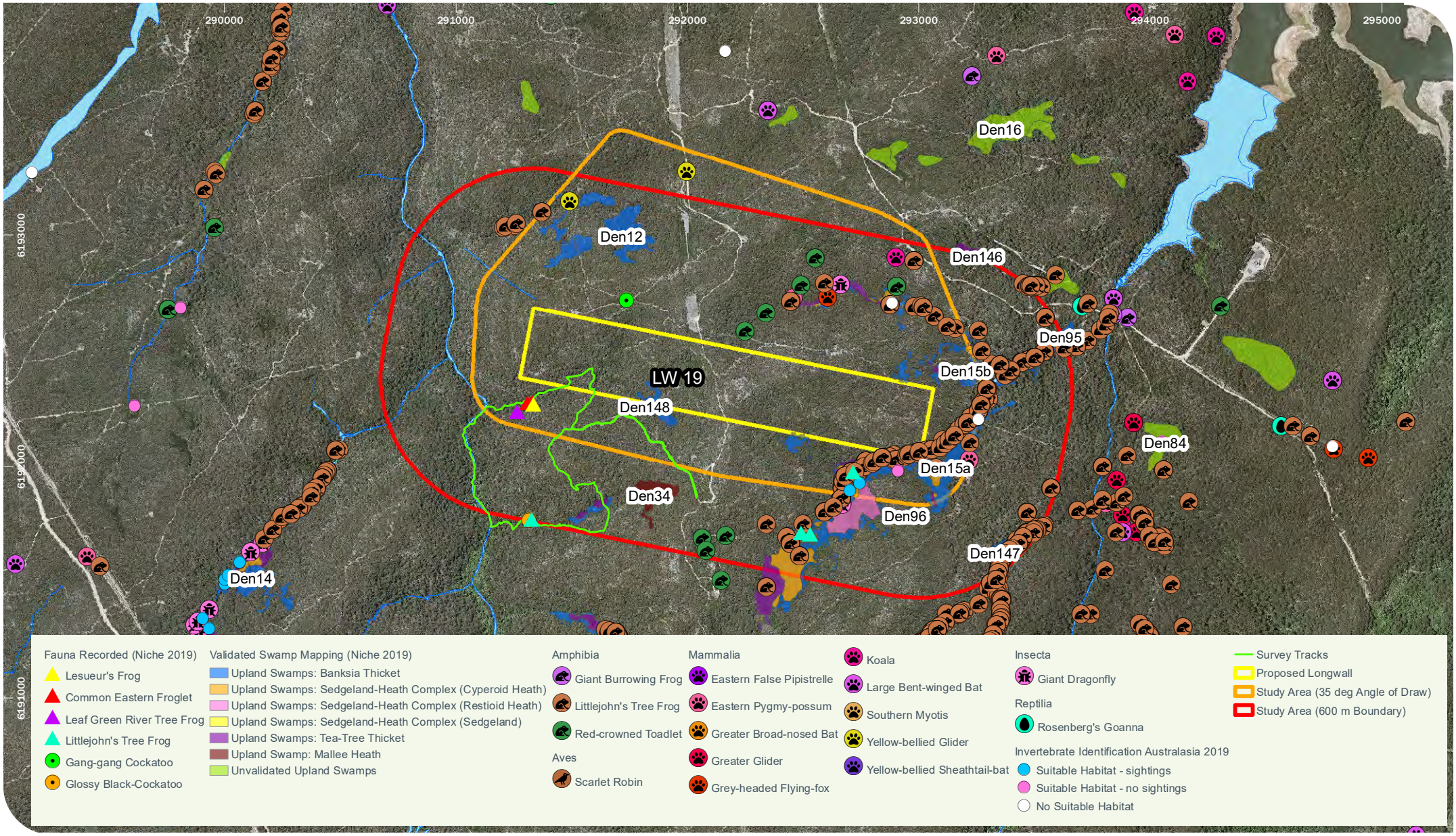
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# Flora Survey Effort, Vegetation Mapping and Threatened Flora Records
## Dendrobium Area 3A Longwall 19 - Terrestrial Flora and Fauna Assessment

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Figure 4

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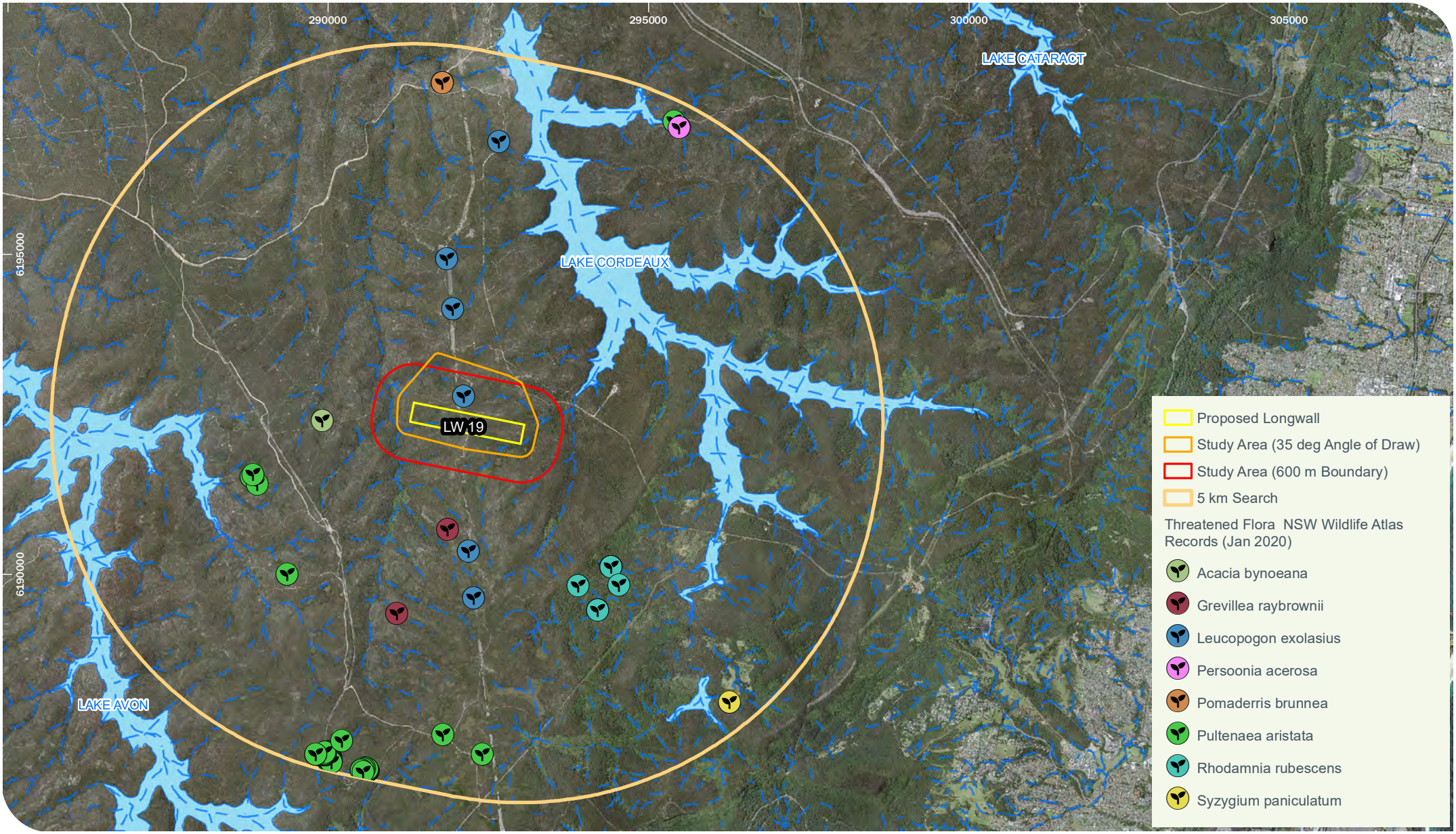
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# Fauna Survey Effort, Results and Threatened Fauna Records
## Dendrobium Area 3A Longwall 19 - Terrestrial Flora and Fauna Assessment

Figure 5




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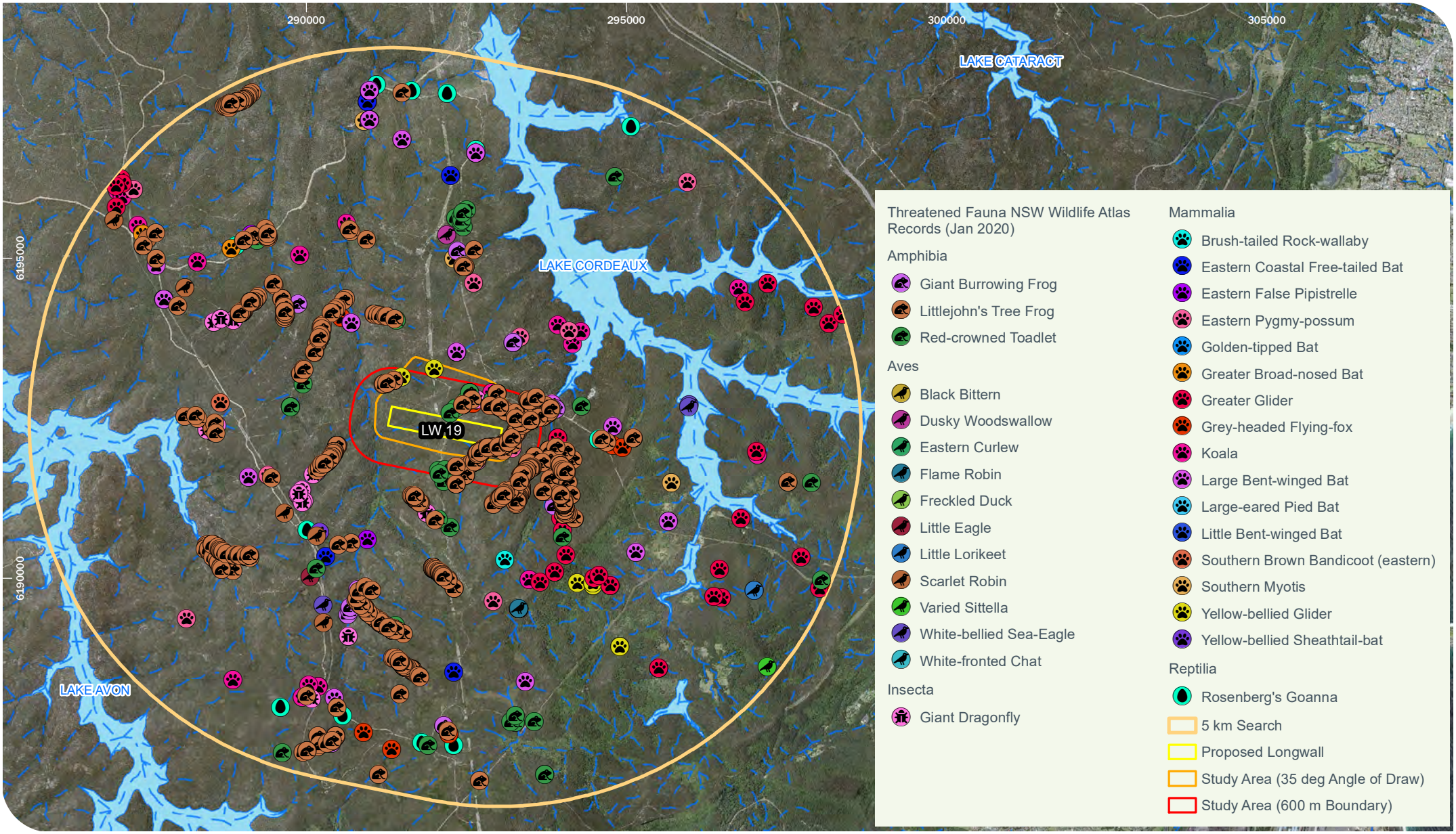
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# NSW Bionet Atlas Threatened Species 5km Search – Flora

## Dendrobium Area 3A Longwall 19 - Terrestrial Flora and Fauna Assessment

Figure 6

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Client: South32

# NSW Bionet Atlas Threatened Species 5km Search - fauna

## Dendrobium Area 3A Longwall 19 - Terrestrial Flora and Fauna Assessment

Figure 7

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# Appendices

## Appendix 1: Threatened species likelihood of occurrence tables

| Scientific Name | Common Name | BC Act | EPBC Act | Habitat | Likelihood of Occurrence | Potential for Impact |
|---|---|---|---|---|---|---|
| ***Amphibians*** | | | | | | |
| *Heleioporus australiacus* | Giant Burrowing Frog | V | V | Prefers hanging swamps on sandstone shelves adjacent to perennial non-flooding creeks (Daly 1996, Recsei 1996). Can also occur within shale outcrops within sandstone formations. In the southern part of its range can occur in wet and dry forests, montane sclerophyll woodland and montane riparian woodland (Daly 1996). Individuals can be found around sandy creek banks or foraging along ridge-tops during or directly after heavy rain. Males often call from burrows located in sandy banks next to water (Barker 1995). | High | High |
| *Litoria aurea* | Green and Golden Bell Frog | E | V | Inhabits marshes, dams and stream-sides, particularly those containing bullrushes (Typha spp.) or spikerushes (Eleocharis spp.). Optimum habitat includes water-bodies that are un-shaded, free of predatory fish such as Plague Minnow (*Gambusia holbrooki*), have a grassy area nearby and diurnal sheltering sites available. | None | None |
| *Litoria Littlejohni* | Littlejohn's Tree Frog | V | V | Occurs in wet and dry sclerophyll forests associated with sandstone outcrops between 280 and 1000 m on the eastern slopes of the Great Dividing Range (Barker 1995). Prefers rock flowing streams, but individuals have also been collected from semi-permanent dams with some emergent vegetation (Barker 1995). Forages both in the tree canopy and on the ground, and has been observed sheltering under rocks on high exposed ridges during summer. It is not known from coastal habitats. | Known. Previously recorded in Swamps Den15a, Den15b and SC10 in the study area. | High |
| *Pseudophryne australis* | Red-crowned Toadlet | V | - | Occurs on wetter ridge tops and upper slopes of sandstone formations on which the predominant vegetation is dry open forests and heaths. This species typically breeds within small ephemeral creeks that feed into larger semi-perennial streams. After rainfall these creeks are characterised by a series of shallow pools lined by dense grasses, ferns and low shrubs (Thumm 1997). | High | High |

| Scientific Name | Common Name | BC Act | EPBC Act | Habitat | Likelihood of Occurrence | Potential for Impact |
|---|---|---|---|---|---|---|
| *Mixophyes balbus* | Stuttering Frog | E | V | This species is usually associated with mountain streams, wet mountain forests and rainforests (Barker 1995). It rarely wanders very far from the banks of permanent forest streams, although it will forage on nearby forest floors. Eggs are deposited in leaf litter on the banks of streams and are washed into the water during heavy rains (Barker 1995). | Low | Low |
| ***Birds*** | | | | | | |
| *Botaurus poiciloptilus* | Australasian Bittern | E | E | The Australasian Bitterns is widespread but uncommon over south-eastern Australia. In NSW they may be found over most of the state except for the far north-west. Favours permanent freshwater wetlands with tall, dense vegetation, particularly bullrushes (Typha spp.) and spikerushes (Eleoacharis spp.). | Low | Low |
| *Ninox connivens* | Barking Owl | V | - | Generally found in open forests, woodlands, swamp woodlands and dense scrub. Can also be found in the foothills and timber along watercourses in otherwise open country (Pizzey 1997). | Moderate | Low |
| *Ixobrychus flavicollis* | Black Bittern | V | - | Usually found on coastal plains below 200 m. Often found along timbered watercourses, in wetlands with fringing trees and shrub vegetation. The sites where they occur are characterized by dense waterside vegetation. | Low | Low |
| *Monarcha melanopsis* | Black-faced Monarch | - | M | A migratory species found during the breeding season in damp gullies in temperate rainforests. Disperses after breeding into more open woodland (Pizzey 1997). | Moderate | Low |
| *Artamus cyanopterus cyanopterus* | Dusky Woodswallow | V | - | Often reported in woodlands and dry open sclerophyll forests, usually dominated by eucalypts, including mallee associations. It has also been recorded in shrublands and heathlands and various modified habitats, including regenerating forests; very occasionally in moist forests or rainforests. | Moderate | Low |
| *Dasyornis brachypterus* | Eastern Bristlebird | E | E | Found in coastal woodlands, dense scrub and heathlands, particularly where it borders taller woodlands (Pizzey and Knight 1997). | Low | Low |

| Scientific Name | Common Name | BC Act | EPBC Act | Habitat | Likelihood of Occurrence | Potential for Impact |
|---|---|---|---|---|---|---|
| *Petroica phoenicea* | Flame Robin | V | - | Flame Robins are found in a broad coastal band from southern Queensland to just west of the South Australian border (Australian Museum 2009). The species is also found in Tasmania. The preferred habitat in summer includes eucalyptus forests and woodland, whilst in winter prefers open woodlands and farmlands. It is considered migratory. The Flame Robin breeds from about August to January (Morcombe 2003). | High | Low |
| *Apus pacificus* | Fork tailed Swift | - | M | The Fork-tailed Swift is almost exclusively aerial, flying from less than 1 m to at least 300 m above ground and probably much higher. | Low to moderate - overfly habitat only. | Low |
| *Stictonetta naevosa* | Freckled Duck | V | - | The freckled duck breeds in permanent fresh swamps that are heavily vegetated. Found in fresh or salty permanent open lakes, especially during drought. Often seen in groups on fallen trees and sand spits (Simpson, 1996). | Low | Low |
| *Callocephalon fimbriatum* | Gang-gang Cockatoo | V | - | In summer, occupies tall montane forests and woodlands, particularly in heavily timbered and mature wet sclerophyll forests (Higgins 1999). Also occur in subalpine Snow Gum woodland and occasionally in temperate or regenerating forest (Forshaw 1981). In winter, occurs at lower altitudes in drier, more open eucalypt forests and woodlands, particularly in box-ironbark assemblages, or in dry forest in coastal areas (Shields 1992). It requires tree hollows in which to breed (Gibbons 1997). | Known | Low |
| *Calyptorhynchus lathami* | Glossy Black-Cockatoo | V | - | Inhabits forest with low nutrients, characteristically with key Allocasuarina spp. Tends to prefer drier forest types (NPWS 1999) with a middle stratum of Allocasuarina below Eucalyptus or Angophora. Often confined to remnant patches in hills and gullies (Higgins 1999). Breed in hollows stumps or limbs, either living or dead (Higgins and Davies 1996). | Known | Low |
| *Hieraaetus morphnoides* | Little Eagle | V | - | Most abundant in lightly timbered areas with open areas nearby. Often recorded foraging in grasslands, crops, treeless dune fields, and | High | Low |

| Scientific Name | Common Name | BC Act | EPBC Act | Habitat | Likelihood of Occurrence | Potential for Impact |
|---|---|---|---|---|---|---|
| | | | | recently logged areas. May nest in farmland, woodland and forest in tall trees. | | |
| *Glossopsitta pusilla* | Little Lorikeet | V | - | Distributed in forests and woodlands from the coast to the western slopes of the Great Dividing Range in NSW, extending westwards to the vicinity of Albury, Parkes, Dubbo and Narrabri. Mostly occur in dry, open eucalypt forests and woodlands. They feed primarily on nectar and pollen in the tree canopy. Nest hollows are located at heights of between 2 m and 15 m, mostly in living, smooth-barked eucalypts. Most breeding records come from the western slopes. | High | Low |
| *Tyto novaehollandiae* | Masked Owl | V | - | Inhabits a diverse range of wooded habitat that provide tall or dense mature trees with hollows suitable for nesting and roosting (Higgins, 1999). Mostly recorded in open forest and woodlands adjacent to cleared lands. Nest in hollows, in trunks and in near vertical spouts or large trees, usually living but sometimes dead (Higgins 1999). Nest hollows are usually located within dense forests or woodlands (Gibbons 1997). Masked owls prey upon hollow-dependent arboreal marsupials, but terrestrial mammals make up the largest proportion of the diet (Gibbons 1997, Higgins 1999). | High | Low |
| *Cuculus optatus, Cuculus saturatus* | Oriental Cuckoo | - | M, MA | Mainly inhabits coniferous, deciduous and mixed forests. Breeds in northern hemisphere. Brood parasite, laying eggs in nests of other birds. | Low | Low |
| *Rostratula benghalensis* | Painted Snipe (Australian subspecies) | E | - | In NSW, this species has been recorded at the Paroo wetlands, Lake Cowell, Macquarie Marshes and Hexham Swamp. Most common in the Murray-Darling Basin. Prefers fringes of swamps, dams and nearby marshy areas where there is a cover of grasses, lignum, low scrub or open timber. Nests on the ground amongst tall vegetation, such as grasses, tussocks or reeds. | None | None |
| *Ninox strenua* | Powerful Owl | V | - | Occupies wet and dry eucalypt forests and rainforests. Can occupy both un-logged and lightly logged forests as well as undisturbed forests where it usually roosts on the limbs of dense trees in gully | High | Low |

| Scientific Name | Common Name | BC Act | EPBC Act | Habitat | Likelihood of Occurrence | Potential for Impact |
|---|---|---|---|---|---|---|
| | | | | areas. It is most commonly recorded within Red Turpentine in tall open forests and Black She-oak within open forests (Debus 1994a;Debus 1994b). Large mature trees with hollows at least 0.5 m deep are required for nesting (Garnett, 1992). Tree hollows are particularly important for the Powerful Owl because a large proportion of the diet is made up of hollow-dependent arboreal marsupials (Gibbons, 1997). Nest trees for this species are usually emergent with a diameter at breast height of at least 100 cm (Gibbons 1997). | | |
| *Anthochaera phrygia* | Regent Honeyeater | CE | CE | The Regent Honeyeater mainly inhabits temperate woodlands and open forests of the inland slopes of south-east Australia. Birds are also found in drier coastal woodlands and forests in some years. has contracted dramatically in the last 30 years to between north-eastern Victoria and south-eastern Queensland. There are only three known key breeding regions remaining: north-east Victoria (Chiltern-Albury), and in NSW at Capertee Valley and the Bundarra-Barraba region. In NSW the distribution is very patchy and mainly confined to the two main breeding areas and surrounding fragmented woodlands. In some years flocks converge on flowering coastal woodlands and forests. | Moderate | Low |
| *Rhipidura rufifrons* | Rufous Fantail | - | M | Migratory species that prefers dense, moist undergrowth of tropical rainforests and scrubs. During migration it can stray into gardens and more open areas (Pizzey 1997). | Low | Low |
| *Myiagra cyanoleuca* | Satin Flycatcher | - | M | Migratory species that occurs in coastal forests, woodlands and scrubs during migration. Breeds in heavily vegetated gullies (Pizzey 1997). | High | Low |
| *Petroica boodang* | Scarlet Robin | V | - | In NSW Scarlet Robin occur from the coast to the inland slopes. After breeding, some Scarlet Robins disperse to the lower valleys and plains of the tablelands and slopes. Some birds may appear as far west as the eastern edges of the inland plains in autumn and winter. | Known | Low |
| *Tyto tenebricosa* | Sooty Owl | V | - | Often found in tall old-growth forests, including temperate and subtropical rainforests. In NSW mostly found on escarpments with a mean altitude <500 m. Nests and roosts in hollows of tall emergent | High | Low |

| Scientific Name | Common Name | BC Act | EPBC Act | Habitat | Likelihood of Occurrence | Potential for Impact |
|---|---|---|---|---|---|---|
| | | | | trees, mainly eucalypts (Higgins 1999) often located in gullies (Gibbons and Lindenmayer 1997). Nests have been located in trees 125 to 161 centimetres in diameter (Gibbons and Lindenmayer 1997). | | |
| *Monarcha trivirgatus* | Spectacled Monarch | - | M | Coastal north-eastern and eastern Australia, including coastal islands, from Cape York, Queensland to Port Stephens, New South Wales. Prefers thick understorey in rainforests, wet gullies and waterside vegetation, as well as mangroves. | Moderate | Low |
| *Lathamus discolor* | Swift Parrot | E | CE | The Swift Parrot occurs in woodlands and forests of NSW from May to August, where it feeds on eucalypt nectar, pollen and associated insects . The Swift Parrot is dependent on flowering resources across a wide range of habitats in its wintering grounds in NSW . This species is migratory, breeding in Tasmania and also nomadic, moving about in response to changing food availability. | High | Low |
| *Daphoenositta chrysoptera* | Varied Sittella | V | - | Inhabits wide variety of dry eucalypt forests and woodlands, usually with either shrubby under storey or grassy ground cover or both, in all climatic zones of Australia (Higgins and Peter 2002). Usually in areas with rough-barked trees, such as stringybarks or ironbarks, but also in paperbarks or mature Eucalypts with hollows. | High | Low |
| *Haliaeetus leucogaster* | White-bellied Sea-Eagle | V | MA | Inhabits coastal and near coastal areas, building large stick nests, and feeding mostly on marine and estuarine fish and aquatic fauna. | Low | Low |
| *Epthianura albifrons* | White-fronted Chat | V | - | Low vegetation in salty coastal and inland areas and crops. Runs along ground and is found in local flocks in Winter. | None | None |
| *Hirundapus caudacutus* | White-throated Needletail | - | V | An aerial species found in feeding concentrations over cities, hilltops and timbered ranges. | Low-moderate - overfly habitat only. | Low |
| *Motacilla flava* | Yellow Wagtail | - | M | Breeds in temperate Europe and Asia. The Yellow Wagtail is a regular wet season visitor to northern Australia. Increasing records in NSW suggest this species is an occasional but regular summer visitor to the Hunter River region. The species is considered a vagrant to Victoria, South Australia and southern Western Australia. Habitat requirements | Low | Low |

| Scientific Name | Common Name | BC Act | EPBC Act | Habitat | Likelihood of Occurrence | Potential for Impact |
|---|---|---|---|---|---|---|
| | | | | for the Yellow Wagtail are highly variable, but typically include open grassy flats near water. Habitats include open areas with low vegetation such as grasslands, airstrips, pastures, sports fields; damp open areas such as muddy or grassy edges of wetlands, rivers, irrigated farmland, dams, waterholes; sewage farms, sometimes utilise tidal mudflats and edges of mangroves. | | |
| ***Invertebrates*** | | | | | | |
| *Petalura gigantea* | Giant Dragonfly | E | - | The Giant Dragonfly is found along the east coast of NSW from the Victorian border to northern NSW. It is not found west of the Great Dividing Range. There are known occurrences in the Blue Mountains and Southern Highlands, in the Clarence River catchment, and on a few coastal swamps from north of Coffs Harbour to Nadgee in the south (DECCW undated b). Live in permanent swamps and bogs with some free water and open vegetation. Adults emerge from late October and are short-lived, surviving for one summer after emergence. | High | High – not recorded in the present study but numerous records within the locality and habitat present within most of the swamps of the study area. |
| ***Mammals*** | | | | | | |
| *Petrogale penicillata* | Brush-tailed Rock-wallaby | E | V | Found in rocky areas in a wide variety of habitats including rainforest gullies, wet and dry sclerophyll forest, open woodland and rocky outcrops in semi-arid country. Commonly sites have a northerly aspect with numerous ledges, caves and crevices (Eldridge 1995). | Low | Low |
| *Miniopterus schreibersii* | Eastern Bentwing-bat | V | - | Eastern Bent-wing Bats occur along the east and north-west coasts of Australia. Caves are the primary roosting habitat, but also use derelict mines, storm-water tunnels, buildings and other man-made structures. | Known | Moderate, however limited significance. Maternity caves would not occur within the study area. If roosting occurs it is unlikely to be widespread or significant and minimal impacts from subsidence of features such as cliffs are expected to occur given the |

| Scientific Name | Common Name | BC Act | EPBC Act | Habitat | Likelihood of Occurrence | Potential for Impact |
|---|---|---|---|---|---|---|
| | | | | | | limited propensity of roosting.<br>No further assessment or offsetting is considered required. |
| *Falsistrellus tasmaniensis* | Eastern False Pipistrelle | V | - | Inhabit sclerophyll forests, preferring wet habitats where trees are more than 20 m high (Churchill 1998). Two observations have been made of roosts in stem holes of living eucalypts (Phillips 1995). There is debate about whether or not this species moves to lower altitudes during winter, or whether they remain sedentary but enter torpor (Menkhorst 1995). This species also appears to be highly mobile and records showing movements of up to 12 km between roosting and foraging sites (Menkhorst 1995). | High | Low |
| *Mormopterus norfolkensis* | Eastern Freetail-bat | V | - | Most records are from dry eucalypt forests and woodlands to the east of the Great Dividing Range. Appears to roost in trees, but little is known of this species' habits (Allison 1995, Churchill 1998). | High | Low |
| *Cercartetus nanus* | Eastern Pygmy-possum | V | - | Inhabits rainforest through to sclerophyll forest and tree heath. Banksias and myrtaceous shrubs and trees are a favoured food source. Will often nest in tree hollows, but can also construct its own nest (Turner, 1995). Because of its small size it is able to utilise a range of hollow sizes including very small hollows (Gibbons 1997). Individuals will use a number of different hollows and an individual has been recorded using up to 9 nest sites within a 0.5 ha area over a 5 month period (Ward 1990). | High | Low |
| *Kerivoula papuensis* | Golden tipped bat | V | - | The Golden-tipped Bat is distributed along the east coast of Australia in scattered locations from Cape York Peninsula in Queensland to south of Eden in southern NSW. Also occurs in New Guinea. Found in rainforest and adjacent wet and dry sclerophyll forest up to 1000 m. Also recorded in tall open forest, Casuarina-dominated riparian forest and coastal Melaleuca forests. | High | Low |

| Scientific Name | Common Name | BC Act | EPBC Act | Habitat | Likelihood of Occurrence | Potential for Impact |
|---|---|---|---|---|---|---|
| *Scoteanax rueppellii* | Greater Broad-nosed Bat | V | - | Prefer moist gullies in mature coastal forests and rainforests, between the Great Dividing Range and the coast. They are only found at low altitudes below 500 m (Churchill, 1998). In dense environments they utilise natural and human-made opening in the forest for flight paths. Creeks and small rivers are favoured foraging habitat (Hoye 1995). This species roosts in hollow tree trunks and branches (Churchill, 1998). | High | Low |
| *Petauroides volans* | Greater Glider | - | V | The Greater Glider is restricted to eastern Australia, occurring from the Windsor Tableland in north Queensland through to central Victoria. It is typically found in highest abundance in taller, montane, moist eucalypt forests with relatively old trees and abundant hollows. | Moderate | Low |
| *Pteropus poliocephalus* | Grey-headed Flying-fox | V | V | This species is a canopy-feeding frugivore and nectarivore of rainforests, open forests, woodlands, melaleuca swamps and banksia woodlands. Bats commute daily to foraging areas, usually within 15 km of the day roost (Tidemann 1995) although some individuals may travel up to 70 km (Augee 1999). | High | Low |
| *Phascolarctos cinereus* | Koala | V | - | Inhabits eucalypt forests and woodlands. The suitability of these forests for habitation depends on the size and species of trees present, soil nutrients, climate and rainfall (Reed 1990). | Known | Low |
| *Chalinolobus dwyeri* | Large-eared Pied Bat | V | V | Located in a variety of drier habitats, including the dry sclerophyll forests and woodlands to the east and west of the Great Dividing Range (Hoye 1995). Can also be found on the edges of rainforests and in wet sclerophyll forests (Churchill 1998). This species roosts in caves and mines in groups of between 3 and 37 individuals (Churchill 1998). | High | Low |
| *Miniopterus australis* | Little bent-wing Bat | V | - | East coast and ranges of Australia from Cape York in Queensland to Wollongong in NSW. Moist eucalypt forest, rainforest, vine thicket, wet and dry sclerophyll forest, Melaleuca swamps, dense coastal forests and banksia scrub. Generally found in well-timbered areas. | High | Moderate, however limited significance. Maternity caves would not occur within the study area. If roosting occurs it is unlikely to be widespread or significant and minimal |

| Scientific Name | Common Name | BC Act | EPBC Act | Habitat | Likelihood of Occurrence | Potential for Impact |
|---|---|---|---|---|---|---|
| | | | | | | impacts from subsidence of features such as cliffs are expected to occur given the limited propensity of roosting.<br>No further assessment or offsetting is considered required. |
| *Potorous tridactylus tridactylus* | Long-nosed Potoroo | V | V | Inhabits coastal heath and wet and dry sclerophyll forests. Generally found in areas with rainfall greater than 760 mm. Requires relatively thick ground cover where the soil is light and sandy. | Moderate | Low |
| *Pseudomys novaehollandiae* | New Holland Mouse | V | | Known to inhabit open heathlands, woodlands and forests with a heathland understorey and vegetated sand dunes. It is a social animal, living predominantly in burrows shared with other individuals. Distribution is patchy in time and space, with peaks in abundance during early to mid stages of vegetation succession typically induced by fire. | Low | Low |
| *Isoodon obesulus* | Southern Brown Bandicoot (eastern) | E | - | Prefers sandy soils with scrubby vegetation and/or areas with low ground cover that are burn from time to time (Braithwaite 1995). A mosaic of post fire vegetation is important for this species (Maxwell 1996). | High | Low |
| *Myotis macropus* | Southern Myotis | V | - | The Large-footed Myotis is found in the coastal band from the north-west of Australia, across the top-end and south to western Victoria. Generally roost in groups of 10 - 15 close to water in caves, mine shafts, hollow-bearing trees, storm water channels, buildings, under bridges and in dense foliage. | Moderate | Moderate |
| *Dasyurus maculatus* | Spotted-tailed Quoll | V | - | Spotted-tailed Quoll is found on the east coast of NSW, Tasmania, eastern Victoria and north-eastern Queensland. | Moderate | Low |
| *Petaurus australis* | Yellow-bellied Glider | V | - | Occur in tall mature eucalypt forest generally in areas with high rainfall and nutrient rich soils. Forest type preferences vary with | Low | Low |

| Scientific Name | Common Name | BC Act | EPBC Act | Habitat | Likelihood of Occurrence | Potential for Impact |
|---|---|---|---|---|---|---|
| | | | | latitude and elevation; mixed coastal forests to dry escarpment forests in the north; moist coastal gullies and creek flats to tall montane forests in the south. Found along the eastern coast to the western slopes of the Great Dividing Range, from southern Queensland to Victoria. | | |
| *Saccolaimus flaviventris* | Yellow-bellied sheathtail Bat | V | - | The Yellow-bellied Sheathtail-bat is a wide-ranging species found across northern and eastern Australia. In the most southerly part of its range - most of Victoria, south-western NSW and adjacent South Australia - it is a rare visitor in late summer and autumn. There are scattered records of this species across the New England Tablelands and North West Slopes. Roosts singly or in groups of up to six, in tree hollows and buildings; in treeless areas they are known to utilise mammal burrows. | High | Low |
| ***Reptiles*** | | | | | | |
| *Hoplocephalus bungaroides* | Broad-headed Snake | E | V | Mainly occurs in association with communities occurring on Triassic sandstone within the Sydney Basin. Typically found among exposed sandstone outcrops with vegetation types ranging from woodland to heath. Within these habitats they generally use rock crevices and exfoliating rock during the cooler months and tree hollows during summer (Webb 1996, Webb 1998). | Moderate | Moderate |
| *Varanus rosenbergi* | Rosenberg's Goanna | V | - | This species is a Hawkesbury/Narrabeen sandstone outcrop specialist (Wellington 1985). Occurs in coastal heaths, humid woodlands and both wet and dry sclerophyll forests (Cogger 1992). | High | Moderate |
| ***Plants*** | | | | | | |
| *Acacia bynoeana* | Bynoe's Wattle | V | E1 | Grows mainly in heath and dry sclerophyll forest in sandy soils. Mainly south of Dora Creek-Morisset area to Berrima and the Illawarra region, west to the Blue Mountains, also recorded from near Kurri Kurri in the Hunter Valley and from Morton National Park. ROTAP: 3VC- | Yes. Previously recorded in Area 3C in the Biosis (2007) SIS along Fire Road 6. | Low |

| Scientific Name | Common Name | BC Act | EPBC Act | Habitat | Likelihood of Occurrence | Potential for Impact |
|---|---|---|---|---|---|---|
| *Allocasuarina glareicola* | | E | E | Primarily restricted to the Richmond (NW Cumberland Plain) district, but with an outlier population found at Voyager Point, Liverpool. Grows in Castlereagh woodland on lateritic soil. Found in open woodland with Parramatta Red Gum, Broad-leaved Ironbark, Narrow-leaved Apple, Scribbly Gum and Paperbarks. | Low | Low |
| *Caladenia tessellata* | Tessellated Spider Orchid | V | E1 | The Tessellated Spider Orchid is found in grassy sclerophyll woodland on clay loam or sandy soils, though the population near Braidwood is in low woodland with stony soil. Known from the Sydney area (old records), Wyong, Ulladulla and Braidwood in NSW. Populations in Kiama and Queanbeyan are presumed extinct. ROTAP: 3V | Low | Low |
| *Cryptostylis hunteriana* | Leafless Tongue Orchid | V | V | Grows in swamp-heath on sandy soils, chiefly in coastal districts, south from the Gibraltar Range. ROTAP: 3VC- | High | Moderate |
| *Cynanchum elegans* | White-flowered Wax Plant | E | E | Recorded from rainforest gullies scrub and steep slopes from the Gloucester district to the Wollongong area and inland to Mt Dangar. ROTAP: 3ECi | Low | Low |
| *Epacris purpurascens var. purpurascens* | | - | V | Grows in sclerophyll forest, scrubs and swamps on sandstone from Gosford and Sydney districts. ROTAP: 2KC- | High | Moderate |
| *Genoplesium baueri* | Bauer's Midge Orchid | E | E | Grows in dry sclerophyll forest and moss gardens over sandstone. Flowers February to March. Has been recorded between Ulladulla and Port Stephens. Currently the species is known from just over 200 plants across 13 sites. The species has been recorded in Berowra Valley Regional Park, Royal National Park and Lane Cove National Park and may also occur in the Woronora, O'Hares, Metropolitan and Warragamba Catchments. | Low | Low |
| *Grevillea parviflora ssp. parviflora* | Small-flower Grevillea | V | V | Grows in heathy associations or shrubby woodland, in sandy or light clay soils usually over shale substrates. Occurs west and south of Sydney from west of Prospect (where now almost certainly extinct), Kemps Creek and lower Georges River south to Camden, Appin and | High | Low |

| Scientific Name | Common Name | BC Act | EPBC Act | Habitat | Likelihood of Occurrence | Potential for Impact |
|---|---|---|---|---|---|---|
| | | | | Cordeaux Dam, with disjunct northern populations south of Putty and near Cessnock and Cooranbong, possibly also south of Moss Vale. | | |
| *Grevillea raybrownii* | | V | | It occurs in Eucalyptus open forest and woodland with a shrubby understorey on sandy, gravelly loam soils derived from sandstone that are low in nutrients. Generally occurs on ridgetops and, less often, slopes and benches of Hawkesbury Sandstone and Mittagong Formation. restricted to an area bounded by Dapto, Robertson and Berrima, possibly also Bungonia. | High | Low |
| *Haloragis exalata subsp. exalata* Square Raspwort | | V | V | Occurs in 4 widely scattered localities in eastern NSW. It is disjunctly distributed in the central coast, south coast and north-western slopes botanical subdivisions of NSW. The species appears to require protected and shaded damp situations in riparian habitats. | Low | Low |
| *Leucopogon exolasius* | Woronora Beard-heath | V | V | Grows in woodland on sandstone. Restricted to the Woronora and Grose Rivers and Stokes Creek, Royal National Park. ROTAP: 2VC- | High | Moderate |
| *Melaleuca biconvexa* | Biconvex Paperbark | V | V | Biconvex Paperbark generally grows in damp places, often near streams or low-lying areas on alluvial soils of low slopes or sheltered aspects. Scattered and dispersed populations found in the Jervis Bay area in the south and the Gosford-Wyong area in the north. | Low | Low |
| *Melaleuca deanei* | Dean's Low Melaleuca | V | V | Grows in wet heath on sandstone in coastal districts from Berowra to Nowra. ROTAP: 3RC- | Moderate to High | Low |
| *Persicaria elatior* | Tall Knotweed | V | V | This species normally grows in damp places, especially beside streams and lakes. Occasionally in swamp forest or associated with disturbance. | Low. No records within 10km of study area. | Low |
| *Persoonia acerosa* | Mossy Geebung | V | V | Occurs in heath or dry sclerophyll forest on sandstone, from central Blue Mountains south to Hill Top. ROTAP: 2VC- | High | Low |
| *Persoonia hirsuta* | | E | E | The Hairy Geebung is found in sandy soils in dry sclerophyll open forest, woodland and heath on sandstone. | Moderate to High | Moderate |

| Scientific Name | Common Name | BC Act | EPBC Act | Habitat | Likelihood of Occurrence | Potential for Impact |
|---|---|---|---|---|---|---|
| *Pomaderris brunnea* | Rufous Pomaderris | V | V | Brown Pomaderris grows in moist woodland or forest on clay and alluvial soils of flood plains and creek lines in association with *Eucalyptus amplifolia*, *Angophora floribunda*, *Acacia parramattensis, Bursaria spinosa* and *Kunzea ambigua*. ROTAP: 2VC- | Low | Low |
| *Pterostylis saxicola* | Sydney Plains Greenhood | E | E | Restricted to western Sydney between Freemans Reach in the north and Picton in the south. Most commonly found growing in small pockets of shallow soil in depressions on sandstone rock shelves above cliff lines. The vegetation communities above the shelves where *Pterostylis saxicola* occurs are sclerophyll forest or woodland on shale/sandstone transition soils or shale soils. | Low | Low |
| *Pultenaea aristata* | Prickly Bush-pea | V | V | Grows in moist, dry sclerophyll woodland to heath on sandstone, specifically the drier areas of Upland Swamps. Restricted to the Woronora Plateau, a small area between Helensburgh, south of Sydney, and Mt Keira above Wollongong. ROTAP: 2V | High. Previously recorded in Biosis (2007) SIS in DA3 (but not DA3A) | Low |
| *Pultenaea glabra* | Smooth Bush-Pea | V | V | Grows in swamp margins, hillslopes, gullies and creekbanks and occurs within dry sclerophyll forest and tall damp heath on sandstone. Restricted to the higher Blue Mountains. | Low | Low |
| *Rhodamnia rubescens* | Scrub Turpentine | | | Occurs in coastal districts north from Batemans Bay in New South Wales, approximately 280 km south of Sydney, to areas inland of Bundaberg in Queensland. Populations of R. rubescens typically occur in coastal regions and occasionally extend inland onto escarpments up to 600 m a.s.l. in areas with rainfall of 1,000-1,600 mm. Found in littoral, warm temperate and subtropical rainforest and wet sclerophyll forest usually on volcanic and sedimentary soils. | Low | Low |
| *Syzygium paniculatum* | Magenta Lilly Pilly | E | V | Found only in NSW, in a narrow, linear coastal strip from Bulahdelah to Conjola State forest. On the south coast the species occurs on grey soils over sandstone, restricted mainly to remnant stands of littoral rainforest. On the central coast it occurs on gravels, sands, silts and clays in riverside gallery rainforests and remnant littoral rainforest communities. | Low | Low |

| Scientific Name | Common Name | BC Act | EPBC Act | Habitat | Likelihood of Occurrence | Potential for Impact |
|---|---|---|---|---|---|---|
| *Thelymitra kangaloonica* | Kangaloon Sun-orchid | CE | CE | Recorded from shallow black peaty soil in coastal heath on sandstone. *Thelymitra sp. Kangaloon* is a terrestrial orchid endemic to New South Wales, and is known from three locations near Robertson in the Southern Highlands. | Low | Low |
| *Thesium australe* | Austral Toadflax | V | V | Grows in very small populations scattered across eastern NSW, along the coast, and from the Northern to Southern Tablelands. It is also found in Tasmania and Queensland and in eastern Asia. Occurs in grassland or grassy woodland. Grows on Kangaroo Grass tussocks but has also been recorded within the exotic Coolatai Grass. | Low | Low |
| *Xerochrysum palustre* | Swamp Everlasting | - | V | Found in Kosciuszko National Park and the eastern escarpment south of Badja. Also found in eastern Victoria. Grows in swamps and bogs which are often dominated by heaths. Also grows at the edges of bog margins on peaty soils with a cover of shrubs or grasses. | Low | Low |

Key: CE = Critically Endangered; E, E1 = Endangered; EP = Endangered Population; V = Vulnerable; M = Migratory.

Fauna that are exclusively dependant on marine environments, including near shore environments, were not included in the assessment due to lack of suitable habitat.

Habitat descriptions taken from the relevant profiles on the OEH Threatened Species website unless otherwise stated.

## Appendix 2: Fauna recorded from targeted survey

| Group | Scientific Name | Common Name | Status NSW | Status Common wealth | Quant ity | Latitude | Longitude |
|---|---|---|---|---|---|---|---|
| Amphibia | *Crinia signifera* | Common Eastern Froglet | P | - | 20 | -34.3899 | 150.73 |
| | *Crinia signifera* | Common Eastern Froglet | P | - | 1 | -34.3899 | 150.7302 |
| | *Litoria littlejohni* | Littlejohn's Tree Frog | V | V | 30 | -34.3667 | 150.7429 |
| | *Litoria littlejohni* | Littlejohn's Tree Frog | V | V | 50 | -34.3667 | 150.7433 |
| | *Litoria littlejohni* | Littlejohn's Tree Frog | V | V | 50 | -34.3945 | 150.73 |
| | *Litoria littlejohni* | Littlejohn's Tree Frog | V | V | 35 | -34.3952 | 150.7427 |
| | *Litoria littlejohni* | Littlejohn's Tree Frog | V | V | 75 | -34.3953 | 150.7431 |
| | *Litoria littlejohni* | Littlejohn's Tree Frog | V | V | 60 | -34.3929 | 150.7452 |
| | *Litoria lesueuri* | Lesueur's Frog | P | - | 1 | -34.39 | 150.7302 |
| | *Litoria nudidigita* | Leaf Green River Tree Frog | P | - | 5 | -34.3903 | 150.7295 |
| Aves | *Callocephalon fimbriatum* | Gang-gang Cockatoo | V | - | 1 | -34.386 | 150.7347 |
| | *Calyptorhynchus lathami* | Glossy Black-Cockatoo | V | - | 2 | -34.3945 | 150.7299 |

# Appendix 3: Weather data from the survey period

# Daily Maximum Temperature (degrees Celsius)

## CAMPBELLTOWN (MOUNT ANNAN)

Station Number: 068257 · State: NSW · Opened: 2006 · Status: Open · Latitude: 34.06°S · Longitude: 150.77°E · Elevation: 112 m

| 2019 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1st** | 35.0 | 21.8 | *30.7* | *22.4* | 25.3 | 20.3 | 17.2 | *20.6* | *24.1* | 22.3 | *31.8* | *26.4* |
| **2nd** | 33.9 | 25.9 | *30.9* | *22.2* | 24.3 | 20.7 | 21.1 | *19.2* | *22.5* | 28.2 | *33.2* | *21.3* |
| **3rd** | 31.9 | 34.0 | *31.4* | *26.5* | 18.9 | 17.9 | 19.1 | *22.6* | *26.1* | 31.1 | *32.6* | *28.2* |
| **4th** | 35.3 | 35.6 | *34.6* | *22.5* | 22.6 | 13.8 | 16.8 | *19.6* | *28.2* | 33.5 | *27.8* | *30.5* |
| **5th** | 40.1 | 27.0 | *34.4* | *22.7* | 20.7 | 16.5 | 15.9 | *20.6* | *24.8* | 17.7 | *21.7* | *32.8* |
| **6th** | 21.4 | 31.7 | *36.7* | *27.7* | 21.5 | 19.3 | 19.2 | *21.4* | *30.0* | 26.1 | *30.4* | *32.6* |
| **7th** | 25.3 | 32.2 | *23.2* | *29.6* | 22.7 | 19.4 | 19.1 | *23.0* | *17.6* | 25.5 | *30.7* | *30.4* |
| **8th** | 32.3 | 34.7 | *32.1* | *32.4* | 19.8 | 14.3 | 19.1 | *20.3* | *18.8* | 23.0 | *30.0* | *27.6* |
| **9th** | 32.0 | 31.7 | *26.1* | *27.5* | 20.8 | 21.0 | 17.6 | *16.0* | *17.7* | 20.5 | *21.8* | *31.1* |
| **10th** | 23.7 | 27.2 | *33.7* | *21.2* | 18.6 | 22.2 | 16.9 | *14.6* | *19.0* | 21.1 | *27.1* | *38.3* |
| **11th** | 28.9 | 32.8 | *30.4* | *19.9* | 21.1 | 24.8 | 18.6 | *15.5* | *22.2* | 18.4 | *30.7* | *26.8* |
| **12th** | 35.5 | 36.4 | *35.0* | *22.7* | 22.2 | 21.5 | 19.9 | *19.0* | *25.7* | 18.5 | *36.7* | *25.1* |
| **13th** | 28.2 | 28.3 | *22.2* | *26.8* | 22.5 | 23.1 | 14.1 | *19.1* | *23.6* | 20.8 | *27.2* | *25.8* |
| **14th** | 31.9 | 27.1 | *27.8* | *23.8* | 24.3 | 19.6 | 15.3 | *19.2* | *23.2* | 26.2 | *30.0* | *30.6* |
| **15th** | 36.8 | 29.3 | *24.0* | *24.3* | 22.9 | 19.5 | 17.7 | *20.8* | *30.0* | 29.1 | *33.5* | *32.2* |
| **16th** | 38.0 | 29.8 | *24.6* | *25.7* | 22.4 | 13.9 | 20.1 | *24.9* | *29.7* | 25.9 | *24.5* | *25.0* |
| **17th** | 39.4 | 34.5 | *19.4* | | 23.8 | 18.0 | 18.8 | *20.2* | *13.6* | 27.0 | *24.0* | *28.3* |
| **18th** | 39.3 | 38.1 | *21.9* | *27.6* | 24.1 | 18.4 | 20.0 | *23.3* | *16.6* | 26.8 | *30.9* | *34.5* |
| **19th** | 29.2 | 32.7 | *26.9* | *26.0* | 23.6 | 16.8 | 19.6 | *15.9* | *21.5* | 28.3 | *38.0* | *40.0* |
| **20th** | 27.8 | 25.8 | *28.1* | *26.3* | 23.2 | 14.9 | 19.1 | *20.3* | *23.5* | 24.0 | *27.0* | *29.6* |
| **21st** | 25.6 | 24.7 | *28.2* | *26.2* | 26.5 | 15.0 | 23.3 | *20.8* | *26.5* | 26.1 | *34.8* | *41.2* |
| **22nd** | 35.2 | 25.9 | *27.6* | *27.0* | 26.5 | 16.1 | 23.4 | *19.8* | *25.4* | 29.4 | *29.4* | *24.2* |
| **23rd** | 33.9 | 26.5 | *28.7* | *25.3* | 23.8 | 16.8 | 23.2 | *18.5* | *21.8* | 31.2 | *25.0* | *27.6* |
| **24th** | 30.2 | 26.0 | *31.8* | *26.4* | 23.7 | 17.2 | 19.9 | *25.0* | *22.4* | 33.1 | *24.6* | *28.3* |
| **25th** | 37.2 | 27.4 | *25.7* | *29.3* | 25.8 | 17.2 | 19.5 | *23.4* | *20.9* | 37.0 | *35.7* | *29.7* |
| **26th** | 39.8 | 30.7 | *25.4* | *27.7* | 22.2 | 18.6 | 19.3 | *14.6* | *23.3* | 30.3 | *34.7* | *32.7* |
| **27th** | 38.2 | 28.1 | *22.8* | *20.4* | 19.0 | 19.9 | 20.4 | *18.3* | *26.6* | 26.0 | *27.7* | *32.9* |
| **28th** | 30.7 | 31.3 | *26.6* | *26.3* | 17.4 | 20.0 | 19.7 | *22.0* | *21.8* | 23.4 | *31.9* | *37.9* |
| **29th** | 34.4 | | *27.9* | *23.2* | 20.0 | 20.8 | 21.1 | *13.7* | *24.3* | 29.9 | *33.2* | *35.1* |
| **30th** | 32.8 | | *24.9* | *23.9* | 15.7 | 17.4 | 18.5 | *16.4* | *20.3* | 33.0 | *26.9* | *38.9* |
| **31st** | 39.3 | | *21.1* | | 19.9 | | 19.2 | *19.5* | | 32.9 | | *43.1* |
| **Highest daily** | 40.1 | 38.1 | *36.7* | *32.4* | 26.5 | 24.8 | 23.4 | *25.0* | *30.0* | 37.0 | *38.0* | *43.1* |
| **Lowest daily** | 21.4 | 21.8 | *19.4* | *19.9* | 15.7 | 13.8 | 14.1 | *13.7* | *13.6* | 17.7 | *21.7* | *21.3* |
| **Monthly mean** | 33.0 | 29.9 | 27.9 | 25.3 | 22.1 | 18.5 | 19.1 | 19.6 | 23.1 | 26.7 | 29.8 | 31.2 |

Quality control: 12.3 Done & acceptable, *12.3* Not quality controlled or uncertain, or precise date unknown

Product code: IDCJAC0010 reference: 58504888

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Daily Maximum Temperature (degrees Celsius)

CAMPBELLTOWN (MOUNT ANNAN)

Station Number: 068257 · State: NSW · Opened: 2006 · Status: Open · Latitude: 34.06°S · Longitude: 150.77°E · Elevation: 112 m

## Statistics for this station calculated over all years of data

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Mean** | 30.5 | 28.7 | 27.2 | 24.2 | 21.3 | 17.8 | 17.8 | 19.3 | 22.5 | 25.1 | 27.3 | 28.5 |
| **Highest monthly mean** | 33.0 | 31.3 | 29.2 | 28.1 | 23.0 | 18.6 | 19.4 | 20.9 | 25.0 | 27.1 | 30.1 | 31.3 |
| **Lowest monthly mean** | 27.6 | 25.4 | 24.8 | 22.1 | 19.7 | 16.3 | 16.4 | 17.4 | 21.2 | 22.6 | 25.2 | 23.9 |
| **Highest daily** | 45.5 | 45.6 | 39.7 | 36.1 | 28.8 | 24.8 | 27.1 | 28.9 | 35.7 | 37.0 | 42.1 | 43.1 |
| **Date of highest daily** | 4th 2020 | 11th 2017 | 18th 2018 | 9th 2018 | 1st 2016 | 11th 2019 | 30th 2017 | 23rd 2012 | 23rd 2017 | 25th 2019 | 20th 2009 | 31st 2019 |
| **Lowest daily** | 20.2 | 18.0 | 18.1 | 15.0 | 13.9 | 12.0 | 10.2 | 11.1 | 13.6 | 15.0 | 16.6 | 17.5 |
| **Date of lowest daily** | 12th 2020 | 2nd 2012 | 21st 2008 | 20th 2015 | 31st 2015 | 27th 2016 | 16th 2015 | 22nd 2008 | 17th 2019 | 3rd 2009 | 7th 2007 | 15th 2006 |

1) Calculation of statistics

Summary statistics, other than the Highest and Lowest values, are only calculated if there are at least 10 years of data available.

2) Gaps and missing data

Gaps may be caused by a damaged instrument, a temporary change to the site operation, or due to the absence or illness of an observer.

3) Further information

http://www.bom.gov.au/climate/cdo/about/about-airtemp-data.shtml.



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# Daily Maximum Temperature (degrees Celsius)

## CAMPBELLTOWN (MOUNT ANNAN)

Station Number: 068257 · State: NSW · Opened: 2006 · Status: Open · Latitude: 34.06°S · Longitude: 150.77°E · Elevation: 112 m

| 2020 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1st** | 30.6 | *45.3* | *31.9* | | | | | | | | | |
| **2nd** | 27.4 | *38.2* | *36.9* | | | | | | | | | |
| **3rd** | 34.4 | *34.4* | *20.6* | | | | | | | | | |
| **4th** | 45.5 | *23.2* | *22.4* | | | | | | | | | |
| **5th** | 27.4 | *26.9* | *21.8* | | | | | | | | | |
| **6th** | 25.3 | *23.3* | *27.5* | | | | | | | | | |
| **7th** | 34.6 | *20.9* | *25.0* | | | | | | | | | |
| **8th** | 27.4 | *22.5* | *23.1* | | | | | | | | | |
| **9th** | 26.1 | *21.1* | | | | | | | | | | |
| **10th** | 36.1 | *29.3* | | | | | | | | | | |
| **11th** | 22.2 | *31.2* | | | | | | | | | | |
| **12th** | 20.2 | *27.8* | | | | | | | | | | |
| **13th** | 26.5 | *27.4* | | | | | | | | | | |
| **14th** | 30.2 | *27.8* | | | | | | | | | | |
| **15th** | 30.8 | *29.4* | | | | | | | | | | |
| **16th** | 29.7 | *26.5* | | | | | | | | | | |
| **17th** | 21.9 | *24.7* | | | | | | | | | | |
| **18th** | 24.0 | *32.5* | | | | | | | | | | |
| **19th** | 24.5 | *27.4* | | | | | | | | | | |
| **20th** | 31.2 | | | | | | | | | | | |
| **21st** | 32.8 | *26.4* | | | | | | | | | | |
| **22nd** | 34.8 | *24.0* | | | | | | | | | | |
| **23rd** | 40.9 | *24.0* | | | | | | | | | | |
| **24th** | 26.9 | *29.1* | | | | | | | | | | |
| **25th** | 30.5 | *31.4* | | | | | | | | | | |
| **26th** | 37.7 | *32.9* | | | | | | | | | | |
| **27th** | 33.0 | *26.6* | | | | | | | | | | |
| **28th** | 34.2 | *26.6* | | | | | | | | | | |
| **29th** | 29.9 | *27.4* | | | | | | | | | | |
| **30th** | 33.3 | | | | | | | | | | | |
| **31st** | 37.9 | | | | | | | | | | | |
| **Highest daily** | 45.5 | *45.3* | *36.9* | | | | | | | | | |
| **Lowest daily** | 20.2 | *20.9* | *20.6* | | | | | | | | | |
| **Monthly mean** | 30.6 | | | | | | | | | | | |

Quality control: 12.3 Done & acceptable, *12.3* Not quality controlled or uncertain, or precise date unknown

Product code: IDCJAC0010 reference: 58504821

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Daily Maximum Temperature (degrees Celsius)

CAMPBELLTOWN (MOUNT ANNAN)

Station Number: 068257 · State: NSW · Opened: 2006 · Status: Open · Latitude: 34.06°S · Longitude: 150.77°E · Elevation: 112 m

## Statistics for this station calculated over all years of data

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Mean** | 30.5 | 28.7 | 27.2 | 24.2 | 21.3 | 17.8 | 17.8 | 19.3 | 22.5 | 25.1 | 27.3 | 28.5 |
| **Highest monthly mean** | 33.0 | 31.3 | 29.2 | 28.1 | 23.0 | 18.6 | 19.4 | 20.9 | 25.0 | 27.1 | 30.1 | 31.3 |
| **Lowest monthly mean** | 27.6 | 25.4 | 24.8 | 22.1 | 19.7 | 16.3 | 16.4 | 17.4 | 21.2 | 22.6 | 25.2 | 23.9 |
| **Highest daily** | 45.5 | 45.6 | 39.7 | 36.1 | 28.8 | 24.8 | 27.1 | 28.9 | 35.7 | 37.0 | 42.1 | 43.1 |
| **Date of highest daily** | 4th 2020 | 11th 2017 | 18th 2018 | 9th 2018 | 1st 2016 | 11th 2019 | 30th 2017 | 23rd 2012 | 23rd 2017 | 25th 2019 | 20th 2009 | 31st 2019 |
| **Lowest daily** | 20.2 | 18.0 | 18.1 | 15.0 | 13.9 | 12.0 | 10.2 | 11.1 | 13.6 | 15.0 | 16.6 | 17.5 |
| **Date of lowest daily** | 12th 2020 | 2nd 2012 | 21st 2008 | 20th 2015 | 31st 2015 | 27th 2016 | 16th 2015 | 22nd 2008 | 17th 2019 | 3rd 2009 | 7th 2007 | 15th 2006 |

1) Calculation of statistics

Summary statistics, other than the Highest and Lowest values, are only calculated if there are at least 10 years of data available.

2) Gaps and missing data

Gaps may be caused by a damaged instrument, a temporary change to the site operation, or due to the absence or illness of an observer.

3) Further information

http://www.bom.gov.au/climate/cdo/about/about-airtemp-data.shtml.



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# Daily Rainfall (millimetres)

## CAMPBELLTOWN (MOUNT ANNAN)

Station Number: 068257 · State: NSW · Opened: 2006 · Status: Open · Latitude: 34.06°S · Longitude: 150.77°E · Elevation: 112 m

| 2019 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1st** | 4.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **2nd** | 0 | 1.2 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **3rd** | 0 | 0.4 | 0.2 | 0.6 | 0 | 2.0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **4th** | 0 | 0.2 | 0 | 0 | 7.4 | 18.6 | 0.2 | 0 | 0 | 0 | 14.8 | 0 |
| **5th** | 0 | 0 | 0 | 1.8 | 0 | 5.8 | 5.8 | 0 | 0 | 9.2 | 0.2 | 0 |
| **6th** | 13.4 | 0 | 0 | 0.4 | 0.2 | 0.8 | 2.8 | 0 | 0 | 0.8 | 0 | 0 |
| **7th** | 0 | 0 | 0 | 0 | 0 | 0 | 1.8 | 0 | 0 | 0 | 0 | 0 |
| **8th** | 0 | 0.2 | 0 | 0.2 | 0 | 0 | 0.8 | 0 | 0 | 0 | 0 | 0 |
| **9th** | 6.2 | 13.0 | 0 | 0 | 0 | 0 | 0.2 | 0 | 0 | 0 | 0 | 0 |
| **10th** | 0 | 0.2 | 0 | 0 | 0 | 0.2 | 0 | 0 | 0.2 | 0 | 0 | 0 |
| **11th** | 3.8 | 0 | 0 | 0 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **12th** | 10.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.0 | 0 | 0 |
| **13th** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.6 | 0 | 1.0 |
| **14th** | 0 | 0 | 1.0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **15th** | 0 | 0 | 26.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **16th** | 0 | 0 | 3.4 | 0 | 0.2 | 2.0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **17th** | 0 | 0 | 29.8 | 0 | 0 | 16.2 | 0 | 0 | 18.0 | 0 | 0 | 0 |
| **18th** | 0 | 0 | 34.2 | 0.4 | 0 | 0 | 0 | 0 | 25.0 | 0 | 0 | 0 |
| **19th** | 0 | 0 | 0.8 | 0 | 0 | 0 | 0 | 0 | 4.6 | 0 | 0 | 0 |
| **20th** | 0 | 0 | 1.0 | 0 | 0 | 0 | 0 | 0 | 4.2 | 0 | 0 | 0 |
| **21st** | 1.2 | 0.2 | 0 | 0 | 0 | 0.8 | 0 | 0 | 0.2 | 0 | 0 | 0 |
| **22nd** | 10.4 | 0.8 | 0 | 0 | 0 | 0.2 | 0.2 | 0 | 0 | 0 | 0 | 0 |
| **23rd** | 0.6 | 0 | 0.2 | 0 | 0 | 0 | 0.2 | 0 | 0 | 0 | 1.6 | 0 |
| **24th** | 0 | 0.6 | 0.6 | 0 | 0 | 8.8 | 0 | 0 | 0 | 0 | 0.2 | 0.2 |
| **25th** | 0 | 0 | 3.4 | 0 | 0.2 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0.6 |
| **26th** | 0 | 0 | 0.2 | 0 | 0 | 0.2 | 0 | 0 | 0 | 0 | 3.8 | 0 |
| **27th** | 0 | 0 | 0 | 0 | 0 | 0.2 | 0 | 3.4 | 0 | 0 | 2.0 | 0 |
| **28th** | 24.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **29th** | 0.4 | | 0 | 0 | 0 | 0.2 | 0 | 0 | 0 | 0 | 0 | 0 |
| **30th** | 0 | | 19.4 | 0 | 0 | 0 | 0.8 | 14.6 | 0 | 0 | 0 | 0 |
| **31st** | 0 | | 0.4 | | 0 | | 0 | 0 | | 0 | | 0 |
| **Highest daily** | 24.4 | 13.0 | 34.2 | 1.8 | 7.4 | 18.6 | 5.8 | 14.6 | 25.0 | 9.2 | 14.8 | 1.0 |
| **Monthly Total** | 75.0 | 16.8 | 121.4 | 3.4 | 8.4 | 56.4 | 12.8 | 18.0 | 52.2 | 12.6 | 22.6 | 1.8 |

Annual total for 2019 = 401.4mm

↓ This day is part of an accumulated total
Quality control: 12.3 Done & acceptable, 12.3 Not completed or unknown

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Daily Rainfall (millimetres)

CAMPBELLTOWN (MOUNT ANNAN)

Station Number: 068257 · State: NSW · Opened: 2006 · Status: Open · Latitude: 34.06°S · Longitude: 150.77°E · Elevation: 112 m

## Statistics for this station calculated over all years of data

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Highest daily** | *118.8* | *172.4* | *55.2* | *83.4* | *46.0* | *146.6* | *28.0* | *50.2* | *35.2* | *27.6* | *64.4* | *38.8* |
| **Date of highest daily** | 29th 2013 | 10th 2020 | 8th 2012 | 21st 2015 | 24th 2013 | 6th 2016 | 22nd 2011 | 18th 2014 | 15th 2010 | 15th 2014 | 2nd 2010 | 14th 2018 |

1) Calculation of statistics

Summary statistics, other than the Highest and Lowest values, are only calculated if there are at least 20 years of data available.

2) Gaps and missing data

Gaps may be caused by a damaged instrument, a temporary change to the site operation, or due to the absence or illness of an observer.

3) Further information

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Product code: IDCJAC0009 reference: 58504853 Created on Mon 09 Mar 2020 12:05:14 PM EST

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# Daily Rainfall (millimetres)

## CAMPBELLTOWN (MOUNT ANNAN)

Station Number: 068257 · State: NSW · Opened: 2006 · Status: Open · Latitude: 34.06°S · Longitude: 150.77°E · Elevation: 112 m

| 2020 | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1st** | *0* | *0* | *0* | | | | | | | | | |
| **2nd** | *0* | *0* | *0* | | | | | | | | | |
| **3rd** | *0* | *6.6* | *0* | | | | | | | | | |
| **4th** | *0* | *0* | *5.6* | | | | | | | | | |
| **5th** | *0* | *0* | *8.2* | | | | | | | | | |
| **6th** | *0* | *1.2* | *22.8* | | | | | | | | | |
| **7th** | *1.2* | *35.8* | *0.2* | | | | | | | | | |
| **8th** | *11.0* | *46.2* | *1.6* | | | | | | | | | |
| **9th** | *0* | *43.6* | *0* | | | | | | | | | |
| **10th** | *0* | *172.4* | | | | | | | | | | |
| **11th** | *0.2* | *0* | | | | | | | | | | |
| **12th** | *0.4* | *0* | | | | | | | | | | |
| **13th** | *7.6* | *6.8* | | | | | | | | | | |
| **14th** | *0* | *1.6* | | | | | | | | | | |
| **15th** | *0* | *0* | | | | | | | | | | |
| **16th** | *10.4* | *0.8* | | | | | | | | | | |
| **17th** | *32.0* | *0.8* | | | | | | | | | | |
| **18th** | *7.6* | *0.6* | | | | | | | | | | |
| **19th** | *3.2* | | | | | | | | | | | |
| **20th** | *1.8* | | | | | | | | | | | |
| **21st** | *16.6* | | | | | | | | | | | |
| **22nd** | *0* | *0* | | | | | | | | | | |
| **23rd** | *0* | *1.4* | | | | | | | | | | |
| **24th** | *2.4* | *0.4* | | | | | | | | | | |
| **25th** | *5.6* | *0* | | | | | | | | | | |
| **26th** | *0* | *0* | | | | | | | | | | |
| **27th** | *0* | *0.4* | | | | | | | | | | |
| **28th** | *0* | *0* | | | | | | | | | | |
| **29th** | *0* | *0* | | | | | | | | | | |
| **30th** | *0* | | | | | | | | | | | |
| **31st** | *0* | | | | | | | | | | | |
| **Highest daily** | *32.0* | *172.4* | *22.8* | | | | | | | | | |
| **Monthly Total** | *100.0* | | | | | | | | | | | |

↓ This day is part of an accumulated total
Quality control: 12.3 Done & acceptable, *12.3* Not completed or unknown

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Daily Rainfall (millimetres)

CAMPBELLTOWN (MOUNT ANNAN)

Station Number: 068257 · State: NSW · Opened: 2006 · Status: Open · Latitude: 34.06°S · Longitude: 150.77°E · Elevation: 112 m

## Statistics for this station calculated over all years of data

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Highest daily** | *118.8* | *172.4* | *55.2* | *83.4* | *46.0* | *146.6* | *28.0* | *50.2* | *35.2* | *27.6* | *64.4* | *38.8* |
| **Date of highest daily** | 29th 2013 | 10th 2020 | 8th 2012 | 21st 2015 | 24th 2013 | 6th 2016 | 22nd 2011 | 18th 2014 | 15th 2010 | 15th 2014 | 2nd 2010 | 14th 2018 |

1) Calculation of statistics

Summary statistics, other than the Highest and Lowest values, are only calculated if there are at least 20 years of data available.

2) Gaps and missing data

Gaps may be caused by a damaged instrument, a temporary change to the site operation, or due to the absence or illness of an observer.

3) Further information

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Impact assessments
Development and activity approvals
Rehabilitation
Stakeholder consultation and facilitation
Project management

**Environmental offsetting**
Offset strategy and assessment (NSW, QLD, Commonwealth)
Accredited BAM assessors (NSW)
Biodiversity Stewardship Site Agreements (NSW)
Offset site establishment and management
Offset brokerage
Advanced Offset establishment (QLD)

## Attachment G – Geology of Longwall 19

# GEOLOGY OF LONGWALL 19

**February 2020**
IMC Technical Services


## Summary

Longwall 19 is planned to be developed for future extraction, including Maingate (MG) 19[1] roadways between Wongawilli Creek and Sandy Creek in Dendrobium Area 3A and this panel is located immediately south of Longwall 8. Previous panels in Area 3A were developed from South Mains with Longwall's 6, 7 and 8 being extracted towards the east. MG19 will be developed from Wongawilli Mains development panel to the east between 20 and 23 cut troughs (CT) with Longwall extraction towards the west. Development is yet to commence.

In general, the geology appears to be mostly benign, although some known geological features are known to occur to the south and west of Longwall 19. Extensive exploration activities have been undertaken to increase the understanding of geology in Dendrobium Area 3A. The Longwall 19 panel is covered by a significant amount of geological data along its entire length including:

| Surface Vertical boreholes | Underground Inseam (UIS) boreholes |
|---|---|
| S1388 | MG8-A11-IS1 |
| S1720 | MG8-A11-IS2 |
| S1722 | MG8-A11-IS3 |
| S1738 | MG8-A11-IS4 |
| S1879 | MG8-A19-IS5 |
| S1885 | MG8-A19-IS6 |
| S1887 | MG8-A19-IS7 |
| S1888 | MG7-Z7-IS2 |
| S1890 | SM-D14-IS1 |
| S1907 | SM-D14-IS2 |
| S1934 | SM-D14-IS3 |

- Numerous 2D seismic lines;
- Surface geological mapping;


[1] Refer to Longwall 19 Subsidence Management Plan – Plan 1 (DEN-01-7753) for mine layout detail.

- Underground geological mapping; and
- Aeromagnetic and related remote sensing surveys.

Additional underground inseam drilling is planned once MG19 development commences and will add further confidence in the geology of MG19.

## STRUCTURE

The geological data available for Longwall 19, including from MG8 and South Mains suggests a relatively benign geological setting with no significant faulting expected. The panel is orientated mostly across strike and as such is expected to be relatively flat with the seam dipping gently to the northwest at dips of ~2º. Seam elevations are 50 m above mean sea level (amsl) at MG19 panel entry from where the seam is expected to gently rise all the way to a maximum of 75m amsl around the southeast corner of installation face.

The main geological structures that are expected to impact mining will be igneous in nature rather than fault related. The Dendrobium Nepheline Syenite sill largely determines the length of the Longwall 19 block and is the primary reason this block was not extracted after Longwall 8. Current inseam drilling data indicates the sill may be present in the bleeder roadway at 21CT. This intrusion has been exposed in several other locations at Dendrobium and it consists of a variable thickness sill that generally sits relatively high in the Wongawilli Seam above the working section at the base of the seam. However, the sill is known to migrate down into the working section and this area is highlighted by the red hatched polygon in Figure 1 below. The zone where the sill is in the seam but above the working section is denoted by the orange hatched polygon. These is a zone in the inbye portion of Longwall 19 where the sill is expected to be present above the working section, mainly between 17 and 21 CT's. More UIS drilling is planned from MG19 to further define the edge of this sill.

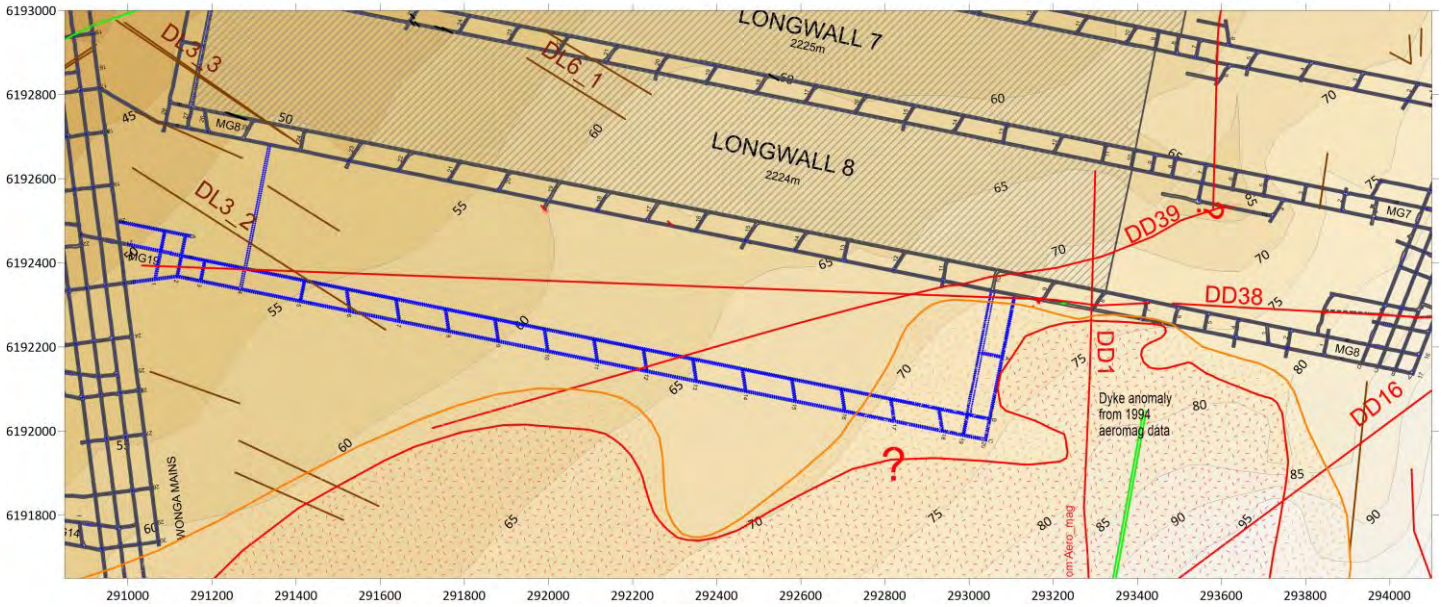


Figure 1 – Geological Structure and seam Floor Contours

Also expected to be intersected, are two thin dykes that have been mapped in MG8, DD38 and DD39. Of these DD38 is the more prominent with thickness ranging from 0.3 to 1.3 m but with a thinning trend to the west. DD39 is thinner ranging 0.2-0.6 m wide. Both dykes have been projected well into the Longwall 19 block but there is no strong evidence of them being present inside the block. DD1 is a prominent aeromag dyke but it occurs to the east of any proposed workings for Longwall 19.

Apart from the igneous structure the mining conditions in MG8 have been good with little roof deformations and no significant roof falls. There is a prominent NW-SE joint orientation which is consistent for surface lineaments but these joints have no impact on roof conditions or water make.

## DEPTH OF COVER

Depth of Cover for MG19 ranges from 250 to 365 m, with the highest values in the center of the panel around 12-15 CT (Figure 2). Depths of cover then drop off to 250 m towards Wongawilli Creek in the west and 300 m towards Sandy Creek in the west, although there are no proposed workings within 650 m of Sandy Creek.

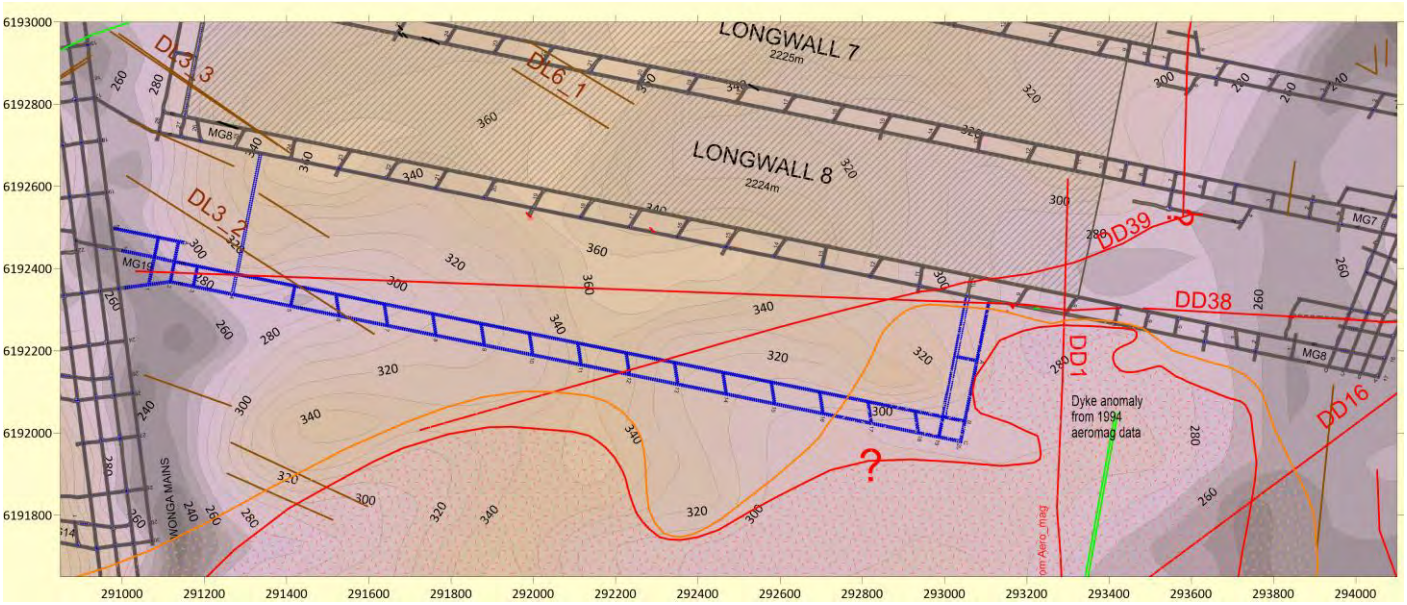



Figure 2 – Depth of Cover

## SEAM THICKNESS

Seam thickness for MG19 ranges from 3.3 to 3.7 m, which is generally some 0.4-0.5 m less than most of area 3B (Figure 3). This is due to the lack of the basal WW12 ply in the working section in Area 3A, compared with Area 3B. While the seam is slightly thinner in Longwall 19 as a result washability is expected to improve and coking yields are expected to be higher compared with Area 3B.

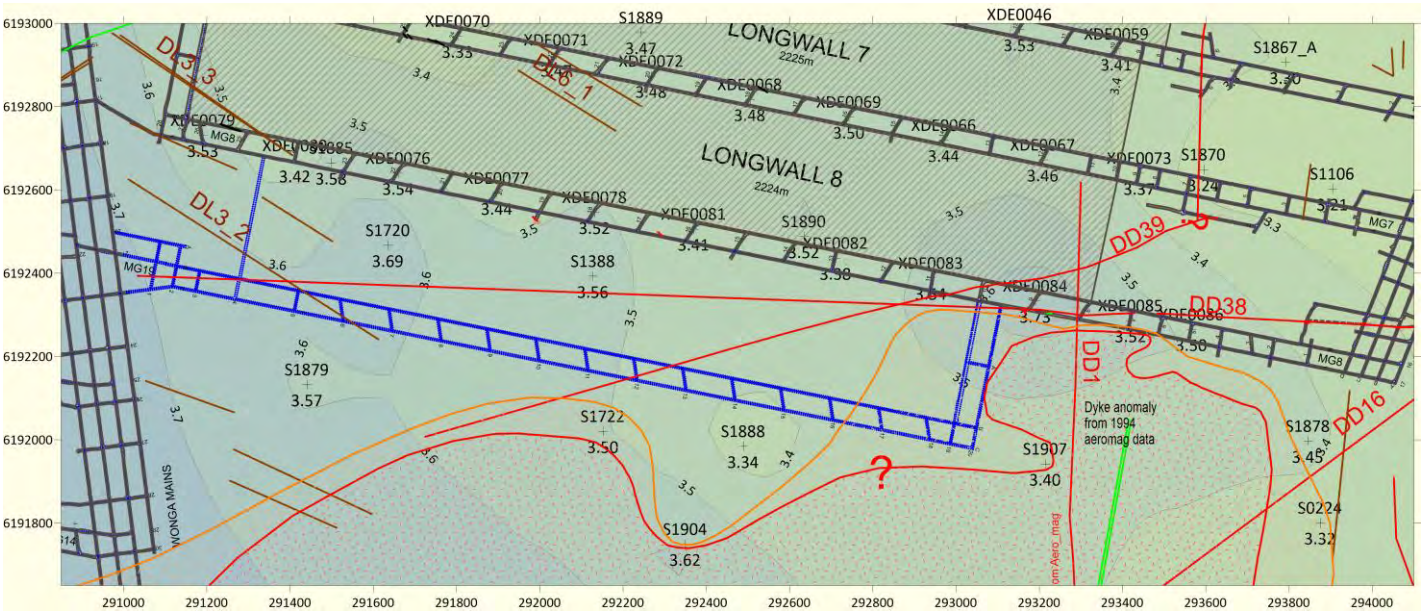



Figure 3 – Seam Thickness (Working Section)

## CONCLUSION

The geological setting present within the Longwall 19 block appears relatively benign in consideration of the exploration data currently available. Mining conditions are expected to be comparable to those previously experience in Area 1, 2 3A and 3B with only minor impacts from geological features expected. Further definition of the extent of the Dendrobium Nepheline Syenite sill will be confirmed by additional inseam drilling. The two small dykes may be present on the longwall face but are expected to be manageable as they are thin and are expected to thin further to the west.

## Attachment H – Groundwater Model Peer Review

**KALF AND ASSOCIATES Pty Ltd**
**Hydrogeological, Numerical Modelling Specialists**

# South32 – Illawarra Coal
# Dendrobium Mine:

# KA Peer Review of SLR Groundwater Modelling Assessment of Longwall 19 extraction

**Dr F. Kalf**
**B.Sc. M.App.Sc Cert. Eng. Hydrology, PhD.**
**28 Jan 2020**

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## Background and Key Issues Summary

This report is the Kalf and Associates Pty Ltd (KA) peer review of the Dendrobium Mine Longwall 19 groundwater and modelling assessment commissioned by Illawarra Metallurgical Coal (IMC), a subsidiary of South32.

Longwall mining has been conducted at Dendrobium since early 2005 and has included Areas 1, 2, 3A, 3B and 3C. This review report relates specifically to mining coal from the Wongawilli seam at longwall 19 (Figure 1). SLR consulting was engaged to determine impacts, in particular drawdown due to longwall 19 extraction in Area 3A. A subsidence plan is being prepared beforehand to determine the influence on groundwater due to mining subsidence. Longwall 19 is situated 0.9km south-west of Lake Cordeaux.

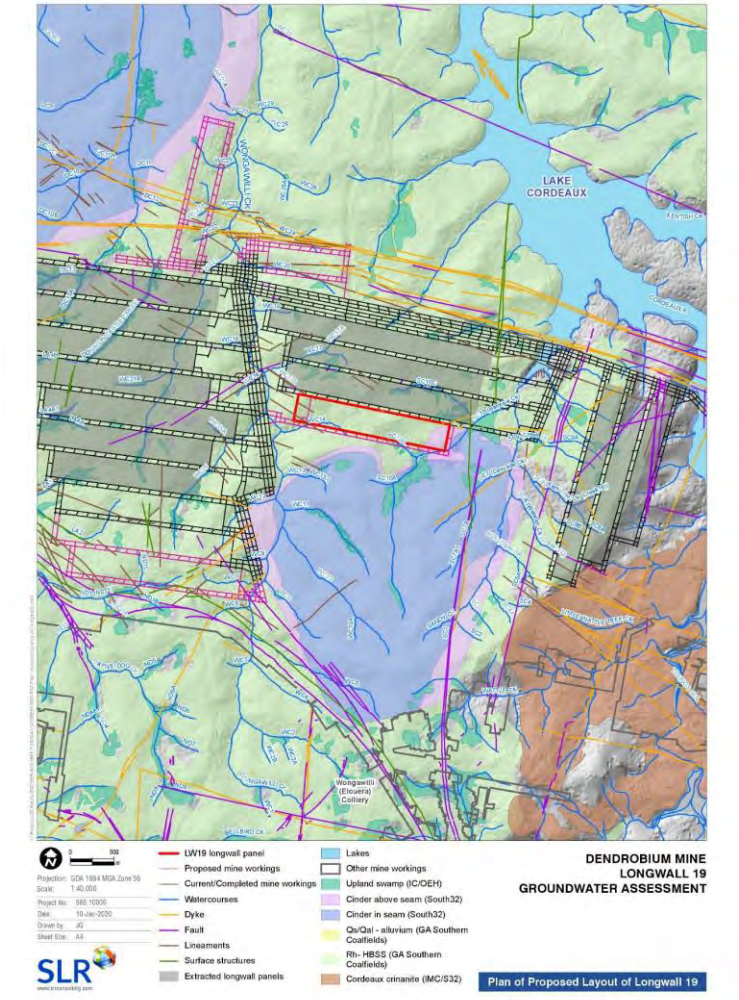



Figure 1. Location of longwall 19 (red outline) from SLR report.

The proposed seam extraction lies within a depth of cover of between 248m to 404m (Table 1-1 SLR (Dec 2018) with an extraction thickness proposed of 3.9m. Longwall widths are 295m, while longwall void widths vary from 245m to 295m and length 820m to 2013m. W/H ratios are therefore in the range 0.730 to 0.987.

Mining at Dendrobium occurs within the Permian-Triassic stratigraphic geological sequence The Coal Measures are overlain by a series of sandstone, siltstone and claystone units with thickness in the range 3m up to 100m, and the Hawkesbury Sandstone typically 120m thick at the top of the sequence. The SLR (2019) report Table 7 presents a summary of the regional geology of the region.

Modeling calibration has yielded a broad spread of results as shown in Figure 11 (SLR 2019) although the observed and transient model yielded an approximate 11% in correlation that lies just outside the maximum of 10%. The modelling parameters are suitable although it is noted that for some layers values of specific storage lie outside those recommended by Rau et al 2018 ( $10^{-5}$ $m^{-1}$ to $10^{-7}$ $m^{-1}$ ) and which are currently being adopted by the modelling community. However, it is unlikely any changes would influence overall results.

The modelling results match the inflow to the Dendrobium mine. Longwall 19 mining would increase inflow from Area 3A from 1.5 ML/day to 3 Ml/day during 2023. There is no Incremental leakage from the Avon or Cordeaux Reservoirs with leakage from these structures less than the Dams Safety NSW prescribed tolerable limit.

Surface water losses due to the presence of longwall 19 are estimated at 90 ML/yr for a total loss of 1400 Ml/yr over the area.

No registered groundwater structures are affected with drawdown less than 0.1m.

The nearest high priority Groundwater Dependent Ecosystem would not be affected.
There would be minimal groundwater quality changes.

### *Peer Review Assessment*

For this modelling review the available Modelling Guideline documents (NWC 2012, MDBC 2001) have been taken into consideration. A modelling appraisal checklist is provided herein as an Appendix.

### *Previous Studies and Reviews*

The proposed mining area has had numerous assessments conducted that are listed in the reports references Section of the SLR report.

### *Hydrogeological and Modelling Description*

The hydrogeological description of the region and modelling work described in the SLR (2019) report is quite detailed. The report covers a wide range of topics that are included within 9 main section headings that deal with: Introduction; Hydrogeological Setting; Hydrogeological Conceptual model; Groundwater Model; Model Results; Monitoring; Conclusions; Recommendations and References.

There are also 4 Appendices dealing with: **A** Model timing; **B** Aquifer Permeability data summary; **C** Simulated extent of connected fracturing and surface cracking; **D** Comparison of modelled and observed groundwater levels. Coverage of these headings are considered suitable although a section on baseflow depletion Section 2.1.3 is discussed before Section 2.2 and 2.2.1 on Geology and stratigraphy.

There is no section that deals specifically with either sensitivity or uncertainty. However, given the previous experience of mining at Dendrobium, there is already considerable information on the behaviour of strata at the longwall site.

### *Model Conceptualisation and Simulation Methods*

SLR (2019) have used the United States Geological Survey (USGS) MODFLOW-USG (USG) code as opposed to the well-known MODFLOW-SURFACT (MS) code because of the USG code's flexibility in representing non-rectilinear orientation and variable sized longwall

panels including other geological features within layering configurations, as well as dealing more efficiently with layer 'pinch-outs' and conduits. The USG code also uses 'upstream weighting' similar to the 'pseudo soil' function in MS and therefore eliminating the need to define precisely the unsaturated/saturated properties of the media and avoiding variably saturation difficulties and consequent "dry cells". Adoption of the USGS code is considered to be suitable.

Model conceptualisation is considered to be valid as well as the model layering configuration Section 4-1 (SLR 2019). A total of 17 model layers were used with cell resolutions of between 50m and 215m with 53,775 mesh cells per layer. The model mesh resolution and layer assignment are considered to be adequate.

The 'River' type boundaries have been used to represent variable reservoir levels based on historical records. Watercourses, (i.e. rivers, creeks and un-named streams), were also modelled using 'river' (variable stream stage) boundaries rather than routing procedures in order to reduce simulation times, with variable stages based on runoff from the water balance model.

The model uses variable gross recharge as a percentage of rainfall and evapotranspiration as input and output respectively, which is suitable, rather than application of variable net recharge. Table 2-5 in the report indicates the various estimates made about recharge using different methods.

The SLR (2019) report notes (Section 4.4.3.1) that an increase of 2 to 5 times rate of recharge was tested above extracted longwalls with a value of 2.5 times adopted. (12-30%)

Three different methods have been assessed to simulate mine extraction and subsequent free draining fractures zone above the caving zone. The methods include:

1. Time-Varying hydraulic parameters
2. 'Stacked' drains
3. Connected linear Networks (CLN)

Method 1 can, to a certain extent, be 'calibrated' with variable hydraulic parameters applied in the vertical direction based on piezometer pressure head response and inflow. The method utilises empirical linear (1D) regression equations of height of fracturing which has recently been criticised as not being entirely robust (Galvin 2017,MER 2017).

'Stacked' drains application includes setting up these above the mined out seam to a given height and are applied progressively but with changes in conductance to allow for porous media flow rather than fracture flow and other factors which are then allowed to drain as indicated by the model. Method 2 has been used largely because it provided better results for matching the 'peakiness' of inflows and also is faster and with much improved stability. The stacked drains conductance can be changed in order to match recorded inflow and to allow some control and reduction of fracture hydraulic conductivity in the vertical direction. KA has no objection to the use of this 'Stacked Drain' method as it has been used for a number of years and has proved to be suitable. In addition it has been found on some projects to overestimate the mining effects such as drawdown and overall inflow and therefore can be considered to be a conservative overall methodology for determining fracture propagation and associated draining in the geological profile.

For option 3 whilst CLN between cell boundaries is relatively new and largely untested it should be considered at present as a proxy and possible candidate although it needs to be tested in various environments. The advantages and disadvantages of these methods are outlined in Table 4-2 (SLR 2019).

The IESC (2018) document has stated that USG groundwater modelling *"is incapable of realistically simulating groundwater responses to ground movement of strata."* While it is valid that USG modelling does not include simultaneous groundwater flow and geotechnical fracture simulation, it is incorrect to imply that USG groundwater modelling code cannot, based on other methods determine fracture propagation and drainage extent, in a conservative manner, within a geological profile. This is allowed for by making use of the 'stacked drains' method together with an assessment of ***W/H*** ratios, seam cutting height and subsidence estimate that can provide a conservative approach that over time can be supported by ongoing monitoring.

While it is true that ***W/H*** cannot determine the height of fracturing in a mined geological profile experience in other coal projects ***W/H*** has demonstrated that it does provide a screening device to determine whether there is the likelihood of fracturing near to or at the ground surface.

For example, in a previous KA review it was determined that based on quite high width (of panel)-to-depth (of cover) (***W/H***) ratios were very likely indicating fracturing near to or at the ground surface. It has now been established that this conclusion has been confirmed where the ***W/H*** ratio approached a value typically greater than 0.9 or so it has caused connected fracturing and subsequent inflow from the surface. Correspondingly in another mine where inflow was quite low with no effect from surface fracturing had ***W/H*** ratios of 0.3 to 0.4.[1]

In the SLR (2019) report surface cracking has also been allowed for by including valley closure and floor strata modification factor. Surface cracking was simulated for the most part to a depth of 10 x the seam cutting height with horizontal conductivity increase by a factor of 3 and vertical conductivity increased by 50%. Drain conductance is described in Sections 4.5.1.1, surface cracking zone, 4.5.2, off Goaf (valley closure, strata deformation) 4.5.3 and floor strata 4.5.4 (SLR 2019).

Increased porosity is discussed in Section 4.5.5.

For the remaining panels less than 305m wide the 'conservative' Tammetta equation has been used. The Tammetta equation produces $H_d$ for void widths of 305m rather than 285m since this latter depth only occurs in two instances (Table 1-7 HD 2019).

Specific yield and porosity enhancement is presented in Table 4-3

It is important to conduct ongoing monitoring and review over time, as is often recommended by KA and authorities, usually every 3 to 5 years. The IESC in their 2018 report prefer long term case studies for comparison. However, this is in most cases impractical and idealistic and would never quite resolve the issue, therefore ongoing monitoring is much preferred.

[1] Galvin (2017) has noted the following:
*"Factors that influence the behaviour of the rock mass overlying an excavation include geology (e.g. composition of stratum, stratum distribution and thickness); the geomechanical properties of the rock mass (e.g. stratum strength and elastic modulus); pre-mining stress field;* ***and, very importantly, panel width to depth ratio, W/H.*** *Consideration of panel width in isolation of consideration of the depth of the panel, and vice-versa, is important but is also essential that the two parameters are considered together when evaluating rock mass response to mining and its impacts on the subsurface and surface."*

## *Groundwater Model, Calibration and Performance*

The model used was previously used for area 3B and 3C.

Calibrated and modelled hydraulic parameters are presented in Table 4-4.

Manual calibration was used to change hydraulic conductivity and specific yield. The objective was to match mine inflow and groundwater levels while using packer and core test results to constrain hydraulic conductivity. This approach was also conducted using a local-scale model with results passed back to the regional model.

Model run times were in the range 15 to 20 hours for the stacked drain approach and 30 to 50 hours using other methods.

Steady-state simulation was used to set up initial conditions and was combined with transient runs in the SLR (2019) model.

The total water balance for the calibrated simulation is presented in Table 4-7 in Section 4.9.4 for the period 1990 to 2053. Mine inflow constitutes close 6% of the rainfall recharge according to the SLR report.

## *Predictive Modelling and Impact Assessment*

Predictive scenarios are discussed in Sections 5, 5.1 and 5.2. While simulated Groundwater Levels are discussed in Section 5.3. Figures 27 to 38 present the groundwater levels and depth of the watertable. A pressure head section prior to, during maximum development and post mining recovery is shown in Figure 39. This shows dewatering well above Longwall 19 but no dewatering across a zone near the surface.

Mine inflow is summarised in their Figure 24

Baseflow depletion is provided in section 2.1.3,

## *Groundwater Monitoring*

SLR (2019) have provided details of groundwater quality objectives and in particular proposed management triggers for Areas 5 and 6.The issue of swamp monitoring is covered in Section 2.3.

## *Conclusions and Considerations*

The SLR (2019) simulations and report reviewed herein, has provided considerable detailed information throughout the text about the existing and proposed mining of longwall 19 at the Dendrobium mine. There is on occasion a subject out of sequence when baseflow depletion Section 2.1.3 is discussed before section 2.2 and 2.2.1 on Geology and stratigraphy.

While some descriptions are comprehensive and simulations are considered to be adequate ongoing monitoring of model performance is important.. The modelling described using the *'stacked drain'* approach is considered to be the most suitable for the *'full simulation'* and the additional options as outlined in the report (SLR 2019).

However mining longwall 19 inflow increase is stated to be 1.5 ML/day. KA nevertheless supports continued further research by SLR in assessing height of fracturing based on

monitored mine inflow, pressure head profiles and making comparisons between the various modelling methods which give the best available estimates. However, despite the approaches used, the current methodology does contain remaining uncertainty that can only be resolved by those monitoring results from both deeper standpipe and multi-piezometer installations and measured inflow and shallow standpipe bore holes in the geological profile. It is clear that over time, ongoing monitoring and a re-evaluation of the modelling results will be required for both drawdown and inflow reported based on field mine inflow measurements. It is suggested that a review should be conducted every 3 to 5 years of the project outcomes and a re-evaluation of the model predictions that may be required.

# References

**Caers, J. 2011.** *Modeling Uncertainty in the Earth Sciences. Wiley-Blackwell Pub.*

**Galvin (2017)** *Review of PSM report on height of fracturing Dendrobium Area 3B 24 February.*

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**MER (2017)** *Height of fracturing at Dendrobium Mine – Peer Review of PSM report. Letter to DEP Feb.*

**Murray Darling Basin Commission (MDBC) 2001.** *Groundwater Flow Modelling Guideline. Report prepared by Middlemis, H., Merrick, N., and Ross, J., Jan.*

**National Water Commission (NWC) 2012** *Australian Groundwater Modelling Guidelines. Report prepared by Barnett, B., et. al. Waterlines Report Series No 82, June.*

***Rau et al 2018*** *Quantifying Compressible Groundwater Storage by Combining Cross-Hole Seismic Surveys and Head Response to Atmospheric Tides.*AGU100 Journal of Geophysical Research: Earth Surface.

**SCT (2017)** *Dendrobium Area 5 Pre-feasibility Study: Numerical Modelling Geotechnical Assessment of Bulli Seam Longwall Caving (Draft). Report 324671, December 2017.*

**SCT (2018b)** *Overburden Hydraulic Conductivity Assessment: Dendrobium Area 6. Report STH324727, March 2018.*

**Tammetta, P. 2012.** *Estimation of the Height of Complete Groundwater Drainage Above Mined Longwall Panels. Groundwater Journal, National Groundwater Association.*

# Appendix
# Model Appraisal

| | ISSUES | Not applicable or Unknown | | | | | COMMENTS |
|---|---|---|---|---|---|---|---|
| **1.0** | **THE REPORT** | | | | | | |
| 1.1 | Is there a clear statement of project objectives in the modelling report? | | Missing | Deficient | Adequate | Very good | |
| 1.2 | Is the level of model complexity clear or acknowledged? | | Missing | No | Yes | | |
| 1.3 | Is a water or mass balance reported? | | Missing | Deficient | Adequate | Very good | |
| 1.4 | Has the modelling study satisfied project objectives? | | Missing | Deficient | Adequate | Very good | |
| 1.5 | Are the model results of any practical use? | | | No | Maybe | Yes | |
| **2.0** | **DATA ANALYSIS** | | | | | | |
| 2.1 | Has hydrogeology data been collected and analysed? | | Missing | Deficient | Adequate | Very good | |
| 2.2 | Are groundwater contours or flow directions presented? | | Missing | Deficient | Adequate | Very good | |
| 2.3 | Has all relevant potential recharge data been collected and analysed? | | Missing | Deficient | Adequate | Very good | |
| 2.4 | Has all relevant potential discharge data been collected and analysed? | | Missing | Deficient | Adequate | | |
| 2.5 | Have the recharge and discharge datasets been analysed for their groundwater response? | | Missing | Deficient | Adequate | Very good | |
| 2.6 | Are groundwater hydrographs used for calibration? | | | No | Maybe | Yes and inflow | |
| 2.7 | Have consistent data and standard elevation units been used? | | | No | Yes | | |
| **3.0** | **CONCEPTUALISATION** | | | | | | |
| 3.1 | Is the conceptual model consistent with project objectives and the required model complexity? | | Unknown | No | Maybe | Yes | |
| 3.2 | Is there a clear description of the conceptual model? | | Missing | Deficient | Adequate | Very good | |
| 3.3 | Is there a graphical representation of the modeller's conceptualisation? | | Missing | Deficient | Adequate | Very good | |
| 3.4 | Is the conceptual model unnecessarily simple or unnecessarily complex? | | | Yes | No | | |
| **4.0** | **MODEL DESIGN** | | | | | | |
| 4.1 | Is the spatial extent of the model appropriate? | | | No | Maybe | Yes | |
| 4.2 | Are the applied boundary conditions plausible and unrestrictive? | | Missing | Deficient | Adequate | Very good | |
| 4.3 | Is the software appropriate for the objectives of the study? | | | No | Maybe | Yes | |
| **5.0** | **CALIBRATION** | | | | | | |
| 5.1 | Is there sufficient evidence provided for model calibration? | | Missing | Deficient | Adequate | Very good | |
| 5.2 | Is the model sufficiently calibrated against spatial observations? | | Missing | Deficient | Adequate | Very good | |
| 5.3 | Is the model sufficiently calibrated against temporal observations? | | Missing | Deficient | Adequate | Very good | |
| 5.4 | Are calibrated parameter distributions and ranges plausible? | | Missing | No | Maybe | Yes | |
| 5.5 | Does the calibration statistic satisfy agreed performance criteria? | | Missing | Deficient | Adequate | Very good | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5.6 | Are there good reasons for not meeting agreed performance criteria? | | Missing | Deficient | Adequate | Very good | Performance criteria have been met |
| **6.0** | **VERIFICATION** | | | | | | |
| 6.1 | Is there sufficient evidence provided for model verification? | | Missing | Deficient | Adequate | Very good | To be determined by ongoing monitoring and review over time. |
| 6.2 | Does the reserved dataset include stresses consistent with the prediction scenarios? | | Unknown | No | Maybe | Yes | |
| 6.3 | Are there good reasons for an unsatisfactory verification? | | Missing | Deficient | Adequate | Very good | All data used for calibration. Verification dependent on monitoring of previous LW results |
| **7.0** | **PREDICTION** | | | | | | |
| 7.1 | Have multiple scenarios been run for climate variability? | | Missing | Deficient | Adequate | Very good | Climate change variability low and high rainfall |
| 7.2 | Have multiple scenarios been run for operational management alternatives? | | No | Deficient | Adequate | Very good | Multiple scenarios have been run to better define outcomes |
| 7.3 | Is the time period for prediction comparable with the duration of the calibration period? | | Missing | Greater than | Similar to | Less than | |
| 7.4 | Are the model predictions plausible? | | | No | Maybe | Yes | |
| **8.0** | **SENSITIVITY ANALYSIS** | | | | | | |
| 8.1 | Is the sensitivity analysis sufficiently intensive for key parameters/ | | Missing | No | | | Both uncertainty and sensitivity are bound up in the previous response to simulation of the Dendrobium mining. |
| 8.2 | Are sensitivity results used to qualify the reliability of model calibration? | | Missing | No | | | |
| 8.3 | Are sensitivity results used to qualify the accuracy of model prediction? | | Missing | No | | | |
| **9.0** | **UNCERTAINTY ANALYSIS** | | | | | | |
| 9.1 | If required by the project brief, is uncertainty quantified in any way? | | Missing | No | | | |
| 9.2 | **Is the model 'fit-for-purpose'?** | | | No | | | |