Attachment A – Aquatic Flora and Fauna Review

Aquatic Flora and Fauna Assessment

Longwall 18 Subsidence Management Plan

59919104



Prepared for

South32 – Illawarra Metallurgical Coal

12 August 2020

Cardno

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Executive Summary

Introduction

South32 – Illawarra Metallurgical Coal (South32) plans to extract coal from Longwall 18 in Dendrobium Area 3B (DA3B) of the Dendrobium Mine Area (the Project). Longwall 18 is located between Wongawilli Creek and Lake Avon and to the south of DA3B Longwall 17. This Aquatic Flora and Fauna Assessment (AFFA) has been prepared to support the Subsidence Management Plan (SMP) for Longwall 18. The AFFA focuses on the sections of Wongawilli Creek, Native Dog Creek, Lake Avon and their associated drainage lines 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 and Lake Cordeaux are located some distance away from the longwall 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 Native Dog Creek catchments in the Study Area (area within 600 metres (m) of Longwall 18);
- Field survey in Native Dog Creek, the largest drainage line within 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

Native Dog Creek is a third order watercourse partly located in the Study Area. Though it provides Type 1 – Highly Sensitive Key Fish Habitat (KFH) (Type 1 - KFH) and apparent permanent aquatic habitat, it has previously, and continues to, experience impacts to water quality associated with historic mining undertaken further upstream and outside of the Study Area and DA3B. Lake Avon also provides substantial aquatic habitat and Type 1 - KFH within the Study Area. Aquatic habitat in first and second order drainage lines within the Study Area are largely undisturbed though some have been impacted by previous mining in DA3B. Aquatic habitat in drainage lines include small, disconnected and ephemeral pools with limited habitat potential for aquatic flora and fauna. These drainage lines are not KFH. Wongawilli Creek is not located in the Study Area but was considered in the assessment because it provides substantial aquatic habitat.

Although some of the biotic indices derived from AUSRIVAS aquatic macroinvertebrate sampling in Native Dog Creek and across DA3B 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. Macquarie perch are likely to occur in Lake Avon but are considered unable to access Native Dog Creek or Wongawilli Creek in the Study Area due to the presence of natural barriers to fish passage downstream.

Impact Assessment

The mine has been designed to minimise potential impacts to natural features, including watercourses. Longwall 18 is more than 1 km from Wongawilli Creek. Overall, the maximum predicted subsidence effects due to extraction of Longwall 18 are slightly less than the maximum predicted values elsewhere in DA3B. Given that Lake Avon and Wongawilli Creek are not expected to experience adverse subsidence related impacts due to extraction of Longwall 18, impacts to aquatic ecology in this Lake and Creek are not expected. Approximately 0.5 km of Native Dog Creek is within the Study Area, with approximately 0.3 km within 400 m of Longwall 18. Although fracturing may occur within 400 m of Longwall 18, any fracturing is not expected to result in a reduction in water levels in Native Dog Creek and therefore impacts to aquatic habitat and biota are also not expected in the main channel of Native Dog Creek.

Based on predictions of subsidence, it is expected that a reduction in the amount and connectivity of ephemeral aquatic habitat in drainage lines of Wongawilli Creek, Native Dog and Lake Avon would occur due to fracturing of bedrock. Approximately 0.6 km of first and second order drainage lines occur directly above Longwall 18 and a further approximate 2.8 km within 400 m of the longwall. This is expected to impact aquatic biota via reduction in the amount of available habitat and habitat fragmentation. Although impacts to aquatic habitat and biota would be significant at the scale of individual pools and drainage lines, in isolation, impacts associated with extraction of Longwall 18 would be minimal in the context of the upper Avon River and Cordeaux River catchments. 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. Given

that there would be no reductions in the availability of aquatic habitat in Native Dog Creek, Lake Avon and Wongawilli Creek, impacts to the threatened Macquarie perch are not expected. In any case, this species is unlikely to occur in watercourses in and adjacent to the Study Area due to the presence of natural barriers to fish movement further downstream.

The cumulative effect on flows in Wongawilli Creek due to extraction of all DA3A, DA3B and DA3C longwalls should be considered.

Recommendations and Management

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

- Impact minimisation, including the significant distance 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. Mining of DA3B Longwalls 9 to 15 was undertaken between February 2013 to January 2020. Extraction of Longwall 16 commenced February 2020 and is currently underway. Extraction of remaining DA3B Longwalls 17 and 18 is to follow.

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. The SMP for DA3B was submitted in 2012 (BHPBIC 2012). Approval for Longwalls 9 to 13 was granted in 2013 and approval of Longwalls 14 and 15 was granted in 2016. Approval for Longwalls 14 and 15 also required that further individual assessment be undertaken for subsequent DA3B longwalls. The requisite SMPs for Longwalls 16 (South32 2017) and 17 (South32 2019) were approved in 2018 and 2019, respectively.

South32 are proposing to extract coal from Longwall 18 in DA3B (the Project) and invited Cardno (formerly trading as Cardno Ecology Lab and The Ecology Lab Pty Ltd) to prepare a proposal to undertake the Aquatic Ecology Assessment (AEAs) to support the SMP for Longwall 18.

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.

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 third or greater Strahler stream order (order) Wongawilli Creek and Native Dog Creek catchments adjacent to the proposed location of Longwall 18. 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 Native Dog Creek catchment within the Study Area for Longwall 18 (the area within 600 m of the longwall). The aim was to provide information on local aquatic habitat and biota in this creek that may be affected by any subsidence associated with extraction of these longwalls, as it had not been visited during previous investigations.
- Assessment of the potential impacts of the Project on aquatic ecology, including threatened species, and any cumulative impacts, in Wongawilli Creek and Native Dog 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 Development 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) has prepared guidelines for SMP (now known as Extraction Plan (EP)) applications (DRE 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 assessments 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 (Fairfull and Witheridge 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 Coalfield, 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 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 Study Area

The proposed Longwall 18 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 18. The main watercourses within the vicinity of Longwall 18 are Wongawilli Creek and Native Dog Creek, which flow in a northerly direction east and west of the longwall, respectively. Wongawilli Creek is a third 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 Native Dog Creek is third order. There are also several other first and second order drainage lines and upland swamps that flow into these watercourses. Although the main channel of Wongawilli Creek is located outside of the Study Area and at least 1 km away from Longwall 18, it has been included in this this review as a precautionary measure. However, physical impacts are not expected to occur in Wongawilli Creek due to extraction of Longwall 18. Some drainage lines within the Study Area also flow into Wongawilli Creek.

Lake Cordeaux and Cordeaux River are located at least 6 km away from Longwall 18 at the closest point and Avon River is located 2.5 km west of Longwall 18. Avon River and Cordeaux River are not predicted to experience measurable ground movements due to the extraction of Longwall 18 and it is unlikely they would experience adverse impacts due to extraction of Longwall 18 (MSEC 2020). Thus, these and Lake Cordeaux have not been considered further. The full supply level (FSL) of Lake Avon is located 0.3 km west of the proposed longwall and has been considered along with watercourses in the catchments of Wongawilli Creek, Native Dog Creek and Lake Avon within the Study Area. Swamps and associated flora and fauna in the Study Area were assessed by other specialists.

Figure 3-1 also includes the 400 m boundary and the area within the 35° angle of draw. The 35° angle of draw indicates where conventional longwall mine subsidence impacts would be expected to occur. In the Southern Coalfield, subsidence induced fracturing has been observed up to 400 m from longwall extraction. Therefore the 400 m boundary has been used as a reference to make predictions about the extent of impacts to watercourses in MSEC (2020) and in the AFFA.

3.2 Overview of Previous Studies and Field Surveys

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 studies assessed impacts of predicted mine subsidence on aquatic ecology, including threatened species, in DA3, and undertook monitoring before, during and after mining. These included studies in:

- DA1: AEA studies (The Ecology Lab 2001a, b and 2003) and monitoring study (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 2020a). Assessments were also undertaken for Longwalls 20 and 21 in DA3C (Cardno 2019) and Longwall 19 (Cardno 2020b).

In these studies, the primary watercourses considered were in the Wongawilli Creek and Native Dog Creek catchments. Sandy Creek and Donalds Castle Creek are located over 2 km east and north, respectively, of the Study Area and would not be affected by extraction of Longwall 18, thus they are not considered in this assessment. Information on aquatic habitat, water quality, aquatic macroinvertebrates and fish in the Study Area available from these previous studies is reviewed in **Sections 0** to **3.9**. This review of existing information included the findings of surveys undertaken at existing DA3B Sites X5 and X6 on Wongawilli Creek. These are the closest sites to Longwall 18 and would be those most likely to experience impacts associated with extraction, albeit the likelihood of any impacts occurring in Wongawilli Creek are very low due to its distance from Longwall 18. Information from the other nearby sites on Wongawilli Creek upstream and downstream has also been reviewed for comparative purposes. These are Sites 1 to 4 and X4 located downstream of Sites X5 and X6, and Sites X7 and X8 upstream of Sites X5 and X6. These sites were visited

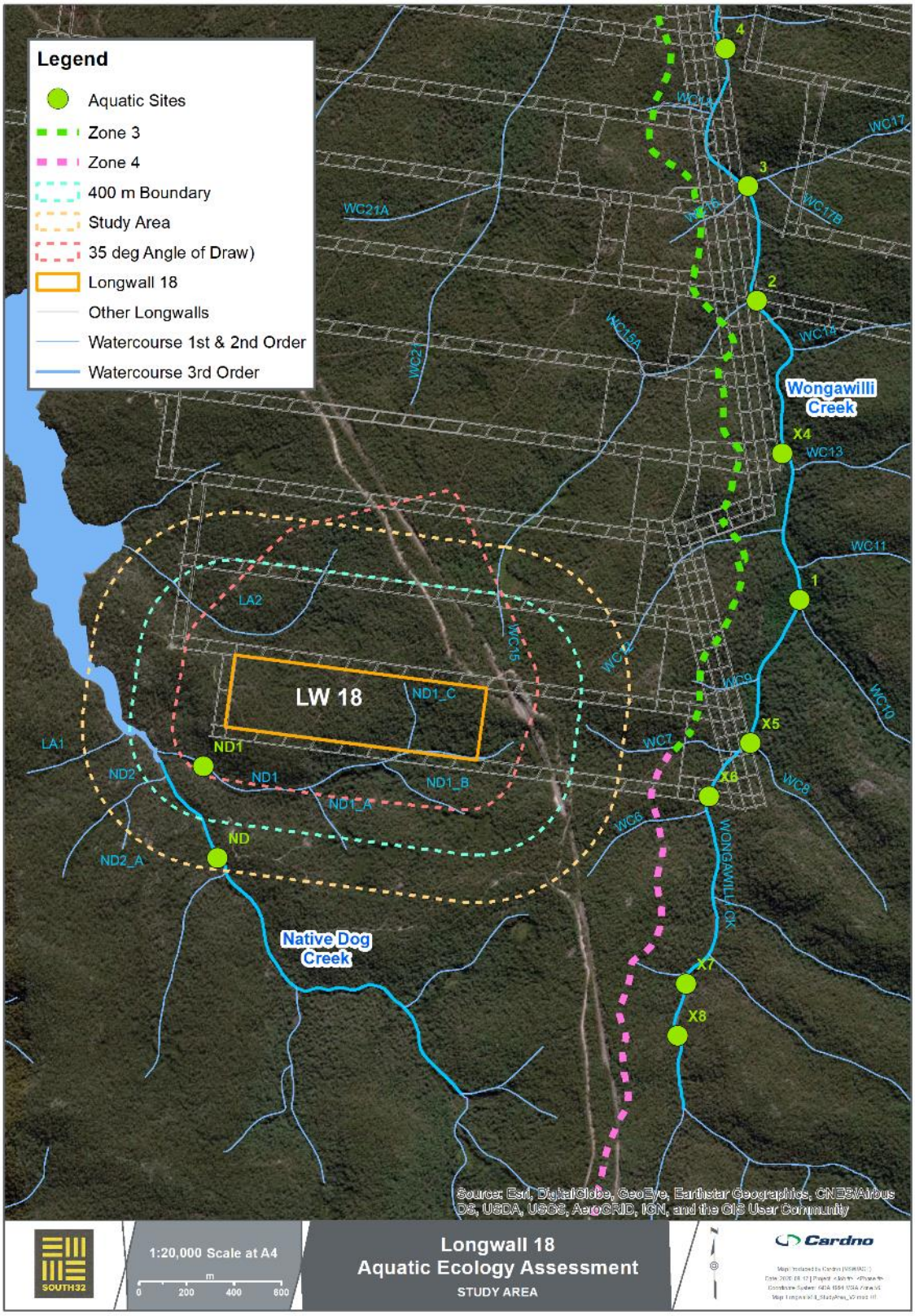


Figure 3-1 Aerial image overlaid with longwall layouts, watercourses and aquatic ecology sites within and adjacent to the Longwall 18 Study Area (600 m boundary). The 400 m boundary is presented to provide context for the subsidence predictions (Fracturing has been observed up to approximately 400 m outside of previously extracted longwalls in the Southern Coalfield (MSEC 2020)) (**Section 4.1**).

most recently on four occasions in 2019 as part of the ongoing DA3B monitoring program. Details of the methods used in these studies and the GPS coordinates of monitoring sites are provided in **Appendix A**.

Additional surveys were undertaken for the current assessment at two new sites in the Native Dog Creek catchment; ND on Native Dog Creek and ND1 on ND1 (a drainage line of Native Dog Creek). This catchment does not form part of the current DA3B monitoring program, though it was considered during the DA3 (The Ecology Lab 2007) and DA3B (Cardno Ecology Lab 2012a) assessments and ND1 was inspected as part of the July 2007 field investigations. These additional sites were included to provide further and more recent information from this catchment that may be affected by extraction of Longwall 18. Surveys of aquatic habitat, water quality, aquatic macroinvertebrates and fish were undertaken here in May 2020 (ND1) and June 2020 (ND following the methods described in **Appendix A** (with the exception of two rather than one AUSRIVAS edge samples collected).

3.3 Aquatic Habitat and Vegetation

3.3.1 Wongawilli Creek

Detailed investigations of Wongawilli Creek were undertaken as part of the initial investigations for DA3 in July 2007 (The Ecology Lab 2007). Four zones with similar habitat characteristics were identified within Wongawilli Creek. Zone 3 (**Plate 1i-ii**) includes Sites 1 to 4, X4 and X5 and is located from the confluence with WC15 upstream to the large waterfall on Wongawilli Creek at Rockbar 36. Zone 4 (**Plate 1iii-iv**) includes Sites X6 to X8 and is located from the large waterfall to the upper reaches of Wongawilli Creek and tributaries WC1 to WC6.

The aquatic habitat within Zones 3 and 4 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 almost fully shades the channel in Zone 3 and partially shades the channel in Zone 4. 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 these zones, including coral ferns (*Gleichenia* sp.) present along the banks of Zone 4.
- The channel morphology of Wongawilli Creek 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. In Zone 4 the main channel was characterised by relatively small, shallow pools separated by retaining sandstone rockbars containing small steps. The substratum was composed of sandstone bedrock in areas where water flowed over the retaining rock bars, but in the pools is dominated by sand, but with significant areas of bedrock and boulder. There were numerous in-stream habitat features including large wood debris and tree roots.
- The distribution of aquatic plants was patchy, with green and brown algae present within Zones 3. No aquatic plants were observed in Zone 4. 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 in Wongawilli Creek. 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 in Zone 3. Mosses were present on bedrock, boulders and large woody debris and appeared to be more prevalent in spring.

Based on description of the four habitat types adapted from Fairfull and Witheridge 2003 (**Appendix A**) Wongawilli Creek through Zone 3 and in Zone 4 upstream to WC12 (i.e. within the Study Area) provides significant aquatic habitat (i.e. watercourses that contain numerous large, permanent pools and generally have flow connectivity except during prolonged drought). Wongawilli Creek in Zone 4 upstream of WC12 and the Study Area provides moderate aquatic habitat (i.e. watercourses that contain some larger permanent and semi-permanent refuge pools, which would persist through prolonged drought, although become greatly reduced in extent).



Plate 1. Wongawilli Creek at i) Site 2 and ii) Site 3 in Zone 3 and at iii) Site X7 and iv) Site X8 in Zone 4.

3.3.2 Native Dog Creek

Native Dog Creek is located to the southwest of Longwall 18. It contains large pools that would likely persist for some time during drought periods and provides moderate aquatic habitat (**Plate 2i-iii**). Aquatic habitat in Native Dog Creek has been impacted by previous extraction of Longwalls 1 to 10 of Elouera Colliery. The extraction of these longwalls led to fracturing of the bedrock, diversion of surface flows and drainage of pools. The iron precipitate currently present in the creek as a result of these impacts (**Section 3.10** may affect the quality and availability of aquatic habitat here by filling interstices between sand and gravel substratum, where aquatic macroinvertebrates and other fauna would otherwise reside. There is a natural barrier to fish passage in Native Dog Creek just upstream of the confluence with Lake Avon (**Plate 2iii**). This barrier is comparable to the barrier on Wongawilli Creek which appears sufficient to prevent movement of Macquarie perch upstream of the Fire Road 6 Crossing to sections of creek upstream of here (**Section 3.7**).

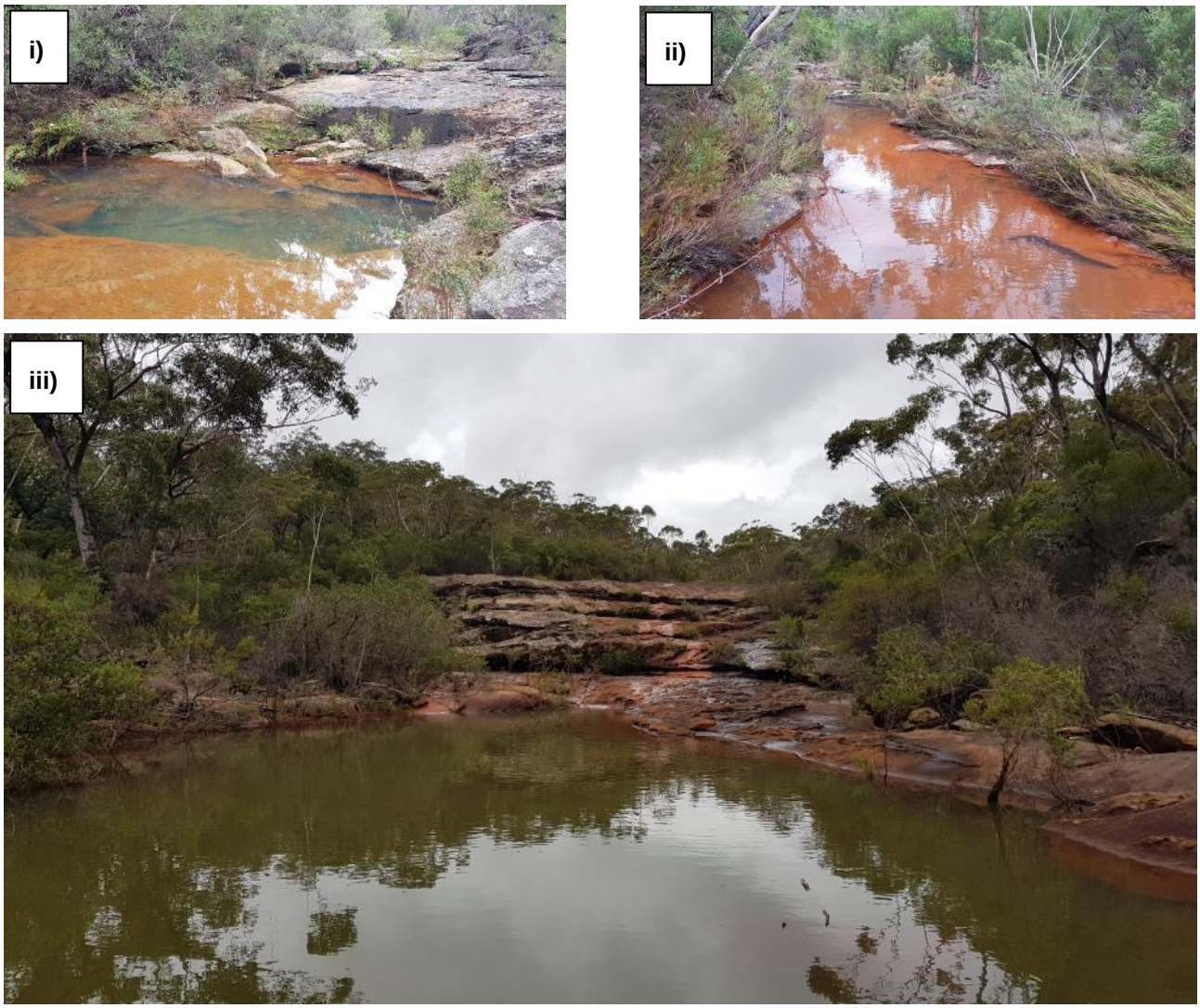


Plate 2. i to iii) Native Dog Creek, with iii) the natural barrier to fish passage just upstream NDC_Pool 6 and the Full Supply Level of Lake Avon

3.3.3 Drainage Lines

IMCEFT has undertaken detailed mapping of drainage lines within the Study Area, which include a number of pools, flow controlling rockbars and other channel features (**Figure 3-2**). Three drainage lines of Wongawilli Creek are located in the Study Area (WC7, WC12 and WC15). The upstream extent of WC15 is located approximately 200 m north of Longwall 18 and provides moderate 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. The series of waterfalls upstream of its confluence with Wongawilli Creek would be a barrier to the passage of Macquarie perch (*Macquaria australasica*) upstream within this drainage line to the Study Area. The lower reaches of WC12 outside the Study Area provides minimal aquatic habitat (i.e. watercourses that contain some small semi-permanent refuge pools which are unlikely to persist through prolonged drought), with its upstream reach within the Study Area and WC7 providing unlikely habitat (i.e. ephemeral drainage lines that only contain flow during and immediately after significant rainfall).

Seven drainage lines of Native Dog Creek are located within the Study Area: ND1 (**Plate 3i-ii**), ND1A (**Plate 3iii**), ND1B (**Plate 3iv**), ND1C (**Plate 3v**), ND2 (**Plate 3vi**) and ND2A. There was very limited aquatic habitat within ND1, apart from some small semi-permanent pools that would support some aquatic invertebrate species including freshwater crayfish and habitat for frogs. As these pools are not expected to persist through prolonged dry periods, Tributary ND1 provides minimal aquatic habitat. The other drainage lines of Native Dog Creek in the Study Area also provide minimal aquatic habitat, with the possible exception of ND2A, which would provide unlikely habitat due to its small size and catchment.

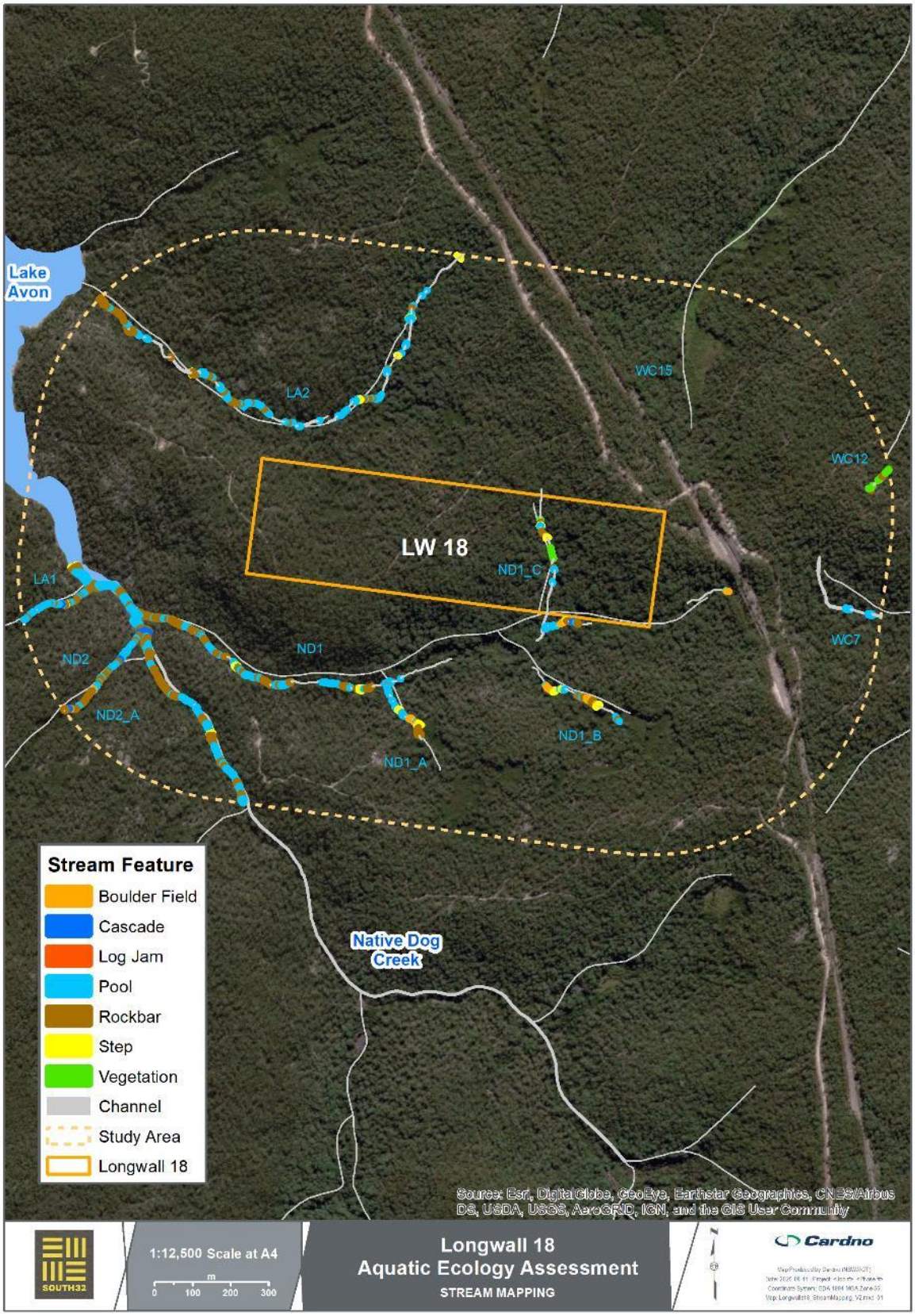


Figure 3-2 Location of pools and flow controlling structures (shallow riffle sections, channel restrictions, debris dams and the major rockbar) mapped within Wongawilli Creek within the Study Area



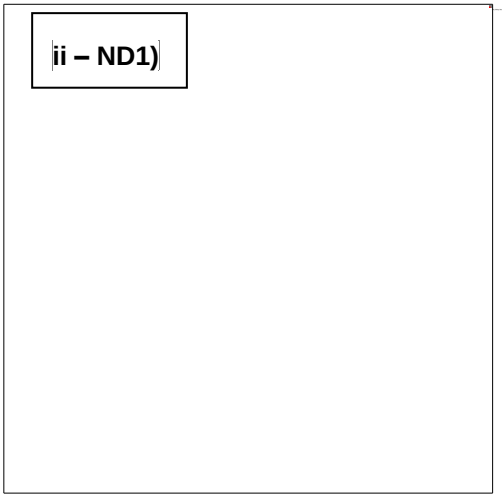














Plate 3. Drainage lines i-ii) ND1, iii) ND1A, iv) ND1B, v) ND1C, vi) ND2, vii) LA1 and viii) LA2

Two drainage lines of Lake Avon are located within the Study Area: LA1 (**Plate 3vii**) and LA2 (**Plate 3viii**). LA1 and LA2 contain some semi-permanent pools that provide minimal aquatic habitat.

3.3.4 RCE Inventory

Results of the RCE assessment are provided in **Appendix B**. Total scores ranged from 46 to 51 on Wongawilli Creek and was 48 at ND and ND1. 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.

3.4 Key Fish Habitat

The broad scale KFH map for Wollongong available on the NSW DPI website indicates that third order sections of Wongawilli Creek and Native Dog Creek are KFH (NSW DPI 2020). The first and second order drainage lines that traverse the Study Area are not identified as KFH by this map. Wongawilli Creek provides Type 1 – Highly sensitive KFH, and contains areas of aquatic plants, large rocks and large wood debris. First and second order streams, including the first and second order drainage lines of Wongawilli Creek (WC7, WC12 and WC15) within the Study Area, are not KFH (NSW DPI 2013a) (**Figure 3-3**). Nevertheless, lower sections of these drainage lines near the main creek channels 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.

Native Dog Creek also contains large rocks and large wood debris and its third order reach is classified Type 1 – Highly Sensitive KFH. Though it is acknowledged that this creek provides less substantial aquatic habitat than Wongawilli Creek, existing impacts associated with previous mining may limit the quality of the habitat it currently provides for fish and other aquatic biota. First and second order reaches of Native Dog Creek, its drainage lines and drainage lines of Lake Avon within the Study Area, do not provide KFH.

Lake Avon may also provide habitat for the listed threatened Macquarie perch (**Section 3.8**). As such, it provides Type 1 – Highly Sensitive KFH.

3.5 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.
- 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.
- DO levels at all the sites on the creek fell below the lower DTV (90 % saturation) during some surveys. This more commonly occurred at the sites downstream (1, 2, 3, 4, 5 and X4) than at sites within (X6 and X5), the Study Area. 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.

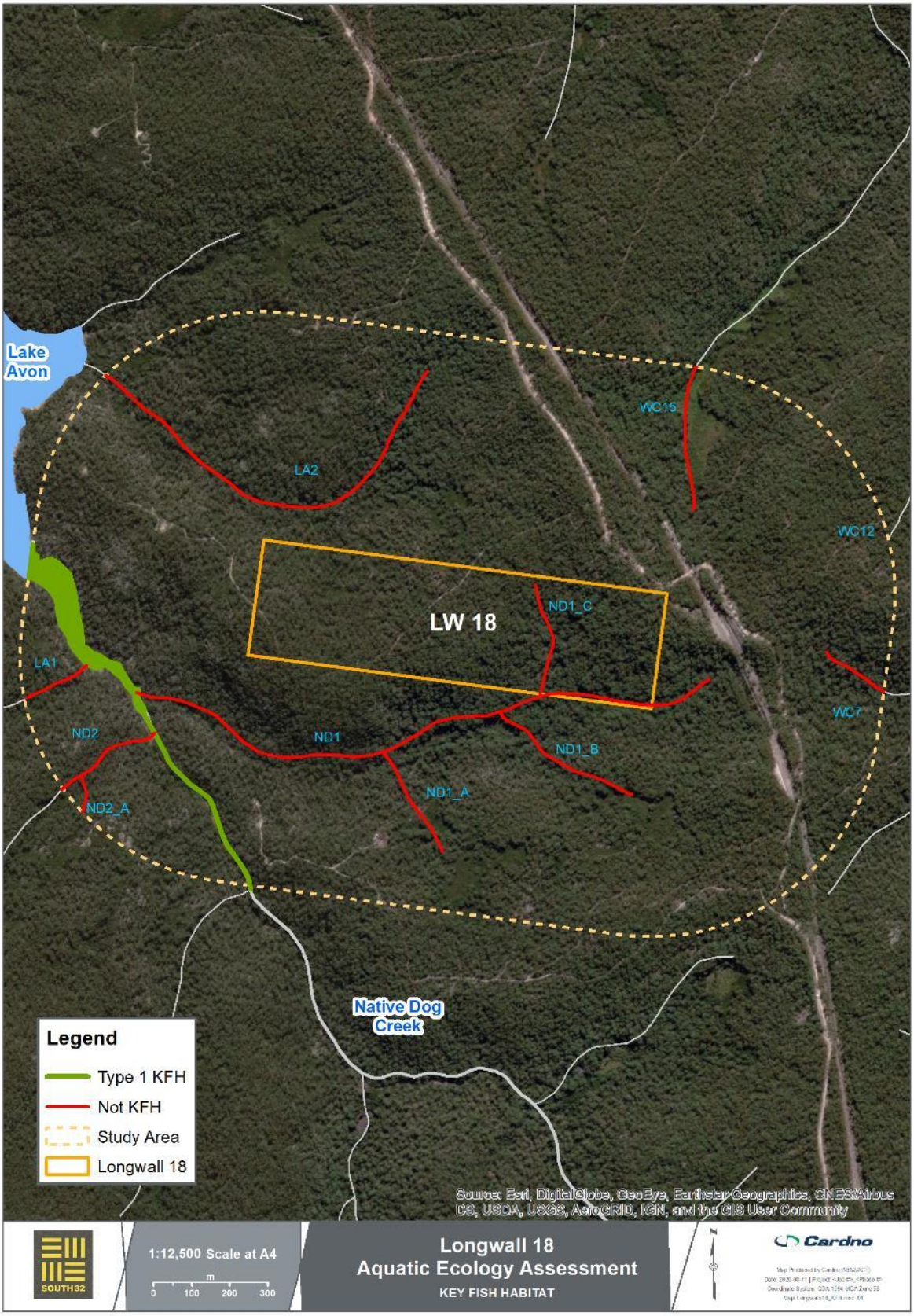


Figure 3-3 Key fish habitat mapped within the Study Area

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. They 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.

BHPBIC conducted water quality monitoring at a number of sites in Native Dog Creek, as part of the environmental monitoring for Longwalls 1 to 10 of Elouera Colliery. The weathering of the underlying marcasite mineral in un-weathered bedrock exposed by fracturing resulted in the following impacts on water quality (Ecoengineers 2006):

- Increased acidity of the water;
- Oxygen depletion due to oxidation of the ferrous and manganese ions released;
- Release of metals from the marcasite, particularly manganese, nickel, zinc and aluminium and possible ecotoxic effects;
- Smothering of pool boulder and bed surfaces downstream with precipitated iron and manganese hydrous oxides.

Iron precipitate continues to be present in Native Dog Creek.

The findings of the water quality sampling by Cardno at ND and ND1 in May and June 2020 are presented in **Appendix C**. Measures in ND1 were comparable with those from other watercourses in the Dendrobium Mine Area. EC was within DTVs while pH was below the lower DTV. DO and turbidity were also below the lower DTV, though only marginally, and was not cause for concern. The limited data collected suggested pH, EC, DO and turbidity at ND were greater than at ND1. This was likely related to changes in water quality related to previous mining, and iron staining was evident through the site visited in June 2020. All measures of water quality at ND were within DTVs, albeit likely outside what would be expected in this creek naturally (based on other comparable watercourses in this catchment and that of nearby Wongawilli Creek).

Water quality is regularly (at least monthly) monitored at sites on watercourses LA1, LA2, NDC, ND1 and Wongawilli Creek. A review of 11 years of baseline data undertaken for the surface water assessment (Hgeo 2020) for the Longwall 18 SMP indicates these (and other watercourses draining the Dendrobium Mine Area) are relatively fresh and within ANZECC (2000) water quality guidelines (EC generally <150 µS/cm) though contain sodium and chloride ions, reflecting mostly direct rainfall runoff. pH is generally mildly acidic (pH 4.9 to 6.5) and below guidelines, 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 available). An exception is dissolved aluminium and zinc in some locations. Elevated concentrations of zinc in in some sites, including the upstream section of Native Dog Creek, may be related to previous mining at Elouera (1994 to 2007) which passed beneath some watercourses outside of the current Study Area. 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 % saturation and 95% saturation and within or slightly below guidelines.

3.6 Macroinvertebrates

The several AUSRIVAS surveys undertaken in Wongawilli 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 ranged from more diverse than AUSRIVAS reference condition (AUSRIVAS Band X) to severely impaired (Band C) (**Appendix D**). AUSRIVAS Band scores are derived from the OE50 Taxa Scores, which is a biotic index of habitat and water quality (**Appendix A**). 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 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 in Wongawilli Creek within and outside of the Study Area (**Table 3-1**). The number of taxa, OE50 Taxa Score and SIGNAL2 Index tended to be greater at sites on Wongawilli Creek outside of the Study Area, but only during autumn. However, 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
Within Study Area						
Wongawilli Creek: Sites X5 and X6						
Mean	17.2	0.81	4.8	13.0	0.65	4.4
SE	0.9	0.05	0.1	0.6	0.03	0.2
Native Dog Creek: ND						
Mean				9.5	0.54	4.5
SE				1.5	0.005	0.5
Native Dog Creek: ND1						
Mean				8.0	0.54	4.2
SE				1.0	0.08	0.3
Outside Study Area:						
Wongawilli Creek: Sites 1, 2,3, 4, X7, X8						
Mean	17.4	0.74	4.7	15.8	0.83	4.6
SE	0.4	0.02	0.0	0.5	0.02	0.1

The macroinvertebrate taxa identified from each AUSRIVAS sample collected from ND and ND1 are provided in **Appendix E**. Indices appeared comparable between the two watercourses (**Table 3-1**) with AUSRIVAS Bands ranging from C to B (sever to significantly impaired relative to reference condition). There was more variability in the OE50 Taxa Score at ND1 than at ND, with scores indicative of band C and B at ND1, and band B at ND. SIGNAL 2 scores on ND were indicative of moderate to mild water pollution and on ND1 were indicative of severe to moderate 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. There was also no obvious evidence in these limited data of impacts to macroinvertebrates in Native Dog Creek associated with previous mining. Although relatively low, the values of indices were not outside the range expected of comparable undisturbed watercourses.

Neither Adams emerald dragonfly or Sydney hawk dragonfly have been identified in any of the AUSRIVAS samples collected by Cardno in the Dendrobium Mine Area.

3.7 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 for 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.

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 and 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). There are no known records of Macquarie perch from Native Dog Creek, and based on the size of pools and the present of frequent rockbars that would hinder passage of this species (at least during normal flow), this creek likely provides marginal habitat for this species. The natural barrier to fish passage in Native Dog Creek just upstream of its confluence with Lake Avon is comparable to that on Wongawilli Creek just upstream of Fire Road 6, and it is probable that this barrier would prevent any Macquarie perch in Lake Avon from accessing any more than the first few 10s of metres of the creek.

Most recently in 2019, 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. Numbers were comparable with those caught in this watercourse previously (Cardno 2020a). No fish were caught whilst backpack electrofishing or in bait traps deployed in ND and ND1 in June and May of 2020, respectively. Crayfish burrows were observed in the banks and tadpoles in the disconnected pools.

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.

3.8 Listed Threatened Species, Populations and Ecological Communities

3.8.1 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 Native Dog 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 2020) 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 18;
- 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 2020) was also searched for records of species of fish (including invertebrates and vertebrates) listed under the FM Act occurring in the catchments of Lake Avon, Wongawilli Creek and Native Dog 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. Amphibians, aquatic mammals, reptiles and Giant dragonfly (*Petalura gigantea*) are being considered by other specialists and were excluded from the search.

3.8.2 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 0**) it has been recorded also in Lake Avon and Lake Cordeaux (ALA 2020) and suitable habitat exists in the upper reaches of Cordeaux and Avon Rivers and in Lake Avon (NSW DPI 2016a). It is noted records from Lake Avon are from the 1970s, with no known more recent records from upstream of Avon Dam wall. 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 National Recovery Plan for Macquarie perch (DEE 2018). 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.

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.

3.8.3 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.

3.8.4 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 2020). 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.

3.8.5 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 2020). 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 abundant riparian vegetation (NSW DPI 2013b). 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 NSW DPI 2013b) 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.

3.8.6 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 (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 Wongawilli Creek upstream but it has not been caught during numerous surveys in Wongawilli Creek upstream of Fire Road 6, possibly due to the presence of natural barriers to fish movement further downstream. Based on records from the 1970s and NSW DPI distribution maps, it is possible this species occurs in Lake Avon, though is unlikely to be present in Native Dog Creek due to the presence of a natural barrier to movement where it flows into Lake Avon. Very unlikely to occur in drainage lines in the Study Area due to the limited aquatic habitat provided by these watercourses.
Adams emerald dragonfly (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 (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 (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.

3.9 Critical Habitat

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

3.10 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 and reductions in pool water levels in SC10C (a tributary of Sandy Creek) and WC17 (a tributary of Wongawilli Creek) in DA3A. 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. 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 Ecology Lab (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 0**).

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 2020).

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 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. 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 (HGeo 2018). 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 are 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 DA3C 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.

3.11 Summary

The findings of the current and previous investigations indicated that aquatic habitat in drainage lines within the Study Area is relatively limited. This habitat comprises relatively small (in terms of length, catchment size and area of aquatic habitat) first and second order drainage lines of Wongawilli Creek, Native Dog Creek and Avon River. These drainage lines support semi-permanent pools that would retain water for some time after rainfall and provide habitat for aquatic biota and have been largely unaffected by mining. 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.

Although the main channel of Native Dog Creek has, and continues to, experience impacts (changes in water quality and potential alteration of habitat due to infilling of interstices with iron floc) associated with previous mining, it still provides relatively substantial aquatic habitat. There also does not appear to be any existing fracturing that is affecting aquatic habitat availability and flow in the section within the Study Area and, albeit based on a limited dataset, the AUSRIVAS macroinvertebrate assemblage is comparable to that which could be expected of an un-modified watercourse. Macquarie perch may occur in Lake Avon, but not in Native Dog Creek or in Wongawilli Creek within the Study Area.

Though some of the biotic indices derived from AUSRIVAS aquatic macroinvertebrate sampling in the Native Dog Creek catchment in nearby Wongawilli 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 provides the most substantial habitat for native fish, aquatic plants and macroinvertebrates in DA3. 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 very unlikely to occur in watercourses in the Study Area. 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.

4 Assessment of Impacts

4.1 Predicted Ground Movements

The layout design for Longwall 18 includes measures to minimise potential impacts on aquatic habitat and biota. This includes a set back from Lake Avon of at least 300 m and a reduced extraction height of 3.9 m. Overall, the maximum predicted subsidence effects due extraction of Longwall 18 are slightly less than the maximum predicted values elsewhere in DA3B (MSEC 2020).

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 may occur in watercourses and in Lake Avon 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 ground movements predicted to occur at the watercourses and Lake Avon by MSEC (2020) are summarised as follows:

- Lake Avon is predicted to experience less than 20 mm vertical subsidence and although it could experience low level vertical subsidence, it is not expected to experience measurable tilts, curvature or conventional strains. The maximum predicted valley related effects at Lake Avon due to mining of all DA3B longwalls are 50 mm upsidence and 100 mm closure. The maximum effects occur where the lake is closest to the longwalls. Whilst the predicted valley related effects are small, it is possible that minor cracking could occur in the bedrock. It is not expected that this minor cracking in the lake bed would result in adverse impacts on the reservoir.
- The maximum predicted incremental vertical subsidence, upsidence and closure for Wongawilli Creek are all less than 20 mm. While the creek could experience very small subsidence effects, it is not expected to experience measurable tilts, curvatures or strains and it is unlikely adverse impacts would occur along Wongawilli Creek.
- Native Dog Creek is predicted to experience less than 20 mm incremental vertical subsidence and 30 mm incremental closure, it is not expected to experience measurable conventional tilts, curvatures or strains. The compressive strain due to valley closure could result in fracturing in the creek bed, where it is located within approximately 400 m of Longwall 18. 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) are, however, not expected.
- Drainage lines are located across the Study Area, with two (ND1 and ND1C) located at least partly above Longwall 18. Drainage lines within the Study Area could experience subsidence of between 20 mm and 2,750 mm. The maximum predicted incremental (i.e. due solely to Longwall 18) change in grade is 4.0% or 1 in 25. The natural gradients of the drainage lines vary from 5% 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. Fracturing could also occur outside the extents of the longwall, with minor and isolated fracturing expected 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 longwall. It is possible that minor and localised increased ponding could develop in LA2, NDC1 and WC12, though it would mostly be related to

extraction of the previous Longwalls 16 and / or 17. 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. Changes in surface water flows due to mining-induced tilt are expected to be small in comparison with those which occur during natural flooding conditions.

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 18 was based on the maximum predicted movements for the sections of creeks and drainage lines that flow through and adjacent to the Study Area and their predicted impacts on the physical (MSEC 2020) and surface water (HGeo 2020) characteristics of the waterways.

Given that Lake Avon and Wongawilli Creek are not expected to experience adverse impacts due to extraction of Longwall 18 (**Section 4.1**), impacts to aquatic ecology are not expected in these watercourses. **Sections 4.2.1** to **4.2.4** therefore concentrate on impacts to Native Dog Creek and drainage lines within the Study Area (WC7, WC12, WC15, ND1, ND1A, ND1B, ND1C, ND2, ND2A, LA1 and LA2).

4.2.1 Aquatic Habitat

4.2.1.1 Ponding, Flooding and Scouring of Banks

The predicted post-mining grades of drainage lines 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. Changes in surface water flows due to mining-induced tilt are expected to be small in comparison with those which occur during natural flooding conditions.

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. No impacts are expected in Native Dog Creek as there would be no changes in tilt.

4.2.1.2 Fracturing and Flow Diversions

Approximately 0.5 km of Native Dog Creek is within the Study Area, with approximately 0.3 km within 400 m of Longwall 18 (approximately 15 % of the 2 km long third order section of the creek). Although fracturing may occur within 400 m of Longwall 18, any fracturing is not expected to result in a reduction in water levels in the creek (MSEC 2020), and therefore impacts to aquatic habitat (including KFH) are also not expected.

Drainage lines directly above Longwall 18 would be most at risk of flow diversions and reductions in aquatic habitat area and quality due to a greater potential for subsidence and fracturing to occur here. Approximately 0.6 km of first and second order drainage lines occur directly above Longwall 18 and a further approximate 2.8 km within 400 m of the longwall. These drainage lines support limited aquatic ecology (i.e. consist of few disconnected pools, if any) and experience flow during and soon after rainfall only. Fracturing induced flow diversions would reduce the volume and duration of ephemeral flows, however, there would also not be any fundamental change in habitat type (i.e. it would still be ephemeral watercourse). 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.

Due to the limited aquatic habitat supported by these drainage lines 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 the majority of WC15, which is located mostly downstream of the Study Area, has experienced impacts (fracturing, flow diversions and reductions in availability of aquatic habitat) due to extraction of previous DA3A and DA3B longwalls.

KFH is not present in the first and second order drainage lines and its availability and quality would not be affected by the impacts that occur in these watercourses.

4.2.1.3 Water Quality and Availability

Impacts to water quality due to mining are expected to be minor or undetectable in stream reaches within subsidence affected areas (LA2, ND1 and Native Dog Creek) (HGeo 2020). Impacts may be observed in the first order tributary ND1C which crosses Longwall 18; however, those impacts are not expected to influence significantly water quality in ND1. Effects, if they occur, 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. Water quality impacts are not expected to be negligible and undetectable in Lake Avon and none are expected to occur in Wongawilli Creek.

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 regional groundwater modelling, it is predicted that:

- The number of days with no-flows at ND1 would increase from approximately 8 % to 10% of the time to approximately 30 % to 52 % of the time. Based on more recent analysis, it is considered more likely that the increase in cease-to-flow would be 20% rather than 40 % (HGeo 2020).
- The number of days with no-flows on Native Dog Creek would increase from approximately 6 % of the time to approximately 20 % to 33 % of the time. Based on more recent analysis, it is considered more likely that the increase in cease-to-flow would be 14 % rather than 33 % (HGeo 2020).

The incremental effect of Longwall 18 on flows in Wongawilli Creek was also modelled as a reduction of up to 0.08 ML/d. While this alone would result in cease-to-flow conditions occurring in Wongawilli Creek 14 % to 18 % of the time (from a natural proportion of 10 %), such an increase is considered highly unlikely based on analysis of historical field data (Hgeo 2020). Based on comparison of modelling results with field observations, it is expected that Longwall 18 would cause a negligible increase in the duration and length over which cease-to-flow conditions can occur in Wongawilli Creek during drought periods (when any effect on flow is most noticeable). The effect of this longwall would therefore be undiscernible from natural variability or from the effects of other historical, approved and proposed longwalls. The cumulative effect of extraction of DA3A, DA3B and DA3C longwalls on flows in Wongawilli Creek should, however, be considered (**Section 4.2.4**).

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 in drainage lines are expected to have no more than minor and localised impacts on aquatic habitat (**Section 4.2.1.1**), and thus biota. No impacts are expected in Native Dog Creek as no changes in tilt would occur.

4.2.2.2 Fracturing and Flow Diversions

Drainage of pools and loss of aquatic habitat following fracturing leading to flow diversion in drainage lines 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 levels, their ability to migrate to nearby unaffected areas, weather conditions, the underlying substratum and duration of exposure.

If fracturing occurred in Native Dog Creek it would not result in reductions in water levels and there would therefore be no reduction in the availability of aquatic habitat (**Section 4.2.1.2**). As such impacts to aquatic biota in Native Dog Creek are not expected.

Given the limited amount of ephemeral pool habitat that would be impacted in drainage lines directly above and within 400 m of Longwall 18, associated impacts to aquatic biota would be minor at the catchment scale. 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 18 would be minor. A complete drainage of a pool or section of pool would reduce longitudinal connectivity in the drainage lines and impact the ability of aquatic biota to move in search of food and refuge. However, connectivity would currently be limited in these ephemeral watercourses.

4.2.2.3 Water Quality and Availability

Impacts to water quality due to mining are expected to be minor or undetectable (**Section 4.2.1.3**) and thus associated impacts to aquatic biota are not expected. The effect of this Longwall 18 on water availability in Wongawilli Creek would not be discernible from natural variability or from the effects of other historical, approved and proposed longwalls (**Section 4.2.1.3**). Thus, impacts to aquatic biota associated with extraction of Longwall 18 in isolation, would not be expected.

While reductions in availability and connectivity of aquatic habitat could occur following groundwater depressurisation and reduced flows and be associated with potential impacts to aquatic biota in ND1 and Native Dog Creek, these changes do not suggest substantial changes to natural conditions would occur. In particular, ND1 is ephemeral, and would naturally contain disconnected pool habitat. 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 ND1. The likely increase (to 14 %) in zero flow days in Native Dog Creek would not be expected to result in significant impacts to aquatic ecology here, given zero flow days occur here naturally (6 % of the time) 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 in each of these watercourses).

Fracturing of the stream substrate in drainage lines 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 18 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 from Native Dog Creek and ND1 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. Lake Avon has potential to provide habitat for Macquarie perch, however, impacts associated with extraction of Longwall 18 are considered unlikely to occur here. 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.

4.2.4 Cumulative Impacts

Based on predicted ground movements and associated impacts to water availability and quality, associated impacts to aquatic habitat and biota due to fracturing and flow diversions associated with extraction of Longwall 18 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 4.2.4**).

Although extraction of Longwall 18 would result in a negligible contribution to the predicted cumulative reductions to baseflow in Wongawilli Creek, groundwater depressurisation due to extraction of DA3A, DA3B and DA3C longwalls would result in an increase in zero flow days in Wongawilli Creek. 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 (Watershed HydroGeo, 2020) provides conservative estimates of a decline in baseflow due to all DA3A and DA3B longwalls that could cause an increase in zero flow days up to 27% of the time in the mid-Wongawilli Creek reach. Although the groundwater model predicts the cumulative impact of extraction of DA3A and DA3B longwalls would be to increase the proportion of zero flow days from 5 % to between 20 % and 40 % of the time at WWL (located downstream of the Study Area near the Fire Road 6 crossing), such a decline has not been observed to date and are within the scale of natural variability (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. Such reductions in baseflow due to groundwater drawdown, while small in absolute magnitude, can be a significant portion or all of the flow down the reach of Wongawilli Creek adjacent to DA3B longwalls in extreme drought periods, as was experienced 2017 into early 2020.

5 Recommendations

Four approaches would be used to manage potential impacts on aquatic ecology within the Study Area from Longwall 18:

- 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 18 on aquatic habitats and biota in Wongawilli Creek will be minimised as the mining is 1 km from Wongawilli Creek. 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 18; 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 month 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 any 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 DA3B on Wongawilli Creek. Impact sites applicable to monitoring potential impacts associated with Longwall 18 on Wongawilli Creek (albeit it is unlikely impacts would occur here due to extraction of Longwall 18) are Sites 1 to 4 and X4 to X6. Sites X7 and X8 on Wongawilli Creek 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 18.

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 18 begins in October 2021, baseline 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. Ongoing monitoring for Longwall 18 could be incorporated into the ongoing biennial monitoring for DA3B.

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.

Ongoing monitoring of physical attributes (such flow and depth of water in larger pools) of Native Dog Creek and larger drainage lines would be undertaken by ICEFT. These data would be examined alongside aquatic ecology data during the aquatic ecology reporting. These observations may also trigger additional surveys of aquatic ecology (**Section 5.3**).

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 a greater 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 IMCEFT that may require further investigation into potential impacts on the aquatic ecology include:

- Reductions in flow in Wongawilli Creek that exceed expected increases in the number of zero flow days (HGeo 2020); and

- Greater than minor change in water chemistry (particularly pH, dissolved oxygen, turbidity, or metal concentration) in Wongawilli Creek or Native Dog 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 3B Watercourse Impact Monitoring Management and Contingency Plan (South32 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 18 on aquatic habitats and biota in Wongawilli 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 18 includes measures to minimise potential impacts on aquatic habitat and biota. This includes a set back from Lake Avon of at least 300m and a reduced extraction height of 3.9m. Aquatic ecology impacts in Wongawilli Creek, Native Dog Creek and Lake Avon are not expected.

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 drainage lines in, and adjacent to, Longwall 18. Fracturing and flow diversions have potential to occur in these sections of watercourse and may result in reductions in the availability of aquatic habitat. However, the aquatic habitat provided by these ephemeral drainage lines is relatively limited. While impacts to aquatic biota at the local scale (e.g. individual pools and drainage lines) would be significant at the local level, due to the abundance of this habitat in the Cordeaux River and Avon River catchments, impacts to aquatic biota at this wider scale would be minor. The potential impacts associated with Longwall 18 also represent a 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.

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. Macquarie perch are also unlikely to occur in Native Dog Creek or in Wongawilli Creek within DA3B. Although this species may be present in Lake Avon, no adverse impacts associated with mining are expected to occur here.

Ongoing monitoring associated with DA3B longwalls will incorporate monitoring of impacts to aquatic ecology that may occur due to extraction of Longwall 18. This will also consider the results of monitoring of physical and water quality impacts undertaken by IMCEFT. The detection of physical impacts, such as rockbar fractures resulting in water loss in a pool within Wongawilli Creek or more than minor 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 would determine the type of response. The implementation of such management measures would reduce impacts on aquatic ecology.

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APPENDIX A

SURVEY METHODOLOGY

Site Coordinates

Table A-i. 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
X4	Wongawilli Creek	291083	6191801
X5	Wongawilli Creek	290950	6190581
X6	Wongawilli Creek	290775	6190356
X7	Wongawilli Creek	290795	6189911
X8	Wongawilli Creek	290813	6189774
ND	Native Dog Creek ND1	288709	6190099
ND1	Native Dog Creek ND1	288638	6190463

Datum: GDA 94 Zone 56H

Aquatic Habitat and Vegetation

Habitat Types

The July 2007 investigations (The Ecology Lab 2007) mapped four habitat types (adapted from Fairfull and Witheridge 2003) within Wongawilli Creek, Native Dog 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.

REC Inventory

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) (**Table A-ii**). 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.

Table A-ii. 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

Key Fish Habitat

The occurrence of sensitive fish habitat in the Study Area was assessed using the criteria in NSW DPI (2013a) relevant to freshwater habitat (**Table A-iii**).

Mapping was done initially as a desktop exercise with the aid of existing information from previous surveys including information on habitat types (Fairfull and Witheridge 2003). findings were used to inform the detailed KFH mapping using the updated classifications in NSW DPI (2013a). 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 A-iii. 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)

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.

AUSRIVAS Macroinvertebrates

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 0**).

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 A-iv**.

Table A-iv. 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.

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.

APPENDIX

B

RCE RESULTS

Catchment:	Wongawilli Creek										Native Dog Creek	
RCE Category	1	2	3	4	5	X4	X5	X6	X7	X8	ND	ND1
Land use pattern beyond the immediate riparian zone	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
Completeness of riparian strip of woody vegetation	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
Stream bank structure	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
Channel form	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	3	3
Retention devices in stream	4	4	4	4	3	4	4	4	4	4	4	4
Channel sediment accumulations	3	3	3	3	4	4	4	4	2	2	4	3
Stream bottom	4	2	2	2	4	4	4	4	3	3	3	4
Stream detritus	4	4	4	4	4	4	4	4	4	4	4	4
Aquatic vegetation	3	4	4	4	3	4	3	4	4	4	4	4
Total	48	46	46	46	47	50	50	51	46	47	48	48

APPENDIX C

IN-SITU WATER QUALITY

Water quality measures from each sampling site from May 2020. Grey shading indicates value outside of DTV.

Measure	DTV	ND Rep 1	ND Rep 2	ND1 Rep 1	ND1 Rep 2
Temp (°C)		12.0	12.0	9.7	9.7
Cond (µS/cm)	30-350	150	150	104	104
pH	6.5-8.0	6.60	6.60	5.8	5.7
ORP (mV)		-17.2	-17.2	77.5	78.9
DO (%Sat)	90-110	95.3	95.3	85.9	85.7
Turbidity (NTU)	2-25	7.9	7.9	1.3	1.3

Default Trigger Values (DTV) taken from ANZECC/ARMCANZ (2000) guidelines for slightly disturbed upland rivers in southeast Australia.

APPENDIX

D

COMPILED AUSRIVAS DATA

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
Oct-19	17	0.87	5.8	May-19	8	0.53	4.4
Nov-19	11	0.47	3.7	Jun-19	13	0.62	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
Oct-19	15	0.67	4.7	May-19	14	0.79	5.3
Nov-19	15	0.65	4.5	Jun-19	13	0.97	3.9
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

Spring				Autumn			
Date	No. of Taxa	OE50 Taxa Score	SIGNAL2 Index	Date	No. of Taxa	OE50 Taxa Score	SIGNAL2 Index
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
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
Oct-19	20	1.00	4.6	May-19	17	0.58	5.1
Nov-19	19	0.81	4.7	Jun-19	12	0.55	4.8
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
Oct-19	25	1.09	4.4	May-19	17	0.72	4.4
Nov-19	24	1.14	4.7	Jun-19	10	0.62	5.1
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
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
Oct-19	17	0.73	4.5	May-19	9	0.62	4.2
Nov-19	16	0.87	4.7	Jun-19	11	0.92	4.3
Site X5							
Sep-10	19	1.09	5.2				
Nov-10	19	0.70	5.0				

Spring				Autumn			
Date	No. of Taxa	OE50 Taxa Score	SIGNAL2 Index	Date	No. of Taxa	OE50 Taxa Score	SIGNAL2 Index
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
Oct-19	16	0.77	4.7	May-19	12	0.71	3.8
Nov-19	15	0.75	5.5	Jun-19	12	0.55	3.8
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
Oct-19	14	0.70	4.4	May-19	14	0.65	4.0
Nov-19	15	0.75	4.2	Jun-19	15	0.65	4.8
Site X7							
Oct-19	18	0.67	4.0	May-19	11	0.53	4.0
Nov-19	14	0.59	4.5	Jun-19	15	0.74	4.0
Site X8							
Oct-19	20	0.46	4.2	May-19	10	0.53	4.8
Nov-19	22	0.75	4.7	Jun-19	18	1.11	4.2
Site ND Rep 1							
				Jun-20	11	0.54	4.0
Site ND Rep 2							
				Jun-20	8	0.53	5.0
Site ND1 Rep 1							
				May-20	9	0.62	3.9
Site ND1 Rep 2							
				May-20	7	0.46	4.5

APPENDIX

E

AUSRIVAS DATA AUTUMN 2020

Taxon (max. 10 individuals counted)	ND Rep 1	ND Rep 2	ND1 Rep 1	ND1 Rep 2
Copepoda			2	4
Hydracarina	1	7	9	7
Leptophlebiidae	10	10	10	10
Megapodagrionidae	5	2		
Aeshnidae	1			
Hemicorduliidae	1	1		
Hydrometridae	1		1	
Veliidae			3	3
Gerridae	1			
Notonectidae	1		1	
Dytiscidae	1	1	1	3
Hydrophilidae				2
Chironomidae: Tanypodinae	9	4	2	
Ceratopogonidae	5	1		
Leptoceridae		1	2	4

ND sampled June 2020 and ND1 Sampled May 2020

APPENDIX

F

AOS *M. AUSTRALASICA*

1) 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; 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 natural barrier Native Dog Creek at its confluence with Lake Avon would also likely prevent this species utilising the Native Dog Creek catchment. Macquarie perch are very unlikely to occur in the drainage lines in the Study Area for Longwall 18. Thus, within the Study Area the only area where Macquarie perch is likely to occur is in Lake Avon.

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 longwall is not expected to result in major fracturing in Lake Avon, Native Dog Creek or Wongawilli Creek that could otherwise result in adverse impacts. In any case, due to the presence of natural barriers to fish movement Macquarie perch are not expected to be able to use sections of Wongawilli Creek or Native Dog Creek that may be affect by minor fracturing.

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. Likewise, any impacts to water quality in creeks and Lake Avon 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 fracturing and flow diversions would not occur in Wongawilli Creek and that adverse impacts would not occur due to any minor fracturing in Lake Avon. The section of Native Dog Creek within the Study Area also does not appear to be accessible to Macquarie perch, nor are reductions in the availability of aquatic habitat expected here. 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 National Recovery Plan for Macquarie perch (DEE 218) 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.

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 not expected. The Project would not 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; 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 natural barrier Native Dog Creek at its confluence with Lake Avon would also likely prevent this species utilising the Native Dog Creek catchment. Macquarie perch are very unlikely to occur in the drainage lines in the Study Area for Longwall 18. Thus, within the Study Area the only area where Macquarie perch is likely to occur is in Lake Avon.

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 longwall is not expected to result in major fracturing in Lake Avon, Native Dog Creek or Wongawilli Creek that could otherwise result in adverse impacts. In any case, Macquarie perch are not expected to be able to use sections of Wongawilli Creek or Native Dog Creek that may be affect by minor fracturing due to the presence of natural barriers to fish movement that would prevent the species from accessing these sections of watercourse.

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. Likewise, any impacts to water quality in creeks and Lake Avon 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, reductions in availability of aquatic habitat due to fracturing is not expected in Wongawilli Creek or Native Dog Creek, not would Macquarie perch be expected to occur in sections of these watercourses within the Study Area. Although Macquarie perch may occur in Lake Avon, fracturing resulting in adverse impacts are not expected here. he 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 not expected.

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 not expected. No structures that may hinder fish passage would be installed. Macquarie perch is not expected to occur within drainage lines in 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 not expected. Critical breeding habitat (shallow flowing sections of rivers) is likely 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 any Macquarie perch in Lake Avon or place a viable local population at risk of extinction. Macquarie perch are considered very unlikely to occur in drainage lines 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 not expected 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 National Recovery Plan for Macquarie perch (DEE 218) 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.

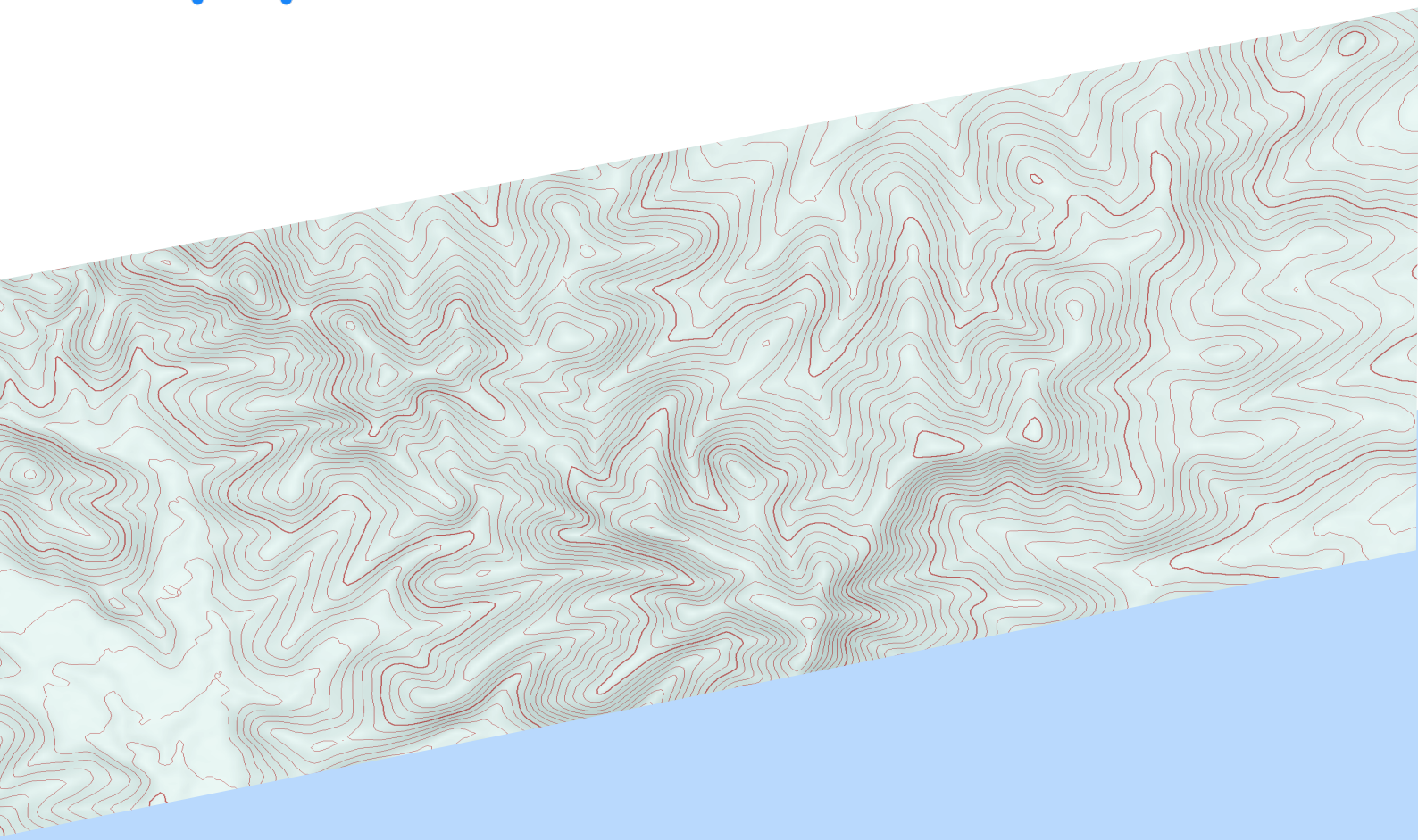
Identified threats include:

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

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 not expected. The Project would not interfere with these objectives and the recovery of the species.

Attachment B – Groundwater Assessment

WATERSHED HYDROGEO



South32 Illawarra Metallurgical Coal

Dendrobium Area 3B

Longwall 18 Groundwater Assessment

August 2020

DOCUMENT REGISTER

Rev/Issue	Date	Comments
1	13 July 2020	Initial (partial) draft for comment
2	21 July 2020	Draft for comment
3	07 August 2020	Incorporating IMC comments
4	11 August 2020	Updated discussion of surface water losses

FILE

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QUALITY CONTROL

Function	Staff	Signature	Date
Authors	Will Minchin		11/08/2020
Approved	Will Minchin		

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ABBREVIATIONS

Abbreviation/Term	Meaning
BCD	Biodiversity and Conservation Division (formerly Office of Environment and Heritage [OEH])
BoM	Bureau of Meteorology
DPIE	NSW Department of Planning, Industry and Environment
EPA	NSW Environment Protection Authority
IMC	Illawarra Metallurgical Coal
ICEFT	Illawarra Coal Environmental Field Team
IEPMC	Independent Expert Panel for Mining in the Catchment (advising DPIE)
IESC	Independent Expert Scientific Committee (advising Federal and state governments)
mAHD	metres above Australian Height Datum (effectively elevation as metres above sea level)
mBG	metres below ground
ML/d	megalitres per day
Q50	Median (50th percentile) flow at a gauge for a specified period
WaterNSW	Bulk water supply and source protection authority for Greater Sydney

1 Introduction

Illawarra Metallurgical Coal (IMC), a subsidiary of South32, extract primarily coking coal at Dendrobium Mine in the Southern Coalfield of NSW. The mine is located approximately 70 km southwest of Sydney and 12 km west of Wollongong. **Figure 1-1** shows that the location of Dendrobium Mine, and illustrates that the mine extends from the Illawarra Escarpment to the west under the Metropolitan Special Area (water supply catchment) managed by WaterNSW.

IMC extract coal from the Wongawilli Seam by longwall mining and since 2005 have extracted 16 longwalls at Dendrobium from Areas 1, 2, 3A and the current domain, Area 3B.

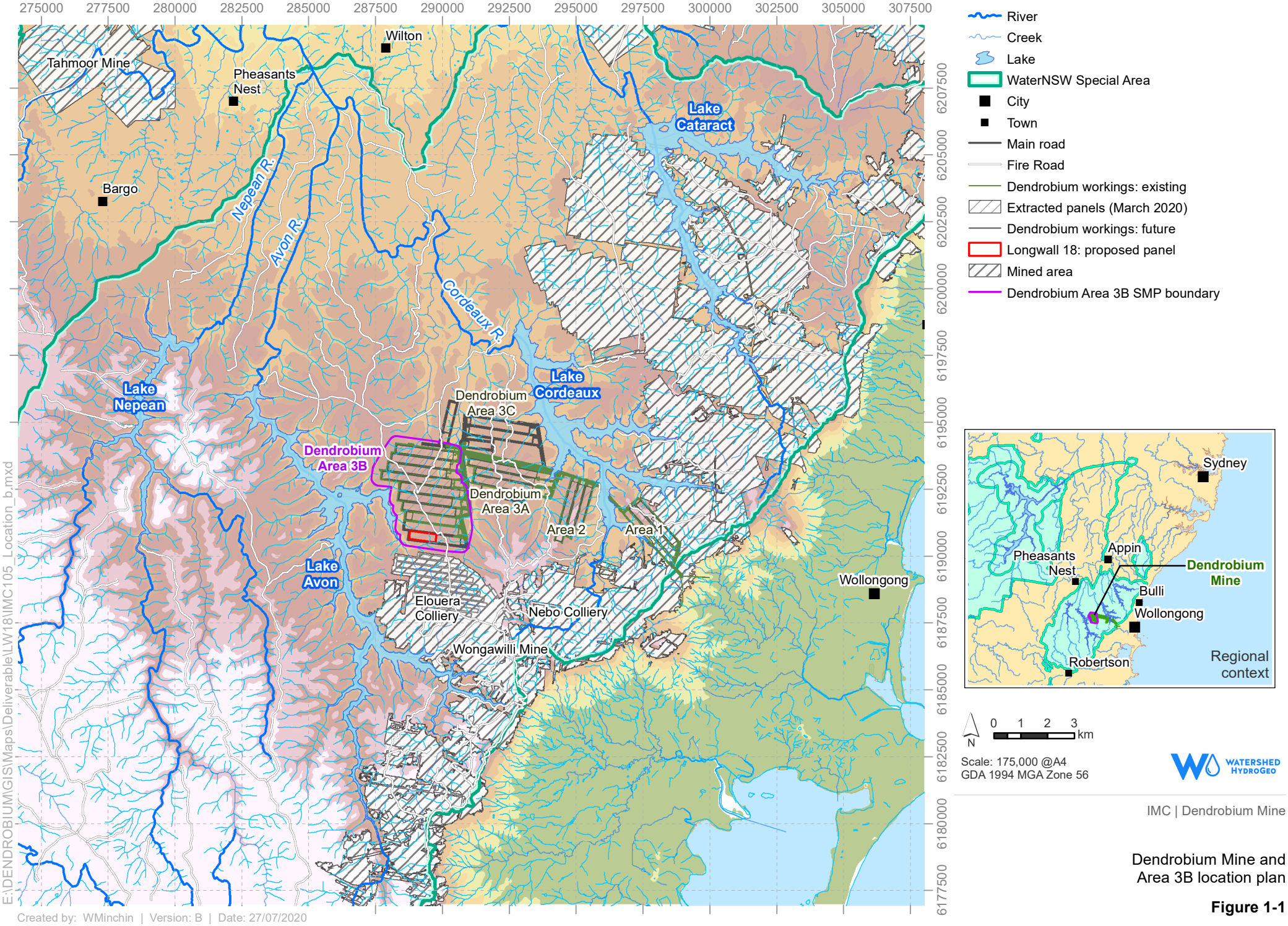
IMC is seeking Department of Planning, Industry and Environment (DPIE) approval to extract the proposed Longwall 18 within Area 3B. IMC is required to prepare a Subsidence Management Plan (SMP) outlining the potential impacts that may occur to environmental and water supply features of significance within and near to this longwall (Section 1.5). Watershed HydroGeo (WatershedHG) was engaged by IMC to prepare an assessment of groundwater-related impacts to inform the SMP application.

1.1 Dendrobium Mine: historical operations

IMC has carried out longwall mining at Dendrobium Mine since 2005 (**Table 1-1**). **Figure 1-2** shows the location of the Dendrobium mining areas including longwalls, location of watercourses and water supply reservoirs. In order of when they were mined, and also from east to west (moving inland from the escarpment):

- Area 1 (Longwalls 1 and 2) completed in 2007.
- Area 2 (Longwalls 3, 4, and 5) completed in 2009.
- Area 3A (Longwalls 6, 7 and 8) extracted between 2010 and 2012. SMP Approval for Longwall 19 has been sought from DPIE.
- Area 3B has been active since February 2013. Seven longwalls have been completed (Longwalls 9, 10, 11, 12, 13, 14 and 5), Longwall 16 is currently being extracted, Longwall 17 has SMP approval, and this report will accompany the Longwall 18 SMP application.

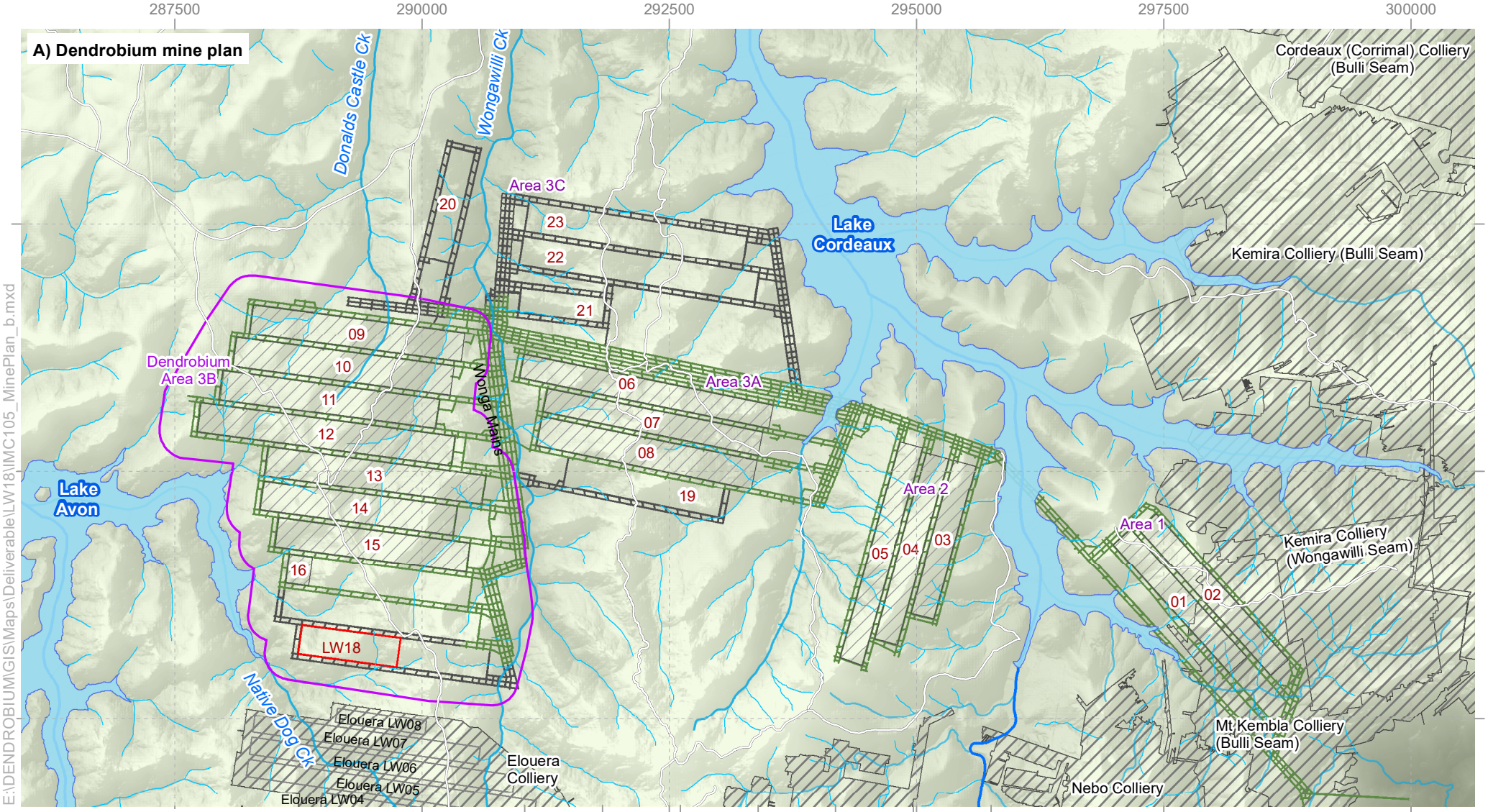
All historical and proposed extraction in Areas 1, 2, 3A, 3B and 3C is from the Wongawilli Coal seam. Longwall dimensions, being panel or void widths and seam cutting heights increased from Area 1 to Area 3B (**Table 1-1**). Maximum cutting heights were approximately 3.7 m in Area 1, and up to 3.9 m in Areas 2 and 3A. Area 3B longwalls up to Longwall 13 had maximum cutting heights between 3.95 and 4.5 m. Recent SMP approvals require that Longwalls 14 to 17 must have a maximum cutting height of no more than 3.9 m. IMC propose the same cutting height (3.9 m) for Longwall 18.



IMC | Dendrobium Mine

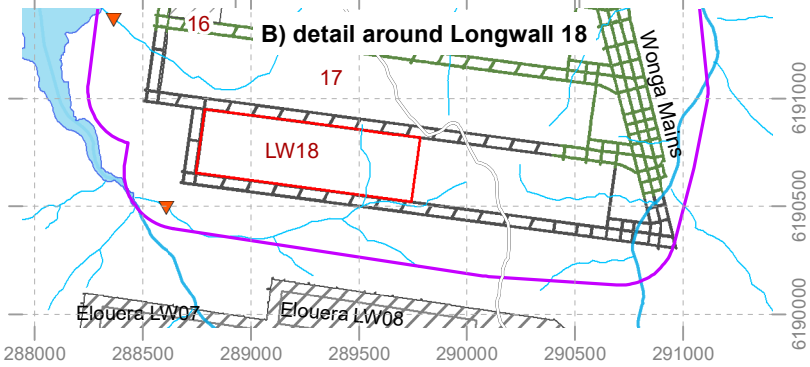
Dendrobium Mine and Area 3B location plan

Figure 1-1



Created by: WMinchin | Version: B | Date: 27/07/2020

- River
- Creek
- Lake
- Fire Road
- Dendrobium Area 3B SMP boundary
- Dendrobium workings: existing
- Mined area
- Longwall 18: proposed panel
- Dendrobium workings: future



N

0 0.4 0.8 1.2 km

Scale: 35,000 @A4
GDA 1994 MGA Zone 56

WATERSHED HYDROGEO

IMC | Dendrobium Mine

Dendrobium and Longwall 18 mine plan

Figure 1-2

Table 1-1 Historical and Proposed Longwall Dates and Dimensions

MINE DOMAIN	LONG-WALL	STATUS	DATE		DAYS	PANEL LENGTH	WIDTH		CUTTING HEIGHT		DEPTH OF COVER [m]		
			Start	End			Panel	Void	Mean	Max	Min	Mean	Max
1	1	**Historical**	30/03/2005	15/12/2005	261	1750	237	247	3.2	3.7	170	262	316
1	2	**Historical**	09/02/06	22/01/07	348	2000	237	247	3.24	3.70	162	264	320
2	3	**Historical**	30/03/07	22/11/07	238	1560	235	245	3.34	3.66	138	211	282
2	4	**Historical**	17/12/07	30/09/08	289	1950	235	245	3.65	3.75	159	249	310
2	5	**Historical**	04/12/08	18/12/09	380	2300	235	245	3.57	3.80	213	252	293
3A	6	**Historical**	9/02/10	28/03/11	413	2610	238.5	248.5	3.7	3.90	287	345	389
3A	7	**Historical**	04/05/11	23/01/12	265	2220	238.5	248.5	3.46	3.60	288	338	379
3A	8	**Historical**	24/02/12	29/12/12	310	2220	295	305	3.38	3.50	261	321	373
3B	9	**Historical**	09/02/13	02/06/14	479	2150	295	305	3.45	3.70	314	381	409
3B	10	**Historical**	20/01/14	20/01/15	366	2200	295	305	3.93	4.50	325	383	406
3B	11	**Historical**	18/02/15	05/01/16	322	2190	295	305	3.86	3.95	327	381	404
3B	12	**Historical**	22/01/16	31/01/17	377	2590	295	305	3.93	3.95	329	376	404
3B	13	**Historical**	04/03/17	19/04/18	411	2210	295	305	3.86	3.95	299	375	400
3B	14	**Historical**	22/05/18	26/02/19	223	1980	295	305	3.89	3.90	325	378	395
3B	15	**Historical**	8/04/2019	22/01/20	243	1963	295	305		3.9	324	370	390
3B	16	**Current**	20/02/2020	*Nov-2020	244	1874	295	305		3.9	280	350	390
3B	17	**Approved**	*Dec-2020	*Sep-2021	243	2013	295	305		3.9	279	345	385
3B	18	**Proposed**	*Oct-2021	*Mar-2022	155	1018	295	305		3.9	300	332	370
3A	19	**Approval pending**	*Apr-2022	*Dec-2022	220	1600	295	305		3.6	287	331	369
3C	21	**Approved**	*Jan-2023	*Apr-2023	100	872	245	256		3.9	338	369	404
3C	22	**Proposed**	*Jun-2023	*May-2024	330	2426	295	305		3.9	270	345	405
3C	23	**Proposed**	*Sep-2024	*May-2025	300	2229	295	305		3.9	275	340	400
3C	20	**Proposed**	*Sep-2025	*Jan-2026	183	1154	245	256		3.9	296	338	382

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

1.2 Dendrobium Mine: proposed mining

Proposed longwall extraction within Area 3B as well as 3A and 3C (**Figure 1-2**) that is relevant to this SMP application are outlined in the following sections.

1.2.1 Area 3B (Longwalls 17 and 18)

These longwalls would extend into the Dams Safety NSW Avon Notification Area, although are proposed to be at least 300 m from the Lake Avon Full Storage Level (FSL), in accordance with Schedule 4, Condition 8 of the 3B SMP Approval. Some of these longwalls have also been shortened at their eastern end to avoid mining under tributaries of Wongawilli Creek or remain a specified distance (400 or 600 m) from Wongawilli Creek (3B SMP Approval Schedule 4, Condition 10).

There are no overlying historical workings associated with or near Longwalls 17 or 18, although Longwall 18 would be 450-500 m north of old workings at Elouera Colliery (Section 1.3), including Elouera Longwall 8.

1.2.2 Area 3A (Longwall 19)

Longwall 19 is proposed to be 305 m wide (**Table 1-1**) consistent with Longwall 8 and all longwalls in Area 3B. Cutting heights would be similar to recent panels, with a maximum of 3.9 m as stipulated in the Conditions of Approval for Area 3B.

The likely effects of this longwall on the groundwater system were described in SLR (2020a). Approval for this panel is currently being considered by DPIE.

1.2.3 Area 3C (Longwalls 20 to 23)

Longwalls 20 and 21 are proposed to be 256 m wide (**Table 1-1**) and are narrower than Area 3B panels. Cutting heights would be similar to recent panels, with a maximum of 3.9 m in accordance with Schedule 3, Condition 5 of the SMP Approval for Area 3C.

The likely effects of these longwalls on the groundwater system were described in Hydrosimulations (HS) (2019c). Longwall 21 has been approved by DPIE, while additional analysis, including groundwater modelling, was requested by DPIE prior to further consideration of Longwall 20.

Longwalls 22 and 23 are proposed to be located to the north of Longwall 21. The proposed details of these are presented in **Table 1-1** and **Figure 1-2**. SMP Approval will be sought in late 2020.

1.3 Mining in the Southern Coalfield

There is a long history of coal mining in the Southern Coalfield, especially along the escarpment to the north-east, east and south of Dendrobium (**Figure 1-1**). Historical and contemporary workings in the Wongawilli Coal seam are located to the south at Elouera and Nebo (merged as part of 'Wongawilli Mine'), and to the east at Kemira. The Bulli Coal seam has been mined at Mt Kembla, partially overlying and east of Dendrobium Area 1.

1.4 Framework for water management

Within NSW water use is managed by the Department of Planning, Industry and Environment-Water (DPIE-Water) and regulated via Water Sharing Plans (WSP).

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

Dendrobium Mine is located within Management Zone 2 of the Nepean Sandstone Groundwater Source of the *Greater Metropolitan Region Groundwater Sources WSP* (NSW Office of Water, 2011). This groundwater source is classified as 'Highly Productive' by DPIE-Water.

1.5 Scope of works

This assessment provides information about potential groundwater behaviour in response to longwall extraction and associated subsidence for consideration by DPIE in the assessment of the SMP. This assessment focuses on the potential impacts of Longwall 18, on groundwater, watercourses and reservoirs.

The cumulative effects of all relevant operations at Dendrobium as well as those from neighbouring operations, in terms of historical and future effects, are considered in this Groundwater Assessment.

The assessment must meet requirements from a number of sources:

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

Details of recent Conditions of Approval and SMP requirements are tabulated in Section 1.5.1, including a reference to where these are addressed in this document. IEPMC comments and recommendations are summarised in Section 1.5.2. Section 1.5.3 outlines the structure of the document as a whole.

As in previous groundwater assessments for Dendrobium Mine, numerical modelling is used here to inform IMC and regulators about the potential effects and impacts that longwall mining has or may have on water features around Dendrobium. Groundwater modelling for Dendrobium was carried by GHD (2007) and has advanced, both in terms of complexity and the requirements, through the modelling of Areas 3A, 3B and 3C (in particular) by Coffey (2012b), HydroSimulations (2014, 2016a, 2018, 2019a and 2019b) and SLR (2020a).

An updated groundwater model was developed for Dendrobium's recent EIS for the Dendrobium Extension Project, which seeks approvals for future Areas 5 and 6. This was reported in HydroSimulations (2019c). A modified version of the EIS model is used here, being developed in tandem by Watershed and by SLR, and incorporating new field data and with modifications to meet requirements by agencies.

1.5.1 Assessment requirements

The Dendrobium Development Consent DA 60-03-2001 was granted by the NSW Minister for Planning in 2008. **Table 1-2** outlines the conditions from Schedule 3 of that document that are relevant to groundwater and identifies where in this report they are addressed.

Table 1-2 Development Consent Conditions and requirements relevant to groundwater

Condition		Detail	Where dealt with
Schedule 3			
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 surface water losses in watercourses (surface water take) (**Section 7.4.5**).
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: • Lake Avon leakage (**Section 7.4.3**); • Lake Cordeaux leakage (**Section 7.4.4**); • loss from watercourses (surface water take) (**Section 7.4.5**); and • losses from water supply catchments (**Sections 7.4.6**).
Groundwater Monitoring Program			
13	The SMPs prepared under condition 7 must include a Groundwater Monitoring Program, which must include:	(a) proposals to develop a detailed regional and local groundwater model, with special reference to flows to and from nearby water storages;	Regional model is presented in Sections 5 to 7. Description of local modelling in HGEO (2019b).
		(b) detailed baseline data to benchmark the natural variation in groundwater levels, yield and quality;	SLR 2020b presents groundwater modelling plan.
		(c) groundwater impact assessment criteria;	Groundwater assessment criteria outlined in Section 1.4 and 1.5.
		(d) a program to monitor the impact of the development on: • groundwater levels, yield and quality (particularly any potential loss of flow to, or flow from, WaterNSW water storages); • coal seam aquifers and overlying aquifers; and • groundwater springs and seeps.	SLR 2020b presents groundwater modelling plan. HGEO (2017b and 2019b) documents investigation into interaction with and losses from Avon Reservoir.
		(d) provide adequate water table contour plots, drawdown plots and pore pressure vertical section plots for predicted and observed conditions;	Modelled groundwater levels and pressures presented in Section 6.4 and 7.3.
		(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	Refer to Section 1.5.2.
		(f) be peer reviewed by a suitably qualified, experienced and independent expert, who is approved by the Secretary.	Refer to Section 6.7.2.

Additional requirements have been set via the SMP Approval for Area 3B, the latest of which is dated 11 July 2019. Those relevant to this groundwater assessment are set out in **Table 1-3**.

Table 1-3 Area 3B SMP requirements relevant to Groundwater Assessments (11/07/2019)

Condition		Detail	Where dealt with
Schedule 3			
18	**Groundwater Model** 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 5.2.3** outlines the stratigraphic units included in the groundwater model. This includes a representation of swamps. **Section 5.3.4** describes the representation of watercourses.
		(b) include all available data on groundwater levels;	Groundwater level targets and calibration (**Section 6.4**)
		(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;	Predictions of surface water losses in watercourses (surface water take) (**Section 7.4.5**).
		(d) provide adequate water table contour plots, drawdown plots and pore pressure vertical section plots for predicted and observed conditions;	**Section 7.3** presents contour groundwater levels, depth to water (in line with IEPMC's request of 28/11/2019), and hydrographs for observations and predictions.
		(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	We have reviewed advice from PSM (2017) and the reviewers of that, considered IEPMC (2019a,b). See **Sections 1.5.1, 1.5.2** and then through out relevant sections of this report.
		(f) be peer reviewed by a suitably qualified, experienced and independent expert, who is approved by the Secretary.	Modelling reviewed by Kalf and Associates (KA) [KA, 2019]. Comments made by KA are incorporated into this report.
19	**Groundwater Monitoring and Height of Cracking**	Undertake a comprehensive program of… investigations of the height of connective cracking.	HGEO (2020c) and Hebblewhite (2020), summarised in **Section 3.6**.
Additional Investigations			
Schedule 4			
13	Prior to the extraction of Longwall 17, the Applicant must undertake additional investigations into:	(a) geological structures near bore S2436 to clarify the nature, extent and significance of monitoring data reported from that bore;	Details provided separately.
		(b) the location and nature of the Elouera Fault, including additional surface drilling and subsequent geotechnical, geophysical and hydrogeological testing; and	Provided separately. A summary is presented in Section 2.5.2.
		(c) report the results of these investigations to the Secretary, WaterNSW and the DSC, to the satisfaction of the Secretary.	Provided separately.

1.5.2 Summary of independent advice to regulators

IEPMC advice regarding Area 3C groundwater modelling (HS, 2019b) has been incorporated by DPIE into Schedule 3, Condition 15 of the Area 3C Approval. This condition was relevant to model cell sizes within longwall areas (Condition 15a) and to the use and justification of Stacked Drains to simulate connected fracturing (Condition 15b). These items are addressed in Sections 5.2.2 and 5.4.5 respectively.

In the IEPMC's updated and extended reports (IEPMC, 2019a and 2019b) a number of issues regarding groundwater modelling were raised, as outlined in **Table 1-4**.

Table 1-4 Summary of IEPMC (2019a,b) recommendations

IEPMC recommendation			Response	Reference
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 observed at Dendrobium. To date, impacts on shallow piezometers at Dendrobium have, all been within 120 m (WatershedHG, 2019a).	Mapped geological structure in **Section 2.5.2**. MSEC (2019) and SRK (2020) describe 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.	IMC have been investigating the major geological structures in Area 3B. Valley closure/basal shears are accounted for in modelling around the deeper valleys near longwalls.	**Section 2.5.2** presents discussion of geological structures around Longwall 18. Modelling of off-goaf effects in **Section 5.4.4**.
Groundwater impacts at Dendrobium Mine				
p.91	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.	Further field investigations to understand fracturing and depressurisation above the goaf have taken place and been reviewed. These have confirmed that deformation occurs through to the surface.	Field investigations presented in **Section 2.6 and 3.6**. Subsequent model representation of fracturing is presented in **Section 5.4**.
p.58	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 does not rely on the geomechanical modelling by SCT, which was previously used in HydroSimulations (2019c). This study has concentrated on constraining the model, where possible, using the recently acquired field data.	Field investigations in **Section 2.6 and 3.6**. Model representation in **Section 5.4**.

IEPMC recommendation			Response	Reference
	8	Groundwater models should: i. continue to be updated ii. be migrated from MODFLOW-SURFACT to MODFLOW-USG only if significant benefits can be demonstrated iii. be underpinned by unified material properties (for common stratigraphic layers) unless differences can be demonstrated to exist through measurements	i) the model has been updated numerous times, with additional layering, parameters and methods for deformation. ii) We 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. iii) Differences in material properties may exist between the two sites identified by IEPMC. The parameters of this model rely heavily on the extensive Dendrobium packer test dataset, as well considering data from other Southern Coalfield sites.	Updates to the model are described in **Section 5**. Further details on model development and evolution is described through Coffey (2012), HydroSimulations (2014, 2016, 2018, 2019a, 2019b, 2019c), SLR (2020a).
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 LW 16 to LW 18.	New surface water monitoring sites have been installed.	Section 2.4.1.
	17	iv. additional basal shear monitoring, implemented as a priority between the Avon Dam and LW 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. Work by HGEO (2019b) and SCT (2017, 2019a) has been reviewed for this assessment.	See network of "Avon monitoring" sites on **Figure 3-2**. Data from these sites are used to inform scenarios (Section 7.2).

Recommendations previously incorporated from the DPIE-commissioned study into the Height of Connected Fracturing (PSM, 2017) for recent SMP application groundwater assessments (HS, 2019a and 2019b; SLR, 2020a) have been described in detail in previous assessments. Most of these recommendations have been retained for the groundwater model utilised in this assessment. A summary is presented in **Table 1-5**.

Table 1-5 Summary of recommendations from PSM (2017) relevant to groundwater modelling

#	Issue / recommendation	Action	How and where addressed
1	Accounting for structures, specifically Elouera Fault	South32 maps structures in the mining area (e.g. IMC, 2020) and has commissioned multiple studies to investigate the role of structures (e.g. MSEC, 2019, SRK, 2020). Specific studies on the Elouera Fault are continuing, but include HGEO (2019b, 2020) and SCT (2020).	There is discussion of geological structures in Section 2.5.2. Elouera Fault investigations are described in Section 2.5.2.2.
2	Valley-bulging (valley-closure) around lakes	This process is incorporated in groundwater modelling by increasing the hydraulic conductivity of the strata along valley walls and beneath valley floors. See response to #4, below.	Measured and modelled increases in hydraulic conductivity (Sections3.6.3 and 5.4.4).
3	Accounting for basal shears	Basal shears have the potential to act as conduits between longwalls/goaves and to connect to Lake Avon. Based on advice from SCT, and the PSM study, these occur around the claystones (BHCS and SPCS). 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."	Basal shears are not modelled explicitly as discrete features, as the evidence from packer testing around Area 3B and Lake Avon (HGEO, 2019b; SCT, 2017) and near Sandy Creek (SCT, 2019a) does not support these being the primary potential groundwater pathways in off-goaf areas. Broader deformation or valley closure is represented in the modelling as outlined in the response to #2 and #4.
4	Off-goaf fracturing	The groundwater model simulates off-goaf Kh enhancement, although this may be accounted for via the 'valley-bulging' mechanism described earlier #2. Enhancement has been represented as occurring up to 600 m from longwalls and being applied as declining with distance.	Sections 3.6.3 and 5.4.4.
5	Representation of fracturing through to surface in Area 3B	Neither the Tammetta (2013) or Ditton (Ditton and Merrick, 2014; DGS, 2016) models were supported by the PSM study or reviews, although IEPMC (2019a) consider the Tammetta method to be an appropriate tool for assessments, in the absence of other more site-specific data. There is clearly some form of fracturing from the seam to the surface above Area 3B and 3A panels (HGEO, 2020c). 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.	The revised modelling in this study began with PSM's conservative assumption, and then worked to calibrate the model to inflow and groundwater levels (drawdown) while holding to the constraints and soft evidence of recent centre-line bore investigations.
6	Geotechnical modelling	Geotechnical modelling could be done prior to groundwater modelling (e.g. FLAC) or coupled (e.g. COSFLOW). Geotechnical (FLAC) modelling has been carried out by SCT for longwalls in other parts of Dendrobium Mine. HydroSimulations (2019c) and then SLR (2020a) 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.). However, this approach is not used in this study.	This update to the model does not rely on the geomechanical modelling by SCT, which had been previously used in HydroSimulations (2019c) and SLR (2020a). This study has concentrated on constraining the model, where possible, using the recently acquired field data by simulating enhanced bulk properties via the TVM package (Section 5.4).

1.5.3 Report structure

The structure of this report is outlined in **Table 1-6**. This report presents a brief description of the relevant environmental features of the site (topography, climate and weather, geological setting) and an update of hydrogeological features and parameters. Further detail of the rainfall, evaporation, topography, geology, as well as detailed descriptions of the conceptual and previous numerical modelling can be accessed through the following reports:

- Coffey, 2012a and 2012b;
- HS, 2014;
- HS, 2016a;
- HS, 2016b;
- HS, 2018;
- HS, 2019a;
- HS, 2019b;
- HS, 2019c; and
- SLR, 2020a.

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

- Groundwater: e.g. HydroSimulations 2012-2016 and HGEO, 2017-2020; and
- Surface Water and Shallow Groundwater, e.g. HGEO, 2017-2020.

A summary of the above work and new field data, analysis and interpretation is presented, as well as changes to groundwater modelling and associated forecasts.

Table 1-6 Outline of report structure

Section	Title	Contents
1	Introduction	Description of operations and the proposal at the Dendrobium Mine and the scope of work.
2	Data analysis	Describes the environmental context for the area where Dendrobium Mine is located.
3	Hydrogeology	A summary and discussion of key facets of the groundwater system, including discussion of relevant points from PSM (2017) and IEPMC (2018 and 2019a;b).
4	Hydrogeological 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.
5	Numerical model development	Describes changes to the groundwater model to meet relevant conditions as well as other modifications.
6	Numerical model history-matching	Outlines the procedure and the results of model history-matching phase of work, focussing on observations and data that are most relevant to the predictions required.
7	Model forecasting	Presents output from the updated model, including predicted groundwater inflow, groundwater level and pressure hydrographs/maps/profiles, and incidental take from surface water features.
8	Conclusions	Summarises the assessment of Longwall 18 and Dendrobium Mine against relevant requirements. Recommendations regarding monitoring.

2 Environmental context

The following sections describe the contextual setting and environmental features relevant to subsequent discussion of the groundwater system (Sections 3 and 4) and numerical modelling (Section 5) of the effects of Dendrobium Mine within that system.

2.1 Land use

Land use is mainly land reserved as part of Sydney's drinking water supply catchments, WaterNSW's Special Areas, as shown on **Figure 1-1**. This includes the major reservoirs of the upper Nepean system (Section 2.4.2). These catchment areas are primarily native forest with some areas of swamp vegetation.

Cleared areas or urban areas are restricted to the coastal plain east of Dendrobium (such as the suburbs around Wollongong) or inland (west) of Dendrobium, e.g. Bargo and Yanderra which are 12 km northwest of Area 3B, and Wilton which is approximately 15 km north of Area 3B.

Mining is present within (under) and outside of the Special Areas, as noted in Section 1.3.

2.2 Topography

Dendrobium Mine is located on the Woronora Plateau above or inland of the Illawarra Escarpment (**Figure 2-1**). The escarpment rises from the coastal plain around Wollongong to elevations greater than 400 mAHD around Dendrobium. On the plateau, topography generally slopes to the north or northwest, toward the centre of the Sydney Basin. The plateau is dissected with the larger valleys incised 50-100 m into the terrain, and these typically host the larger creeks, e.g. Wongawilli Creek, and rivers, e.g. Cordeaux River (Section 2.4), and the reservoirs (Section 2.4.2).

Within the Area 3B longwall footprint, ground elevation ranges between 320 mAHD (northeast corner) to 415 mAHD in the centre of the area, averaging about 400 mAHD. Topographic elevation in the centre of Longwall 18 is approx. 400-410 mAHD and as low as 360 mAHD within the panel footprint. Topography declines to about 302 mAHD at Wongawilli Creek directly to the east, and to about 320 mAHD at the shore of Lake Avon to the west.

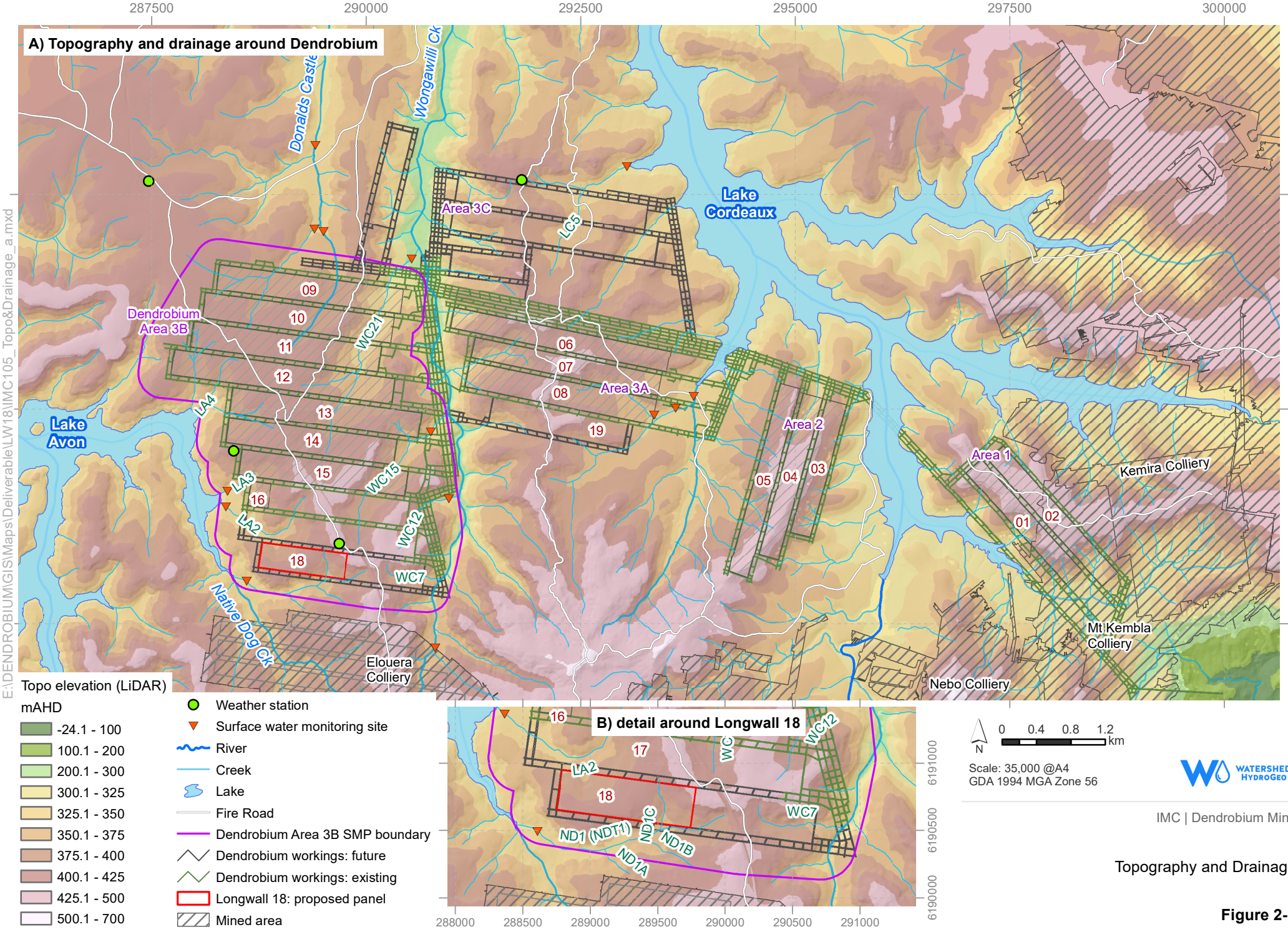
Review of WaterNSW's bathymetry data directly to the west of Longwall 18 indicates that the deepest floor elevation in this part of Lake Avon is approximately 297 mAHD. This is higher than the 286 mAHD directly west of Longwall 15, and 277 mAHD recorded near Longwalls 12 and 13.

2.3 Climate

2.3.1 Rainfall

IMC records daily rainfall at multiple stations around the site, and this is augmented through inspection of long-term averages and records obtained from the Bureau of Meteorology (BoM) and SILO. Average rainfall for the period 1961-1990 was about 1200-1400 mm/yr at Dendrobium. This compares with averages of 1010-1070 mm/yr as recorded at the IMC stations for the period 2003 to March 2020.

Figure 2-2 shows long-term rainfall trends, as defined by the cumulative rainfall deficit curve. This shows the historical occurrence of wetter than average periods (upward trends) and dry periods (downward trends). The low rainfall totals during the 2-3 years to Feb-2020 and the slope of the trend curve are indicative of rainfall deficits assessed by BoM (2020) as 'severe [rainfall] deficiency]' to 'lowest on record'.



IMC | Dendrobium Mine

Topography and Drainage

Figure 2-1

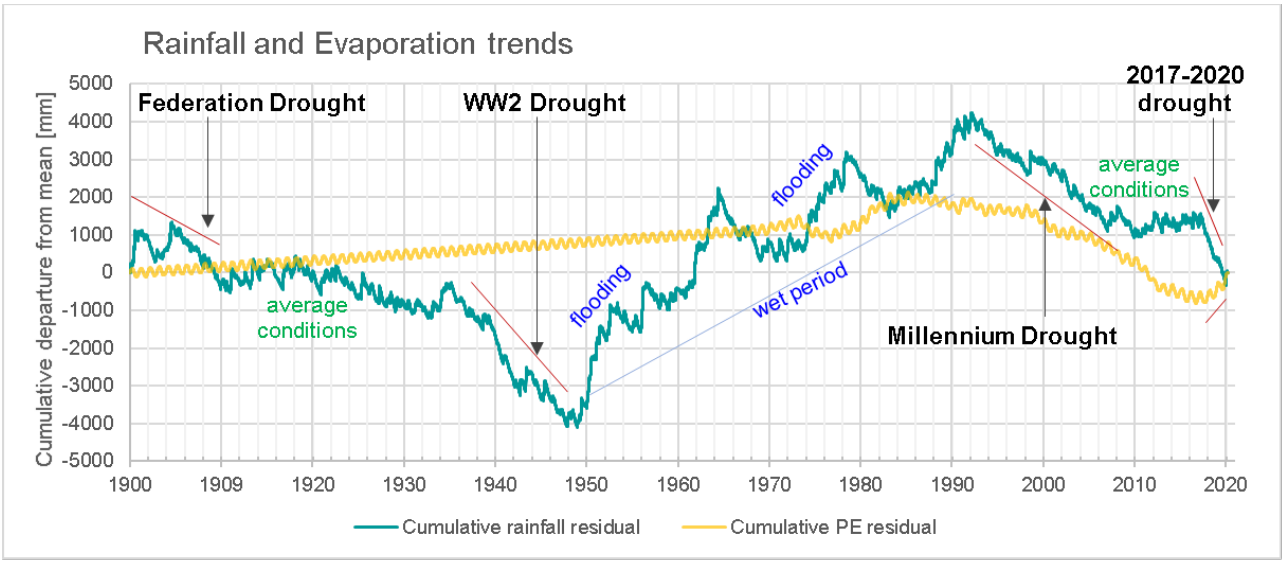


Figure 2-2 Rainfall and evaporation trends

2.3.2 Evaporation

Long-term average potential evaporation (PE) is approximately 1430 mm/yr at Dendrobium, and slightly higher at Wollongong on the coast (1520 mm/yr). Actual ET[1] at Dendrobium is approximately 920 mm/yr. During the recent drought, PE was higher than is typical, exacerbating the effect of the rainfall deficits (**Figure 2-2**). PE rates for the period prior to 1973 are infilled (by BoM/SILO) with the long-term average.

2.4 Drainage and hydrology

The Dendrobium mining area is located within the catchment of the upper Nepean River. Drainage is to the north-northwest, towards the Nepean River, with most of the local surface runoff initially captured in Nepean, Cataract, Cordeaux and Avon lakes, before eventually flowing into the Nepean River. The latter two lakes, which are adjacent to Dendrobium mining areas, are described in more detail in Section 2.4.2.

The significant watercourses around Area 3B are (**Figure 2-1**):

- Wongawilli Creek, which flows north from above Elouera Colliery and between Dendrobium Areas 3A and 3B. The creek is approximately 1050 m east of the edge of Longwall 18. This is significantly further than the distance between Wongawilli Creek and other Area 3B panels, which are typically 300-600 m from the creek.
- Native Dog Creek, which flows northeast from above Elouera Colliery and 350 m to the south or southwest of Longwall 18.
- Donalds Castle Creek, which flows north from above Area 3B. The headwaters of this creek are about 2.5 km north of Longwall 18.

Multiple tributaries to these watercourses and to the reservoirs are identified immediately around Longwall 18 (**Figure 2-1**). These include LA2 and LA3 which flow into Lake Avon, of which LA2 is

[1] Actual ET is the ET that actually takes place, under the condition of existing water supply, from an area so large that the effects of any upwind boundary transitions are negligible and local variations are integrated to an areal average.

100 m to the north of Longwall 18 and directly above Longwalls 16 and 17. WC15, WC12 and WC7, which are tributaries to Wongawilli Creek, are 200 m, 600 m and 700 m to the east or northeast of Longwall 18 respectively. Tributary ND1 of Native Dog Creek flows immediately to the south of Longwall 18, while minor tributary ND1C flows directly over the panel.

2.4.1 Monitoring

IMC has been monitoring stream level and flow around Areas 3A and 3B since late 2007. HGEO (2020) and the *Watercourse Impact Monitoring, Management and Contingency Plan* (WIMMCP) has more detail on surface water monitoring around Area 3B. Monitoring sites are shown in Figure 2-1. Of note are recently installed gauging stations near to Longwall 18:

- LA3S1 on LA3: installed 31/01/2019. This watercourse has possibly been affected by mining of Longwall 15, and would likely be affected by Longwall 16 (HGEO, 2020).
- LA2S1 on LA2: installed 01/02/2019. This watercourse would likely be affected by the extraction of Longwall 16, and then more significantly by Longwall 17.
- ND1S1on ND1: installed 03/03/2019. As noted previously, this watercourse is adjacent to Longwall 18, and would likely be affected by extraction of this panel. (Note that in some mapping and databases, this tributary is referred to as NDT1).

2.4.2 Reservoirs

Lakes Avon and Cordeaux are water supply reservoirs formed by the damming of the upper Avon and Cordeaux Rivers, and form part of the Upper Nepean Scheme, along with Lakes Nepean and Cataract, which are located further from Dendrobium. Relevant details are presented in **Table 2-1**.

Table 2-1 Water supply reservoirs near Dendrobium

Reservoir	Area (sq.km)	Operating Capacity (ML)	FSL (mAHD)	Deepest bed depth (mAHD)	Intersected stratigraphy (from Moffitt, 1999)
Cordeaux	7.8	93,640	303.9	255.8	Hawkesbury Sandstone, Bald Hill Claystone, Bulgo Sandstone, Stanwell Park Claystone, Scarborough Sandstone
Avon	10.5	146,700	320.18	253.4	Hawkesbury Sandstone and Bald Hill Claystone

Sources: http://www.waternsw.com.au/supply/visit/. Lake bed bathymetry data from WaterNSW.

Lake Cordeaux is located approximately 370 m east of Area 3A longwalls and 4.5 km northeast of Longwall 18. The Native Dog Creek arm of Lake Avon is 305 m west of Longwall 18, and all of Longwalls 13-17 have been or will be a similar distance (>300 m) from the Avon shoreline at FSL.

Surrounding shallow groundwater levels are typically higher in elevation, resulting in groundwater discharging to the lake (HS, 2014c), although this is not always the case, and dependent on which geological formations are present along the lake shore and beneath the lakes. Drawdown in units at or below the base of the lakes can result in reversal of groundwater gradients.

2.5 Geology

The Southern Coalfield is part of the Sydney Basin. Outcrop mapping is based on the Southern Coalfield Regional 1:100,000 Geology Map (Moffit 1999) as well as site specific data. 3D mapping of geometry is based on IMC's geological model, derived from exploration data and outcrop mapping.

2.5.1 Stratigraphy

The stratigraphy of the Southern Coalfield is Permo-Triassic sedimentary rock and is underlain by undifferentiated Carboniferous and Devonian aged sediments. The significant parts of the sequence are summarised in **Table 2-2** (which is from HS, 2019c). The thicknesses reported are representative only. The table includes abbreviations for the stratigraphic units which are often used on figures. The whole sequence comprises interlayered sandstone, claystone, siltstone, and, within the Permian strata, coal seams, to significant depth (>400-500 m).

Table 2-2 Summary of the stratigraphic sequence

Period	Group	Sub-group	Formation		Description	Typical thickness (m)
Quat-ernary			"Swamp" deposits		Sands, silts, organics and peat.	1-3
Triassic	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
	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 Subgroup	Bald Hill Claystone (**BHCS**)		Massive chocolate coloured and cream pelletal claystones and mudstones, and occasional fine-grained channel sand units (Moffitt, 1999).	12-20
			Colo Vale Sandstone (**CVSS**)	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	Illawarra Coal Measures				Coal interbedded with siltstone, claystone, quartz-lithic sandstone and minor conglomerate (Moffitt, 1999). Includes the Bulli Coal (**BUSM**/**BUCO**), Balgownie Coal, Wongawilli seam (**WWSM**/**WWCO**) and Tongarra Coal, plus Loddon/Lawrence Ssts (**LRSS**) and Kembla Sandstone (**KBSS**).	200-300
	Shoalhaven Group				various sedimentary and igneous units	

Table modified from HS (2019c)

Figure 2-3A shows that around Area 3B, the dominant outcrop type is the Hawkesbury Sandstone (HBSS), with minor occurrences of Quaternary swamp sediments. There are some exposures of underlying Narrabeen Group, specifically the Bald Hill and Bulgo Sandstone or Colo Vale Sandstone along Wongawilli Creek to the east of Longwall 18.

Cross-sections shown in **Figure 2-5** and **Figure 2-6** (from HGEO, 2020d) illustrate the main units and geometry of the sequence around Longwall 18. These show that the Wongawilli Seam is 300-370 m deep across the footprint Longwall 18, being 340 m at the centroid of the panel. Outside of the panel footprint, depth of cover then declines, mainly associated with variable ground surface topography, to 220-240 m near Wongawilli Creek and down to 240 m beneath Lake Avon.

2.5.2 Structural features

Regional structure, as mapped by Moffitt (1999)[2], is presented on **Figure 2-3A**. Structural features of note around Area 3B are:

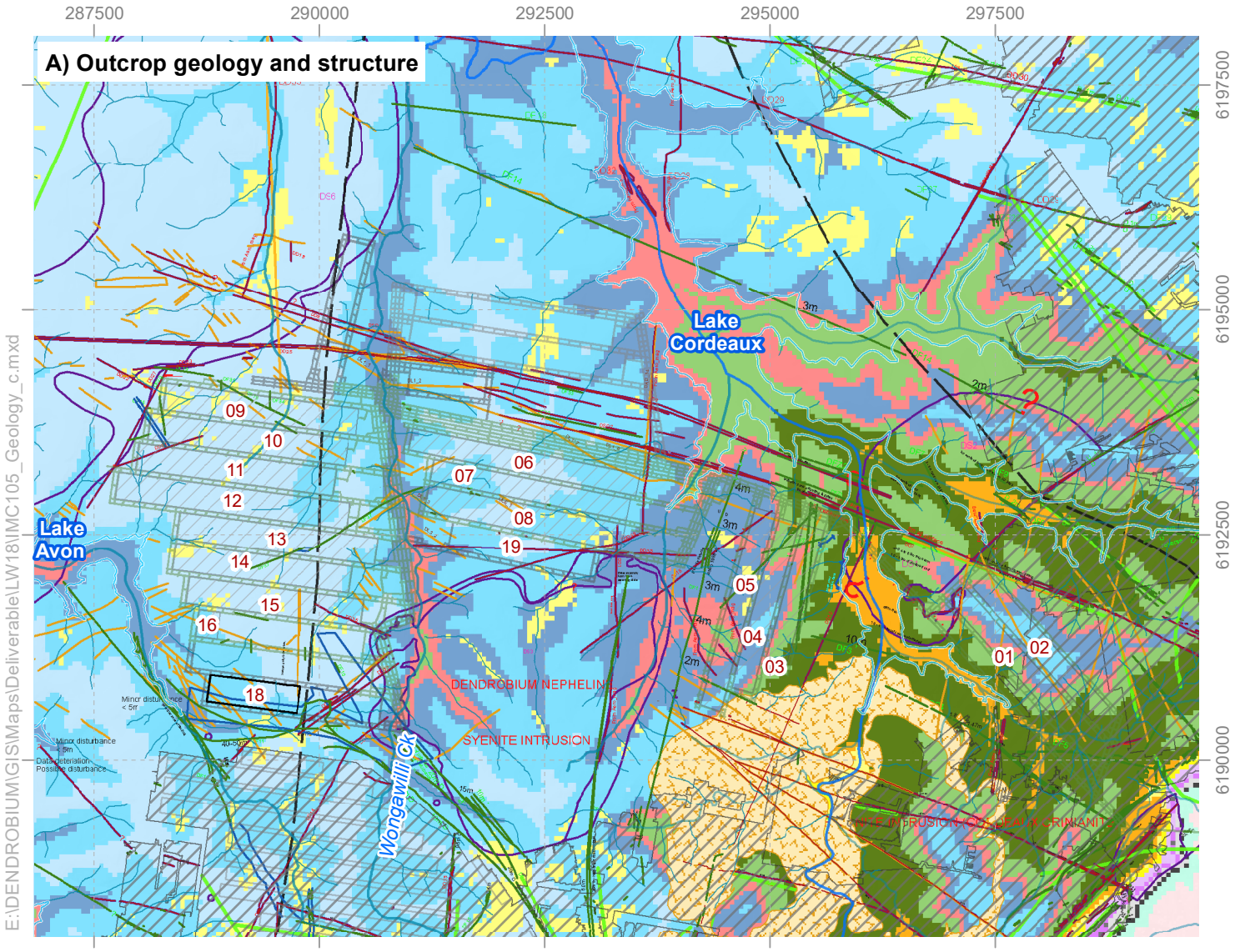
- A large syncline (fold) plunges to the north through Area 3B and Elouera Colliery;
- the Narellan Lineament, which runs north from Longwall 9 and essentially coincident with Donalds Castle Creek; and
- To the east of Area 3B and south of Area 4 is the Dendrobium Nepheline Syenite sill. Within the seam, this occurs around the Wongawilli Mains (**Figure 2-4**), but extends over the top of the Wongawilli Seam working section in the upper parts of the seam. The effects of this structure on mining are expected to be relatively minor (IMC, 2020) because the mine plan essentially avoids this feature.

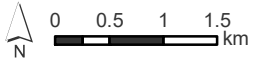
Tonkin and Timms (2015) reviewed historical data on geological structures in the Southern Coalfield and their role in transmitting groundwater. The review found that >95% (1580/1660) of structures near reservoirs and underground workings were not associated with any groundwater flow, and flow at the other 5% was less than 0.001 ML/d, with the exception of two where flows were 0.01 ML/d. Structures were found to be relatively short compared to the depth of cover and often infilled with weathered materials. Horizontal stress was found to typically close, not open, such structures and reduce the effective hydraulic conductivity. This was based on analysis of dyke and fault systems around Dendrobium.

Smaller structures, typically faults and dykes, have been mapped by IMC geologists. As mining approaches an area, knowledge of local structure and geological conditions improve. IMC prepared a technical note as workings moved south toward Longwall 18 (IMC, 2018) and the understanding of conditions at Longwall 18 have improved again since then (IMC, 2020). IMC (2020) describes the investigation of geological structures around Longwall 18 and the evolution of knowledge of these since 2012.

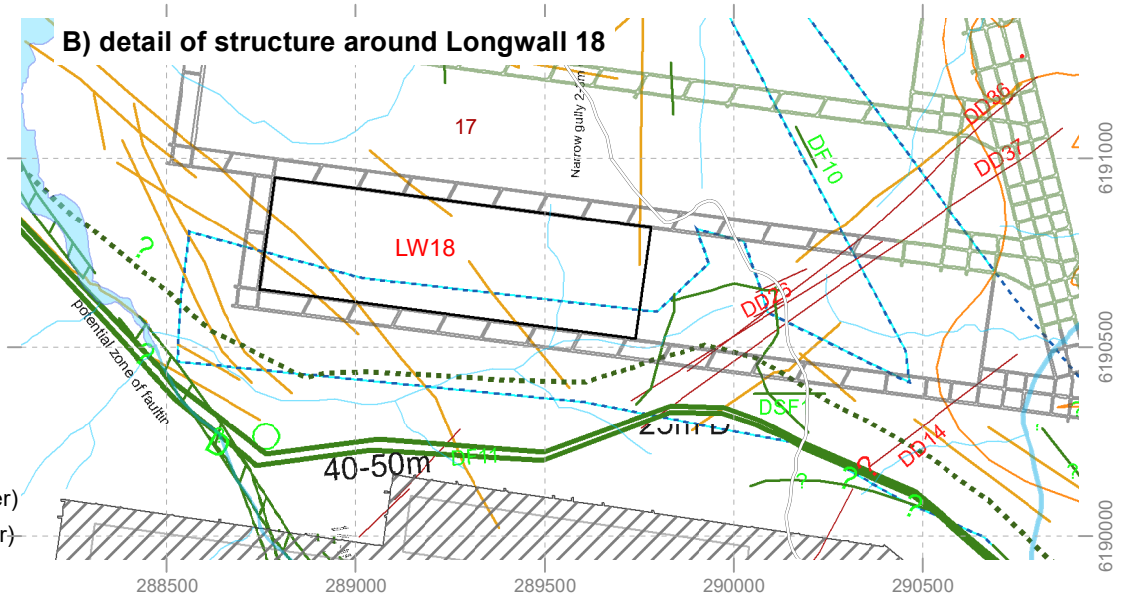
Of most relevance to Longwall 18 are the structural zone between the Wonga Mains (Figure 1-2) and Longwall 18 and also the Elouera Fault zone (to the south and west of the panel). These are shown on **Figure 2-3B** and **Figure 2-4** and described further in the following sections.

[2] If necessary, refer to the original: www.resourcesandenergy.nsw.gov.au/__data/assets/image/0004/352858/Southern_Coalfield_regional_100K_Geology_Map_1st_ed_1999.jpg





Scale: 20,000 @A4
GDA 1994 MGA Zone 56



- Cordeaux Crinanite
- Swamp deposit
- Wianamatta Fm
- HBSS (upper)
- HBSS
- HBSS (lower)
- Bald Hill Claystone
- Bulgo Sst (upper)
- Bulgo Sst (lower)
- Stanwell Park Clst
- Scarborough Sst (upper)
- Scarborough Sst (lower)
- Wombarra Clst
- Coalcliff Sst
- Bulli Coal
- Loddon / Lawrence Sst
- Wongawilli Coal
- lower Coal Measures
- Shoalhaven Group

- Southern CF: fault
- Southern CF: fold
- Southern CF: structure

Geological structure (IMC mapping)

- Fault
- Dyke
- Lineament

Elouera Fault mapping

- Fault trace at surface
- Fault in WW Seam

Created by: WMinchin | Version: C | Date: 27/07/2020

WATERSHED HYDROGEO

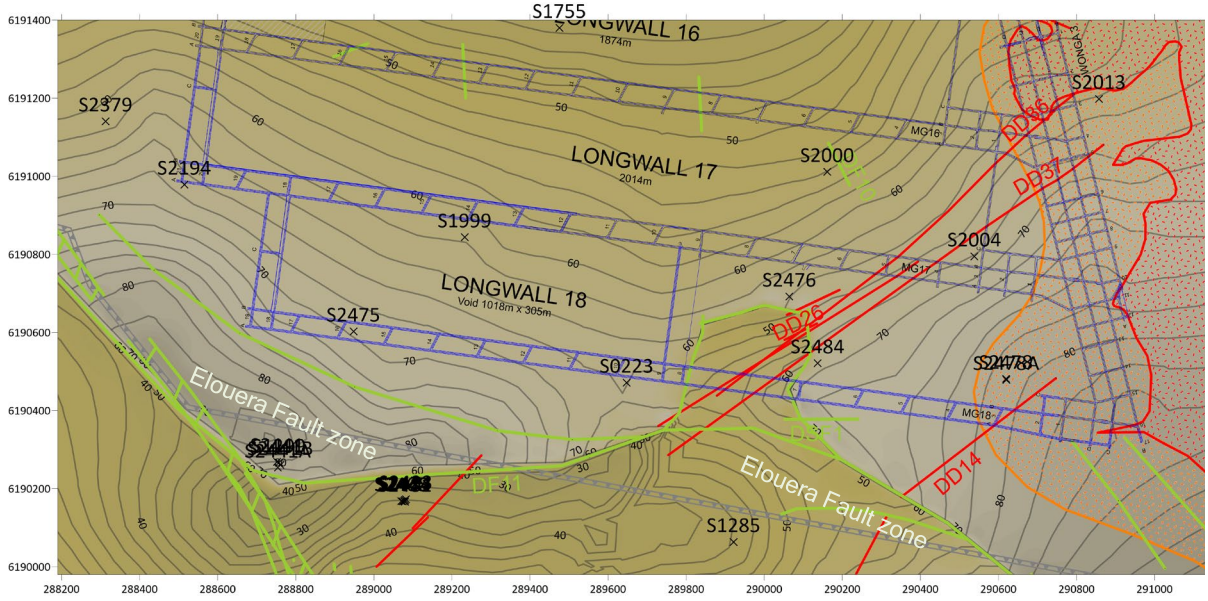
IMC | Dendrobium Mine

Geological setting

Figure 2-3

2.5.2.1 Structural zone east of Longwall 18

This zone was detected by IMC in 2012 from seismic surveys, with recommendations at the time to investigate this zone further when practical and necessary. Since 2018, and as mine workings have approached from the north, inseam drilling and more exploration drilling from the surface and further underground mapping have developed the understanding of this zone.



----	Fault or fault zone		Syenite intrusion above working section
----	Dyke		Syenite intrusion within working section
		x	Exploration bore

Figure 2-4 Coal seam floor elevation and structural features (from IMC, 2020)

A section of the Wongawilli seam is downthrown 10-15 m (**Figure 2-5**), with the eastern edge of the zone being coincident with dykes DD36, DD37 and DD26 (**Figure 2-4**). IMC geologists believe that this fault is connected to the Elouera Fault zone (Section 2.5.2.2). There is no evidence of any surface expression of this feature. IMC geologists speculate that, like many other faults identified within the seam around Dendrobium, displacement diminishes above the seam; this is not confirmed, but the lack of surface expression supports this.

The degree of displacement of the seam has meant that the eastern end of Longwall 18 has been shortened by 800 m from its originally planned length, and setback about 70 m from the fault zone.

2.5.2.2 Elouera Fault (DF11)

IMC's system of mapping and identifying structures has listed the fault in this zone as DF11 (**Figure 2-4**). IMC (2020) describes the Elouera Fault as follows: "To the south of MG18 is a regional fault zone known as the Elouera Fault which is downthrown some 20-40 m to the south and separates the Dendrobium workings from Wollongong Coal's Wongawilli [Elouera] Colliery workings".

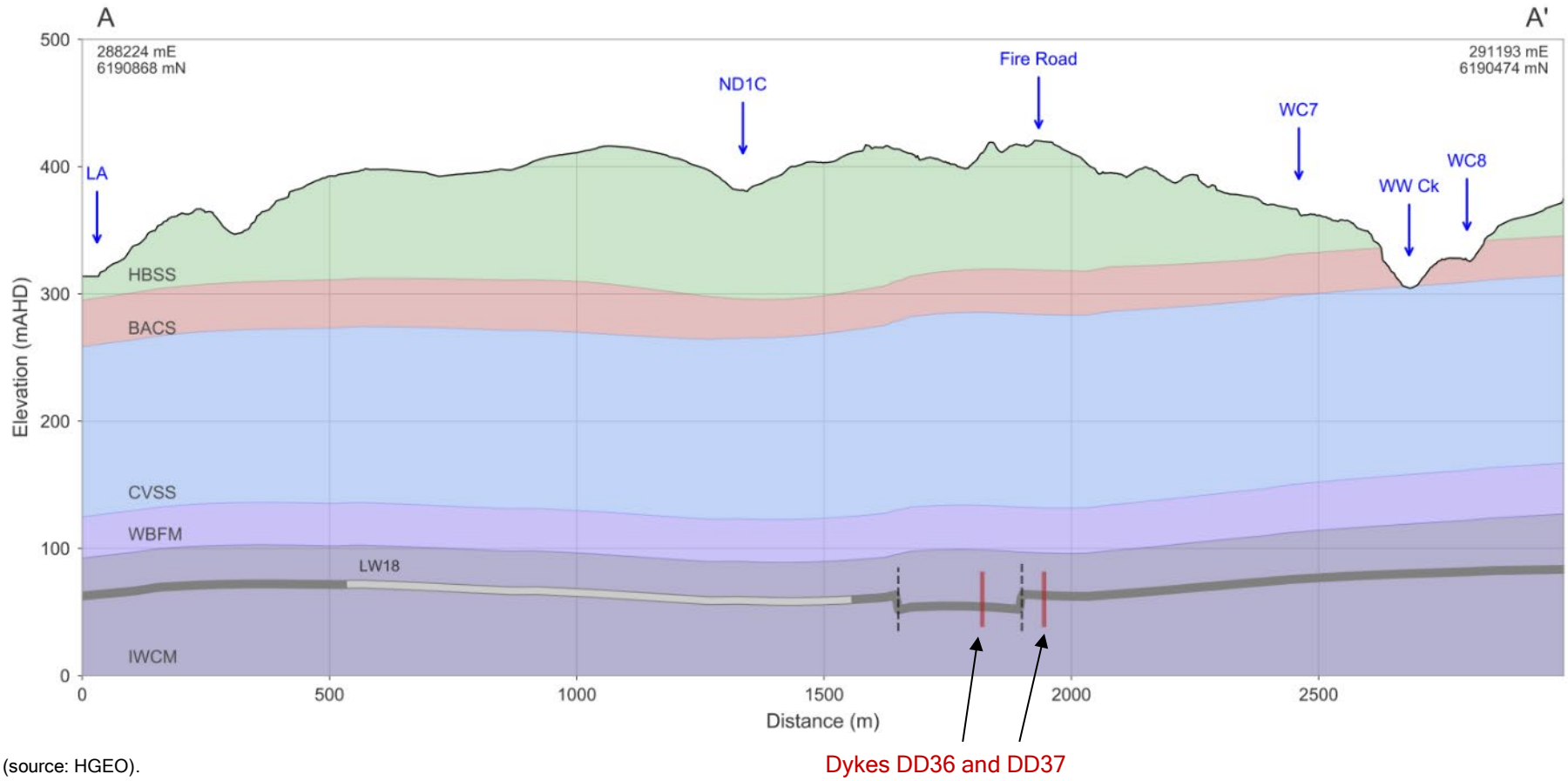
IMC commissioned further investigation into the Elouera Fault, and as of late 2019, nine (9) cored holes had been drilled across 3 sites around the inferred fault zone. Data was analysed by HGEO (2019 and 2020d). Based on vertical and angled drillholes, seismic surveys and packer tests, HGEO made the following observations on the fault zone:

- It comprises three distinct but (structurally) connected fault zones and several splay structures.
- It is most evident in the Wongawilli Seam, where it offsets the seam by up to 40 m (down-thrown to the south, as on **Figure 2-6**). Recent drilling has identified the fault within the Colo Vale Sandstone (CVSS) where the offset is approximately 30-40 m. More recent holes drilled near Swamp 35b indicate that the fault zone is present in the Bald Hill Claystone (BHCS), where the offset is unclear, but is approximately 13 m (HGEO, 2020d).
- The fault zone is inferred to reach to surface. While the projected fault trace appears to correspond to a prominent break in slope and several topographic lineaments in the northern slopes of the ND1 valley, the fault has not been identified in surface mapping.
- The offsets were analysed by HGEO with respect to the potential increase in transverse permeability (across the fault plane). The offsets indicate that at seam level (Wongawilli and Bulli Seams) there will be juxtaposition of these more permeably features with lower permeability rock (claystone, sandstone) units. Higher up the sequence, the offset (13 m) at the BHCS is not sufficient to result in complete offsetting of the CVSS against the HBSS. Furthermore, even if that does occur, the CVSS is not typically an aquifer of sufficient hydraulic conductivity (both absolutely and also in terms of difference with the BHCS) to significantly alter groundwater flow patterns.
- The fault zone is observed as being metres to tens of metres thick (8 to 31 m; HGEO 2020d), with high joint and fracture density compared with adjacent strata. However, despite the high fracture density, the permeability of the fault zone is typically within the range of Colo Vale Sandstone in pre-mining bores at Dendrobium.
- There are zones of elevated permeability near investigation bore S2441A, however other holes do not show the same association suggesting the fault zone permeability is highly variable along its length (i.e. not a longitudinally permeable feature).
- Investigations immediately adjacent to Elouera Longwall 8 indicate that altered stress conditions within the fault due to previous mining at Elouera have not resulted in significant changes in permeability within the fault zone.

The fault dips at approximately 60° to the south, which means that the fault plane is closer to the Longwall 18 footprint higher up in the sequence, as illustrated on **Figure 2-3B** and summarised in **Table 2-3**.

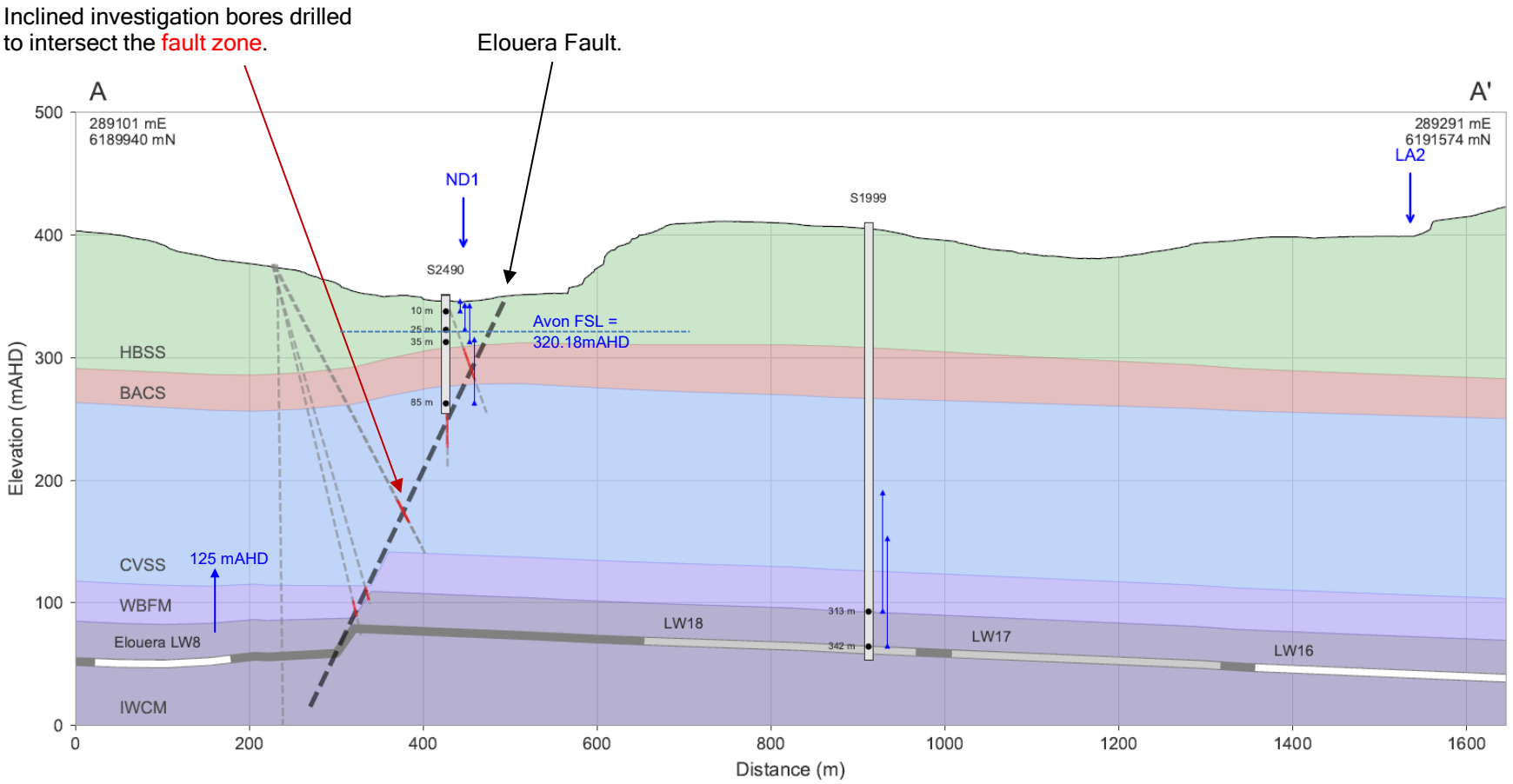
Table 2-3 Distance from Longwall 18 footprint to the Elouera Fault

Longwall 18 position	Distance (m) at seam level	Distance (m) at surface level	Comment
South-eastern corner of panel	190 m SSE	60 m S or SE	This is near Swamp 35a
Middle of panel	330 m S	140-170 m S	This is the area where ND1 (and Swamp 35b) crosses the fault trace
South-western corner of panel	320 m SW	150 m S or SW	This is the area nearest Lake Avon
Western end panel (nearest Lake Avon)	470 m	460 m W	This is where the inferred surface trace intersects Lake Avon



(source: HGEO).

Figure 2-5 Cross-section through Longwall 18 (Lake Avon to Wongawilli Creek)



(source: HGEO).

Figure 2-6 Cross-section through Longwall 18 and Elouera Fault zone (south to north)



(provided by J Doyle, Geosensing)

Figure 2-7 View of Elouera Fault within Elouera Mine

The fault was previously intersected by the Elouera Colliery, as shown in **Figure 2-7**. This intersection is inferred to be at a stub located approximately 2 km southwest of proposed Longwall 18. The observations provided with the photo were:

"*the intersection was in an easterly oriented blind stub, driven as a water sump, to the east of the access roadways on the eastern margin of the longwall area. To my recollection, the sump was typically Wongawilli seam damp with no drippers. Specifically, no water was noted associated with the fault plane*."

2.5.2.3 Lineaments

Four mapped lineaments cross the footprint of Longwall 18; two of those lineaments also cross the ND1 tributary (to the south) and one extends northwest to the Lake Avon shoreline. Underground geological mapping and drilling has not identified structures of the same orientation that would intersect Longwall 18.

SRK (2020) assessed the presence of surface structures, including lineaments, and the role these might play in enhancing subsidence and environmental impacts around mining areas. SRK noted that the conditions at Dendrobium (Southern Coalfield) are different to those in the Western Coalfield (e.g. at Springvale Mine) where lineaments around mining areas enhanced subsidence effects to significant distances, leading the transmission of effects out to hundreds of metres or a kilometre or so from Springvale workings. SRK's conclusions, based on review of structural and historical subsidence data at Dendrobium, were that "*There is evidence of very minor displacement on discontinuous surface*

structures immediately above the mined areas", and more significantly, "*no conclusive evidence … in the data to indicate movement on structures outside the mine areas*". Related to this last point, SRK noted that "*longwall mining activities to date at Dendrobium appear to have had little effect in the reactivation of surface lineaments. Very minor displacement on faults is evident… over Area 3B.*".

2.6 Effects of Longwall Mining on geological strata

The effect of longwall mining, in terms of the physical changes it causes to geological strata is important to the context of subsequent description of hydrogeology. More detail on specific aspects of this is presented in Section 3.6, however it is important to outline the broad behaviours prior to more detailed analysis.

Extraction of coal using longwall methods commonly results in ground subsidence and associated deformation and fracturing of overlying and adjacent strata (Peng and Chiang, 1984; Whittaker and Reddish, 1989). While authors differ in their terminology, there is general agreement on the overall patterns of deformation. Specific 'zones' are often used to describe the conceptual model (as on **Figure 2-8**), although as noted by various authors (PSM, 2017; Mackie, 2017) the reality is that there are typically not discrete boundaries between zones, but more a continuum of fracture modes and intensity depending on the lateral or vertical location above or offset from a longwall panel and the geometry of the longwalls in relation to the depth of cover, and their geological and topographic setting.

Fracturing is most intense and vertically connected immediately above the collapsed longwall (goaf) (the 'caved zone'), and within the 'fracture zone' the intensity of fracturing grades upwards through to less fractured strata (Booth, 2002). Fracturing of the overburden can cause significant changes in aquifer characteristics such as hydraulic conductivity and secondary porosity (storage), and potentially can provide pathways for vertical groundwater movement between shallow groundwater and surface water systems and underground mines (Advisian, 2016; McNally and Evans, 2007).

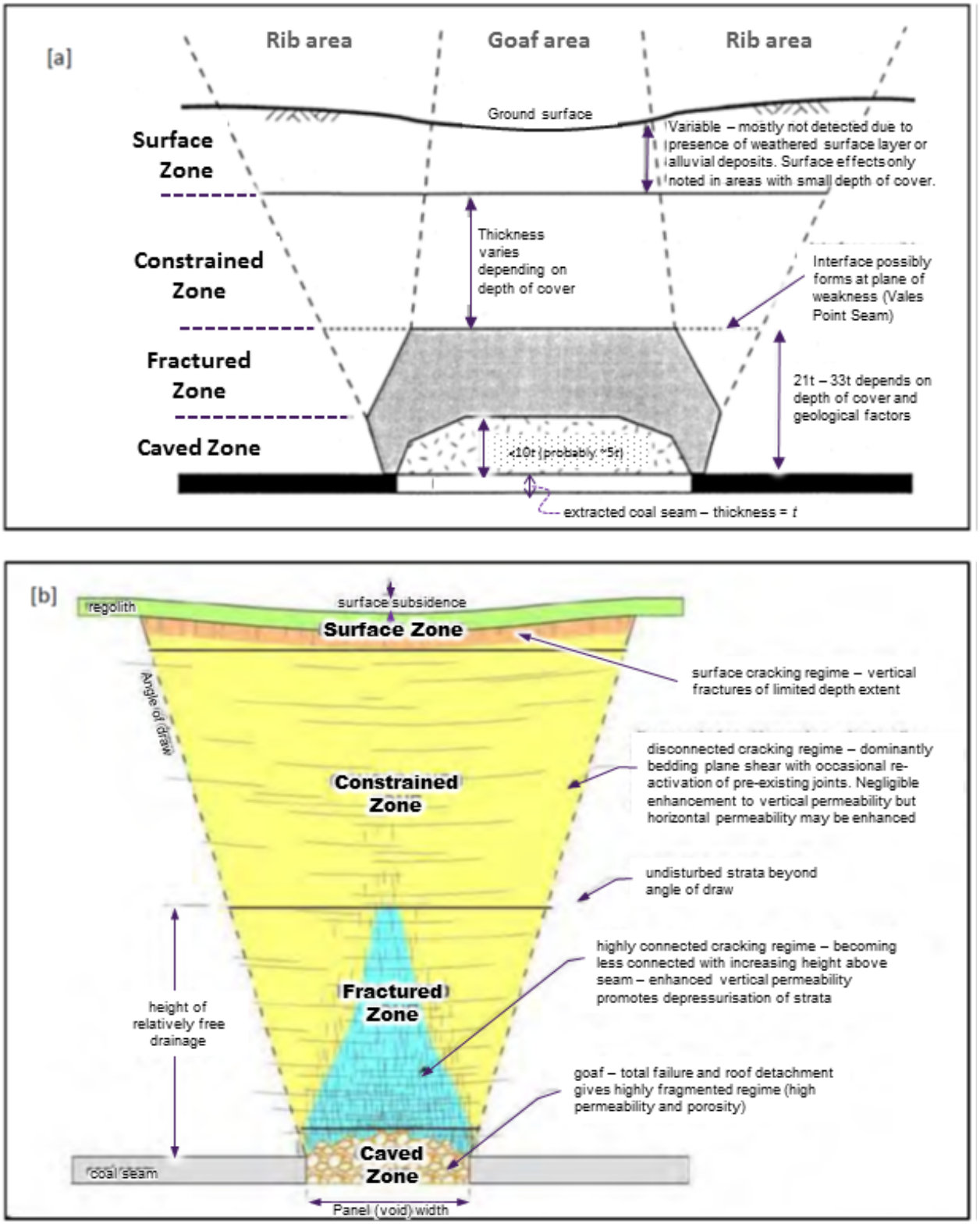
Beneath the mined panel, deformation due to unloading and heaving can occur in the floor strata (Meaney, 1997; Karacan *et al.*, 2011).

Deformation of geological strata may also occur outside the footprint of longwalls. As noted in Section 2.5.2.3, such effects might occur out to distances of over 1 km, such as at Springvale Mine (which is in a different geological and structural setting to Dendrobium). At Dendrobium effects specifically associated with structures are not observed far beyond panels (SRK, 2020). However, valley closure effects, such as at Sandy Creek or the Avon Reservoir shoreline, have been assessed to occur to over 600 m (Section 3.6.3).

At the surface, subsidence and tension across the subsidence trough combine to cause 'surface cracking'. This is significant with respect to impacts on surface water features, such as watercourses and swamps, that may overlie or be adjacent to longwalls.

Between the surface zone and the fractured zone, a 'constrained zone' may occur, with minimal disturbance of strata. The longwall geometry at Dendrobium has not allowed for such a zone to occur.

The height to which vertically-connected and potentially free-draining fracture networks extend above the mined seam and the hydraulic properties (hydraulic conductivity and drainable porosity) within this area are therefore important in assessing potential impact of longwall mining on groundwater and surface water systems. Further analysis of specific effects, including the height of deformation and the effects on strata permeability based on recent investigations at Dendrobium (most significantly, the analysis of HGEO, 2020c), are presented later, in Sections 3.6.1.



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

Figure 2-8 General Conceptual Models of Subsidence and Deformation above Longwalls

3 Hydrogeology

The following sections outline the baseline or existing hydrogeological conditions or parameters. Where longwall mining is considered to affect these, a subsection summarises the relevant studies and data analysis and associated findings.

3.1 Groundwater Users

The distribution of groundwater bores, as registered in the NSW government database, is shown on **Figure 3-1**. Bores around Dendrobium are all exploration and monitoring bores associated with mining. The non-mining bores are located on the coastal plain (east of the escarpment) and 10 km west and further south of Dendrobium, around Bargo/Pheasants Nest and the Southern Highlands respectively. This highlights the lack of population immediately around the Dendrobium mining areas, consistent with the dominant land use (Section 2.1).

The details of the nearest groundwater works that are considered 'water supply works', as per the AIP, are summarised in **Table 3-1**. All other Groundwater Works are further from Longwall 18, and most of them are along the coastal plain, and stratigraphically separated from the coal measures.

Table 3-1 Bores (GW works) nearest Dendrobium Mine

GW work ID	Distance from Dendrobium Mine	Distance from Longwall 18	Description
GW112386	1.9 km north of Area 3A, 0.5 km northeast of A3C Longwall 23.	5.9 km to the NE	Monitoring bore installed by the WaterNSW on western edge of Lake Cordeaux.
GW040945	7.2 km WNW of Area 3B	9 km to the NW	WaterNSW test bore drilled to investigate groundwater supply near L. Avon dam.
GW068119 and others	4.5 km south of Areas 1-2	8.2 km to the 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	15 km to the north	Domestic/stock bore completed in the Hawkesbury Sandstone, just south of Wilton.

3.2 Groundwater Dependent Ecosystems (GDE) and environmental features

3.2.1 High Priority GDEs

There are a number of High Priority GDEs listed in the relevant WSPs in this region (**Figure 3-1**). However, none of these High Priority GDEs are in close proximity to Dendrobium. The nearest such feature is the Macquarie Rivulet Estuary, located 17 km to the south of Longwall 18. These features are therefore not at risk from the extraction of Longwall 18.

3.2.2 Upland Swamps

Figure 3-1 shows the regional distribution of Upland Swamps around the Southern Coalfield, based on regional mapping by NSW OEH (now BCD) and by IMC in the area around Dendrobium.

The Surface Water assessment (HGEO, 2020e) describes these further, and the likely effects of the proposed longwalls.

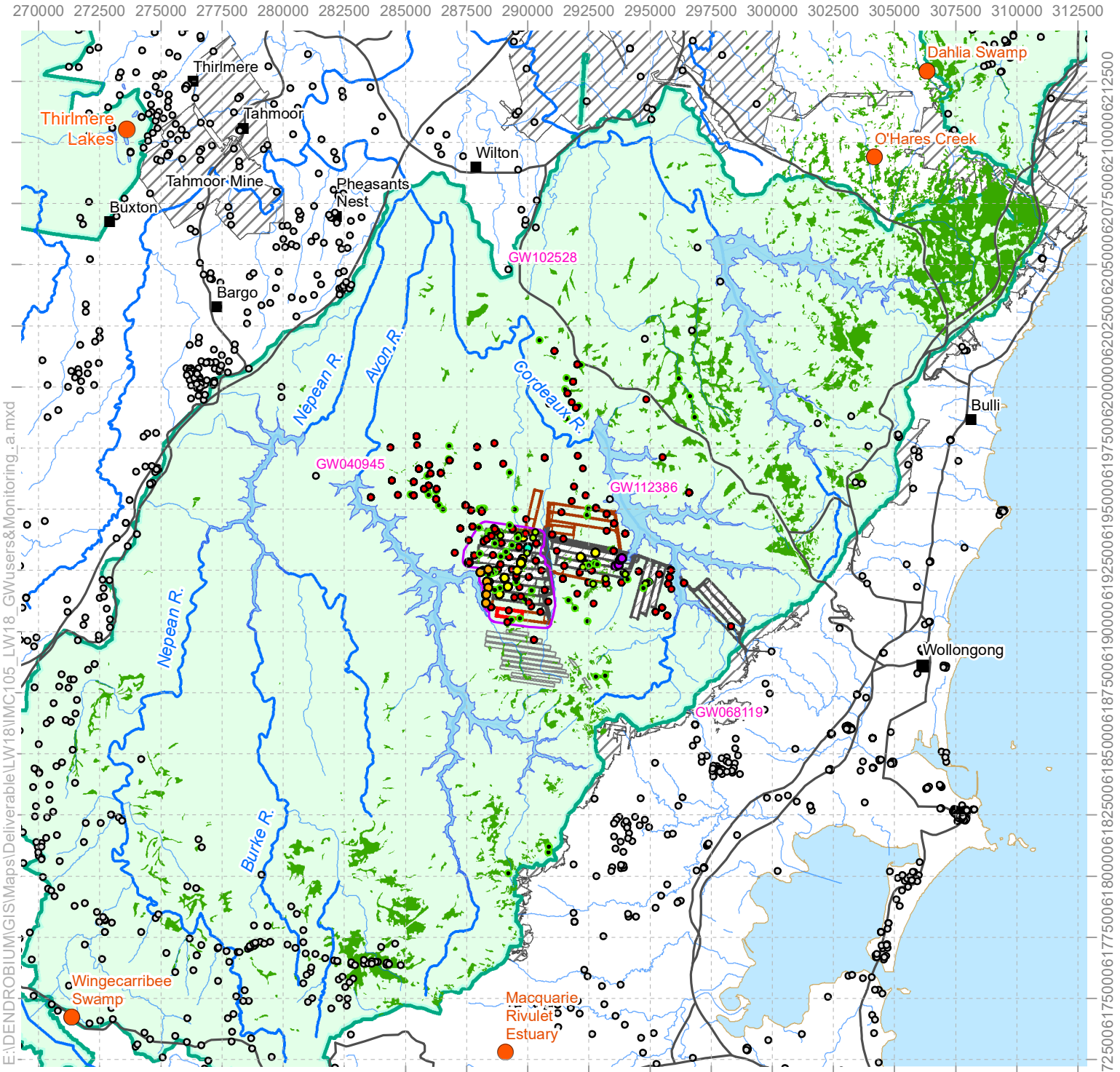
3.3 Monitoring

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

3.3.1 Groundwater Monitoring

Figure 3-1 shows the location of monitoring locations around Dendrobium. The monitoring network is significant, one of the largest in NSW, and is regularly expanded in terms of size and scope. Groundwater level monitoring is typically conducted via:

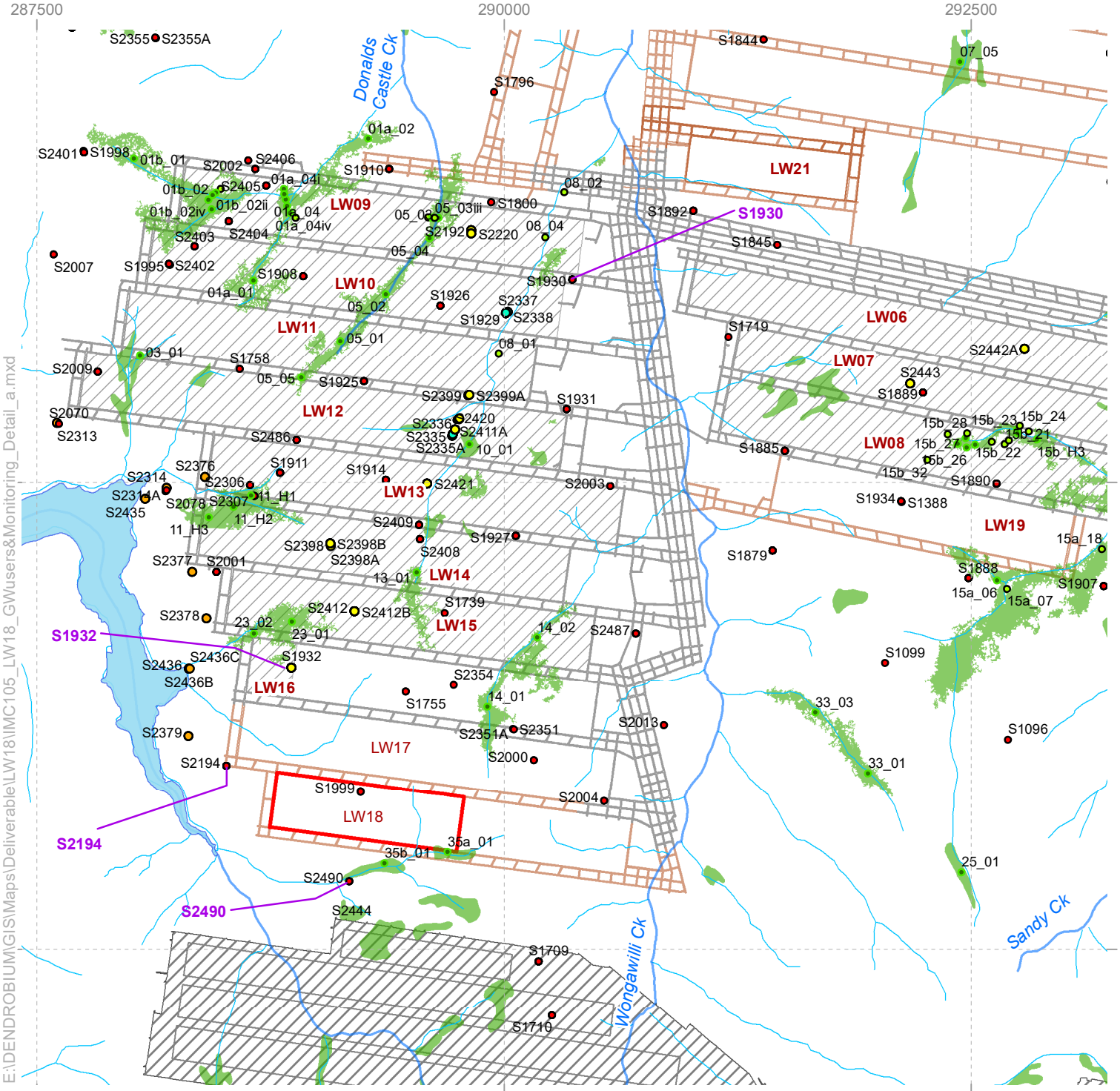
- Multi-level vibrating wire piezometers (VWPs) installed within 'deep' bores. While there are questions about the absolute accuracy of VWPs, they do allow monitoring at multiple levels within a single bore, meaning they maximise the ability to monitor groundwater pressures in 3-dimensions and allow the vertical distribution of pressure, and therefore of drawdown, to be monitored. There are over 160 such bores, with over 860 such instruments, at Dendrobium, and this constitutes the bulk of the monitoring network and available dataset.
- A small set of standpipe piezometers installed into outcropping sandstone (typically 10-20 m deep).
- A network of shallow piezometers installed into shallow substrate, including swamps (typically 1-3 m deep). There are approximately 100 such piezometers at Dendrobium.
- Within the large network of 'deep' VWP-fitted bores listed above, there are a number of special-purpose bores installed to investigate and monitor pre- and post-mining conditions within the footprint of longwalls or offset from longwalls (**Figure 3-1**). These include
  - longwall centre-line bores, such as the 'Longwall 9' investigation (PB, 2015) and then a number of bores more recently above Longwalls 6, 7, 12, 13, 14, 15, 16 and 17 (HGEO, 2020c). More on these is provided in Section 3.6.1.
  - bores drilled between Area 3B and Lake Avon (e.g. S2313, S2314, S2377, S2194 as described in Sections 3.6.3 and 3.7.2).
  - A set of 'shallow sandstone' bores to monitor groundwater levels in the Hawkesbury Sandstone near to shallow swamp piezometers.



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Groundwater users, GDEs and monitoring: regional context

Figure 3-1



Registered GW Work

Dendrobium GW monitoring network

(as of early 2020)

- 'Deep'
- Area 3A Bulgo TARP
- Avon monitoring
- Longwall centreline
- WC21
- Swamp
- Shallow (not in mapped swamp)
- River
- Creek
- Lake
- Upland Swamp (IMC / OEH)
- GDE (High Priority)
- City
- Town
- Main road
- Mined area
- Dendrobium workings: existing
- Dendrobium workings: future
- Longwall 18: proposed panel

N

0 0.2 0.4 0.6 km

Scale: 30,000 @A4
GDA 1994 MGA Zone 56

WATERSHED HYDROGEO

IMC | Dendrobium Mine

Groundwater users, GDEs and monitoring around Longwall 18

Figure 3-2

3.4 Hydrostratigraphy

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

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

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

Bore yields of >5 L/s (which is the threshold for the 'Highly Productive' criteria) are possible, but yield in the area is variable, e.g. testing in 2005 of two bores just north of Lake Nepean (Figure 3-1) by the NSW government produced quite substantially different yields:

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

The deeper units, being the Narrabeen Group and Illawarra Coal Measures, have lower resource potential or productivity.

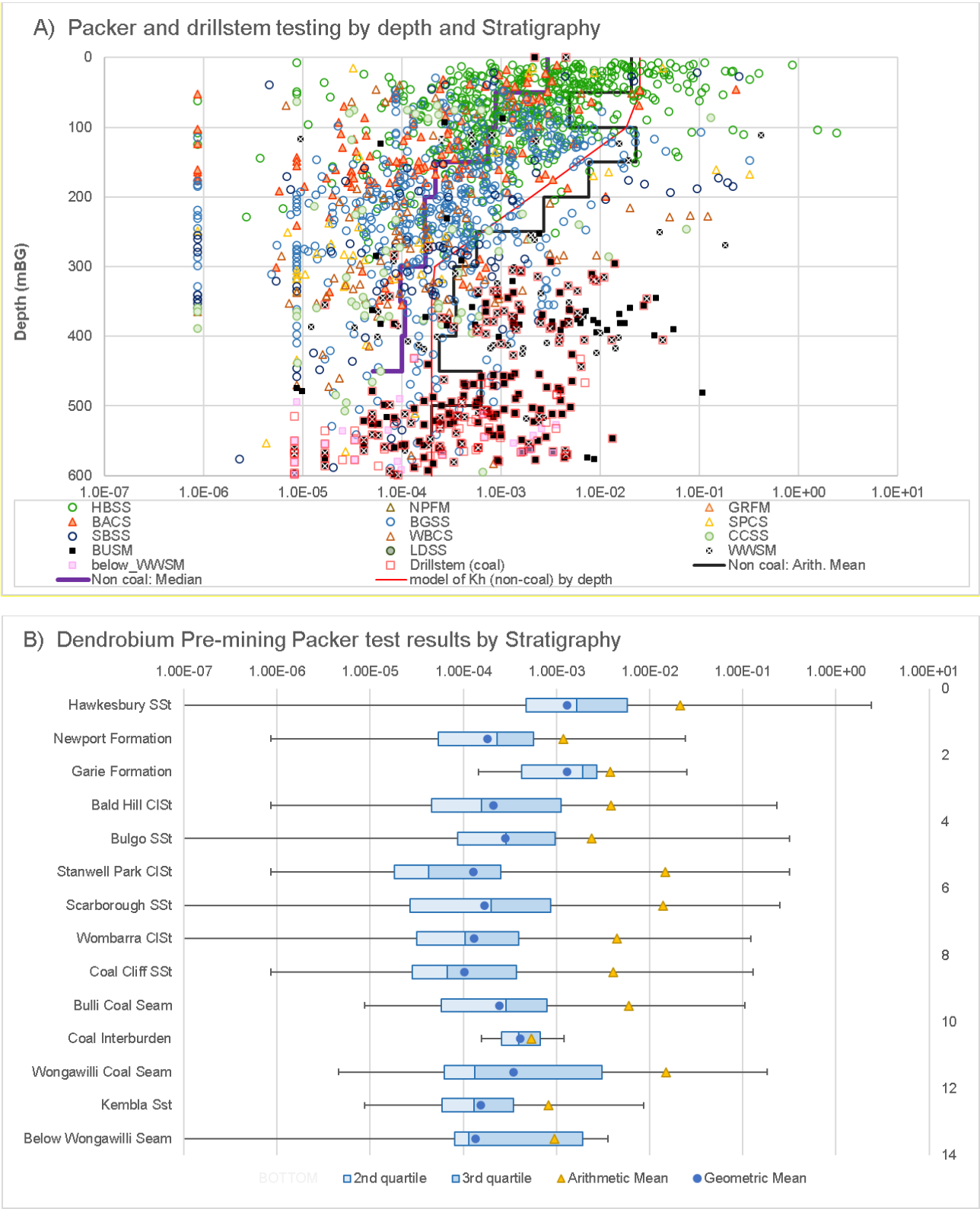
3.5 Hydraulic Properties – host or natural

The following sections outlines pre-mining or 'host' hydraulic properties, and then summarise measurements of post-mining hydraulic properties. Various HGEO and SCT reports, among others, provide more detail on the measurement and analysis of these.

3.5.1 Hydraulic Conductivity (K)

Characterisation of both the horizontal (Kh) and vertical hydraulic conductivity (Kv) has been carried out at Dendrobium. Packer testing is most commonly used to measure Kh in the non-coal strata, while drillstem tests (injection falloff tests or IFOT) are more commonly used to estimate coal hydraulic conductivity. Laboratory analysis of core samples is used to measure Kv.

Figure 3-3A presents all the available pre-mining packer testing data for Dendrobium showing the depth interval of each test and the stratigraphic unit. Drillstem testing of coals is presented as red squares with an underlying symbol to indicate if the test was from the Wongawilli or Bulli Coal. The main observations to be drawn from this are as follows. Kh declines with depth from about 1E-1 m/d down to 1E-4 or 1E-5 m/d. The coal seams are more permeable than rock units (allowing for the different depth profile of these).



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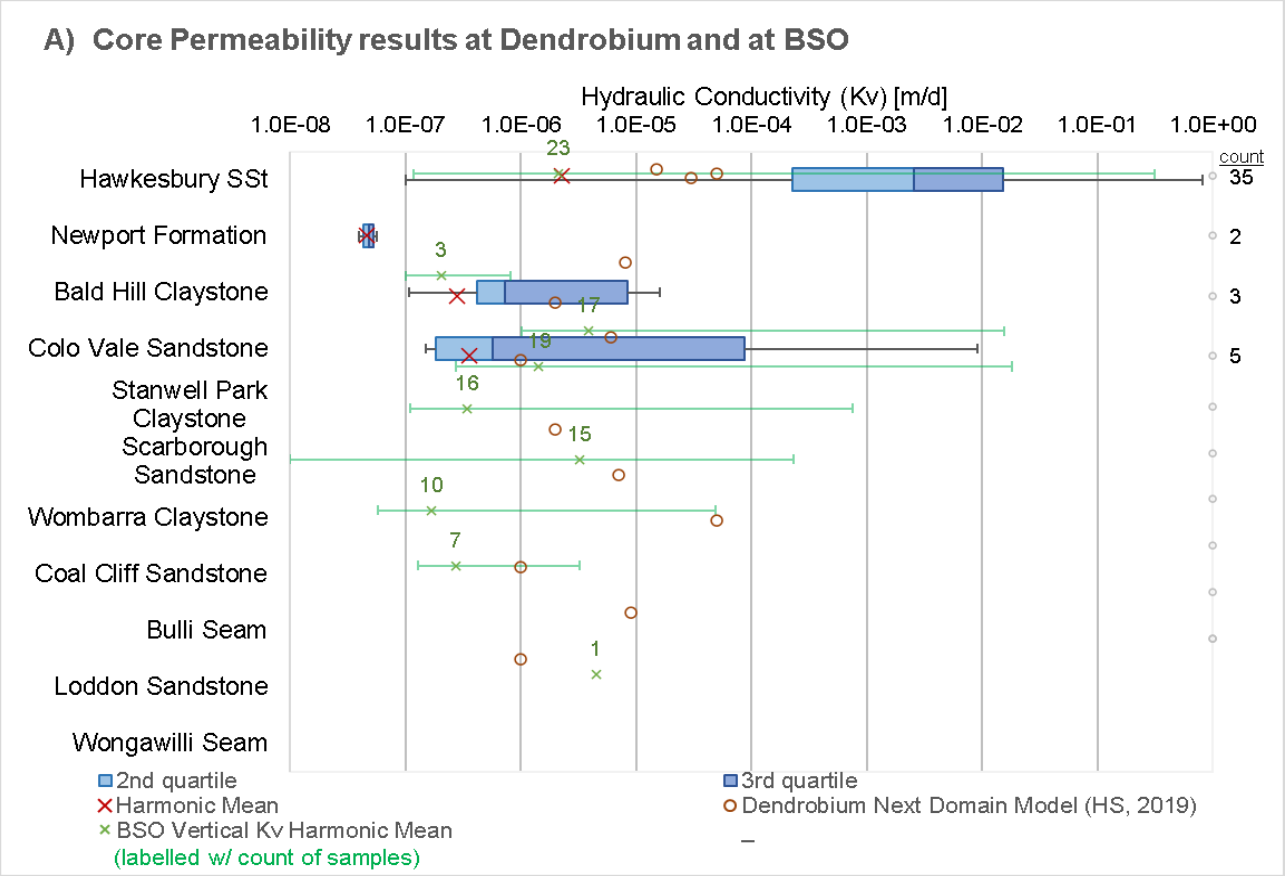
Figure 3-3 Summary of horizontal hydraulic conductivity (Kh) by depth and stratigraphy

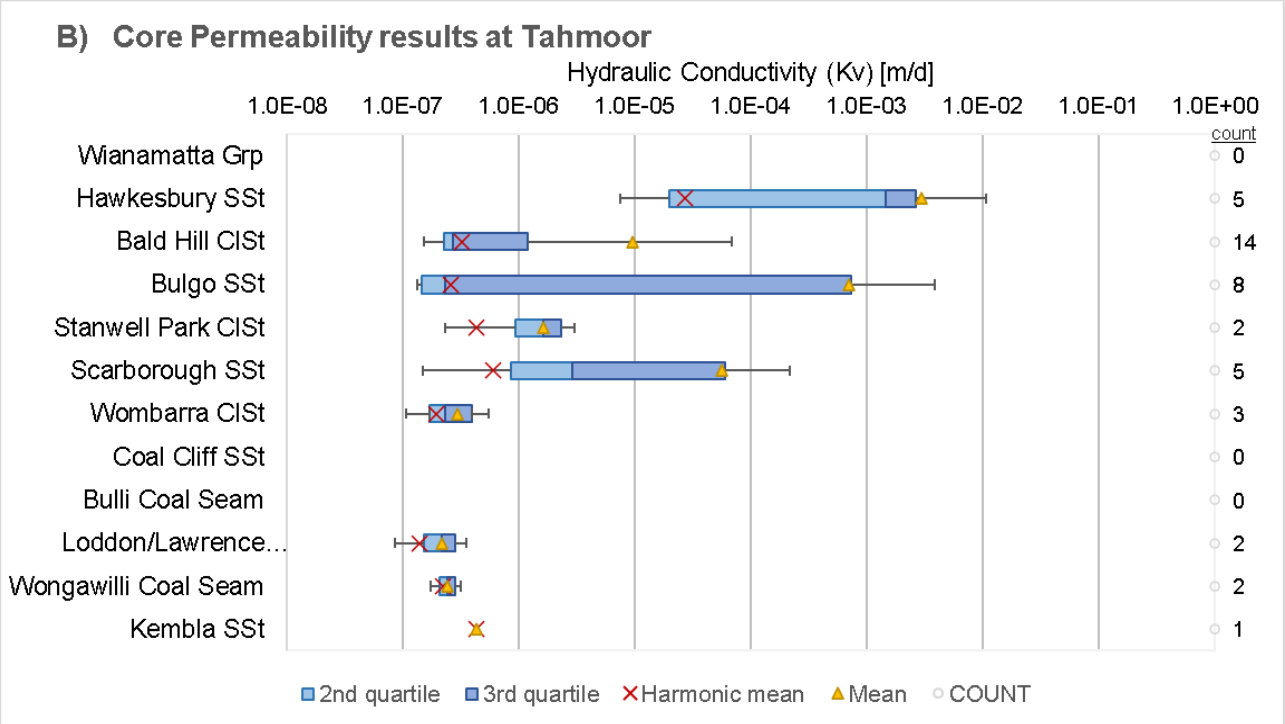
Figure 3-3B presents a summary of the Kh for each stratigraphic unit, ignoring the depth variable. This shows that the claystones (which are shown as triangles **Figure 3-3A**) are often not significantly less permeable (Kh) than surrounding units, e.g. Bulgo Sandstone permeability is typically quite similar to that of the Bald Hill Claystone. Comparison of the variance between stratigraphic units (**Figure 3-3B**) and the relationship with depth (**Figure 3-3A**) suggests that depth is likely more important than lithology.

Further breakdown of the Kh data by stratigraphic unit, depth and also by mining domain is provided in **Appendix A**.

At Dendrobium, core testing of the Hawkesbury Sandstone, Newport Formation, Bald Hill Claystone and Colo Vale Sandstone has been carried out, and the results are summarised in **Figure 3-4A**. This dataset has been augmented with a summary of similar core testing at BSO (from Heritage Computing, 2010), presented as the harmonic mean and the minimum and maximum range in vertical hydraulic conductivity. **Figure 3-4B** presents the extensive core testing dataset from the Tahmoor Mine. Vertical hydraulic conductivity (Kv) is difficult to measure in the field, and laboratory measurements on core samples are the most-often used method of characterising Kv. These values may be somewhat lower than field or *in situ* values because of much smaller sample volume available from core samples, i.e. this technique may not capture hydraulic conductivity due to secondary porosity. The harmonic mean is the recommended method for characterising the effective or representative Kv of a hydrostratigraphic unit (Domenico and Schwartz, 1998).

The extensive datasets, compiled from available data from Dendrobium as well as from neighbouring operations (Tahmoor and BSO), that are presented above are more than sufficient for the purpose of informing and constraining the permeability parameters used in groundwater modelling (Sections 0 and 6.2).





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Figure 3-4 Summary of vertical hydraulic conductivity (Kv)

3.5.2 Aquifer storage (Sy and Ss)

Specific yield (Sy) or drainable porosity has not been measured directly at Dendrobium. Testing of total and effective porosity percentage has been completed for Dendrobium core from the upper stratigraphic units, such as the Hawkesbury Sandstone, Newport Formation, Bald Hill Claystone and Colo Vale Sandstone (the equivalent of the Bulgo Sandstone). Effective porosity is considered a better approximation of Sy, although some practitioners consider that laboratory-determined effective porosity may be an overestimate of the porosity that is 'drainable' in the field. **Table 3-2** provides total and effective porosity results from laboratory testing of core samples, based on a dataset from Dendrobium and from BSO (Heritage Computing, 2010). This includes average porosity and effective porosity for some geological units, where effective porosity is a reasonable approximation for specific yield.

Table 3-2 Summary of porosity (%) determined from Dendrobium and BSO core samples

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

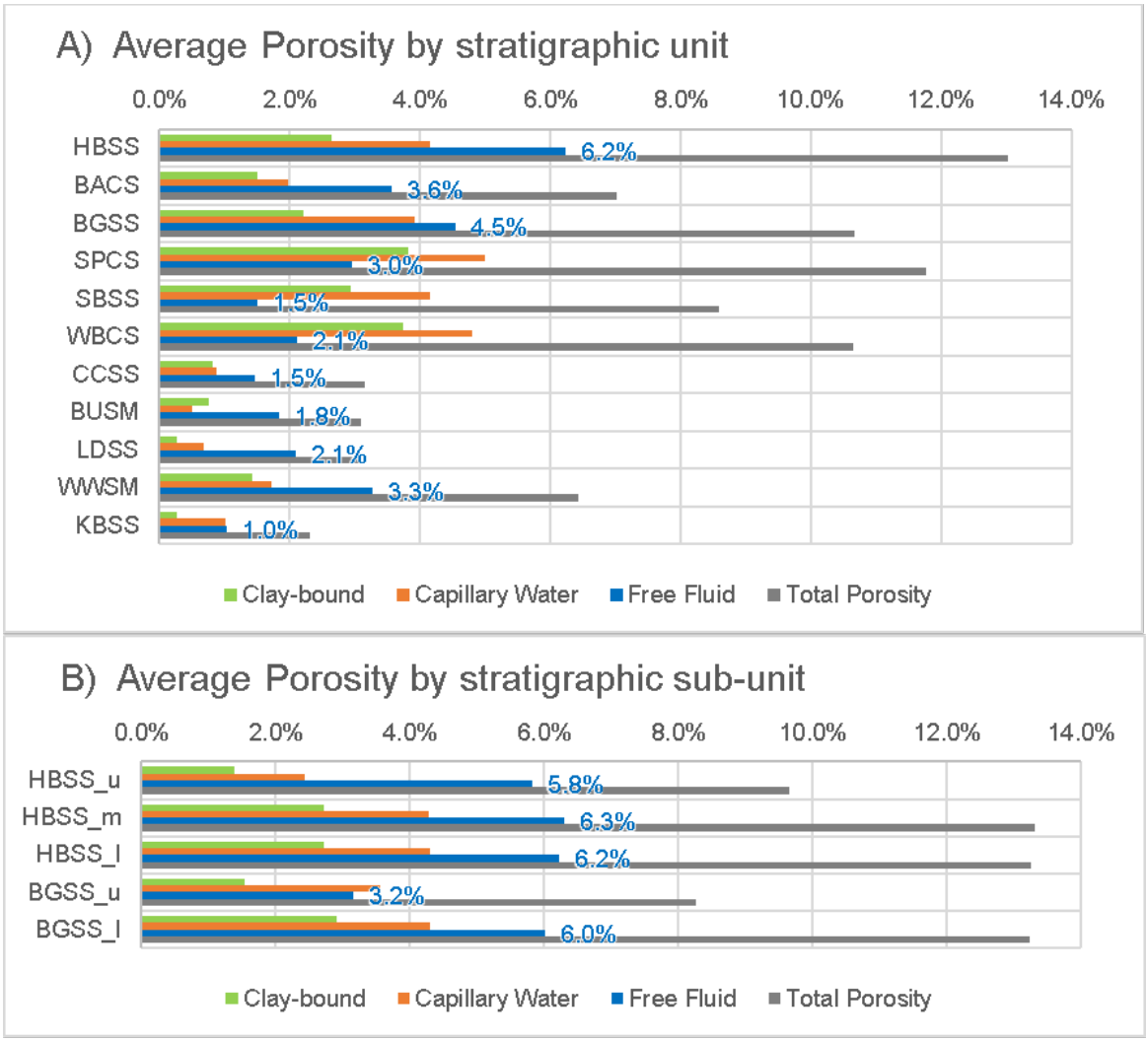
Total porosity data in parentheses () is from BSO. All Effective Porosity measurements are from BSO.

Source: E:\DENDROBIUM\Tech\AquiferProperties\Packer\Dendrobium_AquiferPropertiesDatabase_20161219.xlsx

IMC has also used Borehole Magnetic Resonance (BMR) imaging in selected drillholes to provide continuous logging of density, gamma count, porosity and hydraulic conductivity. More analysis of downhole BMR traces was presented in HS (2019c), and a summary of that is as follows. The BMR porosity estimates are made on a 0.1 m interval, with estimates of total porosity and three constituents: clay-bound water, capillary water, and 'free water'. Of these constituents, free water + capillary water = effective porosity, where we consider that 'free water' is equivalent to drainable porosity or Sy.

Figure 3-5A presents the average of each of the porosity components by stratigraphic unit which correspond to model layers in the subsequent groundwater modelling (Section 5.2.3), with the exception of the more detailed subdivision of the Hawkesbury Sandstone (HBSS) and Bulgo Sandstone (BGSS). For those units, which are subdivided into multiple model layers, **Figure 3-5B** shows the average porosity for the sub-layers.

The BMR 'free water' results indicate that Sy is in the range 1% to 6.3%. For the Hawkesbury Sandstone, the NMR free water volume (approx. 6%) and estimated effective porosity from NMR (6 + 4 = 10%) compare well against the effective porosity from the laboratory (11%, **Table 3-2**). The BMR free water values for Narrabeen Group are typically higher than the effective porosity values in **Table 3-2**.



(from HS, 2019c)

Figure 3-5 Summary of BMR estimates of porosity components

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

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

The information from the core tests and NMR and from previous modelling will be used as the basis for the initial parameterisation of the groundwater model (**Section 6.2**).

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

Estimates of Ss can also be derived from Young's Modulus and porosity, based on calculations in Mackie (2009), and methods utilising porosity determined from core testing are recommended (Evans *et al.*, 2015). Calculations for strata at Dendrobium suggest that for coal, Ss generally lies in the range 5E-6 m^{-1} to 5E-5 m^{-1}, and interburden from 1.7E-6 (unfractured, fresh rock) to 8E-6 (fractured rock). These estimates are similar to model parameters from other mines in the Southern Coalfield which suggest that Ss is in the order of 1E-7 to 3E-5 m^{-1} for the coal seams, and about 1E-6 m^{-1} for overburden or interburden.

As in previous modelling, a trend of generally decreasing Ss with depth is represented in modelling, based on overburden pressure at depth steadily decreasing the 'elastic storage' of the rock formation.

3.6 Hydraulic Properties – post-mining effects

A considerable body of literature has described different aspects of changes to strata due to longwall mining, both in terms of the 3-dimensial extent of changes to strata, and the mode and intensity of these changes. A broad description of the nature of these changes is provided earlier, in Section 2.6.

On-going research by IMC, some in response to comments and recommendations by agencies (including Dams Safety NSW and WaterNSW), independent review (e.g. PSM, 2017) and the IEPMC, has been targeted at addressing some of the uncertainties with respect to the hydrogeological and hydrological impacts of longwall mining.

The following sub-sections summarise recent work that has focussed on:

- Height of fracturing investigations within the footprint of the longwall, including at longwall centreline boreholes.
- Off-goaf deformation effects, specifically between Area 3B and Lake Avon.
- Surface cracking – this is not the stated focus of work at Dendrobium, however recent investigations at Dendrobium and other Southern Coalfield Mines have provided useful information.

3.6.1 Fracturing within and immediately adjacent to longwall panels

HGEO (2020c) presents comparisons of pre- and post-mining conditions at a number of bores in Areas 3A and 3B. The field investigations included packer testing, downhole camera and acoustic televiewer surveys, core logging and water level monitoring.

Most of the boreholes drilled and tested as part of this investigation were within the longwall footprint, and deliberately located along the centreline. However, two bores at Longwall 12 were located off-centre and above a chain pillar to investigate any differences in the pattern and character of fracturing.

Figure 3-6 is an example of HGEO's logs illustrating (A) pre- and (B) post-mining conditions in the centre of a longwall (Longwall 14). This shows, from left to right, the geological log, degree of weathering and calliper survey, the count of all defects and count of 'high angle' defects, packer test results, and groundwater pressures.

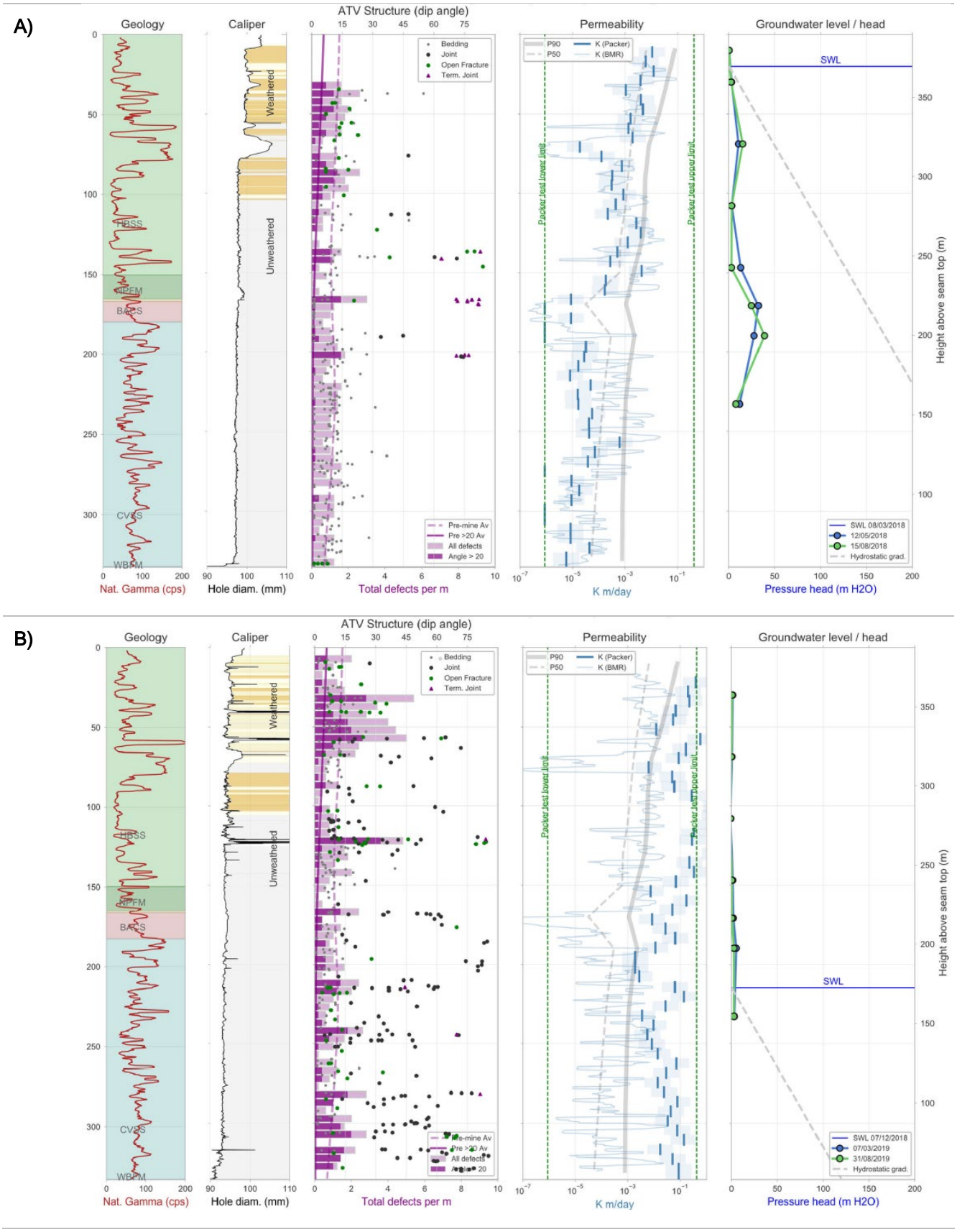


Figure 3-6 Pre- and post-mining conditions above Longwall 14 (boreholes S2398 and S2398A)

The findings from HGEO (2020c) are listed in **Table 3-3**, with some discussion based on our review and consideration of how to represent processes in numerical modelling. The reference # applied in the table is for convenience in referencing here, and is not from HGEO (2020c)

Table 3-3 Summary of findings from fracturing investigations

#	Finding from HGEO (2020a)	Comment
Fracturing:		
1	In both areas, mining-induced fracturing, including high -angle fracturing is highly variable but appears to extend to the surface, or into the pre-longwall surface fracturing zone (<50 m depth). There is a lower density of fracturing above the narrower (249 m) longwalls in Area 3A than the wider (305 m) longwalls in Area 3B.	Agreed. The concept of mine-related fracturing extending to the surface is adopted. The nuance to this is what mode or orientation this fracture is (see #2 and #3). Agreed. The wider panels appear to cause more intense fracturing.
2	In both areas and for both longwall widths, there is a general trend of decreasing fracture density with height above the goaf and a distinctly lower fracture density in the HBSS *[Hawkesbury Sandstone*] than in the underlying CVSS [*Colo Vale Sandstone*]. There is a high fracture density anomaly associated with the BACS [*Bald Hill Claystone*], particularly in Area 3A. There is also an apparent increase in high angle fractures at heights above the goaf of less than ~120 m.	Agreed. Post-mining fracture density appears to decline with height above the goaf. Agreed. BACS is more prone to failure than adjacent strata, possibly because of brittle failure. Agreed - see response to #3.
3	In most over-goaf holes, fractures display a weak preferred orientation parallel to the longwall face within 100 to 200 m above the goaf, transitioning upward to lower-angle or bedding plane fractures with little or no preferred orientation. One hole drilled above a longwall pillar shows a weak preferred orientation parallel to the longwall (length), again transitioning upward into lower-angle structures above 100-200 m.	Agreed. The point about the general transition from more high angle fractures near the goaf to a greater proportion of low-angle fractures at greater height is significant.
Permeability:		
4	All holes drilled above extracted longwalls in both Areas 3A and 3B show significant increases in permeability throughout the profile. Packer tests indicate an increase in permeability of 2 to 3 orders of magnitude relative to pre-mining conditions. At the centreline of Longwall 12 (S2420) there is a zone of apparently unaffected (near median) permeability in the upper CVSS and BACS; however, this is anomalous compared with other over-goaf holes.	Agreed. Packer testing clearly shows Kh increased throughout the sequence above longwalls.
5	Packer tests in the hole above the pillar zone between Longwalls 11 and 12 (S2399) indicate distinctly lower permeability throughout all strata, with only one quarter of tests plotting above the pre-longwall P90. The lower permeability in strata over the pillar zone is consistent with observations of low defect densities over the pillar zone compared with over the goaf.	Agreed. Strata deformation is greater within the footprint than above the pillars. Comparison of the three bores at Longwall 12 (S2420/S2411/S2399) and other centre-line bores suggests that the centreline is more affected than the off-centre positions, which is again more affected than the strata over pillars.
Groundwater conditions:		
6	Holes drilled above the goaf centrelines in both Areas 3A and 3B have standing water levels that are significantly (>100 m) below the estimated pre-mining water table or are dry to the base of the hole. The low SWL reflects strongly depressurised strata conditions, downward head gradients and water losses from the holes through open fractures.	Agreed. Simulating the differential drawdowns through the strata (i.e. large drawdowns close to the seam, declining drawdown at with height above it) will be important. Note that depressurisation may be caused by increased horizontal permeability in the upper horizons and increased porosity, not just by vertical drainage; it is likely a combination of all three.

#	Finding from HGEO (2020a)	Comment
7	VWPs installed after longwall extraction indicate significant depressurisation throughout all strata, with near-zero pressure heads recorded on most piezometers. Holes in both areas show positive pressure heads in some sensors in the upper CVSS and BACS, indicating localised perching or incomplete drainage of fractured rock domains. Minor perching has been observed in post-longwalls holes drilled above Longwall 9. The post-longwall hole above Longwall 14 (S2398) shows depressurisation of all strata above the goaf.	Agreed. See response to #6.
Overarching findings:		
8	There are no clear and consistent step-changes in fracture density associated with any of the predicted heights of fracturing. Rather the data are interpreted to show decreasing fracturing with height above the goaf…	Agreed. Note however that it is easier for conceptual description and assigning model parameters to describe 'zones', even though deformation appears to broadly occur as a continuum.
	… and with anomalous fracturing within the BACS and below 120 m above the goaf.	This is consistent with above findings and will be incorporated in modelling.

The analysis and data presented in HGEO (2020c) provides useful information for setting up and parameterising the groundwater model and are therefore directly relevant to the modelling work to address Condition 15b.

The following section describes key points in applying the findings to a groundwater model, noting that the observations around fracturing and deformation are important to inform inputs to a groundwater model (e.g. "does the geometry and permeability appropriately match observations in the field?"), while observations about depressurisation are important with respect to subsequent outputs of the groundwater model ("does the model appropriately match the observations of depressurisation and inflow?").

Horizontal hydraulic conductivity (Kh) is increased throughout the sequence, from seam to surface, within the longwall footprint. This concept is clearly supported by the count of **low-angle defects** which have clearly and consistently increased from pre- to post-mining throughout the profile. The packer test data constrains the modelled post-mining **Kh**, i.e.:

Post-mining Kh is well constrained

- typically $1E^{-2}$ to $1E^{-3}$ m/d in the Bulgo or Colo Vale Sandstone;
- Slightly higher, $5E^{-2}$ to $5E^{-1}$ in the Hawkesbury Sandstone; and
- which are approximately 2-3 orders of magnitude greater than the host or pre-mining Kh).

The presence of **high angle defects** is not as uniform and appears more intense at depth (closer to the goaf), and then again at the BACS. It is also potentially more intense again in the upper or mid-HBSS, although this last observation is not consistent across all centreline bores, and seems mainly related to natural weathering.

Logs give a clear indication of where high angle fracturing occurs

There is no **Kv** data directly available from field investigations. However, the packer tests constrains the possible Kv (i.e. it must be equal to or lower than the Kh), because a Kv higher than that would influence the overall K measured by the packer tests.

Kv is unknown…

However, the logs showing the density of high-angle defects (HGEO, 2020c) provide useful soft-evidence for specifying where Kv is enhanced to a greater or less degree. Groundwater level response can give some indication of Kv increases, but drainage of groundwater may be related to Kh.	Kv will be calibrated considering Kh and defect count, inflow and groundwater level response

However, with respect to that last point, the **initial position is to assume that above a longwall, Kv = Kh,** thus beginning model re-calibration from the position of **seam-to-surface connection** (consistent with the presence of some fracturing to the surface) with parameters set by the available packer testing data. If the modelling is unable to match head and inflow responses, this representation will change, while being constrained by field data.

The method of incorporating the above data into the model, in terms of the parameterisation of model inputs and then modifying this during model calibration, is presented in Section 5.4.

3.6.2 Surface Cracking

Surface cracking, as described briefly in Section 2.6, extends downwards from the surface and appear to 'overlap' the 'connected fracture' zone extending upward from the goaf. This conceptual zone was not the focus of HGEO (2020c), although some of the data is relevant. Further data that informs the modelling of this process is available from other studies, e.g. SCT (2016) and SCT (2018).

Both these SCT studies show a substantial increase in packer testing Kh from pre- to post-mining in a zone of 20-40 m below surface. SCT (2016) showed a consistent increase in the count of 'all' defects, consistent with the packer testing, but only a mild increase in the number of >5degree defects in this zone. This last finding is consistent with the findings to be drawn from the bore logs in HGEO (2020c), which do not show a significant increase in high angle defects in the near surface.

The understanding and model representation of this process is an ongoing focus.

3.6.3 Off-Goaf Deformation and Valley Closure

Valley closure relates to valley and horizontal compressive stress. Longwall mining and subsidence causes a redistribution of horizontal in-situ stress, pressure on the valley walls and bedding plane shearing. The contribution of pressure and shear is influenced by the position of nearby longwall panels in relation to the depth of cover and bedding planes.

The occurrence of basal shears, as 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 (specifically, Avon Reservoir) to the connected fracture zone and the goaf, this has warranted additional consideration.

SCT (2015) presented discussion on the presence and behaviour of horizontal planar feature' basal shears associated with the Bald Hill Claystone and floors or valleys adjacent to longwall mining. 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.

Packer testing of pre- and post-mining conditions at a number of boreholes between Area 3B and Lake Avon has indicated a range of post-mining permeabilities (**Table 3-4**). Locations of the relevant 'Avon monitoring bores' are shown on **Figure 3-2**.

Table 3-4 Recent pre- and post-mining packer test locations near Lake Avon

Site	Bore(s)	Distance from longwalls	Pre- to post-mining Kh [m/d]	Change	Comment
AD1	S2313 and S2331	150 m from LW12	2.9E-03 to 5.00E-03	x 2	
AD2	S2314 and S2314A	210 m from LW13	3.04E-02 to 2.10E-01	x 7	
AD3	S2377 and S2377B	104 m from LW14	1.20E-02 to 1.50E-01	x 12	Post-mining re-drill in Dec-2017
AD3	S2377 and S2377C	104 m from LW14	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 LW15	2.80E-03 to 1.30E-02	x 5	
AD6	S2314 and S2376	10 m from LW13	3.04E-02 to 2.90E-02	x 1	
AD7	S2314 and S2435	320 m from LW14	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/d	HGEO, 2018b

data from Table 2 of HGEO (2019b)

Analysis of the above testing results led HGEO to conclude that, despite some pre- and post-mining boreholes showing little to no change in Kh, given the small dataset, numerical 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 3-4**. Based on this, the conceptual model for off-goaf alteration of permeability is:

- There appear to be some transient effects, as at AD3 which has been drilled twice, almost a year apart, following nearby longwall extraction. For conservatism, the apparent reduction in permeability (Kh) that has been inferred or measured in some boreholes could be ignored.
- Enhancement of horizontal permeability can occur up to a maximum of 600 m from longwalls.
- Post-mining Kh declines 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 (possibly due to compression above pillars) 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 (2017) stated that Kh increases of '1-3 orders of magnitude' could occur. However, this, and, specifically the upper part of that range, is not supported by data from Dendrobium Mine or literature. Numerical modelling could be modified in future if further data is supplied to support a change of 3 orders of magnitude, however so far, the data presented above suggests that Kh can change but may only increase mildly or even show no systematic increase.

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 7.2.1 provides additional detail on this.

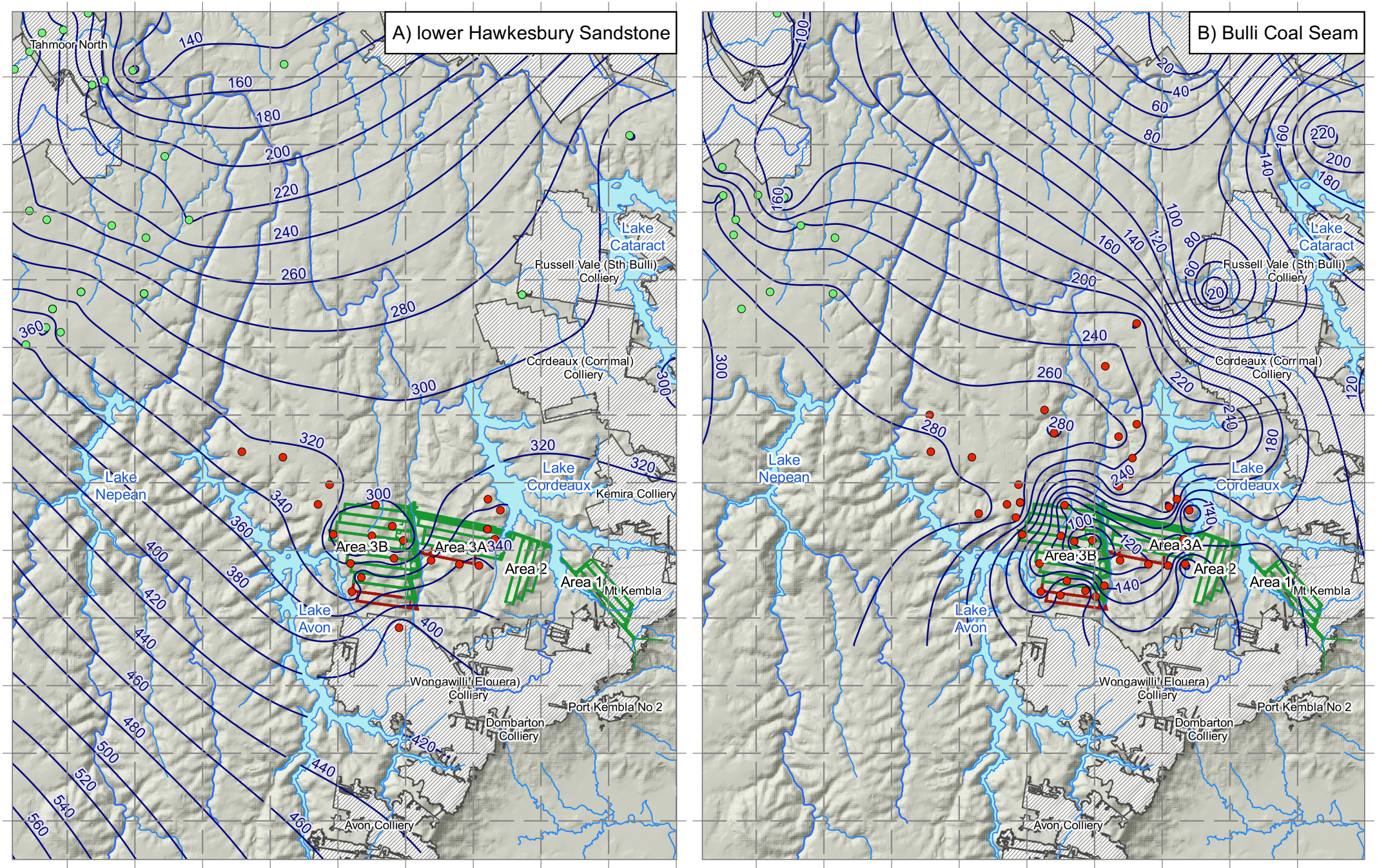
3.7 Groundwater level analysis

Groundwater levels are monitored at numerous sites around the Dendrobium Mine (Section 3.3). The data from many of the bores is analysed regularly as part of the End of Panel reporting process.

3.7.1 Spatial analysis

Groundwater levels contours have been derived from Dendrobium and other mine monitoring sites, and this regional-scale mapping (originally presented in HS, 2019c) is presented on **Figure 3-7**. This shows the water levels from the lower Hawkesbury Sandstone and the Bulli Coal seam. The contours indicate that regional groundwater flow is broadly to the north, toward the centre of the Sydney Basin. Closer to the escarpment, it is likely that groundwater flow was to the southeast, i.e. discharging at the escarpment.

Water levels within the shallower units, such as the upper or mid-Hawkesbury Sandstone would be more locally influenced by watercourses and reservoirs which occupy deeply-incised valleys, and so locally may have gradients that diverge from the regional pattern. Groundwater within deeper units, including the coal seams, are much less influenced of surface water features, however can be influenced by the depressurisation effects of mining operations, such as Dendrobium, Elouera, BSO and Tahmoor (**Figure 3-7**).



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N

0 1 2 3 km

Map Scale: 1:180,000 @ A4
GDA 1994 MGA Zone 56

- River
- Creek
- Lake / reservoir
- Dendrobium - Existing Workings
- Dendrobium - Future Workings
- Mined area
- IMC bore locations
- Other mine bore locations
- Groundwater level contour (mAHD)
  Contouring is indicative, based on composite data from 2013-2018.

WATERSHED HYDROGEO

IMC | Dendrobium Mine

Interpolated groundwater levels: lower Hawkesbury Sandstone and Bulli Coal Seam

Figure 3-7

3.7.2 Temporal trends

Data from a selection of groundwater monitoring bores around Area 3B are presented on **Figure 3-8** to **Figure 3-10**. The bore locations are labelled on **Figure 3-2**.

Bore S1930 (**Figure 3-8**) is located between Longwalls 9 and 10 and Wongawilli Creek. This shows that in 2008, groundwater levels in tall monitored units were similar to or above the level of Wongawilli Creek, indicating groundwater could discharge to the creek and support surface flow. The hydrograph then shows slow depressurisation in the Bulgo Sandstone (BGSS) and lower Hawkesbury Sandstone (HBSS) as mining in Area 3A progressed, and then sudden changes in pressure in these units as Longwall 9 approached (the end of Longwall 9). The upward spike in pressure in early 2014 is a result of strata compression as the longwall approached, followed by a decline. After Longwall 10 was extracted, the lower piezometers failed completely, but prior to this the decline in groundwater level had accelerated. Since then, water levels in the lower Hawkesbury Sandstone have remained consistently 5-10 m below the level of the creek. Water levels in the upper Hawkesbury Sandstone have remained unaffected (in the 9.3 m piezometer) or unaffected/mildly affected (the 45.6 m piezometer). This has been described in other documents (HGEO, 2020b; WatershedHG, 2018), and similar behaviour is expected to occur along the length of Wongawilli Creek between Areas 3A and 3B.

Bore S1932 **(**Figure **3-9**) is located in the centre of Longwall 16, and will be mined through in the near future. Depressurisation has occurred in the deeper units since 2009 (especially noticeable in the more permeable coal seams), but has increased since 2018 as Longwall 14 was extracted, and then with a step change in pressures with the passage of neighbouring Longwall 15. Groundwater pressures within the coal seams have declined by approximately 150-200 m since 2008, while the uppermost Bulgo Sandstone water levels have drawn down a total of 40 m. As with S1930, the shallowest piezometer does not show any obvious decline in water levels, and the second piezometer (48 m-HBSS) indicates a slow downward trend, having declined from a pressure head of 18 m (367 mAHD) in 2008 to 10 m (359 mAHD) in early 2020.

Bore S2194 (**Figure 3-10**) is at the western end of Longwalls 17 and 18, near to Lake Avon. As with S1932, deep water levels have decline as mining through Area 3B has approached. The rise in deep groundwater levels since 2019 is not understood, but may be due to compression of the bore/piezometer, and not representative of groundwater levels (i.e. this is not seen at S1932). In 2013, upper and mid-BGSS groundwater levels were just below the Lake Avon stage, and have declined by 12 and 25 m respectively since then. Water levels in the shallowest three piezometers, all in the HBSS, have not appeared to respond to mining between 2013 and 2020. Water levels in the deepest HBSS piezometer remain at least 8-15 m above Lake Avon stage. By way of comparison, in bore S2377 or S2314 (in similar positions between Area 3B and Lake Avon but closer to recent mining than S2194), groundwater levels in the lower and mid-Hawkesbury Sandstone have fallen below lake stage in a similar manner to the 111 m-BGSS piezometer at S2194 as a result of neighbouring longwalls being extracted. This change in the gradient within strata at or below the lake levels from being gaining to losing as a result of mining was simulated by previous modelling (e.g. HS, 2016) and described more fully in recent End of Panel reports (see Section 3.2.3 in HGEO, 2020b).

Bore S2490 (**Figure 3-11**) is a newly installed monitoring bore located 250 m south of the edge of Longwall 18, in the ND1 valley and just downgradient of Swamp 35b. The data on **Figure 3-11** suggests that Swamp 35b is likely connected to the Hawkesbury Sandstone groundwater system.

S2490 is located above the plane of the Elouera Fault. Water levels in the Bulgo/Colo Vale Sandstone at this site are similar to Avon Reservoir lake stage (**Figure 3-11**), and higher than those at other bores to the north (e.g. Bore S2194, **Figure 3-10**). Water levels in the Hawkesbury Sandstone are close to surface level, and about 20 m above Lake Avon FSL.

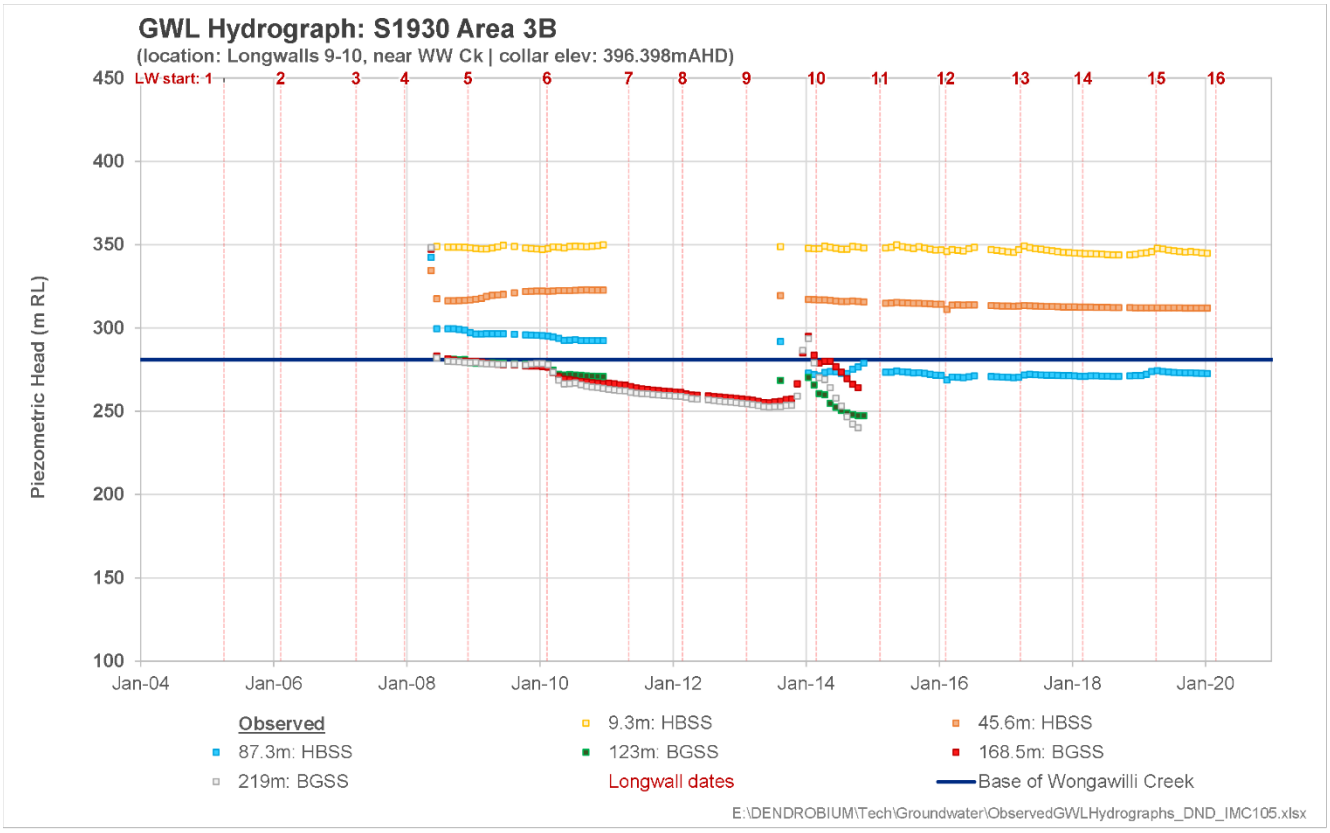


Figure 3-8 Groundwater level trends at bore S1930 (Area 3B, near Wongawilli Creek)

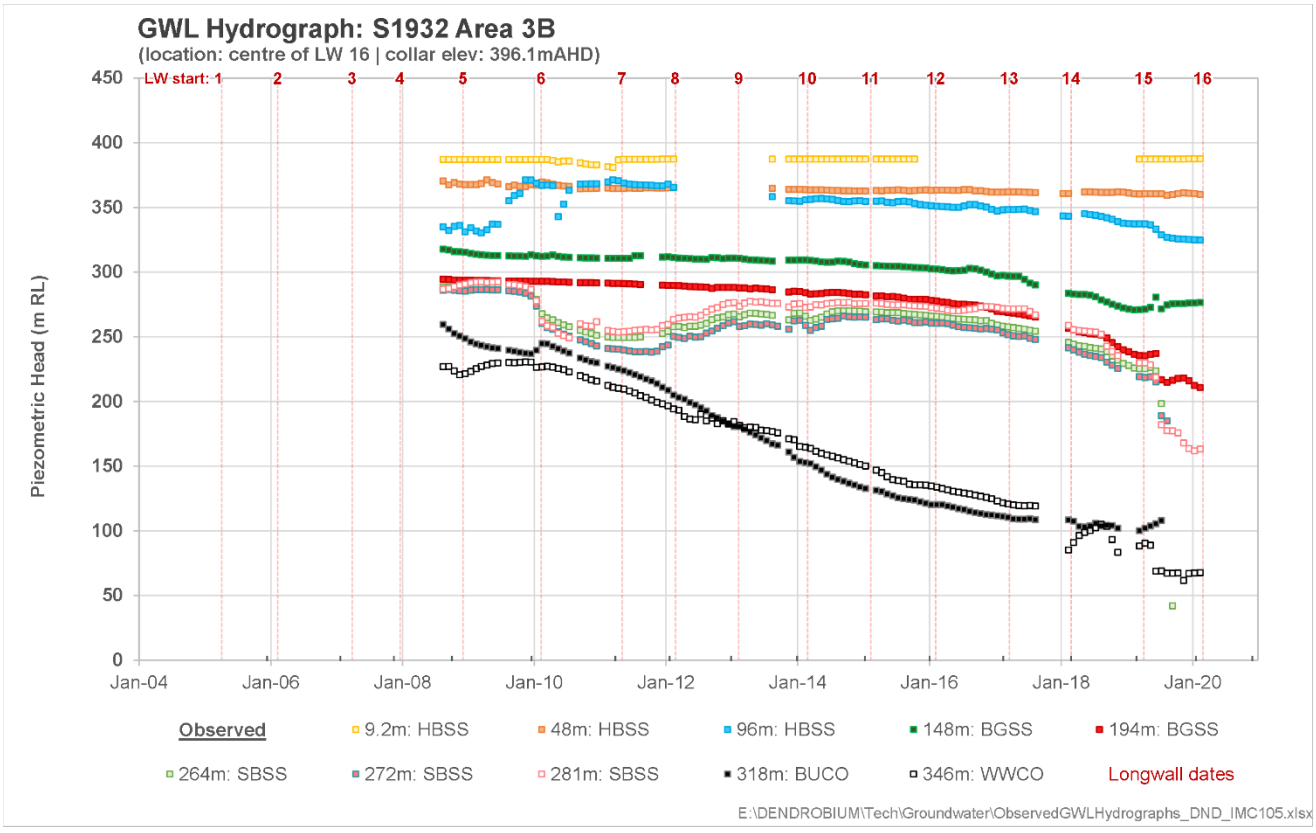


Figure 3-9 Groundwater level trends at bore S1932 (Area 3B, Longwall 16)

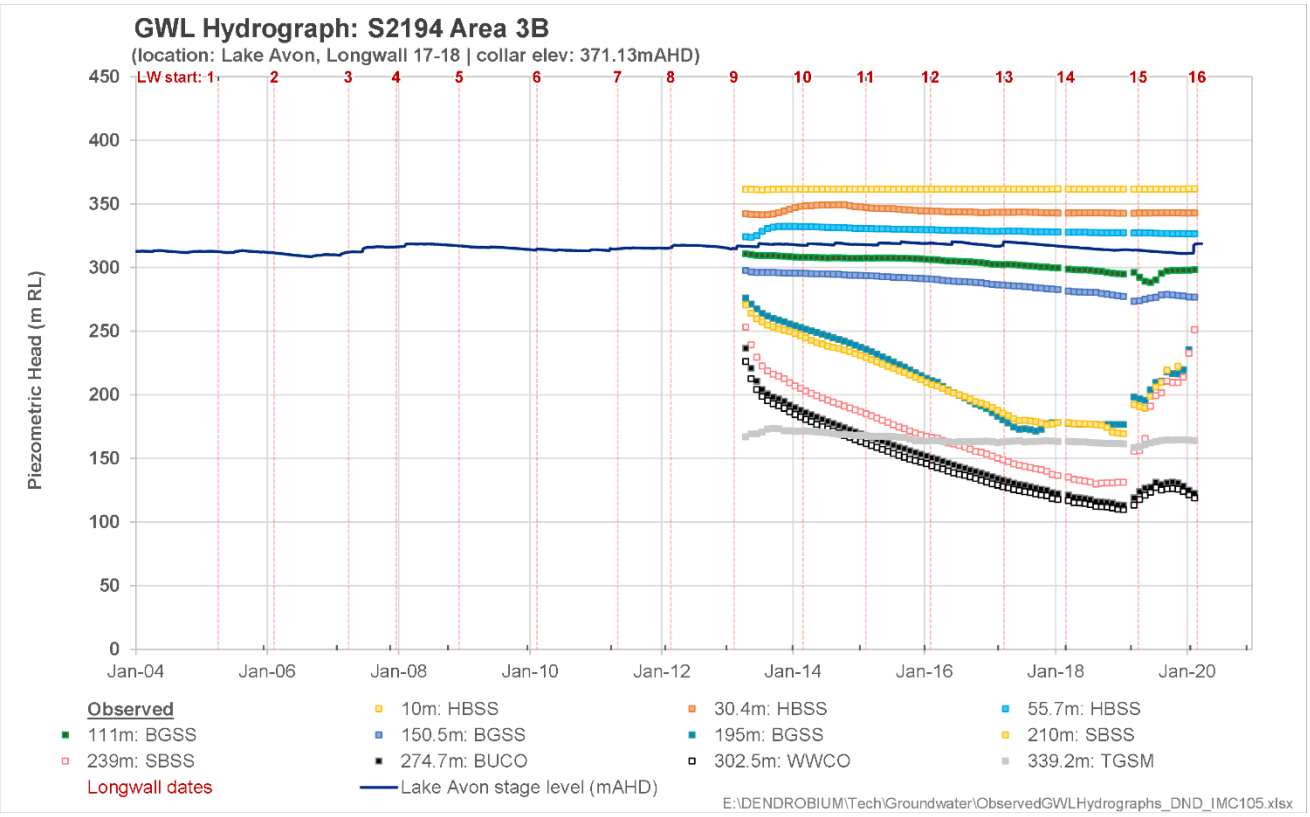


Figure 3-10 Groundwater level trends at bore S2194 (Area 3B, Lake Avon shoreline)

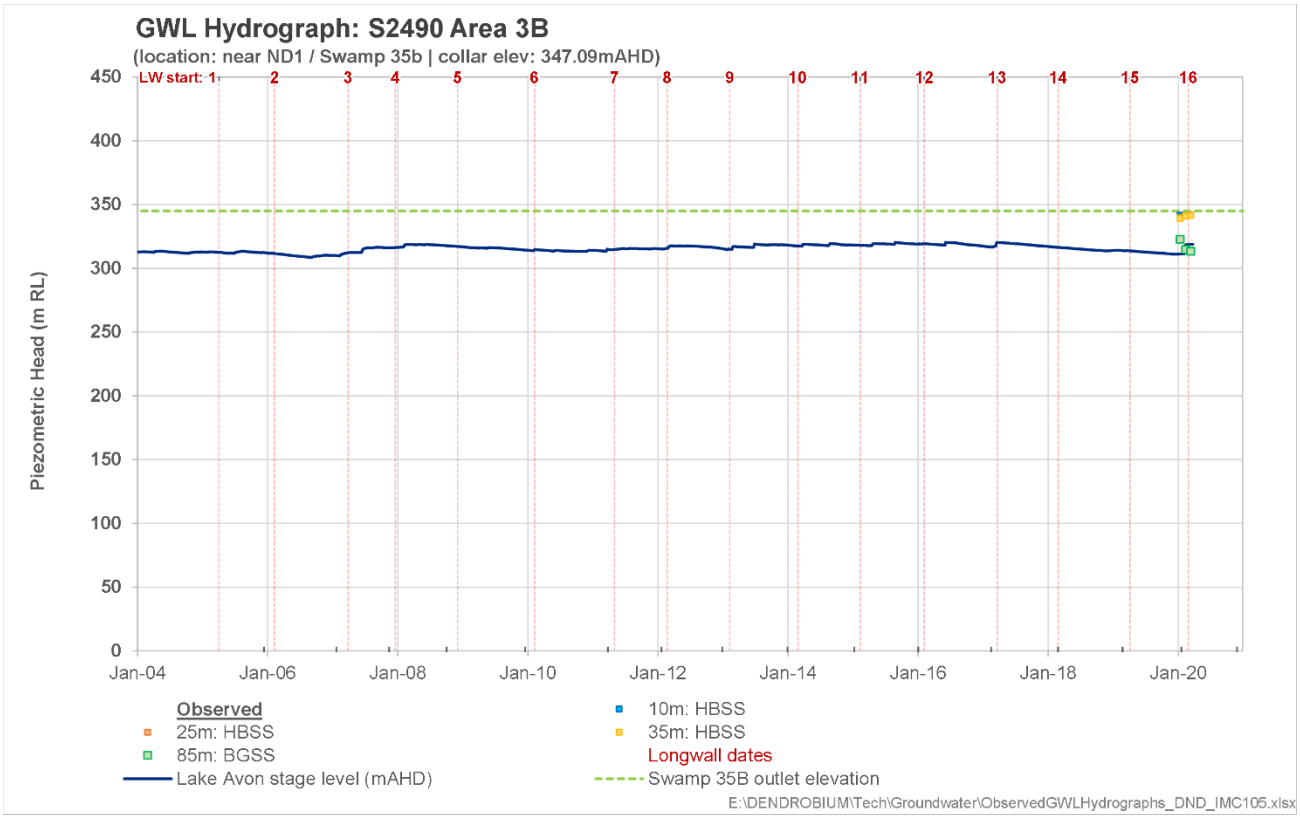


Figure 3-11 Groundwater level trends at bore S2490 (Area 3B, Swamp 35b and ND1)

This suggests that the current condition of the Elouera Fault has not caused significant depressurisation or drainage of Hawkesbury Sandstone (either down to the level of lake stage, or below the lake which could indicate connection to the nearby Elouera Colliery longwalls).

On the southern side of the Elouera Fault, the last of the Elouera longwalls was extracted in 2006-07. Following the cessation of active dewatering in the Elouera part of the Wongawilli Mine complex (in 2007 or within a few years after), water levels have recovered (K. Mills, pers.comm, 2020). Seam level is approximately 60 mAHD, and recent observations in the flooded workings are that the levels are at approximately 125 mAHD, which is well below the inferred overflow point of approximately 220 mAHD for that mine. This indicates recovery of approximately 5 m/yr. This rate of recovery is confirmed by a review of groundwater pressure data from the Bulli Coal seam piezometer in monitoring bore S1709 (70 m recovery between 2009-2020, indicating a recovery rate of almost 7 m/yr).

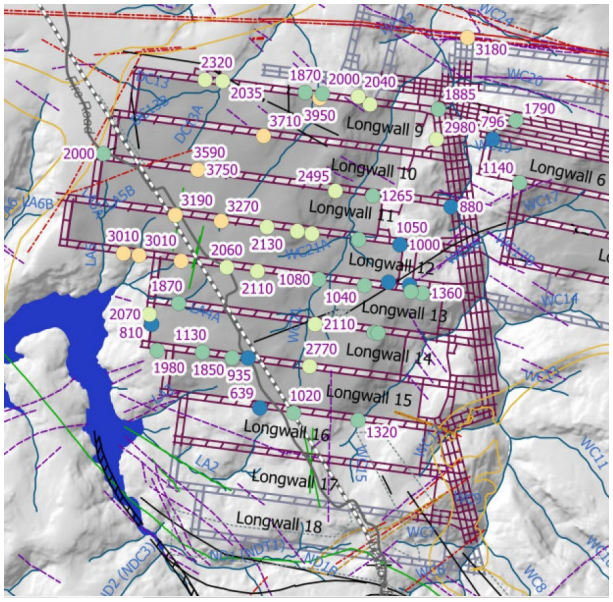
3.8 Water Quality

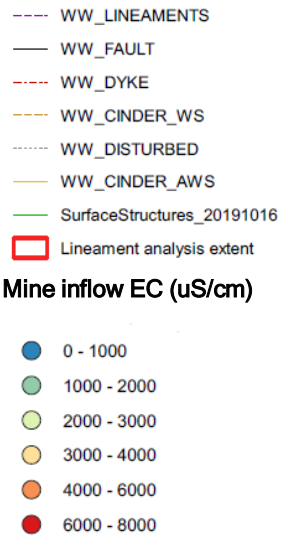
Almost 3,000 water samples have been collected and analysed at Dendrobium Mine since 2004, providing an extensive database with which to assess mine water chemistry against baseline surface water and groundwater chemistry. IMC provides regular reports on water quality data and analysis (e.g. HGEO, 2017d; HGEO, 2020g), and the following discussion is based on that reporting.

3.8.1 Groundwater Quality

Groundwater samples are collected from a set of dedicated bores with installed pumps that sample from the Hawkesbury, Bulgo and Scarborough Sandstones. 'Deep' groundwater samples are collected within mine workings, typically from development roadway roof seepages and mining faces which have not been affected by the formation of the goaf during mining. Roof seepage samples are considered representative of the Wongawilli Coal and adjacent shales. Further samples are collected from goafed areas, and these are a mix of all sources of water entering the mine through the goaf (laterally and from underlying and overlying formations).

Spatial variation in salinity (EC) is primarily 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 (HGEO, 2020g).





(from HGEO 2020g)

Figure 3-12 Distribution of EC in inflow to mine workings

Based on data from Area 3A and 3B mine workings (**Figure 3-12**), the salinity of roof drippers increases from east to west, i.e. fresher near Longwall 6 (EC = 800-1,800 uS/cm), and slightly more saline in the western sections of Longwalls 9-12 (EC = 3,000-4,000 uS/cm). A trend on the north-south axis through Area 3B and toward Longwall 18 is less clear. EC in the southern-most sampling points has been 600-2,000 uS/cm and appears to be freshening slightly to the south.

Groundwater quality is variable depending on sampling depth and the sampled geological formation. There is an increase in the concentration of minor and trace ions with depth, in line with the general increase in EC (HGEO, 2020g).

Table 3-5 presents a summary of electrical conductivity (EC) data. The data shows that groundwater salinity typically increases with stratigraphic age, reflecting the longer residence time in deeper units. Groundwater within the Hawkesbury Sandstone is generally fresh (EC <1,000 µS/cm), with a mixed major ion composition. This water quality is indicative of relatively recent rainfall recharge (noting that the Hawkesbury Sandstone is the main outcropping geology, **Figure 2-3**). Groundwater in deeper stratigraphic units (such as the Bulgo Sandstone and Scarborough Sandstone) is generally more saline.

Table 3-5 Summary of Electrical Conductivity (EC) Variation at Dendrobium

Sample type (in age/depth order)	Site or Area	Electrical Conductivity (uS/cm)				
		5th %ile	Median	Mean	95th %ile	Count (N) (as of late 2019)
Rain	Rain	72	85	86	103	28
Surface Water	Wongawilli Ck (FR6)	67	94	96	130	596
	Donalds Castle Ck (FR6)	73	108	110	149	715
	Sandy Ck	66	87	90	112	124
	Lake Cordeaux	72	94	93	113	249
	Lake Avon	56	70	69	78	67
Groundwater	Hawkesbury Sst	70	123	157	357	275
	Bald Hill Claystone	153	200	200	247	2
	Bulgo Sst	137	400	557	2058	67
	Scarborough Sst	468	550	555	763	109
Seeps: pre-longwall	Area 1 seep	2981	3340	4543	7907	7
	Area 2 seep	876	1355	1310	1886	231
	Area 3A seep	1029	2240	1956	2791	58
	Area 3B seep	829	2040	2130	3699	55
Goaf: post-longwall	Area 1 goaf	1700	2350	2246	2579	182
	Area 2 goaf	1015	1560	1510	1882	628
	Area 3A goaf	738	857	919	1223	162
	Area 3B goaf	1786	1930	1942	2235	51

A recent assessment of the potential links between structures and water quality within the mine workings (HGEO, 2020g). This found that, except for an apparent correlation between salinity and

proximity to mapped dykes, there was no correlation or very poor correlation between water quality parameters, including tritium, to proximity to structures mapped at seam level or at the surface.

3.8.2 Water Source Discrimination

Water quality monitoring at Dendrobium has shown a number of dissolved constituents that can be useful in discriminating ("finger-printing") 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 (i.e. as sampled at seeps in the workings) 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.

3.8.3 Modern Water and Mine Inflow

As recommended by IEPMC (2019a), the contribution of 'modern' water to mine inflow is the subject of on-going investigation. IMC's groundwater database currently includes over 700 analyses of tritium at Dendrobium, 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. A summary of recent analysis is presented in the discussion of mine inflow (Section 3.9.3).

3.9 Groundwater flow processes

Groundwater recharge occurs via infiltration of diffuse rainfall and possibly from leakage from surface water features, mainly from watercourses during and after periods of heavy rainfall. These processes are discussed and, where possible, quantified in Section 3.9.1.

Groundwater discharge occurs via a number of processes. These include:

- abstraction by 'water supply works' or bores (minor in this area, as in Section 3.1);
- dewatering by mines (Section 3.9.3);
- discharge of groundwater to swamps may occur and evapotranspiration in areas where the water table is close to the surface such as swamps but also typically along riparian corridors (Section 3.9.2); and

- discharge to surface water which typically occurs where incised valleys hosting creeks, rivers and lakes intersect groundwater (Section 3.9.4). Springs and seeps may also occur along the escarpment to the coastal plain, where erosion has truncated the stratigraphic units.

3.9.1 Recharge

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

As per the geological outcrop mapping, rainfall recharge primarily occurs to the Triassic Hawkesbury Sandstone or to the outcropping Narrabeen Group (around Areas 1 and 2 and the escarpment), and to the smaller isolated areas of swamp deposits.

Estimates of average or long-term rainfall recharge to surficial strata have been collated from a review of literature and from analysis of Dendrobium field data. 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 3-6 Summary of Recharge Estimates

Reference	Analysis method	Recharge	
		% LTA rain	mm/yr
URS, 2007	water table fluctuation ("WTF")	3-10%*	n/a
DPI, 2011	unknown	6%	n/a
Coffey, 2012a,b	Baseflow separation, WTF	2.7 or 6%	n/a
Pells, 2013	unknown	5%	50
EMM, 2015	Sydney Basin-wide estimate, based on review of Crosbie, modelling assessments. Table 5.1 indicates 1% to Permian, 5% to HBSS/Narrabeen Group, <5% Wianamatta Group.	5 % Triassic	
		1 % Permian	
Crosbie, 2015	Chloride mass balance in shallow groundwater.	3-8.5%	40-100
HS, 2016b	Chloride mass balance baseflow separation, WTF	6.5%	65
BoM, 2020	AWRA-L model (2005 to Feb-2020)	7.7%	91
This study	Soil moisture balance model (2005 to Feb-2020)	7%	81

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

A soil moisture balance model that accounts for varying rainfall and evaporation on a daily basis (from SILO), and accounts for soil moisture deficits was described in previous modelling presented in HS (2016b and 2019c). This water balance model has been updated for this study.

The series of modelled recharge, as calculated by the water balance model on a daily basis and then aggregated into model stress periods, is presented on **Figure 3-13A**. 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, which matches well with independent estimates made by BoM's AWRA-L model to Feb-2020 (7.7%).

Of note from **Figure 3-13A** is the extended period of low (or no) recharge from mid-2017 to early 2020.

3.9.2 Evapotranspiration

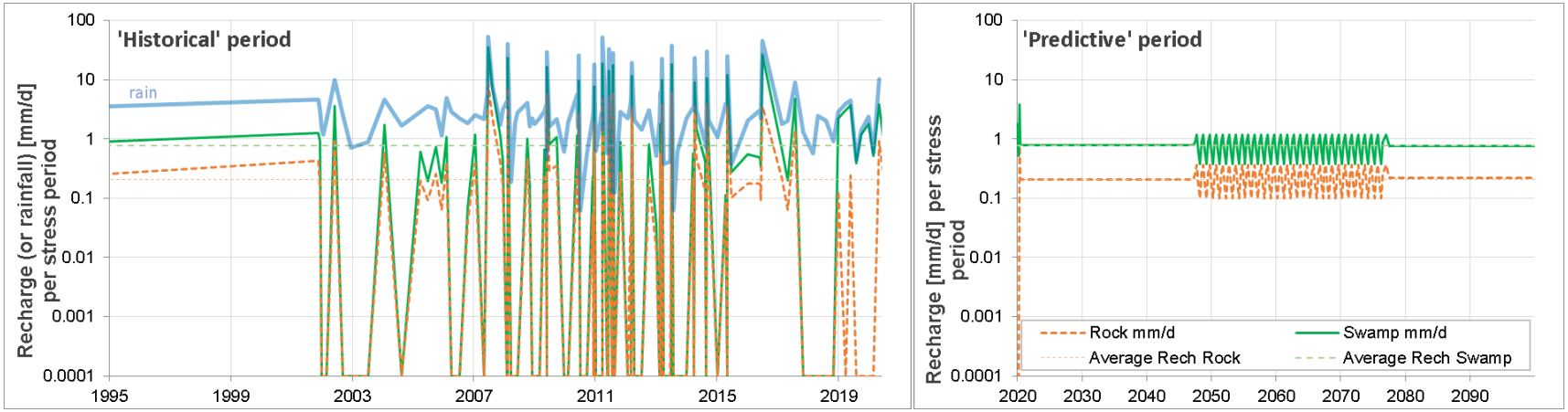
The same soil moisture/water balance model described in the previous section also accounts for the energy balance (i.e. potential evaporation, PE). The model estimates actual evapotranspiration (AE) from the soil zone and keeps account of excess PE. This is calculated on a daily basis and aggregated into model stress periods, as shown on **Figure 3-13B**.

Of note from **Figure 3-13B** is the increase in PE and the resultant increase in potential demand by evaporation on shallow groundwater during the period mid-2017 to early 2020. This was caused by both a lack of rainfall, and an increase in the PE.

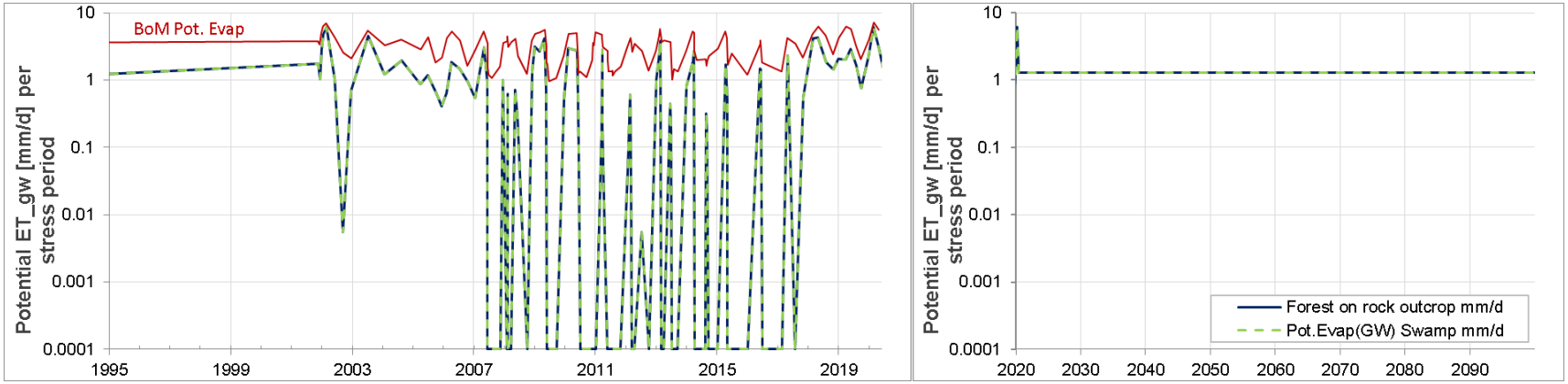
Evapotranspiration by vegetation is governed by rooting depth. A review of literature, including Canadell *et al.* (1996), Florabank[3], Lamontagne *et al.* (2005), Allen *et al.* (2006) and Zolfaghar (2013) was carried out. Rooting depth is likely controlled by the geomorphology and depth of soil deposits. A compilation of reported maximum rooting depth of sclerophyllous shrubland and forest (Canadell *et al.*, 1996) indicates an average for such species is 5.2 m (±0.8 m). Zolfaghar, 2013 indicated the rooting depth for sclerophyll forest in the southern Sydney Basin could be up to 9 m.

[3] http://www.florabank.org.au/

A) Modelled rainfall recharge



B) Modelled potential evapotranspiration fromgroundwater



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Figure 3-13 Modelled recharge and evaporation timeseries

The rooting depth of the swamp deposits is likely controlled by the geomorphology of these deposits. The unconsolidated peat and sand deposits are typically 1-2 m thick above the underlying rock stratum. Recent field work by SMI Environment Centres (2019) found that the vertical extent of roots within swamp deposits was 0.4-0.8 m.

3.9.3 Mine inflow

Groundwater inflow to mine workings cannot be directly measured but is determined through a water balance. The accounting of water via pumping stations is monitored and controlled in real-time through the System Control and Data Acquisition (SCADA) system and used to calculate a daily Mine Water Balance[4]. This detailed water balance accounts for water that enters, circulates and leaves the mine (e.g. air moisture and coal moisture), and groundwater inflow is determined for each mine area.

Table 3-7 summarises the average inflow to each area for the 12 months to the end of May 2020. Total accumulated inflow over this period was approx. 2,100 ML, equivalent to a daily average of 5.7 ML/d.

Table 3-7 Dendrobium Mine inflow: 12-month summary for June-2019 to May-2020

Statistic	Area 1*	Area 2	Area 3A	Area 3B	Dendrobium Total
Minimum	--	0.03	0.01	0.02	**0.50**
Mean	0.33	0.95	0.69	3.90	**5.68**
Maximum	--	3.55	1.91	7.18	**8.22**

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

Figure 3-14 plots the record of groundwater inflow to each mine area in the context of longwall timing and rainfall trends (residual mass). IEPMC (2018) commented that there is "*need to consider the runoff-infiltration component in a cumulative way*". Modelled recharge has been included on the charts to show that the infiltration component, which is a function of accumulated rainfall and antecedent soil moisture conditions, is considered in our analysis. The recharge model used here, and for groundwater modelling, is described in Section 3.9.1.

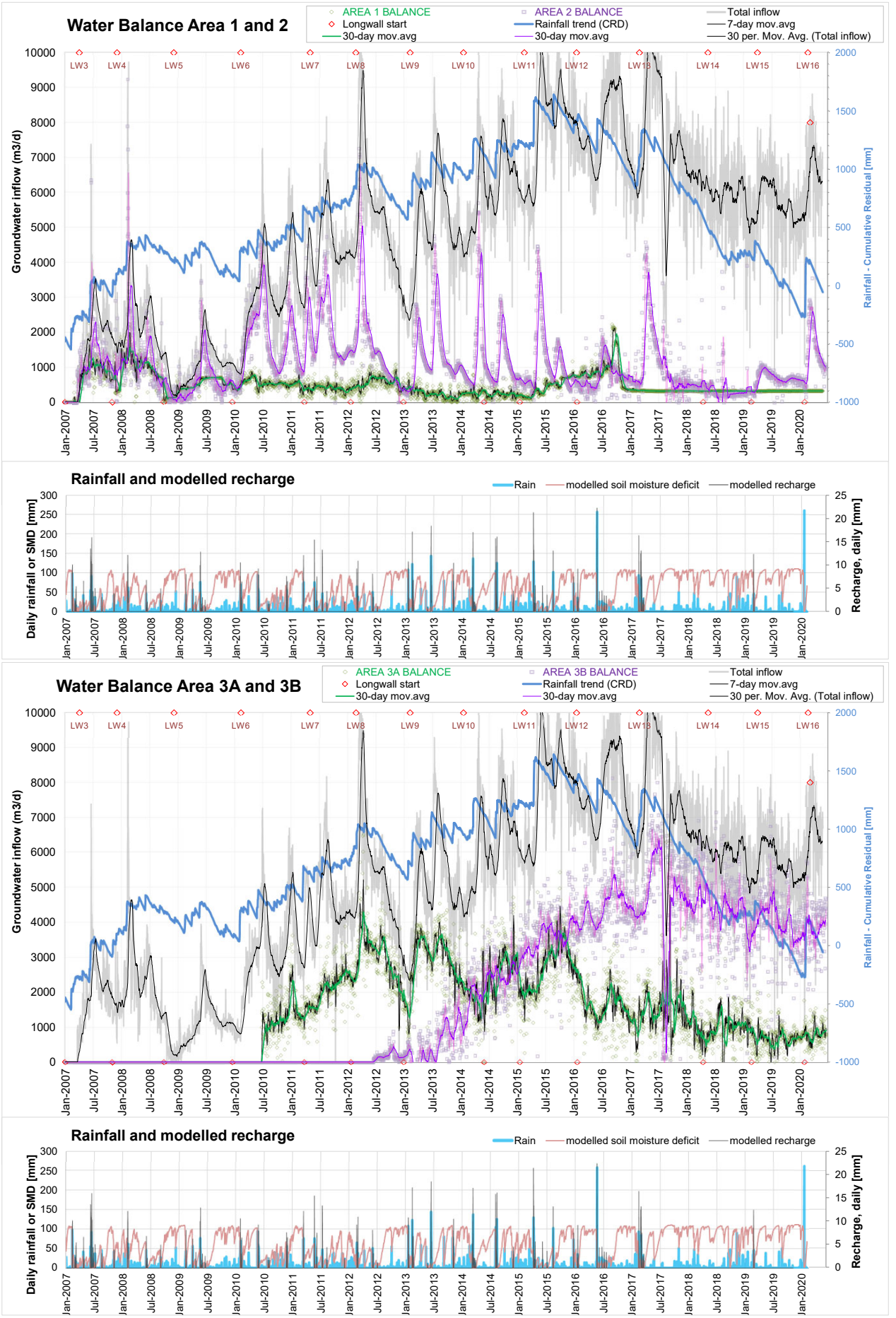
Figure 3-14 shows that since the commencement of Area 3B Longwall 9 total groundwater inflow to Dendrobium Mine has ranged between about 4,000-12,000 m3/d (i.e. 4-12 ML/d) (averaging 6.7 ML/d). The highest water-year total was 3,040 ML in 2016-17.

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

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

Area 3B increased consistently with newly-extracted area until 2017 (Longwall 13), and has plateaued since then, even declining since late 2017 (counter to the trend of increasing inflow with longwall area). This decline could be due to either (or both) persistent dry conditions since 2017 (Section 2.3.1) and declining groundwater levels or storage in and around additional Area 3B longwalls leading to lower inflow.

[4] IMC Procedure DENP0049 - Mine Water Balance v4.0.



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Figure 3-12 Groundwater Inflow Trends by Mine Area

HGEO (2020) reports on methods to identify and quantify rapid ingress of rainfall or surface water vs the inflow from older groundwater storage. These methods include a baseflow separation approach (to filter short-term and long-term variation, similar to the approach of Mackie, 2016) as well as finger-printing via inspection of tritium and other isotopes and more general groundwater chemistry. Findings for Area 2 and Area 3B, which are considered the 'end-members' in terms of hydrograph behaviour, are summarised in **Table 3-8**.

Table 3-8 Estimates of the source of mine inflow at Dendrobium

Mine Area	Rainfall contribution from filtering/smoothing	Rapid ingress from baseflow separation	Tritium-based estimate of modern water
Area 2	90%	83%	14-31%
Area 3B		13% (8-17)%	Median = 0% 90%ile = 5.4%
Source	Mackie, 2016	HGEO, 2020	HGEO, 2020

Using a baseflow separation method, HGEO (2020 estimated that the rainfall-induced component of inflow to Area 3B during the last three longwalls was 8-17% of the total (i.e. approximately 0.3-0.7 ML/d). HGEO also state that as of 23 September 2019, there is no detectable component of modern water in Area 3B inflow. Despite potential for tritium to be absorbed or lost via diffusion or exchange in strata between the surface and the workings, it is clearly detected in Area 2 (**Table 3-8**) and the contrast, when considering the description of the inflow hydrographs (earlier in this section) is indicative that the contribution of modern water to Area 3B inflow is very limited.

Of note in recent times is the response to the heavy rainfall (approximately 260 mm) in mid-February 2020 (**Figure 3-14**). Area 2 inflow responded to this rainfall within a week, rising from 0.4-0.6 ML/d to 2.9 ML/d by mid-March and declining since then. Areas 3A does not show any response to rainfall that appears to be the result of that rainfall event, while Area 3B has a spike coincident with the rainfall event, but this increase is no different to other spikes that have occurred during the preceding drought period. As of late June, the inflow to Area 3B has not shown a response or spike that is clearly related to that heavy rainfall in February. As noted in HGEO (2020), it may be that the lag (4 months from mid-February to late June) has been insufficient for it to be evident in the inflow hydrograph, however it does not support the concept of a rapid flow path.

3.9.4 Baseflow Estimates

Baseflow discharge to watercourses in the Dendrobium area was assessed using flow and electrical conductivity (EC) data at a number of the gauging stations around Areas 3A and 3B (HS, 2019c). The estimated baseflow indices (BFI), baseflow yield (mm/yr) and % long-term average rainfall are summarised in **Table 3-9**. These estimates of BFI are consistent with the regional average of about 10% concluded by Advisian (2016).

Table 3-9 Summary of calculated BFI and Baseflow Yield

Watercourse	Gauge	BFI	Baseflow yield [mm/yr]	%of LTA rainfall
Wongawilli Creek	WWL	10-16 %	31 to 50	2.5 to 4.2%
Donalds Castle Creek	DCU	1-6 %	1.5 to 10	0.1 to 1%
Sandy Creek	SCL2	8-20 %	22 to 55	1.8 to 4.6%

E:\DENDROBIUM\Tech\SurfaceWater\Baseflow\Summary.xlsx

The analysis summarised here suggests 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.

The higher porosity of swamp deposits means that these features are considered to supply reliable baseflow to watercourses for an extended period after rainfall. Further work by various agencies is investigating swamp water balances. It seems likely that swamps do contribute some baseflow to downstream watercourses, however, the significance of that baseflow would be dependent on swamp-specific factors (sediment type, position in the catchment) and catchment-specific factors (topography, slope, geology, rainfall). The relatively shallow nature of the swamp deposits also limits the volume of water that can be stored in them, despite their higher porosity.

3.9.5 Surface flow depletion

Mining-induced subsidence and depressurisation can result in behaviours such as reductions in low-flows and increase in the duration of cease-to-flow conditions. Report such as HS (2016a,b) and McMahon (2015) discussed that, while the loss of surface flow in undermined headwaters streams such as WC21, DC13S1, DCS2 is discernible on hydrographs for those streams (HS, 2016c; HGEO, 2017). The loss of surface water flow is now better quantified in relation to the hydrology at 'reference sites' (WatershedHG, 2019b). The latest End of Panel Report (HGEO, 2020a) showed that flow reductions due to mining were both clearly evident at headwaters streams WC21, DC13 among others, and could be quantified as being reduction in median flow (Q50) of about 30%, or 60% in the case of DC13, due to mining, along with a clear increase in the number of cease-to-flow days. Effects on Q50 are likely to be related, in part, to rainfall and the availability of flow (Section 3.2 of HGEO, 2020e), and so may vary from the effects assessed in recent End of Panel reports by a factor of 3 (or more).

At downstream gauging stations which are more distant from longwalls (DCU, WWL) changes in surface water flow remain difficult to discern from natural variability (HGEO ,2020a). At the end of Longwall 15, DCU shows a mild increase in the number of cease-to-flow days due to mining, but no effects are discerned for Q50 at this site, and no effects are detected at WWL. In the case of WWL, this could be because of gauging accuracy and the relatively small magnitude of loss compared to total flow at the downstream gauging stations. However, that argument is not valid for DCU, where the effects on Q50 at upstream sites DCS2 and DC13 represent a significant proportion of Q50 at DCU.

With respect to effects on Wongawilli Creek, while the recent End-of-Panel reports (HGEO 2018c, 2019a, 2020a) indicate no discernible effect beyond the scale of natural variability at WWL, the reach of Wongawilli Creek adjacent to Longwalls 6-14 experiencing very low flows (discontinuous flow) is likely to have increased. The reach from gauging station WWU to the confluence with WC21 (or the northern edge of Areas 3A and 3B) is termed here as 'mid' Wongawilli Creek. In the last few years, there has been a periodic cessation of continuous flow through this reach during very dry periods (including an instance identified in the last End of Panel report, HGEO 2020a). The evidence is that this is not caused by fracturing of the creek bed, as occurs in streams overlying or nearer to longwalls, but is likely caused by groundwater drawdown and depressurisation from the longwall areas, which are on both eastern and western flanks of the creek. This drawdown results in baseflow loss or capture of the residual 'dry weather' flows in the creek (WatershedHG, 2018).

The lack of significant effects at DCU or WWL, despite clear effects on hydrology in their headwaters, is consistent 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 HS (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).

4 Hydrogeological Conceptual Model

4.1 Effects of longwall mining at Dendrobium

This section follows on from the literature-based review in Section 2.6 and **Figure 2-8**. As described in that section, 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.

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 hydrogeologists (e.g. HGEO, HS, WatershedHG), geotechnical engineers (SCT) and mine geologists (IMC), a conceptual model diagram has been developed and adopted for groundwater assessment and modelling, both in terms of the geomechanical behaviour and groundwater response. This conceptual model is described in **Figure 4-1** and **Table 4-1**, and draws in findings from HGEO (2020c) (Section 3.6.1) and recent End of Panel reports (e.g. HGEO, 2020b).

Table 4-1 is based mainly on the geotechnical zones proposed by Mills (2011), but with consideration of other published works. It is acknowledged that in reality, the conceptual zones are not clearly distinguished, and would occur as a continuum with gradual changes between zones.

The following text in this section describe the conceptual model of the changes that occur to the hydraulic conductivity and storage properties of the strata around Dendrobium Mine. In the following text, numbers in circles, e.g. ①-⑳, correspond to the zones on **Figure 4-1**, some of which are also listed in **Table 4-1Table 4-1**.

After panels of coal are extracted the strata immediately overlying the extracted seam collapses into the void (forming a 'goaf'). The strata above the goaf deform and fracture in response, and subsidence occurs at the ground surface, manifesting as a trough along the axis of the extracted panel. At Dendrobium, some mode of fracturing due to mining subsidence occurs from the seam to the surface (**Figure 4-2**).

This surface subsidence reduces the volume available to offset the extracted coal. MSEC (2017) calculated subsidence of 0.8 m (above pillars) and 2.5 m (along the longwall centreline) 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 leaves a residual void space of 2.4 m (calculated as 3.9 m – 1.5 m).

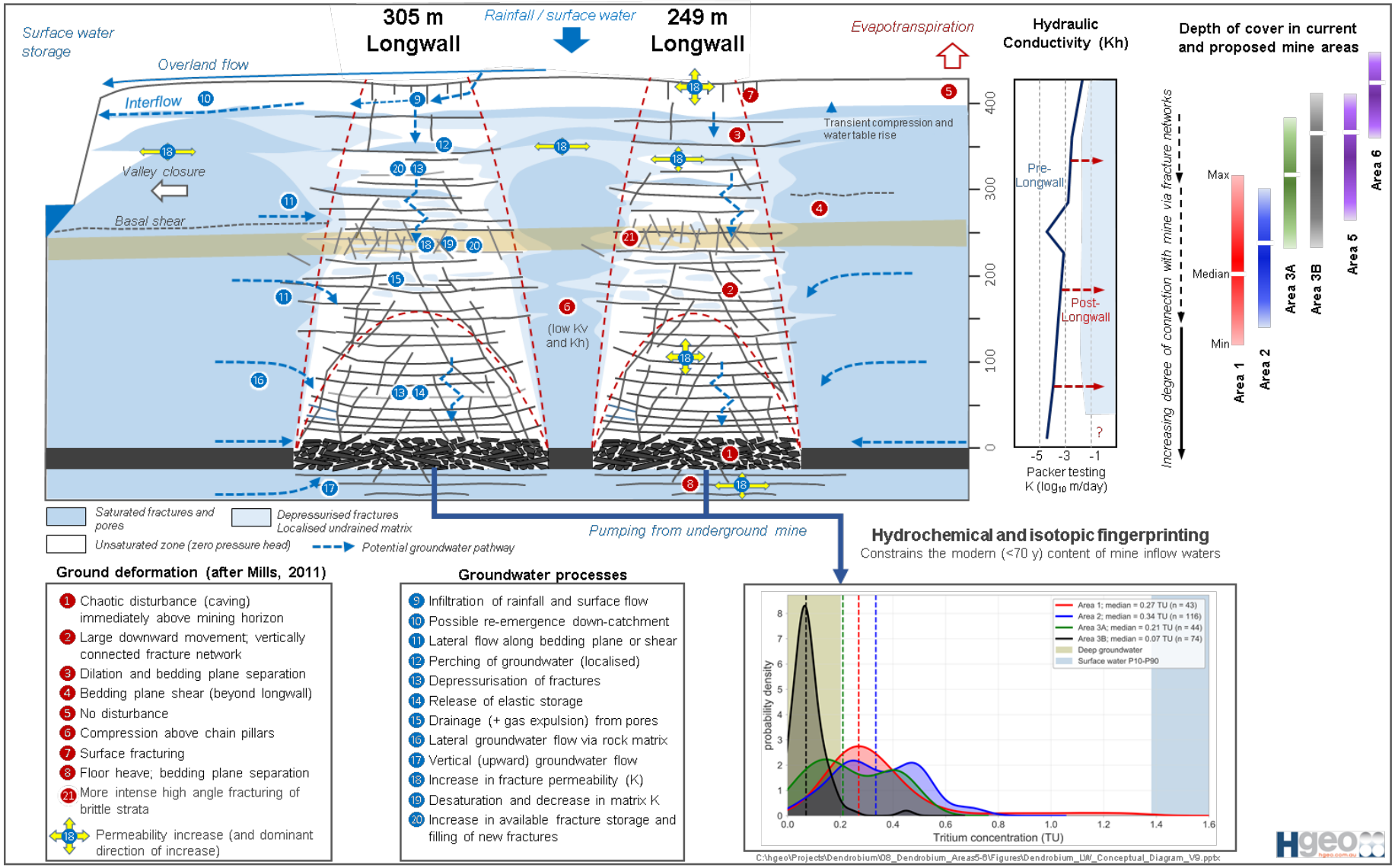


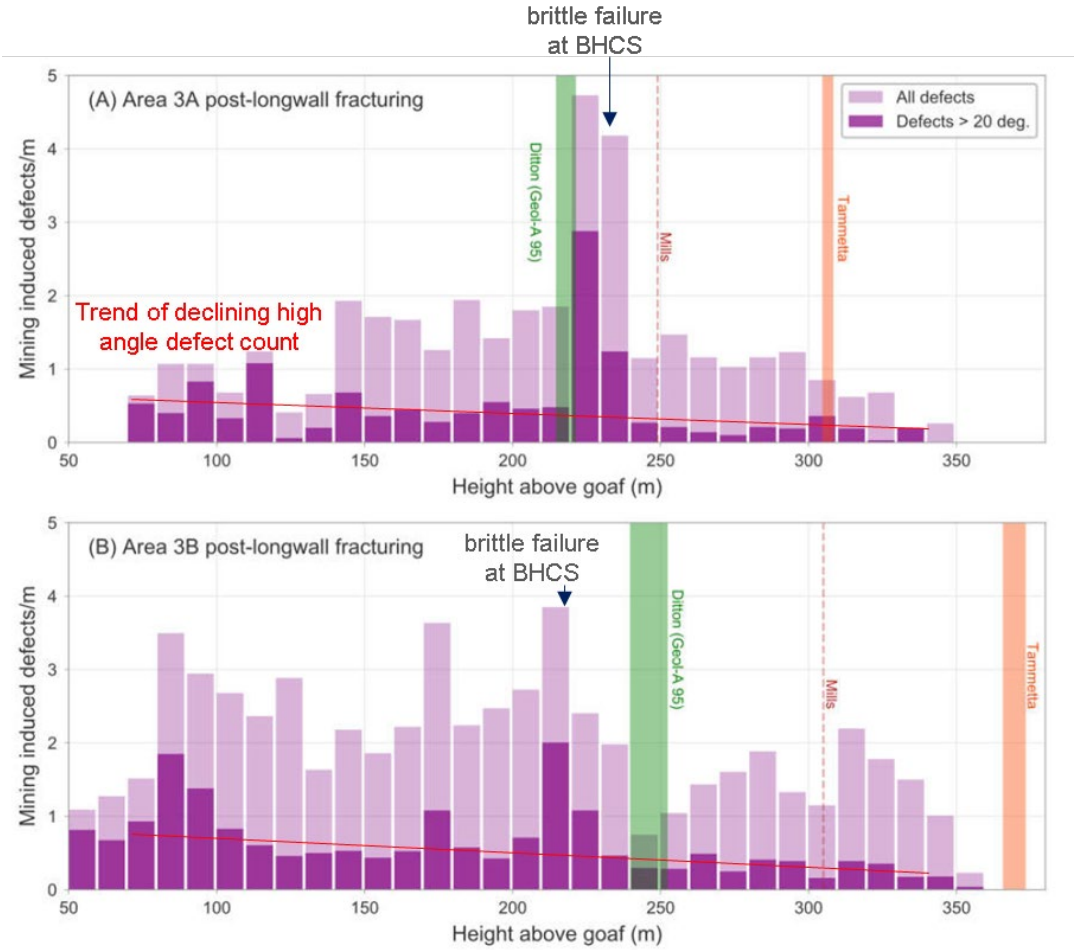
Figure 4-1 Geomechanical and groundwater conceptual model

The strata in the lower parts of the fractured zone ①② shows significantly more low angle and high angle defects than host rock (**Figure 4-2**), and are known to have a substantially higher hydraulic conductivity ⑱ than the undisturbed host rocks ⑤:

- horizontal hydraulic conductivity (Kh) is known, from recent packer testing, to be increased by 2-3 orders of magnitude (Section 3.6.1); and
- while vertical hydraulic conductivity cannot be measured, but based on the defect logging and presence of intense high angle fracturing, is assumed to be significantly higher than host strata.

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

The intensity of high angle fracturing due to panel extraction generally reduces with height above the extracted panel, while low angle fracturing occurs more consistently to the surface (**Figure 4-2**).



(modified after HGEO, 2020c)

Figure 4-2 Change in fracture mode with height above extracted panel

This declining continuity between separate fractures with increasing height above the seam means that fracturing becomes gradually less well-connected in a vertical sense (i.e.), tending toward being vertically 'disconnected' ③). Kh increases due to the parting of bedding planes by 1-2 orders of magnitude in the upper part of the sequence above a panel, being enhanced more than Kv due to reduced frequency of these high angle fractures to act as vertical pathways.

Table 4-1 Conceptual zones of deformation associated with longwall mining

Conceptual Zone			Mills (2011)	Tammetta (2012)	Ditton (2014)	Geometry
⑦	Surface cracking 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.
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 (Section 3.6.1and 3.6.1HGEO, 2020c).
③	Fractured Zone	upper zone of Disconnected Fracturing	Zone of stress relaxation (#4); Zone of bedding plane dilation, some fracturing (#3)		B-zone	▶ 1.6 x panel width (W) (Mills, 2011); ▶ B/B95 - Ditton and Merrick (2014); or ▶ H (Tammetta, 2012)*.
②		lower zone of Connected Fracturing	Zone of large downward movement (#2)	Collapsed Zone	A-zone	▶ 1 x panel width (W) (Mills, 2012); ▶ H (Tammetta, 2012)*; or ▶ 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); ▶ 5-20 m (Mills, 2011).
	Mined seam (extracted panel)					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 4-1.**
* Tammetta's conceptual model is for groundwater response, not geomechnical changes, so can be applicable to both ② and ③.

In these zones where low angle fractures are numerous but high angle fractures much less so, 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 high angle fracturing is insufficiently continuous or connected (i.e. insufficiently transmissive) to cause drainage of groundwater from the upper zone toward the mine workings and goaf. Furthermore, the observed significant changes to Kh will cause depressurisation due to lateral drainage.

At distances exceeding approximately 500-600 m from the mine, strata are assumed to be relatively unaffected ⑤ (noting that in different geological settings, such as the Western Coalfield, the effects of

geological structure has been shown to result in changes to permeability and effects on environmental receptors to much greater distances (Section 2.5.2.3). This has not been the case for Dendrobium.

Within approximately 600 m of the longwall goaf 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 and permeability to develop (as described for Longwall 12 investigations in HGEO, 2020c), 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. fracturing is observed through the sequence above these longwalls (Section 3.6.1).

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

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

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). MSEC indicate that the furthest observed effect was at 290 m from Dendrobium longwalls.

Surface fracturing is likely to result in persistent or permanent changes to hydrology ⑨, such as the effects analysed in headwater streams around Area 3B which include 20-60% reduction in median flow and 15-40% increase in the average number of cease-to-flow days (HGEO, 2020a). Leakage of water into the surface fracturing zone can result in effects on water quality (McNally and Evans, 2007).

Surface water that is redirected into and through near-surface fractures ⑨ may either migrate downwards towards the goaf ⑬, be lost to some other process such as evapotranspiration, be returned to surface drainage somewhere down-gradient ⑩, or some combination of these. In the case of returned flow, net loss from the catchment is minimal. Recent analysis (Section 3.9.5 and HGEO, 2020a) indicates that the return of surface flows is very plausible, i.e. the strongest evidence for this appears to be in the Donalds Castle Creek catchment (the DCU gauging station), despite significant localised flow reductions immediately above extracted longwall panels (at DC13, DCS2).

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

The zones of enhanced K, i.e. the deformation zones ①②③⑦, above the mine void/goaf on **Figure 4-1** 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 2.6, PSM (2017)). There are also methods and schemes for estimating change in K (e.g. Tammetta, 2014; Guo *et al.*, 2007). Significantly, the recent post-mining investigations have provided good quantitative data on the changes to Kh, and some 'soft' information on how Kv is enhanced (Section 3.6.1). The height of conceptual zones and K are tested during groundwater model calibration (Sections 5.4 and 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 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.

Recent testing at the Lake Avon monitoring bores (SCT, 2017; HGEO, 2019b) did not consistently detect 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 3.6.3). 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.

Although the degree of enhancement of Kh in areas offset from a longwall is unclear and subject to on-going investigation, it is considered prudent that the effects of an increase in Kh are modelled (Section 5.4.4). For the purpose of modelling, it is 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 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 4-1**) 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 3.8.3)) 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 18 is slightly less than that of recent Area 3B panels, at about 330 m, but has a higher 'minimum' depth of cover than most other recent panels (**Table 1-1**).

The greatest drawdown effects occur in the strata within or immediately above the mined coal seam. Within and adjacent to the connected fracture zone ② which, at Area 3B includes the Scarborough and Bulgo Sandstones. The Bald Hill Claystone is also potentially within this 'connected' zone due to the brittle failure of the unit. The drawdown is often >50 m, or the strata become completely depressurised (pressure head is zero). Above the connected fractured zone (i.e. where fracturing is poorly connected or disconnected ③), the degree of drawdown becomes less towards the surface. Drawdown in the mid-Hawkesbury Sandstone is typically about 10-20 m, and in the shallower horizons of the Hawkesbury Sandstone it has been observed to be approximately 5-10 m (e.g. at S2192-S2220 directly overlying Longwall 9 and in the 23-26 m pre- and post-mining piezometers in S2335/S2335A).

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

Within Dendrobium Mine there are not domains or areas where inflow has ceased, although 'baseline' inflow to Area 2 is approximately 0.5 ML/d and inflow is clearly declining in Area 3A (down from approximately 2 ML/d to less than 1 ML/d in recent years) (Section 3.9.3). It is expected that drawdown would persist until after 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, as well as due to post-closure management (e.g. including the type and location of any seals within the workings or the continuation of dewatering).

Some effects will persist, possibly for decades or even permanently. Most significantly, surface cracking effects in the bed of undermined watercourses or streams adjacent to longwalls, will likely persist in the long-term. Rehabilitation is a possibility, and trials are being planned at Dendrobium (WC21) and have been carried out at Tahmoor (Redbank Creek) and other areas. The effectiveness of this is unclear. If such measures are ineffective, persistent flow losses in undermined creeks, such as those estimated in recent End of Panel assessments (HGEO, 2020a), are likely to continue. Losses that occur to drawdown are more likely to be transient; these might be short-lived if caused by

increased strata porosity, but if caused by drawdown within and around zones of connected fracturing these effects may persist long after dewatering ceases.

4.2 Structure

Geological structures are mapped on **Figure 2-3** and **Figure 2-4** and discussed in Section 2.5.2.

4.2.1 Lineaments

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 2.5.2.3).

As described in SRK (2020) and Hebblewhite (2019), the Western Coalfield is different to the Southern Coalfield, and the experience at Dendrobium is different to that identified by IEPMC (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 enhanced subsidence around lineaments beyond the edge of longwall panels is not evident at Dendrobium.

Based on the interpretation above, there is no need to explicitly represent lineaments in the regional groundwater model.

4.2.2 Elouera Fault

In terms of groundwater or hydrological effects, the key properties of the Elouera Fault are:

- Current condition with respect to transverse transmissivity;
- Current condition with respect to longitudinal transmissivity;
- Potential for fault reactivation and possible changes to hydraulic conductivity.

These are addressed in the following sub-sections, based on Section 2.5.2.2 which presents data on the current condition of the fault, summarised from review of HGEO (2020d).

In general terms, transmissivity across the fault plane (i.e. transverse connectivity) is governed by stratigraphic units that are adjacent across the fault plane, including any juxtaposition of these due to fault offsets, as well as the presence and properties of any fault gouge within the core of the fault.

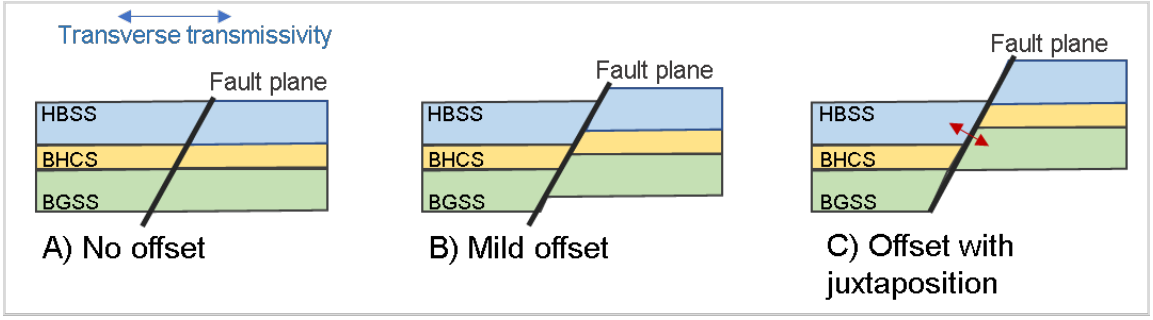


Figure 4-3 Conceptual models of transverse transmissivity and offset strata

HGEO (2020d) has assessed the transverse transmissivity and potential for juxtaposition, with focus on the potential juxtaposition of the HBSS and BGSS across the Bald Hill Claystone (i.e. case C in **Figure 4-3**).

The juxtaposition across the Elouera Fault and inferred hydraulic conductivity of the abutting strata means that a general reduction in transverse (north←→south) transmissivity occurs across this structure. This conclusion ignores the potential role of any fault gouge in the core of the fault; the presence of such material is likely to further reduce transmissivity in this direction.

The fault displacement or offset is known to be approximately 40 m at seam level, declining to 8-13 m around the Bald Hill Claystone (Section 2.5.2.2). When compared to the logged thickness of the Bald Hill Claystone, that unit would not be completely offset to cause juxtaposition of the HBSS with the BGSS/CVSS. That is, the situation at the Elouera Fault is like case B of **Figure 4-3.**

In summary, transmissivity across, or transverse to, the Elouera Fault is not considered to be significantly different to strata in areas away from the fault zone. It is highly unlikely to be more transmissive, with a high probability that it will be reduced compared to undisturbed areas.

Longitudinal transmissivity, i.e. along the plane of the fault, in the current environment will be governed by permeability within the fault zone. A series of boreholes were packer tested and cored, as presented in HGEO (2020d). This analysis has compared fault zone Kh against the 10th-90th percentile range of Kh found elsewhere at Dendrobium; this range is taken to be the 'expected' natural hydraulic conductivity. HGEO has shown that there are individual bores where fault zone Kh is above the 'expected' range, but these are interspersed with bores where the measured Kh is well within the expected range. Therefore, there is no evidence for a continuous high permeability zone in the current environment that would act as a preferential pathway or conduit along the plane of the Elouera Fault (even after the stress relief due to the extraction of Elouera Longwalls 7 and 8, just to the south – see below).

HGEO recommended that tracer testing be conducted around the Elouera Fault as a second method for understanding the transmissivity around this feature. This is planned for late 2020.

The extraction of longwall panels changes the stress regime in the ground surrounding the panel, and in this case there is concern that the extraction of Dendrobium longwalls, especially Longwall 18, could alter stress conditions in a way that reactivates ('unclamps') the Elouera Fault. SCT (2020) has investigated the potential for this reactivation for IMC by considering the current stress regime at Dendrobium and at the Elouera Fault specifically. SCT's main findings are that:

- Historical longwall mining at Elouera Colliery, on the southern side of the Elouera Fault, has resulted in stress relief compared to background (pre-mining) conditions determined at other locations around Dendrobium. This change was estimated to be approximately 6.4 MPa at the Elouera Fault at a depth of 200 m.
- Because of its distance (approximately 700 m) to the fault, "mining of Longwall 17 would not be expected to have a significant effect on the horizontal stresses across the Elouera Fault".
- "Mining Longwall 18 would be expected to cause a slight reduction in horizontal stress at the location of the Elouera Fault, but this reduction would not be as large as the reduction in stress that has already occurred at the fault from the mining of longwall panels at Elouera Colliery". This change was estimated to be approximately 1.6 MPa reduction in horizontal stress.

Hydraulic conductivity in the upper 200-300 m at Dendrobium is strongly influenced by depth (Section 3.5.1), which is related to stress closing fractures. Therefore, in discussion with SCT, the potential for stress relief to affect hydraulic conductivity around the fault has been estimated using the log-linear relationship to depth (stress) in the hydraulic conductivity data.

Overburden pressure increases at about 2-3 MPa/100m, the horizontal stress is approximately double that (5 MPa/100m), and in the upper 300 m the change in hydraulic conductivity is approximately 1 order of magnitude/100m.

The estimated stress change due to Longwall 18 extraction is equivalent to a hydraulic conductivity change of approximately 0.5 orders of magnitude (WatershedHG estimate) or 0.63 orders of magnitude (SCT estimate, K Mills pers comm). As a result, the modelling needs to account for an increase in permeability that is in this range (i.e. fault zone host permeability x 5 approximately). Scenarios to simulate this, as well as two further scenarios simulating host permeability x 1 and x10 (as a means to account for uncertainty) are described in Section 7.2.1.

5 Numerical Model Development and History-matching

As noted in Section 1.5, numerical groundwater modelling has been carried out for Dendrobium since 2007. As IEPMC (2019a) indicate, over this time the requirements of the modelling and the complexity of modelling undertaken has advanced considerably. In response to a recent request by WaterNSW, a brief summary of the history of groundwater modelling at Dendrobium is provided in **Appendix B**.

The groundwater modelling for this study builds on the modelling for the recent EIS for proposed Areas 5 and 6 (HS, 2019c). The following sections are brief, for the purpose of an SMP application. They focus on the key aspects of the modelling, and modifications to the EIS model are highlighted along with any items relevant to agency conditions or recommendations.

5.1 Model Objectives

The groundwater modelling is required to inform IMC and regulators as to the potential effects of Longwall 18, in the context of Area 3B and other approved Dendrobium mine workings. This includes providing incremental and cumulative impact estimates of:

- Groundwater inflow to Dendrobium workings;
- Groundwater head and drawdown responses;
- Changes to surface water flow in nearby watercourses; and
- Induced leakage from water supply reservoirs.

5.2 Model Implementation

5.2.1 Software selection

Over time (see **Appendix B**), modelling has progressed from 2-dimensional (2D) 'slice' modelling in GHD (2007) to 3D models of Coffey (2012b) and subsequent. Coffey and HydroSimulations (up to and including 2014) used MODFLOW-SURFACT. Later models rely on MODFLOW-USG (Panday *et al.* 2013), which has come to be the industry standard in Australia. This version of the Dendrobium groundwater model, like other recent versions, uses the enhanced version of MODFLOW-USG, sometimes referred to as MODFLOW-USG-beta or MODFLOW-USG-Transport (Panday, 2019).

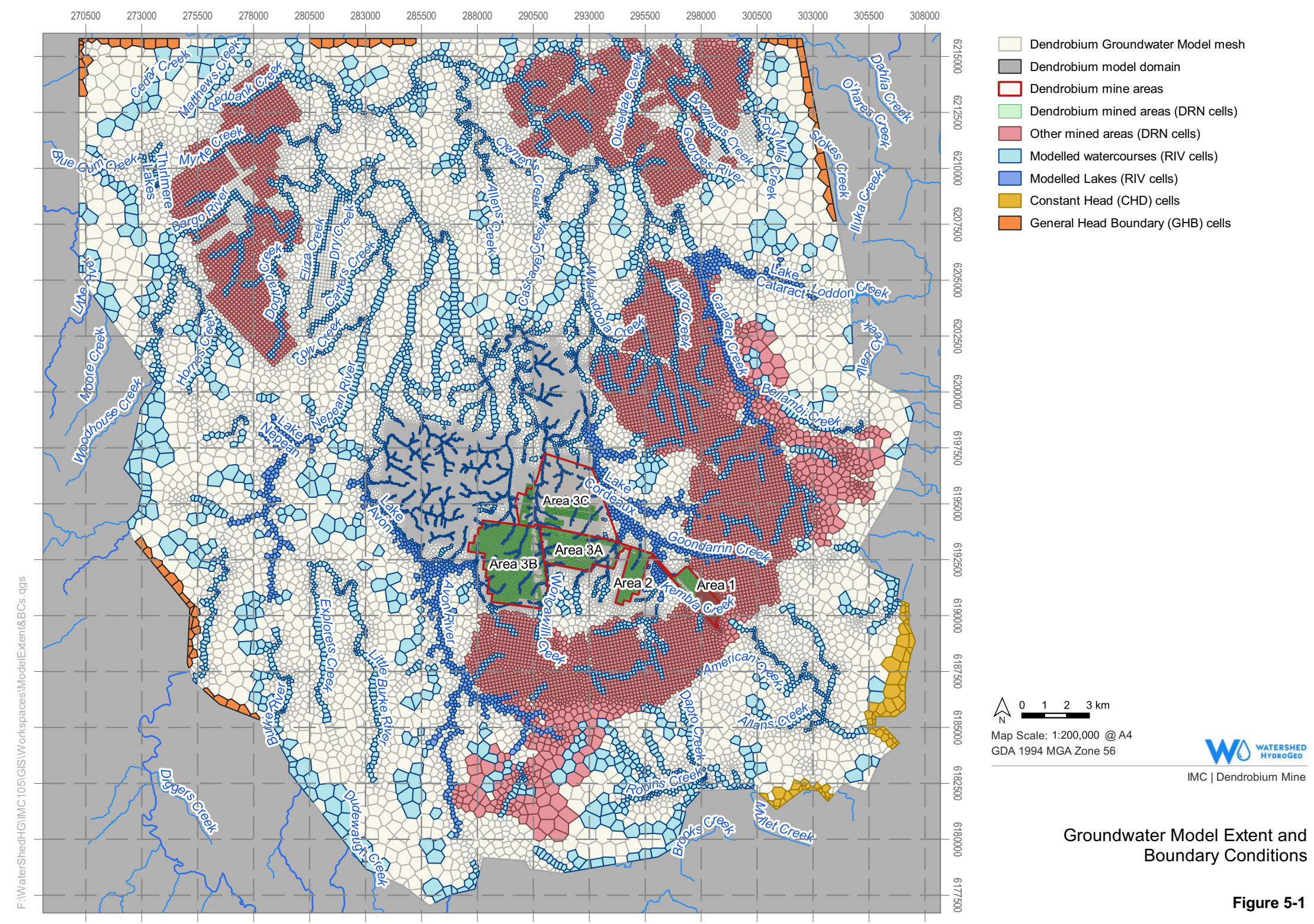
The model uses the 'upstream weighting' method for simulating unsaturated conditions (similar to the 'pseudo-soil' function in MODFLOW-SURFACT), as per recent modelling. Some earlier versions of the Dendrobium groundwater model have used Richards' equation (e.g. HS, 2014; 2016a).

The head closure criterion specified in the MODFLOW-USG SMS solver was set at 0.05 m, which is appropriate for the objectives and has not affected the model mass balance error (Section 6.3).

5.2.2 Model Mesh and Spatial Discretisation

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

The model mesh was created using AlgoMesh Software v2.0 (HydroAlgorithmics, 2020). Greater cell refinement was applied to areas of interest, such as mine footprints and watercourses. Cells within the mining footprint were given a regular grid structure (i.e. square cells) oriented as consistently as possible with longwall panels. **Figure 5-1** shows the model mesh geometry as well as indicating the boundary conditions applied to the model.



Groundwater Model Extent and Boundary Conditions

Figure 5-1

Cells used to represent the approved mining areas at Dendrobium (Areas 1-3B) are given a uniform width and length of 60 m, while those for proposed domains (Areas 3C, 5 and 6) are assigned uniform width and length of 50 m. That is, Longwall 18 is simulated with a 60 m square grid.

The model consists of 17 layers (as per the EIS model, HS, 2019c), but with further modification from the EIS model around future Area 3C, so each layer now has a maximum of 47,359 cells. The 'pinch-out' functionality was used for this model and removed any cells where the thickness was calculated as less than 0.1 m. This results in a total of 741,889 active cells.

5.2.3 Model Geometry and Hydrostratigraphy

Table 5-1 summarises the stratigraphy framework for the 17 layers adopted in this project. This is the same as in HydroSimulations (2019c). The geometry of the model layering is based on the geological model supplied by IMC, which is defined by hundreds of exploration drill logs. Layers have a variable thickness across the model domain, but the average thickness across the model domain and the typical thickness within Longwall 18 are described in **Table 5-1**.

Table 5-1 Model layer assignment

Layer	Stratigraphy	Secondary Lithology	Thickness [m], mean	Thickness, LW18
1	Regolith	Swamp deposits	Regolith: 5, swamp: 2	Regolith: 5
2	Hawkesbury Sandstone (upper)		24	1
3	Hawkesbury Sandstone (middle)		40	43
4	Hawkesbury Sandstone (lower)	Crinanite (Area 2)	33	40
5	Bald Hill Claystone	plus Garie and Newport Fms / Crinanite (Area 2)	27	36
6	Bulgo Sandstone (upper)	Colo Vale Sandstone (Area 3B) / Crinanite (A2)	53	45
7	Bulgo Sandstone (lower)	Colo Vale Sandstone (A3B) / Crinanite (A2)	40	45
8	Stanwell Park Claystone	Colo Vale Sandstone (A3B) / Crinanite (A2)	17	15
9	Scarborough Sandstone	Colo Vale Sandstone (A3B) / Crinanite (A2)	35	35
10	Wombarra Claystone	Crinanite (A2)	25	21
11	Coalcliff Sandstone	Wombarra Formation (A3B)	11	12
12	Bulli Coal Seam		2.3	2.1
13	Lawrence & Loddon Sandstones		28	25
14	Wongawilli Coal Seam	(working section)	4.2	4
15	Kembla Sandstone		19	20
16	lower Permian Coal Measures		24	25
17	Shoalhaven Group and older		100	100

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

5.2.4 Model Temporal Discretisation

The model stress period schedule is included as **Appendix C** to this report, along with annotations of longwall extraction and rainfall events mentioned below. The stress period schedule has been modified slightly for this study compared to the modelling in HS, 2019a or 2019c.

The modelled time period, covering 1940 to 2200, was discretised into a total 203 stress periods. Stress periods were set at a fine resolution for the duration of historical, approved and proposed mining at Dendrobium so that each longwall was typically represented by 3 or 4 stress periods. This allows for a reasonable simulation of the progressive changes in the groundwater system in response to longwall extraction.

Furthermore, to attempt to simulate the dynamics of very high rainfall periods, such as those leading to the 'inflow' events observed in Area 2 (Section 3.9.3) the key events have been identified. A series of shorter stress periods of a few days or a week have been defined to capture the intense rainfall event and the following period where the bulk of the inflow occurs. Fifteen such high rainfall/inflow sequences or events are included in the model time period (**Appendix C**).

5.3 Boundary Conditions

Almost all the boundary conditions remain identical to the modelling presented in HydroSimulations (2019c). A summary of the boundary conditions is presented below, with emphasis on any changes.

5.3.1 Diffuse Recharge

Rainfall recharge is simulated using the MODFLOW Recharge (RCH) package consistent with previous modelling (e.g. HS, 2019a, 2019c).

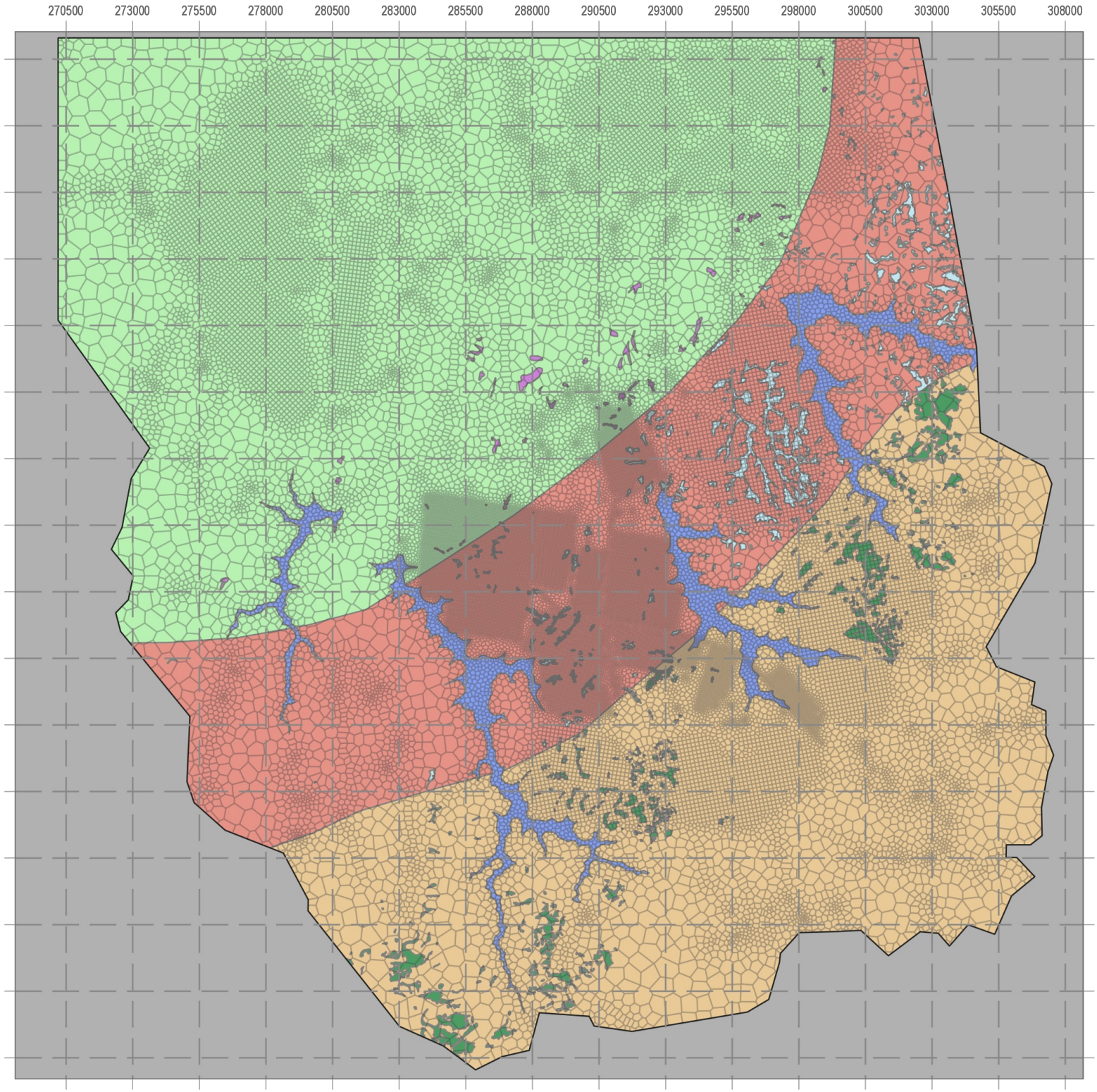
The model domain is divided into three zones representing broad 'average rainfall' zones, aligned with BoM long-term average rainfall contours, with higher rainfall and recharge at the top of the escarpment, declining to the west (away from the coast), consistent with estimates by AWRA and Crosbie (2015). These are then sub-divided into two zones based on outcrop geology: unconsolidated (swamps) and rock units. The recharge rate for the area immediately around or above Dendrobium mining areas (Zones 3 and 6, **Figure 5-2**) is the subject of the calculations described below, and then the recharge to the inland and escarpment areas (which are generally drier and wetter, respectively) has been weighted by comparison with the results of Crosbie (2015).

Temporal variation in rainfall recharge to the area above Dendrobium mining areas has been calculated based on a water balance calculated on a daily timestep and accounting for runoff, soil moisture deficit and recharge based on inputs of rainfall and potential evaporation (Section 3.9.1). Rainfall and potential evaporation data are available from several sources:

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

This water balance has been calibrated against literature values, especially Crosbie (2015) and AWRA model estimates by BoM (Section 3.9.1). The modelled estimates of recharge were then aggregated across model stress periods (**Figure 3-13**). Estimates of rainfall recharge to unconsolidated deposits within swamp areas are not available but are conceptualised as being more than that of the rock outcrop. As a result, average modelled recharge of about 330 mm/year is assumed, equivalent to 25-30% of long-term average rainfall. On-going research by universities may improve on these estimates in future.

The groundwater model simulates variable recharge rates until model stress period 119 (equivalent of February 2020), and then a constant recharge rate representing approximately average conditions (calculated from the period 2000-2020) has been utilised to simulate recharge and evapotranspiration from stress period 120 until the end of the simulation. Although this does not allow short-term variability to be represented in predictions of future conditions, using a constant rate allows stresses and associated impacts in the predictive period to be identified more clearly.



Dendrobium Groundwater Model mesh

Dendrobium model domain

Recharge Zones

- 1 - No recharge
- 2 - Triassic and Permian outcrop (coastal/escarpment)
- 3 - Triassic and Permian outcrop
- 4 - Triassic and Permian outcrop (inland)
- 5 - Swamp (escarpment)
- 6 - Swamp
- 7 - Swamp (inland)

N

0 1 2 3 km

Map Scale: 1:200,000 @ A4

GDA 1994 MGA Zone 56

WATERSHED HYDROGEO

IMC | Dendrobium Mine

F:\WaterShedHG\IMC105\GIS\Workspaces\ModelExtent&BCs.qgs

Modelled Recharge Zones

Figure 5-2

5.3.2 Evapotranspiration

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

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

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

5.3.3 Reservoirs

'River' boundary conditions have been employed to represent the reservoirs or lakes, as in previous modelling. The historical record of water levels in the Avon and Cordeaux Reservoirs has been employed, as in HydroSimulations (2016a, 2019a, 2019c), but updated to include recent data. The predictive modelling uses the reservoir FSL as the stage. These are 320.18 mAHD for Lake Avon, and 303.76 mAHD for Lake Cordeaux.

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

5.3.4 Watercourses (creeks and rivers)

Watercourses are represented using the MODFLOW 'River' package as per the 2019a and 2019c models. The model simulates variable stream stages based on historical weather conditions until model stress period 119 (equivalent of February 2020 – **Appendix C**).

A constant stage representing average conditions has been used to simulate watercourses during the predictive period (stress period 119 until the end of the simulation). This allows the watercourses to 'leak' water to the underlying groundwater system to obtain suitable estimates of surface water losses as a result of mining activities.

Rivers are all set within model layer 1. Bed conductance has been estimated as 2-268, averaging 22 m^2/d. This is based on an assumed hydraulic conductivity of 0.01 m/d, assumed watercourse widths (1.5 to 25 m), and cell "lengths" (calculated as the square root of the cell area).

5.3.5 Regional groundwater flow

General Head Boundaries (GHB) are set around parts of the model domain where regional groundwater flow is conceptualised as being into or out of the model (rather than predominantly 'parallel' to the edge of the model). Inflow is conceptualised as occurring along the southwestern boundary to represent northward groundwater from the Southern Highlands entering the active model domain, while outflow occurs along the northern boundary to represent the continued northward flow toward the centre of the Sydney Basin (Section 3.7.1).

In these areas GHBs are set to allow groundwater flux in the more transmissive parts of the hydro-stratigraphic sequence, typically layers 2, 3, 4, 6, 7, 9, 10, 12 and 14 (Section 5.2.3). The elevation or stage of these is based on nearby groundwater levels from observation bores (where available), otherwise extrapolated levels from contouring or previous modelling.

5.3.6 Mine dewatering

MODFLOW 'Drain' boundary conditions are used to represent mining, specifically simulating the dewatering of the workings. Drains were activated to fit the scheduling of all mining areas, but focussing on Dendrobium, as outlined in **Table 1-1** and **Appendix C**.

Drains are set at 0.1 m above the base of the mined seam to simulate dewatering of the workings. Conductances were set as summarised in **Table 5-2**, although may vary slight based on cell size.

Table 5-2 Model Drain parameters

Mine	Coal Seam	Model Layer	Drain Cell Conductance (m^2/day)
Dendrobium			
Longwalls - Areas 1 to 3C + 6	Wongawilli Coal	14	2.5
Longwalls - Area 5	Bulli Coal	12	2.5
Mains and roadways		12 and 14 (by Area)	0.025
Other			
Longwalls (e.g. Kemira, Elouera)	Wongawilli Coal	14	10
Longwalls (e.g. Appin/BSO, Cordeaux, Tahmoor, Mt Kembla)	Bulli Coal	12	10
Bord and pillar / partial extraction (e.g. Kemira, Elouera)	Wongawilli Coal	14	8
Bord and pillar / partial extraction (e.g. Appin/BSO, Cordeaux, Tahmoor, Mt Kembla)	Bulli Coal	12	8

5.4 Modelled subsidence and strata deformation

Background to this section is provided in Sections 2.6 and 4.1. Simulation of mining-induced changes to the hydraulic properties of rock strata within and above longwall panels has typically been limited to simulating the 'connected fracture zone'. Previous modelling at Dendrobium has employed, at different times, three different methods of simulating the fracturing and deformation processes, which were summarised in HydroSimulations (e.g. 2019a, 2019c) and in SLR, 2020a and IEPMC, 2019b:

- Transient of time-varying material ('TMP' or 'TVM') properties;
- 'Stacked Drains';
- Connected Linear Networks (CLN).

Each of these have their strengths and limitations. The 'Stacked Drains' method has been employed in recent modelling at Dendrobium (e.g. HS, 2019a, 2019c; SLR, 2020a).

Given that IMC has initiated a (separate) study investigating post-closure hydrology and there is newly-available data from Dendrobium's centreline bore investigations (HGEO, 2020c and Section 3.6), the use of time-varying material properties (TVM) functionality in MODFLOW-USG has been adopted for this modelling. We consider that this equivalent porous media approach to simulating fracturing and deformation is superior because it is an appropriate scale for comparison to

observations such as the centreline bore packer testing data. The TVM method (or its equivalent in MODFLOW-SURFACT) was previously used at Dendrobium in HS, 2013 and HS, 2014 model variants and is also used at other sites in the Southern Coalfield (e.g. Tahmoor Mine, Metropolitan Mine).

Surface flow reductions predicted by the groundwater model presented in the EIS (HS, 2019c) or for recent SMP approvals have been overly conservative compared to flow losses that have been estimated in the last End Of Panel report (HGEO, 2020b) via the revised TARP calculation methods agreed with agencies (described in WatershedHG, 2019 and the latest Area 3A, 3B and 3C WIMMCP documents).

However, calibration of this revised model, thus far using TVM alone, has not yet simulated surface water reductions that sufficiently match the historical losses estimated in recent End of Panel assessment (HGEO, 2020a). 'Stacked Drains' have been implemented in conjunction with TVM (Section 5.4.5). This will be the subject of further work (Section 8.2).

5.4.1 Modified hydraulic properties

The conceptual "zones" of deformation and fracturing are represented in the model via an enhanced Kh and Kv. **Table 5-3** summarises these, both within the longwall footprint and outside or off the goaf. **Figure 5-3** presents the modelled profiles of hydraulic conductivity against data from the recent HOF investigation (HGEO, 2020a), as described briefly in Section 3.6. Some commentary on specific zones is provided below, along with a schematic (**Figure 5-4**) showing the application of the zones across and above modelled longwall panels.

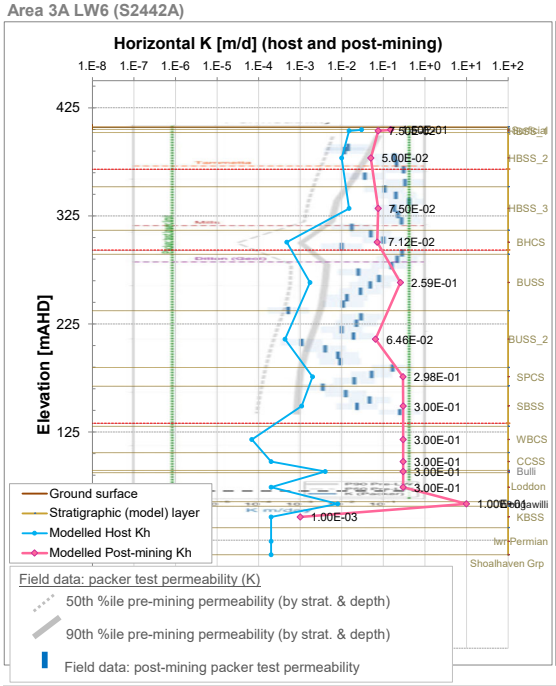
Table 5-3 Summary of enhanced hydraulic properties used in the TVM package

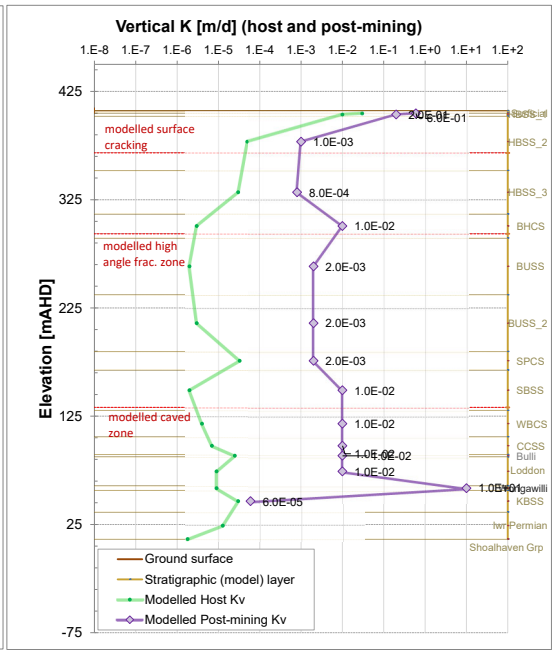
Feature	Longwall 18 model representation		Comment
within footprint	Kh (post-mining)	Kv (post-mining)	
Surface cracking zone	x 5	X 20	
Low angle fracture zone	x 20	x 15	
High angle (connected fracture) zone	Max of: x 150 and 0.01	Max of: x 50 and 0.002	Applied to centre-line model cells, based on comparison of Longwall 12 bore investigations
Caved zone	0.3	0.01	
Longwall (seam)	10	10	
Roadway / partial extraction	100	0.1	
Underlying floor	x 5	x 2	
Outside footprint			
Off-goaf <100m	x 2		
Off-goaf <300m	x 2		
Off-goaf <600m	x 2		
Elouera Fault zone	a) no change; b) x 5; c) x 10.	a) no change; b) x 5; c) x 10.	Scenarios for permeability change under stress relief

TVM parameters from:
\Model\GWmodel\Construction\FracZone\DND5\FracZone_DND5TR46_Dend_OtherMines_Offgoaf_TVM_EFault.xlsm

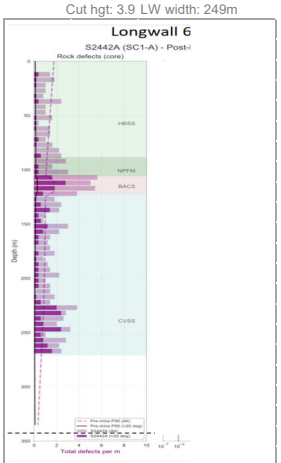
Area 3A LW6 (S2442A)

Model cell: 2DNode: 3203





Position in mine workings:
Longwall Centreline
Cut hgt: 3.9 LW width: 249m

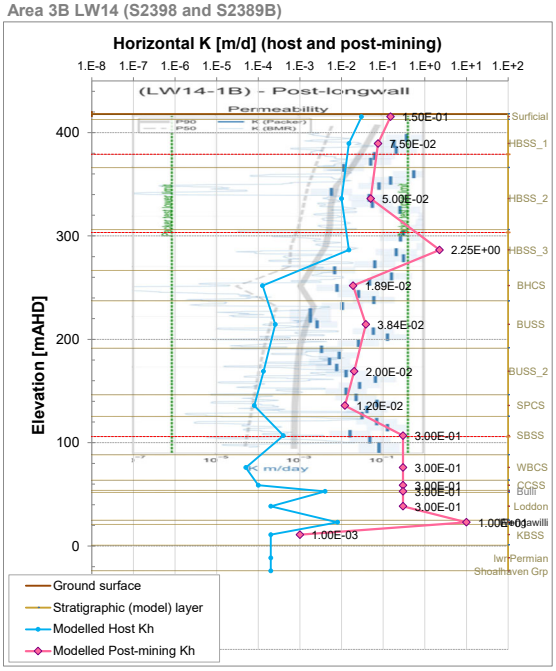


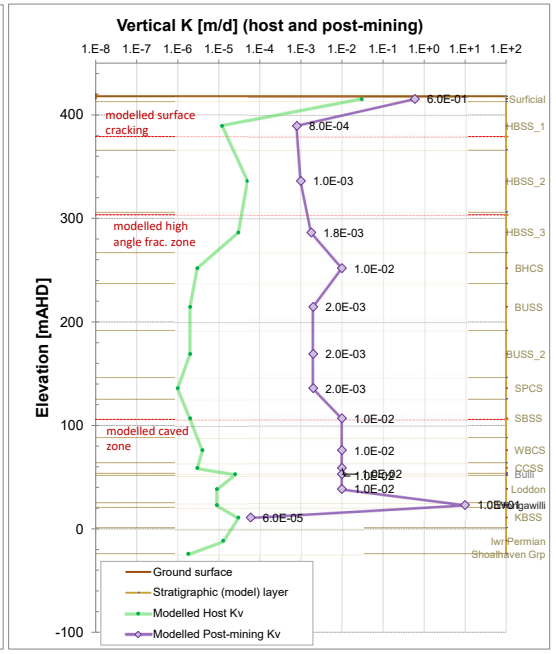
Down-hole defect count
(post-mining)

Field data - post-mining defects:
All defect frequency
High angle defect freq.

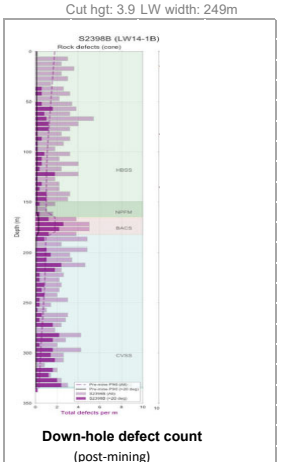
Area 3B LW14 (S2398 and S2389B)

Model cell: 2DNode: 19313





Position in mine workings:
Longwall Centreline
Cut hgt: 3.9 LW width: 249m

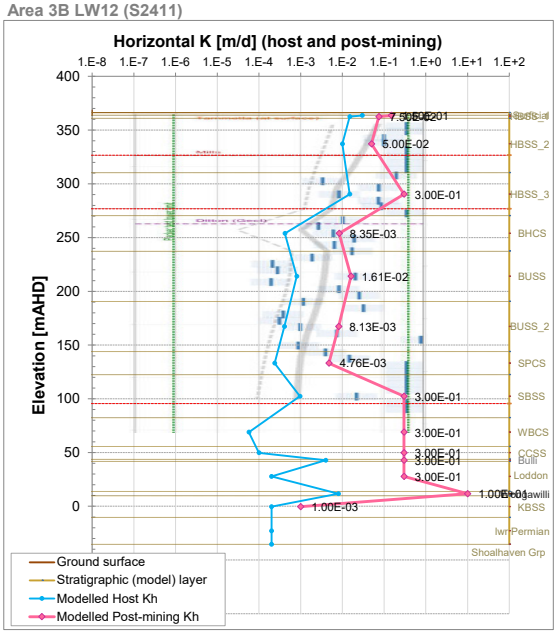


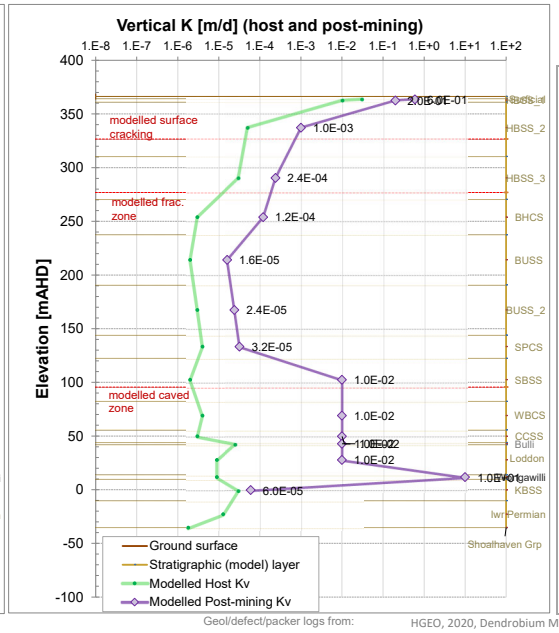
Down-hole defect count
(post-mining)

Field data - post-mining defects:
All defect frequency
High angle defect freq.

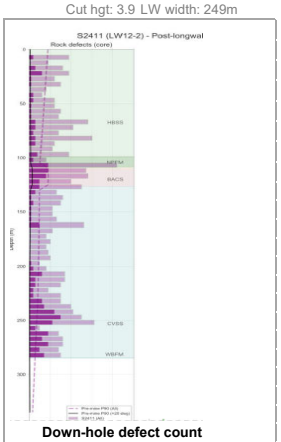
Area 3B LW12 (S2411)

Model cell: 2DNode: 8994





Position in mine workings:
Longwall Off-centre
Cut hgt: 3.9 LW width: 249m



Down-hole defect count
(post-mining)

Field data - post-mining defects:
All defect frequency
High angle defect freq.

Geol/defect/packer logs from: HGEO, 2020, Dendrobium Mine Investigation into the height of fracturing above extracted longwalls in Area 3, Dendrobium, report no. D19341.

E:\DENDROBIUM\Model\GWmodel\Construction\FracZone\DND5\[FracZone_DND5TR46_Dend_OtherMines_Offgoaf_TVM_EFault.xlsm]Report

Modelled deformation and fracturing profiles compared against field data **Figure X-X**

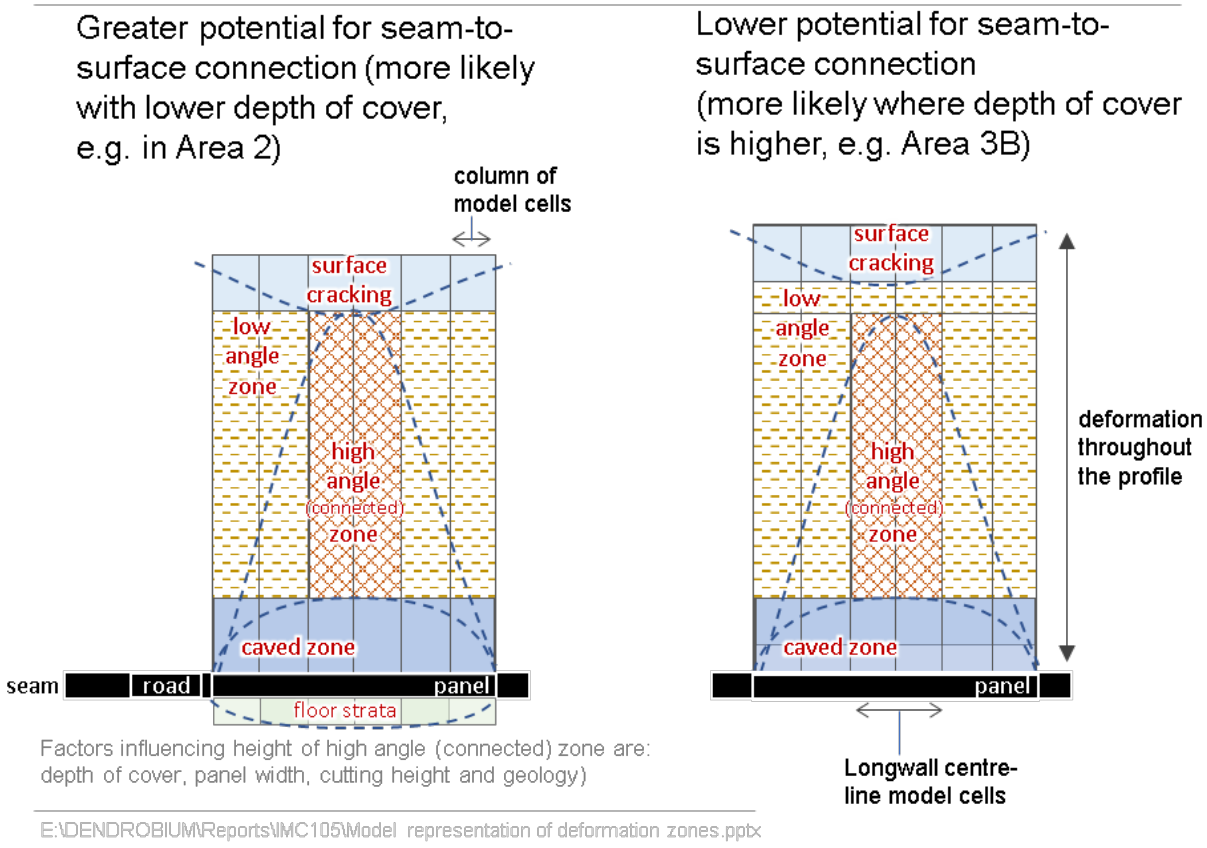


Figure 5-4 Model representation of conceptual property zones above the goaf

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

The results of model calibration to mine inflow, suggested that along with modification of the hydraulic conductivity, differentiation of model cells that are along the centre-line of panels and those that are off-centre should be adopted (**Figure 5-4**). **Figure 5-3a,b** show modelled profiles along centre-line locations in Areas 3A and 3B, while **Figure 5-3c** shows the profile at locations closer to the edge of a longwall panel (Area 3B Longwall 12).

5.4.3 Surface cracking zone

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

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

The representation of this surficial and near-surface process has been the primary focus of recent calibration effort.

5.4.4 Off Goaf (Valley Closure and Strata Deformation)

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

Initially, the Kh multipliers selected were x15, x5 and x3 (for areas <100 m, <300 and <600 m from panels, respectively), however given the issues during calibration in previous studies to do with enhanced permeability flattening the inflow hydrograph, lower Kh factors of x4, x3 and x2 were simulated. HGEO (2018b and 2019b) revised the estimates of how Kh enhancement should be simulated in order to carry out a conservative assessment of the potential connection between Lake Avon and the goaf. As a result of these, absolute values of 6E-2 (representative) to 2.5 E-1 m/d (conservative/maximum) for model cells lying within 300 m of a panel edge is also viewed as a alternatives to using multipliers (Section 7.2.1).

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 between Areas 3A, 3B and 3C.

5.4.5 Stacked Drain parameters

As noted in Section 5.4, 'Stacked Drains' were eventually re-adopted for the purpose of this SMP Groundwater Assessment. The simulation of inflow and groundwater drawdown using TVM alone was appropriate, especially in the Illawarra Coal Measures and Narrabeen Group strata, but the simulated reduction in surface water was not matching that assessed from field data. More work, modifying hydraulic conductivities and/or the modelled height of the high angle fracture zone, will be carried out to improve this.

However, in the short-term, 'Stacked Drains' were set in 2 layers – the layer at the top of the estimated high angle (connected) fracture zone and in the layer above this. These Drains were set to have a stage 0.1 m above the bottom of the layer, and with a conductance adopted from the Stacked Drains in the corresponding layer as estimated in HydroSimulations (2019c), which was estimated from host hydraulic conductivity (Kh and Kv) and from SCT's FLAC modelling.

5.4.6 Other Workings

Roadways (gate roads and mains) and bord and pillar areas are simulated with the parameters set out in **Table 5-3**.

6 Model history-matching or calibration

6.1 Approach

Calibration is focussed on replicating observed mine inflow and groundwater levels, while constraining the pre-mining hydraulic conductivity with the large dataset of permeability testing results available at Dendrobium and supported by data from neighbouring mines (Appin, Tahmoor).

Calibration targets are mine inflow and groundwater levels, while constraining the hydraulic conductivity based on the large dataset of packer and core test results. These were available at Dendrobium supported by data from neighbouring mines (BSO, Tahmoor). There is now the further constraint of newly available post-mining permeability (Kh) data and defect logging from the extensive field investigation (HGEO, 2020c) that is briefly summarised in Section 3.6.

The modelling relies on many available values of hydraulic conductivities and storage parameters (Section 3.4), review of independent estimates of recharge (Sections 3.9.1 and 5.3.1), boundary conditions and conductances. Manual calibration methods were used to modify the hydraulic conductivity (horizontal and vertical), and specific yield of modelled layers or zones (Section 6.2), and the vertical hydraulic conductivity of deformation zones to match the inflow and groundwater level targets.

Groundwater level responses in bores in Areas 2, 3A and 3B has been a focus, with particular attention on water levels near Wongawilli Creek and Avon Reservoir (Section 6.4). Calibration has been attempted for inflow to each of Areas 1, 2, 3A and 3B (Section 6.5). This is important as the different character of inflow at each area, especially in Areas 2 and Area 3B.

6.2 Calibrated parameters

Model parameters have been assigned based on ranges of hydraulic properties produced in the analysis of the packer, drillstem and core testing databases (Section 3.5). The parameters adopted in the modelling are well-constrained by that field data. They are generally between the arithmetic mean and median values for horizontal hydraulic conductivity, are close to the harmonic mean for vertical hydraulic conductivities, and do not represent a marked departure from previous modelling (see HS, 2019c or SLR, 2020a). A table of the calibrated model parameters by modelled hydrostratigraphic unit is included in **Appendix E** of this report.

Figure 5-3 presented a comparison of modelled and observed hydraulic parameters for three over-longwall bore locations. Two of these are centreline bores positioned over Longwall 6 (S2442A) and Longwall 14 (S2398-S2398B), while the final location is an off-centre bore positioned over Longwall 12 (S2411). The pre- and post-mining field data presented in **Figure 5-3** has been sourced from the recent compilation and analysis of this data in HGEO (2020). The pre- and post-mining Kh field data is well matched by the model for all stratigraphic units simulated in the model, although possibly slightly too high in the lower Hawkesbury Sandstone. Kv cannot be measured *in situ* (unlike Kh), but the model configuration is guided by the post-mining Kh data, and the relative change in the count and intensity of high angle defects through the sequence, as well as guided by calibration to drawdown and inflow.

6.3 Water balance

The modelled regional groundwater balance is summarised in **Table 6-1**, which presents the average water balance for 1940-2020. This includes Dendrobium (up to Longwall 13), historical mining around Dendrobium (e.g. Nebo, Elouera, Wongawilli, Kemira etc.), and the parts of BSO, Tahmoor and Cordeaux Mines within the active model domain (**Figure 5-1**).

Table 6-1 Modelled Water Balance for Calibration Period (1991-2020)

MODFLOW component	Conceptual process	In [ML/d]	Out [ML/d]
RECHARGE	rainfall recharge	158.0	0.0
RIVER LEAKAGE	watercourses, reservoirs	42.8	45.9
EVT	evapotranspiration	0.0	158.3
DRAINS	mine inflow	0.0	24.1
HEAD DEP BOUNDS	regional GW flow	12.7	1.5
CONSTANT HEAD	flow to ocean, estuaries	0.0	0.0
STORAGE	groundwater storage	136.8 (decline in GWLs)	120.6 (rise in GWLs)
Total		350.3	350.3

Units are in ML/d. Results are from model run 5TR50 to SP119.

Rainfall recharge is the dominant input, while evapotranspiration and baseflow to watercourses/springs/reservoirs are the dominant outputs. The model simulates historical mine inflow for all mines in the model domain equal to approximately 14% of the recharge. The model simulates a net reduction in groundwater storage (decline in groundwater levels) during the reported period.

Water balance error was computed by MODFLOW to be less than 0.01%.

6.4 Groundwater Levels

6.4.1 Summary

As per SMP Condition of Approval 16(b) (**Table 1-3**), a large dataset of groundwater levels has been collated across a total of over 800 target instruments (bores, piezometers) at which over 50,000 targets have been used to assess model calibration to groundwater levels. The locations of boreholes and piezometers used for groundwater level calibration are mapped in **Figure 3-1** and **Figure 3-2**.

Of those sites/piezometers, 615 are piezometers in 'deep' bores. From the sub-daily or daily data recorded at those sites, the data have been converted into over 39,000 targets by taking the median value over each model stress period.

Water levels from 98 'shallow' piezometers have also been used as targets. Almost all of these piezometers 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 modelled heads are plotted against the observed head targets on **Figure 6-1**.

The key reasons for the variation between observed and modelled heads on the X:Y plot are:

- difficulty in matching the timing of drawdown. The model may match the pre-mining head 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 (examples of this are on the later hydrographs, e.g. **Figure 6-4** and **Figure 6-5**);
- longwall progression and commencement of significant impacts at a monitoring point occurs over small time increments compared to model stress periods;

- potentially incorrect layer assignment. Some VWPs located in the mid-Bulgo Sandstone may be assigned to the lower Bulgo Sandstone but could be validly assigned to the upper Bulgo Sandstone;
- incorrect or suspect data which has not been identified or cannot be confirmed as incorrect;
- incorrect or imperfect parameterisation of the model re: K and S parameters, either on a local or larger-scale; and
- overestimation of drawdown by the model in areas above the goaf occurs, as seen by the vertical series of "Layer 1 Swamps/regolith" targets on the right of **Figure 6-1**. This shows that the model overestimates drawdown at many these shallow piezometers.

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).

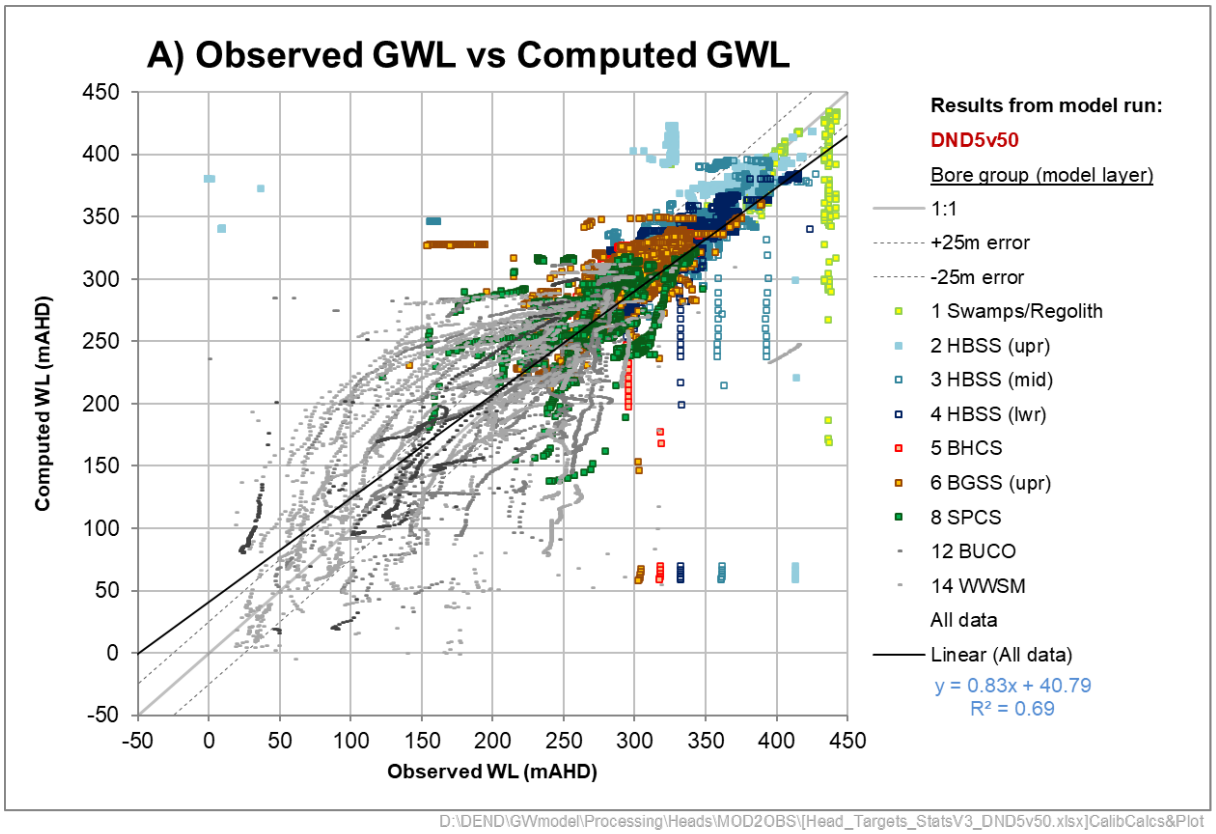


Figure 6-1 Summary X:Y plot of modelled vs observed groundwater levels

The SRMS error for the correlation between observed data and the transient model groundwater levels is 5.8%. This values is within the often-quoted example of 10 % (MDBC, 2001; Barnett et al., 2012), and considered acceptable for a model of this scale and complexity, in a fractured rock environment, and considering the accuracy of the VWPs and the size of the dataset. The mean residual groundwater level is -5.9 m. Both of these statistics represent a significant improvement from the groundwater model used in the Longwall 20 and 21 Groundwater Assessment (HS, 2019b).

6.4.2 Temporal trends (hydrographs)

A subset of calibration hydrographs is presented in **Figure 6-2** to **Figure 6-6**, while a larger set of hydrographs are provided in **Appendix F**. On these hydrographs, the observed groundwater levels are plotted as coloured symbols, with the corresponding modelled series in a solid line of similar colour.

These include groundwater levels at S1870 in Area 3A near Lake Cordeaux (**Figure 6-2**), at S1931 between Area 3B and Wongawilli Creek (**Figure 6-3**), a long record at S1932 above Longwall 16 (**Figure 6-4**), water levels between Area 3B and the Avon Reservoir (S2194 - **Figure 6-5** and S2313 - **Figure 6-6**), and at S2490 near Swamp 35b (**Figure 6-7**). Of these locations, S2194 and S2490 are both near to Longwall 18.

The match between modelled and observed hydrographs is generally good, with the relative drawdown with depth (i.e. drawdown of >150 m in the coal seams, drawdowns of approximately 50 m or more in the Bulgo Sandstone and Scarborough Sandstones, and lower magnitude of drawdown (tens of metres or less) in the Hawkesbury Sandstone) being represented well.

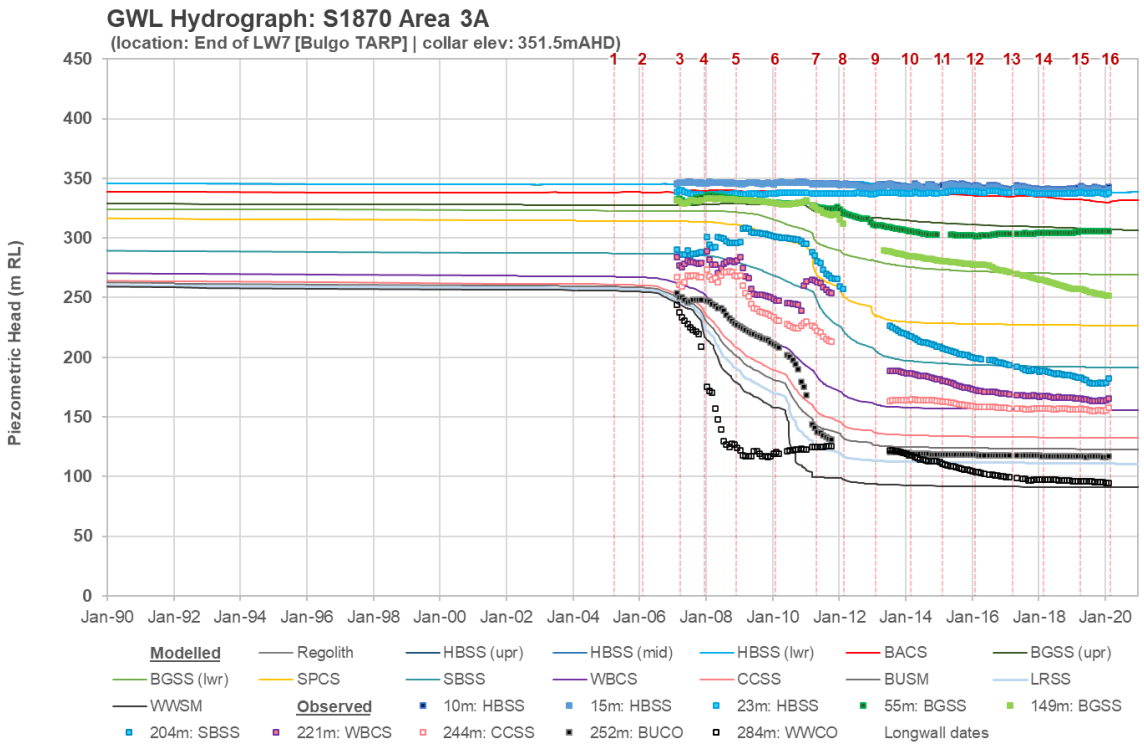


Figure 6-2 Modelled vs observed groundwater levels: S1870

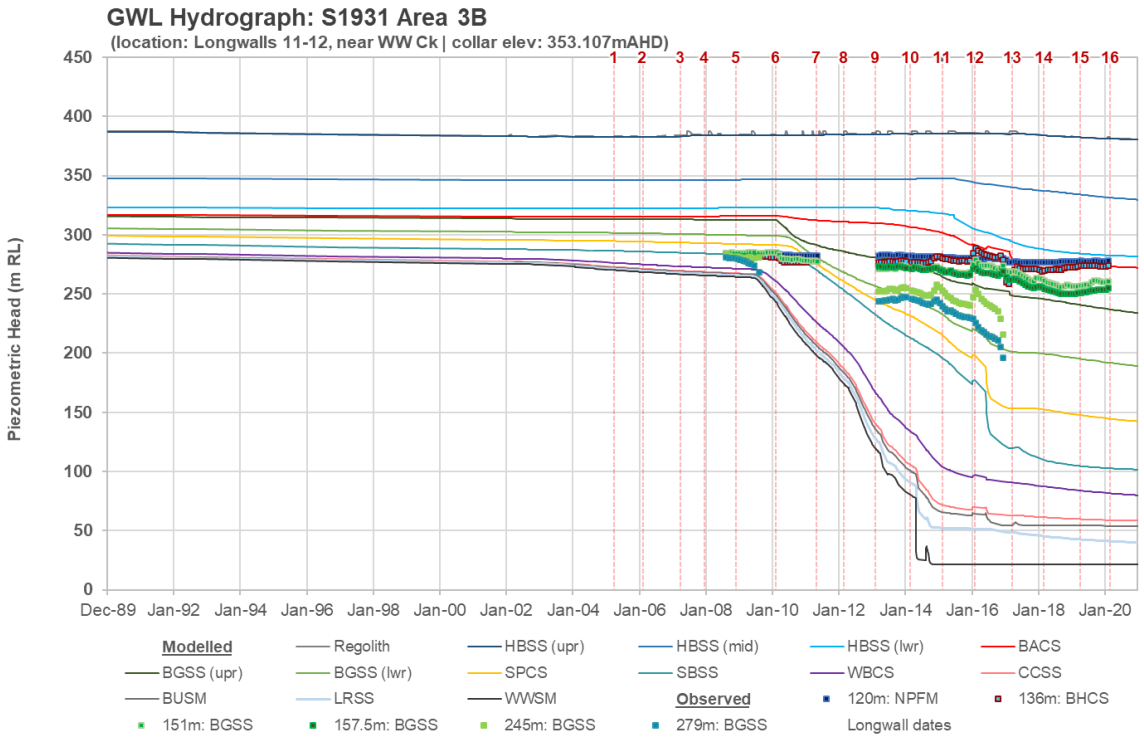


Figure 6-3 Modelled vs observed groundwater levels: S1931

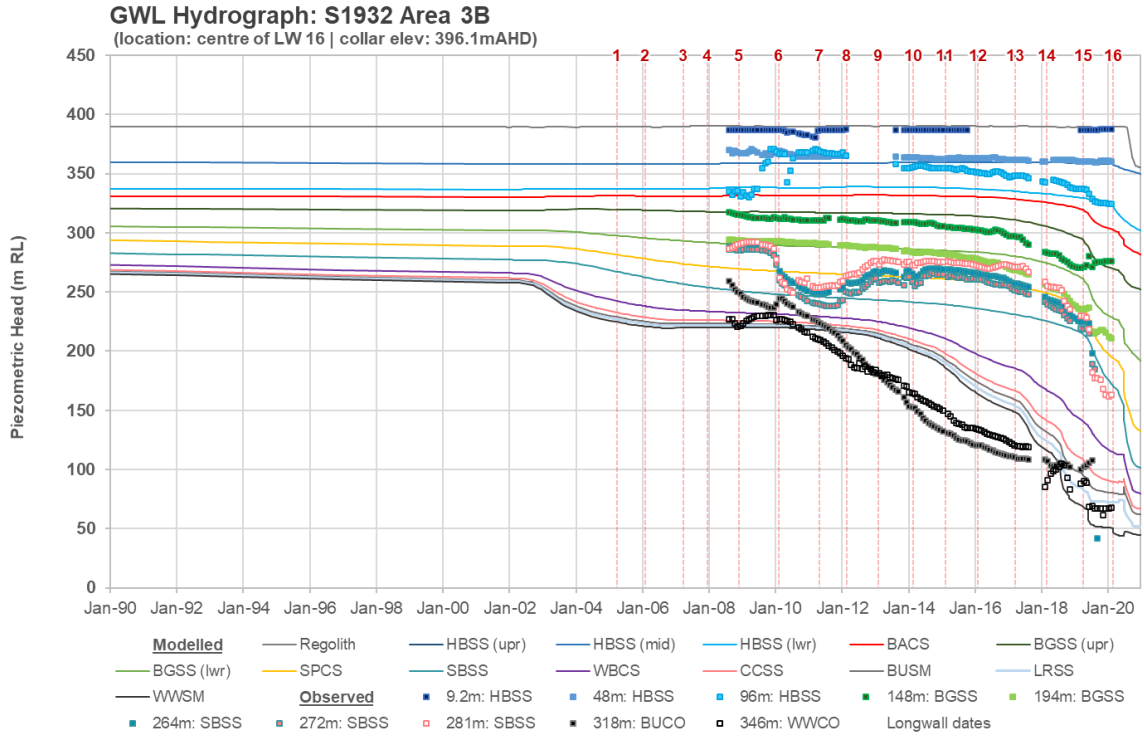


Figure 6-4 Modelled vs observed groundwater levels: S1932

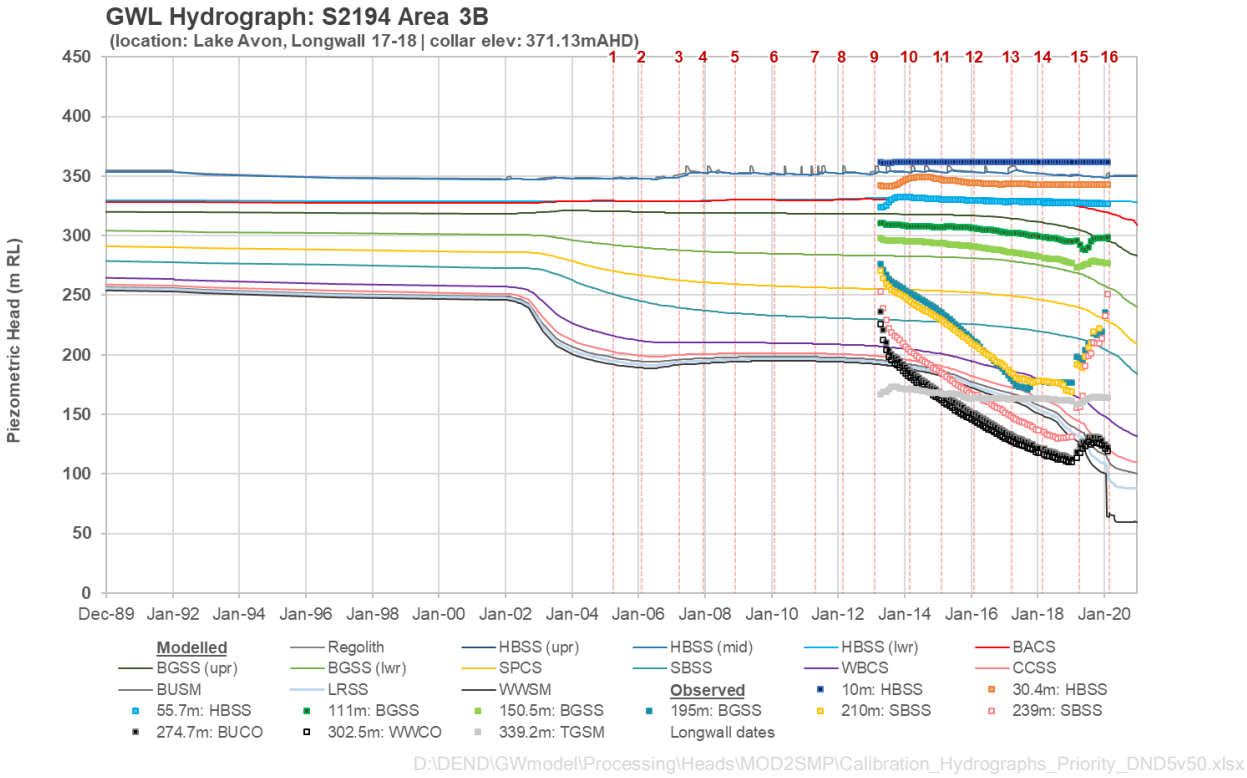


Figure 6-5 Modelled vs observed groundwater levels: S2194

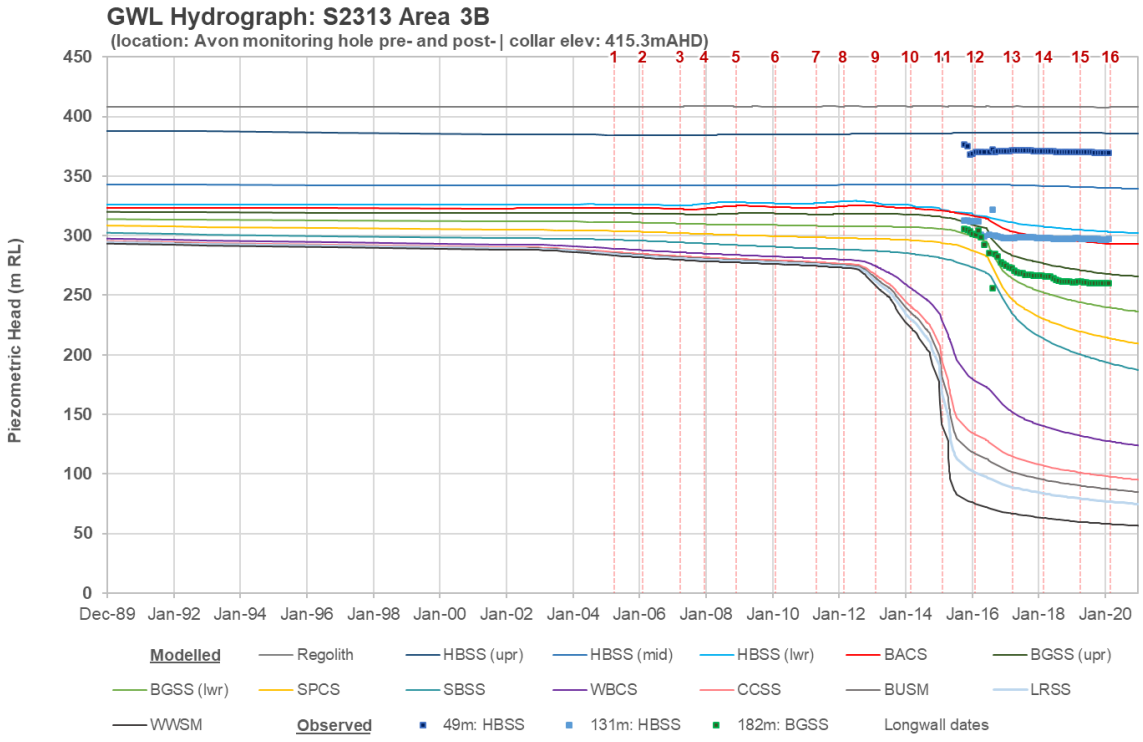


Figure 6-6 Modelled vs observed groundwater levels: S2313

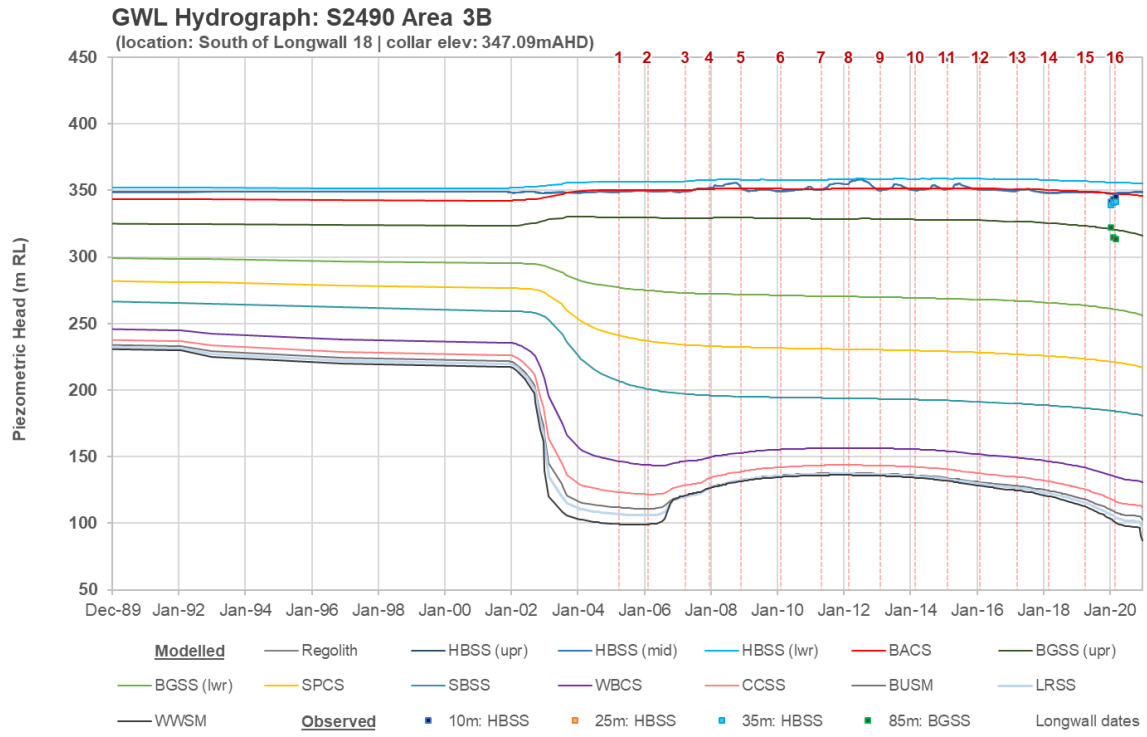


Figure 6-7 Modelled vs observed groundwater levels: S2490

The main weakness evident in the hydrographs is 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 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).

6.4.3 Spatial distribution of heads

A series of groundwater level contour plots are provided in **Appendix G**. These maps show modelled groundwater level elevation on the left-hand pane and, as following a previous request by the IEPMC, the estimated depth to water on the right-hand pane. These show modelled groundwater levels for:

- the water table;
- lower Hawkesbury Sandstone (model layer 4);
- upper Bulgo Sandstone (layer 6); and
- the Wongawilli Seam (layer 14).

The water levels for these strata are presented for specific time intervals (two historical and two predictive periods):

- the 'pre-mining case' (model stress period 1);
- Jan-2020 (stress period 118);
- Apr-2022 (stress period 132); and
- 2200 (stress period 203).

These are supplied in one series to enable review of changing water levels through time.

Figure G5 to **Figure G9** (in **Appendix G**) present modelled groundwater level contour plots for model stress period 118 (Jan-2020).

The modelled water table (**Figure G5**) shows the strong signature of local topography and drainage on surface water features. The contours bend around large rivers such as the Cordeaux, Avon and Nepean Rivers, and also other watercourses such as Wongawilli Creek. The reservoirs generally receive groundwater baseflow from the water table as indicated by the higher flow gradient along their margins. Groundwater levels drop steeply over the escarpment to the south and east as the land surface declines towards the coastline. Comparison against **Figure G1** shows how the model has simulated the change from the natural or pre-mining condition to "present day" (2020), including drawdown concentrated above longwall panels.

Modelled groundwater levels in the lower Hawkesbury Sandstone (**Figure G6**) also indicate an influence from local topography and surface water features. Mining impacts on the groundwater levels are discernible from the 'bending' of contour lines in areas of mining. At Dendrobium this can be observed as occurring over the northern section of Area 3B in the area occupied by Longwalls 9-14, which were extracted between 2013 to 2019. Comparison against **Figure G2** shows how the model has simulated the change from the natural or pre-mining condition to 2020.

Contour patterns indicating mining related drawdown are more discernible in the lower Bulgo Sandstone (**Figure G7**). Tightly grouped groundwater contours are present around the longwall footprints of Dendrobium Areas 1, 2 and 3A, and also in Area 3B. Comparison against **Figure G3** shows how the model has simulated the change from the natural or pre-mining condition to 2020.

The Wongawilli Coal Seam (**Figure G8**) shows significant drawdown, as expected of the mined seam for the historical and active workings at Dendrobium. The extent of the drawdown footprint is influenced to the south of Area 3B by mining activity at the Wongawilli (Elouera) Colliery. Comparison against **Figure G4** shows how the model has simulated the change from the natural or pre-mining condition to 2020.

6.5 Mine Inflow

Mine inflow is calculated using the IMC site water balance, which is a key target for calibration. Groundwater model estimates of inflow to each mine area have been calculated considering time-weighted averages, with reference to model output times in each stress period. **Figure 6-8** and **Figure 6-9** compare the 'observed' and modelled inflows to each mine area and Dendrobium as a whole, respectively.

Model calibration to observed groundwater inflow is good, and with the exception of Area 2, the modelled volume of inflow is close to or slightly higher than what has been calculated. This allows a reasonable and conservative estimate of the regional groundwater response and representation of mining by the groundwater model. Key points from the inflow hydrographs on **Figure 6-8** are:

- Area 1 inflows are over-estimated for the calibration period, with the greatest difference between the modelled and observed datasets in the order of 1.2 ML/d. Despite this, the model provides an upper end estimate of total inflow to the mine area, making for a conservative estimate.
- Observed inflows to Area 2 show a baseline inflow of approximately 0.5-1 ML/d interspersed with short-lived peaks in response to heavy rainfall events. The model overestimates inflow during the period of longwall extraction in Area 2 (2007-2010). Following that, the modelled

estimate is not able to capture the magnitude of the observed peaks, however, it does represent the timing well.

- Modelled inflow to Area 3A at the start of the longwall development is overestimated compared to the observed values yet represents similarly timed peaks during this period. These peaks become muted over time after the completion of Longwall 8 in this area and the commencement of mining in Area 3B (Longwall 9). The modelled inflows follow the trendline of the calculated inflows well during this period, however, are unable to capture large inflow events after the period of longwall extraction.

  Modelled inflows to Area 3B are quite good with the trend being consistent with calculated data. Modelled inflows during Longwalls 12 to 14 of Area 3B represent the upper end of observed inflows, and the model is a good match for these. The model overestimates inflow during 2018-2020 by about 2 ML/d. This remains a task for further investigation (Section 8.2).

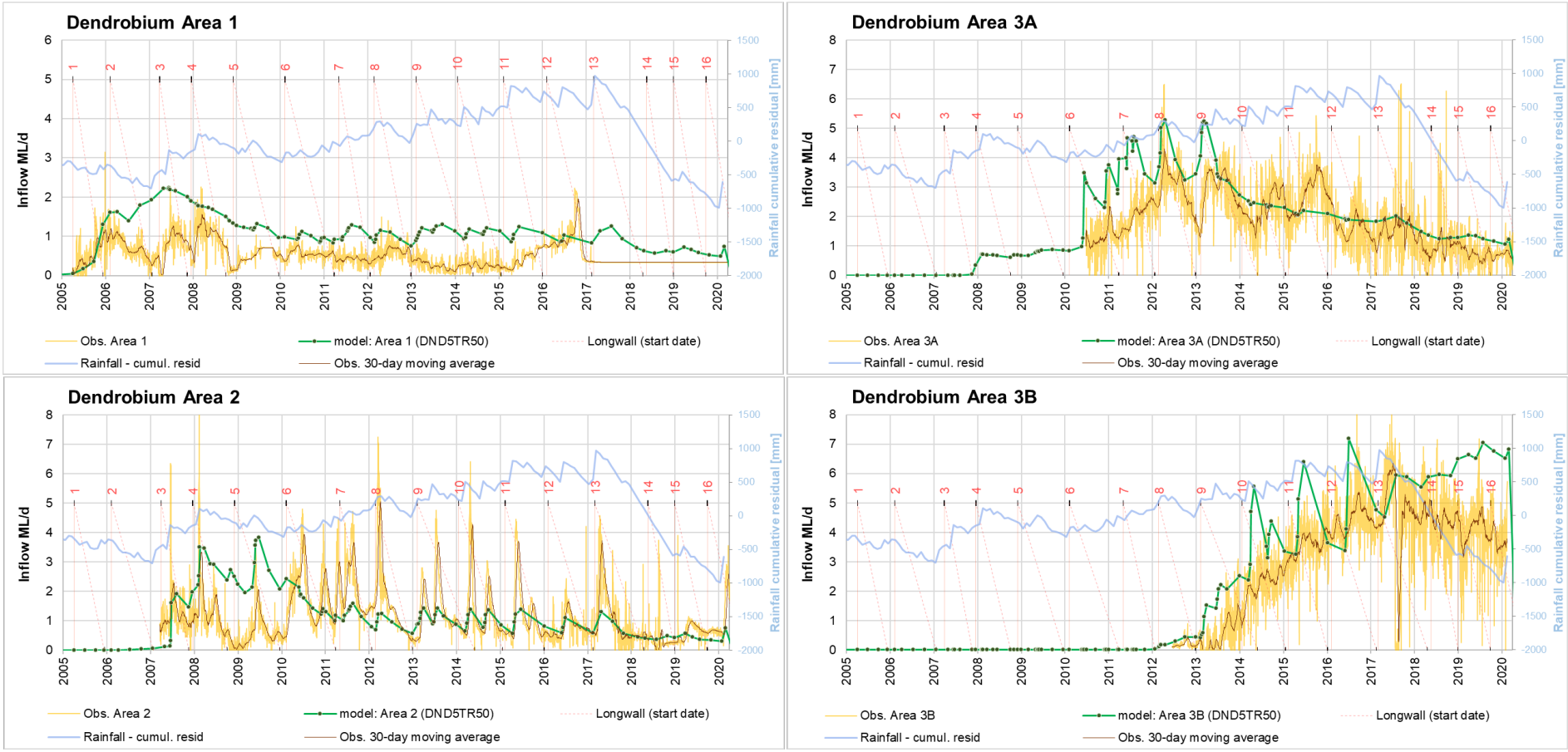
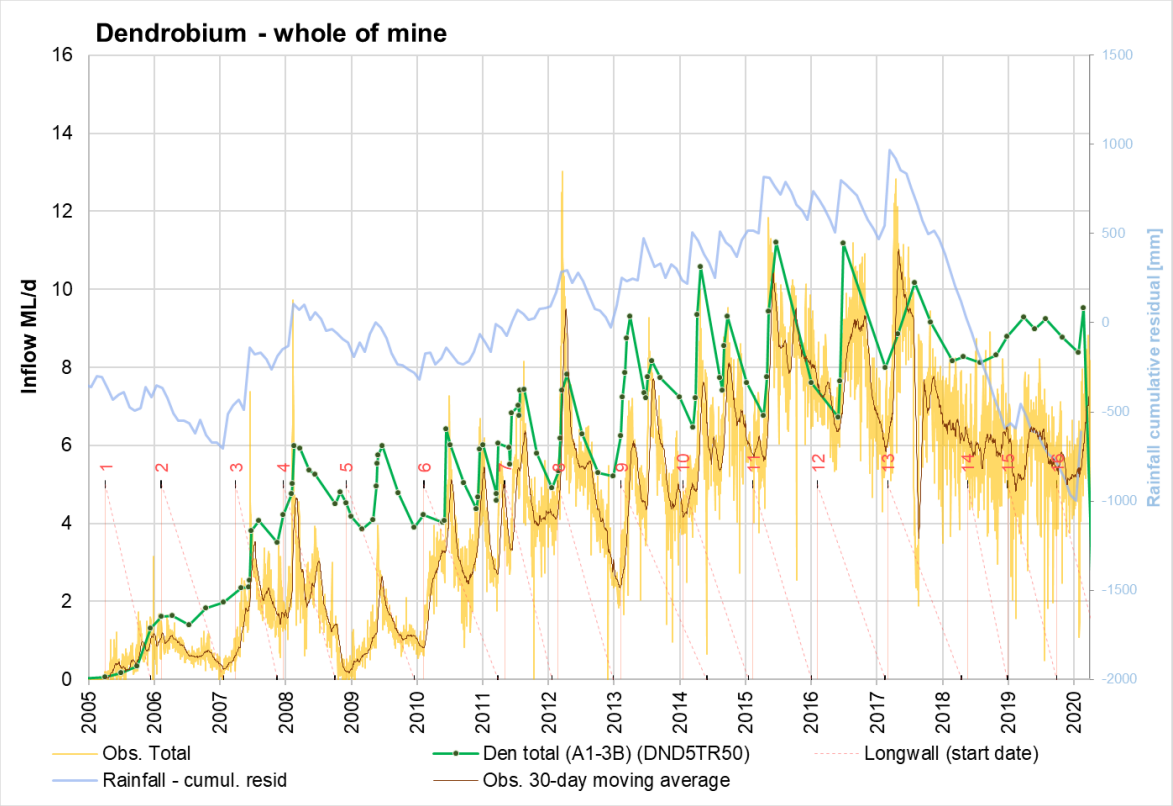


Figure 6-8 Modelled vs observed mine inflow :by area



D:\DEND\GWmodel\Processing\Zonebudget\Inflow\[MineInflow_ZBud_DND5TR50_&_DND5v6.xlsx]Calibration

Figure 6-9 Modelled vs observed mine inflow: Dendrobium total

A comparison of modelled and calculated inflows to the whole of mine (**Figure 6-9**) shows it is an appropriate match for the purpose of understanding the effect on the water balance of this groundwater system. The modelled inflows provide a more conservative, upper range estimate of the calculated inflows during mine progression.

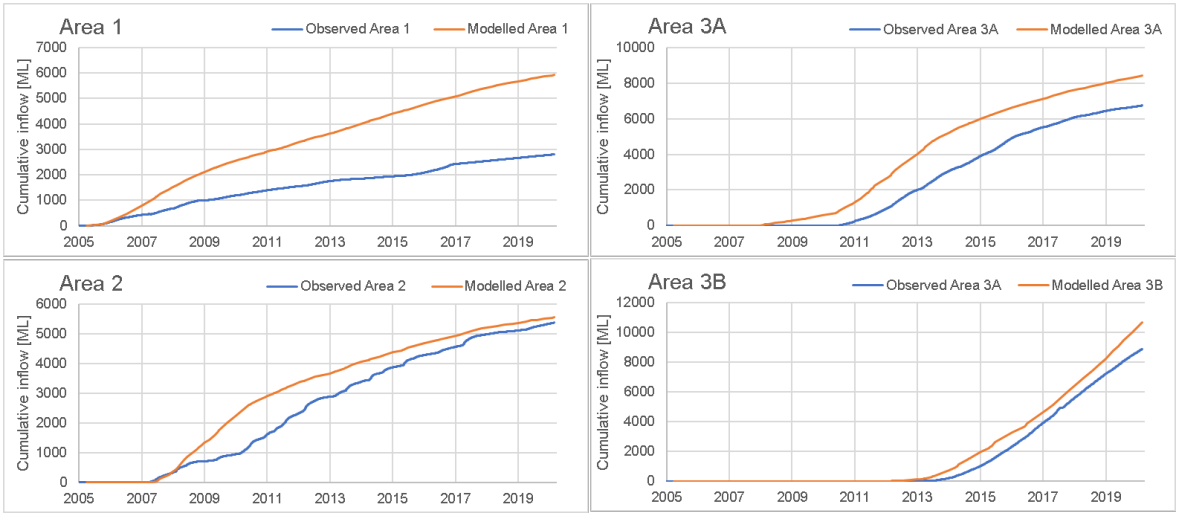


Figure 6-10 Cumulative modelled vs observed mine inflow by area

This is supported by a review of cumulative mine inflow to each mine area in **Figure 6-10**. The calibration to inflow indicates that the model reasonably represents recharge and permeability characteristics of the mining-affected system. Overall, the ability of the model to capture the variability

of inflows to each mine area is sufficient to constrain the water balance and provide reasonable estimates of the water balance effects of future development.

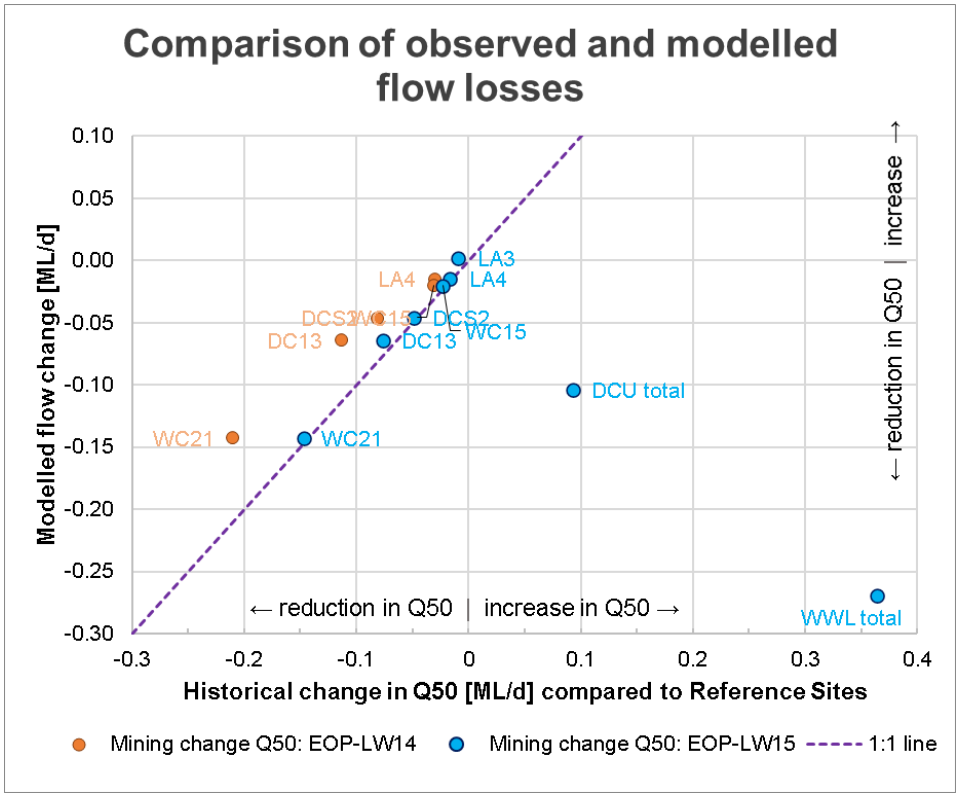
Versions of the model tested during calibration had lower and higher rates of inflow (to Area 3B, most importantly), however did not appropriately simulate losses from surface water systems, so the current model has been favoured, despite the higher than observed inflow in Area 3B.

6.6 Surface water flow loss

Recent analysis of flow data (Watershed HydroGeo, 2019 and HGEO, 2020a) showed that flow reductions due to mining were evident in headwaters streams and generally not discernible at downstream gauging stations.

Modelled surface water losses have been compared to these estimated historical losses as a means of model calibration and to understand the potential error in groundwater model predictions (Figure 6-11).

With respect to the downstream gauging sites DCU and WWL, the modelling is clearly conservative compared to the results derived from field data. With respect to LA3, the result from End of Panel for Longwall 15 cannot be relied on because it is based on very short records for both pre-mining and post-mining periods. Given those exceptions, the main findings from Figure 6-11 are that the model provides an appropriate match to the losses estimated in the End of Panel report for Longwall 15, while underestimating those from the End of Panel report for Longwall 14.



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Figure 6-11 Comparison of historical and modelled surface water losses

IEPMC (2019a) stated that "*groundwater models should not be relied upon to give accurate estimates of future surface water losses. Complementary approaches should be investigated. This may include adjusting groundwater model results according to their under- or over-estimation of losses for previous*

LWs.". With regard to the first part of that statement, this revised groundwater model does provide reasonable estimates of historical losses, but as described in HGEO (2020e) and Section 3.9.5, estimated historical losses seem to be influenced by 'wetness' or the availability of flow. That is, in dry periods there is less surface water flow available and so losses are smaller than in periods where there is more flow available. As a result, predictions need to account for uncertainty in modelled hydrogeological parameters, mining effects and also variability in rainfall and flow. Therefore, the groundwater model predictions of surface water losses provided in Section 7.4.5 are scaled and presented as a range to account for this.

6.7 Model Performance

The regional model takes about 8 hours to run for the calibration or historical model (stress periods 1-119), with a further 4-5 hours for the predictive period (stress periods 120-203).

6.7.1 Model 'Confidence Classification'

The Australian Groundwater Modelling Guideline (Barnett et al, 2012) includes a 'Confidence Classification'. This has been populated and is presented in **Appendix D**.

The modelling presented here is generally a Level 2 confidence model, with a number of aspects of Level 3 confidence. This is appropriate for impact assessment purposes, and reflective of the amount of data gathered, the analysis carried out for this site, as well as the magnitude of future stresses (i.e. those from the proposed Longwall 18) being similar to the historical observed and simulated stresses.

6.7.2 Peer Review

Modelling for Dendrobium has been peer-reviewed, including most recently by Frans Kalf for Longwall 19 SMP application and before that also by Frans Kalf for the Dendrobium Extension Project EIS (HS, 2019c).

7 Model forecasting

This section describes the forecast model scenarios carried out for impact assessment and presents the results of these. Given the amount of model output that could be generated, only the key results, notably fluxes, have been discussed in detail in the following sections.

Section 7.1 briefly outlines the model set up for predictive scenarios, while Section 7.2 describes the 'resource development' scenarios used to carry out the quantitative impact assessment. Some additional deterministic scenarios (Section 7.2.1) have been carried out to quantify the effects of uncertain features of the hydrogeological systems.

Section 7.3 presents predicted effects on groundwater levels via a number of methods, as per Condition 13a (**Table 1-3**).

Section 7.4 presents flux results, including mine inflow, losses from reservoirs and losses from watercourses. There is also a sub-section on surface water take from the water supply catchments that are within the model domain (Section 7.4.6), to meet a recommendation by the IEPMC (2018). These results are typically presented for Dendrobium as a whole as well as the incremental effect of the proposed Longwall 18.

7.1 Forecast model configuration

The calibrated or base case model is used as the basis for forecast modelling, specifically the hydraulic conductivity and storage parameters, the representation of subsidence and deformation (fracturing) and the boundary conditions. The key features of the forecast modelling that are different to the historical period are:

- The predictive period does not include variation in rainfall recharge, although the rates simulated is the average based on the calculated historical patterns.
- Generally, stress periods are set at 4-6 per year for the predictive mining period, lengthening to yearly or longer periods after the simulated end of mining (**Appendix C**).
- Mining scenarios (i.e. MODFLOW Drains to represent dewatering) and specific parameters to describe fracturing and deformation are described in Section 7.2.

7.2 Model Scenarios

The mine plan and schedule are presented in **Table 1-1** and **Appendix C**. Model forecast scenarios, which are summarised in Table 7-1, have been carried out to provide a forecast of the effects of the proposed Longwall 18 and of Dendrobium as a whole.

7.2.1 Uncertainty Analysis

A series of deterministic scenarios, as per the IESC Uncertainty Guidelines (Middlemis and Peeters, 2019) have been carried out to help assess the uncertainty associated with particular predictions. These scenarios consider potential changes to hydraulic conductivity associated with valley-bulging and reactivation of the Elouera Fault, and focus on predictions of mine inflow, losses from the reservoirs and effects on watercourses that might be caused by mining at Dendrobium. A summary of these is as shown in **Table 7-1**.

The Elouera Fault scenarios simulate permeability increases in both horizontal and vertical directions, based on the concept of stress relief resulting in an increase in fracture aperture and permeability (Section 4.2.2).

Table 7-1 Summary of modelled mine development and uncertainty scenarios

Scenario	Run	Name	Dendrobium	Connected fracture zone method	Other Mines	Comment
A	DND5TR45	Null	No Dendrobium	None	None	Hypothetical natural conditions
B	DND5TR49	Baseline	No Dendrobium	TVM	All	Baseline condition Comparison against D isolates effects of Dendrobium.
C	DND5TR48	Dendrobium, no LW 18	All Areas 1, 2, 3A, 3C (LW 20-23) and all 3B except LW 18	TVM + Stacked Drains	All	Comparison against D isolates effects of LW 18.
D	DND5TR50	Full Impact	All Areas	TVM + Stacked Drains	All	Enhanced K x 0.5 order of magnitude along 'Elouera Fault zone' following stress relief due to LW 18.
Deterministic uncertainty scenarios						
D2	DND5TR46	Full Impact: EF scenario1	as for D	as for D	as for D	Enhanced K x 10 (1 order of magnitude) along 'Elouera Fault zone' following stress relief due to LW 18
D3	DND5TR51	Full Impact: EF scenario2	as for D	as for D	as for D	'Elouera Fault zone' K not changed post- LW 18
D4	DND5TR52	Full Impact: Offgoaf 1	as for D	as for D	as for D	Greater off-goaf permeability (Kh 6E-2 m/d), based on HGEO, 2019b.
D5	DND5TR54	Full Impact: Offgoaf 2	as for D	as for D	as for D	Greater off-goaf permeability (Kh 2.5E-1 m/d) based on bores S2314/2435 (HGEO, 2019b).
C4	DND5TR53	Dendrobium, no LW 18	as for C	as for C	as for C	Greater off-goaf permeability (Kh 6E-2 m/d)

7.2.2 Model Performance

All predictive runs had overall mass balance errors of <0.02% 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 hydraulic properties in many cells and activation of 'Stacked Drains' in those periods.

7.3 Forecast groundwater level response

The following sections present groundwater level responses to mining via:

- Modelled groundwater level contour maps for key stratigraphic units, as well as the estimated depth to groundwater, for a set of key times.
- Modelled groundwater level hydrographs to illustrate trends in pressure/drawdown through time in a number of stratigraphic units.
- Profiles of pressure head.
- Predicted groundwater drawdown at the nearest water supply works (bores).

7.3.1 Contour Maps – Groundwater levels

A series of groundwater level contour plots are provided in **Appendix G** (as discussed in Section 6.4.3). These maps show modelled groundwater level elevation on the left-hand pane and the estimated depth to water on the right-hand pane. These show modelled groundwater levels for:

- the water table;
- lower Hawkesbury Sandstone [HBSS] (model layer 4);
- upper Bulgo Sandstone [BGSS] (layer 6); and
- the Wongawilli Seam [WWSM] (layer 14).

The water levels for these strata are presented for specific time intervals including modelled historical groundwater levels (**Figures G1-G8**) to enable review of changing water levels through time. **Figures G9-G12** present the results Apr-2022 (stress period 132), at the end of Longwall 18, while **Figures G13-G16** present results for 2200 or approximately 175 years after mining (stress period 203).

Figures G9-G12 indicate that significant drawdown would occur within the WWSM (up to 270 m from pre-mining conditions within the footprint of Longwall 18), upper BGSS (approximately 80 m) and lower HBSS (10-20 m). The water table, as described above, is also disturbed by about 10 m in some locations around Longwall 18.

Drawdown or depressurisation is predicted to occur at some distance outside the footprint of the longwalls (e.g. simulated heads in the lower HBSS (Layer 4) are about 340 mAHD at a point approximately 1 km northwest of Area 3B (**Figure G2**) and have declined almost 30 m to 310 mAHD (**Figures G7 and G10**)). At the same location, the depressurisation in the BGSS (Layer 6) is also simulated to show a 40 m decline in groundwater levels, falling from 330 mAHD (**Figure G2**) to 290 mAHD (**Figure G10**). The drawdown in the WWSM is about 120 m at the same point (declining from 320 mAHD to approximately 200 mAHD).

At a distance of approximately 3 km north of Area 3B, modelled drawdown in the lower HBSS is approximately 1 m (comparing **Figures G2 and G10**), while in the BGSS the drawdown is approximately 5 m at this location, and was 25 m in the WWSM.

Comparison of groundwater levels well into the future (**Figures G13-G16**) with pre-mining conditions (**Figures G1-G8**) suggest that water levels in the lower HBSS would recover to close to pre-mining levels. Water levels in the BGSS and WWSM are predicted to remain depressed by 10-20 m (in the area of Longwall 18) compared to pre-mining conditions, and the water table would also remain depressed by 5-10 m.

7.3.2 Hydrographs – Groundwater Levels

A series of hydrographs are presented to illustrate predicted groundwater trends at a number of locations around Longwall 18 and Area 3B. Broadly 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 in these locations which are outside longwall areas but selected because of their proximity to features around Longwall 18.

Groundwater levels at monitoring bore S2194, to the north-west of Longwall 18 are presented on **Figure 7-1.** The effects of mine dewatering on pressures in the WWSM are clear: the simulated effects of Elouera Colliery are evident in the 2003-05, followed by a further 150 m drawdown as Dendrobium Area 3B workings approach this location. Recovery in the WWSM is indicated to be to levels about 50 m above the 'No Dendrobium' baseline, due to simulated connection with overlying strata. In the BGSS, maximum drawdown is predicted to be up to about 80 m, and the incremental drawdown due to Longwall 18 is less than 2 m.

Maximum drawdown in the lower HBSS is predicted to be almost 15 m, declining to below the lake FSL. Drawdown in the water table at this location is predicted to be approximately 3 m.

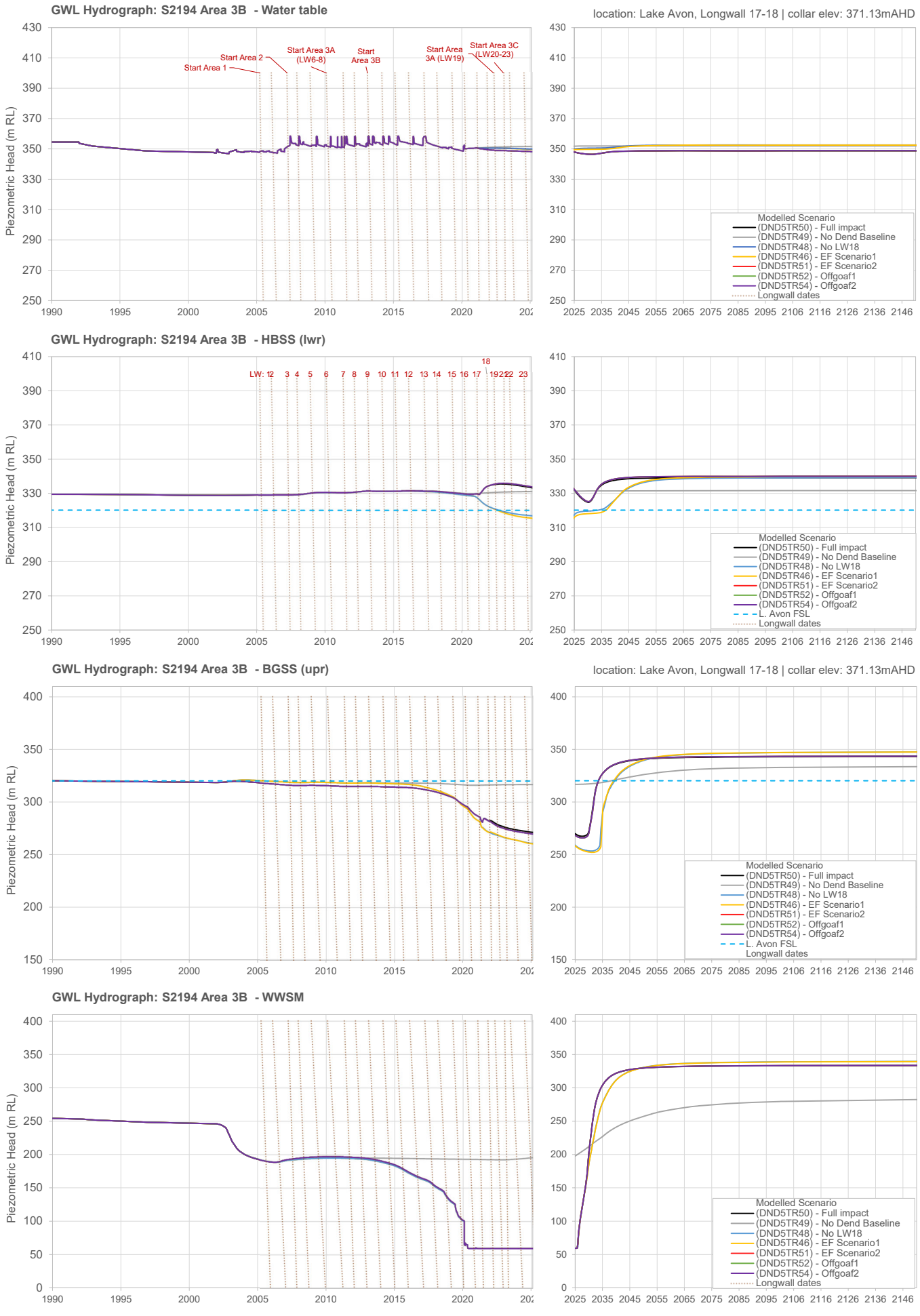
The scenarios testing different permeability around the Elouera Fault do not suggest much difference in drawdown at this location.

Groundwater levels at monitoring bore S2490, to the south of Longwall 18 and adjacent to Swamp 35b, are presented on **Figure 7-2**. Like water levels in the WWSM at S2194, drawdown of up to 130 m is simulated in response to Elouera Colliery longwall extraction (approx. 120 m drawdown) and then Dendrobium Area 3B. The model suggests that incremental drawdown due to Longwall 18 extraction would be about 12 m at this location. Modelled BGSS water levels show drawdown of about 10 m due to Elouera Colliery operations, and a further 25 m due to Area 3B. Of that, the simulated incremental drawdown due to Longwall 18 is in the order of 20 m.

In the lower HBSS, water levels are predicted to be drawn down by 5-15 m in response to Longwall 18. These drawdowns are likely to cause a decline in regional water levels below the base of Swamp 35b, and suggest a reduction in the baseflow that is inferred to occur at that swamp (Section 3.7.2), and therefore likely to occur to parts of tributary ND1. The water table shows a very small (<1 m) but persistent decline, depending on the scenario (this might be due to the presence of MODFLOW-River boundary condition at this location, so the result from the lower HBSS should be considered more representative of the environmental effect at this location).

Groundwater levels at a location between Longwall 18 and Wongawilli Creek (approximately 150 m west of Wongawilli Creek) are presented on **Figure 7-3**. Like water levels in the WWSM at S2194, drawdown of up to 200 m is simulated in response to Elouera Colliery longwall extraction and Dendrobium Area 3B. The model suggests that incremental drawdown due to Longwall 18 extraction would be about 12 m at this location. The BGSS water levels show milder drawdown due to Elouera Colliery operations, and a further 30 m due to Area 3B. The incremental drawdown due to Longwall 18 is in the order of 1-2 m.

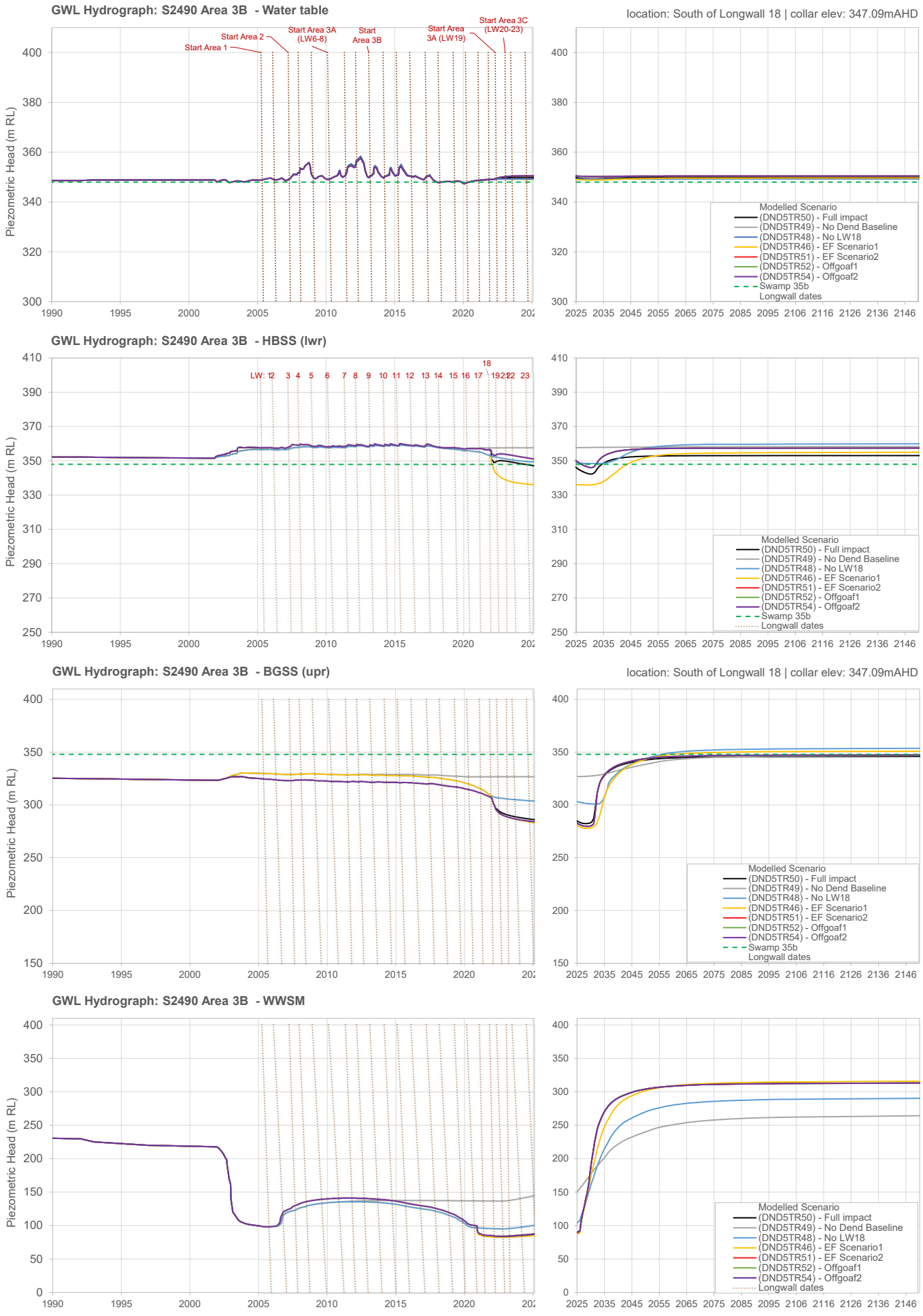
In the lower HBSS, water levels are predicted to be drawn down by 7-15 m in response to the end of Longwall 17. These drawdowns are likely to cause a decline in regional water levels below Wongawilli Creek, suggesting a reduction in the baseflow in this reach. The model indicates that Longwall 18 could cause an incremental drawdown of up to 0.5 m in the long-term at this location, which is relatively small compared to that of the previous Area 3B longwalls. The water table shows a persistent decline of 0-7 m due to all of Dendrobium mining, depending on the scenario.



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Simulated groundwater levels at bore: S2194 **Figure 7-1**

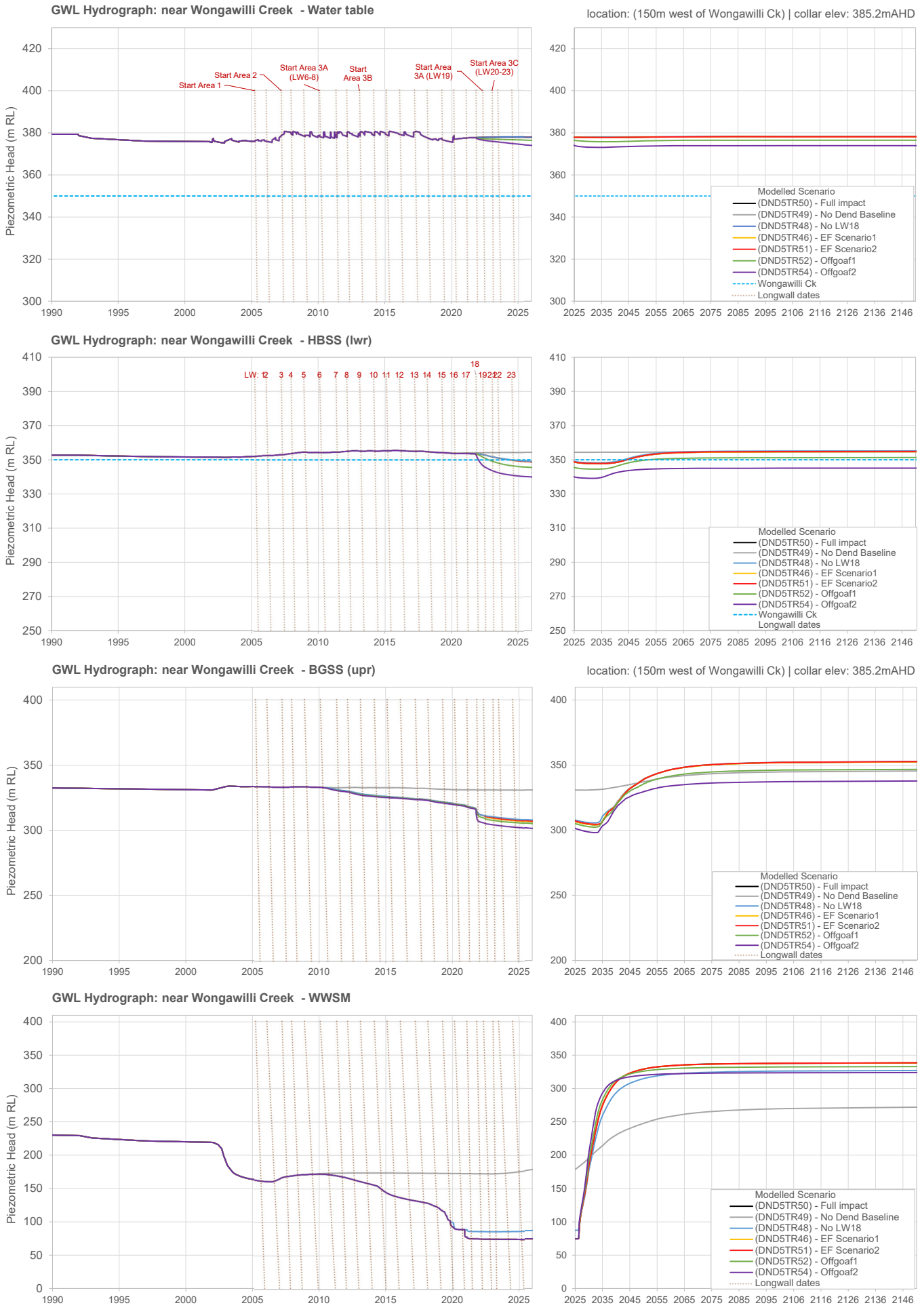
WatershedHG



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Simulated groundwater levels at bore: S2490 **Figure 7-2**

WatershedHG



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Simulated groundwater levels between LW18 and Wongawilli Ck **Figure 7-3**

WatershedHG

7.3.3 Pressure Head Profiles

This section presents modelled pressure head profiles around Longwall 18. Each figure shows pressure head profiles through time and for the full vertical sequence of layers. Pressure head is calculated as the groundwater level (mAHD) minus the elevation of the centroid of the relevant model cell. MODFLOW calculates heads that are averaged across a model cell. As a result of this, some structural error will occur, especially across thick units (e.g. Hawkesbury Sandstone and Bulgo Sandstone layers).

Figure 7-4 shows the modelled pressure head profile in the centre of Longwall 18. There is no monitoring bore here, so the modelled profiles are not compared to observed data. The modelled profiles show the pre-mining conditions in 2000, then the effect of nearby Elouera is evident as drawdown in 2015, and pressures at the approximate present day in early 2020. Following Longwall 18 extraction, pressures drop significantly, with negative pressures simulated through much of the profile. 2026 is the approximate period when pressures are at their lowest, and recovery commences from there. The model predicts that by 2070 there would be full recovery in the upper layers, and recovery beyond natural in lower layers as a result of greater connection (via fracturing) to the upper layers.

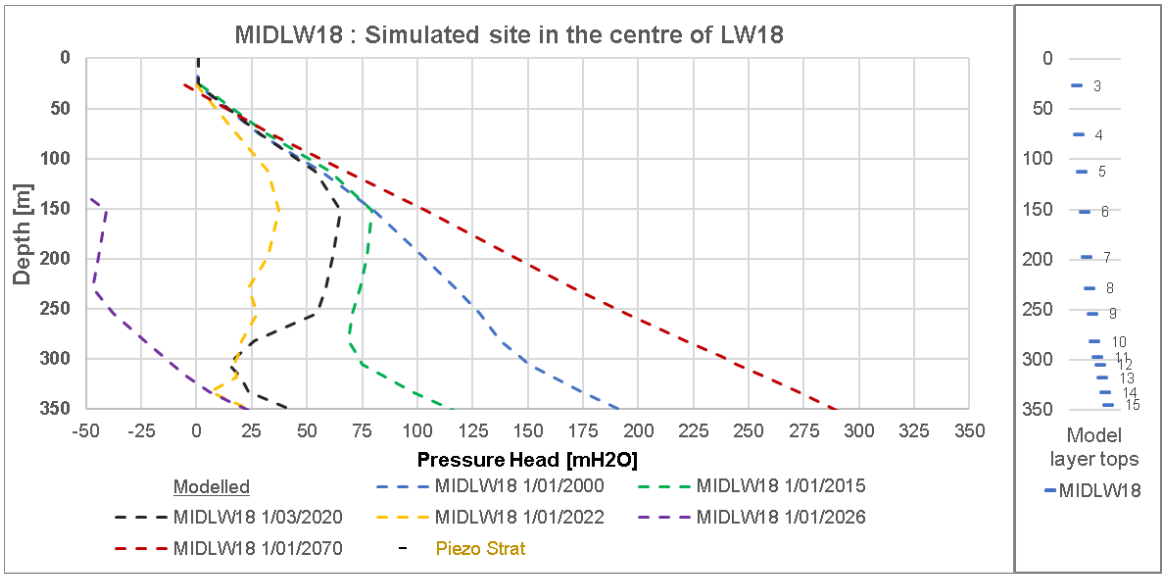


Figure 7-4 Modelled groundwater pressure profile within Longwall 18

Figure 7-5 shows the modelled pressure head profile at monitoring bore S2490 to the south of Longwall 18 (beneath Swamp 35b). There is monitoring data for 2020, so the modelled profile for March-2020 is compared to observed data. This shows a reasonable match to the observed data.

As with **Figure 7-4** (above), the modelled profiles for S2490 show the pre-mining conditions in 2000, then the effect of nearby Elouera is evident as drawdown in 2015, and pressures at the approximate present day in early 2020. Following Longwall 18 extraction, pressures drop significantly, with positive pressures simulated through much of the profile, but being 25-20 m lower than pre-mining in the upper layers, including in the near-surface strata around the base of Swamp 35b. The model predicts that by 2070 there would be full recovery in the upper layers, and recovery beyond natural in lower layers as a result of greater connection (via fracturing) to the upper layers.

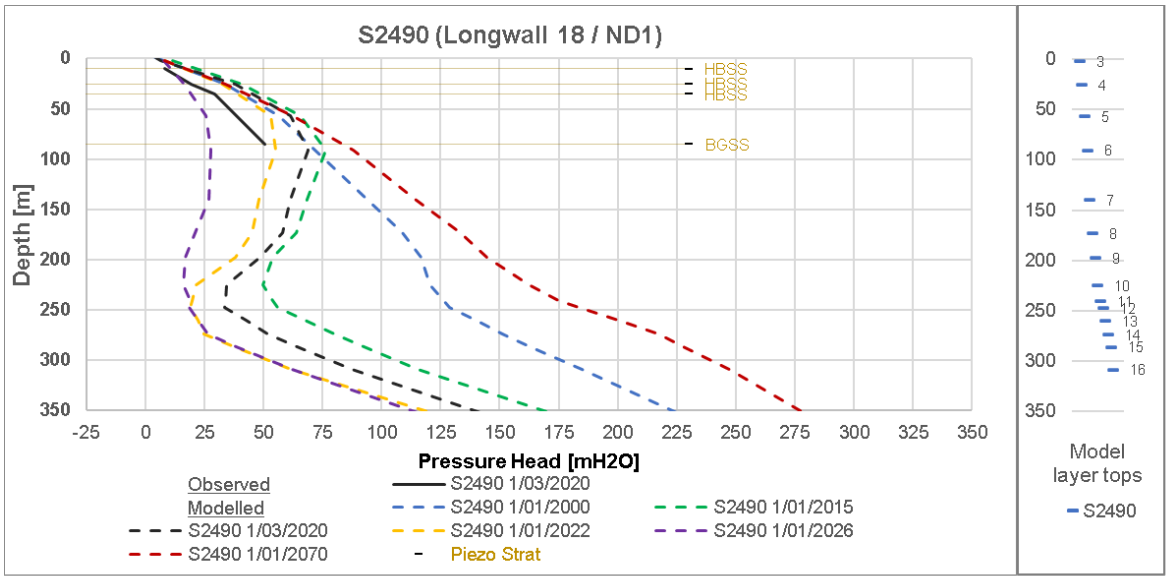


Figure 7-5 Modelled groundwater pressure profile at S2490

Figure 7-6 shows the modelled pressure head profile 250 m directly west of Longwall 18, 150 m from Avon Reservoir. There is no monitoring bore here, so the modelled profiles are not compared to observed data. The modelled profiles show the pre-mining conditions in 2000, then the effect of nearby Elouera, and possibly from earlier Area 3B longwalls, is evident as drawdown in 2015, and pressures at the approximate present day in early 2020. Following Longwall 18 extraction, pressures decline further, with low but positive pressures simulated through much of the profile. From about 2026, recovery commences and the model simulates full recovery in this area by 2050-2070.

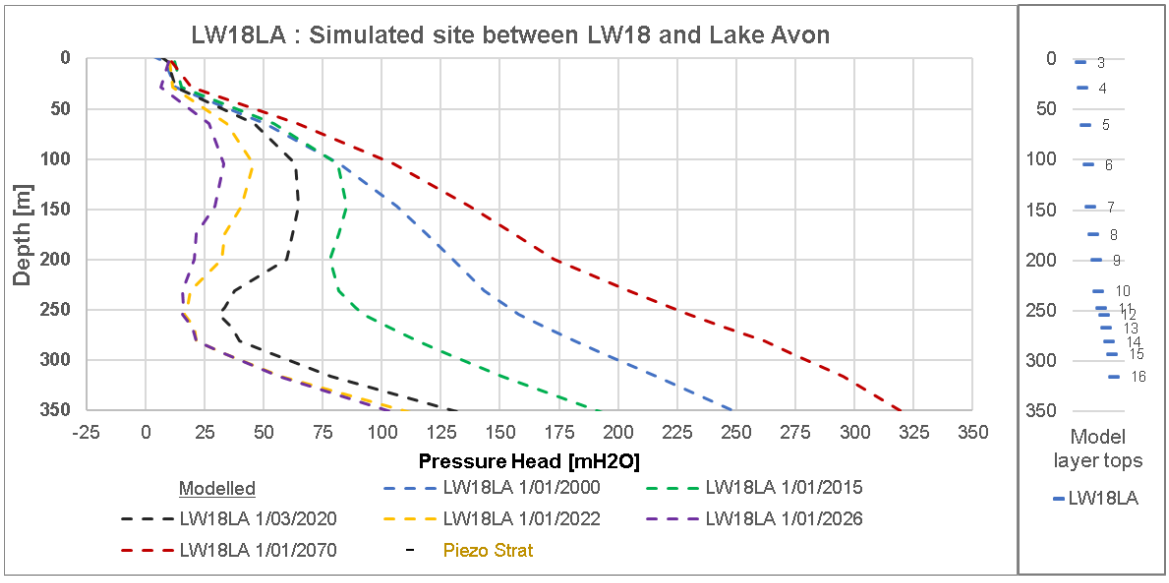


Figure 7-6 Modelled groundwater pressure profile between Longwall 18 and Avon Reservoir

7.3.4 Groundwater Drawdown at Groundwater Bores

The nearest Groundwater Works from the NSW government database are described in Section 3.1. Of those bores, the nearest of them (GW112386) is a monitoring bore, not a water supply work, and there is no requirement under the AIP to assess drawdown at monitoring bores.

The maximum estimated drawdown at each water supply bores is listed in **Table 7-2**. The AIP states that the threshold for 'minimal harm' is 2 m of drawdown. The modelling indicates that none of the nearest bores would be adversely affected by the extraction of Longwall 18 or by Dendrobium Mine as a whole.

Table 7-2 Maximum Predicted Drawdown at Groundwater Works

GW Works #	Depth	Stratigraphy	Layer	Predicted Max. Drawdown (m) due to:	
				Dendrobium A1-3C	Longwall 18 increment
GW0490945	110-170 m	HBSS	4	0.0	0.0
GW068119	9-19 m	Shoalhaven Group	17	0.0	0.0
GW102528	17-169 m	HBSS	3, 4	0.0	0.0

7.4 Forecast changes to water balance and fluxes

In the following sections, predicted changes to fluxes as a result of further mining at Dendrobium, including proposed Longwall 18, are presented. These fluxes include:

- regional mass balance;
- mine inflow to Dendrobium;
- mine inflow to Elouera (considered for the purpose of assessing the behaviour or role of Elouera Fault);
- losses from Avon and Cordeaux Reservoirs; and
- reduction in surface water flows in watercourses ('surface water take').

7.4.1 Regional groundwater mass balance

The modelled regional groundwater balance is summarised in **Table 7-3**, which presents the average water balance for 2020-2060, which is consistent with 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 18), historical mining around Dendrobium, and the parts of approved Tahmoor Mine and the Appin/BSO Mine that lie within the active model domain.

Table 7-3 Modelled Water Balance for Calibration Period (2020-2060)

MODFLOW component	Conceptual process	In [ML/d]	Out [ML/d]
RECHARGE	rainfall recharge	190.4	0.0
RIVER LEAKAGE	watercourses, reservoirs	47.5	26.2
EVT	evapotranspiration	0.0	197.9
DRAINS	mine inflow	0.0	7.6
HEAD DEP BOUNDS	regional GW flow	4.6	1.6
CONSTANT HEAD	flow to ocean, estuaries	0.0	0.03
STORAGE	groundwater storage	7.0 (decline in GWLs)	16.3 (rise in GWLs)
Total		249.6	249.6

Units are in ML/d. Results are from model run 5TR50: SP119-197.

Rainfall recharge is the dominant input, while evapotranspiration and baseflow to watercourses/springs/reservoirs are the dominant outputs. The model simulates historical mine inflow for all mines in the model domain equals approximately 3-4% of recharge. During the reported period, there is a net increase in groundwater storage (i.e. groundwater level recovery).

7.4.2 Forecast Groundwater Inflow

Inflow to Dendrobium

Modelled inflow to Area 3B (with and without Longwall 18) is presented on **Figure 7-7**, and total inflow to Areas 1-3C on **Figure 7-8**. These figures show the results from the base case model without Longwall 18 (green) and the results from deterministic scenarios with Longwall 18 (specifically scenarios considering higher off-goaf permeability and changes to Elouera Fault zone permeability – Section 7.2).

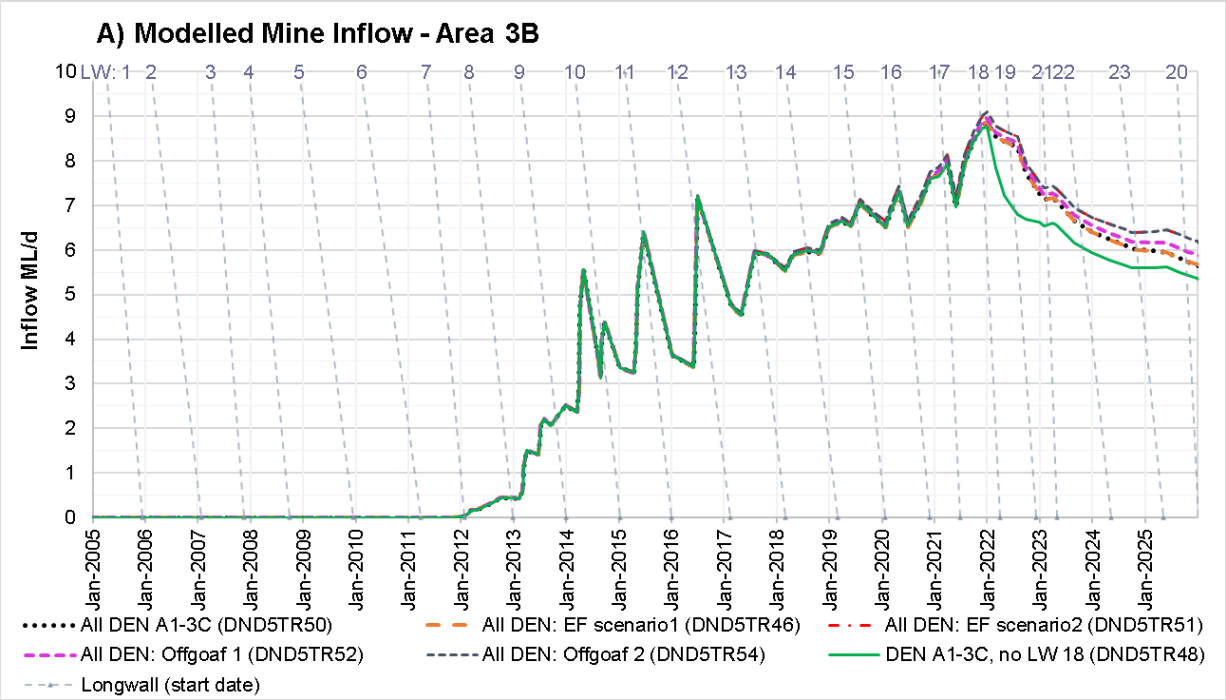
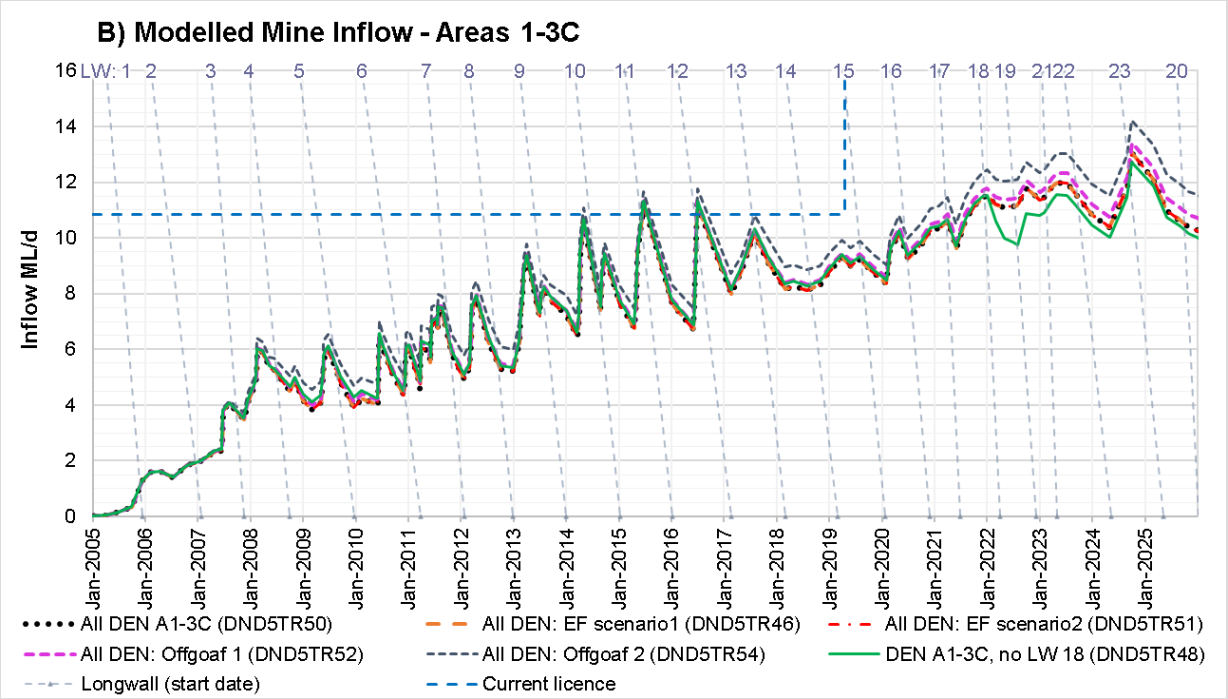


Figure 7-7 Modelled groundwater inflow to Area 3B

Within Area 3B (**Figure 7-7**), the incremental effect of Longwall 18 is expected to be an increase of 0.5-1.5 ML/d. The current inflow to Area 3B is above 4 ML/d (Section 3.9.3), indicating the model is overestimating recent inflow to this domain by about 2 ML/d (Section 6.5). Taking this into consideration, the expected inflow to Area 3B with the addition of Longwall 18 is expected to be in the range of 5-9 ML/d, most likely in the lower end of this range.

Longwall 18 is forecast to contribute a 0.5-1.5 ML/d (2-10%) increase in peak total inflow to Dendrobium. The model forecasts that inflow could rise to about 12 ML/d (**Figure 7-8**), although it is noted that the model tends to overestimate inflow by about 2 ML/d. Inflow is forecast to remain below the current annual groundwater entitlement held for Dendrobium Mine (9,185 ML/yr or >25 ML/d).



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Figure 7-8 Modelled groundwater inflow to Area 3B

Inflow to Elouera workings

Modelled inflow to Elouera workings, including the longwalls, to the south of Area 3B has been reviewed. The inflow results for the scenarios indicated that additional inflow to Elouera due to the extraction of Longwall 18 and simulated reactivation scenarios was approximately 0.01-0.05 ML/d.

This does not suggest that the stress relief and fault reactivation anticipated (SCT, 2020 and Section 4.2.2) would result in significant increases to inflow to either Dendrobium or Elouera workings. This finding is consistent with the modelled leakage from Avon Reservoir (Section 7.4.3).

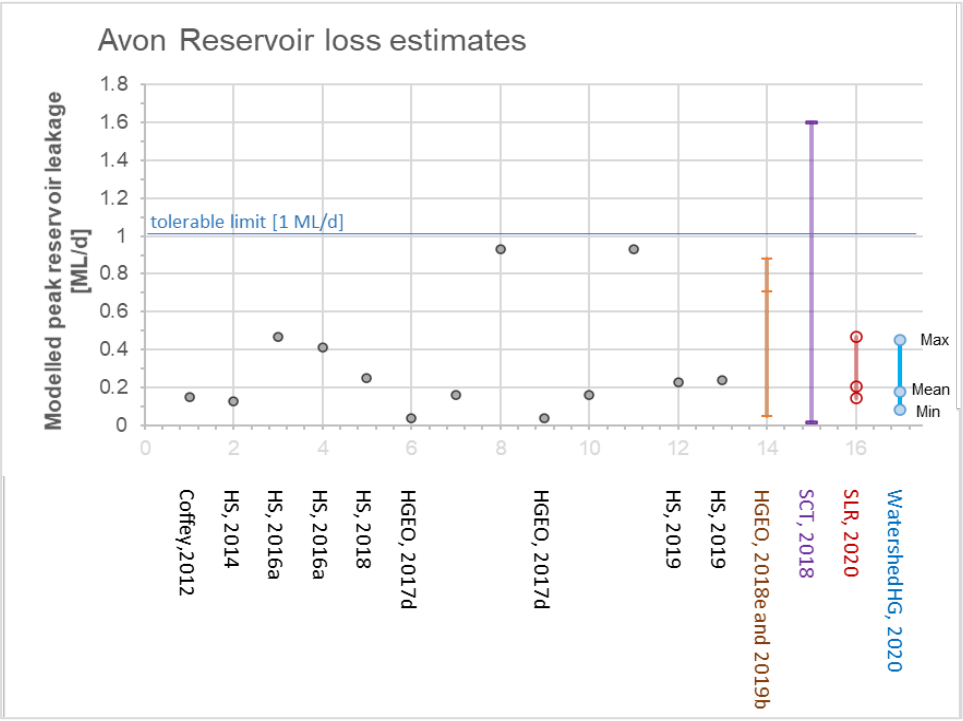
7.4.3 Simulated Leakage from Avon Reservoir

The maximum leakage from Avon Reservoir as a result of mining at Dendrobium has been estimated from the deterministic scenarios, and is predicted to be between 0.09 and 0.45 ML/d, with an average of the scenarios being 0.18 ML/d. These results are plotted on the right-hand side of **Figure 7-9**, alongside results from all previous modelling at Dendrobium.

The results from this study are very similar to those from SLR (2020a) even though a different model (e.g. rectilinear/structured versus unstructured mesh, different approach to hydraulic conductivity parameterisation) has been used.

The deterministic scenarios which result in greatest leakage from the reservoir (0.17 and 0.45 ML/d) are the two scenarios where higher off-goaf permeability is simulated (DND5TR52 and DND5TR54 - **Table 7-1**), and not the scenarios where Elouera Fault properties are enhanced. Of these, the former is more likely, given that it uses the average of all Avon shoreline post-mining packer testing results, while the higher leakage is based on just the highest two sets of packer test results (HGEO, 2019 and **Table 7-1**), and so quite conservative.

These leakage estimates are less than the Dams Safety NSW's prescribed tolerable limit for Avon Reservoir (1 ML/d, as shown on **Figure 7-9**).



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Figure 7-9 Estimated leakage from Avon Reservoir

The estimates from this study are similar to estimates from previous regional models in Coffey, 2012, HS, 2014, HS, 2016a, of which the highest was in HS, 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 recent groundwater inflow to Area 3B (approx. 4 ML/d), while 0.7 ML/d is approximately 15-20%.

Given the improved calibration to groundwater levels near to just below the base of the lake along the shoreline of Avon Reservoir (e.g. **Figure 6-5** and **Figure 6-6**), the calibration to watercourse losses and both the declining trend in observed inflow to Area 3B and the overestimation of modelled inflow to that domain, as well as the constraint of modelled hydraulic conductivities to the observed dataset, the modelled leakage results from this regional groundwater model appear reliable indicators that inflow is less than the tolerable limit (1 ML/d) set by Dams Safety NSW.

The model estimates that the incremental leakage from Avon Reservoir due to Longwall 18 would be 0.01-0.13 ML/d (average 0.04 ML/d). The high range estimate is from the "Offgoaf 2" scenario (**Table 7-1**), which simulates the most conservative valley closure permeability enhancement (Section 5.4.4).

7.4.4 Simulated Leakage from Cordeaux Reservoir

Based on the scenarios outlined in **Table 7-1**, the range in simulated maximum leakage from Lake Cordeaux due to Dendrobium operations is 0.09-0.32 ML/d, averaging 0.14 ML/d. This average is similar to previously reported estimates of 0.14 ML/d (HS, 2019a), 0.08 ML/d (HS, 2019b), and 0.1 ML/d (SLR, 2020a). Even the upper estimate from the modelling presented here (0.32 ML/d) is lower than Dams Safety NSW's prescribed tolerable limit for Lake Cordeaux (1 ML/d).

This estimate appears reliable given the improved calibration to Bulgo Sandstone groundwater levels in Area 3A (e.g. **Figure 6-2**), as well as the fact that recent 'baseline' inflow to Areas 1, 2 and 3A (which are located around Lake Cordeaux) totals approximately 1.5-2 ML/d.

Incremental leakage from Cordeaux Reservoir due to Longwall 18 is zero.

7.4.5 Simulated 'Incidental Take' from Watercourses

Condition 16(c) required estimates of baseflow capture to be provided in 5-yearly intervals out to 30-years after the proposed completion of Area 3B. The same approach has been here.

The results from MODFLOW budget files have been extracted from the predictive scenarios, and net difference, the 'take' from surface water, has been calculated for a number of zones. **Appendix H** presents charts showing the incremental and whole-of-mine effects on watercourses around Dendrobium. These charts show a range of surface water losses for the 5-year periods. Where historical losses (reductions in median flow) are available from recent End of Panel Assessments, these are plotted to illustrate the performance of the model.

Based on the results in **Appendix H**, results for the watercourses near to and most-affected by Longwall 18 have been selected and tabulated below. Results for other watercourses can be provided but are not tabulated in this report. The range in the following tables represents the minimum to maximum loss, which is also shown in the charts in **Appendix H**. The maximum losses in **Appendix H** and the following tables accounts for potential permanency of effects.

Table 7-4 summarises the predicted surface water losses due Longwall 18 and **Table 7-5** summarises the predicted surface water losses due Dendrobium as a whole.

Table 7-4 Predicted change in surface water flow (ML/d): Longwall 18 increment

5 Year Interval	LA2	LA3	ND1	Native Dog Ck (inc. ND1)	Wongawilli Creek (to WWL)
2016-20	0	0	0	0	0
2021-25	0.000 - -0.002	0.000 - -0.002	-0.020 - -0.069	-0.031 - -0.108	-0.002 - -0.011
2026-30	0.000 - -0.002	0.000 - -0.002	-0.043 - -0.149	-0.065 - -0.229	-0.005 - -0.017
2031-35	0.000 - -0.002	0.000 - -0.002	-0.039 - -0.149	-0.063 - -0.229	-0.005 - -0.019
2036-40	-0.002 - -0.006	0.000 - -0.002	-0.034 - -0.149	-0.055 - -0.229	-0.017 - -0.059
2041-45	-0.002 - -0.008	0.000 - -0.002	-0.025 - -0.149	-0.044 - -0.229	-0.020 - -0.069
2046-50	-0.003 - -0.009	0.000 - -0.002	-0.018 - -0.149	-0.039 - -0.229	-0.021 - -0.072
2051-55	-0.003 - -0.009	0.000 - -0.002	-0.013 - -0.149	-0.038 - -0.229	-0.021 - -0.074

Negative value = reduction in surface water flow.
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This shows that, because of the effects of preceding longwalls, especially Longwalls 16 and 17, the incremental effects of Longwall 18 on tributaries LA2 and LA3 are predicted to be low.

Longwall 18 is predicted to have the greatest impact on ND1 and Native Dog Creek, due to the distance to these watercourses. Effects on Wongawilli Creek are relatively small, especially when compared to whole-of-mine effects (**Table 7-5**), but would primarily occur as a reduction in flow in tributary WC7 (to the east of Longwall 18 - **Figure 2-1**) and a mild reduction in baseflow to the middle reach of Wongawilli Creek (approximately 0.01-0.04 ML/d). Through time, the incremental effect of Longwall 18 is only approximately 2% of the modelled cumulative effect of all Dendrobium longwalls on the middle reach of Wongawilli Creek.

The total take from Wongawilli Creek and Donalds Castle Creeks is predicted to be up to 430 ML/yr (moderate impact estimate, but ranging 280 to 1000 ML/yr).

We consider that the likely impact or take is toward the lower end of these estimates (based on comparison against End of Panel assessment results – Section 6.6 and **Appendix H**). The 'most likely' impact, based on comparison of the modelled and historical losses has been provided in HGEO

(2020e), noting that future rainfall and flow conditions as well as uncertainties in the groundwater model representation of mining effects, will influence future losses.

Short-term effects may be higher than is 'expected' based on the requested 5-year intervals (**Table 1-3**).

Table 7-5 Predicted change in surface water flow (ML/d): Dendrobium total

5 Year Interval	LA2	LA3	ND1	Native Dog Ck (inc. ND1)	Wongawilli Creek (to WWL)
2016-20	0.000 - -0.002	0.000 - -0.003	0.000 - -0.002	-0.001 - -0.005	-0.27 - -0.94
2021-25	-0.035 - -0.121	-0.013 - -0.045	-0.026 - -0.092	-0.043 - -0.152	-0.54 - -1.90
2026-30	-0.041 - -0.143	-0.015 - -0.053	-0.061 - -0.215	-0.097 - -0.339	-0.62 - -2.18
2031-35	-0.041 - -0.143	-0.015 - -0.053	-0.062 - -0.216	-0.099 - -0.346	-0.63 - -2.22
2036-40	-0.040 - -0.143	-0.015 - -0.053	-0.055 - -0.216	-0.090 - -0.346	-0.56 - -2.23
2041-45	-0.037 - -0.143	-0.014 - -0.053	-0.044 - -0.216	-0.073 - -0.346	-0.41 - -2.23
2046-50	-0.029 - -0.143	-0.012 - -0.053	-0.033 - -0.216	-0.059 - -0.346	-0.29 - -2.23
2051-55	-0.022 - -0.143	-0.011 - -0.053	-0.026 - -0.216	-0.054 - -0.346	-0.23 - -2.23
Maximum annual take ML/yr	15 to 52	6 to 19	23 to 79	36 to 126	230 to 810

7.4.6 Simulated Take from Water Supply Catchments

As recommended in IEPMC (2019a) the groundwater model has been used to estimate the total surface water losses from the catchments to the Avon and Cordeaux Reservoirs.

The surface water catchment to Cordeaux Reservoirs is completely within the active extent of the groundwater model, while about 95% of the catchment of Avon Reservoir is within that domain.

Table 7-6 Predicted reduction in surface water flow to reservoirs (ML/yr)

5 Year Interval	Avon Reservoir catchment		Cordeaux Reservoir catchment	
	Moderate	Range	Moderate	Range
2016-20	-5	-3 to -11	-136	-91 to -318
2021-25	-59	-39 to -137	-153	-102 to -357
2026-30	-180	-120 to -419	-221	-147 to -515
2031-35	-232	-155 to -542	-261	-174 to -609
2036-40	-233	-155 to -544	-265	-177 to -618
2041-45	-191	-128 to -446	-227	-151 to -529
2046-50	-113	-75 to -264	-133	-89 to -311
2051-55	-53	-35 to -123	-54	-36 to -127

Negative value = reduction in surface water flow.
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Taken alongside the results in Section 7.4.5, the revised model suggests that Dendrobium Mine could take up to 930 ML/yr (range 615 to 2100 ML/yr) of surface water during the period 2020-2040 and declining thereafter:

- 500 ML/yr (range: 330-1100 ML/yr) from the water supply catchments and
- 430 ML/yr (range 285-1000 ML/yr) from Wongawilli and Donalds Castle Creeks.

Note that there is uncertainty in these estimates, based on the uncertainty regarding future weather conditions as well as uncertainty in model parameters and mining effects.

8 Conclusions

The numerical groundwater model has been revised from previous modelling (see **Appendix B**). This update was carried out following the acquisition of newly available pre- and post-mining data from longwall areas (Sections 3.6 and 5.4), as well as from the Elouera Fault investigation (Sections 2.5.2.2 and 4.2.2).

This model is assessed for calibration against a large dataset of groundwater levels from more than 600 target locations, as required by the Conditions of the SMP Approval, as well as against mine inflow in each mine area, while constraining the model to field-derived values of permeability, including the use of a K-depth relationship, which is evident from field data, to parameterise the model.

These new data and modifications have allowed significantly improved model calibration for groundwater levels (as shown in hydrographs in Section 6.4) as well as some improvement to mine inflows. The modelling has also now incorporated calibration against surface water losses calculated in recent End of Panel reporting to attempt to provide more realistic, but still conservative (as per IEPMC, 2019a), estimates of future surface water take as a result of mining operations.

The key results from the revised groundwater model and groundwater assessment as a whole are:

- 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 inflow or groundwater take is predicted to be up to 12 ML/d, although this is still slightly (approximately 2 ML/d) greater than is considered realistic given the calibration to Areas 3A and 3B. The extraction of Longwall 18 would cause an increase in Area 3B inflow of up to 1.5 ML/d during 2022-23.
- Simulated mine inflow to Elouera Colliery has been reviewed for the scenarios considering different degrees of stress relief due to Longwall 18 extraction and potential permeability enhancement along the Elouera Fault. The model results indicate that there would be little change to groundwater inflow to Elouera Colliery.
- The simulated incremental leakage from the Avon Reservoir due to extraction of Longwall 18 would be 0.01-0.13 ML/d (average 0.04 ML/d). Losses due to all of Dendrobium Areas 1-3C are predicted to be up to 0.45 ML/d and therefore less than Dams Safety NSW's prescribed tolerable limit.
- The losses from Avon Reservoir are also considered under different scenarios considering stress relief (including fault reactivation) and permeability enhancement around Area 3B longwalls. These modelling suggests that leakage from the reservoir is more sensitive to the uncertainty in off-goaf permeability changes (due to valley closure) than to the simulated changes in Elouera Fault permeability.
- Simulated leakage from Cordeaux Reservoir is also predicted to be less than the prescribed tolerable limit, and the incremental rate of loss due to Longwall 18 is zero, given the significant distance between the panel and this reservoir.
- Incidental surface water capture has been estimated using the groundwater model and tabulated as required in **Table 7-4** and **Table 7-5**. The predicted take is up to 930 ML/yr (range 615 to 2100 ML/yr) from all surface water sources and catchments, while the incremental surface water take due to Longwall 18 is up to about 35 ML/yr (range 23-110 ML/yr).
- ND1 will be the watercourse most affected by extraction of Longwall 18. Given the distance from Longwall 18 to Wongawilli Creek, the incremental effects of Longwall 18 on that

watercourse (i.e. drawdown leading to baseflow loss) will be less than those from other Area 3B or Area 3A panels.

- The nearest High Priority GDE, as defined in the relevant WSP (Section 3.2.1) is the Macquarie Rivulet Estuary which is approximately 17 km from Dendrobium Area 3B (**Figure 2-1**). No drawdown effects will occur at this location as a result of mining at Dendrobium.
- Effects on Upland Swamps are described more fully in the accompanying Shallow Groundwater and Surface Water Assessment (HGEO, 2020e), however it is likely that groundwater drawdown due to extraction of Longwall 18 will reduce the inferred baseflow contribution to nearby Swamp 35b.
- The nearest registered "water supply work" (i.e. private bore) is >4 km south or south-east of Dendrobium Area 1, and over 8 km from Longwall 18. Drawdown due to Dendrobium operations is predicted to be effectively zero at these sites. No water supply works are predicted to be affected to any degree and none exceed the 2 m threshold in the AIP.

8.1 Assessment against the Aquifer Interference Policy

Assessment against the AIP is summarised in **Table 8-1**.

Table 8-1 Summary of AIP Assessment

Aquifer	**Sydney Basin Nepean Sandstone Groundwater Source, Management Zone 2**
Category	Highly Productive groundwater
Level 1 Minimal Impact Consideration	**Assessment**
Water Table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: - high priority groundwater dependent ecosystem; or - high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR a maximum of a 2 m water table decline cumulatively at any water supply work.	The relevant Water Sharing Plan is the 'Greater Metropolitan Groundwater Sources' (2011). High Priority GDEs There are no High Priority 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. High Priority Culturally Significant Sites 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. 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). **Level 1 minimal impact consideration classification.**
Water pressure A cumulative pressure head decline of not more than a 2m decline, at any water supply work.	There is a very minor risk of depressurisation in excess of the water supply work drawdown criterion within the Permo-Triassic strata (at GW112386). **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. **Level 1 minimal impact consideration classification.**

8.2 Recommendations

Recommendations for future groundwater monitoring, data analysis and modelling are as follows:

Monitoring and analysis

Monitoring of shallow (swamp) water table elevation at Swamp 35B already occurs. Monitoring of 'shallow' sandstone (10-50 mBG) is recommended to understand impacts at or near Swamp 35b. Given that access for drill rigs can be difficult, monitoring at S2490 may be the most practical method to achieve this.

HGEO (2020d) includes plans for tracer testing be conducted around the Elouera Fault as a second method for understanding the transmissivity around this feature. This is planned for late 2020. Analysis of this testing should be aimed at refining the current conceptual model of transmissivity around the fault zone.

Modelling

The over-estimation of inflow, especially for recent years in Area 3B and the underestimation of peak inflows in Area 2 requires further investigation. This requires finding a balance between maintaining current calibration to groundwater levels, while reducing Area 3B inflow and possibly increasing Area 2 inflow, and improving surface water loss estimates.

Further investigation and calibration of Kv (and perhaps Kh) within the deformed zones inside the panel footprint. The difficulty thus far is balancing too much inflow in Area 3B with too little take from watercourses (hence the adoption here of 'Stacked Drains'), as well as trying to increase the response to rainfall in Area 2. Further model testing and calibration should aim to completely remove the 'Stacked Drains' and rely solely on the TVM method of simulating enhanced hydraulic properties as a result of fracturing.

It would be useful to better understand and then simulate operations and water management at the Wongawilli Colliery (Nebo/Elouera/Wongawilli workings). This is not essential for SMP applications for Dendrobium, but may affect simulated post-closure behaviour at both mines.

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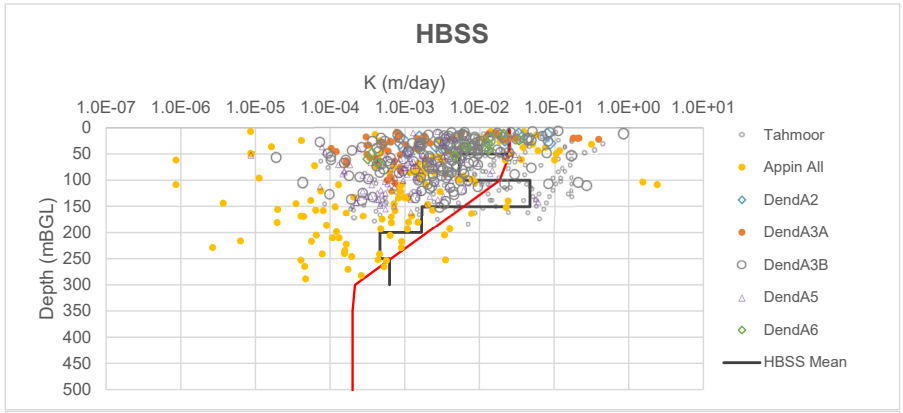
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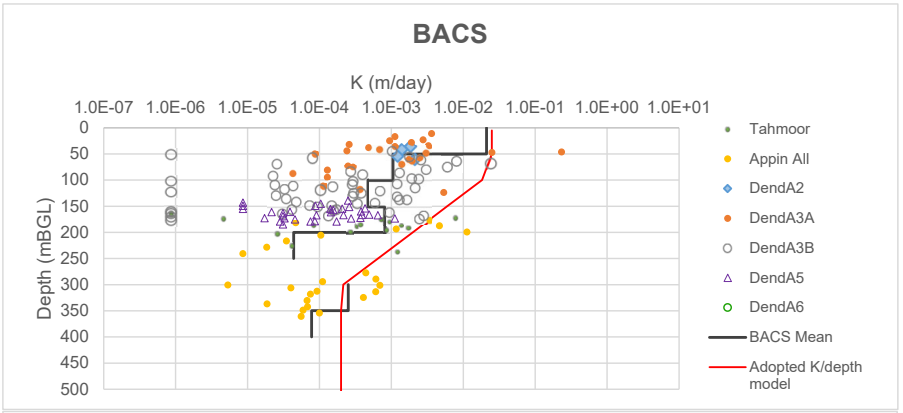
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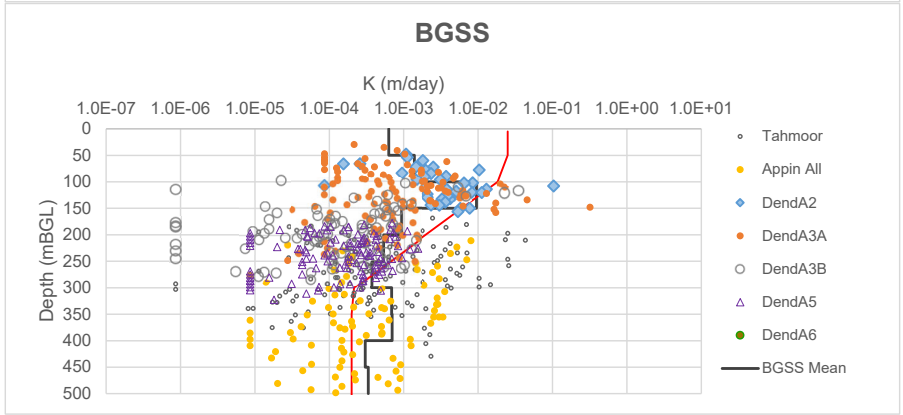
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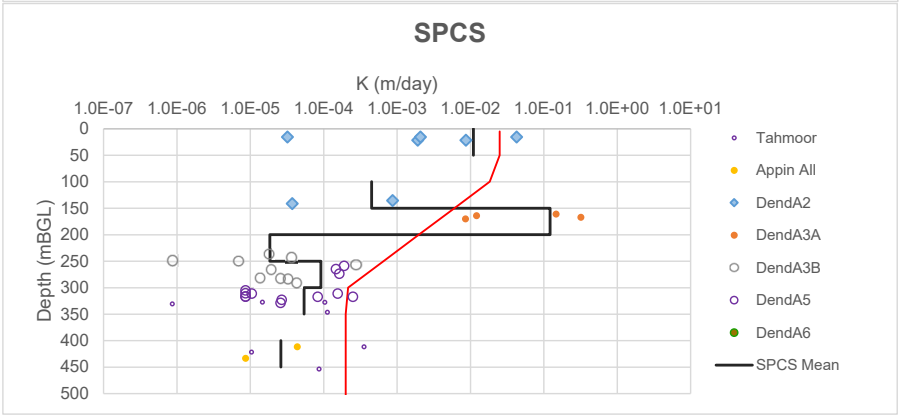
Appendix A: Hydraulic conductivity data

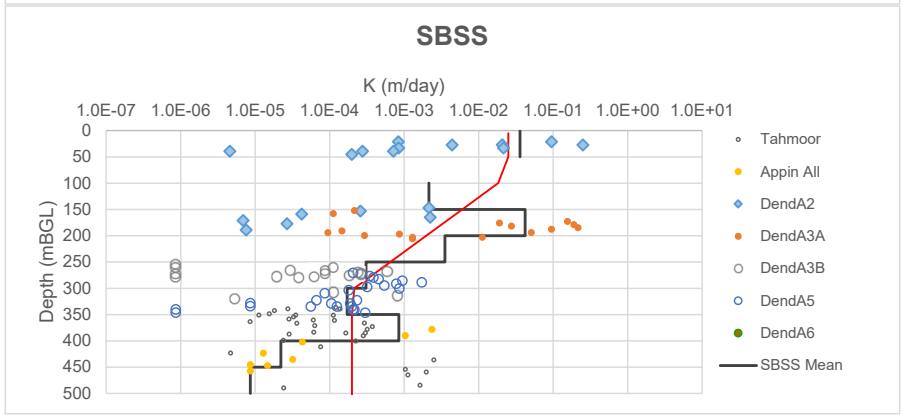
Summary of packer and drillstrem testing: by Area/Domain, depth and stratigraphy

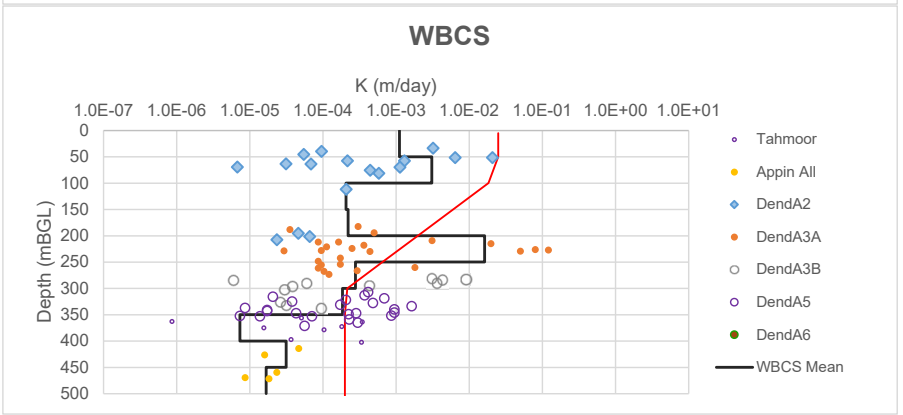




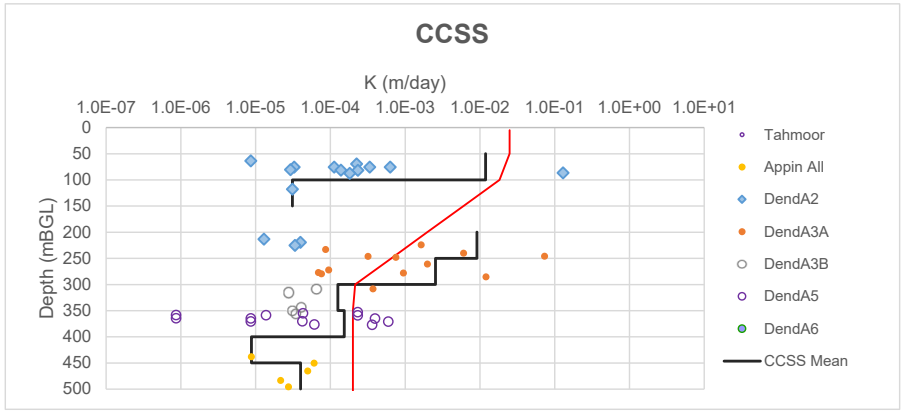


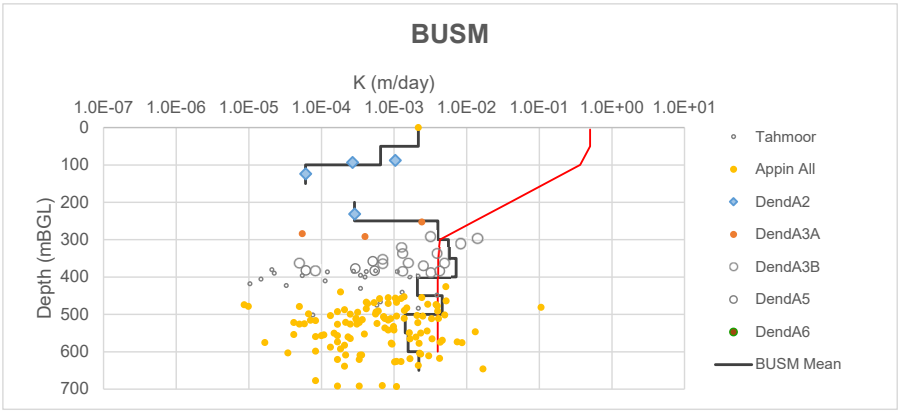


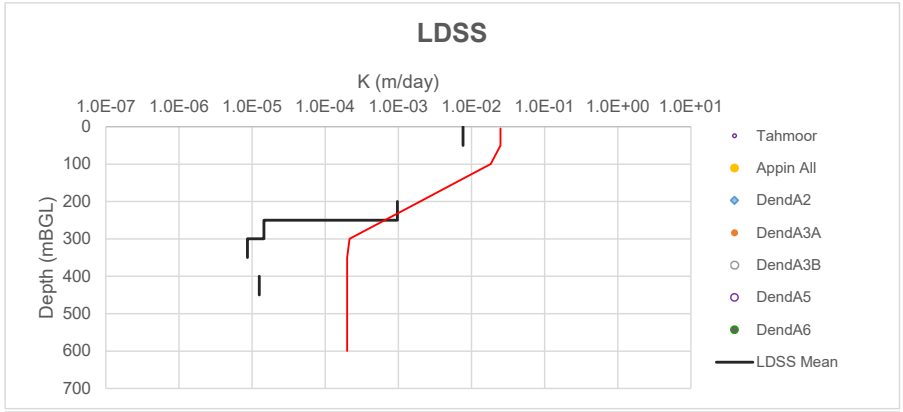


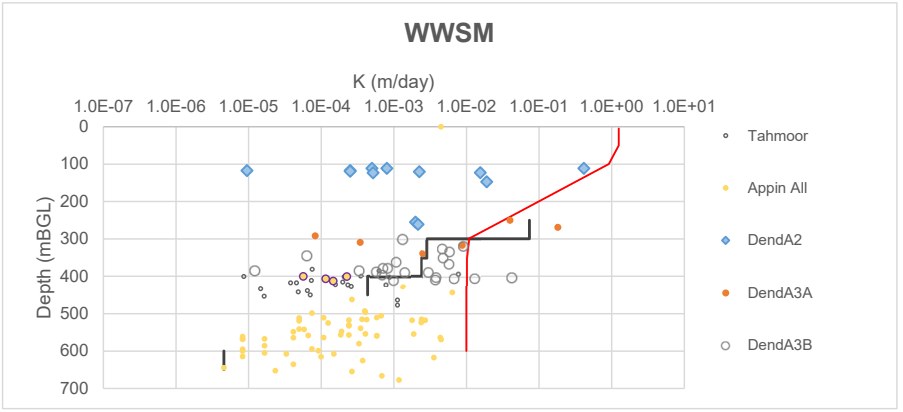


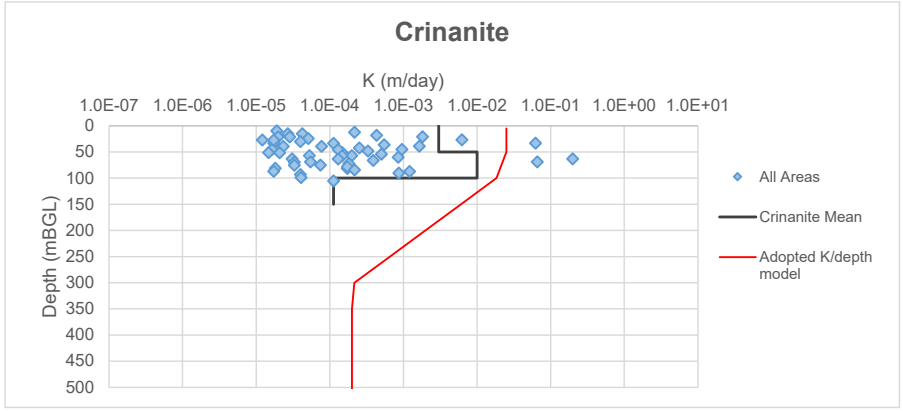
Summary of packer and drillstrem testing: by Area/Domain, depth and stratigraphy











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Appendix B: Groundwater model history

In response to a request by WaterNSW, the following table summarises the history and key features of groundwater modelling for Dendrobium Mine.

Report	Project / Requirement	Software	Grid	Key features	Other features	Peer Review
GHD, 2007. Document: 21/11716/03/AY116.	Area 3 Application	SEEP/W v.6.20	2D "slice" or cross-section model	2D slice model focussing on Area 3A.	Simulated mining: Areas 2-3A Layers: n/a (finite element model). Recharge: estimated as ~2.5% of rainfall. Hydraulic conductivity: zones. Inflow calibration: not calibrated to inflow.	
Coffey, 2012. Document: GEOTLCOV 24507AA-AB2.	Area 3B SMP Approval	MODFLOW-SURFACT v.3	3D rectilinear grid. Detail around A3B.	Fractured zone representation: 'Stacked Drains'. Height of connected fracturing estimated by: Tammetta (2012) H.	Simulated mining: Areas 1-3B. Layers: 15. Recharge: estimated as 2.7% of rainfall. Hydraulic conductivity: zones. Inflow calibration: total mine inflow.	Noel Merrick (Heritage Computing)
HydroSimulations, 2013. Document: HC2013-28.	A3B SMP approval condition	MF-SURFACT v.3	3D (as for Coffey, 2012)	Fracture zone representation: as for Coffey, 2012. Improved representation of topography. Improved simulation of watercourses (MODFLOW-SFR) and included swamp deposits/regolith.	Simulated mining: Areas 1-3B. Layers: 16 (swamp deposits added). Recharge: as per Coffey, 2012 Hydraulic conductivity: zones. Inflow calibration: total mine inflow.	
HydroSimulations, 2014. Document: HC2014-04.	A3B SMP approval condition / DPIE request	MF-SURFACT v.3	3D (as for Coffey, 2012)	Fractured zone represented: transient material properties (TMP). Height of connected fracturing estimated by: Ditton (2012) A-zone.	Simulated mining: Areas 1-3B. Layers: 16. Recharge: as per Coffey, 2012 Hydraulic conductivity: zones. Inflow calibration: total mine inflow.	
HydroSimulations, 2016. Document: HC2016-02c.	Longwalls 14-18 SMP Application	MODFLOW-USG ('transport')	3D (as for Coffey, 2012)	Fractured zone representation: Connected Linear Networks (CLN). Height of connected fracturing estimated as Ditton (2014) A and as Tammetta H. First incorporation of surface cracking via time-varying material properties (TVM) package. Reservoirs simulated with transient stage for historical period.	Simulated mining: Areas 1-3B. Layers: 16. Recharge: soil moisture balance model calibrated against independent estimates. Hydraulic conductivity: zones. Inflow calibration: total mine inflow.	
HydroSimulations, 2017. Document: HS2017-37e.	Longwalls 16-18 SMP Application	MF-USG-T	3D (as for Coffey, 2012)	Fractured zone representation: Stacked Drains with high conductance in line with PSM (2017) conceptualisation. Assumed seam-to-surface connection as per PSM conceptualisation for >300m panels (otherwise Tammetta H). Incorporation of off-goaf valley closure via TVM. Improved representation of surface cracking depth, surface cracking modelled via TVM. Watercourses simulated w\ MODFLOW River package.	Simulated mining: Areas 1-3B. Layers: 17 (additional layer to allow swamps to sit about uppermost rock layer). Recharge: soil moisture balance model calibrated against independent estimates. Hydraulic conductivity: zones. Inflow calibration: area-by-area calibration.	Frans Kalf (Kalf and Associates)
HydroSimulations, 2019a.	Longwall 17 SMP Application	MF-USG-T		Fractured zone representation: primarily Stacked Drains with high conductance in line with PSM (2017) conceptualisation.	Simulated mining: Areas 1-3B.	

Report	Project / Requirement	Software	Grid	Key features	Other features	Peer Review
Document: HS2018-72c.			3D (as for Coffey, 2012)	Assumed seam-to-surface connection as per PSM conceptualisation for >300m panels (otherwise Tammetta H). Surface cracking and off-goaf valley closure via TVM.	Layers: 17. Recharge: soil moisture balance model calibrated against independent estimates. Hydraulic conductivity: zones. Inflow calibration: area-by-area calibration.	Frans Kalf (Kalf and Associates)
HydroSimulations, 2019b. Document: HS2019-19g.	Longwall 20-21 SMP Application	MF-USG-T	3D (as for Coffey, 2012)	Fractured zone representation: primarily Stacked Drains with high conductance in line with PSM (2017) conceptualisation. Assumed seam-to-surface connection as per PSM conceptualisation for >300m panels (otherwise Tammetta H). Surface cracking and off-goaf valley closure via TVM.	Simulated mining: Areas 1-3B + 3C (20-21). Layers: 17 Recharge: soil moisture balance model calibrated against independent estimates and against BoM AWRA model. Hydraulic conductivity: zones. Inflow calibration: area-by-area calibration.	
HydroSimulations, 2019c. Document: HS2018-76.	Area 5 and 6 EIS	MF-USG-T	3D unstructured mesh, detail around longwalls, local watercourses	Fractured zone representation: primarily Stacked Drains with new method for estimating conductance → better groundwater level and inflow calibration. Assumed seam-to-surface connection as per PSM conceptualisation for >300m panels (otherwise Tammetta H). Surface cracking / off-goaf valley closure via TVM.	Simulated mining: Areas 1-3B + 3C + A5 + A6 Layers: 17 Recharge: soil moisture balance model calibrated against independent estimates and against BoM AWRA model. Hydraulic conductivity: K/depth relationship and zones. Inflow calibration: area-by-area calibration.	Frans Kalf (Kalf and Associates)
SLR, 2020a Document: 665.10009-R02.	Longwall 19 SMP Application	MF-USG-T v.1.3	3D (as for Coffey, 2012)	Fractured zone representation: primarily Stacked Drains using drain conductance parameters from HydroSimulations, 2019c. Assumed seam-to-surface connection as per PSM conceptualisation for >300m panels (otherwise Tammetta H). Surface cracking / off-goaf valley closure via TVM.	Simulated mining: Areas 1-3B. Layers: 17 Recharge: soil moisture balance model calibrated against independent estimates and against BoM AWRA model. Hydraulic conductivity: zones. Inflow calibration: area-by-area calibration.	Frans Kalf (Kalf and Associates)
WatershedHG, 2020. Document: Rr014i4.	Longwall 18 SMP Application	MF-USG-T v.1.4.0	3D unstructured. Modified from HS (2019c). 50m regular mesh applied in A3C/5/6 longwalls.	Fractured zone representation: TVM, constrained by data from centreline goaf bore investigations (e.g. HGEO, 2020). Applied 'Stacked Drains' to improve estimation of surface water losses in headwater streams. Surface cracking and off-goaf valley closure via TVM.	Simulated mining: Areas 1-3B + 3C (to LW23) Layers: 17 Recharge: soil moisture balance model calibrated against independent estimates and against BoM AWRA model. Hydraulic conductivity: K/depth relationship and zones. Inflow calibration: area-by-area calibration. Calibration to surface water losses from EOPs.	

Appendix C: Groundwater model temporal discretisation

Stage	SP	Days	DateFrom	DateTo	Scheduled Mining	Rainfall / Inflow signal	Total days
	1		***Steady State***				1
CALIBRATION	**2**	18993	1/01/1940	31/12/1991			18994
	3	3608	1/01/1992	16/11/2001			22602
	4	20	17/11/2001	6/12/2001			22622
	5	20	7/12/2001	26/12/2001			22642
	6	20	27/12/2001	15/01/2002			22662
	7	40	16/01/2002	24/02/2002			22702
	8	100	25/02/2002	4/06/2002			22802
	9	100	5/06/2002	12/09/2002			22902
	10	100	13/09/2002	21/12/2002			23002
	11	200	22/12/2002	9/07/2003			23202
	12	200	10/07/2003	25/01/2004			23402
	13	200	26/01/2004	12/08/2004			23602
	14	232	13/08/2004	1/04/2005			23834
	15	90	2/04/2005	30/06/2005	Start LW1		23924
	16	90	1/07/2005	28/09/2005			24014
	17	74	29/09/2005	11/12/2005	End LW1		24088
	18	60	12/12/2005	9/02/2006			24148
	19	60	10/02/2006	10/04/2006	Start LW2		24208
	20	95	11/04/2006	14/07/2006			24303
	21	95	15/07/2006	17/10/2006			24398
	22	96	18/10/2006	21/01/2007	End LW2		24494
	23	99	22/01/2007	30/04/2007	Start LW3		24593
	24	44	1/05/2007	13/06/2007			24637
	25	4	14/06/2007	17/06/2007		A2rain1	24641
	26	8	18/06/2007	25/06/2007		A2week1	24649
	27	43	26/06/2007	7/08/2007		A2inflow1	24692
	28	100	8/08/2007	15/11/2007	End LW3		24792
	29	33	16/11/2007	18/12/2007			24825
	30	47	19/12/2007	3/02/2008	Start LW4		24872
	31	6	4/02/2008	9/02/2008		A2 Rain2	24878
	32	8	10/02/2008	17/02/2008		A2 week2	24886
	33	36	18/02/2008	24/03/2008		A2 inflow2	24922
	34	50	25/03/2008	13/05/2008			24972
	35	32	14/05/2008	14/06/2008			25004
	36	110	15/06/2008	2/10/2008	End LW4		25114
	37	31	3/10/2008	2/11/2008			25145
	38	30	3/11/2008	2/12/2008			25175
	39	31	3/12/2008	2/01/2009	Start LW5		25206
	40	60	3/01/2009	3/03/2009			25266
	41	60	4/03/2009	2/05/2009			25326
	42	17	3/05/2009	19/05/2009			25343
	43	5	20/05/2009	24/05/2009		A2rain3	25348
	44	8	25/05/2009	1/06/2009		A2week3	25356
	45	22	2/06/2009	23/06/2009		A2inflow3	25378
	46	88	24/06/2009	19/09/2009			25466
	47	90	20/09/2009	18/12/2009	End LW5		25556
	48	53	19/12/2009	9/02/2010			25609
	49	105	10/02/2010	25/05/2010	Start LW6		25714
	50	10	26/05/2010	4/06/2010		A2rain4	25724
	51	8	5/06/2010	12/06/2010		A2week4	25732
	52	22	13/06/2010	4/07/2010		A2inflow4	25754
	53	75	5/07/2010	17/09/2010			25829
	54	72	18/09/2010	28/11/2010			25901
	55	9	29/11/2010	7/12/2010		A2rain5	25910
	56	8	8/12/2010	15/12/2010		A2week5	25918
	57	22	16/12/2010	6/01/2011		A2inflow5	25940
	58	71	7/01/2011	18/03/2011			26011
	59	4	19/03/2011	22/03/2011		A2rain6	26015
	60	8	23/03/2011	30/03/2011	End LW6	A2week6	26023
	61	60	31/03/2011	29/05/2011	StartLW7	A2inflow6	26083
	62	4	30/05/2011	2/06/2011		A2rain7	26087
	63	8	3/06/2011	10/06/2011		A2week7	26095
	64	38	11/06/2011	18/07/2011		A2inflow7	26133
	65	5	19/07/2011	23/07/2011		A2rain8	26138
	66	8	24/07/2011	31/07/2011		A2inflow8	26146
	67	22	1/08/2011	22/08/2011		A2inflow8	26168
	68	69	23/08/2011	30/10/2011			26237
	69	85	31/10/2011	23/01/2012	End LW7		26322
	70	35	24/01/2012	27/02/2012	Start LW8		26357

Stage	SP	Days	DateFrom	DateTo	Scheduled Mining	Rainfall / Inflow signal	Total days
	71	11	28/02/2012	9/03/2012		A2rain9	26368
	72	8	10/03/2012	17/03/2012		A2week9	26376
	73	31	18/03/2012	17/04/2012		A2inflow9	26407
	74	85	18/04/2012	11/07/2012			26492
	75	85	12/07/2012	4/10/2012			26577
	76	86	5/10/2012	29/12/2012	End LW8		26663
	77	41	30/12/2012	8/02/2013			26704
	78	11	9/02/2013	19/02/2013	Start LW9		26715
	79	12	20/02/2013	3/03/2013		A2rain10	26727
	80	8	4/03/2013	11/03/2013		A2week10	26735
	81	22	12/03/2013	2/04/2013		A2inflow10	26757
	82	80	3/04/2013	21/06/2013			26837
	83	9	22/06/2013	30/06/2013		A2rain11	26846
	84	8	1/07/2013	8/07/2013		A2week11	26854
	85	22	9/07/2013	30/07/2013		A2inflow11	26876
	86	48	31/07/2013	16/09/2013			26924
	87	106	17/09/2013	31/12/2013	End LW9		27030
	88	77	1/01/2014	18/03/2014	Start LW10		27107
	89	13	19/03/2014	31/03/2014		A2rain12	27120
	90	8	1/04/2014	8/04/2014		A2week12	27128
	91	22	9/04/2014	30/04/2014		A2inflow12	27150
	92	107	1/05/2014	15/08/2014			27257
	93	12	16/08/2014	27/08/2014		A2rain13	27269
	94	8	28/08/2014	4/09/2014		A2week13	27277
	95	22	5/09/2014	26/09/2014		A2inflow13	27299
	96	106	27/09/2014	10/01/2015	End LW10		27405
	97	96	11/01/2015	16/04/2015	Start LW11		27501
	98	16	17/04/2015	2/05/2015		A2rain14	27517
	99	8	3/05/2015	10/05/2015		A2week14	27525
	100	45	11/05/2015	24/06/2015		A2inflow14	27570
	101	196	25/06/2015	6/01/2016	End LW11		27766
	102	149	7/01/2016	3/06/2016	Start LW 12		27915
	103	7	4/06/2016	10/06/2016		rain15	27922
	104	20	11/06/2016	30/06/2016			27942
	105	233	1/07/2016	18/02/2017	End LW 12		28175
	106	71	19/02/2017	30/04/2017	Start LW 13		28246
	107	92	1/05/2017	31/07/2017			28338
	108	92	1/08/2017	31/10/2017			28430
	109	120	1/11/2017	28/02/2018	End LW 13		28550
	110	61	1/03/2018	30/04/2018	Start LW 14		28611
	111	92	1/05/2018	31/07/2018			28703
	112	92	1/08/2018	31/10/2018			28795
	113	61	1/11/2018	31/12/2018	End LW 14		28856
	114	90	1/01/2019	31/03/2019	Start LW 15		28946
	115	61	1/04/2019	31/05/2019			29007
	116	61	1/06/2019	31/07/2019			29068
	117	61	1/08/2019	30/09/2019			29129
	118	92	1/10/2019	31/12/2019	End LW 15		29221
	119	59	1/01/2020	28/02/2020		rain16	29280
PREDICTION	**120**	62	29/02/2020	30/04/2020	Start LW 16		29342
	121	61	1/05/2020	30/06/2020			29403
	122	92	1/07/2020	30/09/2020			29495
	123	61	1/10/2020	30/11/2020	End LW 16		29556
	124	62	1/12/2020	31/01/2021	Start LW 17		29618
	125	59	1/02/2021	31/03/2021			29677
	126	61	1/04/2021	31/05/2021			29738
	127	61	1/06/2021	31/07/2021			29799
	128	61	1/08/2021	30/09/2021	End LW 17		29860
	129	61	1/10/2021	30/11/2021	Start LW 18		29921
	130	31	1/12/2021	31/12/2021			29952
	131	59	1/01/2022	28/02/2022			30011
	132	61	1/03/2022	30/04/2022	End LW 18		30072
	133	61	1/05/2022	30/06/2022	Start LW 19		30133
	134	31	1/07/2022	31/07/2022			30164
	135	61	1/08/2022	30/09/2022			30225
	136	92	1/10/2022	31/12/2022	End LW 19		30317
	137	31	1/01/2023	31/01/2023	Start LW 21		30348
	138	59	1/02/2023	31/03/2023			30407
	139	30	1/04/2023	30/04/2023	End LW 21		30437

Stage	SP	Days	DateFrom	DateTo	Scheduled Mining	Rainfall / Inflow signal	Total days
	140	71	1/05/2023	10/07/2023			30508
	141	52	11/07/2023	31/08/2023	Start LW 22		30560
	142	122	1/09/2023	31/12/2023			30682
	143	121	1/01/2024	30/04/2024	End LW 22		30803
	144	123	1/05/2024	31/08/2024			30926
	145	30	1/09/2024	30/09/2024	Start LW 23		30956
	146	151	1/10/2024	28/02/2025			31107
	147	92	1/03/2025	31/05/2025	End LW 23		31199
	148	92	1/06/2025	31/08/2025			31291
	149	61	1/09/2025	31/10/2025	Start LW20		31352
	150	61	1/11/2025	31/12/2025			31413
	151	90	1/01/2026	31/03/2026	End LW20		31503
	152	153	1/04/2026	31/08/2026			31656
Recovery	**153**	122	1/09/2026	31/12/2026			31778
	154	90	1/01/2027	31/03/2027			31868
	155	91	1/04/2027	30/06/2027	End LW 501W		31959
	156	153	1/07/2027	30/11/2027	Start LW 502W		32112
	157	122	1/12/2027	31/03/2028			32234
	158	91	1/04/2028	30/06/2028	End LW 502W		32325
	159	153	1/07/2028	30/11/2028	Start LW 503W		32478
	160	121	1/12/2028	31/03/2029			32599
	161	91	1/04/2029	30/06/2029	End LW 503W		32690
	162	153	1/07/2029	30/11/2029	Start LW 504W		32843
	163	121	1/12/2029	31/03/2030			32964
	164	122	1/04/2030	31/07/2030	End LW 504W		33086
	165	61	1/08/2030	30/09/2030	Start LW 505WA		33147
	166	61	1/10/2030	30/11/2030			33208
	167	31	1/12/2030	31/12/2030	End LW 505WA		33239
	168	365	1/01/2031	31/12/2031	Start LW 505WB		33604
	169	366	1/01/2032	31/12/2032	End LW 505WB		33970
	170	365	1/01/2033	31/12/2033	Start LW 505WC		34335
	171	365	1/01/2034	31/12/2034			34700
	172	365	1/01/2035	31/12/2035	End LW 505WC		35065
	173	366	1/01/2036	31/12/2036	Start LW 506WA		35431
	174	365	1/01/2037	31/12/2037			35796
	175	365	1/01/2038	31/12/2038	End LW 506WA		36161
	176	365	1/01/2039	31/12/2039	Start LW506WB		36526
	177	366	1/01/2040	31/12/2040			36892
	178	365	1/01/2041	31/12/2041	End LW506WB		37257
	179	365	1/01/2042	31/12/2042	Start LW 506WC		37622
	180	365	1/01/2043	31/12/2043			37987
	181	366	1/01/2044	31/12/2044	End LW 506WC		38353
	182	365	1/01/2045	31/12/2045	Start LW507W		38718
	183	365	1/01/2046	31/12/2046			39083
	184	365	1/01/2047	31/12/2047			39448
	185	366	1/01/2048	31/12/2048	End LW 507W		39814
	186	365	1/01/2049	31/12/2049	Start LW 508WA		40179
	187	365	1/01/2050	31/12/2050			40544
	188	365	1/01/2051	31/12/2051	End LW 508WA		40909
	189	366	1/01/2052	31/12/2052	Start LW 508WB		41275
	190	365	1/01/2053	31/12/2053			41640
	191	365	1/01/2054	31/12/2054	End LW 508WB		42005
	192	365	1/01/2055	31/12/2055	Start LW 502E		42370
	193	366	1/01/2056	31/12/2056			42736
	194	365	1/01/2057	31/12/2057	End LW 502E		43101
	195	365	1/01/2058	31/12/2058	Start LW503E		43466
	196	365	1/01/2059	31/12/2059			43831
	197	366	1/01/2060	31/12/2060	End LW503E		44197
	198	1826	1/01/2061	31/12/2065	Start LW 501S		46023
	199	1826	1/01/2066	31/12/2070			47849
	200	3653	1/01/2071	31/12/2080	End LW501S		51502
	201	3652	1/01/2081	31/12/2090	Start LW 502S		55154
	202	3652	1/01/2091	31/12/2100			58806
	203	36524	1/01/2101	31/12/2200	End LW502S		95330

Appendix D: Groundwater model 'Confidence Classification'

The following pages present the Model Confidence Classification as per the *Australian Groundwater Modelling Guidelines* (Barnett *et al*., 2012).

Model Confidence Classification: Dendrobium Area 3B: Longwall 18 SMP - Groundwater model.

(July, 2020)

Table 2-1: Model confidence level classification—characteristics and indicators

Confidence level classification	*Data*	*Calibration*	*Prediction*	*Key indicator*	*Examples of specific uses*
Class 3	• Spatial and temporal distribution of groundwater head observations adequately define groundwater behaviour, especially in areas of greatest interest and where outcomes are to be reported. • Spatial distribution of bore logs and associated stratigraphic interpretations clearly define aquifer geometry. • Reliable metered groundwater extraction and injection data is available. • Rainfall and evaporation data is available. • Aquifer-testing data to define key parameters. • Streamflow and stage measurements are available with reliable baseflow estimates at a number of points. • Reliable land-use and soil-mapping data available. • Reliable irrigation application data (where relevant) is available. • Good quality and adequate spatial coverage of digital elevation model to define ground surface elevation.	• Adequate validation* is demonstrated. • Scaled RMS error (refer Chapter 5) or other calibration statistics are acceptable. • Long-term trends are adequately replicated where these are important. • Seasonal fluctuations are adequately replicated where these are important. • Transient calibration is current, i.e. uses recent data. • Model is calibrated to heads and fluxes. • Observations of the key modelling outcomes dataset is used in calibration. ✓ Inflow ✓ GWLs ✓ Watercourse impacts ☒ Reservoir leakage	• Length of predictive model is not excessive compared to length of calibration period. • Temporal discretisation used in the predictive model is consistent with the transient calibration. • Level and type of stresses included in the predictive model are within the range of those used in the transient calibration. • Model validation* suggests calibration is appropriate for locations and/or times outside the calibration model. • Steady-state predictions used when the model is calibrated in steady-state only.	• Key calibration statistics are acceptable and meet agreed targets. • Model predictive time frame is less than 3 times the duration of transient calibration. • Stresses are not more than 2 times greater than those included in calibration. • Temporal discretisation in predictive model is the same as that used in calibration. • Mass balance closure error is less than 0.5% of total. • Model parameters consistent with conceptualisation. • Appropriate computational methods used with appropriate spatial discretisation to model the problem. • The model has been reviewed and deemed fit for purpose by an experienced, independent hydrogeologist with modelling experience.	• Suitable for predicting groundwater responses to arbitrary changes in applied stress or hydrological conditions anywhere within the model domain. • Provide information for sustainable yield assessments for high-value regional aquifer systems. • Evaluation and management of potentially high-risk impacts. • Can be used to design complex mine-dewatering schemes, salt-interception schemes or water-allocation plans. • Simulating the interaction between groundwater and surface water bodies to a level of reliability required for dynamic linkage to surface water models. • Assessment of complex, large-scale solute transport processes.
Class 2 *Cont'd overleaf*	• Groundwater head observations and bore logs are available but may not provide adequate coverage throughout the model domain.	• Validation* is either not undertaken or is not demonstrated for the full model domain. • Calibration statistics are generally reasonable but may suggest significant errors in parts of the	• Transient calibration over a short time frame compared to that of prediction. • Temporal discretisation used in the predictive model is different from that used in transient	• Key calibration statistics suggest poor calibration in parts of the model domain. • Model predictive time frame is between 3 and 10 times the duration of transient calibration. • Stresses are between 2 and 5 times greater than those	• Prediction of impacts of proposed developments in medium value aquifers. • Evaluation and management of medium risk impacts.

Model Confidence Classification: Dendrobium Area 3B: Longwall 18 SMP - Groundwater model.

(July, 2020)

Confidence level classification	*Data*	*Calibration*	*Prediction*	*Key indicator*	*Examples of specific uses*
Class 2 *Cont'd*	• Metered groundwater-extraction data may be available but spatial and temporal coverage may not be extensive. • Streamflow data and baseflow estimates available at a few points. • Reliable irrigation-application data available in part of the area or for part of the model duration.	model domain(s). • Long-term trends not replicated in all parts of the model domain. • Transient calibration to historic data but not extending to the present day. • Seasonal fluctuations not adequately replicated in all parts of the model domain. • Observations of the key modelling outcome data set are not used in calibration.→ cannot observe reservoir losses	calibration. • Level and type of stresses included in the predictive model are outside the range of those used in the transient calibration. • Validation* suggests relatively poor match to observations when calibration data is extended in time and/or space.	included in calibration. • Temporal discretisation in predictive model is not the same as that used in calibration. • Mass balance closure error is less than 1% of total. • Not all model parameters consistent with conceptualisation. • Spatial refinement too coarse in key parts of the model domain. • The model has been reviewed and deemed fit for purpose by an independent hydrogeologist.	• Providing estimates of dewatering requirements for mines and excavations and the associated impacts. • Designing groundwater management schemes such as managed aquifer recharge, salinity management schemes and infiltration basins. • Estimating distance of travel of contamination through particle-tracking methods. Defining water source protection zones.
Class 1	• Few or poorly distributed existing wells from which to obtain reliable groundwater and geological information. • Observations and measurements unavailable or sparsely distributed in areas of greatest interest. • No available records of metered groundwater extraction or injection. • Climate data only available from relatively remote locations. • Little or no useful data on land-use, soils or river flows and stage elevations.	• No calibration is possible. • Calibration illustrates unacceptable levels of error especially in key areas. • Calibration is based on an inadequate distribution of data. • Calibration only to datasets other than that required for prediction.	• Predictive model time frame far exceeds that of calibration. • Temporal discretisation is different to that of calibration. • Transient predictions are made when calibration is in steady state only. • Model validation* suggests unacceptable errors when calibration dataset is extended in time and/or space.	• Model is uncalibrated or key calibration statistics do not meet agreed targets. • Model predictive time frame is more than 10 times longer than transient calibration period. • Stresses in predictions are more than 5 times higher than those in calibration. • Stress period or calculation interval is different from that used in calibration. • Transient predictions made but calibration in steady state only. • Cumulative mass-balance closure error exceeds 1% or exceeds 5% at any given calculation time. • Model parameters outside the range expected by the conceptualisation with no further justification. • Unsuitable spatial or temporal discretisation. • The model has not been reviewed.	• Design observation bore array for pumping tests. • Predicting long-term impacts of proposed developments in low-value aquifers. • Estimating impacts of low-risk developments. • Understanding groundwater flow processes under various hypothetical conditions. • Provide first-pass estimates of extraction volumes and rates required for mine dewatering. • Developing coarse relationships between groundwater extraction locations and rates and associated impacts. • As a starting point on which to develop higher class models as more data is collected and used.

(*Refer Chapter 5 for discussion around validation as part of the calibration process.)

Appendix E: Modelled hydraulic conductivity

Calibrated Hydraulic Properties (K and S)

Layer	Zone#	Geology	abbrev.	Kh factor	K_h m/d	K_v m/d	Ss m-1	Sy
1	11	Swamps		n/a	1	0.05		0.3
	1, 3	Alluvium		n/a	10, 3	0.3, 5e-3		0.1
	2	Wianamatta Formation	WMFM	n/a	0.015	2.0E-05		0.1
	10	Regolith		n/a	0.03	0.03		0.1
2	20	Hawkesbury Sst (upper)	HBSS	1.3	*K-depth*	1E-05	5E-03	0.05
3	30	Hawkesbury Sst (mid)	HBSS	0.6	*K-depth*	1E-04	1E-06	0.025
4	40	Hawkesbury Sst (lower)	HBSS	1	*K-depth*	3E-05	1E-06	0.012
5	50	Bald Hill Claystone	BACS	0.03	*K-depth*	3E-06	1E-06	0.006
	51	Crinanite (weathered)		0.8	*K-depth*	3E-03	5E-04	0.01
6-11	multiple	Crinanite		0.05	*K-depth*	5E-05	5E-04	0.01
6	60	Bulgo Sst (upper)	BGSS	0.2	*K-depth*	1E-04	9E-07	0.008
	61	Bulgo Sst (upper)	BGSS	0.25	*K-depth*	5E-05	9E-07	0.008
	62	Bulgo Sst (upper) / CVSS	BGSS	0.14	*K-depth*	1E-06	9E-07	0.008
	64	Bulgo Sst (upper) (A2 outcrop)	BGSS	0.3	*K-depth*	2E-06	9E-07	0.008
7	70	Bulgo Sst (lower)	BGSS	0.3	*K-depth*	2E-05	8E-07	0.007
	71	Bulgo Sst (lower)	BGSS	0.2	*K-depth*	5E-05	8E-07	0.007
	72	Bulgo Sst (lower) / CVSS	BGSS	0.2	*K-depth*	2E-06	8E-07	0.007
	74	BGSS (lwr) near A2/crinanite	BGSS	0.6	*K-depth*	6E-06	8E-07	0.007
8	80	Stanwell Park Claystone	SPCS	0.25	*K-depth*	3E-05	7E-07	0.005
	81	Stanwell Park Claystone	SPCS	0.25	*K-depth*	2E-06	7E-07	0.005
	83	SPCS, near A2	SPCS	2	*K-depth*	4E-06	7E-07	0.005
9	90-92	Scarborough Sst	SBSS	2	*K-depth*	1E-06	6E-06	0.01
10	100	Wombarra Claystone	WBCS	0.25	*K-depth*	5E-06	5E-07	0.0035
11	110	Coalcliff Sandstone	CCSS	1	*K-depth*	7E-06	4E-07	0.004
	111	Coalcliff Sandstone	CCSS	0.5	*K-depth*	5E-06	4E-07	0.004
12	120	Bulli Seam	BUSM	20	*K-depth*	1E-06	2E-07	0.004
	121	Bulli Seam – cindered	BUSM	0.4	*K-depth*	6E-06	1E-06	0.016
	123	Bulli Seam – faulted (mylonite)	BUSM	0.1	*K-depth*	3E-05	1E-06	0.016
13	130	Lawrence and Loddon Ssts	LDSS	1	*K-depth*	1E-06	2E-07	0.004
	131	Nepheline syenite		0.4	*K-depth*	2E-06	3E-07	0.005
	132	Fault/mylonite		0.3	*K-depth*	9E-06	3E-07	0.005
14	140	Wongawilli Seam	WWSM	40	*K-depth*	1E-06	2E-07	0.004
	141	Nepheline syenite		0.4	*K-depth*	3E-06	4E-06	0.02
	142	Wongawilli Seam – cindered	WWSM	0.5	*K-depth*	2E-06	3E-06	0.012
	143	Fault/mylonite		0.5	*K-depth*	9E-06	1E-06	0.015
15	150	Kembla Sandstone	KBSS	1	*K-depth*	3E-05	3E-07	0.0045
	151	Kembla Sandstone – outcrop	KBSS	1	*K-depth*	1E-05	1E-04	0.02
	152	Kembla Sandstone – outcrop	KBSS	1	*K-depth*	8E-04	1E-04	0.02
16	160	lower Permian Coal Meas.	IPCM	1	*K-depth*	1E-05	3E-07	0.004
	161	lower Permian Coal Meas.	IPCM	1	*K-depth*	8E-04	3E-06	0.03
17	170	Shoalhaven Group		1	*K-depth*	2E-06	3E-07	0.005

"K-depth" = means that Kh is primarily determined by depth of mid-point of model cell (see Equation 1 and 2).

Kh factor used to provide additional control based on lithology, facies variation. The K from the K-w-depth relationship is multiplied by this factor. DND5_mesh_Kwdepth_5v44.xlsx

The K-depth relationship is based on the formulation from AGC (1984):

$$\mathrm{K} = \mathrm{K}_o . \exp(-cz)$$ **Equation 1**

- where,

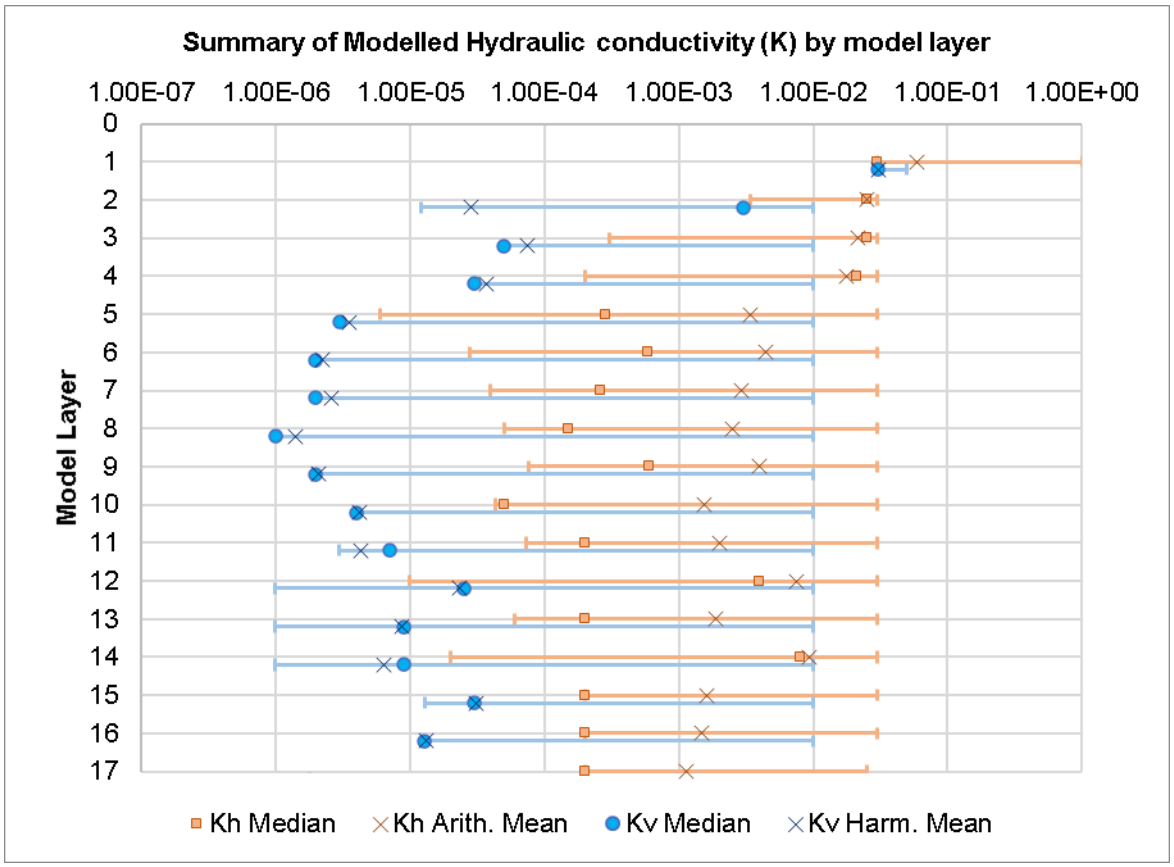
  c = gradient; z = depth [m].

The broad Kh-depth relationship at Dendrobium was calculated to be:

$$\mathrm{K} = 0.022 \exp(-80 - z)$$ **Equation 2**

- where,

  the hydraulic conductivity K calculated by this relationship is limited to the range 2E-4 to 2.5E-2 m/d

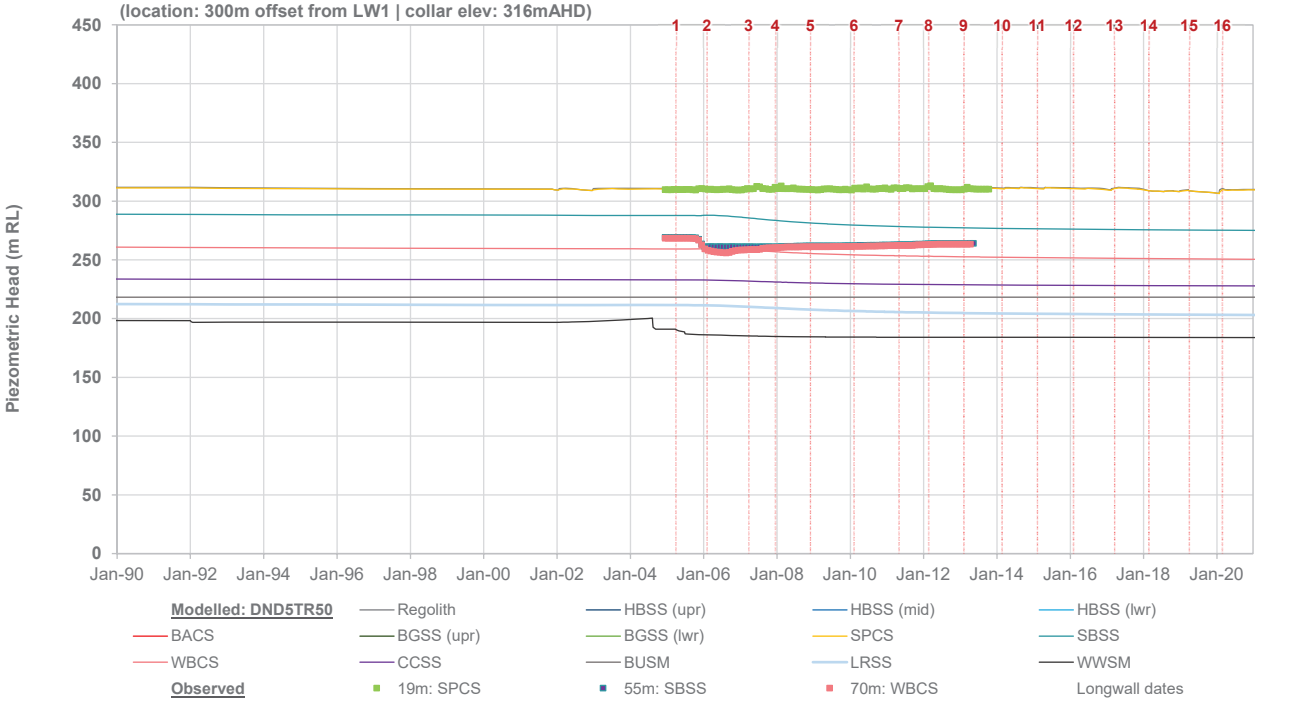


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Appendix F: Modelled groundwater level calibration hydrographs

GWL Hydrograph: S1557 Area 1

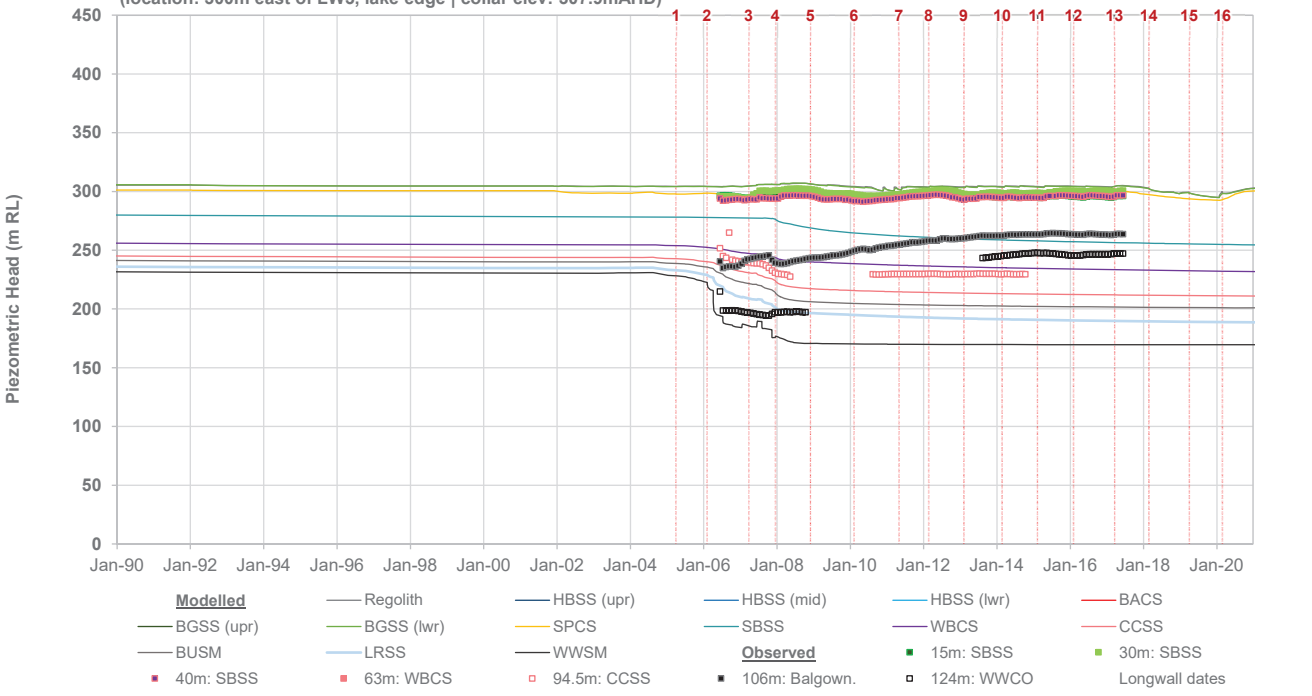
(location: 300m offset from LW1 | collar elev: 316mAHD)



D:\DEND\GWmodel\Processing\Heads\MOD2SMP\Calibration_Hydrographs_Priority_DND5v50.xlsx

GWL Hydrograph: S1830 Area 2

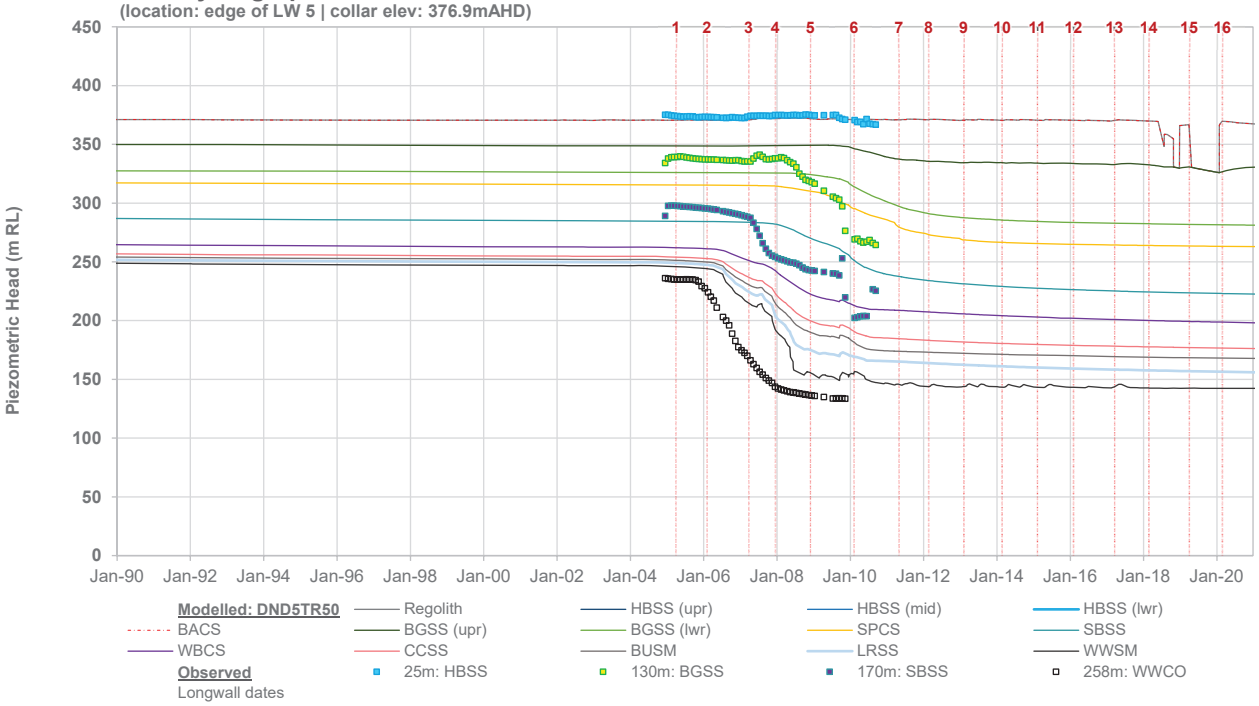
(location: 300m east of LW3, lake edge | collar elev: 307.9mAHD)



D:\DEND\GWmodel\Processing\Heads\MOD2SMP\Calibration_Hydrographs_Priority_DND5v50.xlsx

GWL Hydrograph: S1577 Area 2

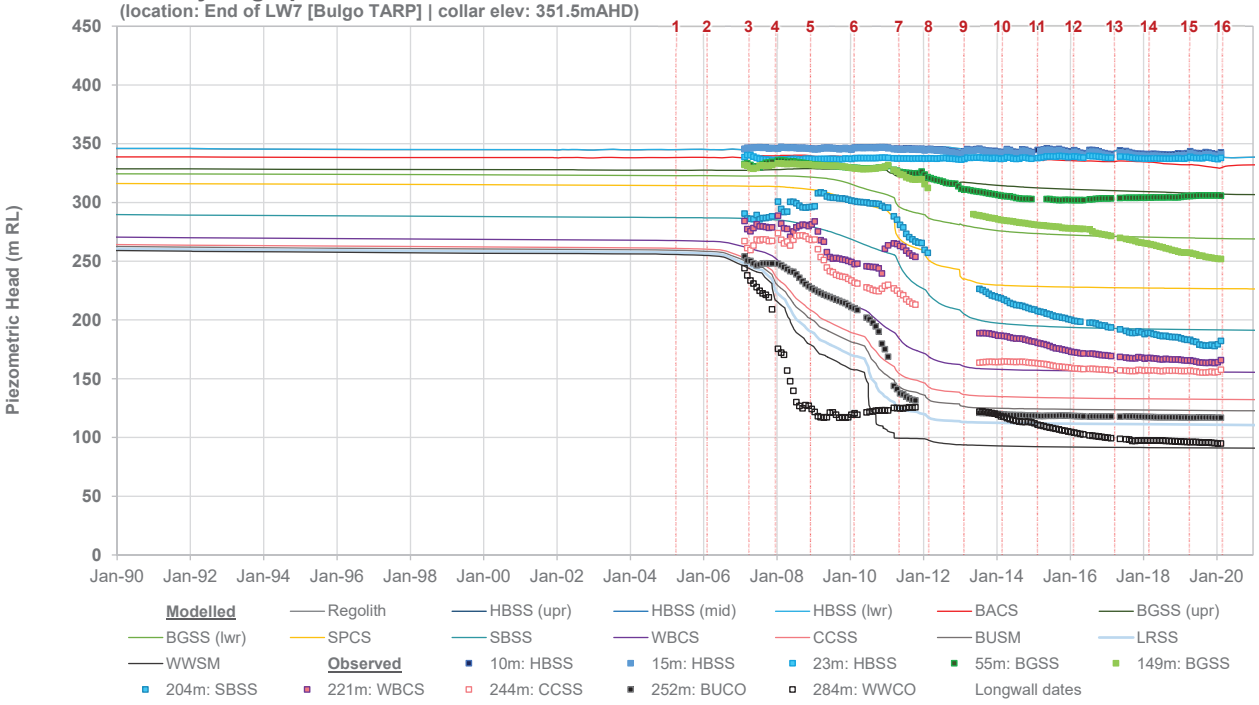
(location: edge of LW 5 | collar elev: 376.9mAHD)



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GWL Hydrograph: S1870 Area 3A

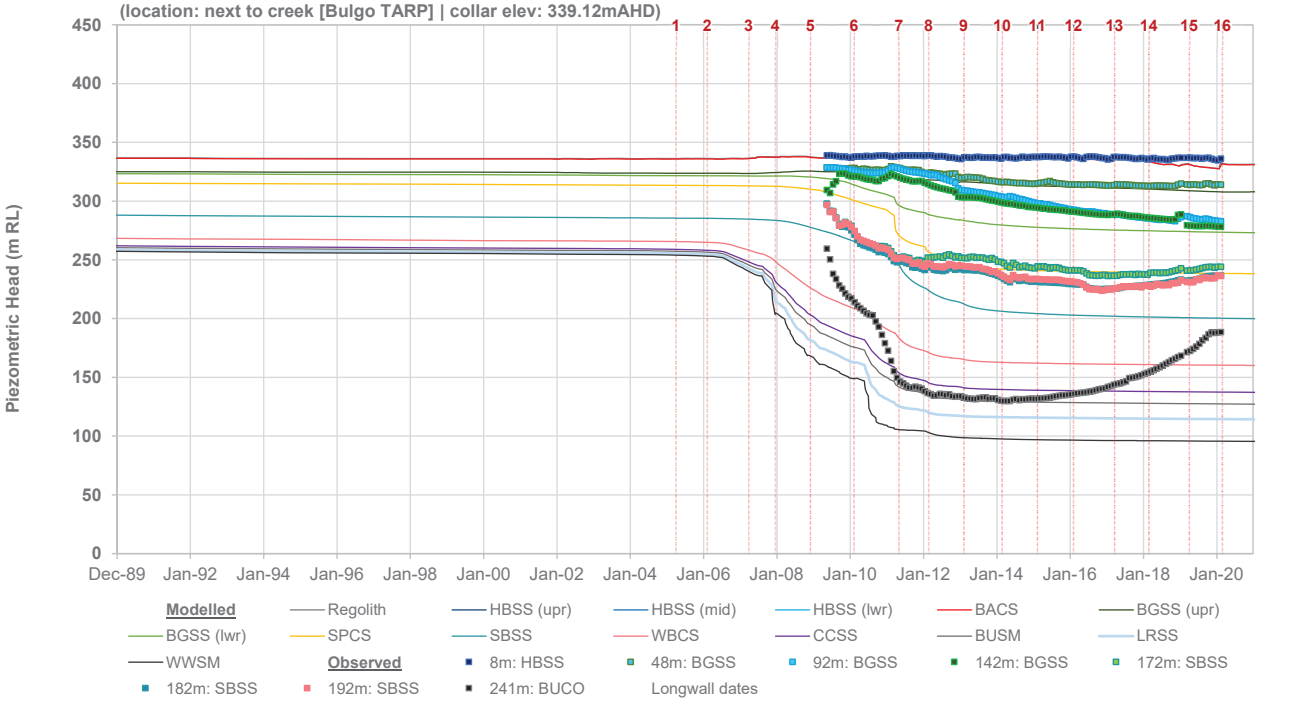
(location: End of LW7 [Bulgo TARP] | collar elev: 351.5mAHD)



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GWL Hydrograph: S1992 Area 3A

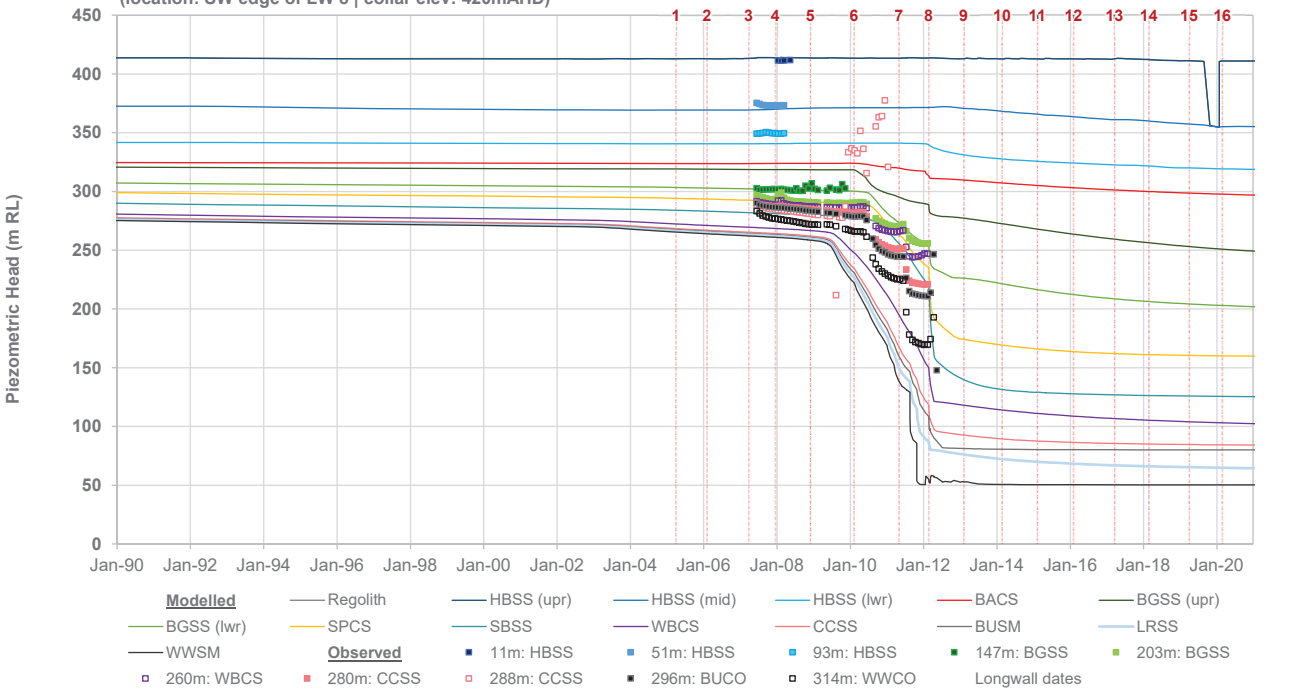
(location: next to creek [Bulgo TARP] | collar elev: 339.12mAHD)



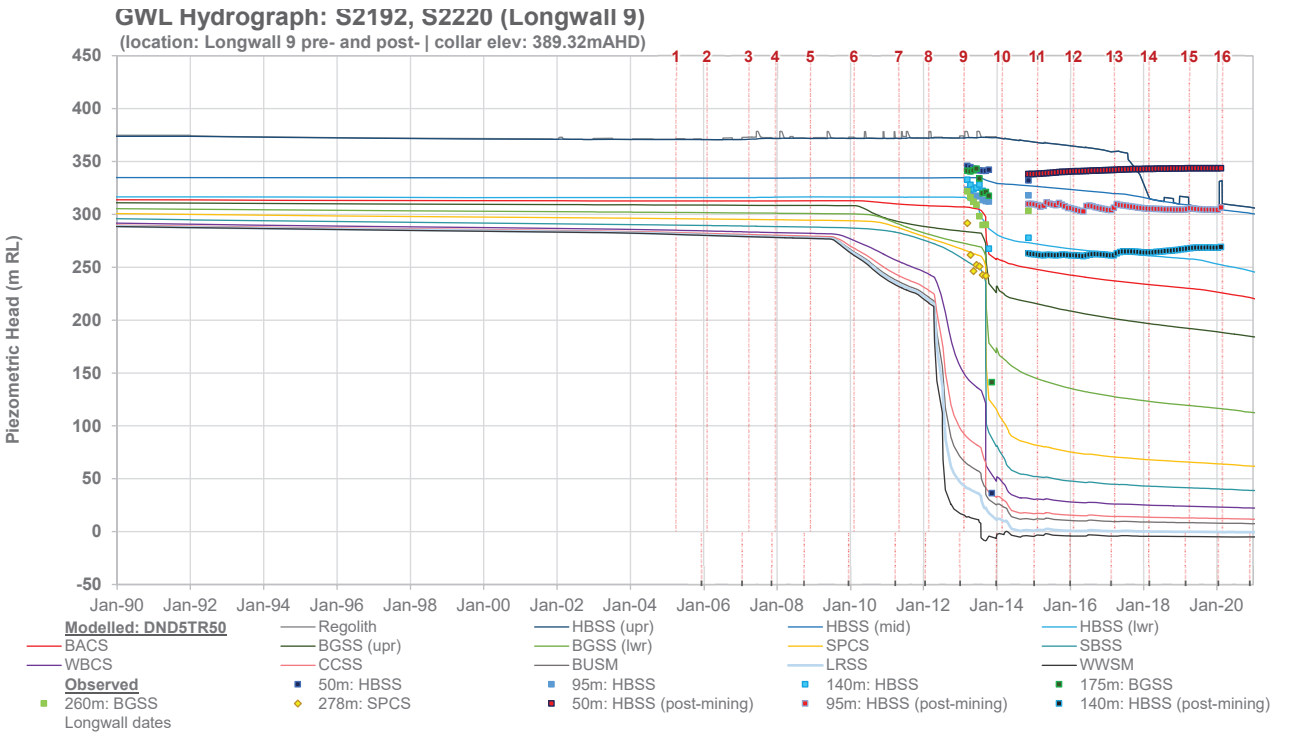
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GWL Hydrograph: S1885 Area 3A

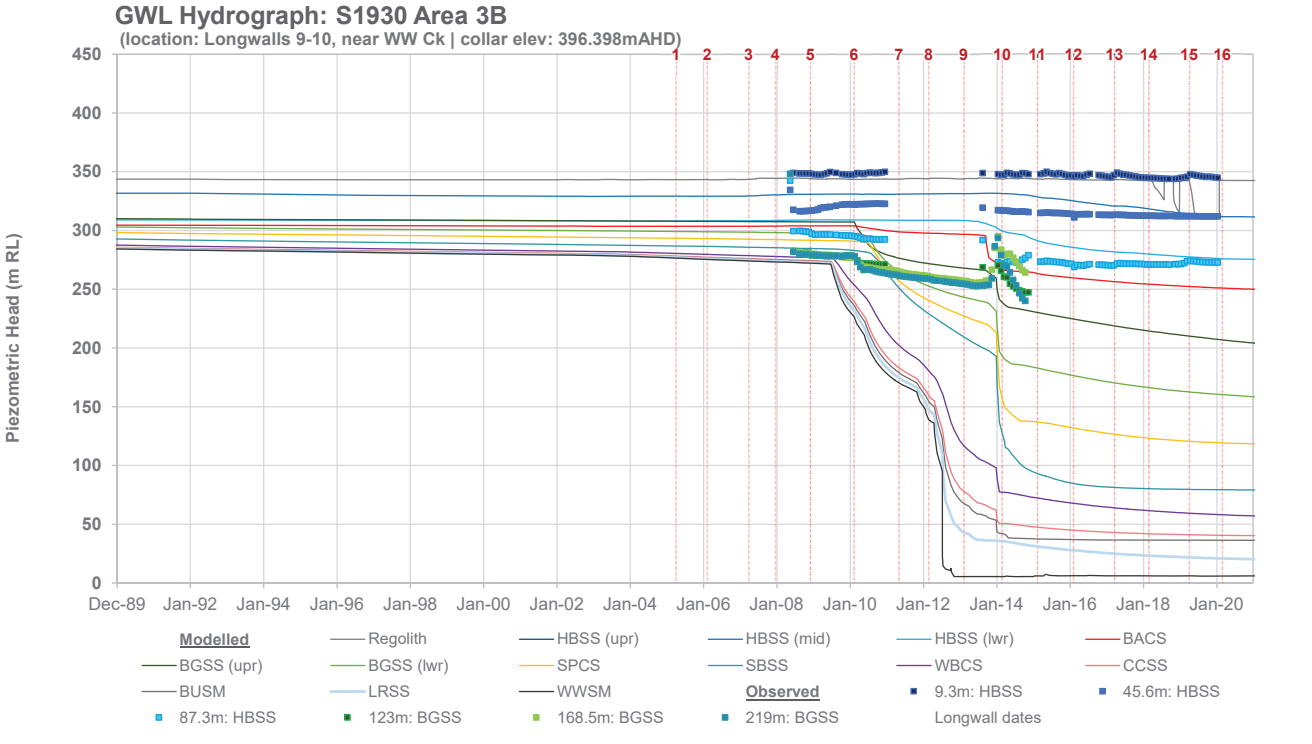
(location: SW edge of LW 8 | collar elev: 420mAHD)



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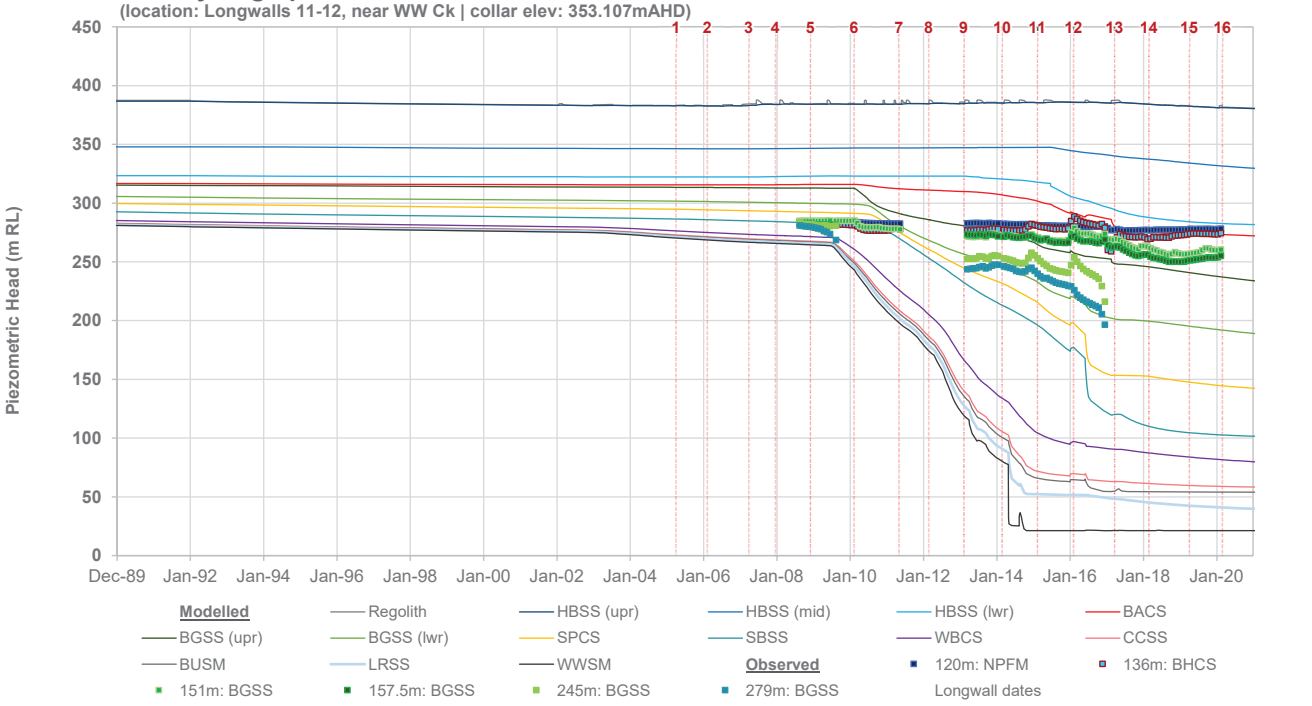
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GWL Hydrograph: S1931 Area 3B

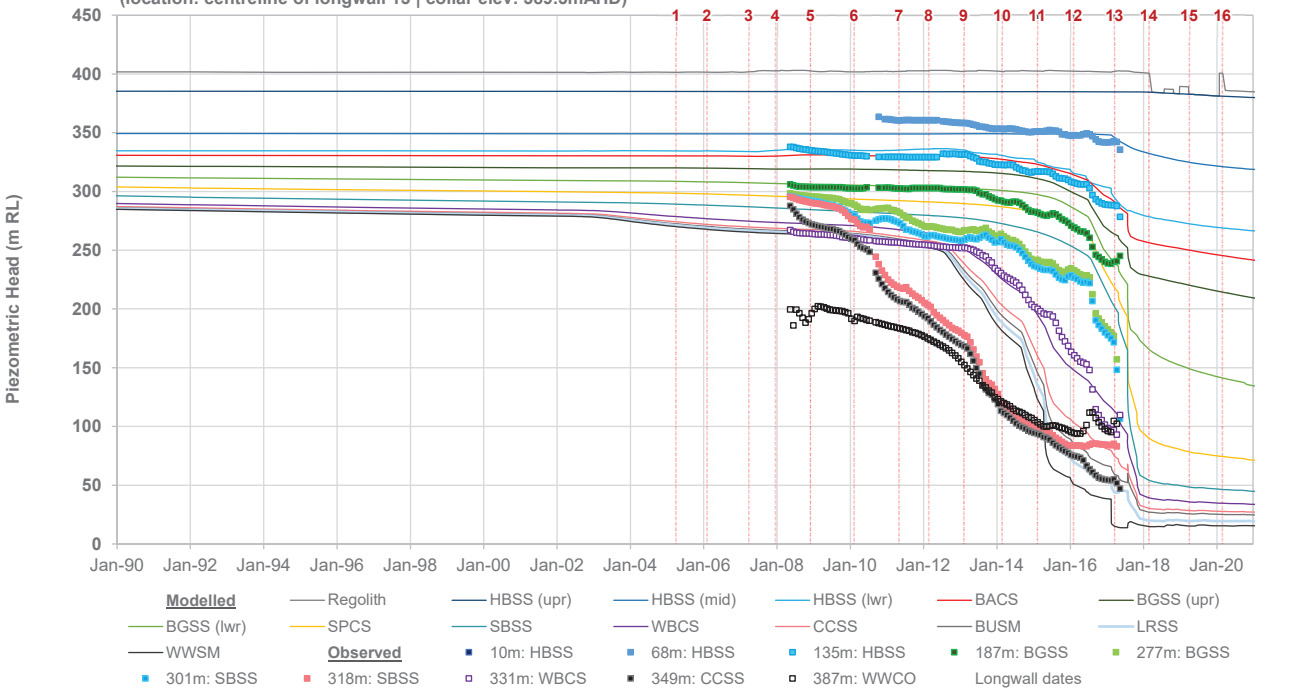
(location: Longwalls 11-12, near WW Ck | collar elev: 353.107mAHD)



D:\DEND\GWmodel\Processing\Heads\MOD2SMP\Calibration_Hydrographs_Priority_DND5v50.xlsx

GWL Hydrograph: S1911 Area 3B

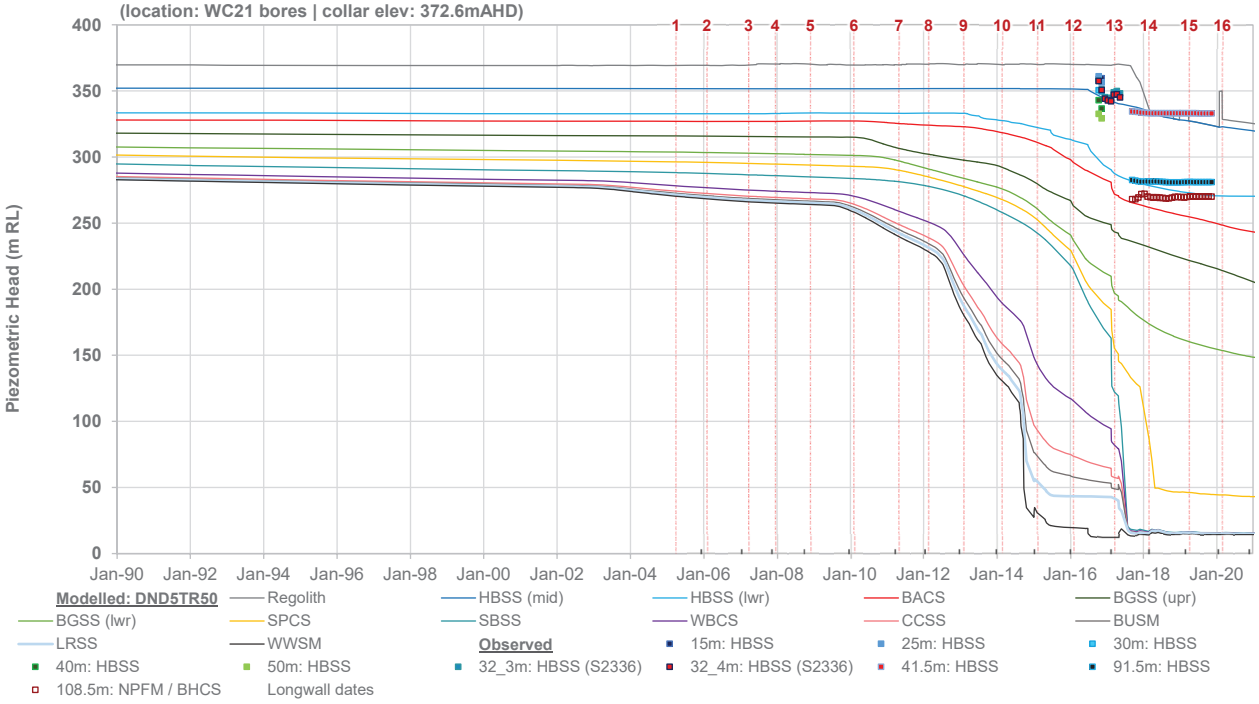
(location: centreline of longwall 13 | collar elev: 389.3mAHD)



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GWL Hydrograph: S2335-6 Area 3B

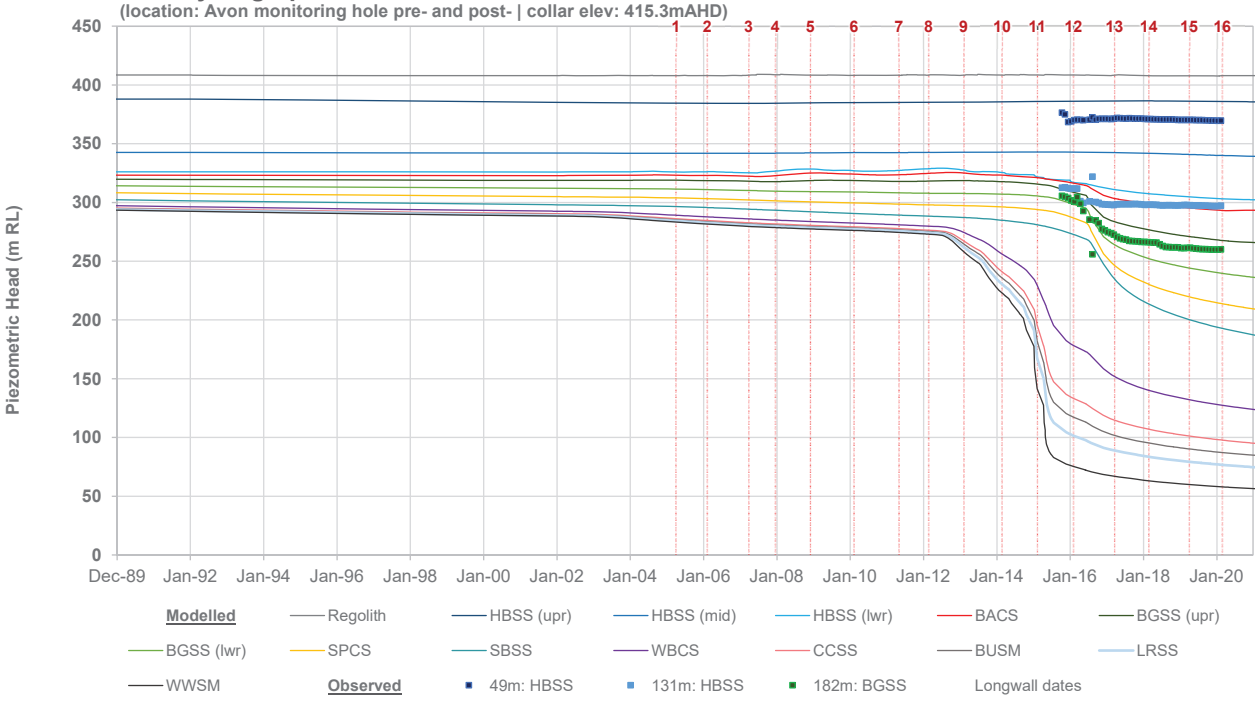
(location: WC21 bores | collar elev: 372.6mAHD)



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GWL Hydrograph: S2313 Area 3B

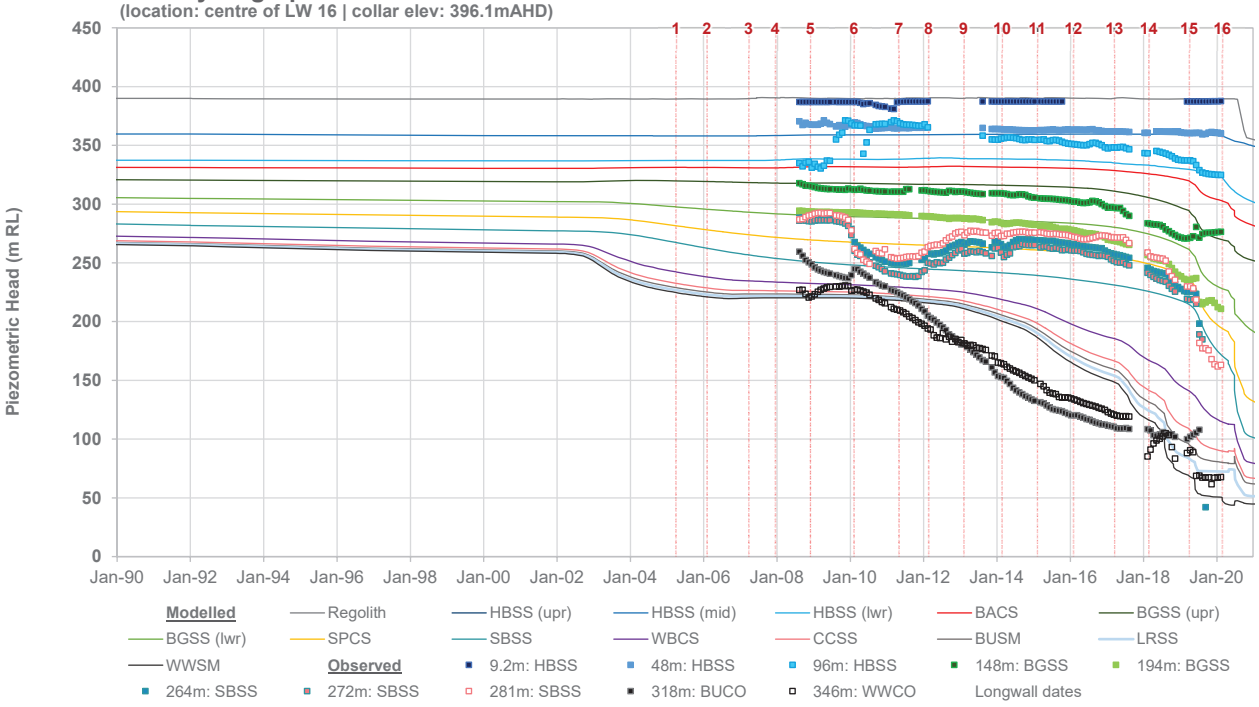
(location: Avon monitoring hole pre- and post- | collar elev: 415.3mAHD)



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GWL Hydrograph: S1932 Area 3B

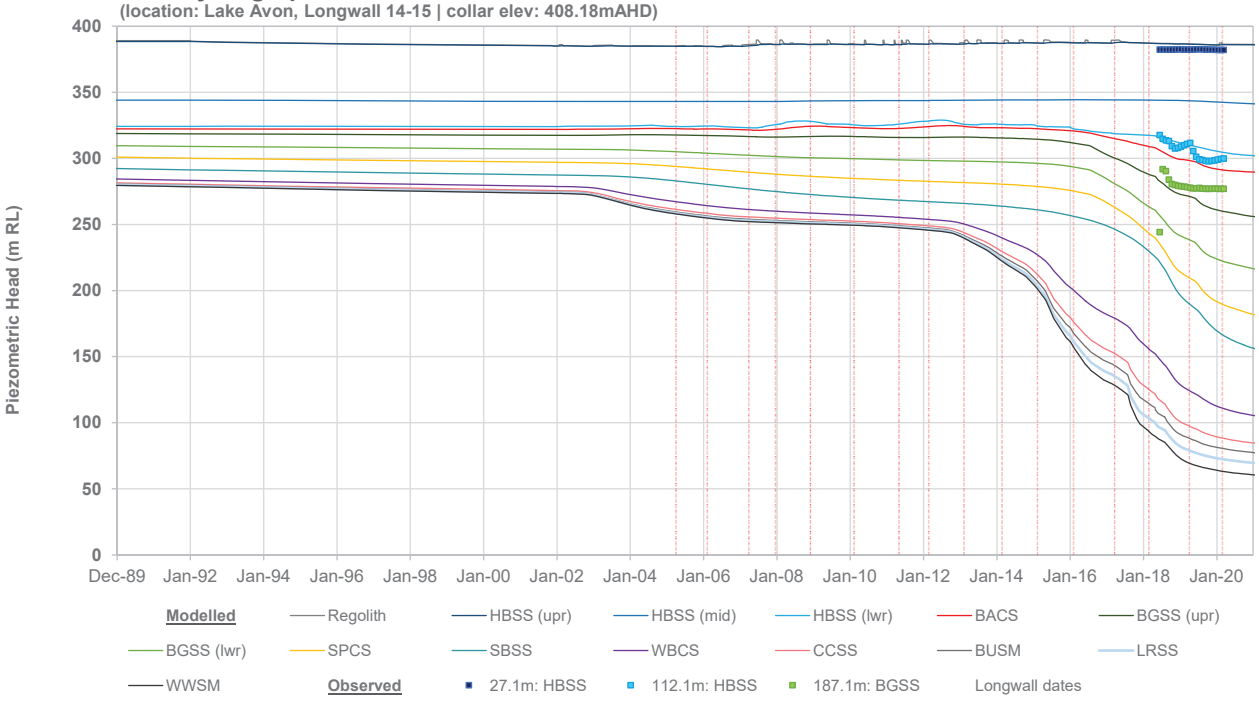
(location: centre of LW 16 | collar elev: 396.1mAHD)



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GWL Hydrograph: S2377 Area 3B

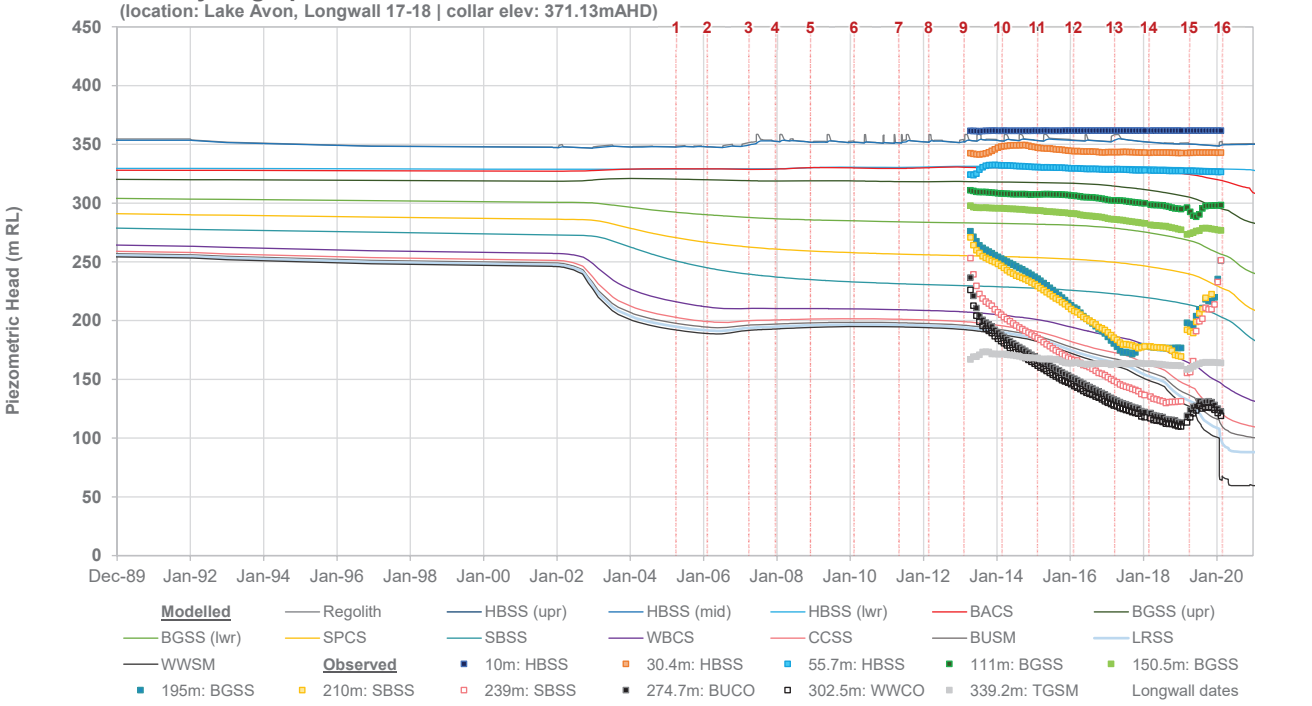
(location: Lake Avon, Longwall 14-15 | collar elev: 408.18mAHD)



D:\DEND\GWmodel\Processing\Heads\MOD2SMP\Calibration_Hydrographs_Priority_DND5v50.xlsx

GWL Hydrograph: S2194 Area 3B

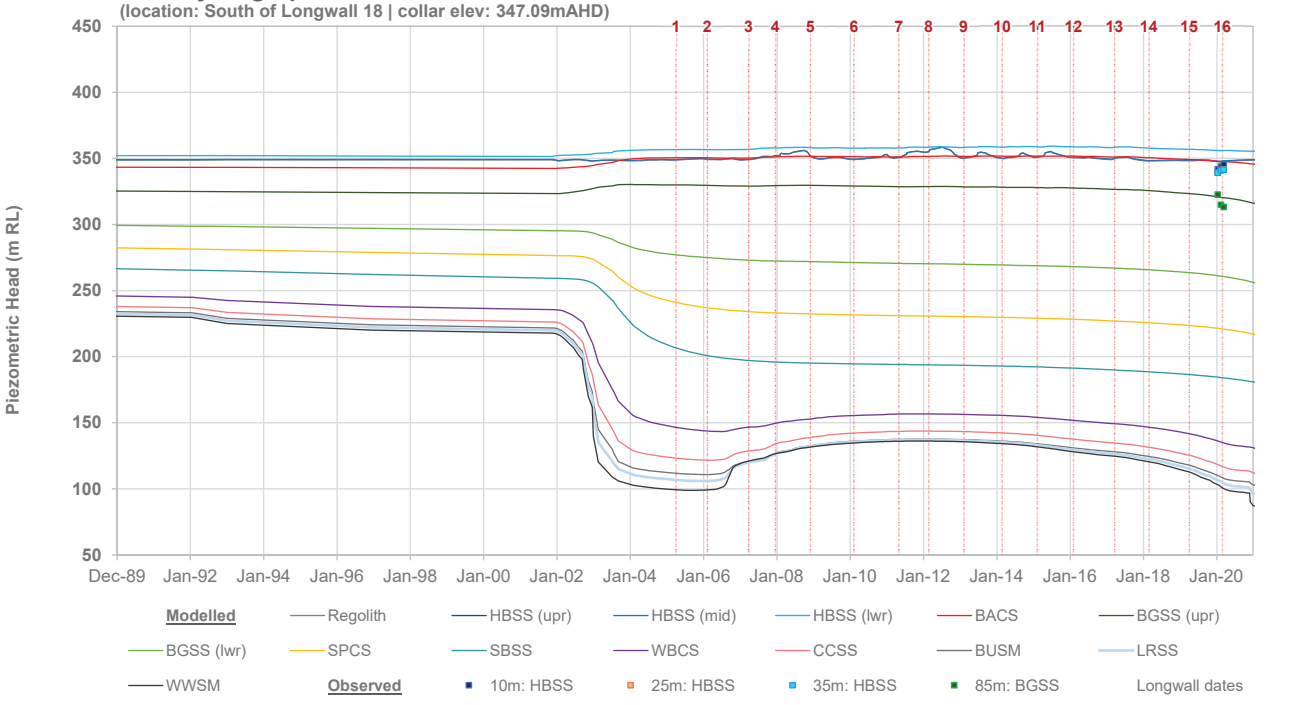
(location: Lake Avon, Longwall 17-18 | collar elev: 371.13mAHD)



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GWL Hydrograph: S2490 Area 3B

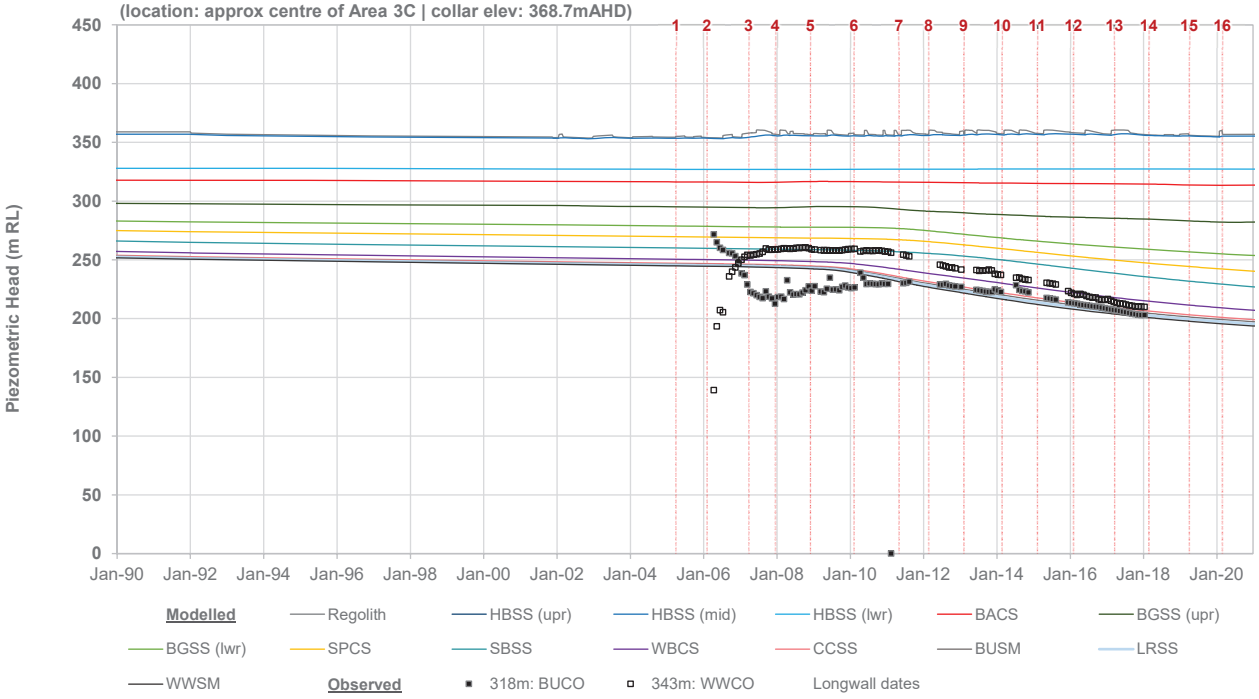
(location: South of Longwall 18 | collar elev: 347.09mAHD)



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GWL Hydrograph: S1779 Area 3C

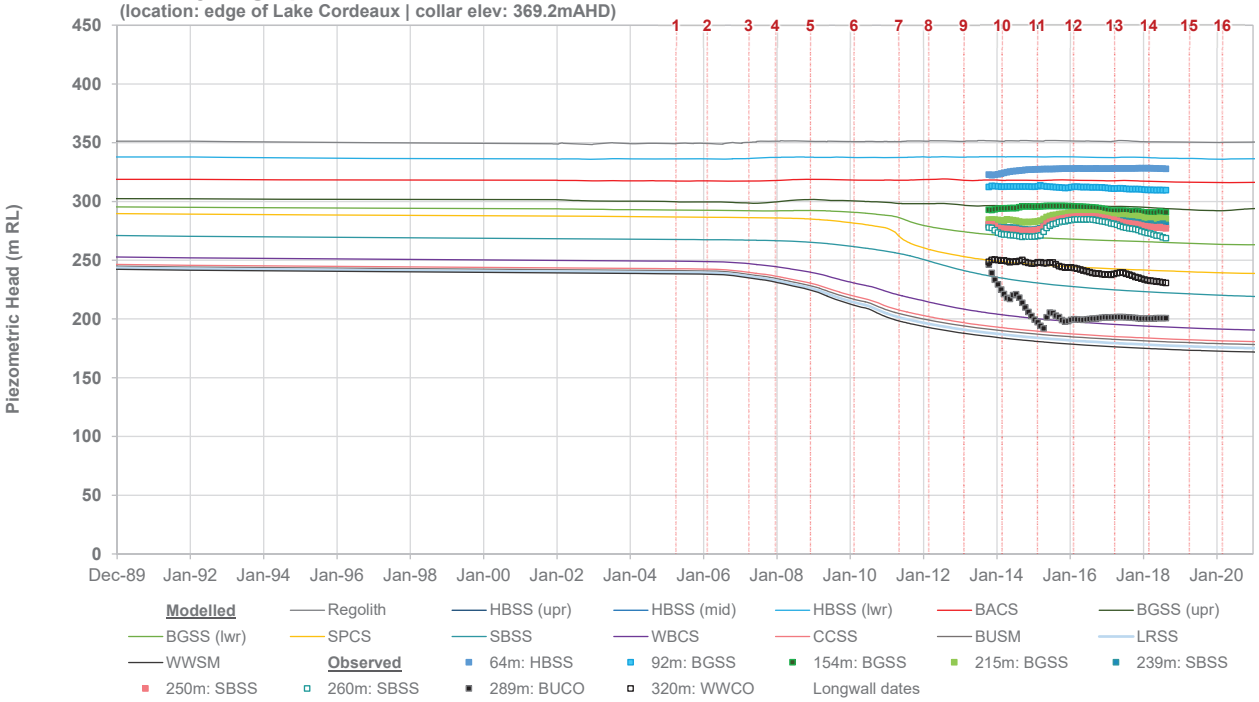
(location: approx centre of Area 3C | collar elev: 368.7mAHD)



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GWL Hydrograph: S2212 Area 3C

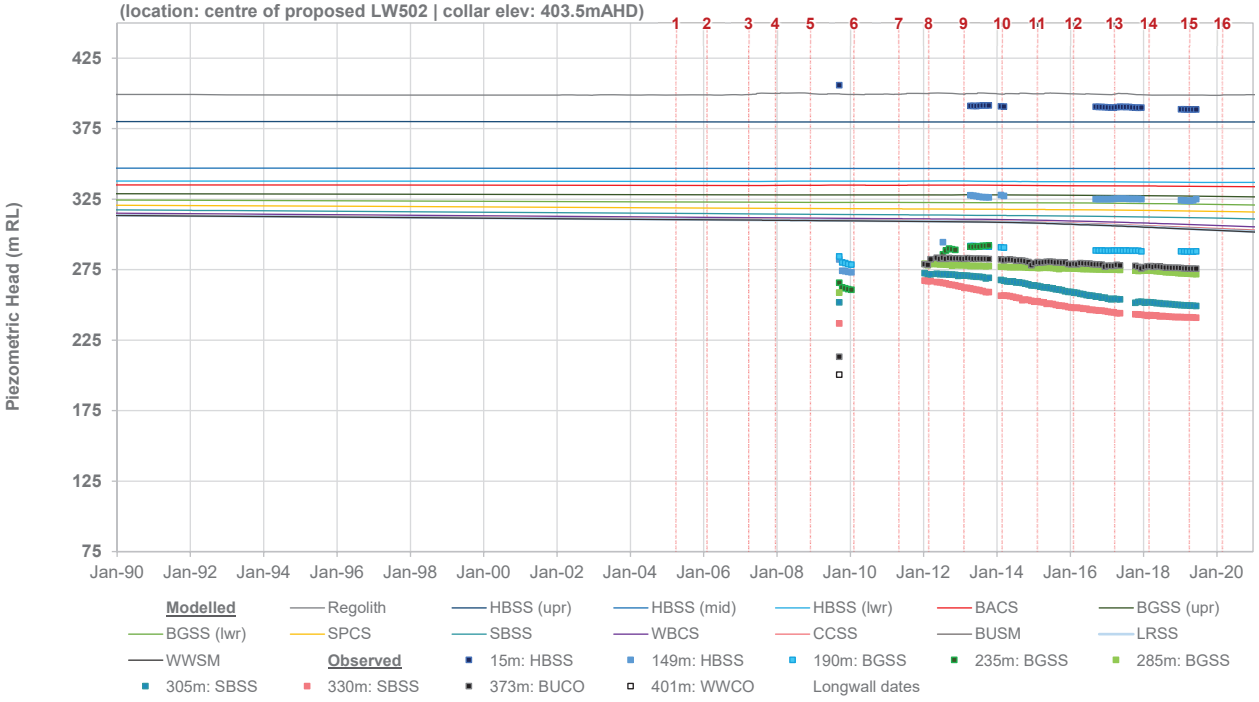
(location: edge of Lake Cordeaux | collar elev: 369.2mAHD)



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GWL Hydrograph: S2064 Area 5

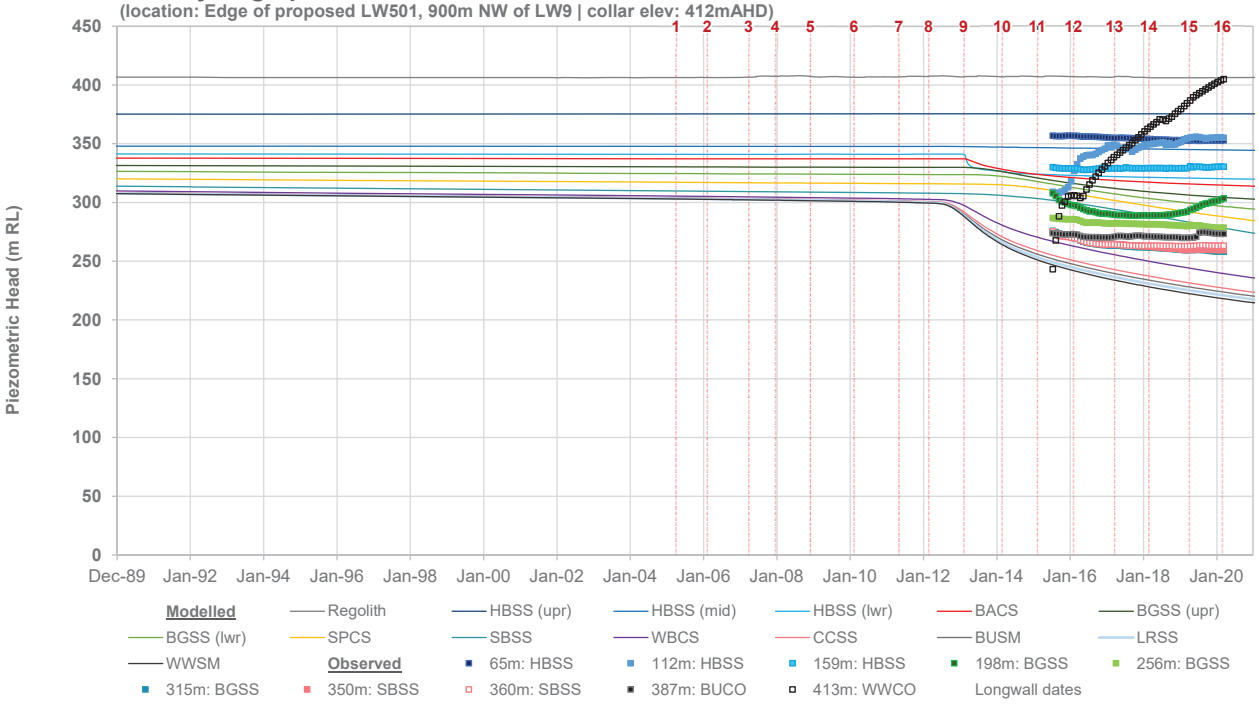
(location: centre of proposed LW502 | collar elev: 403.5mAHD)



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GWL Hydrograph: S2309 Area 5

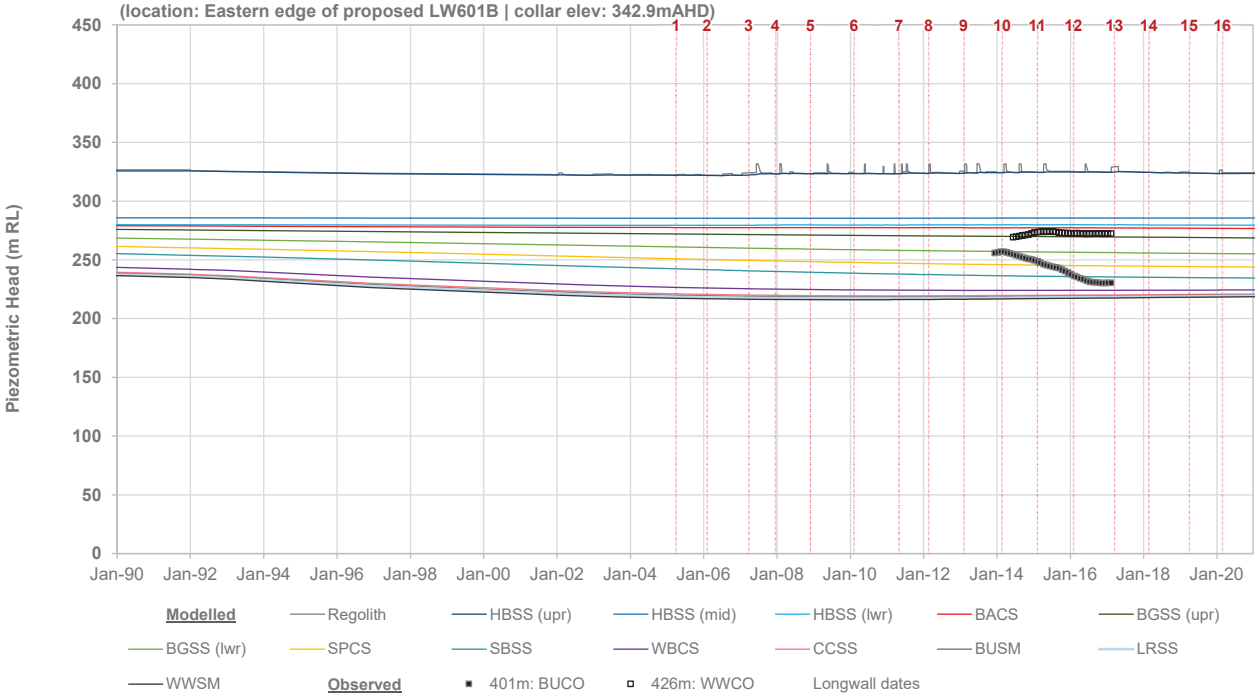
(location: Edge of proposed LW501, 900m NW of LW9 | collar elev: 412mAHD)



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GWL Hydrograph: S2206 Area 6

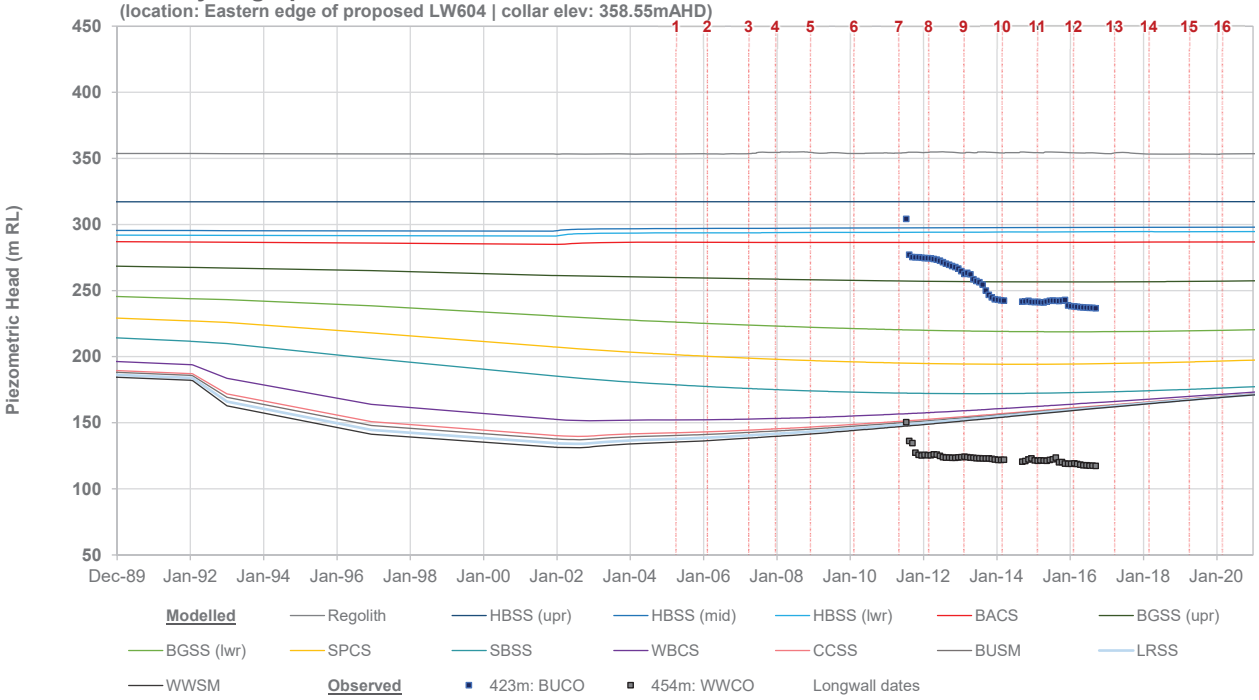
(location: Eastern edge of proposed LW601B | collar elev: 342.9mAHD)



D:\DEND\GWmodel\Processing\Heads\MOD2SMP\Calibration_Hydrographs_Priority_DND5v50.xlsx

GWL Hydrograph: S2116 Area 6

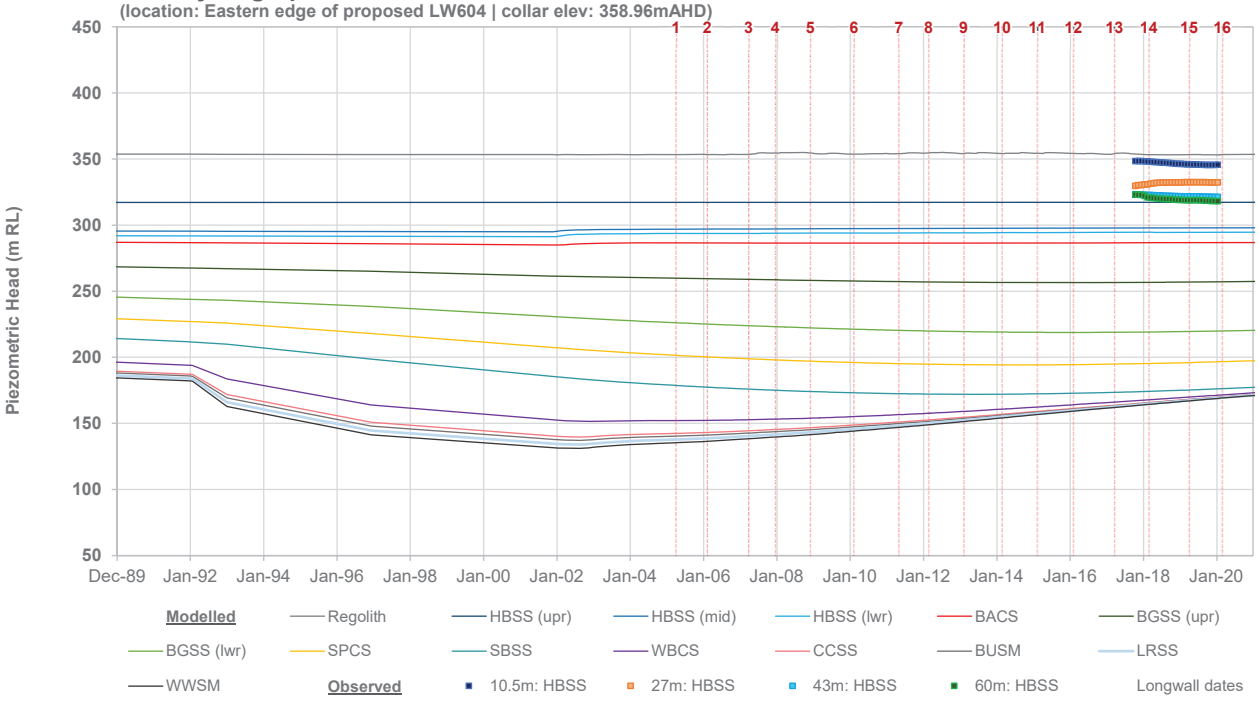
(location: Eastern edge of proposed LW604 | collar elev: 358.55mAHD)



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GWL Hydrograph: S2373 Area 6

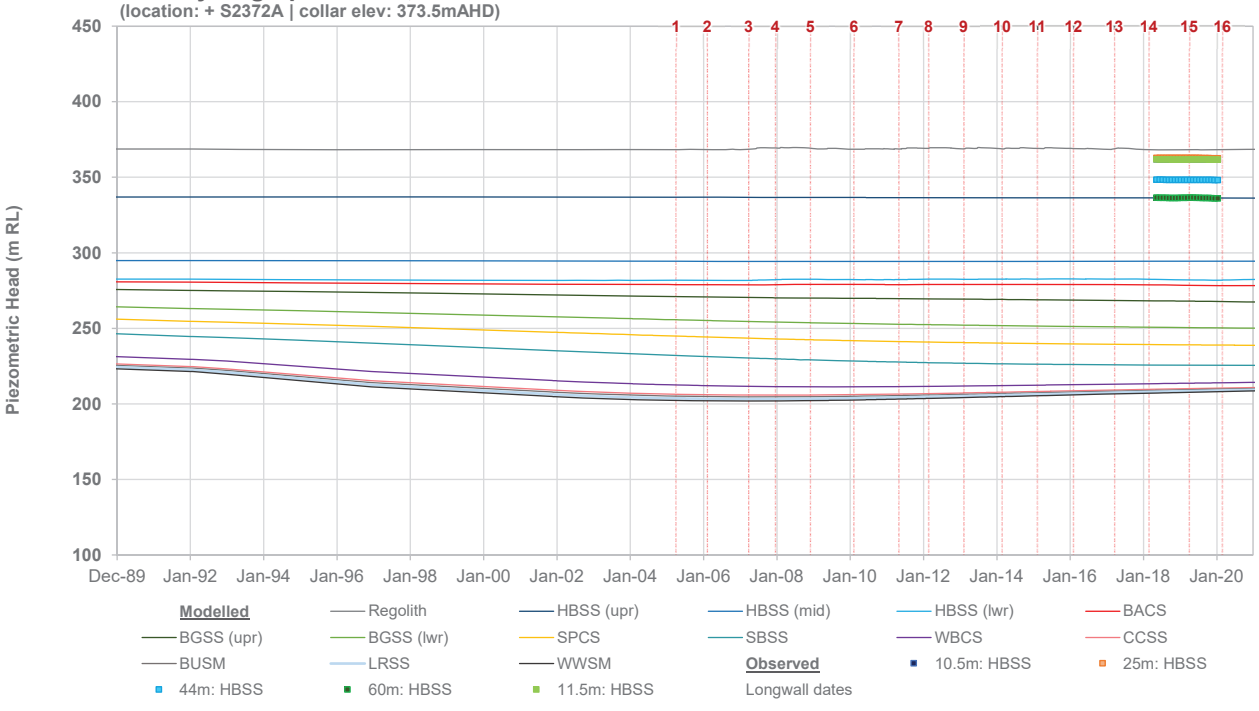
(location: Eastern edge of proposed LW604 | collar elev: 358.96mAHD)



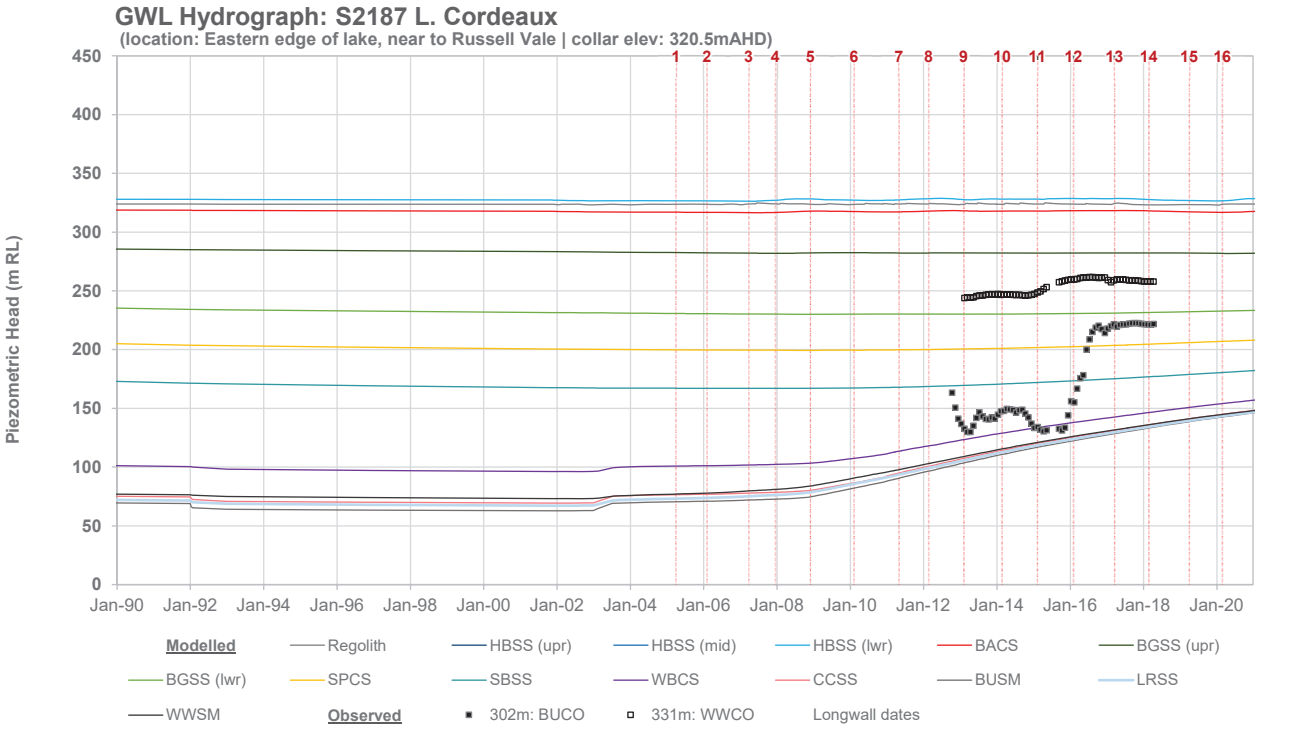
D:\DEND\GWmodel\Processing\Heads\MOD2SMP\Calibration_Hydrographs_Priority_DND5v50.xlsx

GWL Hydrograph: S2372, Area 6

(location: + S2372A | collar elev: 373.5mAHD)

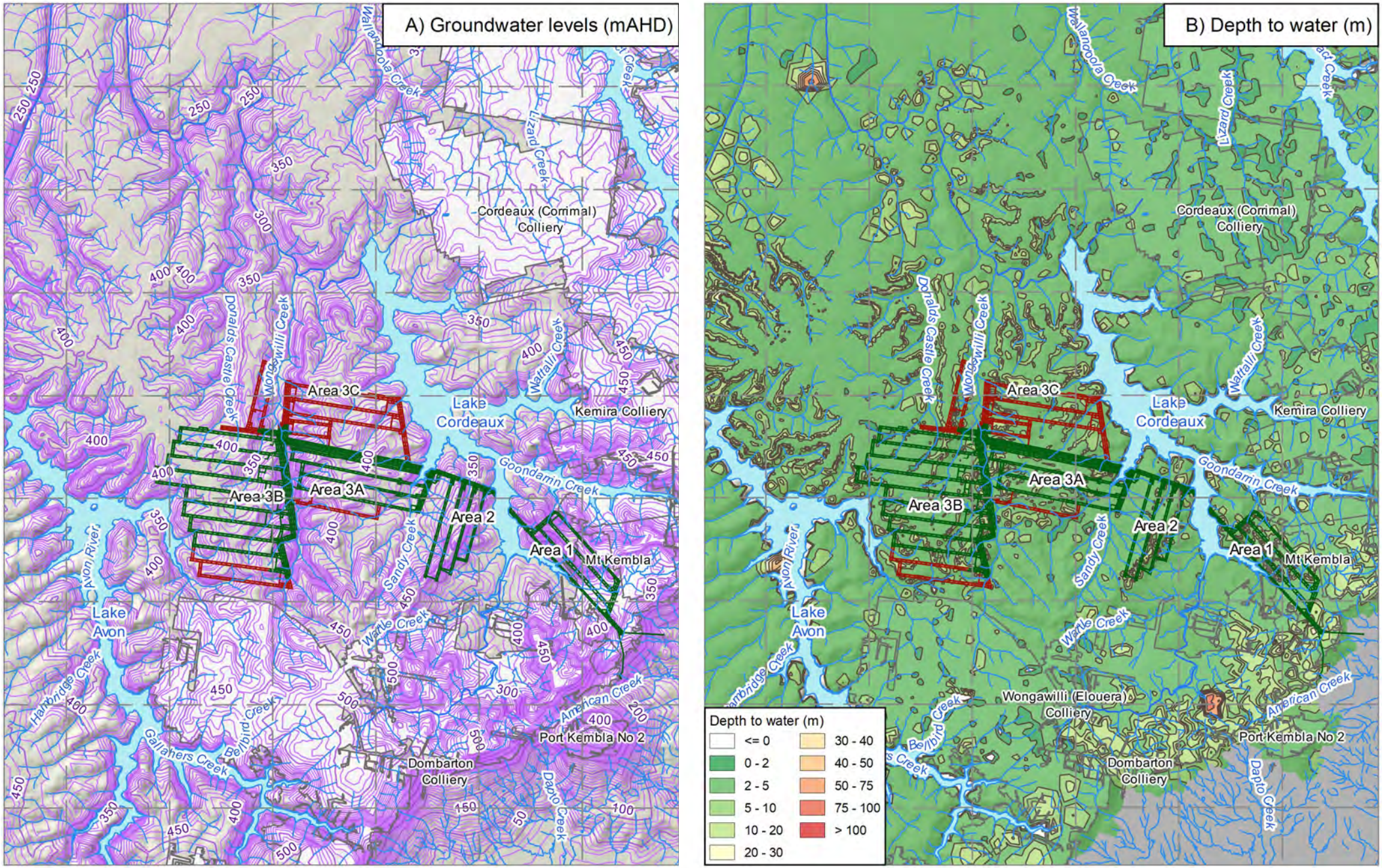


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D:\DEND\GWmodel\Processing\Heads\MOD2SMP\Calibration_Hydrographs_Priority_DND5v50.xlsx

Appendix G: Modelled groundwater level maps



0 1 2 3 km

Map Scale: 1:120,000@ A4
GDA 1994 MGA Zone 56

- Dendrobium - Existing Workings
- Dendrobium - Future Workings
- 10m groundwater level contour
- 50m groundwater level contour
- Depth to water contour (m)
- River
- Creek
- Lake / reservoir
- Mined area
- Model domain extent

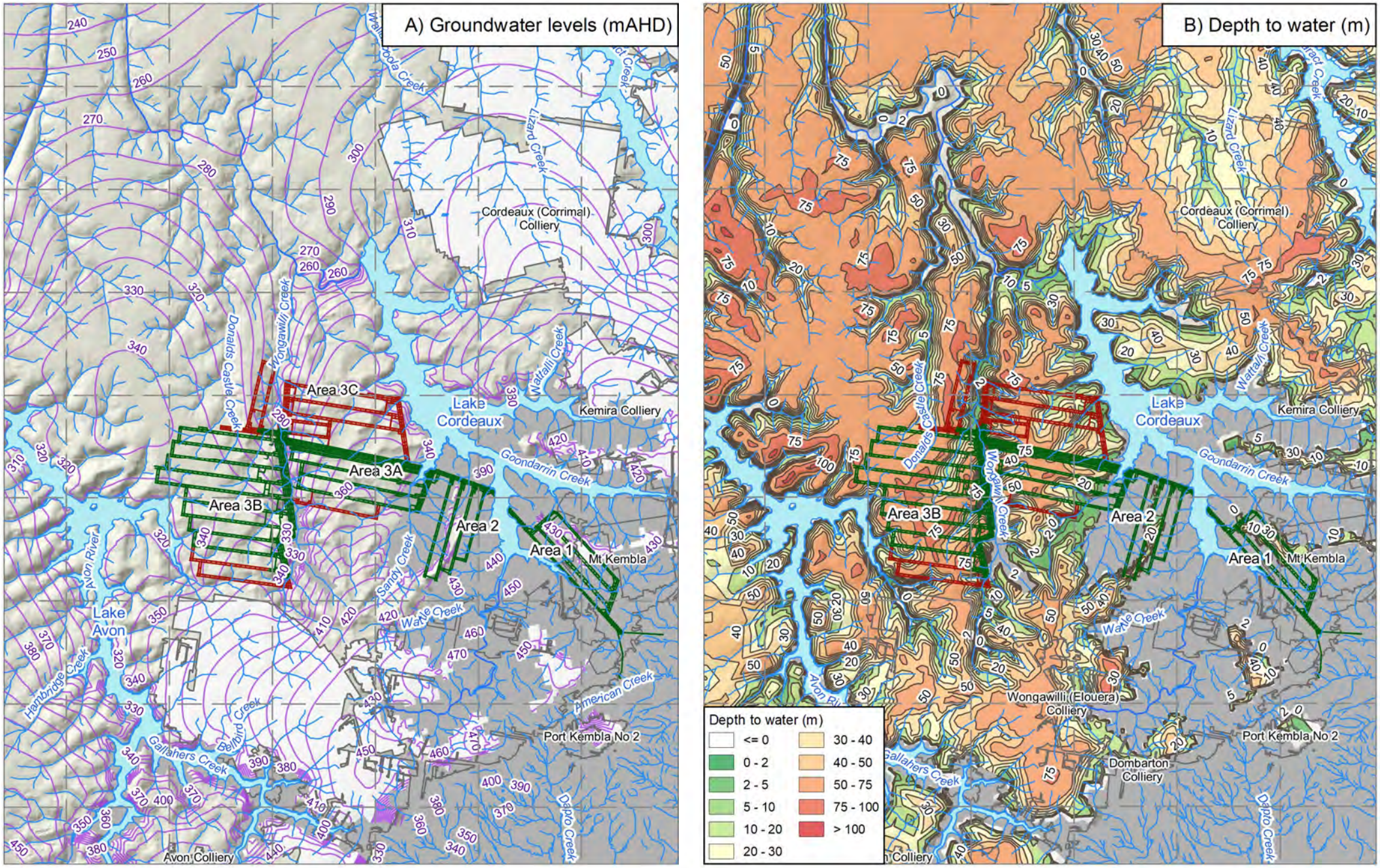
F:\WaterShed\HG\IMC105\GIS\Workspaces\PredGWLs_Depth2Water.qgs

WATERSHED HYDROGEO

IMC | Dendrobium Mine

Modelled groundwater levels and depth to water: Water table - Pre-mining

Figure G-1



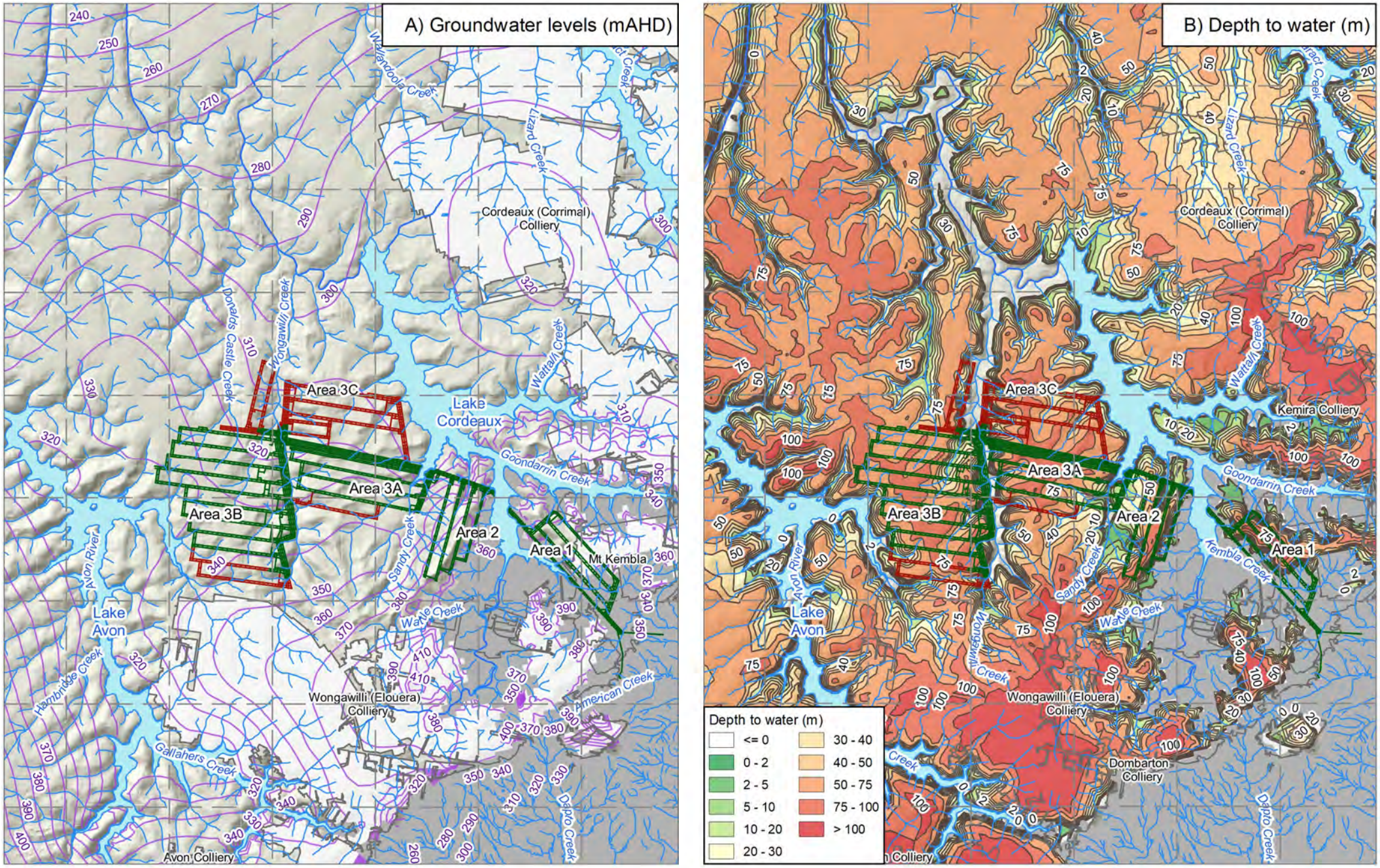
F:\Water\Shed\HG\IMC105\GIS\Workspaces\PredGWLs_Depth2Water.qgs

WATERSHED HYDROGEO

IMC | Dendrobium Mine

Modelled groundwater levels and depth to water: lower Hawkesbury Sandstone - Pre-mining

Figure G-2



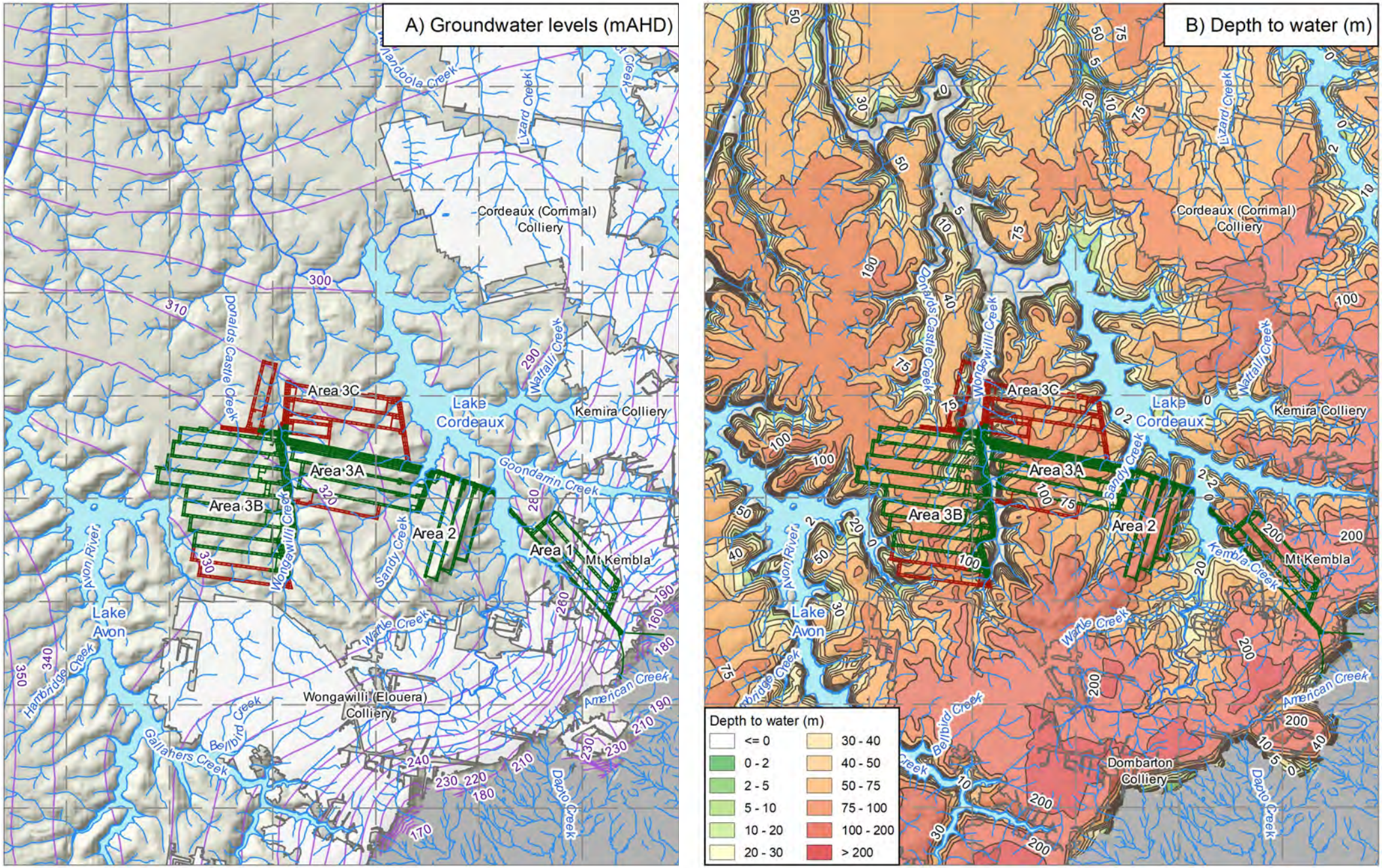
F:\Water\Shed\HG\IMC105\GIS\Workspaces\PredGWLs_Depth2Water.qgs

WATERSHED HYDROGEO

IMC | Dendrobium Mine

Modelled groundwater levels and depth to water: Bulgo Sandstone - Pre-mining

Figure G-3

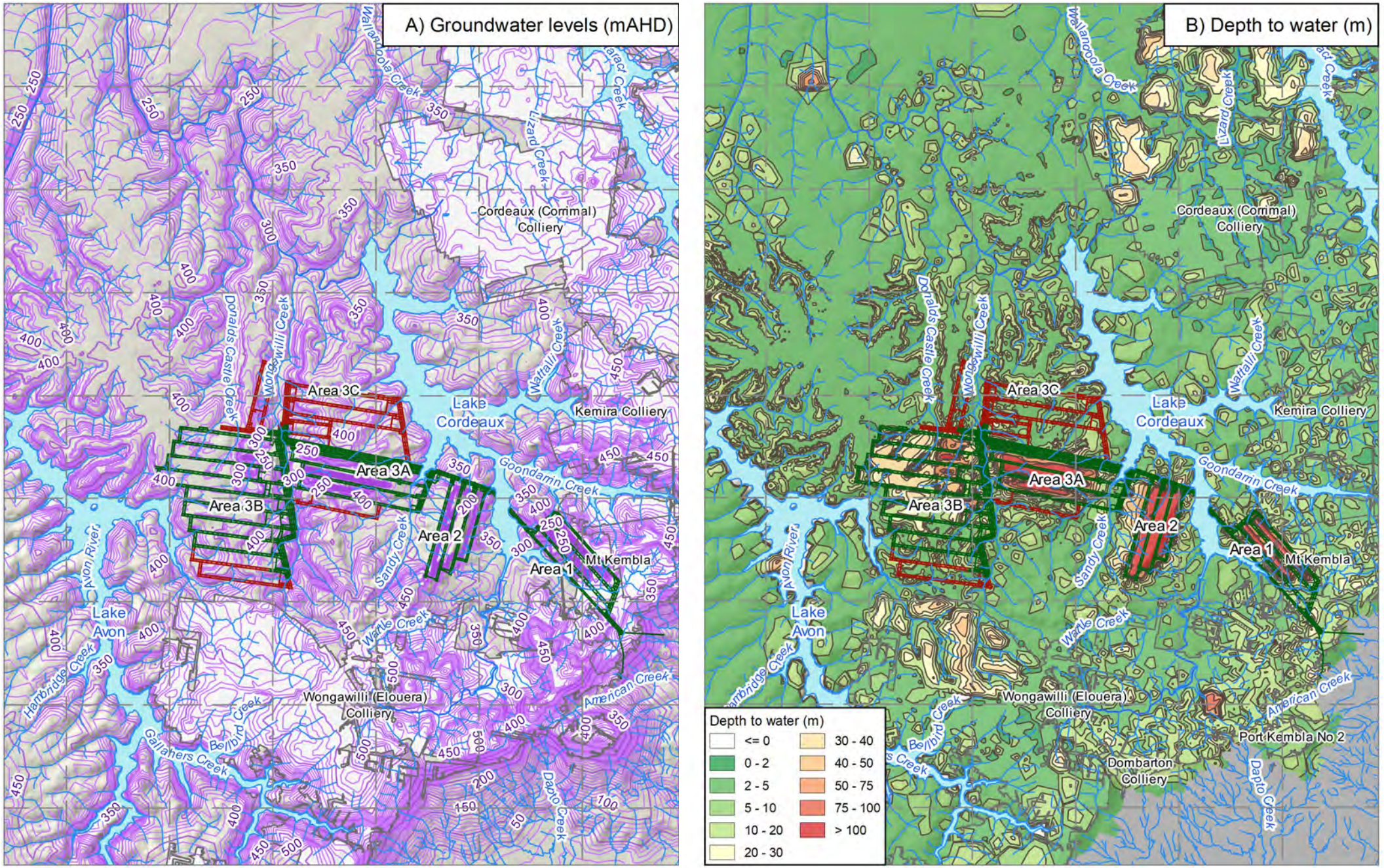


WATERSHED HYDROGEO

IMC | Dendrobium Mine

Modelled groundwater levels and depth to water: Wongawilli Coal Seam - Pre-mining

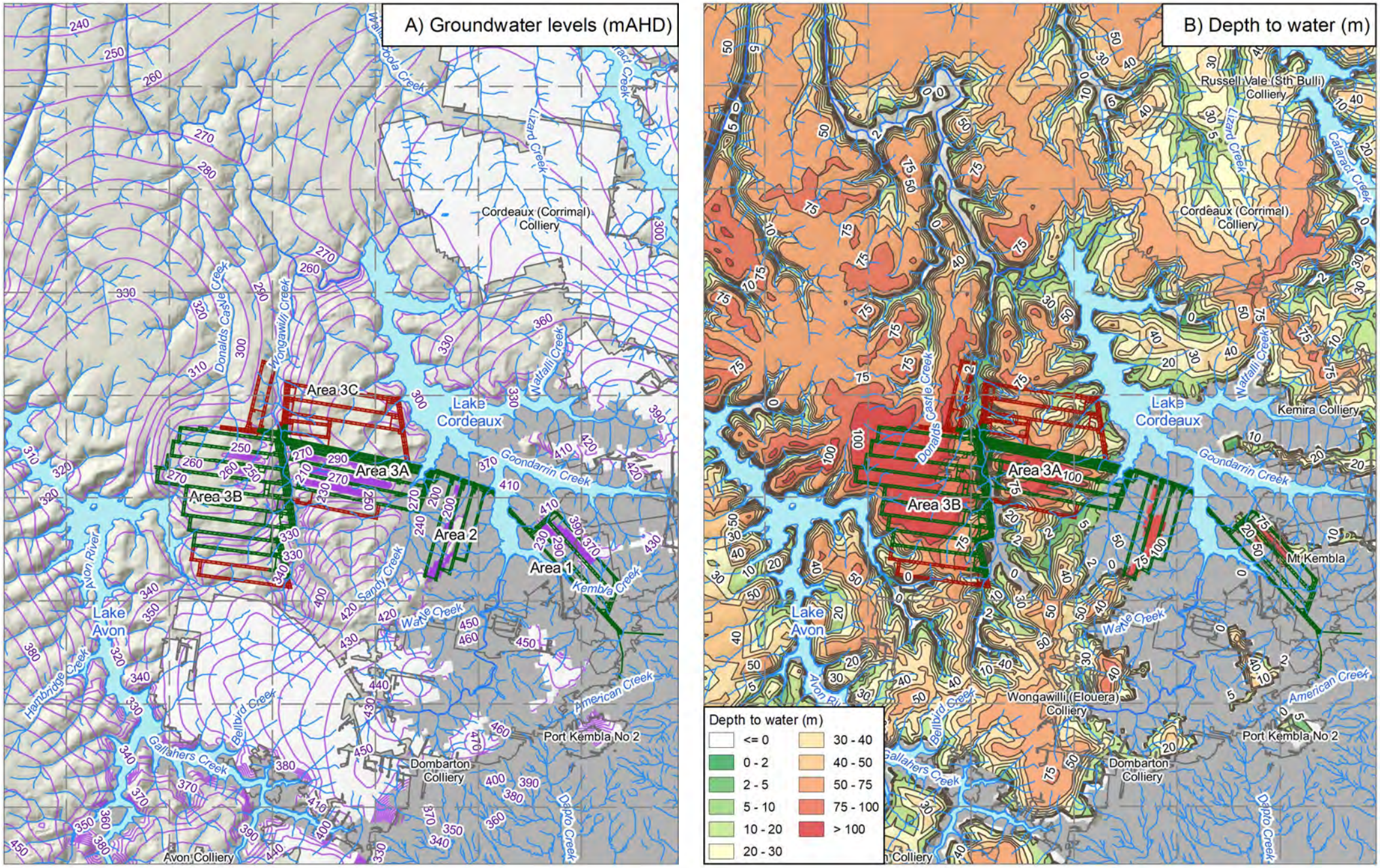
Figure G-4



IMC | Dendrobium Mine

Modelled groundwater levels and depth to water: Water table - January 2022

Figure G-5



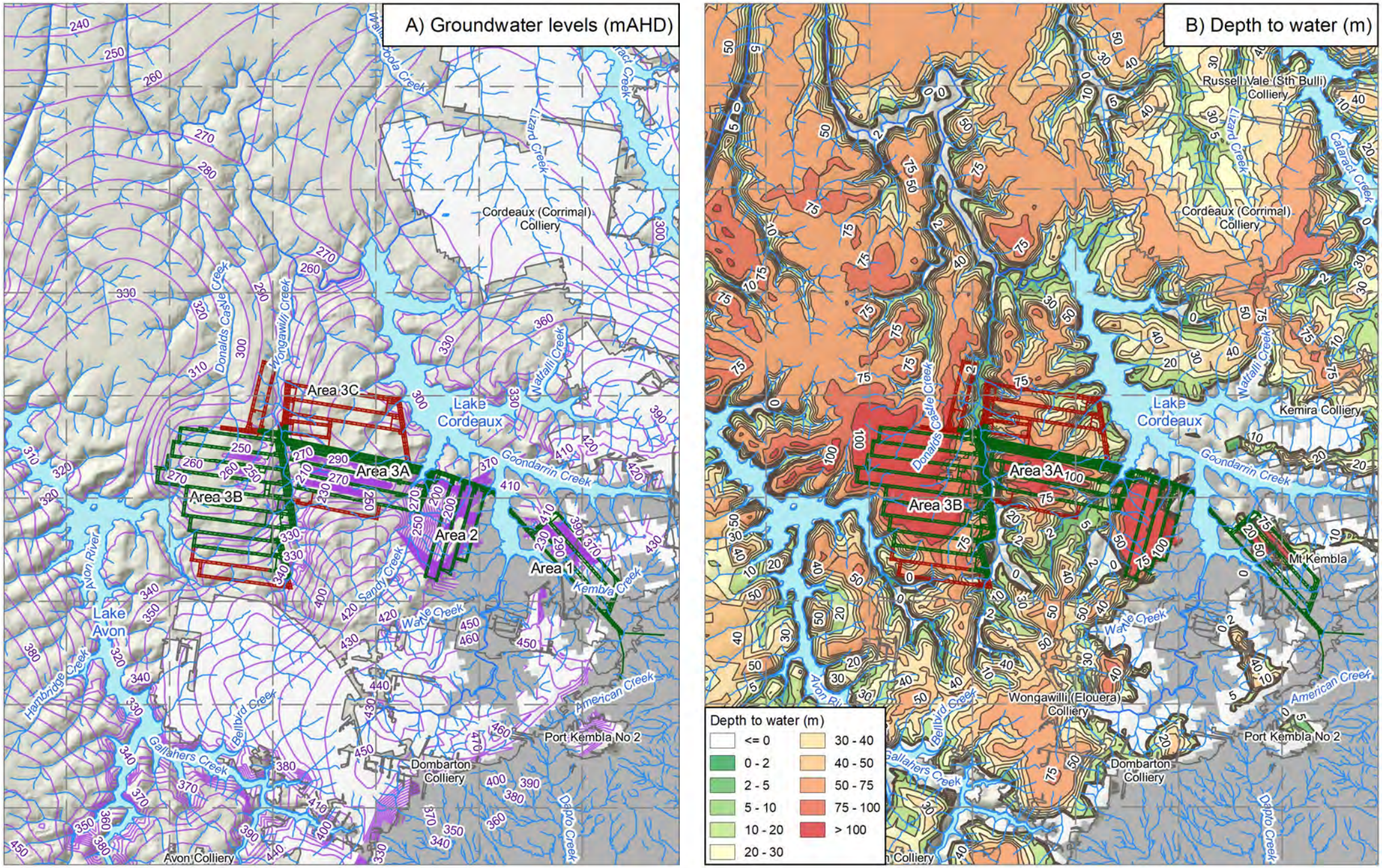
F:\WaterShedHG\IMC105\GIS\Workspaces\PredGWLs_Depth2Water.qgs

WATERSHED HYDROGEO

IMC | Dendrobium Mine

Modelled groundwater levels and depth to water: lower Hawkesbury Sandstone - January 2020

Figure G-6



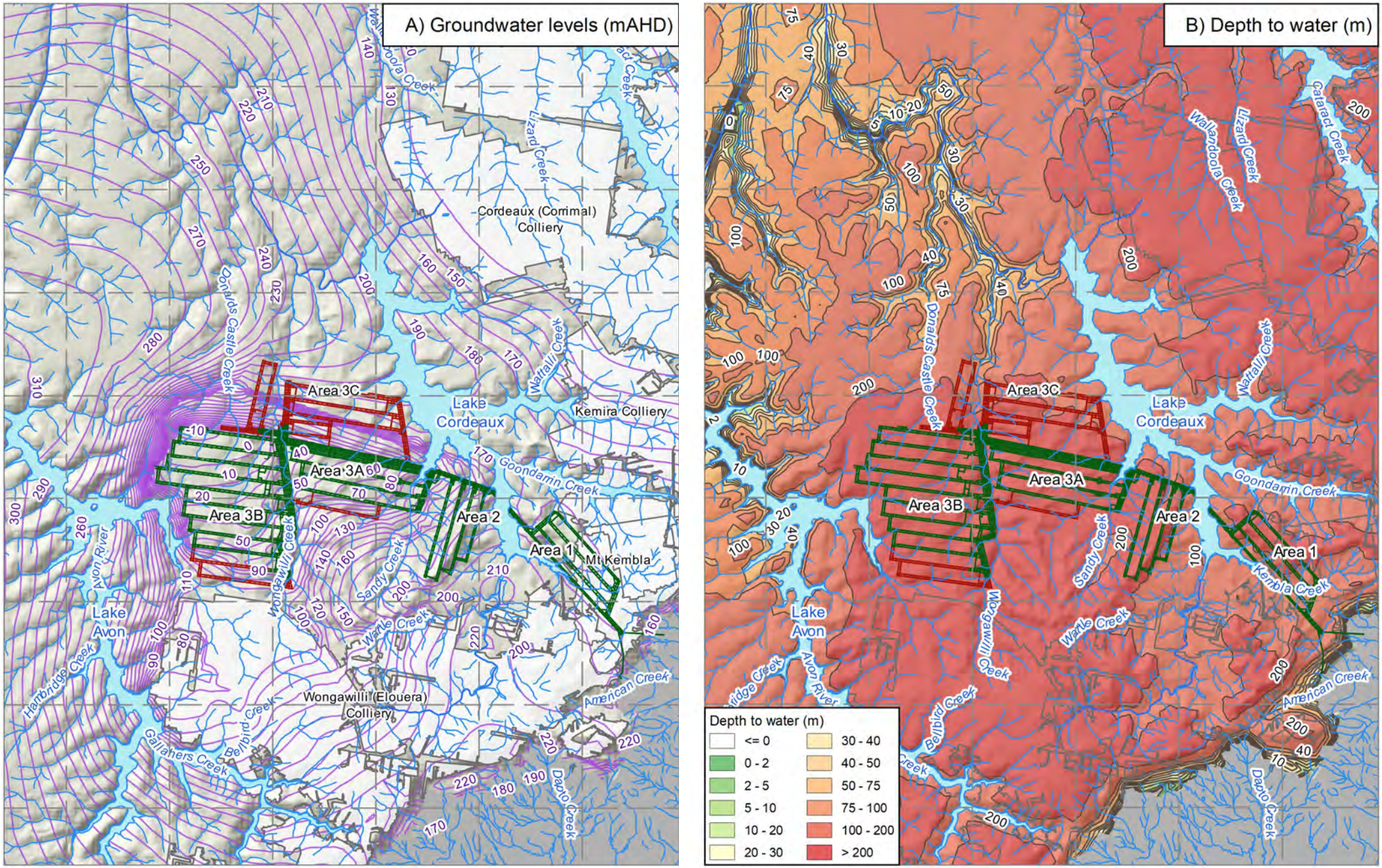
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WATERSHED HYDROGEO

IMC | Dendrobium Mine

Modelled groundwater levels and depth to water: Bulgo Sandstone - January 2020

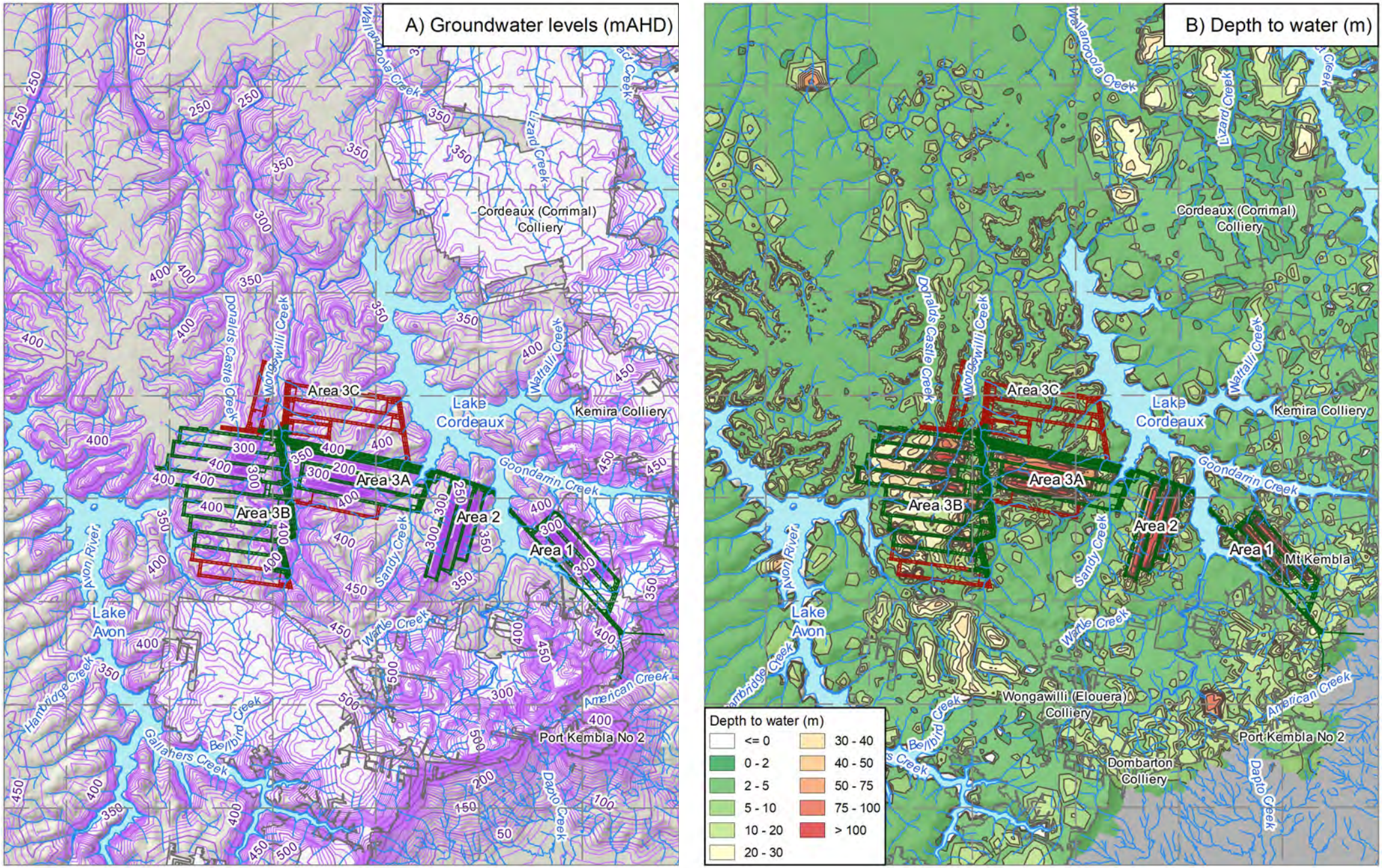
Figure G-7



IMC | Dendrobium Mine

Modelled groundwater levels and depth to water: Wongawilli Coal Seam - January 2020

Figure G-8



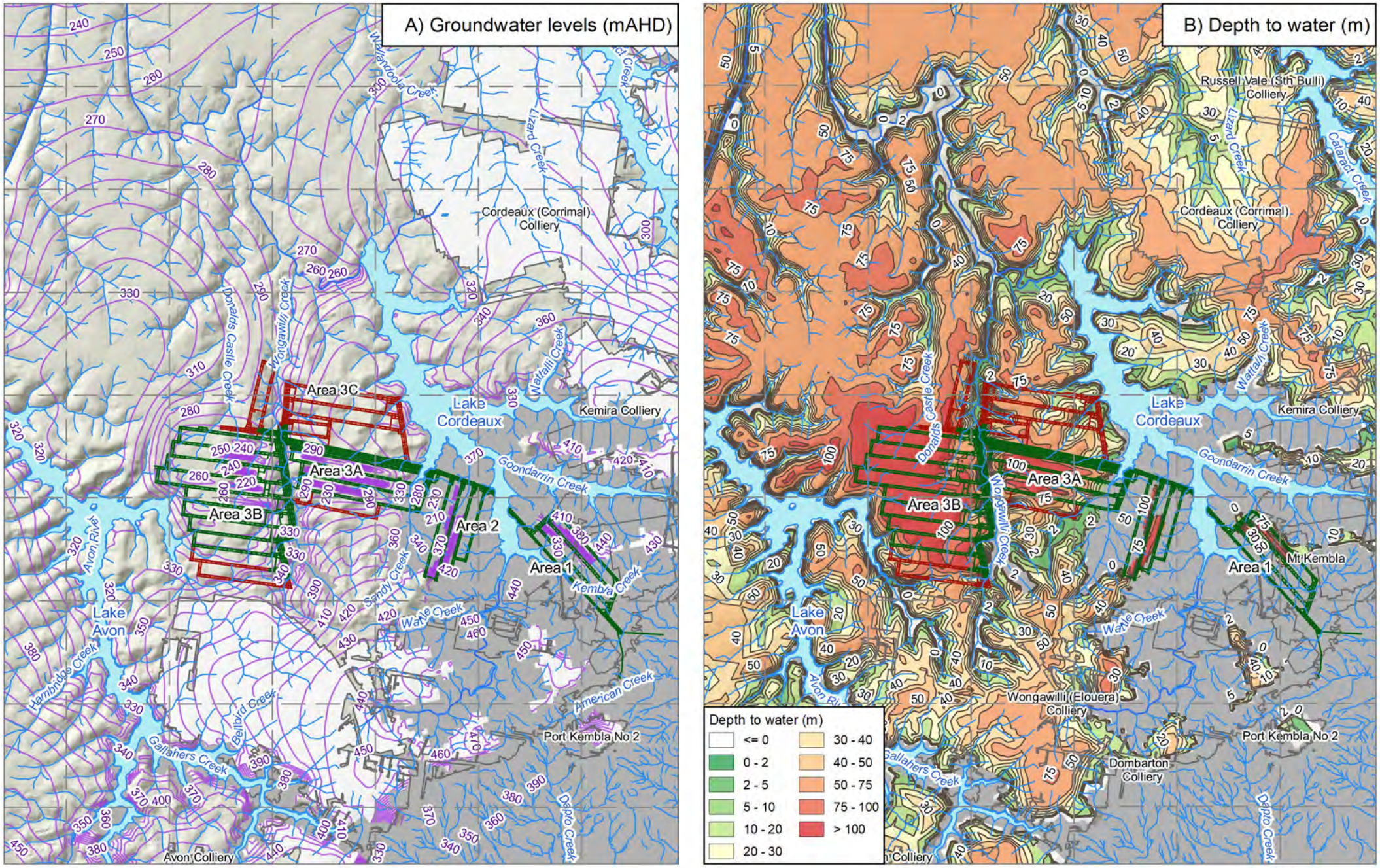
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WATERSHED HYDROGEO

IMC | Dendrobium Mine

Modelled groundwater levels and depth to water: Water table - April 2022 (end of Longwall 18).

Figure G-9



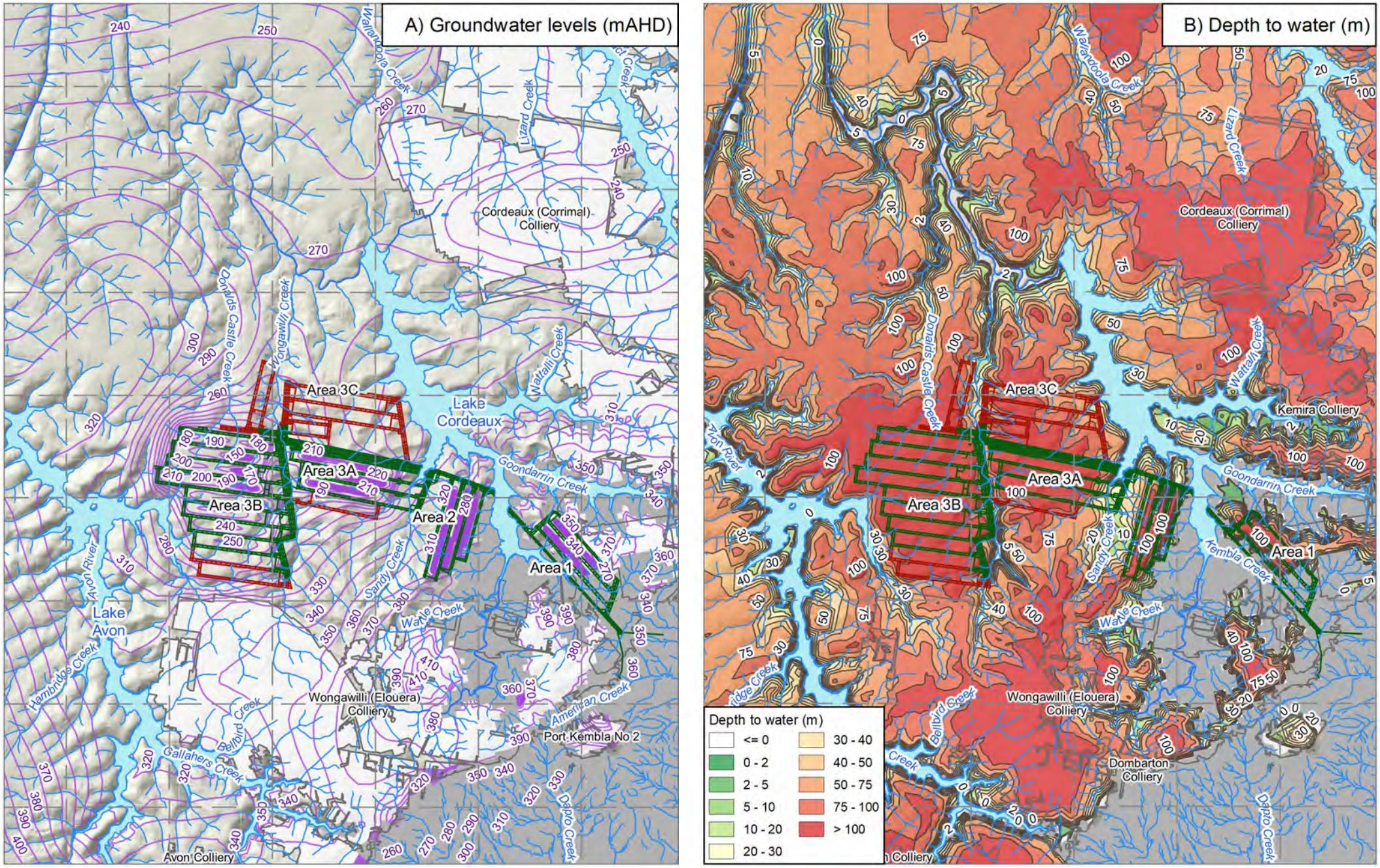
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WATERSHED HYDROGEO

IMC | Dendrobium Mine

Modelled groundwater levels and depth to water: lower Hawkesbury Sandstone - April 2022 (end of Longwall 18)

Figure G-10



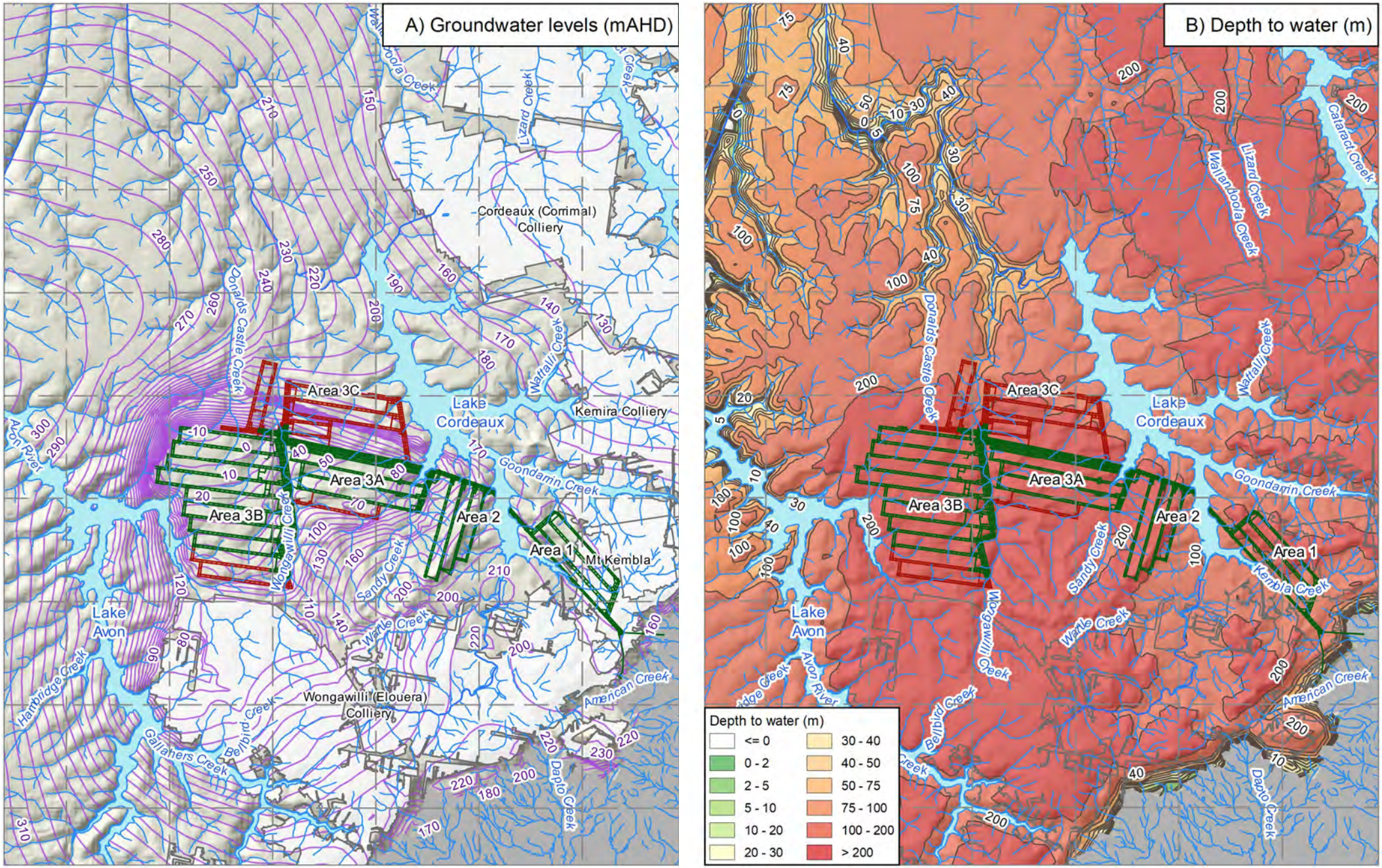
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WATERSHED HYDROGEO

IMC | Dendrobium Mine

Modelled groundwater levels and depth to water: Bulgo Sandstone - April 2022 (end of Longwall 18)

Figure G-11



0 1 2 3 km

Map Scale: 1:120,000@ A4
GDA 1994 MGA Zone 56

- Dendrobium - Existing Workings
- Dendrobium - Future Workings
- Groundwater level contour (mAHD)
- Depth to water contour (m)
- River
- Creek
- Lake / reservoir
- Mined area
- Model domain extent
- Inactive model cells

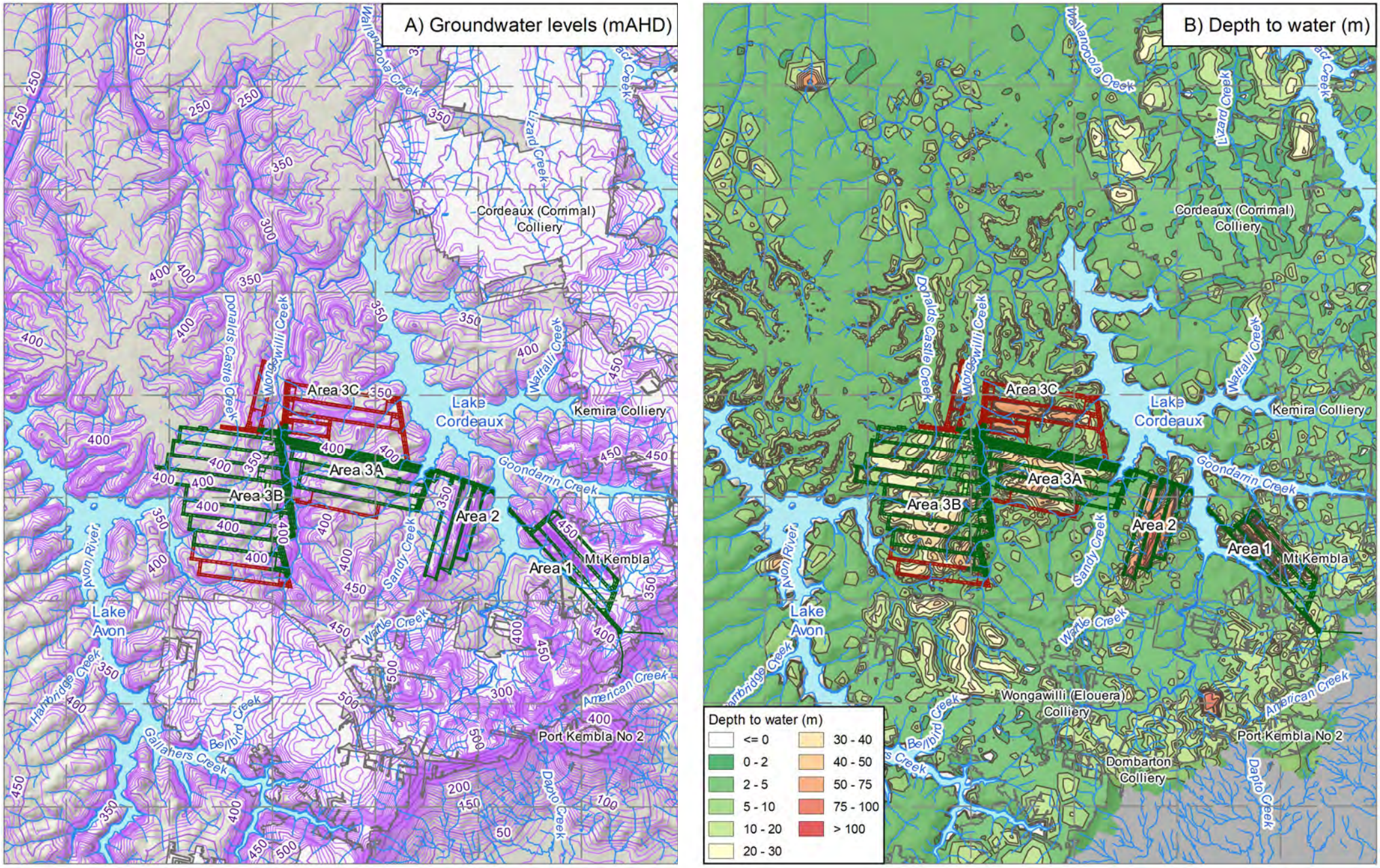
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WATERSHED HYDROGEO

IMC | Dendrobium Mine

Modelled groundwater levels and depth to water: Wongawilli Coal Seam - April 2022 (end of Longwall 18)

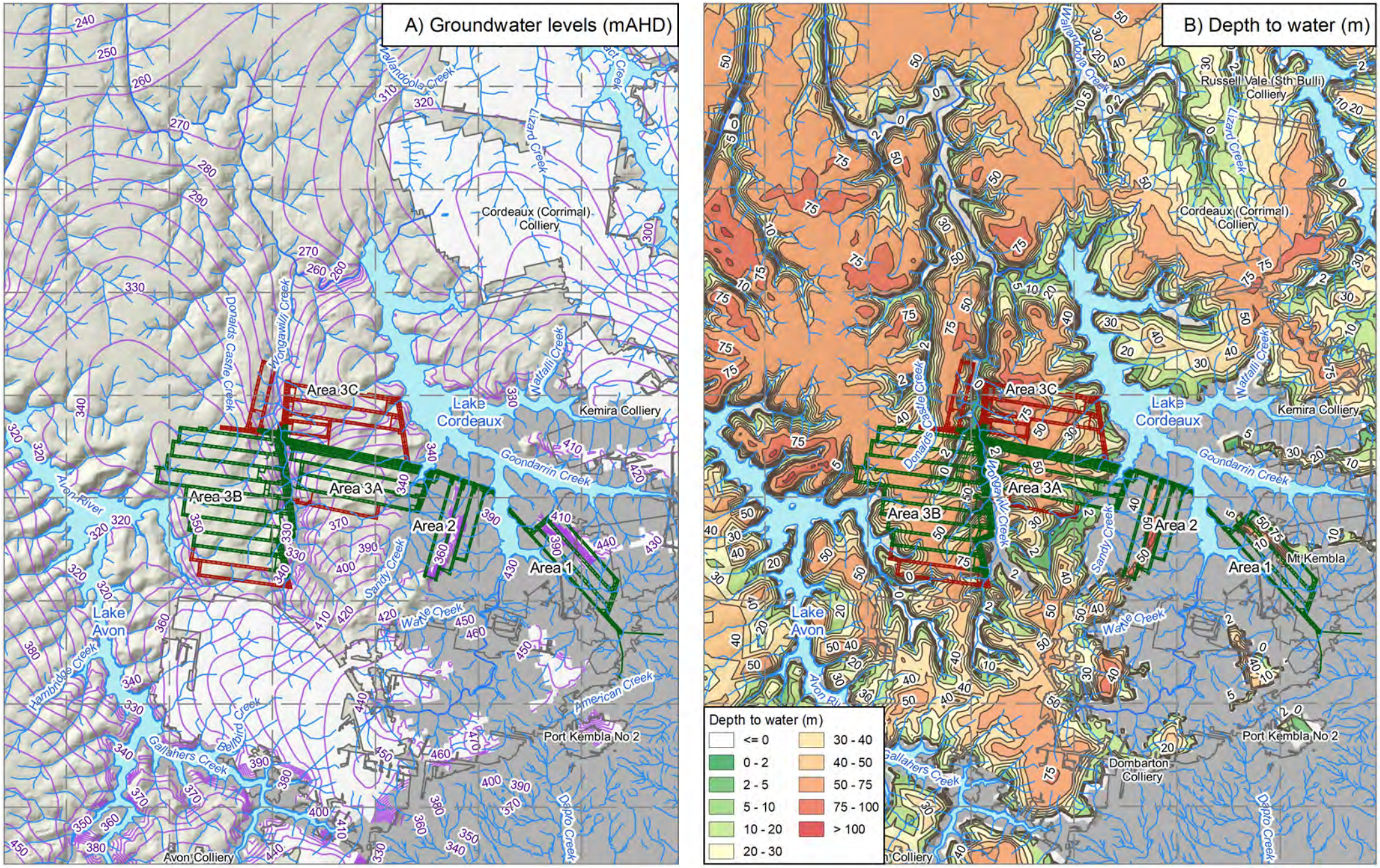
Figure G-12



IMC | Dendrobium Mine

Modelled groundwater levels and depth to water: Water table - 2200.

Figure G-13



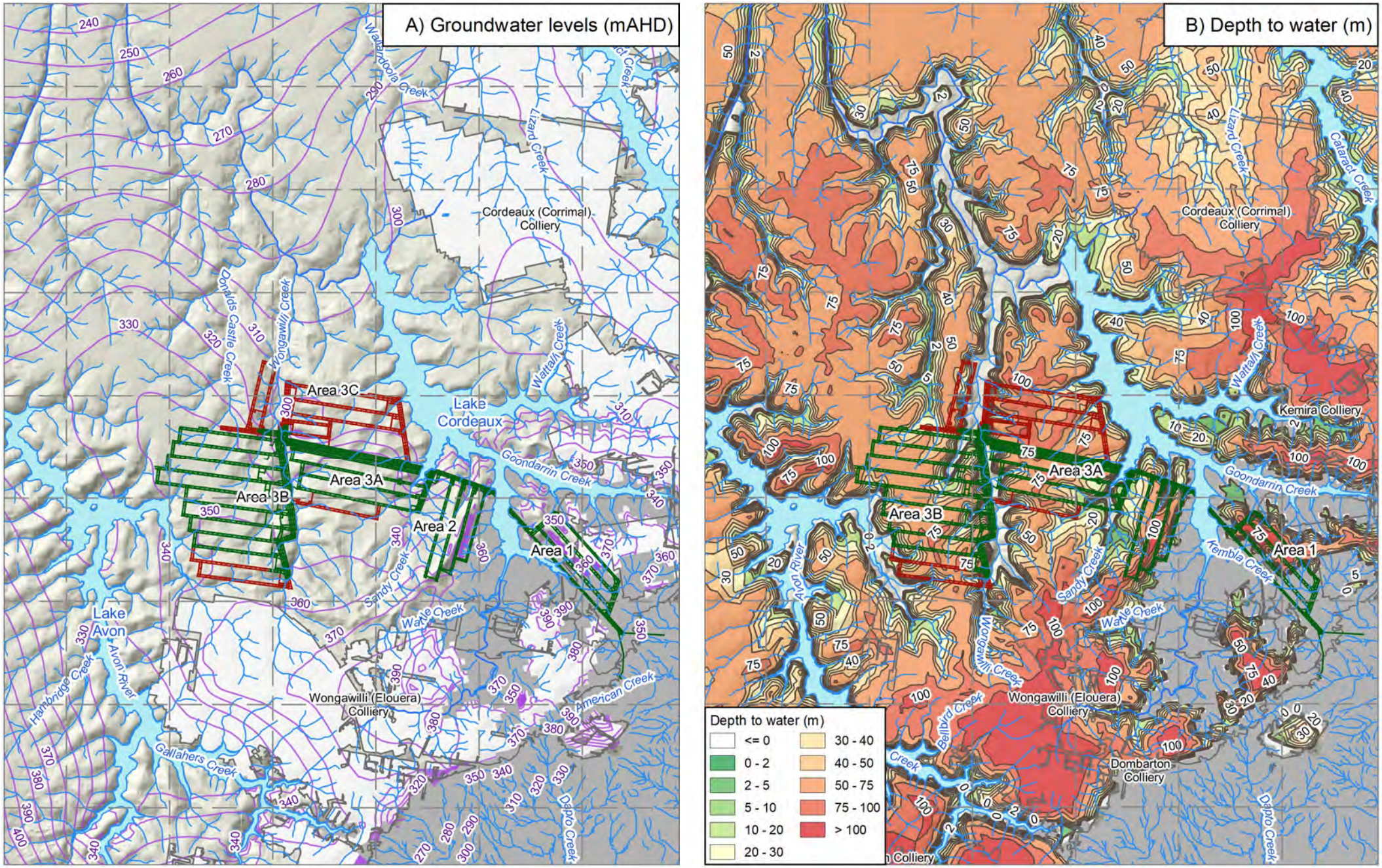
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WATERSHED HYDROGEO

IMC | Dendrobium Mine

Modelled groundwater levels and depth to water: lower Hawkesbury Sandstone - 2200

Figure G-14



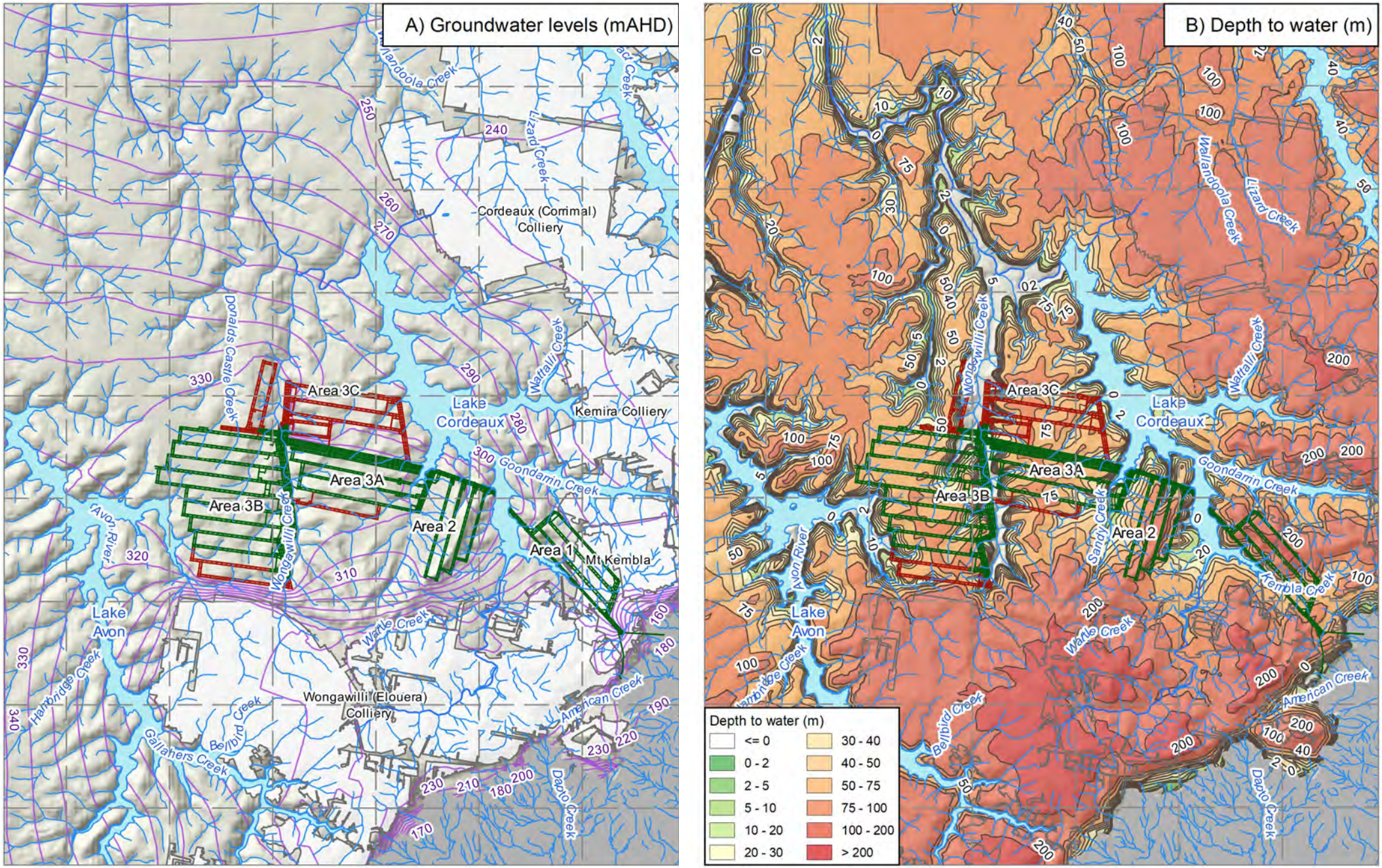
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WATERSHED HYDROGEO

IMC | Dendrobium Mine

Modelled groundwater levels and depth to water: Bulgo Sandstone - 2200

Figure G-15



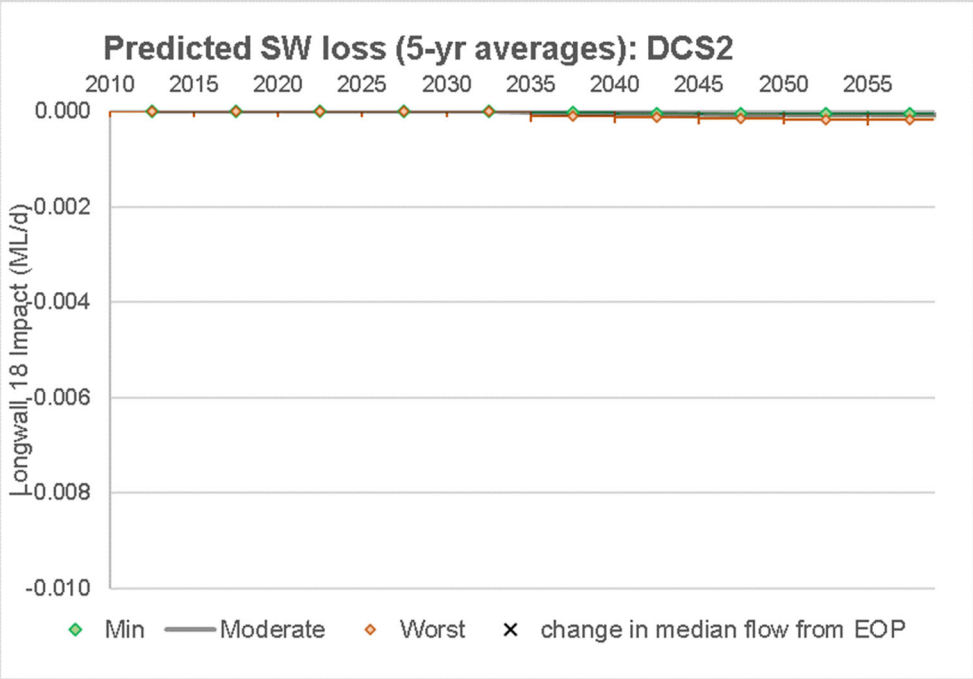
IMC | Dendrobium Mine

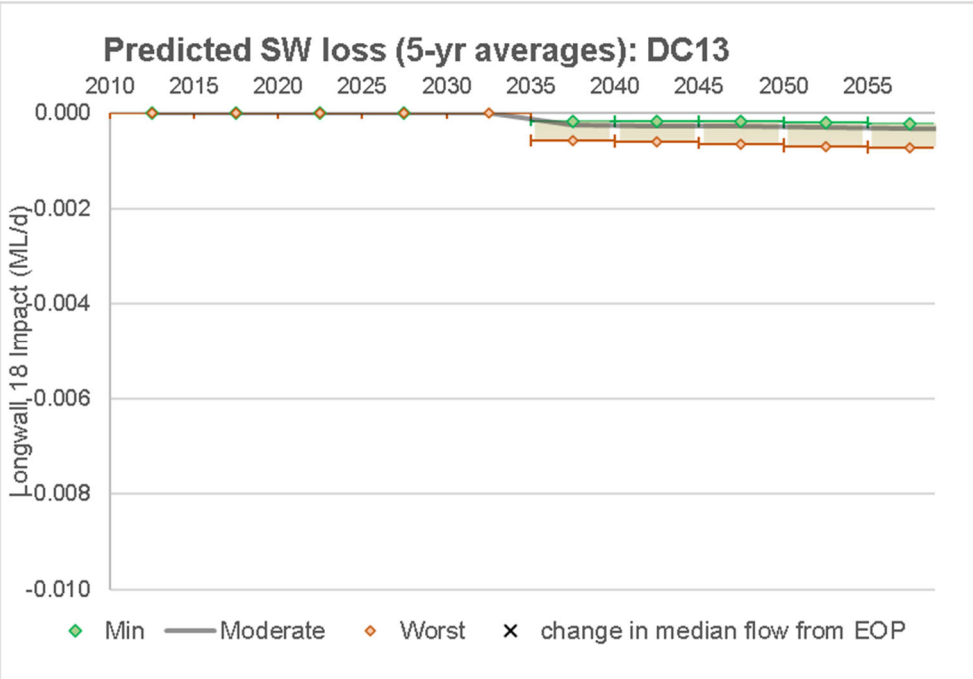
Modelled groundwater levels and depth to water: Wongawilli Coal Seam - 2200

Figure G-16

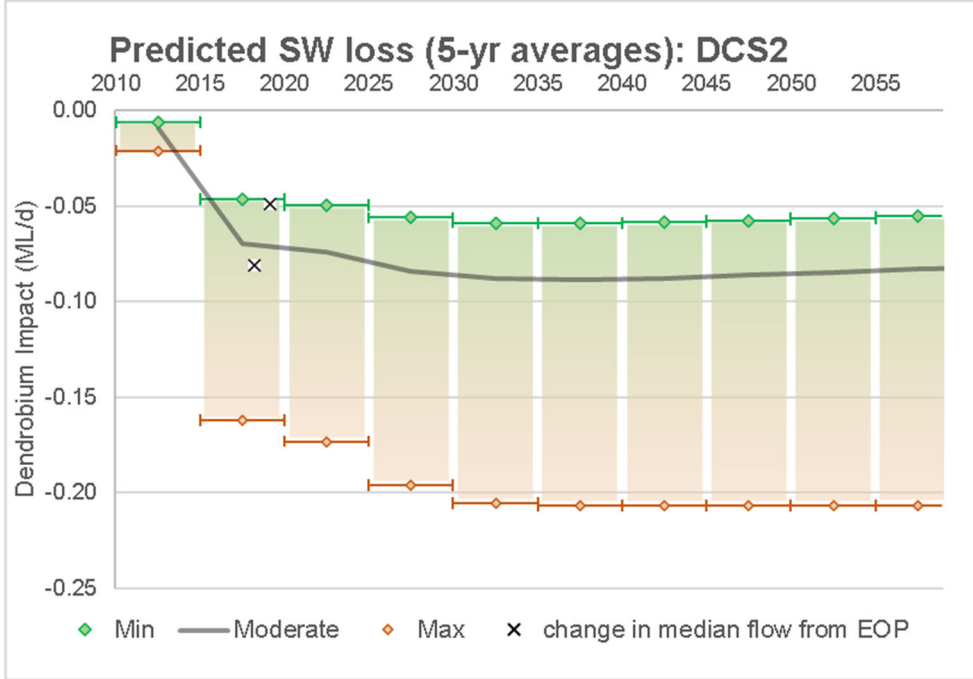
Appendix H: Predicted Surface Water Losses

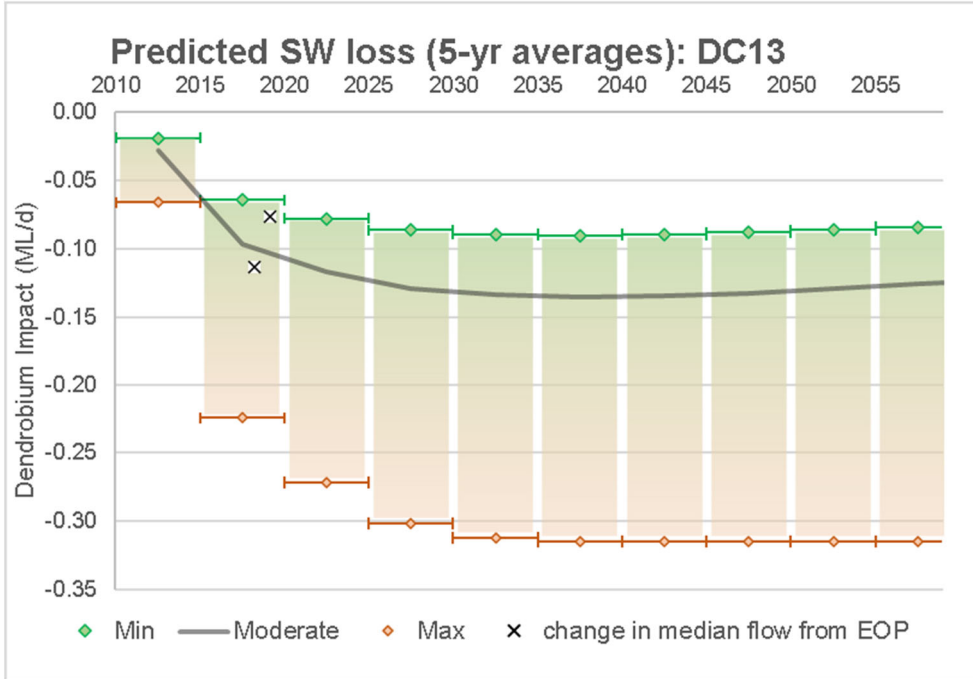
Surface Water losses – Longwall 18 Incremental effect



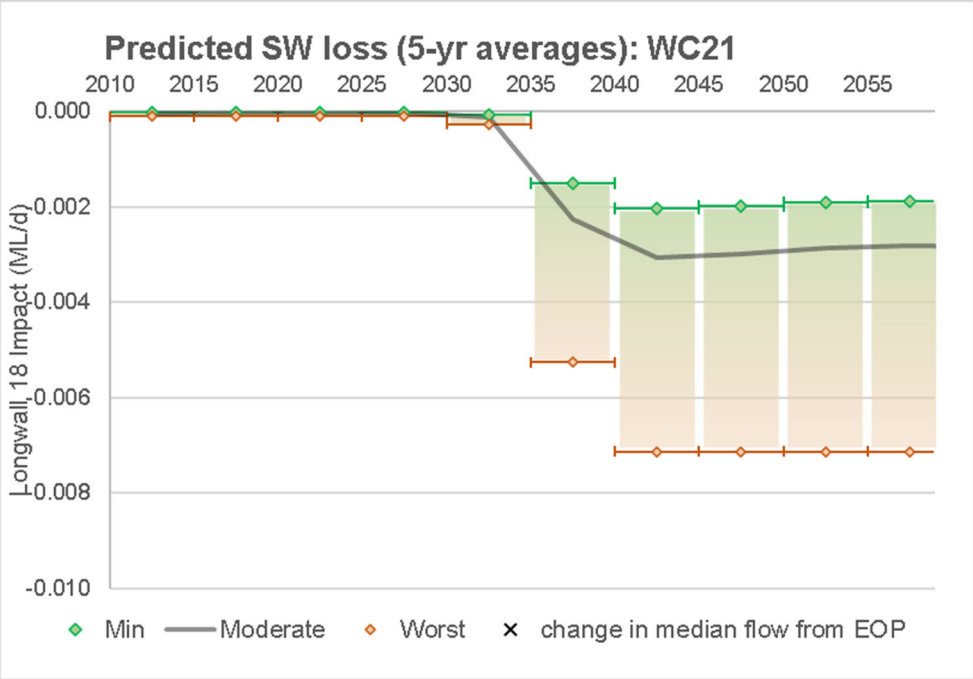


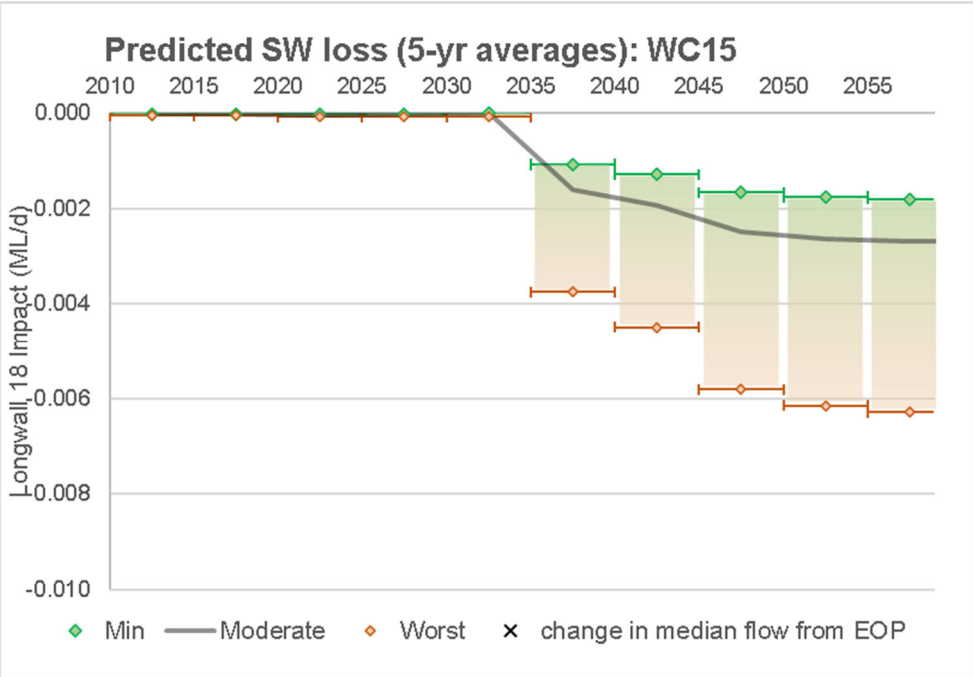
Surface Water losses – Dendrobium whole-of-mine effect



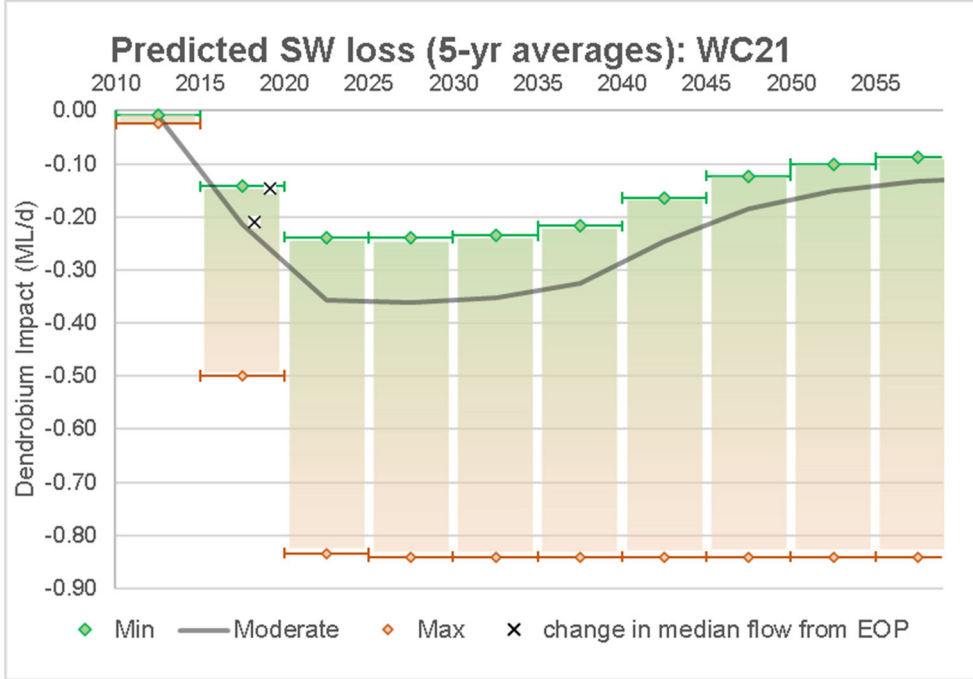


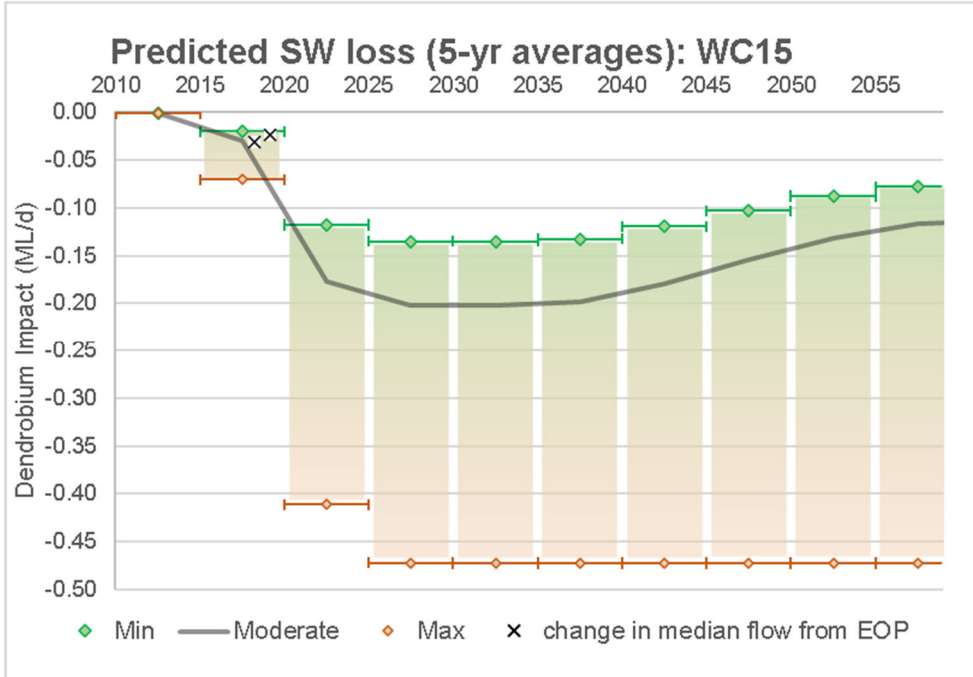
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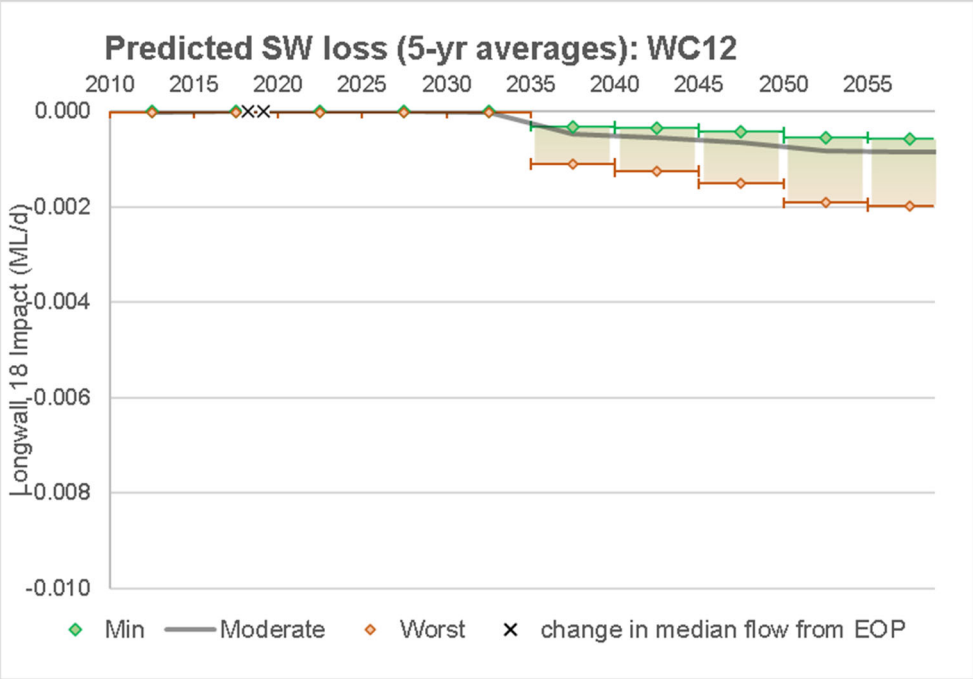


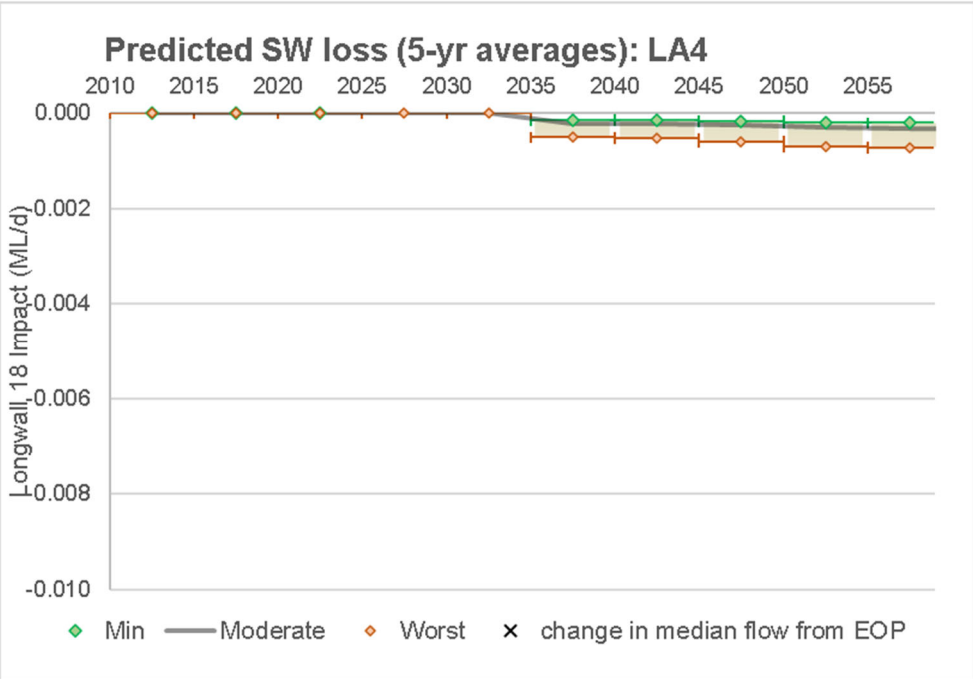
Surface Water losses – Dendrobium whole-of-mine effect



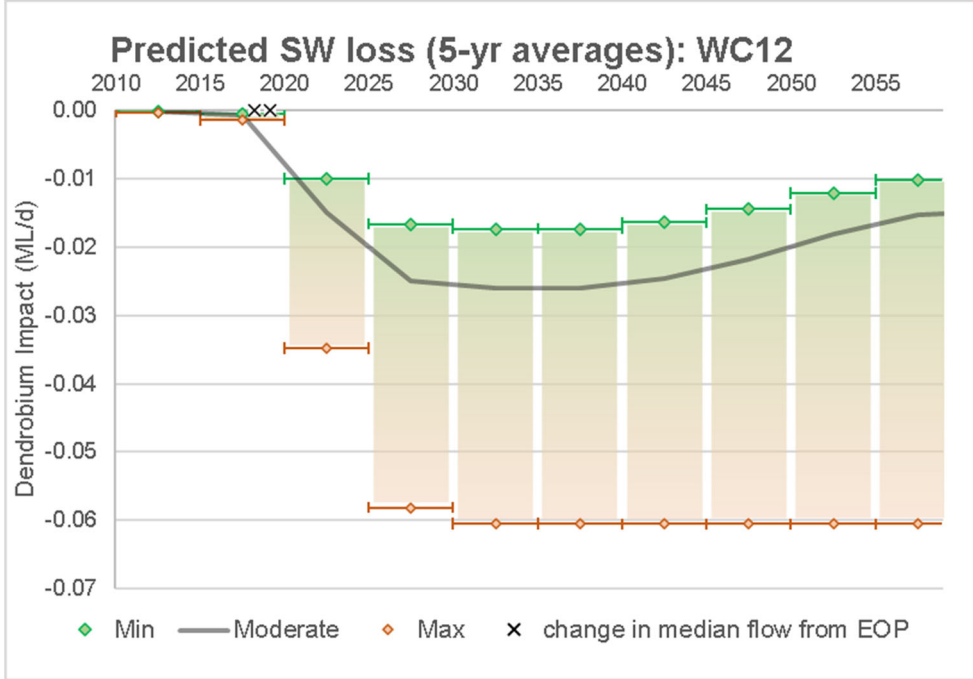


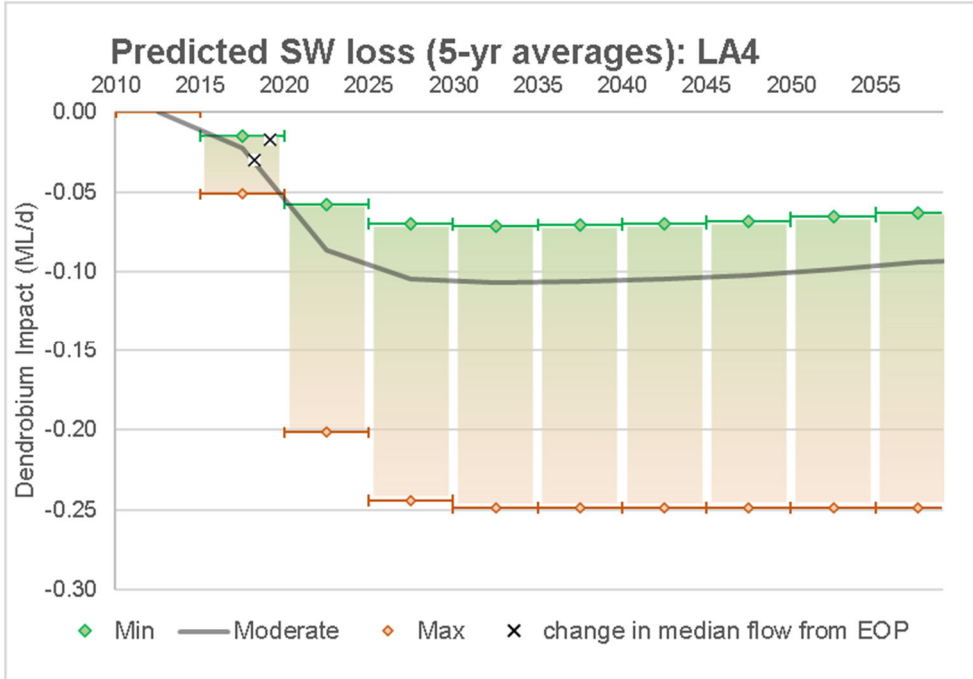
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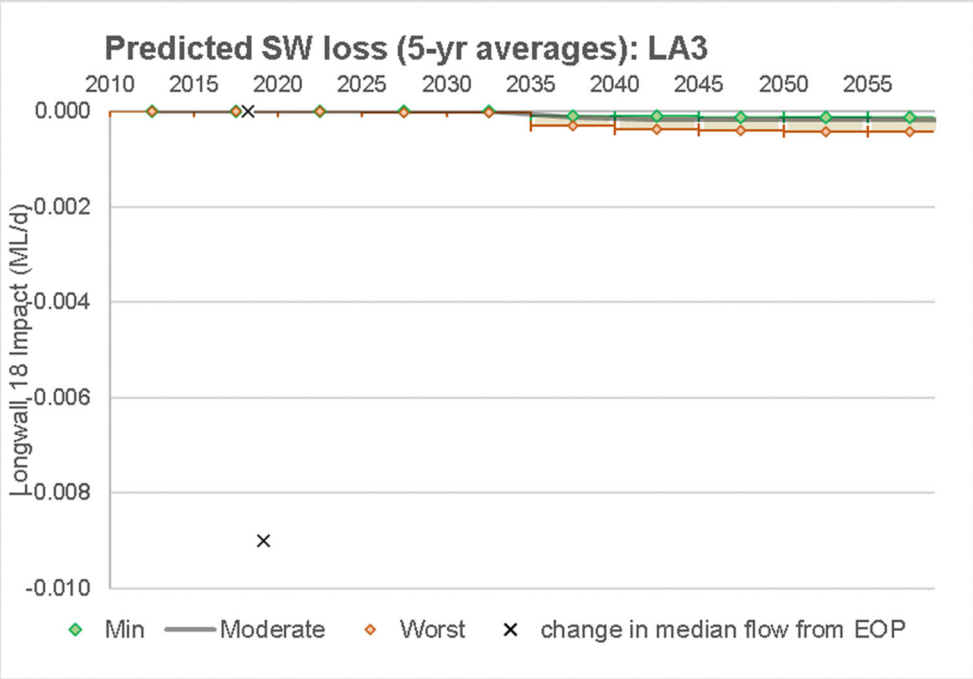


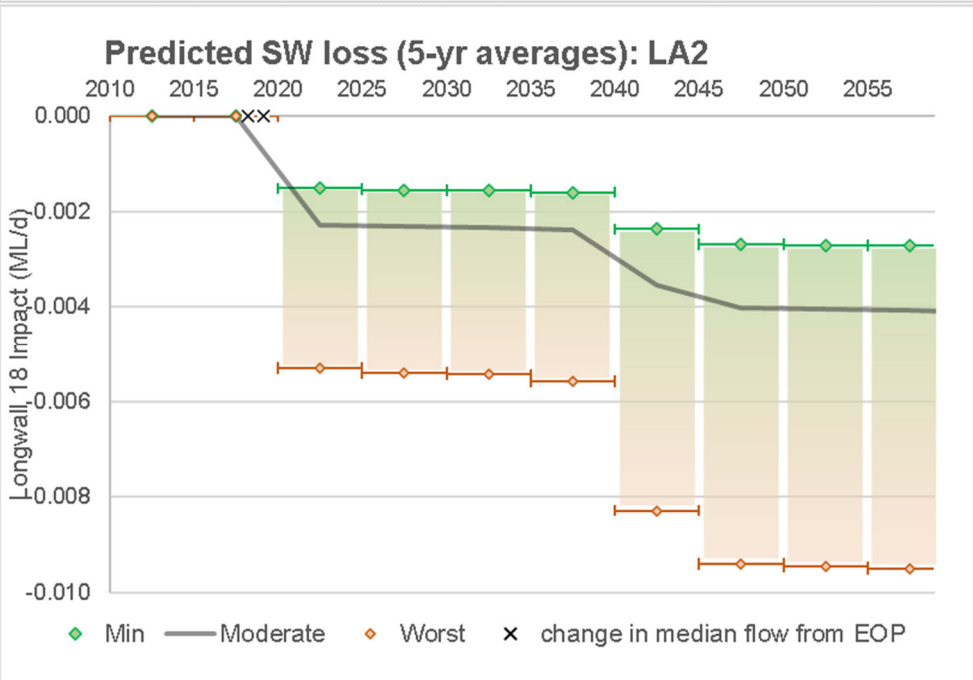
Surface Water losses – Dendrobium whole-of-mine effect



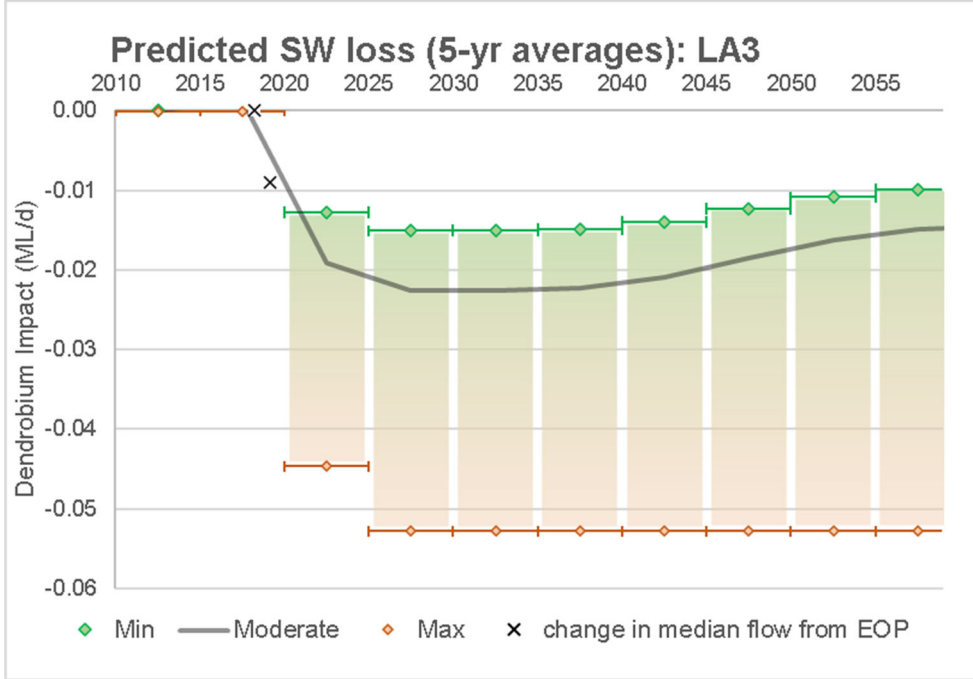


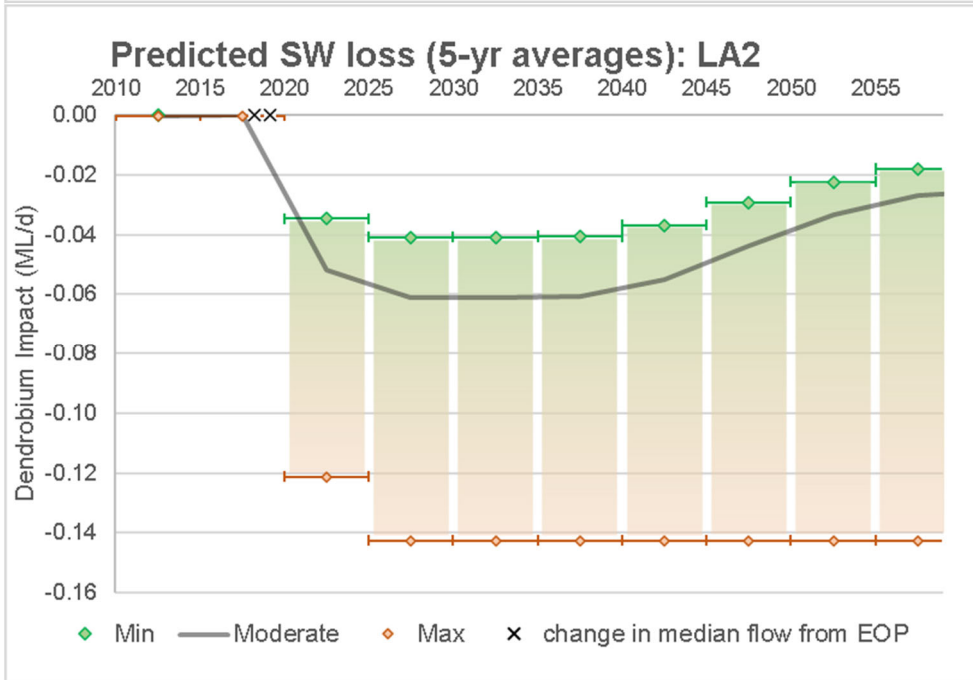
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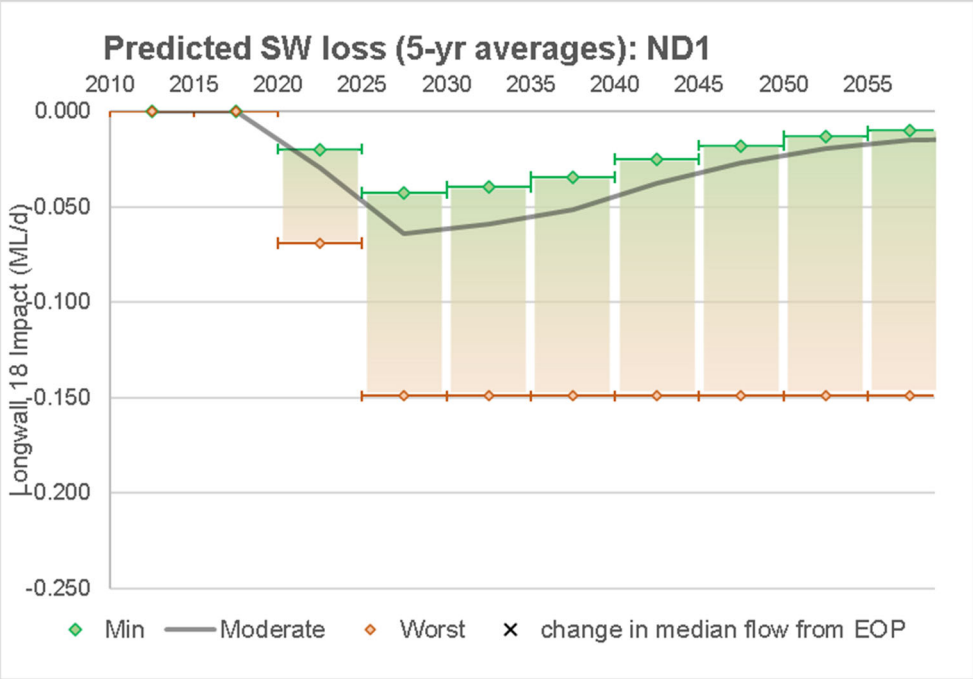


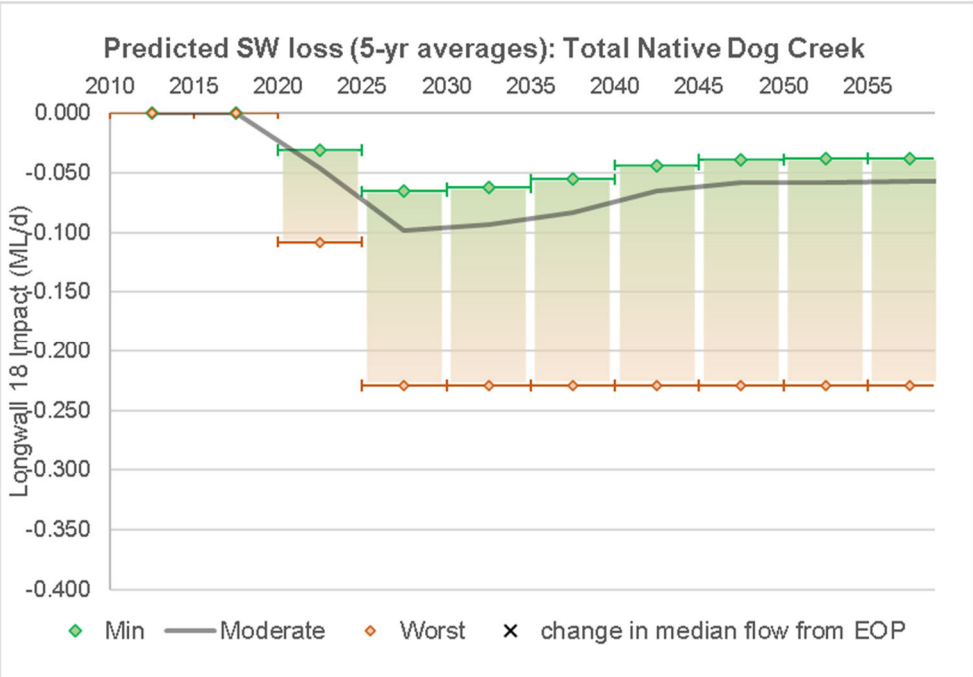
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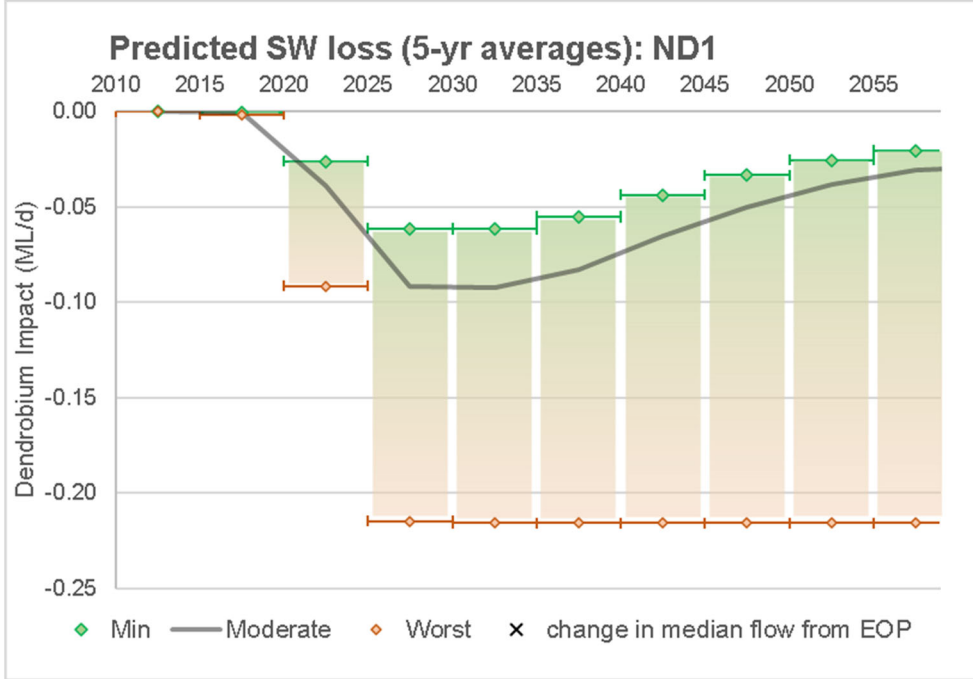


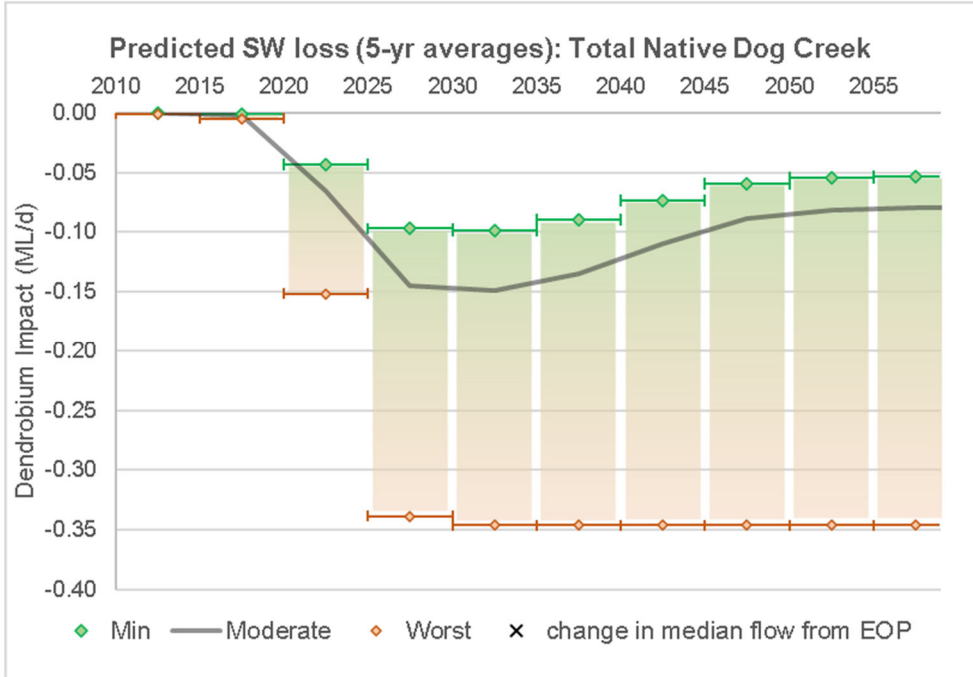
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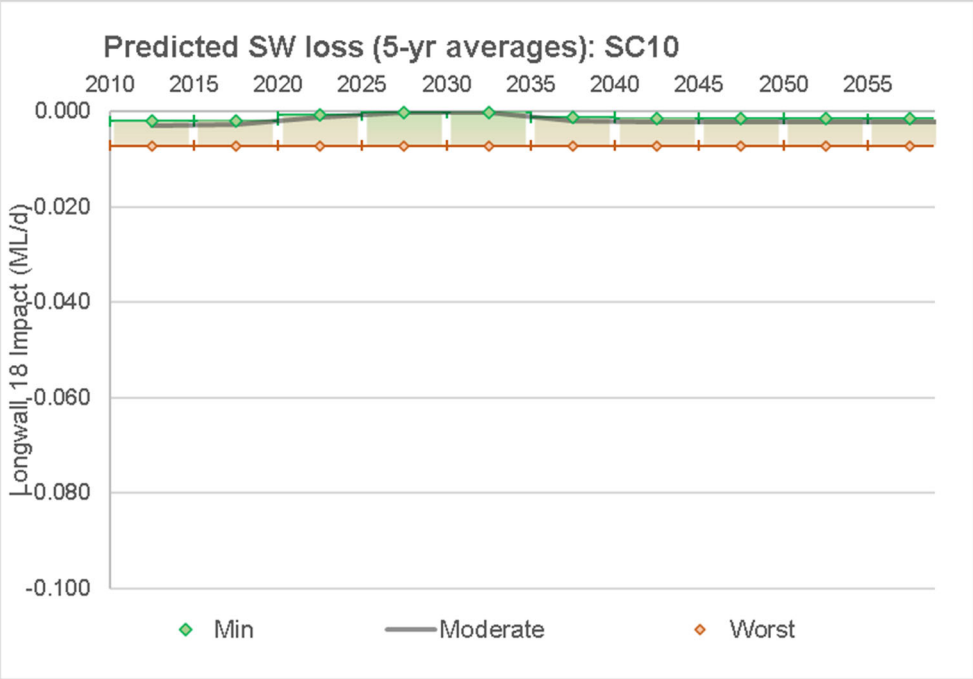


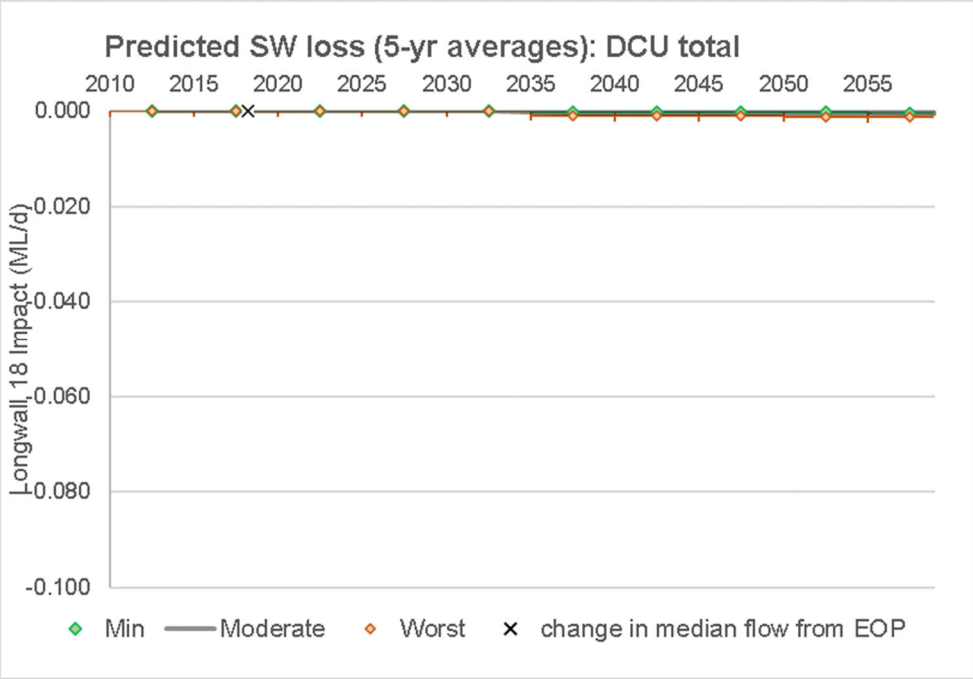
Surface Water losses – Dendrobium whole-of-mine effect



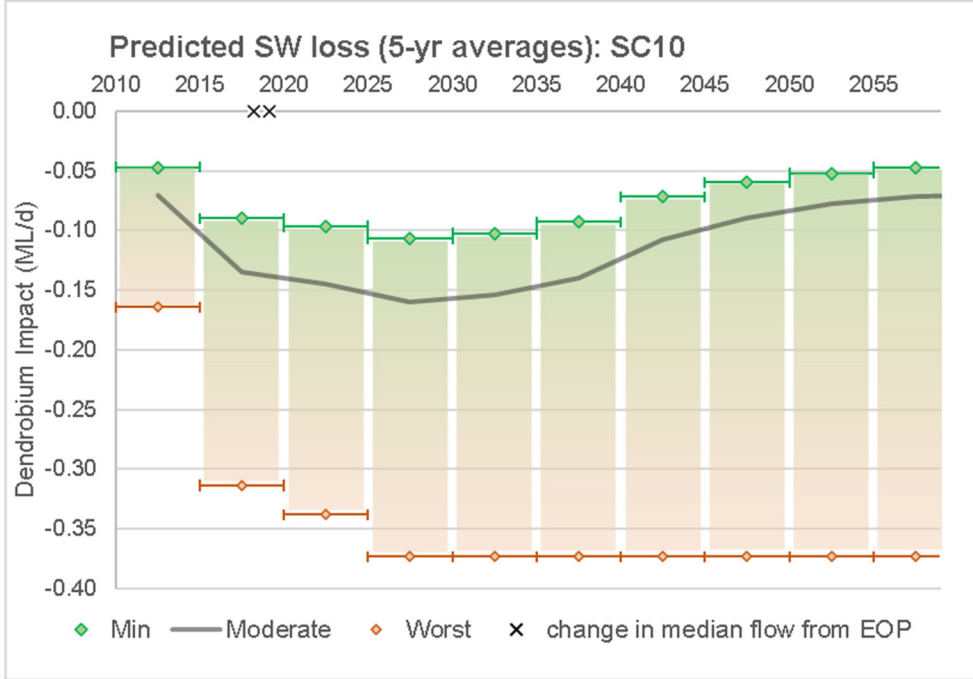


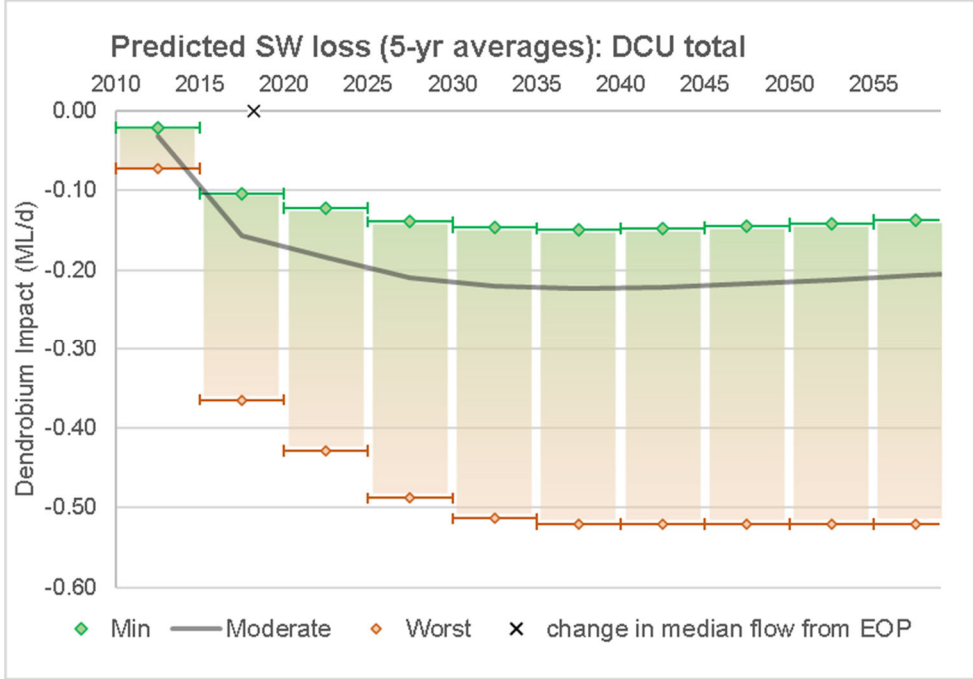
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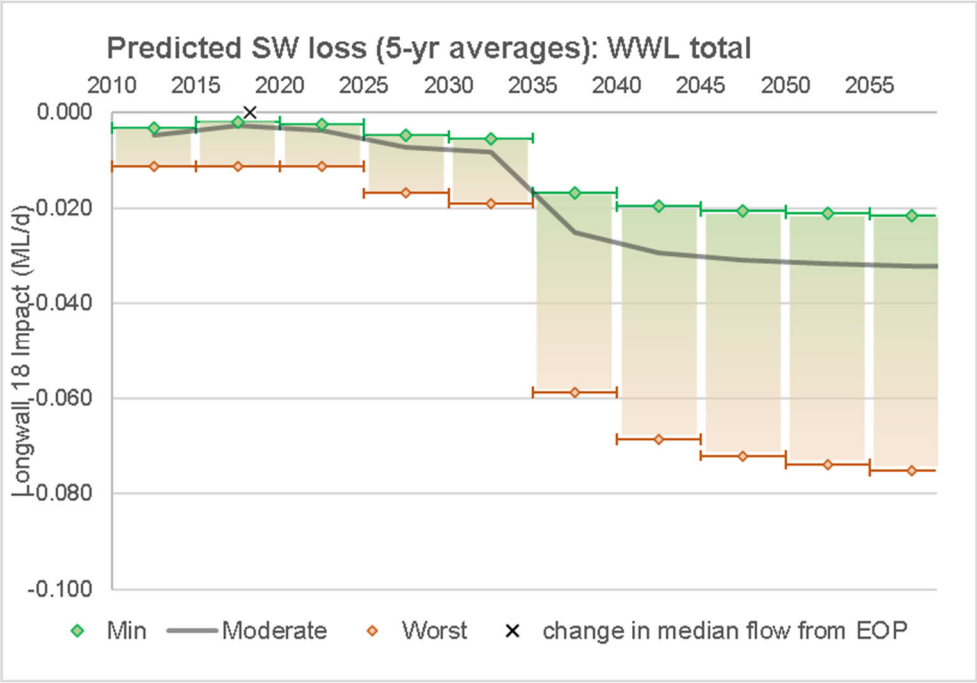


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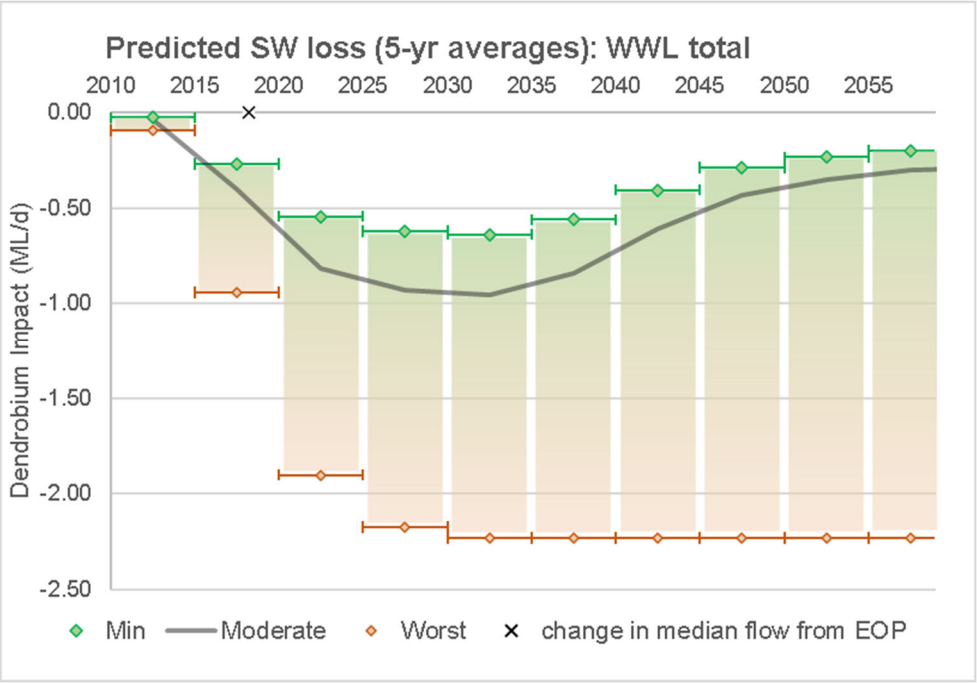




Surface Water losses – Longwall 18 Incremental effect



Surface Water losses – Dendrobium whole-of-mine effect



Attachment C – Subsidence Predictions and Impact Assessments

ILLAWARRA METALLURGICAL COAL:

Dendrobium – Longwall 18

Subsidence Predictions and Impact Assessments for the Natural and Built Features due to the Extraction of the Proposed Longwall 18 in Area 3B at Dendrobium Mine

DOCUMENT REGISTER

Revision	Description	Author	Checker	Date
01	Draft issue	JB	KK	20 Apr 20
A	Final issue	JB	KK	07 May 20
B	Updated swamp mapping	JB	KK	28 May 20
C	Minor updates	JB	KK	23 Jun 20

Report produced to: support the Subsidence Management Plan Application for the proposed Longwall 18 at Dendrobium Mine to be issued to the Department of Planning, Industry and Environment.

Previous reports:

MSEC459 (Rev. B) – *Dendrobium Area 3B – Longwalls 9 to 18 – Subsidence Predictions and Impact Assessments for Natural Features and Surface Infrastructure in Support of the SMP Application*, dated 27 September 2012.

MSEC651 (Rev. A) – *Dendrobium Mine – Area 3B – Longwall 10 – The Effects of the Proposed Modified Commencing End of Longwall 10 in Area 3B at Dendrobium Mine on the Subsidence Predictions and Impact Assessments*, dated 16 October 2013.

MSEC652 (Rev. B) – *Dendrobium Mine – Area 3B – The Effects of the Proposed Modifications to the Commencing End of Longwall 11 and to the Widths of Longwalls 12 to 18 in Area 3B at Dendrobium Mine on the Subsidence Predictions and Impact Assessments*, dated 22 May 2014.

MSEC785 (Rev. A) – *Dendrobium Mine – Area 3B – The Effects of the Proposed Modifications to the Finishing End of Longwall 11 and to the Commencing End of Longwall 12 in Area 3B at Dendrobium Mine on the Subsidence Predictions and Impact Assessments*, dated 29 July 2015.

MSEC792 (Rev. C) – *Dendrobium Area 3B – Longwalls 12 to 18 – Review of the Subsidence Predictions and Impact Assessments for Natural and Built Features in Dendrobium Area 3B based on Observed Movements and Impacts during Longwalls 9 and 10*, dated 9 December 2015.

MSEC865 (Rev. C) – *Dendrobium Mine – Area 3B – The Effects of the Proposed Modifications to the Ends of Longwalls 12 to 18 in Area 3B at Dendrobium Mine on the Subsidence Predictions and Impact Assessments*, dated 3 November 2016.

MSEC914 (Rev. A) – *Dendrobium Mine – Area 3B – The Effects of the Proposed Modified Commencing Ends of Longwalls 15 to 18 in Area 3B at Dendrobium Mine on the Subsidence Predictions and Impact Assessments*, dated 10 August 2017.

MSEC992 (Rev. B) – *Dendrobium – Longwalls 17 and 18 – Subsidence Predictions and Impact Assessments for the Natural and Built Features due to the Extraction of Longwalls 17 and 18 in Area 3B at Dendrobium Mine*, dated 19 November 2018.

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

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EXECUTIVE SUMMARY

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. The Mine is located to the west of Wollongong and the Illawarra Escarpment and to the east of the township of Bargo.

IMC is preparing a Subsidence Management Plan (SMP) Application for Longwall 18 (LW18). This subsidence report provides information to support the SMP Application which will be submitted to the Department of Planning, Industry and Environment.

The predicted subsidence parameters for the proposed LW18 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 3200 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 strains are 8 mm/m tensile and compressive based on the 95 %confidence levels.

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 LW18; 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, drainage lines, cliffs, minor cliffs, rock outcrops, steep slopes, swamps, a disused railway corridor, unsealed roads and tracks, the Avon and Cordeaux Reservoirs and associated dam walls, Aboriginal heritage sites and survey control marks.

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 located 1 km east of the proposed LW18, at its closest point. At this distance, the predicted incremental vertical subsidence, upsidence and closure for the creek, due to the mining of LW18, 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 Wongawilli Creek due to the mining of LW18.

  The Waterfall along Wongawilli Creek (Ref. WC-WF54) is located 1 km from the finishing (i.e. eastern) end of LW18. At this distance, the waterfall is not expected to experience measurable conventional or valley related effects. It is unlikely, therefore, that adverse impacts would occur at the waterfall due to the mining of LW18.

- Native Dog Creek is located 310 m south-west of the proposed LW18, at its closest point. The upper reaches of Native Dog Creek is located directly above the existing longwalls at Elouera Colliery. Fracturing could develop along Native Dog Creek where it is located within approximately 400 m of the proposed LW18. Type 3 impacts are possible, but are considered unlikely, as only two cases have been observed at similar distances from Dendrobium LW9 to LW15.

- Drainage lines ND1, ND1C and their tributaries are located directly above and adjacent to the proposed LW18. Drainage lines LA1, LA2, ND1A, ND1B, ND2, ND2A, WC7 and WC12 are also located within the Study Area based on the 600 m boundary. These drainage lines are first and second order streams that form tributaries to Lake Avon and Wongawilli Creek.

  The drainage lines located directly above the mining area could experience the full range of predicted subsidence effects. Localised ponding due to mining-induced tilt 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 and adjacent to the proposed LW18. 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 no cliffs that have been identified within the Study Area. The nearest cliffs are located along Wongawilli Creek around 1 km east of the proposed LW18. At this distance, the cliffs are not predicted to experience measurable conventional or valley related effects. Impacts on cliffs have not been observed at this distance outside of previous longwall mining in the Southern Coalfield. It is unlikely, therefore, that adverse impacts would occur at the cliffs due to the mining of LW18.

- 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 less than 50 mm up to 150 mm in width.
- There are six swamps that have been identified partially or wholly within the Study Area based on the 600 m boundary. Swamp Den35a is partially located above the proposed LW18 and Swamps Den14 and Den149 are located above the previous LW16 and LW17. Swamps Den35b, Den150 and Den151 are located at minimum distances of 85 m to 325 m south of LW18.

  The predicted post-mining grades within the swamps are similar to the natural grades. There are small reductions in grades along the drainage lines near these swamps; however, adverse changes in the levels of ponding or scouring within the swamps are not anticipated due to the mining-induced vertical subsidence or tilt.

  Fracturing of the bedrock could occur beneath the swamps that are located above and adjacent to the mining area. 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 mining area. 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.
- The disused Maldon-Dombarton railway corridor follows the ridgeline that crosses the north-eastern corner of the proposed LW18. The extraction of the longwalls could result in impacts on the cuttings, including the fracturing and mobilisation of the joints and some spalling of the exposed rock faces that could result in isolated rockfalls. Only minor impacts have been observed along the railway corridor above the previously extracted longwalls in Area 3B at the Mine and at the nearby Elouera Colliery.
- 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.
- Lake Avon, or the Avon Reservoir, is located 300 m west of the proposed LW18, at its closest point. The maximum predicted valley related effects at Lake Avon, due to the mining in Area 3B, are 50 mm upsidence and 100 mm closure.

  Whilst the predicted valley related effects are small, it is possible that minor cracking could occur in the bedrock, as has been observed in the Southern Coalfield up to 400 m from previously extracted longwalls. It is not expected that this minor cracking in the lake bed would result in adverse impacts on the reservoir.

  The Avon Dam Wall is located at the northern end of the reservoir and it is at a distance of approximately 8 km from the proposed LW18. The Cordeaux Dam Wall and the Upper Cordeaux No. 2 Dam Wall are located approximately 7 km north and 6 km east, respectively, from the proposed longwall. At these distances, the predicted vertical and horizontal movements at the dam walls are very small and are unlikely to be measurable**.**
- There are three Aboriginal heritage sites that have been identified within the Study Area. These sites comprise two rock shelters with art and one rock shelter with art and grinding grooves.

  Two rock shelters are located above or adjacent to the chain pillar between LW17 and LW18. The extraction of these longwalls are 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 mining area 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.

  The other rock shelter is located outside of the mining area at a distance of 200 m from the proposed LW18. The potential for adverse impacts at this site are considered low.

  The grinding groove site is located above LW17 immediately adjacent to the longwall maingate. The extraction of LW17 and LW18 are likely to result in fracturing of the exposed bedrock. The potential for adverse impacts on the grinding groove site has been assessed as unlikely (i.e. less than 10 %). However, it is possible that this site could be impacted by fracturing of the bedrock due to mining.
- 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 be re-established after they have stabilised.

The assessments provided in this report indicate that the assessed 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.

Mine Subsidence Engineering Consultants (MSEC) was previously commissioned by IMC to prepare subsidence predictions and impact assessments for Longwalls 9 to 18 (LW9 to LW18) in Area 3B at the Mine. Report No. MSEC459 (Rev. B) was issued in September 2012, which supported the original Subsidence Management Plan (SMP) Application for these longwalls.

Subsequently, the commencing (i.e. western) ends of LW10 to LW18 and the finishing (i.e. eastern) ends of LW11, LW12 and LW14 to LW18 were shortened from the extents adopted in Report No. MSEC459 and the original SMP Application. The maximum mining heights for LW14 to LW18 were also reduced from 4.6 m to 3.9 m. Reports Nos. MSEC651 (Rev. A), MSEC652 (Rev. B), MSEC785 (Rev. A), MSEC865 (Rev. C) and MSEC914 (Rev. A) were prepared in support of the Modification Applications.

The subsidence prediction model was also reviewed and re-calibrated, based on the updated monitoring data from LW7 and LW8 in Area 3A and LW9 and LW10 in Area 3B. The subsidence predictions and impact assessments for the natural and built features were updated based on the re-calibrated subsidence model and were provided in Report No. MSEC792 (Rev. C). The latter Reports Nos. MSEC865 and MSEC914 also adopted the re-calibrated subsidence model.

MSEC also previously prepared Report No. MSEC992 (Rev. B) in support of the SMP Applications for both LW17 and LW18. However, since that report, the finishing end of LW18 has been shortened by 910 m. This subsidence report provides updated subsidence predictions and assessment of potential impacts based on its modified length.

The existing and approved LW9 to LW17 and the proposed LW18 in Area 3B are shown in Drawings Nos. MSEC1103-01 and MSEC1103-02, in Appendix D. The proposed LW18 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.

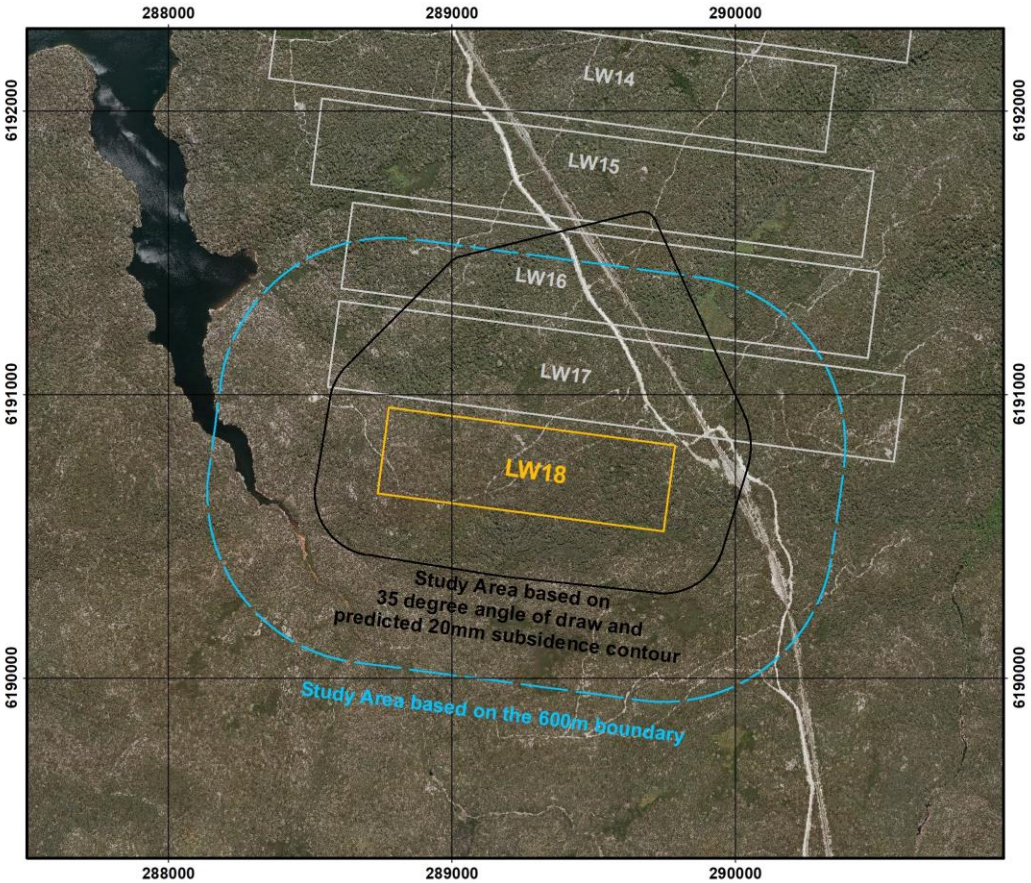


Fig. 1.1 Orthophotograph showing LW18 and the Study Area

IMC is preparing an SMP Application for the proposed LW18 in Area 3B. MSEC has been commissioned by IMC to:

- prepare subsidence predictions for the proposed LW18, 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 LW18 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 LW18 is shown in Drawings Nos. MSEC1103-01 and MSEC1103-02, 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 LW18

Longwall	Overall void length including installation heading (m)	Overall void width including first workings (m)	Overall tailgate chain pillar width (m)
LW18	1018	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 1009 m. The longwall face width excluding the first workings is 295 m. The longwall will be extracted towards the main headings (i.e. retreat mining from the west towards the east) within the Wongawilli Seam.

LW18 has been shortened from its original length of 2053 m, as adopted in Report No. MSEC459 and the original SMP Application for LW9 to LW18. Initially, the commencing (i.e. western) end was shortened by 60 m and the finishing (i.e. eastern) end was shortened by 65 m. Report No. MSEC992 was based on this modified longwall length of 1928 m. The finishing end has now been shortened by an additional 910 m, now providing an overall void length of 1018 m, as adopted in this report.

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. MSEC1103-03 to MSEC1103-05. The definition of the Study Area is provided in Section 2.1.

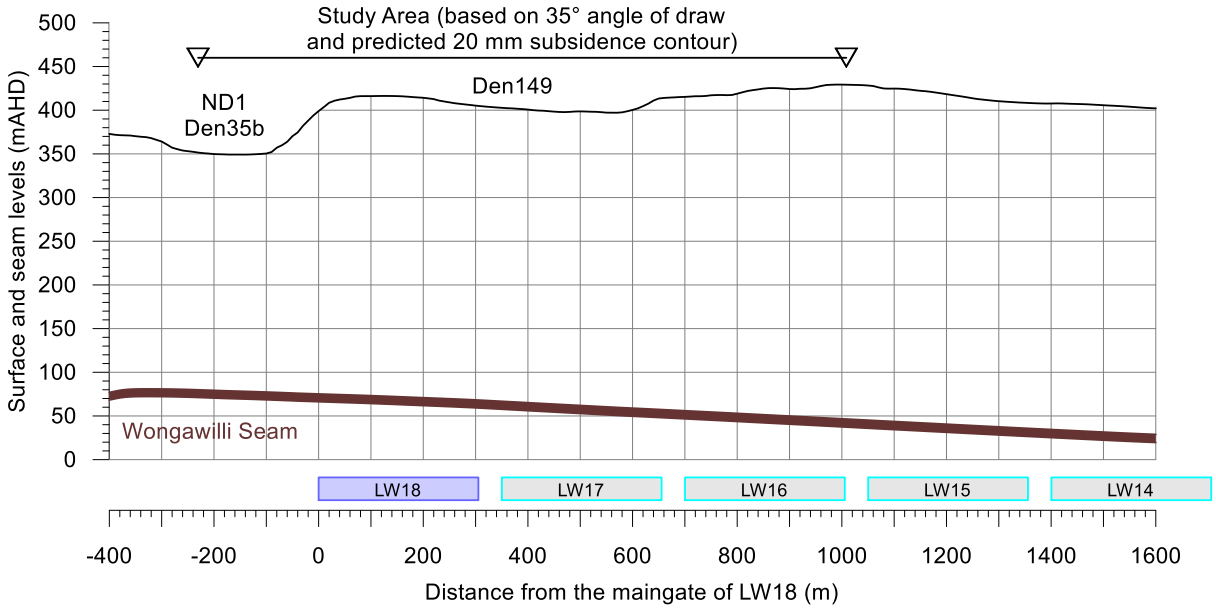


Fig. 1.2 Surface and seam levels along Section 1 (cross-section)

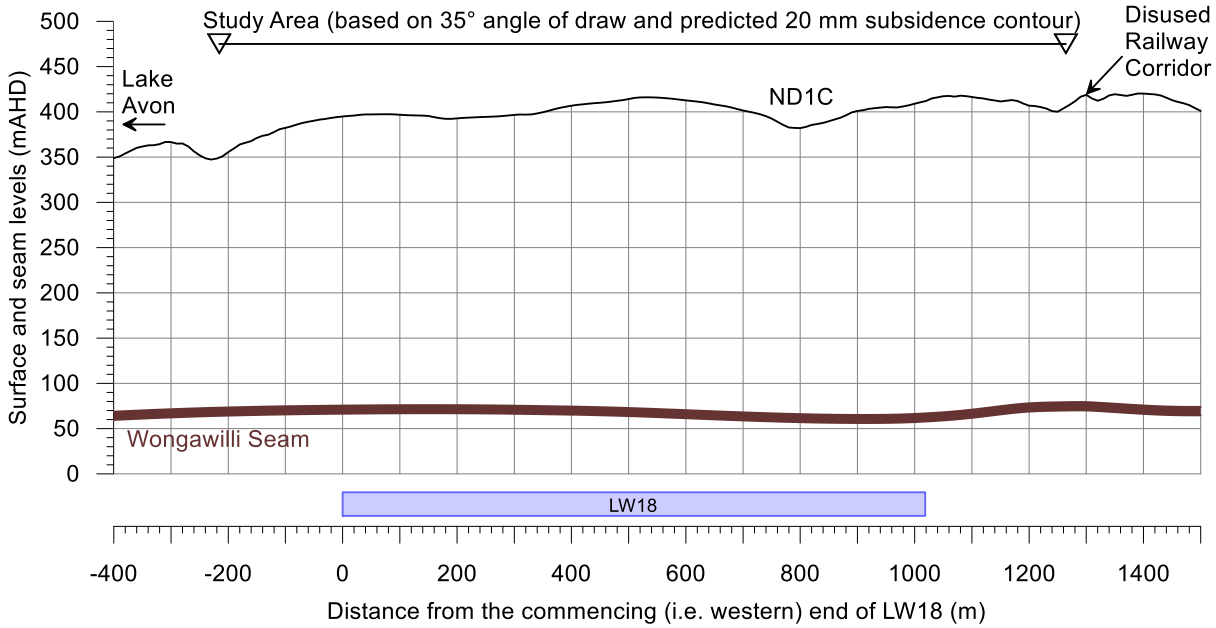


Fig. 1.3 Surface and seam levels along Section 2 (long-section)

The surface level contours are shown in Drawing No. MSEC1103-03. The proposed longwall is located to the east of Lake Avon and to the west of Wongawilli Creek. A ridgeline crosses outside and adjacent to the finishing (i.e. eastern) end of LW18 along which the incomplete and disused Maldon-Dombarton railway corridor generally follows. The drainage lines on the western side of the railway corridor fall towards Lake Avon and the drainage lines on the eastern side of the corridor fall towards Wongawilli Creek.

The surface levels directly above LW18 vary between a minimum of 365 metres above Australian Height Datum (mAHD), along Drainage Line ND1C above the maingate of LW18, and a maximum of 435 mAHD along the ridgeline above the north-eastern corner of the longwall. The natural surface above LW18 falls towards the tributaries to Lake Avon.

The seam floor contours, seam thickness contours and depth of cover contours for the Wongawilli Seam are shown in Drawings Nos. MSEC1103-04, MSEC1103-05 and MSEC1103-06, respectively. The seam generally dips from the south towards the north with an average grade across the mining area of approximately 2 %, or 1 in 50. A syncline crosses LW18 with a north-northeast to south-southwest orientation. The degree of folding increases from the north towards the south of this feature. The maximum seam dip within the mining area is approximately 6 % at the maingate of LW18.

The depths of cover to the Wongawilli Seam directly above the proposed LW18 vary between 300 m and 370 m. The minimum depth of cover occurs along Drainage Line ND1C above the maingate of LW18. The maximum depth of cover occurs along the ridgeline above the north-eastern corner of the longwall. The average depth of cover directly above LW18 is 335 m.

The Wongawilli Seam is nominally 10 m thick and contains numerous bands of non-coal material. The economic part of the Wongawilli Seam is the basal section which has a thickness ranging between 3.6 m to 4.1 m. 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 LW18 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 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).

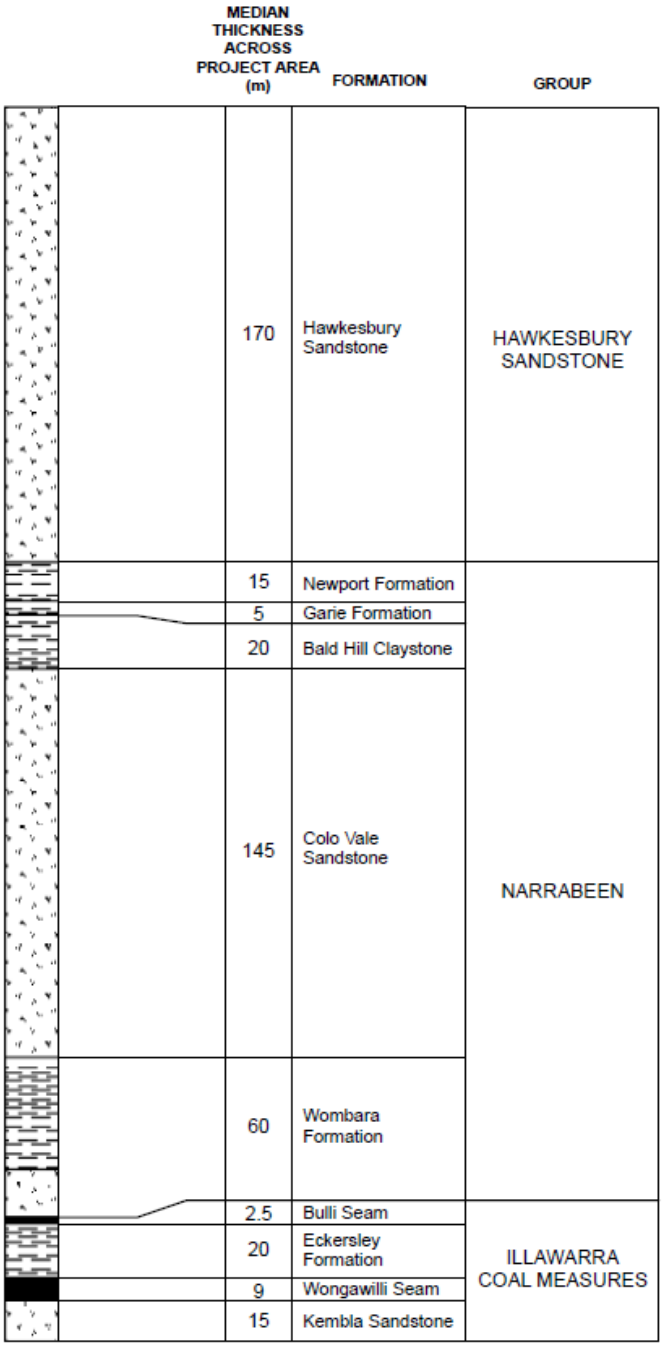


Fig. 1.4 Typical stratigraphic section for the Mine (Source: IMC)

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 LW18 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.

Extensive exploration activities have been carried out by IMC in Dendrobium Area 3B including seismic lines, surface geological mapping, underground geological mapping, aeromagnetic and related remote sensing surveys (IMC, 2020b). The geological structures identified or inferred at the Mine are shown in Drawing No. MSEC1103-07.

The Elouera Fault (DF11) comprises a series of faults located south of LW18, between the current mining area and the existing Elouera workings. This fault zone has a downthrow ranging between 20 m and 40 m. A structurally disturbed zone, comprising a series of three faults with displacements of 10 m to 15 m, crosses the LW18 maingate between cut-throughs 7 and 8. The finishing end of LW18 has been shortened to avoid this structurally disturbed zone (IMC, 2020b).

A series of three dykes (Refs. DD26, DD36 and DD37) with a SW-NE orientation cross the structurally disturbed zone to the east of the proposed LW18. These dykes have been intersected previously and they did not have a significant impact on the mining conditions (IMC, 2020b). The Dendrobium Nepheline Syenite sill is located further to east. This sill has intruded into the upper section of the Wongawilli Seam; however, it has migrated down into the basal section to the east of the main headings.

Surface lineaments with WNW-ESE orientations have been identified above the western end and the central part of the proposed LW18. A surface lineament with a north-south orientation has also been identified above the eastern end of this longwall. 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 LW18 are similar to those mapped elsewhere in Area 3B. It is considered unlikely, therefore, that these structures would adversely affect the subsidence predictions and assessed impacts for the proposed LW18.

The soil landscape profiles within Area 3B can be seen in Fig. 1.5 (DNR, 1996). The surface generally comprises soils derived from highly weathered sandstone. The major soil landscape types within Area 3B are Hawkesbury (ha), Penrose Variant A (pea), Lucas Heights (lh), Gymea (gy) and Stockyard Swamp (ss).

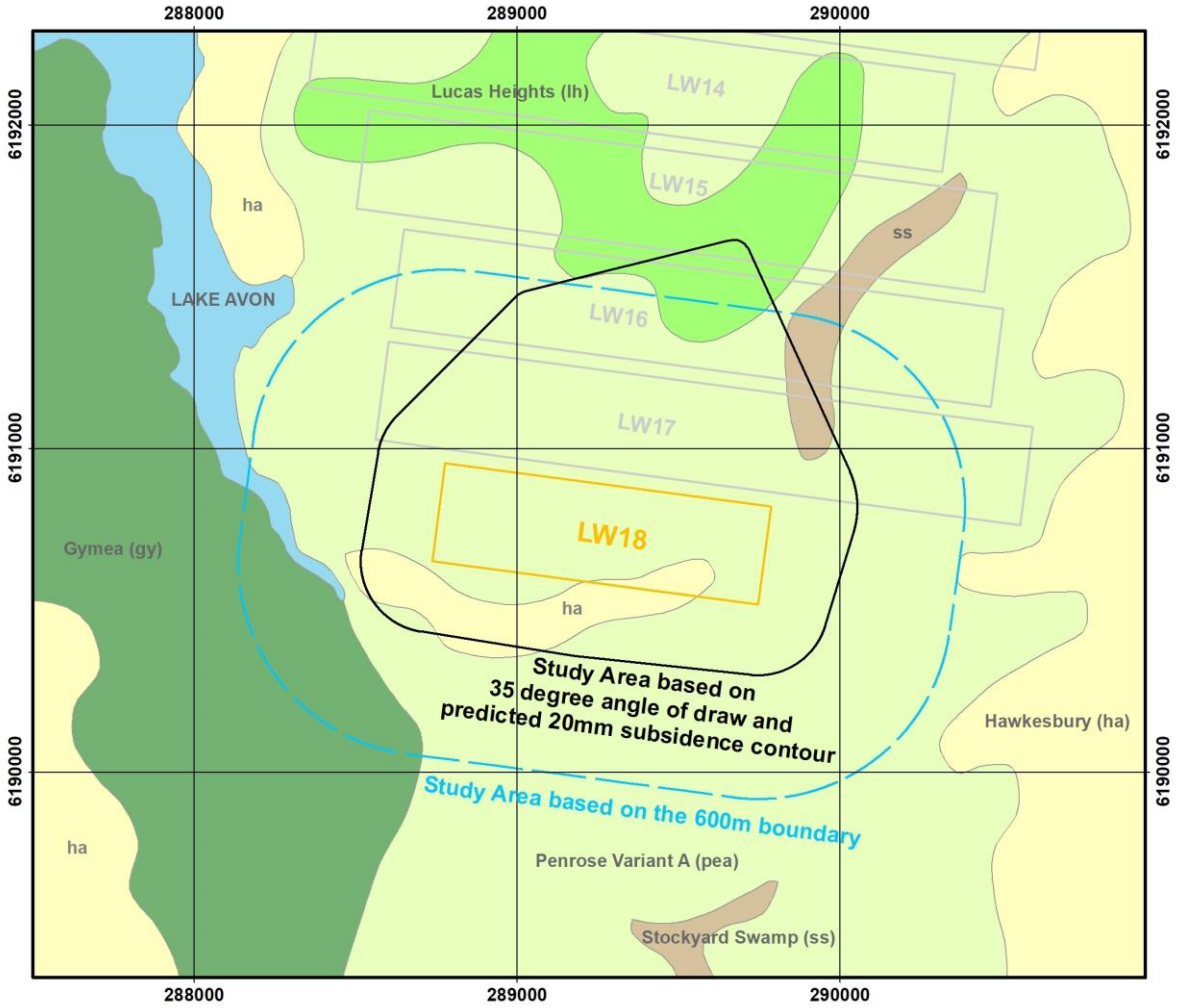


Fig. 1.5 Soil landscape profiles within Area 3B at the Mine (DNR, 1996)

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 LW18. 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 LW18; and
- The predicted limit of vertical subsidence, taken as the incremental 20 mm subsidence contour, due to the mining of LW18 only.

The depths of cover contours for the Wongawilli Seam are shown in Drawing No. MSEC1103-06. The depth of cover varies between 295 m and 380 m directly above the proposed LW18. The 35° angle of draw line, therefore, has been determined by drawing a line that is a horizontal distance varying between 207 m and 266 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 LW18, 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. MSEC1103-11, in Appendix D.

The predicted incremental 20 mm subsidence contour extends beyond the 35° angle of draw above the previous LW16 and LW17. 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. MSEC1103-01 and MSEC1103-02, in Appendix D.

The Study Area based on a 600 m boundary around the extents of the proposed LW18 is also shown in Drawings Nos. MSEC1103-01 and MSEC1103-02. 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 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. MSEC1103-08 to MSEC1103-10, 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	✓	5.3 to 5.5
Aquifers or Known Groundwater Resources	✓	5.6
Springs	×	
Sea or Lake	×	
Shorelines	×	
Natural Dams	×	
Cliffs or Pagodas	×	5.7
Steep Slopes	✓	5.8
Escarpments	×	
Land Prone to Flooding or Inundation	×	
Swamps, Wetlands or Water Related Ecosystems	✓	5.11
Threatened or Protected Species	✓	5.12
National Parks	×	
State Forests	×	
State Conservation Areas	×	
Natural Vegetation	✓	5.12
Areas of Significant Geological Interest	×	
Any Other Natural Features Considered Significant	×	
PUBLIC UTILITIES		
Railways	✓	6.1
Roads (All Types)	✓	6.2
Bridges	×	
Tunnels	×	
Culverts	×	
Water, Gas or Sewerage Infrastructure	×	
Liquid Fuel Pipelines	×	
Electricity Transmission Lines or Associated Plants	×	
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 4.5.

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 high, say greater than 400 m, the observed subsidence profiles along monitoring lines are generally smooth. Where the depth of cover is shallow, say 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 remain 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 observed occurrence of both the conventional and non-conventional ground movements and impacts. The analysis of strains provided in Section 4.3 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 5.8.

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.

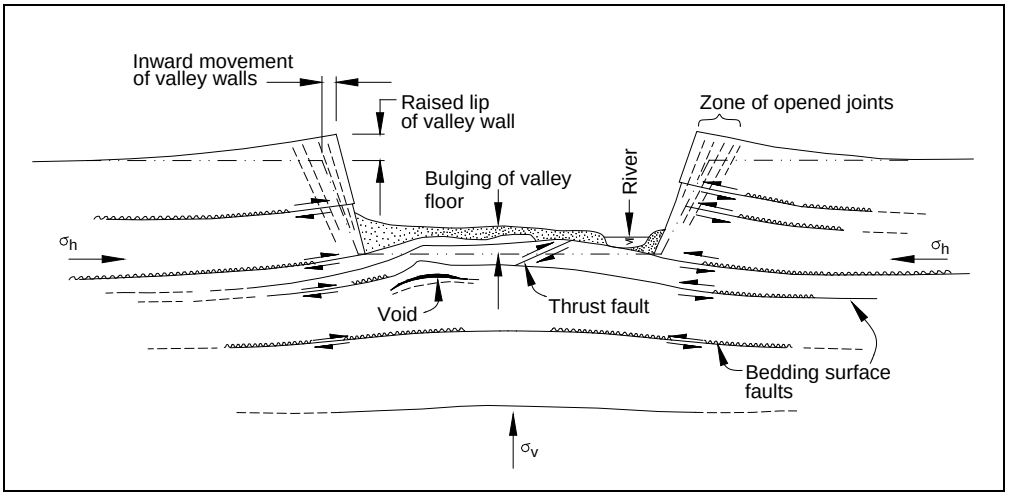


Fig. 3.1 Valley formation in flat-lying sedimentary rocks (after Patton and Hendren 1972)

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. C18015 (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 the 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 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 the 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 original 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 current mining in Area 3B at the Mine are being measured using ALS / LiDAR surveys. The measured changes in surface level due to the extraction of LW9 to LW15 are shown in Fig. 3.2. The data located outside the predicted limit of vertical subsidence (i.e. total 20 mm subsidence contour) have been removed for clarity.

The LiDAR surveys have an accuracy for absolute level in the order of ±100 mm. The accuracy of the measured changes in surface level (i.e. the difference between two surveys), therefore, is in the order of ±200 mm.

The contours of the measured changes in surface level, developed from the LiDAR surveys, show the changes in the heights of points at fixed positions in space (i.e. eastings and northings). This differs from traditional subsidence contours that include both the vertical and horizontal components of the 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 that are fixed to the ground.

The contours can contain artefacts (i.e. locally increased or decreased movements), particularly in the locations of steeply incised terrain, such as at the cliffs and steep slopes. These artefacts can be seen in Fig. 3.2 as the localised areas of dark purple to red contours above the longwalls and the lower level subsidence outside the extents of the longwalls.

The change in surface level at a fixed position in space (i.e. easting and northing), therefore, can be large in the locations of cliffs and steep slopes and does not provide a true indication of the actual vertical subsidence at a point on the ground. However, where the ground is reasonably flat, the contours of the measured changes in surface level should provide a good indication of the actual vertical subsidence.

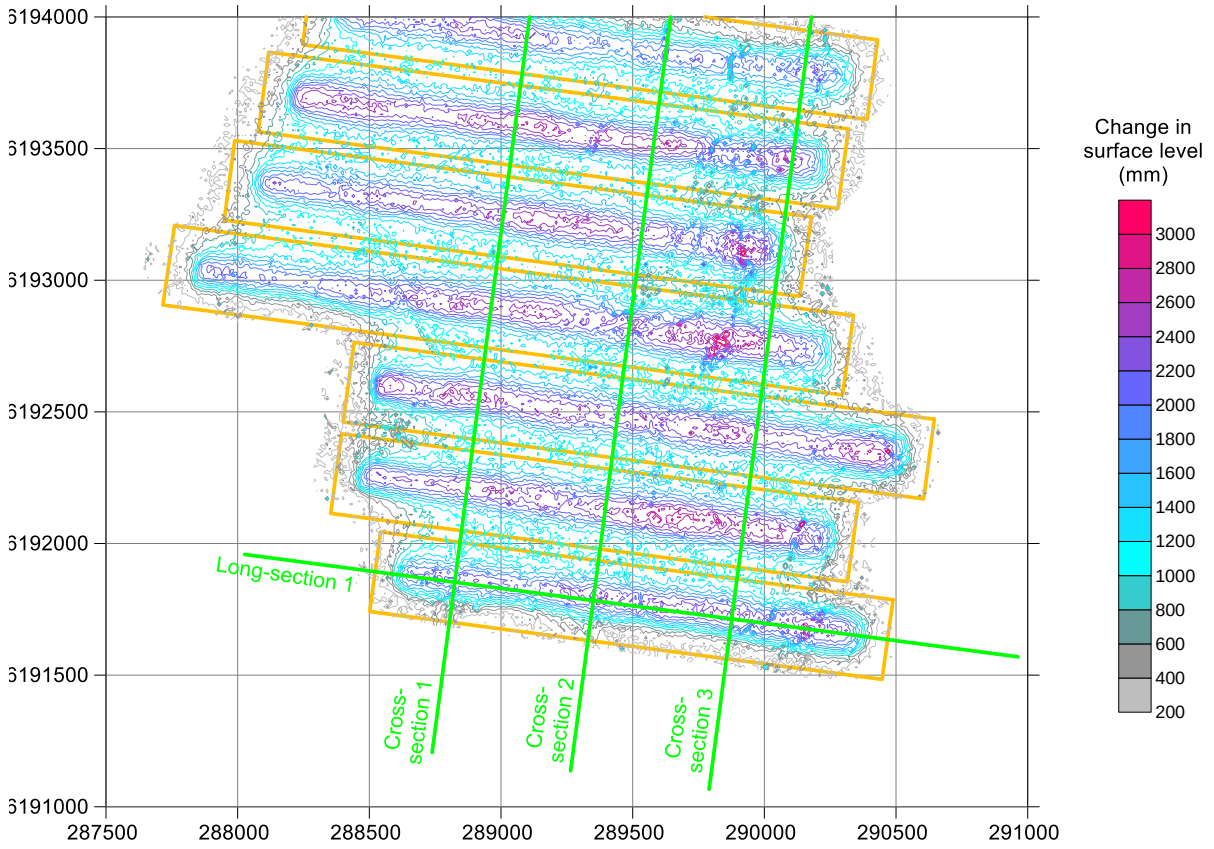


Fig. 3.2 Measured changes in surface level due to LW9 to LW15 in Area 3B

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.

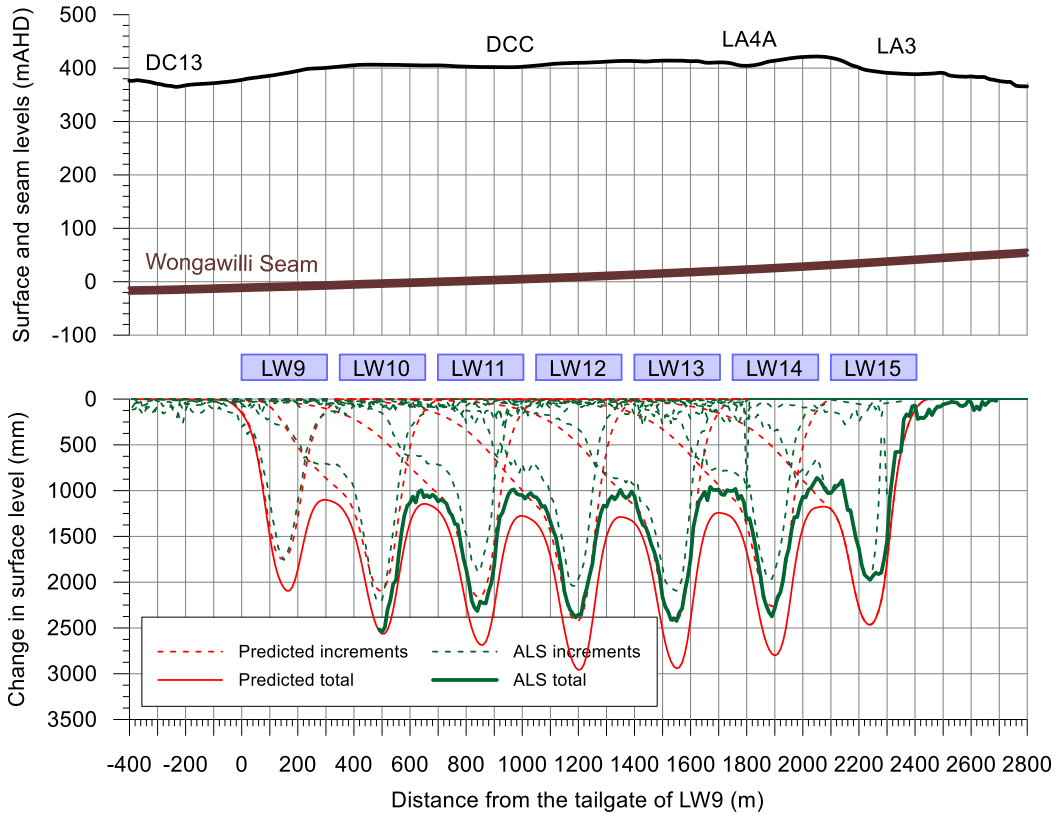


Fig. 3.3 Measured and predicted changes in surface level along Cross-section 1

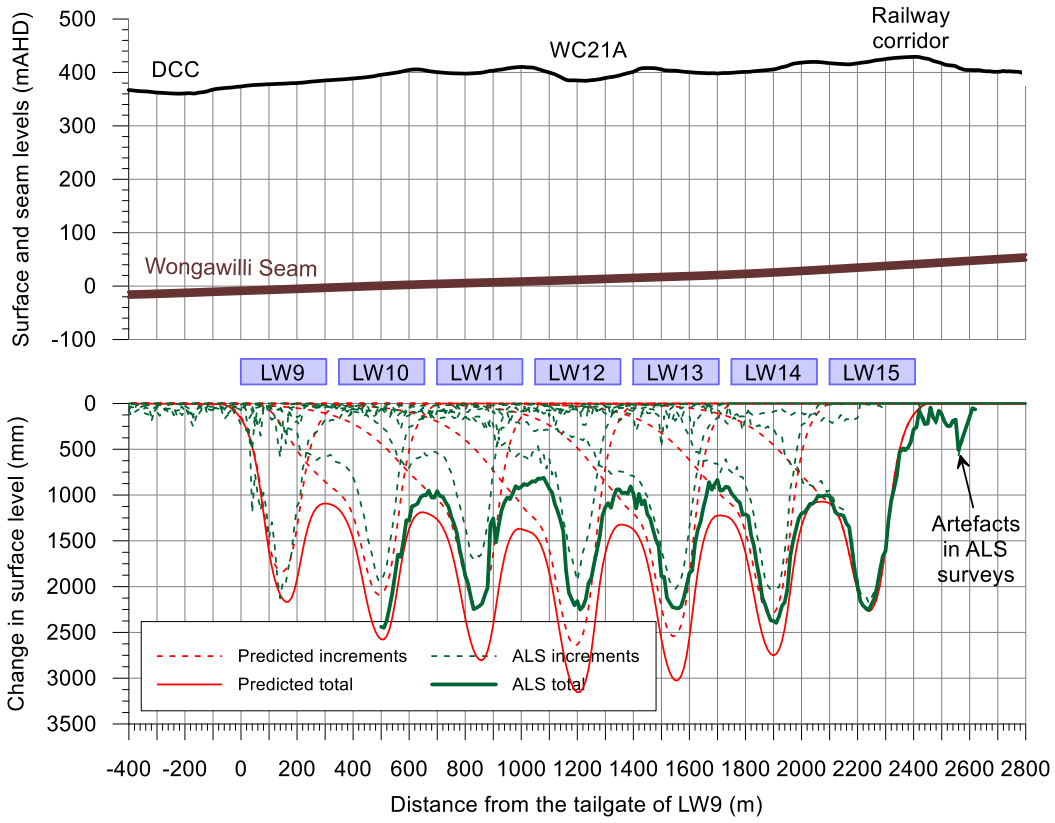


Fig. 3.4 Measured and predicted changes in surface level along Cross-section 2

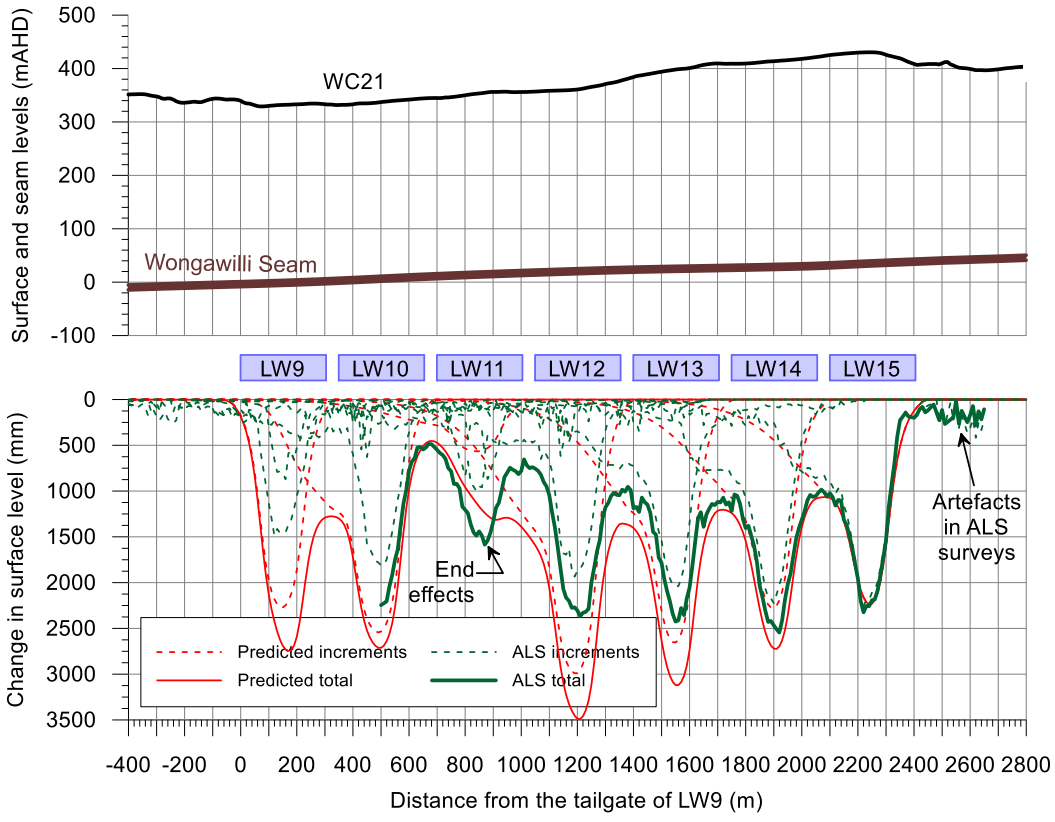


Fig. 3.5 Measured and predicted changes in surface level along Cross-section 3

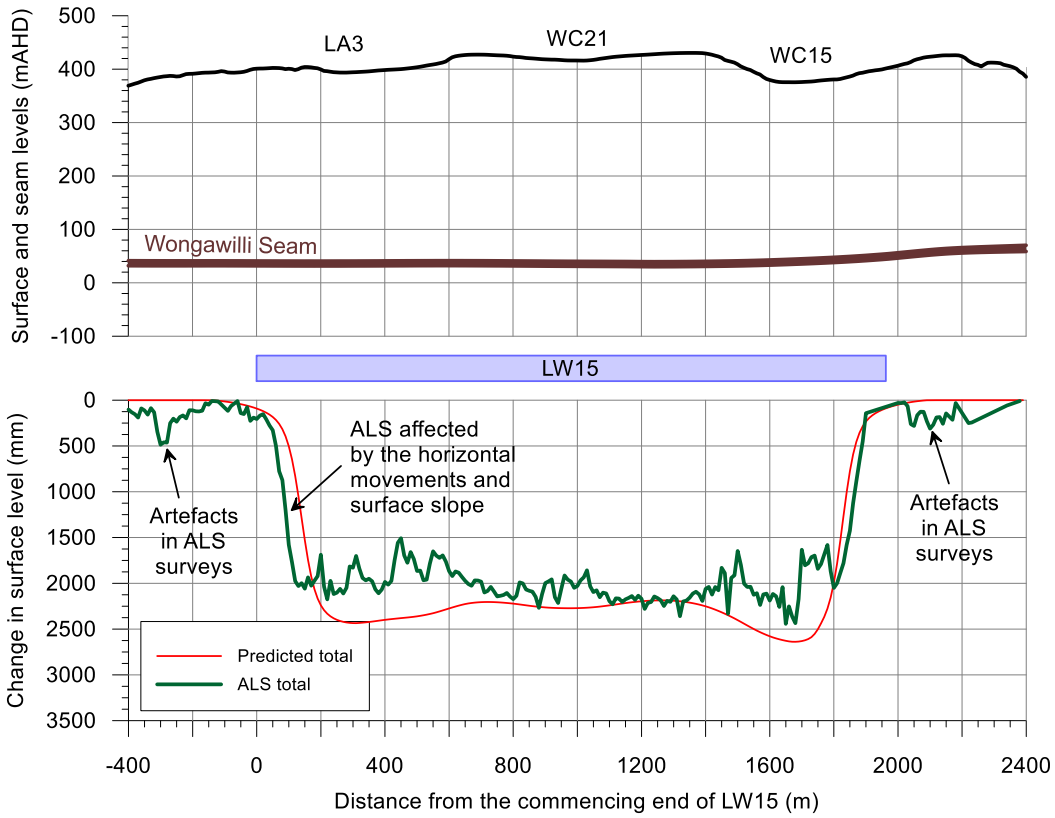


Fig. 3.6 Measured and predicted changes in surface level along Long-section 1

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 similar to or 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.

The measured change in surface level along Cross-section 3 (refer to Fig. 3.5) is slightly greater than the predicted vertical subsidence above LW11. This cross-section is located close to the finishing end of LW11 and, therefore, the predictions are influenced by the longwall end effects. The difference between the measured and predicted movements are in the order of accuracy of the measurement method.

The measured change in surface level along Long-section 1 (refer to Fig. 3.6) is greater than the predicted vertical subsidence above the commencing end of LW15 (i.e. left side of figure). However, this may be partly due to the surveying tolerance and the effects of the horizontal movements and sloping terrain on the LiDAR surveys. The ground directly above the commencing end of LW15 has moved towards the longwall (i.e. following the extraction face) based on the vectors of horizontal movement at the 3D ground monitoring points. The natural surface dips towards the west in this location (i.e. towards Lake Avon). The mining-induced horizontal movement, therefore, results in the measured changes in level at a fixed position to be greater than the true vertical subsidence above the commencing end of LW15.

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.

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 LW15 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 LW15 are illustrated in Fig. 3.7. The measured versus the predicted values are shown on the left-hand side of this figure. The ratios of the measured to predicted values (for magnitudes greater than 50 mm) are shown on the right-hand side of this figure. The predictions are based on the re-calibrated subsidence model using the MSEC792 prediction curves.

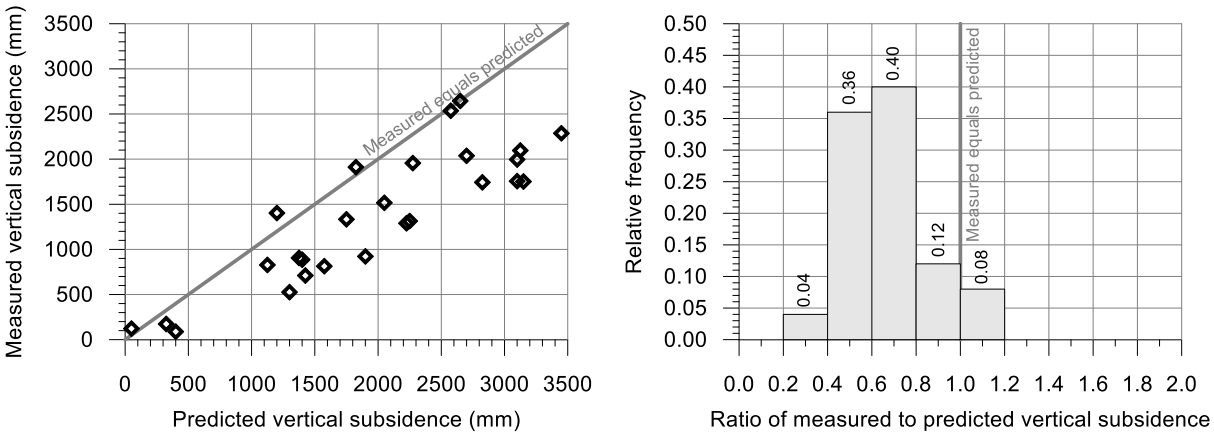


Fig. 3.7 Comparison of measured and predicted subsidence for the ground monitoring lines

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 0.68.

The measured total vertical subsidence movements exceed the predicted values in 2 of the 25 cases (i.e. 8 % of the monitoring lines). The exceedances occur where the monitoring lines are located above or near to 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 two monitoring lines are 1.05 and 1.17 and, therefore, they 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 at the completion of LW15 are illustrated in Fig. 3.8. The measured versus the predicted values are shown on the left-hand side of this figure. The ratios of the measured to predicted values (for magnitudes greater than 50 mm) are shown on the right-hand side of this figure. The predictions are based on the 2002 ACARP method.

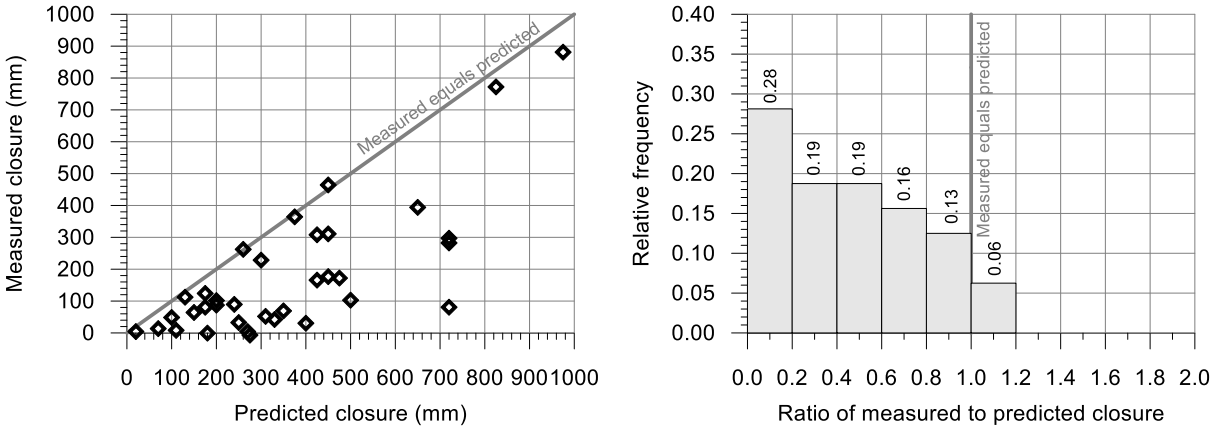


Fig. 3.8 Comparison of measured and predicted closure for the ground monitoring lines

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 0.44, i.e. the measured closures are, on average, around half of those predicted.

The measured total closure movements exceed the predicted values in 2 of the 34 cases (i.e. 6 % of the monitoring lines). It is noted that there were additional cases where the measured closures exceeded the predicted values at the completion of earlier longwalls. However, the measured total closures were less than the predicted values in all but two cases after the completion of LW15. The ratio of the measured to predicted total closure for the two exceedance cases are 1.01 and 1.03 and, therefore, they are 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 %.

3.6.3. Use of the calibrated IPM for the proposed LW18

The calibrated IPM based on the MSEC792 prediction curves has been reviewed based on the ground movement monitoring data from LW9 to LW15 in Area 3B. A comparison of the mining geometry for the proposed LW18 with that for the completed longwalls in Area 3B is provided in Table 3.1.

Table 3.1 Comparison of the mine geometry for the longwalls in Areas 3B

Parameter	Proposed LW18		Completed LW9 to LW15	
	Range	Average	Range	Average
Longwall width	305	305	305	305
Depth of cover	295 ~ 380	335	310 ~ 410	380
W/H ratio	0.80 ~ 1.03	0.91	0.74 ~ 0.98	0.80
Extraction height	3.9	3.9	3.4 ~ 4.5	3.9

The depths of cover above LW18 are slightly less than the depths of cover above the completed LW9 to LW15. The width-to-depth ratios for these longwalls, therefore, are slightly greater than those for the completed longwalls. The extraction height for LW18 is similar to the average extraction height for the completed LW9 to LW15.

It was considered that the increased vertical subsidence that developed above the initial longwalls in Area 3B was due to the higher depths of cover and wider longwall void widths, as compared with those in Area 2. The depths of cover above LW18 are slightly less than the depths of cover above LW9 to LW15. The lower depths of cover for LW18 will result is less pillar compression and, hence, lower overall vertical subsidence when compared with that for the initial longwalls in the series.

It is considered appropriate, therefore, to adopt the MSEC792 prediction curves for LW18. These prediction curves provide an additional 30 % to the maximum incremental vertical subsidence for each of the longwalls, when compared with that predicted using the standard IPM model. The calibrated model is therefore anticipated to provide conservative predictions for LW18.

4.1. Introduction

The following sections provide the maximum predicted conventional subsidence parameters resulting from the extraction of the proposed LW18 in Area 3B. 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 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 LW18 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 LW18

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})
LW18	2750	35	0.80	0.80

The predicted total vertical subsidence contours resulting from the mining of LW9 to LW18 are shown in Drawing No. MSEC1103-12, 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, approved and proposed longwalls.

Table 4.2 Maximum predicted total vertical subsidence, tilt and curvature within the Study Area resulting from the mining of LW9 to LW18

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})
LW9 to LW17	3000	35	0.90	0.90
LW18	3200	40	1.0	1.0

The maximum predicted total vertical subsidence of 3200 mm represents 82 % 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 LW18. 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. MSEC1103-11 and MSEC1103-12.

The predicted subsidence effects within the Study Area for LW18 are similar to but slightly less than the maximum predicted values elsewhere in Area 3B. Greater subsidence effects occur above the earlier longwalls in the series due to shallower depths of cover down to 280 m and due to greater mining heights up to 4.6 m. The maximum predicted subsidence anywhere above the existing, approved and proposed longwalls in Area 3B is 3600 mm, which occurs in the northern part of the mining area .

4.3. 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 in 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 LW18, 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 any 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 the 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 LW18, therefore, have been determined using these ground monitoring lines as well as data from other NSW coalfields, where the mining geometries are reasonably similar to those at the Mine.

A comparison of the mining geometry for LW18 with that for the previously extracted longwalls used in the strain analysis is provided in Table 4.3. There is a total of 46 ground monitoring lines located above 111 previously extracted longwalls in the Hunter and Newcastle Coalfields.

Table 4.3 Comparison of the mine geometry for LW18 with the longwalls from the NSW coalfields used in the strain analysis

Parameter	Dendrobium LW18		Longwalls used in strain analysis	
	Range	Average	Range	Average
Longwall width	305	305	120 ~ 410	190
Depth of cover	295 ~ 380	335	100 ~ 360	180
W/H ratio	0.80 ~ 1.03	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 LW18. The strain analysis, therefore, should provide a reasonable indication of the range of potential strains resulting from the mining of LW18.

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.

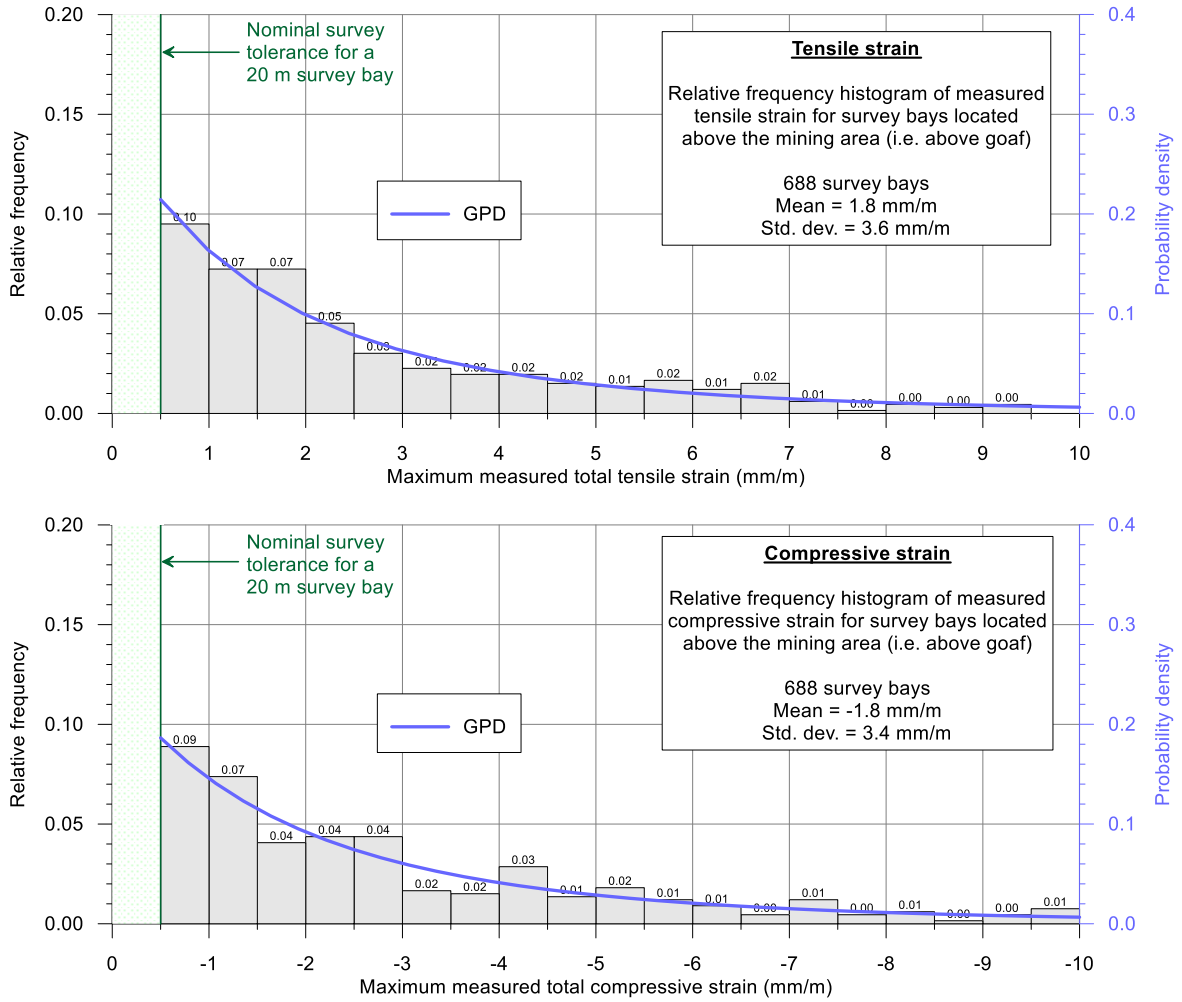


Fig. 4.1 Distributions of the measured maximum tensile and compressive strains during the mining of previous longwalls in the NSW coalfields for bays located above goaf

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.

4.4. 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 LW18 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 approximately 700 mm at the Mine, with an average measured value of approximately 300 mm.

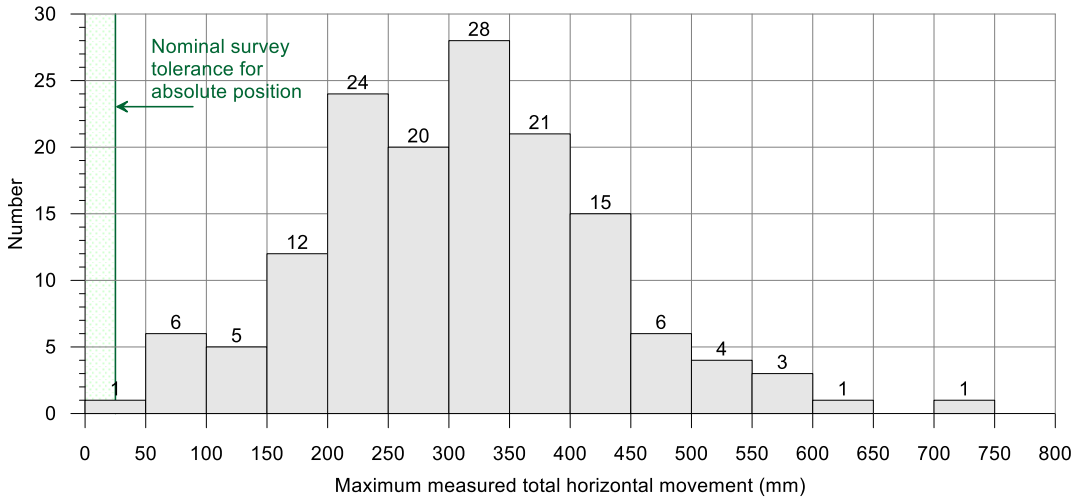


Fig. 4.2 Distribution of the maximum measured horizontal movements for the 3D marks located directly above the longwalls in Dendrobium Areas 1, 2, 3A and 3B

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.

4.5. 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 the 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 the Mine are also shown in this figure.

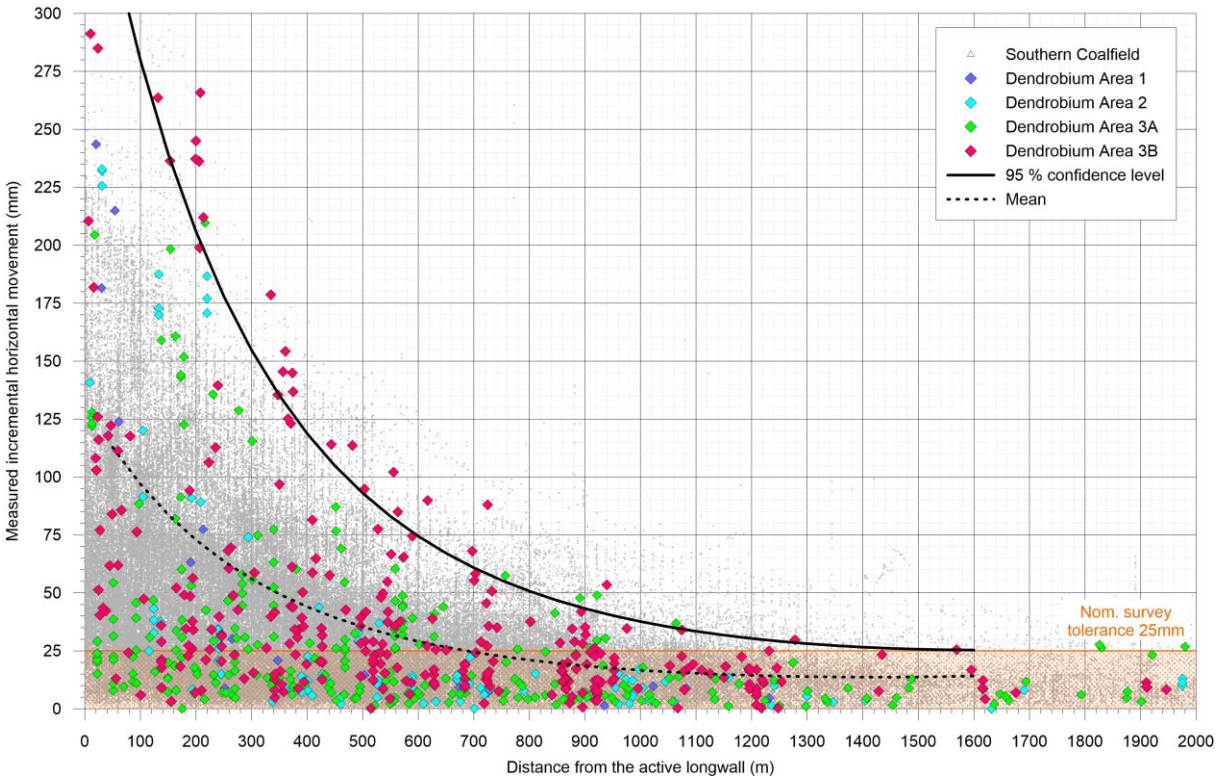


Fig. 4.3 Measured incremental far-field horizontal movements at Dendrobium Mine and elsewhere in the Southern Coalfield

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.

4.6. 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 5.3 to 5.5. 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 5.8.

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, as previously discussed in Section 4.3. 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.

4.7. 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 5.8.

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 5.3 to 5.5.

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 LW15 in Area 3B. The distribution of the measured widths of these surface deformations is illustrated in Fig. 4.4.

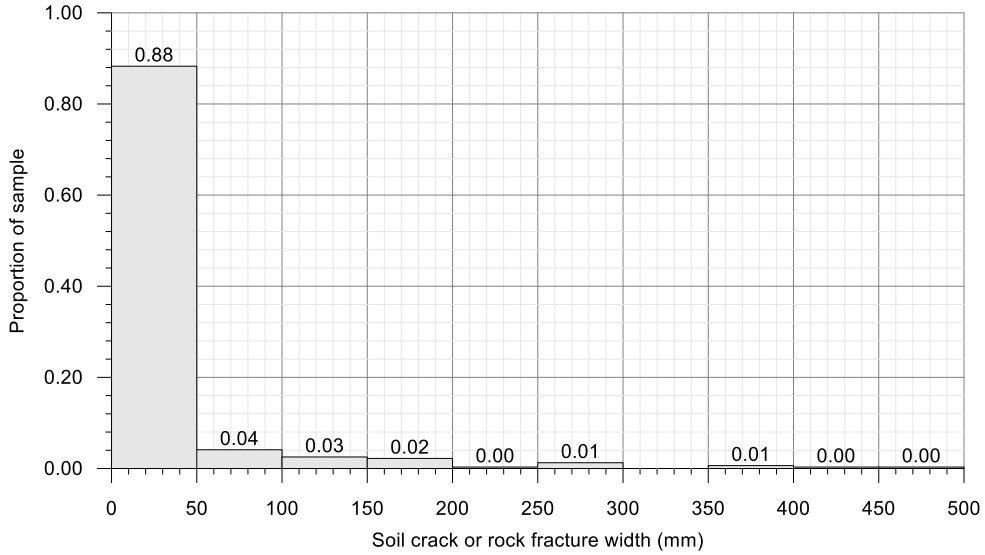


Fig. 4.4 Distribution of measured soil crack and rock fracture widths in Areas 2, 3A and 3B

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 which was the result of downslope movement along a steep slope and fretting away at the crack margin.

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 LW18 are similar to but slightly less than the maximum predicted values for the previously extracted longwalls in Area 3B at the Mine. 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 commencing (i.e. western) end of LW18 is located within the Dams Safety NSW Notification Area for the Avon Reservoir, also known as Lake Avon, as shown in Drawings Nos. MSEC1103-01 and MSEC1103-02. The descriptions, predictions and impact assessments for the Avon Reservoir are provided in Section 6.3.

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. Rivers

There are no rivers within the Study Area. The closest rivers are the Avon River and Cordeaux River downstream of the Avon Dam and Cordeaux Dam, respectively. These rivers are located more than 6 km from LW18, at their closest points.

The Avon and Cordeaux Rivers are not predicted to experience measurable ground movements due to the extraction of LW18. It is unlikely, therefore, that these rivers would experience adverse impacts due to the mining of this longwall.

5.3. Wongawilli Creek

The location of Wongawilli Creek is shown in Drawing No. MSEC1103-09.

Wongawilli Creek is situated on the eastern side of the longwalls in Area 3B. The thalweg (i.e. base or centreline) of the creek is 1 km from the finishing (i.e. eastern) end of LW18, at its closest point. The creek is therefore located outside the Study Area based on the 600 m boundary.

The maximum predicted incremental vertical subsidence, upsidence and closure for Wongawilli Creek, due to the mining of LW18, 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 Wongawilli Creek due to the mining of LW18.

A waterfall (Ref. WC-WF54) is located along Wongawilli Creek to the east of LW18. The centreline of the waterfall is situated 1 km from the finishing (i.e. eastern) end of LW18. At this distance, the waterfall is not expected to experience measurable conventional or valley related effects. Impacts on cliffs or rock features have not been observed at this distance outside of previous longwall mining in the Southern Coalfield. It is unlikely, therefore, that adverse impacts would occur at the waterfall due to the mining of LW18.

5.4. Native Dog Creek

The location of Native Dog Creek is shown in Drawing No. MSEC1103-09.

Native Dog Creek flows into Lake Avon to the south-west of LW18. The thalweg of the creek is 310 m from the commencing (i.e. western) end of LW18, at its closest point. The upper reaches of the creek is located directly above the completed longwalls at Elouera Colliery to the south of LW18 and outside of the Study Area based on the 600 m boundary.

Native Dog Creek is located outside the Study Area based on the 35° angle of draw line and predicted 20 mm subsidence contour for LW18. However, it is partially located within the Study Area based on the 600 m boundary. The total length of creek within the Study Area based on the 600 m boundary is 0.6 km.

The bed of Native Dog Creek comprises exposed bedrock containing rockbars with some standing pools. The surface level along the creek varies between approximately 338 mAHD at the Study Area boundary and approximately 330 m at the confluence with Lake Avon. The average natural gradient of the creek within the Study Area therefore is approximately 13 mm/m (i.e. 1.3 %, or 1 in 77).

A summary of the maximum predicted values of incremental vertical subsidence, upsidence and closure for Native Dog Creek is provided in Table 5.1. The values are the maximum predicted subsidence effects due to the mining of LW18 only.

Table 5.1 Maximum predicted incremental subsidence, upsidence and closure for Native Dog Creek

Location	Due to longwall	Maximum predicted incremental vertical subsidence (mm)	Maximum predicted incremental upsidence (mm)	Maximum predicted incremental closure (mm)
Native Dog Creek	LW18	< 20	20	30

Native Dog Creek is predicted to experience less than 20 mm incremental vertical subsidence due to the mining of LW18. While the creek could experience very low levels of vertical subsidence, it is not expected to experience measurable conventional tilts, curvatures or strains.

The creek is predicted to experience 30 mm incremental closure due to the mining of LW18. The compressive strain due to the valley closure effects has been determined from an analysis of ground monitoring data across valleys that have similar effective heights and are located at similar distances from previous longwall mining. The predicted compressive strain due to valley closure effects for Native Dog Creek is 3 mm/m based on the 95 % confidence level.

The upper reaches of Native Dog Creek is located directly above the existing longwalls at Elouera Colliery. That section of creek is predicted to have experienced up to 1500 mm vertical subsidence, 500 mm upsidence and 700 mm closure. The maximum predicted total subsidence effects within the Study Area based on the 600 m boundary, due to the existing mining at Elouera Colliery and due to LW9 to LW18, are less than 20 mm vertical subsidence, 50 mm upsidence and 80 mm closure. In that location; however, the predicted incremental subsidence, upsidence and closure due to LW18 only are all less than 20 mm.

The mining of the existing longwalls beneath the upper reaches of Native Dog Creek resulted in fracturing of the creek bed and the draining of pools directly above and adjacent to the mining area. The furthest drained pool from Elouera Colliery was located approximately 75 m downstream of the mining area. That affected pool is located just inside the Study Are based on the 600 m boundary for LW18.

Fracturing has also been observed along streams up to 300 m from the extracted longwalls in Area 3B and up to approximately 400 m elsewhere in the Southern Coalfield. 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) have been observed at distances up to 290 m from the extracted longwalls at Dendrobium Mine.

Native Dog Creek is located at a minimum distance of 310 m from the proposed LW18. The compressive strain due to valley closure could result in fracturing in the creek bed, where it is located within approximately 400 m of the proposed longwall. Type 3 impacts are possible, but are considered unlikely, as only two cases have been observed at similar distances from Dendrobium LW9 to LW15.

Further discussions on the potential impacts to Native Dog Creek are provided in the reports by the other specialist consultants on the project.

5.5. Drainage lines

5.5.1. Descriptions of the drainage lines

The locations of the drainage lines are shown in Drawing No. MSEC1103-09.

The drainage lines that are located directly or partially above LW18 include ND1, ND1C and their tributaries. Other drainage lines that are located within the Study Area based on the 600 m boundary include LA1, LA2, ND1A, ND1B, ND2, ND2A, WC7 and WC12. These drainage lines are first and second order streams that form tributaries to Lake Avon and Wongawilli Creek.

The beds of the drainage lines 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. Some sections of the drainage lines are confined within the swamps.

Photographs of typical drainage lines within the mining area are provided in Fig. 5.1.



Fig. 5.1 Typical drainage lines within the mining area

The natural gradients of the drainage lines typically vary between 10 mm/m (i.e. 1 %, or 1 in 100) along the upper reaches and 300 mm/m (i.e. 30 %, or 1 in 3) along the lower reaches. The average natural gradients of the drainage lines, directly above the longwalls, typically vary between 25 mm/m (i.e. 2.5 %, or 1 in 40) and 100 mm/m (i.e. 10 %, or 1 in 10).

5.5.2. 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 Drainage Lines LA2, ND1, ND1C, WC7 and WC12 are shown in Figs. C.03 to C.07, respectively, in Appendix C. The predicted total profiles after the completion of LW9 to LW17 are shown as cyan lines. The predicted total profiles after the mining of LW18 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 5.2. The values are the maximum predicted subsidence effects due to the mining of LW9 to LW18.

Table 5.2 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	LA1	< 20	< 0.5	< 0.01	< 0.01
	LA2	3150	25	0.50	0.70
	ND1	30	0.5	0.01	< 0.01
	ND1A	< 20	< 0.5	< 0.01	< 0.01
	ND1B	20	< 0.5	< 0.01	< 0.01
	ND1C	2850	35	0.80	0.80
	ND2	< 20	< 0.5	< 0.01	< 0.01
	ND2A	< 20	< 0.5	< 0.01	< 0.01
	WC7	< 20	< 0.5	< 0.01	< 0.01
	WC12	1550	17	0.15	0.45
	Remaining	3200	40	1.0	1.0

The maximum predicted total tilt for the drainage lines within the Study Area 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 represents a minimum radius of curvatures of 1 km.

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 compressive. The distribution of the predicted strains due to the extraction of the longwalls is described in Section 4.3. The maximum 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 predicted total subsidence effects are predominately due to the existing and approved longwalls where the drainage lines are located above these previous longwalls. A summary of the maximum predicted values of incremental vertical subsidence, tilt and curvature for the drainage lines is provided in Table 5.3. The values are the maximum predicted subsidence effects due to the mining of LW18 only.

Table 5.3 Maximum predicted incremental subsidence, tilt and curvature for the drainage lines

Type	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})
Drainage lines	LA1	< 20	< 0.5	< 0.01	< 0.01
	LA2	850	12	0.25	0.25
	ND1	30	0.5	0.01	< 0.01
	ND1A	< 20	< 0.5	< 0.01	< 0.01
	ND1B	20	< 0.5	< 0.01	< 0.01
	ND1C	2700	35	0.75	0.75
	ND2	< 20	< 0.5	< 0.01	< 0.01
	ND2A	< 20	< 0.5	< 0.01	< 0.01
	WC7	< 20	< 0.5	< 0.01	< 0.01
	WC12	< 20	< 0.5	< 0.01	< 0.01
	Remaining	2750	35	0.80	0.80

The maximum predicted incremental tilt for the drainage lines within the Study Area is 35 mm/m (i.e. 3.5 %, or 1 in 30). The maximum predicted incremental conventional curvatures are 0.80 km^{-1} hogging and sagging, which represents a minimum radius of curvatures of 1.2 km.

Drainage Lines LA1, LA2, ND1, ND1A, ND1B, ND2, ND2A, WC7 and WC12 are predicted to experience incremental vertical subsidence of 30 mm or less. While these drainage lines could experience low levels of vertical subsidence, they are not expected to experience measurable tilts, curvatures or strains.

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 and tributaries 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, within the Study Area based on the 600 m boundary, along drainage lines LA2, ND1 and ND1C are provided in Table 5.4, Table 5.5 and Table 5.6, respectively. The locations of these features are shown in Figs. C.03 to C.05, in Appendix C.

Table 5.4 Maximum predicted total vertical subsidence, upsidence and closure at the mapped rockbars along drainage line LA2 within the Study Area based on the 600 m boundary

Location	Label	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Rockbars along drainage line LA2	LA2_RB0	< 20	40	50
	LA2_RB1	< 20	40	50
	LA2_RB2	< 20	40	50
	LA2_RB3	< 20	60	60
	LA2_RB4	< 20	70	70
	LA2_RB6A	20	150	100
	LA2_RB6B	90	150	100
	LA2_RB6C	100	150	100
	LA2_RB7	225	150	90
	LA2_RB8	275	150	100
	LA2_RB9	775	225	175
	LA2_RB10	1700	325	275
	LA2_RB11	1750	350	275
	LA2_RB13	1975	425	325
	LA2_RB14	1700	450	375
	LA2_RB17	725	450	500
	LA2_RB24	3175	600	600
	LA2_RB25	3175	575	525
	LA2_RB26	3175	550	500
	LA2_RB31	2650	350	350
	LA2_RB35	1550	325	375

Table 5.5 Maximum predicted total vertical subsidence, upsidence and closure at the mapped rockbars along drainage line ND1 within the Study Area based on the 600 m boundary

Location	Label	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Rockbars along drainage line ND1	ND1_RB1	< 20	40	60
	ND1_RB2	< 20	50	70
	ND1_RB3	< 20	50	70
	ND1_RB4	< 20	60	80
	ND1_RB5	< 20	60	80
	ND1_RB6	< 20	60	80
	ND1_RB7	< 20	60	80
	ND1_RB8	< 20	60	80
	ND1_RB9	< 20	60	80
	ND1_RB10	< 20	60	80
	ND1_RB11	< 20	60	80
	ND1_RB12	< 20	60	80
	ND1_RB13	< 20	70	90
	ND1_RB14	< 20	70	90
	ND1_RB15	< 20	70	100
	ND1_RB16	< 20	70	100
	ND1_RB17	< 20	80	125
	ND1_RB18	< 20	80	125
	ND1_RB19	< 20	90	150
	ND1_RB20	< 20	90	175
	ND1_RB21	< 20	90	175
	ND1_RB22	< 20	90	200
	ND1_RB23	< 20	125	175
	ND1_RB24	< 20	125	175

Table 5.6 Maximum predicted total vertical subsidence, upsidence and closure at the mapped rockbars along drainage line ND1C within the Study Area based on the 600 m boundary

Location	Label	Maximum predicted total vertical subsidence (mm)	Maximum predicted total upsidence (mm)	Maximum predicted total closure (mm)
Rockbars along drainage line ND1C	ND1C_RB2A	2525	325	350
	ND1C_RB2B	2675	300	325
	ND1C_RB3	2300	300	300

The rockbars along drainage line LA2 predicted to experience up to 3175 mm subsidence, 600 mm upsidence and 600 mm closure. These rockbars are located directly above or adjacent to LW17 and, therefore, the majority of these predicted movements develop due to the mining of this previous longwall. The predicted incremental effects for these rockbars, due to the mining of the proposed LW18 only, are up to 700 mm subsidence, 150 mm upsidence and 150 mm closure.

The rockbars along drainage line ND1 are predicted to experience less than 20 mm subsidence and up to 125 mm upsidence and 200 mm closure. The rockbars along drainage line ND1C are predicted to experience up to 2675 mm subsidence, 325 mm upsidence and 350 mm closure. The rockbars along drainage lines ND1 and ND1C are located above LW18 or adjacent to its maingate and, therefore, the majority of these predicted movements develop due to the mining of this proposed longwall.

The rockbars along drainage line WC7 are all located outside the Study Area based on the 600 m boundary. There is only one rockbar along drainage line WC12 which is located just inside the Study Area based on the 600 m boundary (ref. WC12_RB22D), with the remaining rockbars along this drainage line located outside the Study Area. The predicted incremental subsidence, upsidence and closure for the rockbars located along drainage lines WC7 and WC12, due to the mining of the proposed LW18 only, are all less than 20 mm.

5.5.3. Observed impacts for the drainage lines due to LW9 to LW15

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 are 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.

The impacts observed along the drainage lines due to LW15 are described in the End of Panel Report (IMC, 2020a) and these have been summarised below:

> Rock fracturing was observed at three additional sites along WC15, due to the mining of LW15, at distances ranging between 30 m and 140 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. Rock fracturing was also observed at three additional sites along LA4; however, it is likely that these impacts occurred during LW14 and that they only later became visible due to rainfall events which dislodged vegetation and rock fragments.
>
> No new surface water diversions were identified due to the mining of LW15. 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 LW13 to LW15, 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.

5.5.4. 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 40 mm/m (i.e. 4.0 % or 1 in 25). 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 LA2, ND1C and WC12 are illustrated in Fig. 5.2 to Fig. 5.4, respectively. The locations of these drainage lines are shown in Drawing No. MSEC1103-09.

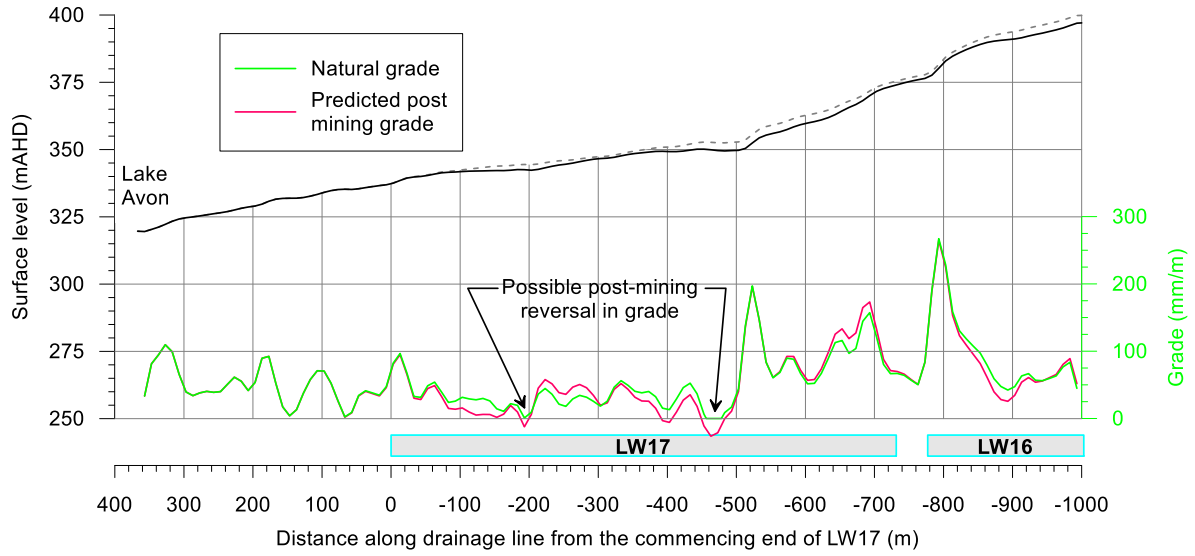


Fig. 5.2 Natural and predicted post-mining surface levels along LA2

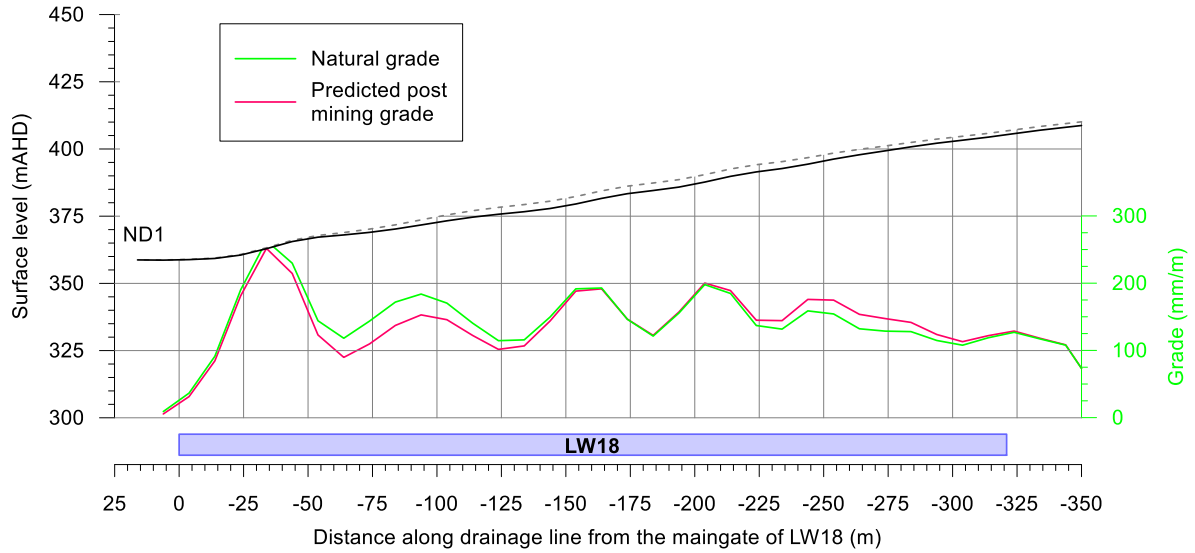


Fig. 5.3 Natural and predicted post-mining surface levels along ND1C

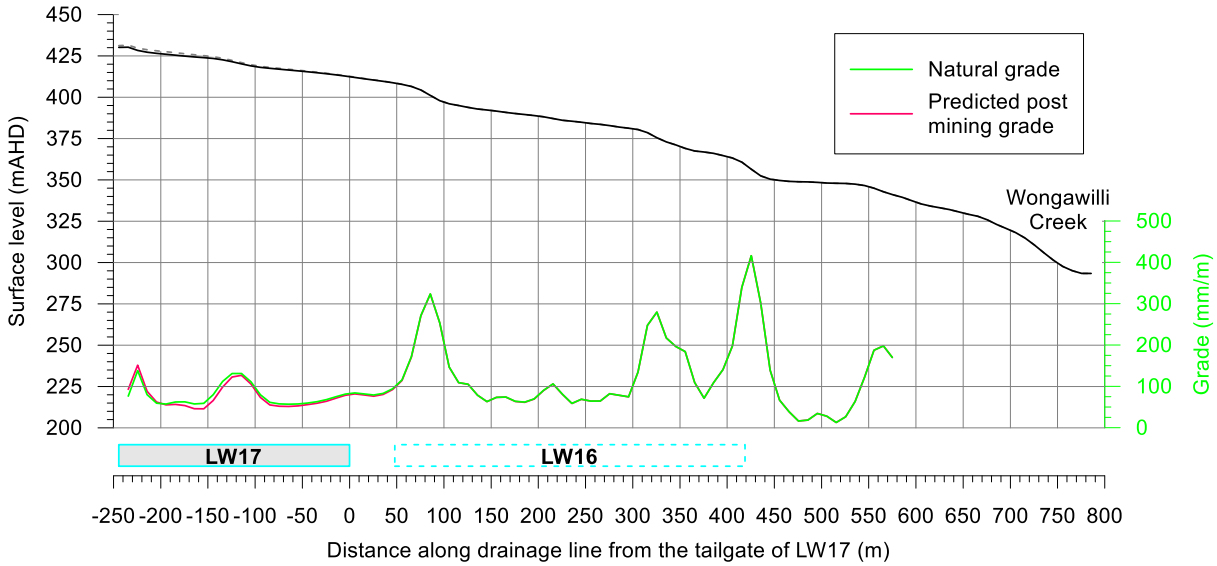


Fig. 5.4 Natural and predicted post-mining surface levels along WC12

It can be seen from Fig. 5.2 that there are predicted reversals in grade along Drainage Line LA2. There is potential for minor and localised increased ponding upstream of these locations. However, this drainage line is located above the previous LW17 and, therefore, the potential for increased ponding occurs due to this previous longwall rather than the proposed LW18.

There are no predicted reversals of stream grade along the remaining drainage lines within the Study Area. There are slight reductions in grades along drainage lines ND1C and WC12, 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 line WC12 is located above the existing LW16 and LW17 and, therefore, the potential for increased ponding occurs due to these previous longwalls rather than the proposed LW18.

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 due to mining-induced tilt 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 LW15 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 LW18 are similar to but slightly less than the maximum predicted values elsewhere 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 LW18 and the adjacent LW16 and LW17. 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).

5.5.5. Recommendations for the drainage lines

IMC has developed management strategies for drainage lines that have been directly mined beneath by previous longwall extractions at the Mine. It is recommended that these management strategies are reviewed and updated to incorporate LW18. It is also recommended that periodic inspections are carried out along the drainage lines during active subsidence.

5.6. 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 (Watershed Hydrogeo, 2020).

5.7. 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. MSEC1103-08.

There are no cliffs that have been identified within the Study Area. The nearest cliffs are located along Wongawilli Creek around 1 km east of the proposed LW18. At this distance, the cliffs are not predicted to experience measurable conventional or valley related effects. Impacts on cliffs have not been observed at this distance outside of previous longwall mining in the Southern Coalfield. It is unlikely, therefore, that adverse impacts would occur at the cliffs due to the mining of LW18.

5.8. Rock outcrops and steep slopes

5.8.1. 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. MSEC1103-08.

The steep slopes within the Study Area have been identified within the valleys of Lake Avon, Wongawilli Creek and their 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 the drainage lines. 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. 5.5.



Fig. 5.5 Typical rock outcropping at the Mine

5.8.2. 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 5.7. The values in this table are the maximum predicted subsidence effects within the Study Area due to LW9 to LW18.

Table 5.7 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	LW9 to LW18	3200	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 4.3. The maximum 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.

5.8.3. Impact assessments for the rock outcrops and steep slopes

It is expected that the rock outcrops located directly above the proposed longwall would experience fracturing and, where the rock is marginally stable, this could then result in instabilities. Previous experience of mining beneath rock outcrops at the Mine indicates that the percentage of rock outcrops that experience adverse impacts is small, representing less than 3 % of the total surface area.

Examples of impacts to rock outcrops due to mining are provided in Fig. 5.6. Fracturing and rockfalls were observed in a rock platform located above the commencing end of LW6 (left-side of figure) and spalling was observed in a rock outcrop towards the finishing end of this longwall (right-side of figure).



Fig. 5.6 Impacts on rock outcrops due to mining at the Mine (Courtesy of IMC)

The impacts on the steep slopes 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 steep slopes and compression ridges forming at the bottoms of the steep slopes.

The distribution of soil cracks and rock fractures in Areas 2, 3A and 3B is illustrated in Fig. 4.4. The measured surface deformations were generally 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 which was the result of downslope movement along a steep slope and fretting away at the crack margin.

Photographs of the surface cracking at the Mine are provided in Fig. 5.7.



Fig. 5.7 Surface tension cracking due to downslope movements at the Mine

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 longwalls, 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.

5.8.4. 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.

5.9. Escarpments

There are no escarpments located within the Study Area. The *Illawarra Escarpment* is located more than 12 km to the east of LW18. At this distance, the escarpment is not expected to experience measurable mining-induced subsidence effects or adverse impacts due to the extraction of the proposed longwall.

5.10. 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 Lake Avon and Wongawilli 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.

5.11. Swamps, wetlands and water related ecosystems

5.11.1. Descriptions of the swamps

The swamps are shown in Drawing No. MSEC1103-09. The locations and extents of the upland swamps have been interpreted from detailed aerial photogrammetry and site inspections.

There are four swamps (Refs. Den14, Den35a, Den35b and Den149) 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 are two additional swamps (Refs. Den150 and Den151) that are partly or wholly located within the Study Area based on the 600 m boundary.

A summary of the swamps located within the combined Study Area is provided in Table 5.8.

Table 5.8 Swamps located within the Study Area

Reference	Location	Description
Den14	Directly above LW16 and LW17	Upper reaches of WC15
Den35a	Directly above the maingate of LW18	Upper reaches of ND1
Den35b	85 m south of the maingate of LW18	Middle reaches of ND1
Den149	Directly above LW17 and partially above LW18	Valley side of LA2
Den150	225 m south of the maingate of LW18	Upper reaches of ND1B
Den151	325 m south of the maingate of LW18	Upper and lower reaches of ND1A

The swamps within the Study Areas are typically valley infill swamps that have formed along the drainage lines. However, Swamp Den149 and parts of Swamps Den150 and Den151 are headwater swamps located further up the valley sides. Photographs of typical valley infill swamps at the Mine are provided in Fig. 5.8.



Fig. 5.8 Typical valley infill swamps at the Mine

Further descriptions of the swamps are provided by *Niche Environment and Heritage* (Niche, 2020).

5.11.2. 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 5.9. 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 LW9 to LW18.

Table 5.9 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})
Den14	2850	25	0.50	0.70
Den35a	225	8	0.17	0.04
Den35b	20	< 0.5	< 0.01	< 0.01
Den149	3000	25	0.70	0.60
Den150	< 20	< 0.5	< 0.01	< 0.01
Den151	< 20	< 0.5	< 0.01	< 0.01

The maximum predicted total tilt for the swamps is 25 mm/m (i.e. 2.5 %, or 1 in 40). The maximum predicted total conventional curvature is 0.70 km^{-1} hogging and sagging, which represents a minimum radius of curvature of 1.4 km.

The predicted conventional hogging curvature contours (i.e. red lines with positive values) and sagging curvature contours (i.e. blue lines with negative values) are illustrated in Fig. 5.9. It is noted that the hogging and sagging curvature contours cross in some locations, such as near the corners of the longwalls, which signifies that these components of curvature occur in orthogonal directions.

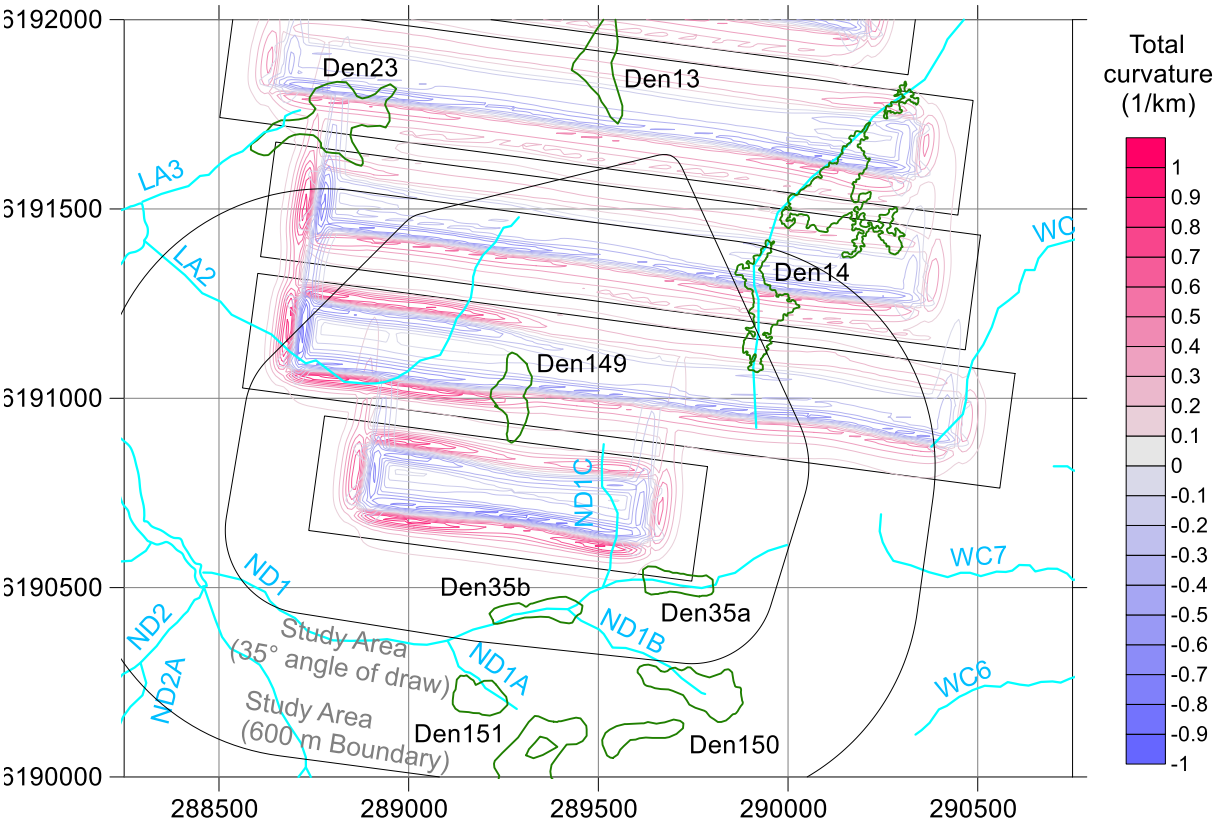


Fig. 5.9 Predicted total hogging and sagging curvatures due to LW9 to LW18

The maximum predicted conventional strains for the swamps, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 11 mm/m tensile and compressive. The distribution of the predicted strains due to the extraction of the longwalls is described in Section 4.3. The maximum 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 Den14 and Den149 are located above the previous LW16 and LW17 and, therefore, the predicted subsidence effects are predominately due to these previous longwalls. A summary of the maximum predicted incremental vertical subsidence, tilt and curvatures for these swamps is provided in Table 5.10. The values are the maximum predicted subsidence effects within 20 m of the mapped extents of the swamps due to the mining of LW18 only.

Table 5.10 Maximum predicted incremental vertical subsidence, tilt and curvatures for Swamps Den14 and Den149

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})
Den14	< 20	< 0.5	< 0.01	< 0.01
Den149	1350	5.5	0.20	0.10

Swamp Den14 is predicted to experience less than 20 mm incremental vertical subsidence due to the mining of the proposed LW18. While this swamp could experience very low levels of incremental vertical subsidence, it is not expected to experience measurable incremental tilts, curvatures or strains.

Swamps Den14, Den35a, Den35b, Den150 and Den151 are located near the bases of the drainage lines and, therefore, they could experience valley related effects. Swamp Den149 is located further up the valley side and, therefore, it is not expected to experience upsidence or compressive strain due to valley closure.

A summary of the maximum predicted total upsidence and closure for the swamps within the Study Area is provided in Table 5.11. The values are the maximum predicted valley related effects for each swamp due to the mining of LW9 to LW18. It is noted that the conventional closures are normally provided separately to the valley related closures, as the associated conventional strains are distributed across the longwalls, as opposed to the valley related compressive strains which are concentrated in the valley bases. Also, in most cases, the valley related closures and conventional closures are orientated obliquely to each other.

Table 5.11 Maximum predicted total upsidence and closure for the swamps

Location	Maximum predicted total valley related upsidence (mm)	Maximum predicted total valley related closure (mm)	Maximum predicted total conventional closure (mm)
Den14	275	400	400
Den35a	125	200	100
Den35b	175	425	25
Den149	N/A	N/A	400
Den150	40	50	< 20
Den151	30	40	< 20

The maximum predicted total closures (i.e. valley plus conventional) after the extraction of LW18 are 800 mm for Den14, 300 mm for Den35a, 450 mm for Den35b and 400 mm for Den149. While Den35b is located outside the mining area, the predicted valley related effects for this swamp are greater than the predicted values for Den35a, as it is located within the more incised valley along the middle reaches of drainage line ND1.

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 the swamps, due to the valley related effects, are in the order of 10 mm/m to 20 mm/m.

Swamps Den14 and Den149 are located above the previous LW16 and LW17 and, therefore, the predicted valley related effects are predominately due to these previous longwalls. A summary of the maximum predicted incremental upsidence and closure for these swamps is provided in Table 5.12. The values are the maximum predicted valley related effects for the swamps due to the mining of LW18 only.

Table 5.12 Maximum predicted incremental upsidence and closure for Swamps Den14 and Den149

Location	Maximum predicted incremental valley related upsidence (mm)	Maximum predicted incremental valley related closure (mm)	Maximum predicted incremental conventional closure (mm)
Den14	< 20	30	< 20
Den149	N/A	N/A	80

The maximum predicted incremental closure (i.e. valley plus conventional), due to the extraction of LW18 only, are 50 mm for Den14 and 80 mm for Den149. The predicted incremental strain for these swamps, due to the valley related effects, is in the order of 1 mm/m to 2 mm/m.

5.11.3. Previous experience of mining beneath swamps at the Mine

Discussions on the previous experience of mining beneath swamps at the 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. 5.10.



Fig. 5.10 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 are 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 LW15 which are described in each of the End of Panel Reports (IMC, 2015, 2016, 2017, 2018, 2019 and 2020a). The groundwater levels were lower than baseline and recession rates greater than baseline for Swamps Den03, Den05, Den10, Den11, Den13, Den14 and Den23. Soil moisture levels below baseline were also reported in Swamps Den05, Den11, Den14 and Den23.

5.11.4. 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 within the Study Area is 25 mm/m (i.e. 2.5 %, or 1 in 40) for Den14 and Den149. The tilts at these swamps develop predominately due to the previous LW16 and LW17, with the predicted incremental tilt due to LW18 being less than 0.5 mm/m (i.e. 0.05 %, or 1 in 2000) for Den14 and 5.5 mm/m (i.e. 0.55 %, or 1 in 180) for Den149. Swamp Den35a is predicted to experience a total tilt of 8 mm/m (i.e. 0.8 %, or 1 in 125).

Swamps Den14, Den35a, Den35b, Den150 and Den151 are located near the bases of the drainage lines. The predicted changes in grade along LA2, ND1C and WC12 are illustrated in Fig. 5.2 to Fig. 5.4, respectively. While there are predicted reversals in grade along LA2, there are no swamps located near the base of this drainage line and the predicted changes predominately occur due to the previous LW16 and LW17. Swamp Den149 is located further up the valley side of LA2 where the natural grades are considerably greater than the mining-induced tilts.

There are no predicted reversals of stream grade along the remaining drainage lines within the Study Area nor within the extents of the swamps. There are small reductions in grades along the drainage lines, 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 near to Swamps Den14 and Den35a. However, Den14 is located above the previous LW16 and LW17, therefore, the potential for increased ponding occurs due to these previous longwalls rather than the proposed LW18. Den35a is located above the maingate of LW18 and only low-level changes are predicted.

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 Den14 and Den149 are located above the previous LW16 and LW17 and Swamp Den35a is partially located above the proposed LW18. 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. Swamp Den35b is located outside the mining area at a minimum distance of 85 m from the proposed LW18. However, this swamp is located in the more incised valley along the middle reaches of drainage line ND1 and, therefore, it could also experience compressive strains due to valley related effects in the order of 10 mm/m to 20 mm/m. It is likely, therefore, that fracturing would occur in the bedrock beneath Den14, Den35a, Den35b and Den149.

The typical fracture widths in the bedrock beneath Swamps Den14, Den35a and Den149 could be similar to the surface deformations previously observed at the Mine, as described in Section 4.7. 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.

Swamp Den35b is located outside the mining area at a minimum distance of 85 m from the proposed LW18. Fracturing has been observed in streams located outside the extents of previously extracted longwalls in the NSW coalfields. Fracturing has been observed in the drainage lines at the Mine at distances of up to 290 m from the previously extracted longwalls in Area 3B. Minor and isolated fractures have also been observed up to 400 m outside of longwalls extracted elsewhere in the Southern Coalfield. Fracture widths in the order of 20 mm to 50 mm have been observed due to valley closure effects at similar distances as Den35b from the proposed LW18. It is possible that a series of smaller fractures, rather than one single fracture, could develop in the bedrock.

Swamps Den150 and Den151 are located outside the mining area at minimum distances of 225 m and 325 m, respectively, from the proposed LW18. Fracturing could occur at these swamps, as has been observed at similar distances from the previously extracted longwalls in Area 3B. Fracture widths in the order of 20 mm could develop at Den150 and Den151.

Swamps Den14, Den35a and Den35b are predicted to experience total upsidence ranging between 175 mm and 275 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 Den14, Den35a and Den35b 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 Den14 is located directly above the previous LW16 and LW17 and, therefore, the potential impacts predominately occur due to these previous longwalls, rather than the proposed LW18. Only a small area of Swamp Den35a is located directly above the proposed LW18 and Den35b is located outside the mining area.

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.

5.11.5. 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.

5.12. Flora and fauna

The land above the longwalls in Area 3B 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 5.3 to 5.11. 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 (2020).

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. Railway infrastructure

6.1.1. Descriptions of the railway infrastructure

There are no operating railways within the Study Area. The incomplete and disused Maldon-Dombarton railway corridor follows the ridgeline that crosses the north-eastern corner of the proposed LW18, as shown in Drawing No. MSE1103-10. At the time of abandoning the work, the major earthworks had been completed, but no tracks or associated equipment had been installed. Any future plans for the corridor remain uncertain and are the subject of continuing review.

The locations of the cuttings and embankments along the disused railway corridor are shown in Drawing No. MSEC1103-10. A summary of the lengths and heights of these features located within the Study Area is provided in Table 6.1.

Table 6.1 Cuttings and embankments along the disused Maldon-Dombarton railway corridor

Label	Location	Length (m)	Type on western side (approx. height)	Type on eastern side (approx. height)
MDB-F8	Above LW15 and LW16	400	Embankment (7 m)	Embankment (7 m)
MDB-F9	Above LW16 and LW17	100	Embankment (5 m)	Embankment (5 m)
MDB-F10	Above LW17	250	Embankment (3 m)	Embankment (7 mm)
MDB-F11	Partially above LW17 and 100 m east of LW18	250	Cutting (15 m)	Cutting (15 metres)
MDB-F12	250 m east of LW18	175	Embankment (15 m)	Embankment (5 m)
MDB-F13	350 m east of LW18	200	Cutting (15 m)	Cutting (5 m)

Photographs of the disused railway corridor are provided in Fig. 6.1. Photographs of an embankment and drainage culvert are provided in Fig. 6.2.



Fig. 6.1 Disused railway corridor and a cutting



Fig. 6.2 Embankment and drainage culvert along the disused railway corridor

6.1.2. Predictions for the disused railway corridor

The predicted profiles of total vertical subsidence, tilt and curvature along the disused railway corridor are shown in Fig. C.08, in Appendix C. The predicted total profiles after the completion of LW9 to LW17 are shown as cyan lines. The predicted total profiles after the mining of LW18 are shown as the blue lines.

A summary of the maximum predicted values of total vertical subsidence, tilt and curvature along the disused railway corridor is provided in Table 6.2. The values are the maximum predicted subsidence effects for the section of the corridor within the Study Area due to the mining of LW9 to LW18.

Table 6.2 Maximum predicted total subsidence, tilt and curvature for the disused railway corridor

Type	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})
Disused railway corridor	LW9 to LW17	2550	20	0.45	0.60
	LW18	2650	20	0.45	0.60

The maximum predicted total tilt for the section of the disused railway corridor within the Study Area is 20 mm/m (i.e. 2.0 %, or 1 in 50). The maximum predicted total conventional curvatures are 0.45 km^{-1} hogging and 0.60 km^{-1} sagging, which represent minimum radii of curvature of 2.2 km and 1.7 km, respectively.

The maximum predicted conventional strains for the disused railway corridor, based on applying a factor of 15 to the maximum predicted conventional curvatures, are 7 mm/m tensile and 9 mm/m compressive. The distribution of the predicted strains due to the extraction of the longwalls is described in Section 4.3. The maximum 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 disused railway corridor is located above the previous LW15 to LW17 and outside of the proposed LW18. The predicted total subsidence effects, therefore, are predominately due to the previous longwalls rather than the proposed LW18.

A summary of the maximum predicted values of incremental vertical subsidence, tilt and curvature for the disused railway corridor is provided in Table 6.3. The values are the maximum predicted subsidence effects due to the mining of LW18 only.

Table 6.3 Maximum predicted incremental subsidence, tilt and curvature for the disused railway corridor

Type	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})
Disused railway corridor	LW18	200	2.0	0.05	0.01

The maximum predicted incremental tilt for the disused railway corridor is 2.0 mm/m (i.e. 0.2 %, or 1 in 500). The maximum predicted incremental conventional curvatures are 0.05 km^{-1} hogging and 0.01 km^{-1} sagging, which represent minimum radii of curvature of 20 km and 100 km, respectively. The predicted incremental conventional strains for the disused railway corridor, based on applying a factor of 15 to the maximum predicted incremental curvatures, are 1 mm/m tensile and 0.5 mm/m compressive.

6.1.3. Impact assessments for the disused railway corridor

The formation and ballast have been constructed, however, there is no track along the section of the disused railway corridor within the Study Area. The as-built railway infrastructure only comprises the cuttings, embankments and drainage culverts.

The maximum predicted total tilt for the cuttings and embankments along the disused railway corridor is 20 mm/m (i.e. 2.0 %, or 1 in 50). However, the predicted total tilt is predominately due to the existing LW15 to LW18, with the predicted incremental tilt due to LW18 only being 2 mm/m (i.e. 0.2 %, or 1 in 500).

The predicted changes in grade are very small and unlikely to adversely impact the surface water drainage along the corridor. The maximum predicted tilt is also considerably less than the as-built grades of the cuttings and embankments, which are in the order of 1 in 1 and, therefore, is unlikely to result in adverse impacts on the stability of these features.

The maximum predicted curvatures and strains for the disused railway corridor could be sufficient to result in impacts on the cuttings, including the fracturing and mobilisation of joints and some spalling of the exposed rock faces which could result in isolated rockfalls. These impacts are expected to predominately occur due to the previous LW15 to LW17 rather than the proposed LW18.

Only minor impacts have been observed along the disused railway corridor above the previously extracted longwalls in Area 3B at the Mine and at the nearby Elouera Colliery. A photograph of fracturing observed in the rock cuttings along the corridor at Elouera Colliery is shown in Fig. 6.3.



Fig. 6.3 Fracturing in a rock cutting above the previously extracted Elouera longwalls

The earth embankments could also experience cracking due to the mining-induced curvatures and strains. Whilst surface cracking is unlikely to result in embankment instability, it is possible that soil erosion channels could develop at any larger cracks if these were left untreated. Surface cracking can be identified in the embankments by visual inspections during mining.

The mining-induced tilts could adversely impact the serviceability of the drainage culverts, by reducing or reversing the as-built grades, in some cases, which could then affect the flow of water through these culverts. If increased ponding were to occur upstream of the culverts, it may be necessary to reconstruct or re-level the adversely affected culverts.

The drainage culverts could also experience cracking in the pipes or the headwalls as a result of the mining-induced curvatures and strains. It is unlikely that these impacts would result in the collapse of the culverts, as this has not occurred previously in the NSW coalfields, where there is extensive experience of mining beneath culverts. The drainage culverts can be remediated, if required, by repairing the cracks or, in some cases, replacing the culverts.

6.1.4. Recommendations for the disused railway corridor

It is recommended that periodic visual inspections of the disused railway corridor are undertaken during active subsidence. Any larger surface cracking in the cuttings and embankments should be remediated if there is potential for long-term erosion. With the appropriate management strategies in place, it is unlikely that there would be more than negligible impacts on the use of the corridor due to the proposed LW18.

6.2. Unsealed roads and tracks

6.2.1. Descriptions of the unsealed roads and tracks

The locations of the unsealed roads and tracks are shown in Drawing No. MSEC1103-10.

Fire Road 6A follows the ridgeline that crosses the north-eastern corner of the proposed LW18. 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. 6.4.



Fig. 6.4 Typical unsealed road

6.2.2. Predictions for the unsealed roads and tracks

Fire roads are located directly above the mining area and, therefore, these 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 6.4. The values in this table are the maximum predicted subsidence effects within the Study Area due to LW9 to LW18.

Table 6.4 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	LW9 to LW18	3200	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 4.3. The maximum 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.

6.2.3. Impact assessments for the unsealed roads and tracks

Fire roads are located directly above the mining area. It is possible that cracking, rippling and stepping of the unsealed road surface could occur due to the mining of the longwalls. The estimated crack widths in the fire roads, 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 4.7. 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. 6.5 (Source: IMC). The impacts on the unsealed roads and tracks were repaired by regrading and recompacting the road surfaces. Similar impacts are anticipated for the fire roads due to the mining of the proposed LW18.



Fig. 6.5 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 the fire roads 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.

6.2.4. Recommendations for the unsealed roads and tracks

IMC has developed management strategies for unsealed roads and tracks that have been affected by subsidence at the Mine. It is recommended that these management strategies are reviewed and updated to incorporate the proposed LW18. It is also recommended that periodic inspections are carried out along the unsealed roads and tracks during active subsidence.

6.3. Dams, reservoirs or associated works

6.3.1. Descriptions of the reservoirs

Lake Avon, also known as the Avon Reservoir, is located to the west of LW18 as shown in Drawing No. MSEC1103-01. Lake Avon is fed by the Avon River and its many tributaries and it has a length of approximately 19 km. The reservoir water storage has a total operating capacity of approximately 147,000 ML. A photograph of Lake Avon is provided in Fig. 6.6.



Fig. 6.6 Lake Avon (Courtesy of IMC)

The commencing (i.e. western) end of LW18 is located within the Dams Safety NSW Notification Area for Lake Avon. The longwall is located at a minimum distance of 300 m from the Full Supply Level (FSL) of the reservoir. The Avon Dam Wall is located at the northern end of the reservoir and it is at a distance of approximately 8 km from the proposed LW18.

Lake Cordeaux is located approximately 4.5 km east of the proposed LW18, at its closest point. The Cordeaux Dam Wall and the Upper Cordeaux No. 2 Dam Wall are located approximately 7 km north and 6 km east, respectively, from the proposed longwall.

6.3.2. Predictions and impact assessments for the reservoirs

The FSL of Lake Avon is located at a minimum distance of 300 m from LW18, at its closest point. At this distance, the lake is predicted to experience less than 20 mm vertical subsidence due to the mining of this proposed longwall. While the reservoir could experience low level vertical subsidence, it is not expected to experience measurable tilts, curvature or conventional strains.

The maximum predicted valley related effects at Lake Avon, due to the mining in Area 3B, are 50 mm upsidence and 100 mm closure. The maximum effects occur where the lake is closest to the longwalls. Whilst the predicted valley related effects are small, it is possible that minor cracking could occur in the bedrock, as has been observed in the Southern Coalfield up to 400 m from previously extracted longwalls. It is not expected that this minor cracking in the lake bed would result in adverse impacts on the reservoir.

The proposed LW18 is located at distances of approximately 8 km from the Avon Dam Wall, 7 km from the Cordeaux Dam Wall and 6 km from the Upper Cordeaux No. 2 Dam Wall. At these distances, the predicted vertical and horizontal movements at the dam walls are very small and are unlikely to be measurable.

The previously extracted longwalls in Areas 1 and 2 at the Mine have been mined to within 0.9 km of the Upper Cordeaux No. 1 and No. 2 Dam Walls. Detailed ground monitoring indicated that the measured movements were very small and were within the order of survey tolerance. The previous mining has not resulted in adverse impacts on these structures.

It is unlikely, therefore, that the Avon and Cordeaux Dam Walls and the associated reservoirs would experience adverse impacts due to the extraction of the proposed LW18. This longwall will be extracted at greater distances from the Avon and Cordeaux Dam Walls than the previously extracted longwalls in Areas 2, 3A and 3B at the Mine.

6.3.3. 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. MSEC1103-10. The details of the heritage sites have been provided by Biosis (2012).

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 no additional sites that are located within the Study Area based on the 600 m boundary.

Details of the Aboriginal heritage sites located within Study Area are provided in Table 6.5.

Table 6.5 Aboriginal heritage sites identified within the Study Area

Reference	Type	Location relative to the longwalls
52-2-1772	Shelter with art	200 m south of the LW18 maingate
52-2-2248	Shelter with art	Directly above the chain pillar between LW17 and LW18
52-2-3068	Shelter with art and grinding grooves	Directly above LW17 and immediately adjacent to the longwall maingate

Further details on the Aboriginal heritage sites are provided in the report by Biosis (2012).

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 is provided in Table 6.6. 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 LW9 to LW18.

Table 6.6 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})
52-2-1772	< 20	< 0.5	< 0.01	< 0.01
52-2-2248	200	6	0.16	0.01
52-2-3068	775	20	0.80	0.06

Site 52-2-1772 is located outside the mining area at a distance of 200 m from the proposed LW18. This site is predicted to experience less than 20 mm vertical subsidence due to the mining of LW9 to LW18. While Site 52-2-1772 could experience low level vertical subsidence, it is not expected to experience measurable tilts, curvatures or strains.

The maximum predicted conventional strains for Sites 52-2-2248 and 52-2-3068, 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 4.3. The maximum 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.

Sites 52-2-1772 and 52-2-2248 are located on the sides of ridgelines. These sites are therefore not expected to experience valley related effects. Site 52-2-3068 is located along Drainage Line LA2. The maximum predicted total valley related effects in this location are 450 mm upsidence and 550 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.

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 (Biosis, 2012).

Rock shelters

There are two rock shelters with art (Refs. 52-2-1772 and 52-2-2248) and one rock shelter with art and grinding grooves (Ref. 52-2-3068) that are located within the Study Area.

Site 52-2-1772 is located outside of the mining area at a distance of 200 m from the proposed LW18. While this site could experience low levels of vertical subsidence, it is not expected to experience measurable conventional tilts, curvatures or strains. Site 52-2-1772 is also not expected to experience valley related upsidence or compressive strain due to valley closure, as these occur near the valley base, rather than along the valley sides. The potential for impacts on Site 52-2-1772 is therefore considered to be very low.

Sites 52-2-2248 and 52-2-3068 are located above or adjacent to the chain pillar between LW17 and LW18. The extraction of these longwalls 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 adjacent to 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 Sites 52-2-2248 and 52-2-3068 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.

Further assessments of the potential impacts on the rock shelters are provided in a report by the specialist heritage consultant for the project.

Grinding groove site

There is one site with grinding grooves (Ref. 52-2-3068) that is located within the Study Area. This site is located above LW17 immediately adjacent to the longwall maingate. The extraction of LW17 and LW18 are likely to result in fracturing of the exposed bedrock. The fracturing is expected to predominately occur directly above the longwalls.

It is extremely difficult to assess the likelihood that fracturing would be coincident with the grinding groove site itself, as this is dependent on the localised response of the bedrock to the mining-induced ground movements. The potential for impacts on the grinding groove site has been based on the previous experience of mining longwalls directly beneath these types of sites in the Southern Coalfield.

The potential for adverse impacts on the grinding groove site has been assessed as *unlikely* (i.e. less than 10 %). However, it is possible that this site could be impacted by fracturing of the bedrock due to mining. Further assessments of the potential impacts on the rock shelters are provided in a report by the specialist heritage consultant for the project.

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. MSEC1103-10. The locations and details of the survey control marks were obtained from *Spatial Services* using the *SCIMS Online* website (SCIMS, 2019).

Survey control marks SS 40783, SS 40784, SS 40785, SS 40786 and PM6167 are located within the Study Area based on the 600 m boundary. The marks located directly above the mining area could experience the full range of predicted movements. The marks located outside the mining area could experience far-field vertical and far-field horizontal effects.

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 4.5.

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. **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.

APPENDIX B. REFERENCES

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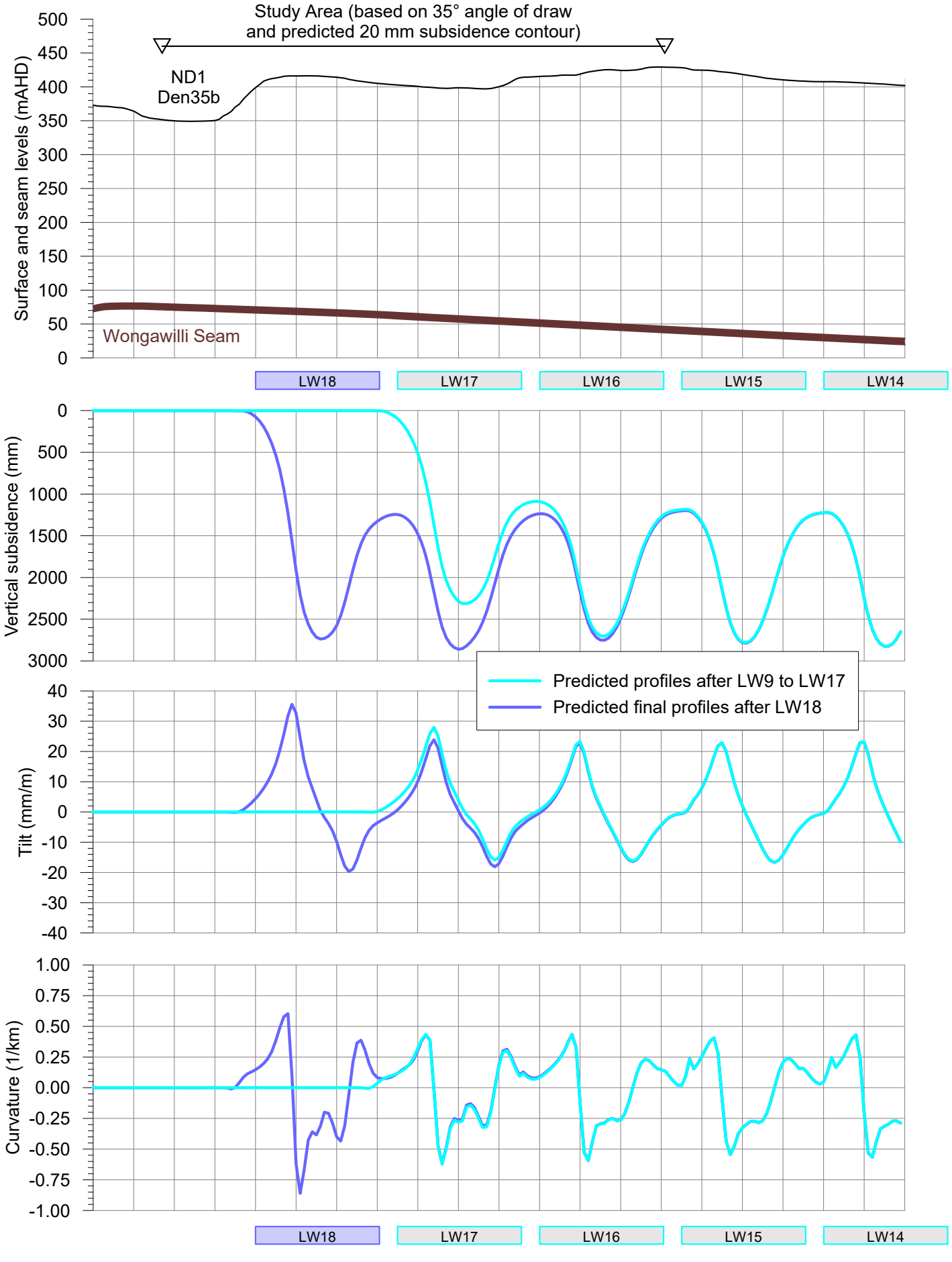
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APPENDIX C. FIGURES

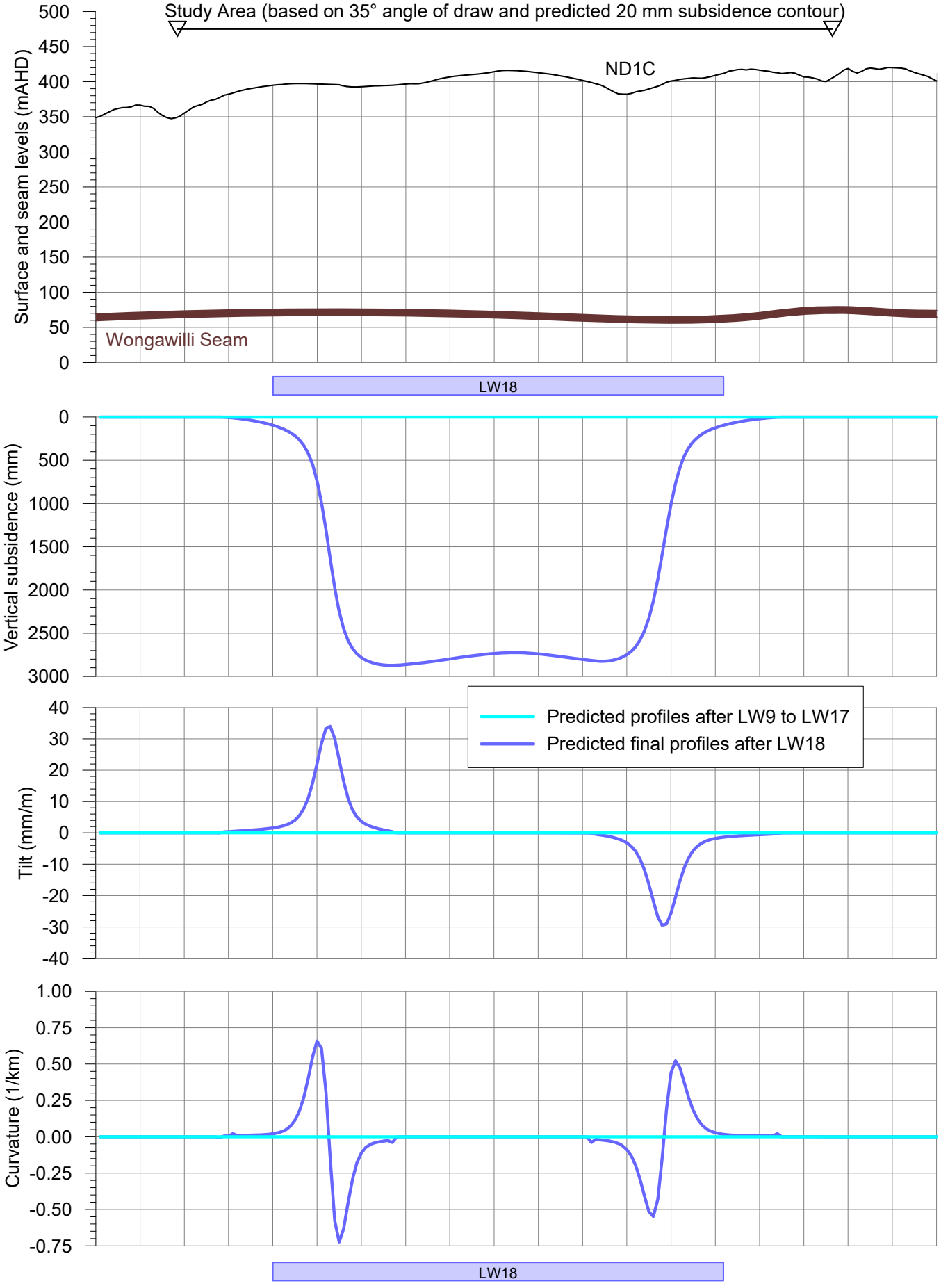
Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 1 due to the extraction of LW9 to LW18



msec

Fig. C.01

Predicted profiles of vertical subsidence, tilt and curvature along Prediction Line 2 due to the extraction of LW9 to LW18



msec

Fig. C.02

Predicted profiles of vertical subsidence, upsidence and closure along Drainage Line LA2 due to the extraction of LW9 to LW18

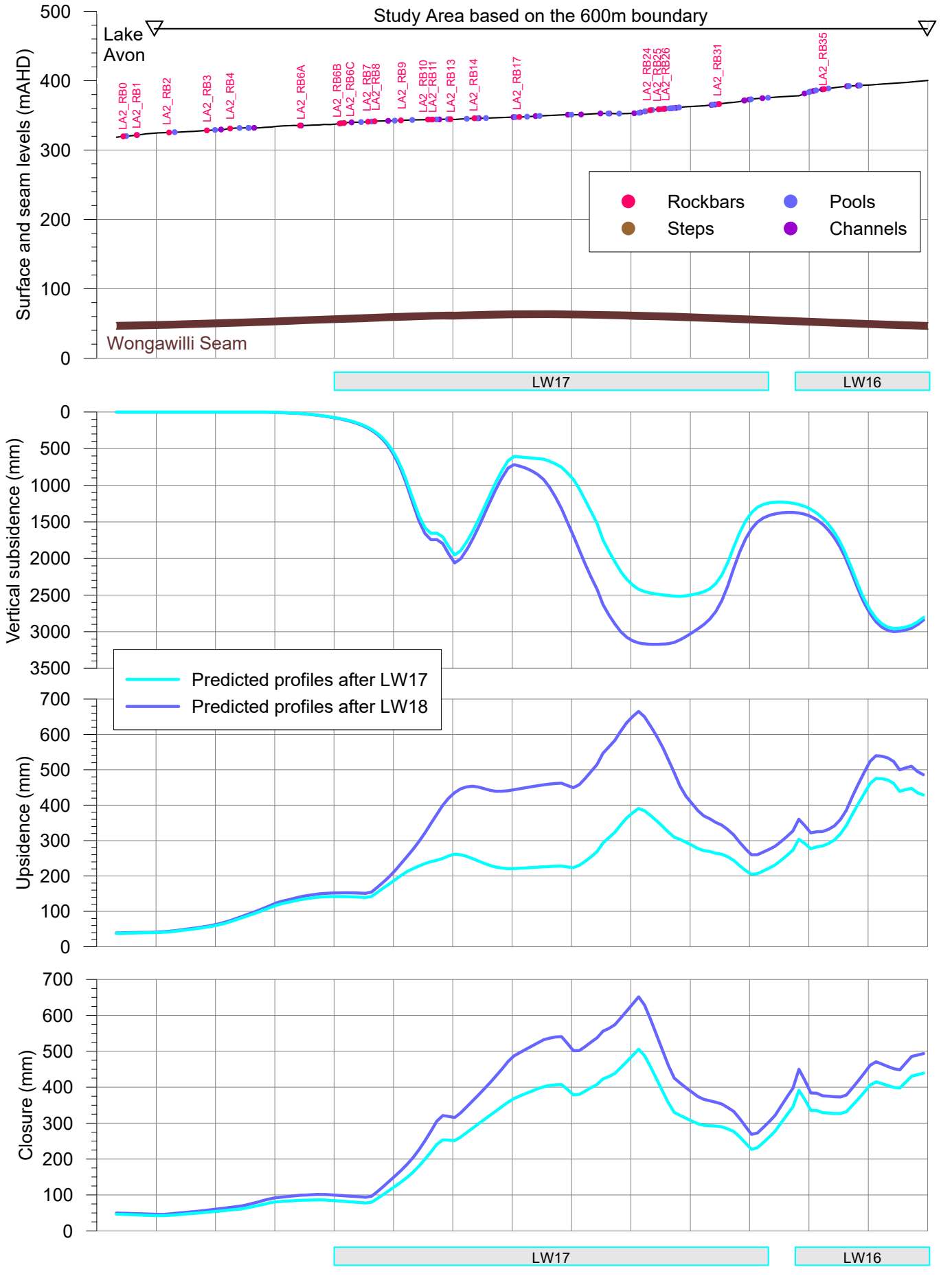
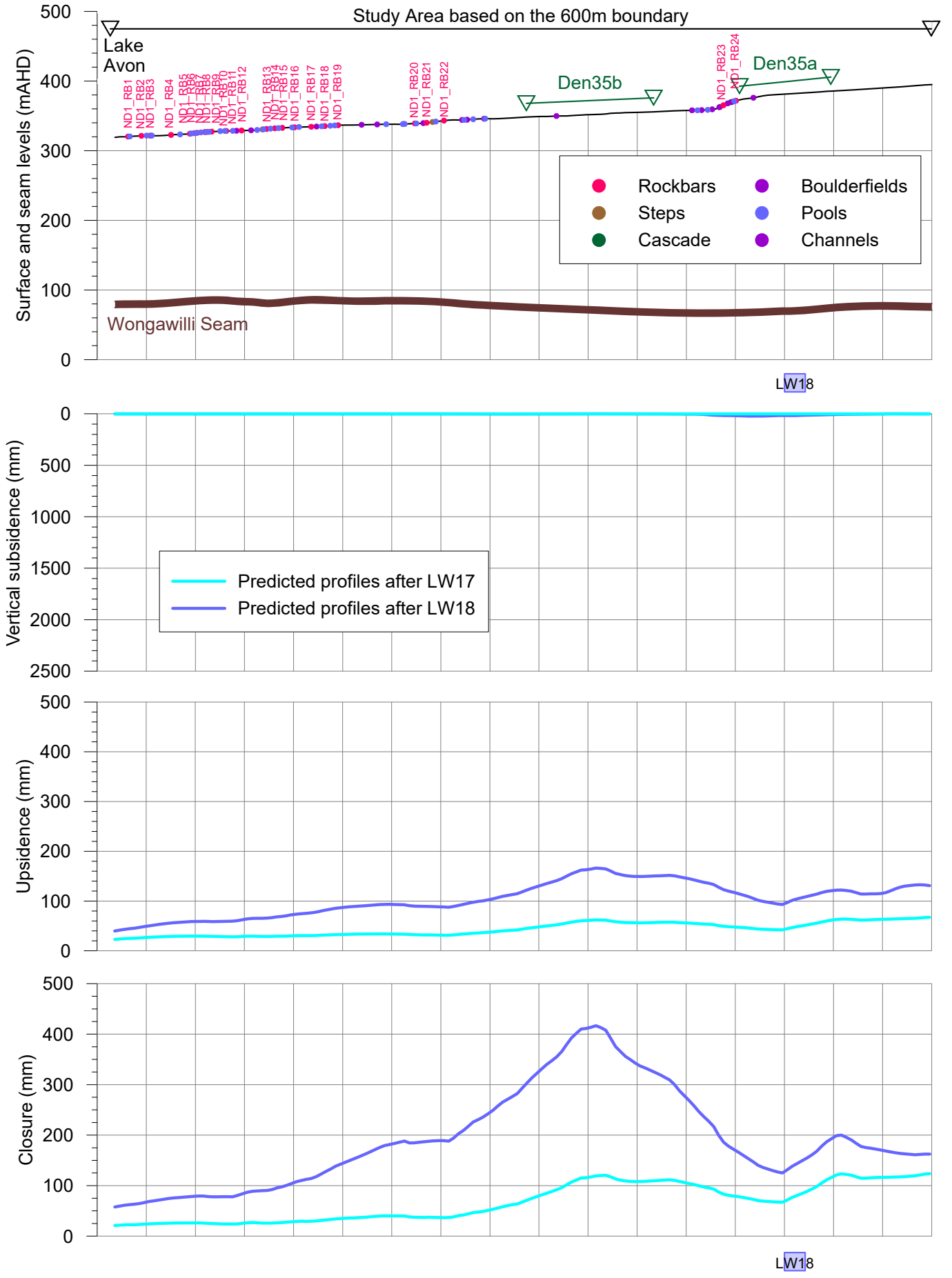


Fig. C.03

Predicted profiles of vertical subsidence, upsidence and closure along Drainage Line ND1 due to the extraction of LW9 to LW18



msec

Fig. C.04

Predicted profiles of vertical subsidence, upsidence and closure along Drainage Line ND1C due to the extraction of LW9 to LW18

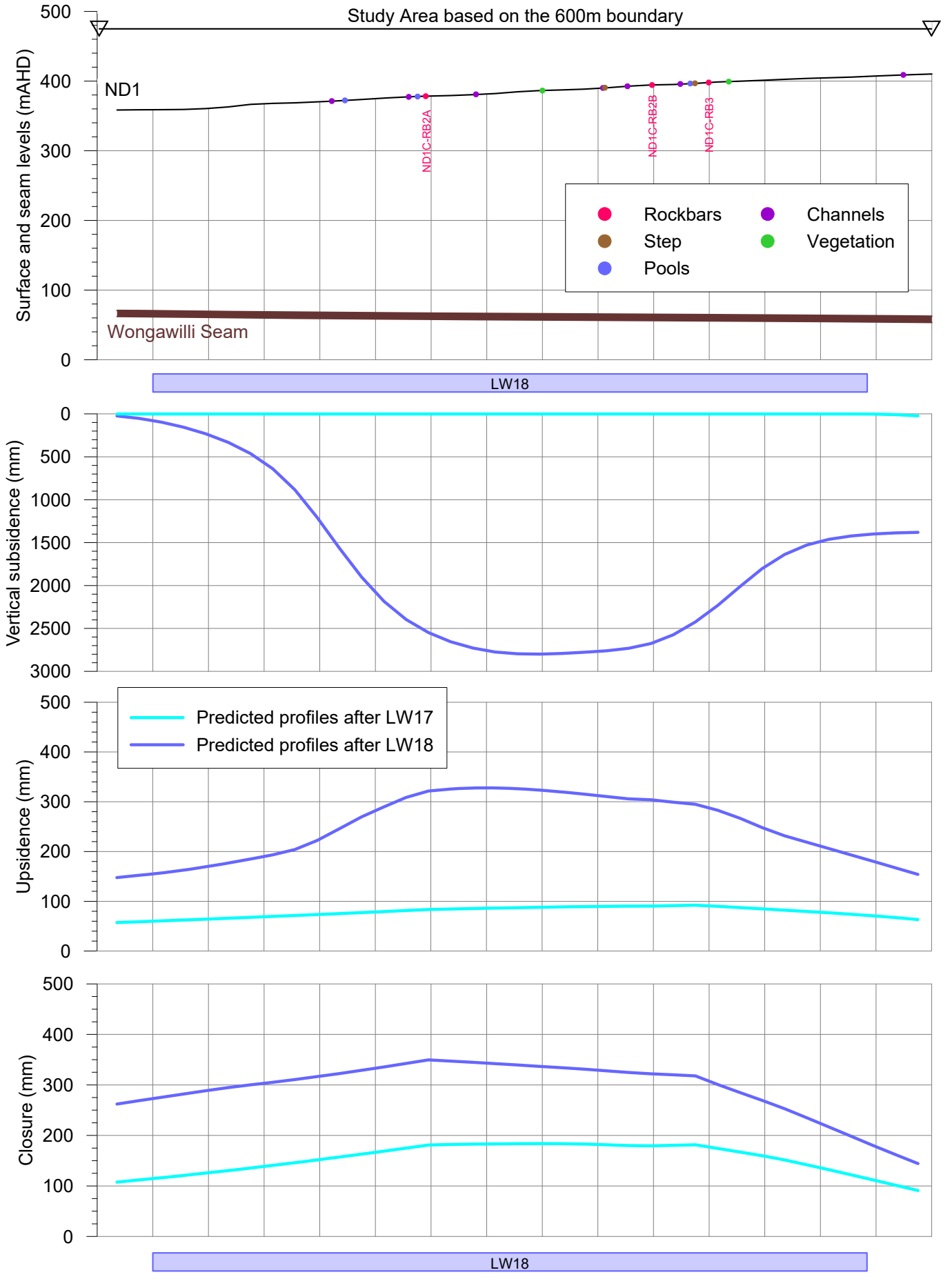
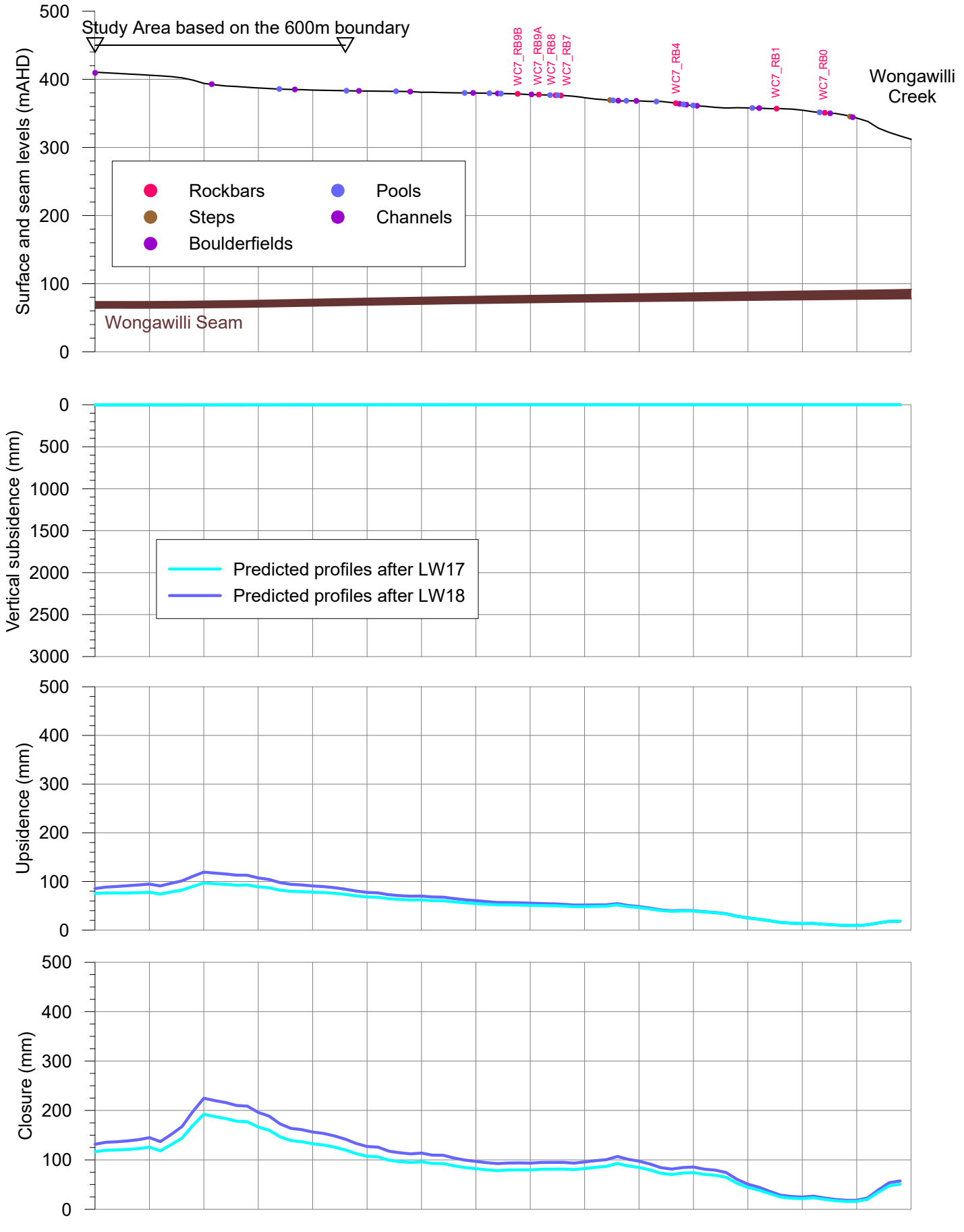


Fig. C.05

Predicted profiles of vertical subsidence, upsidence and closure along Drainage Line WC7 due to the extraction of LW9 to LW18



msec

Fig. C.06

Predicted profiles of vertical subsidence, upsidence and closure along Drainage Line WC12 due to the extraction of LW9 to LW18

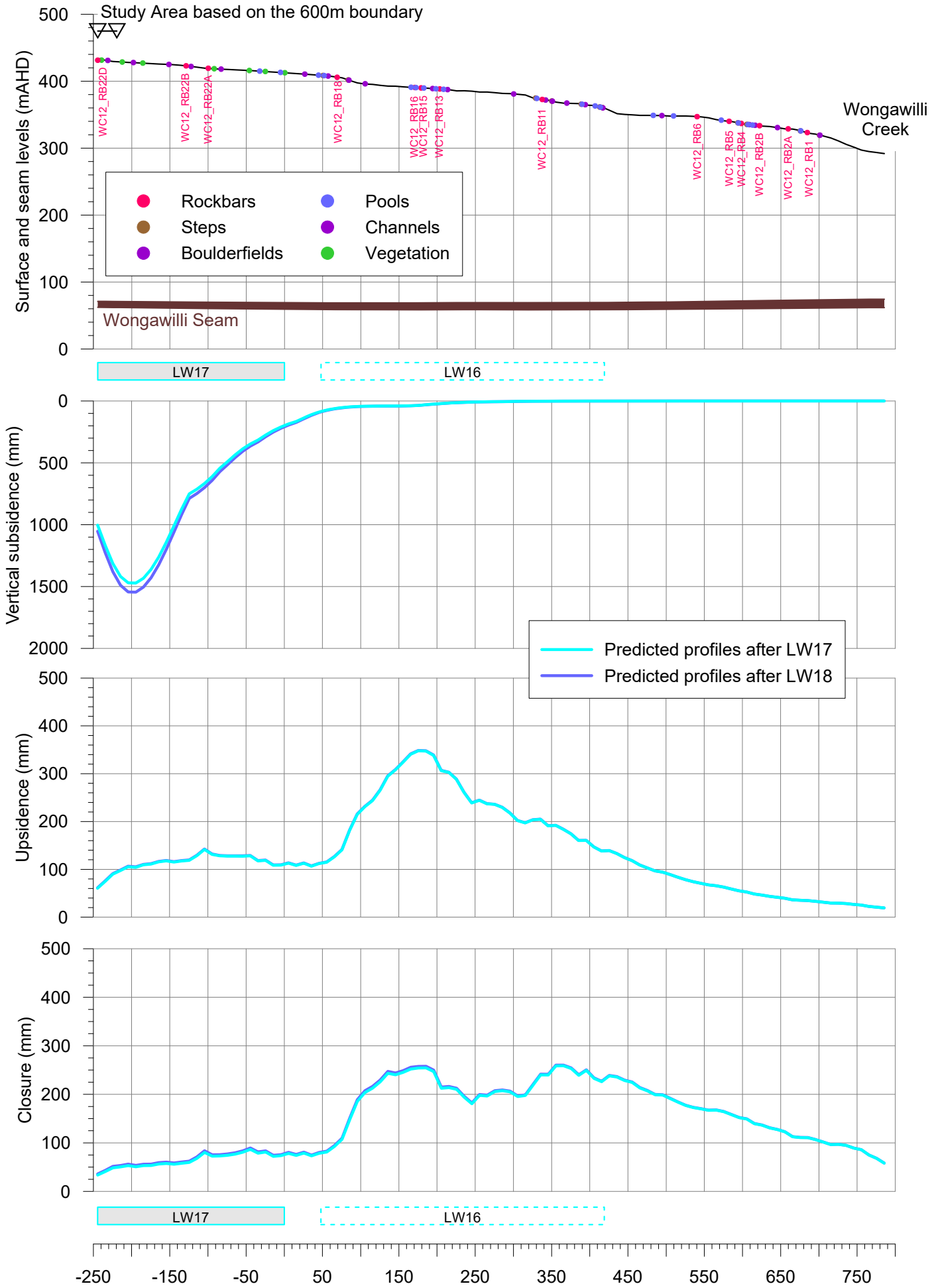
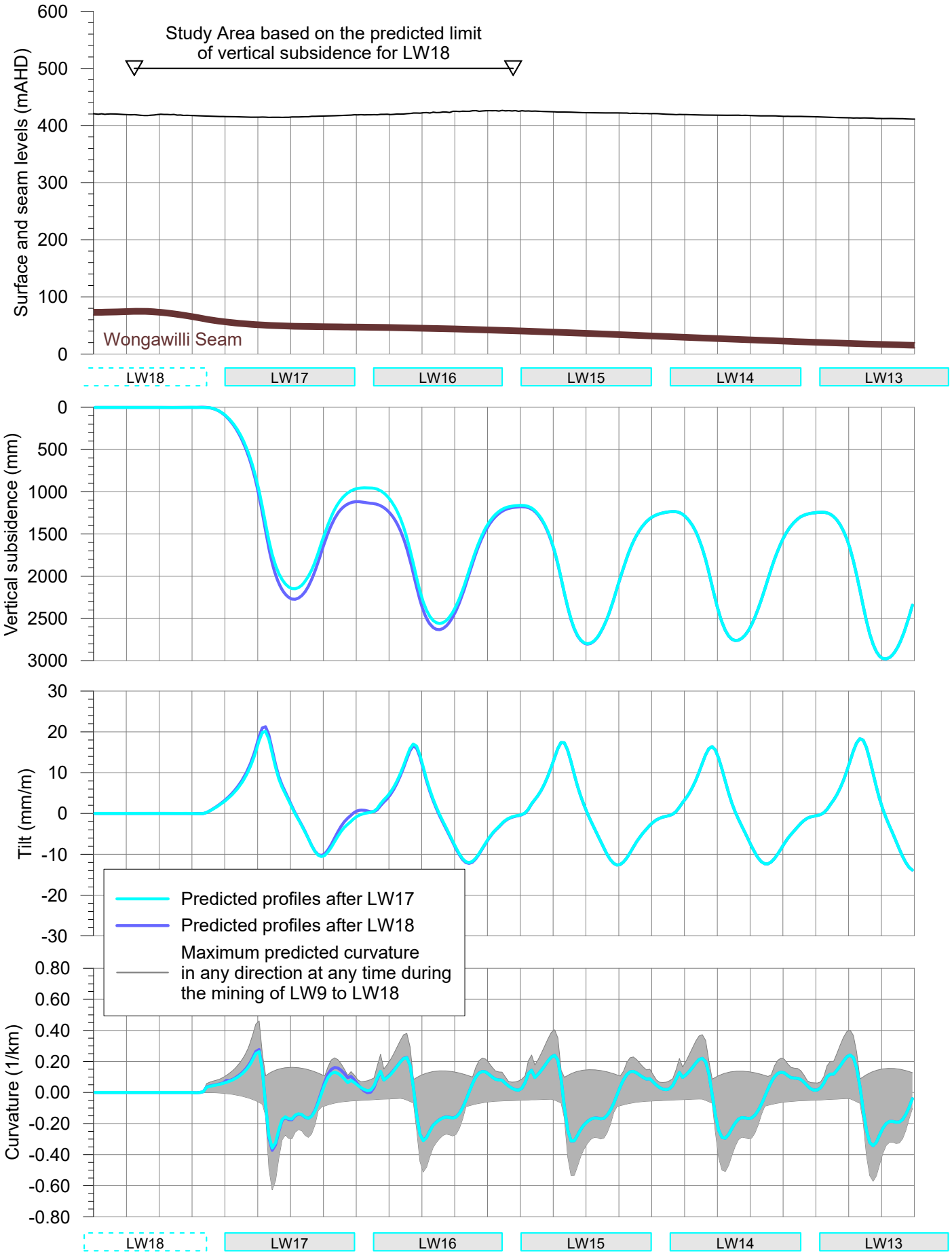


Fig. C.07

Predicted profiles of vertical subsidence, tilt and curvature along the disused railway corridor due to the extraction of LW9 to LW18



msec

Fig. C.08

APPENDIX D. DRAWINGS

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ILLAWARRA COAL
DENDROBIUM COLLIERY - AREA 3B
LONGWALL 18
GENERAL LAYOUT OF LONGWALLS AT DENDROBIUM MINE

DATE:	SCALE:	DRAWING No:	Rev No
23 Jun 2020	1:20000	MSE1103-01	C

LEGEND
EXISTING MONITORING

288000
289000
290000
291000
6194000
6193000
6192000
6191000
6190000

DISUSED MALDON-DOMBARTON RAILWAY

LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

AREA 3A
AREA 3B

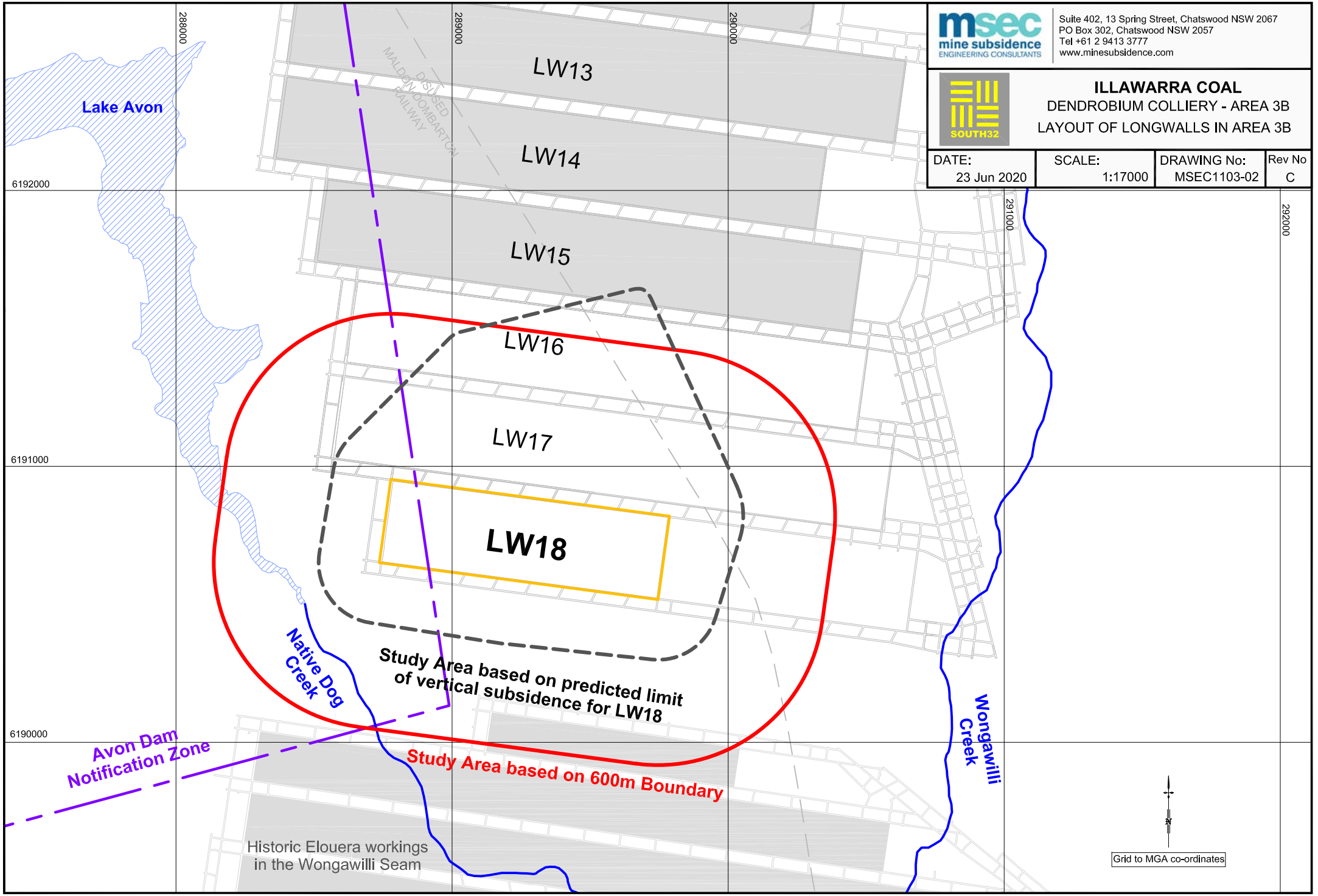
Donalds Castle Creek
Lake Avon
Native Dog Creek
Wongawilli Creek

Study Area based on predicted limit of vertical subsidence for LW18
Study Area based on 600m Boundary
Avon Dam Notification Zone

Historic Elouera workings in the Wongawilli Seam

Grid to MGA co-ordinates

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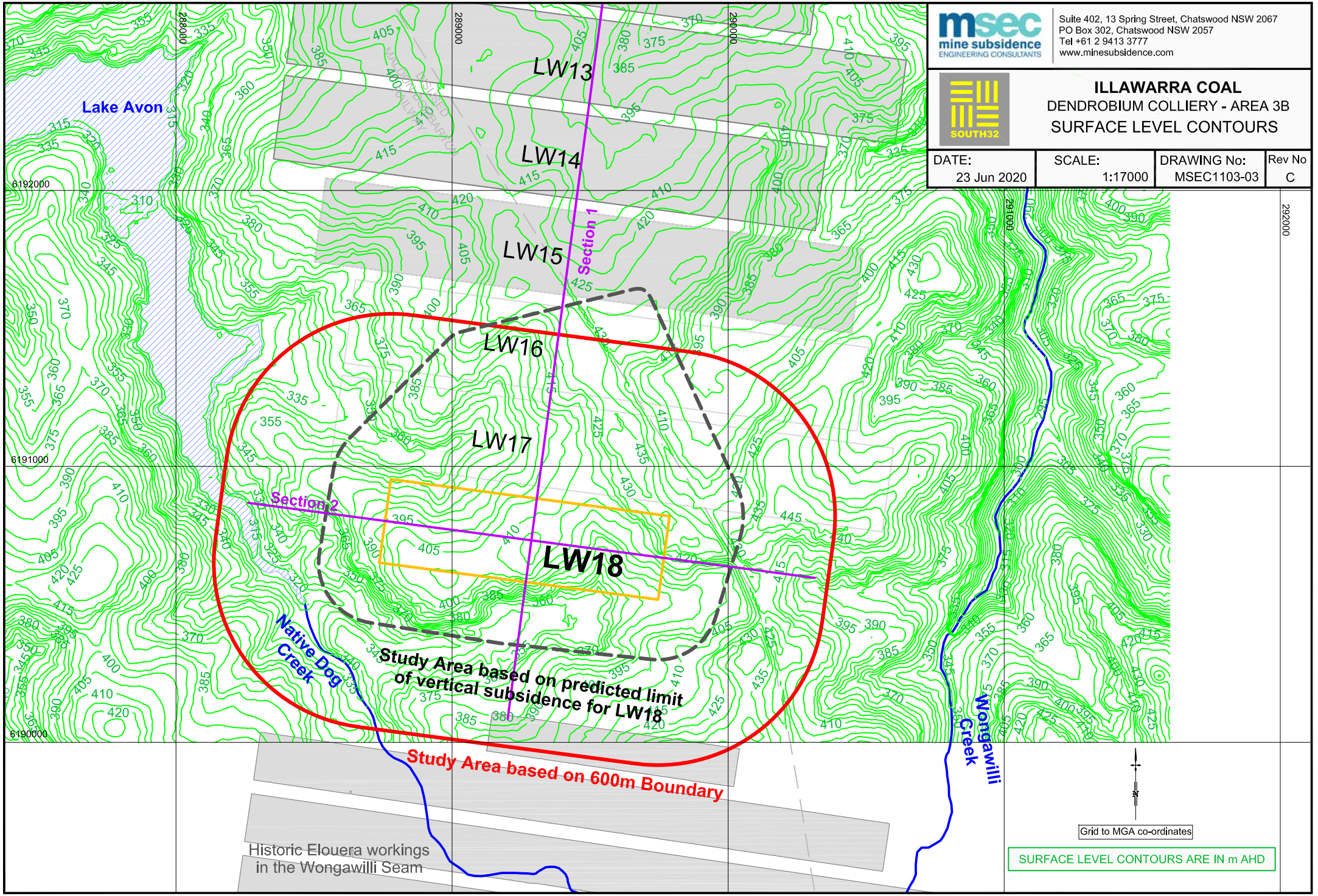
ILLAWARRA COAL

DENDROBIUM COLLIERY - AREA 3B

LAYOUT OF LONGWALLS IN AREA 3B

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23 Jun 2020	1:17000	MSEC1103-02	C

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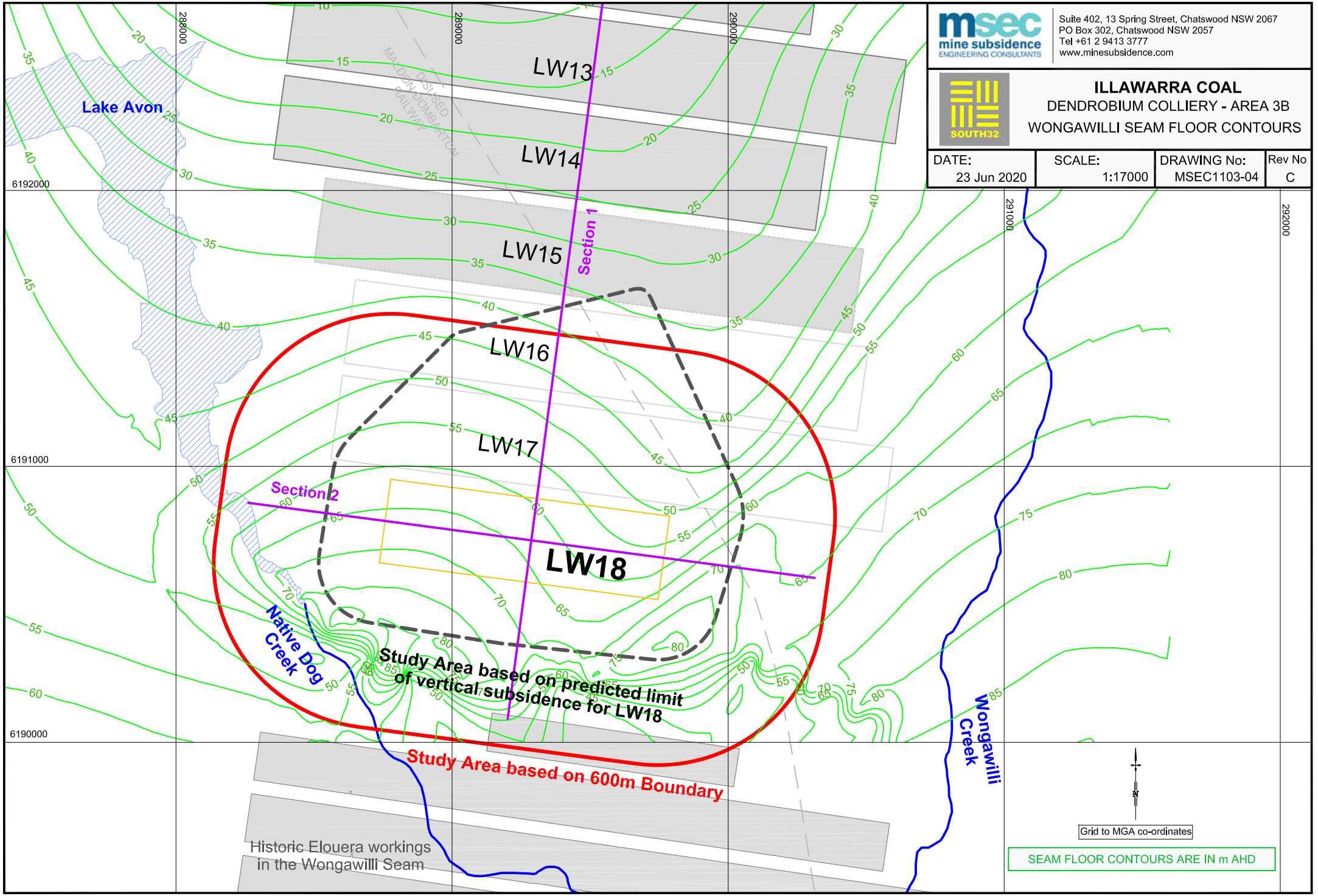
SURFACE LEVEL CONTOURS

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Grid to MGA co-ordinates

SURFACE LEVEL CONTOURS ARE IN m AHD

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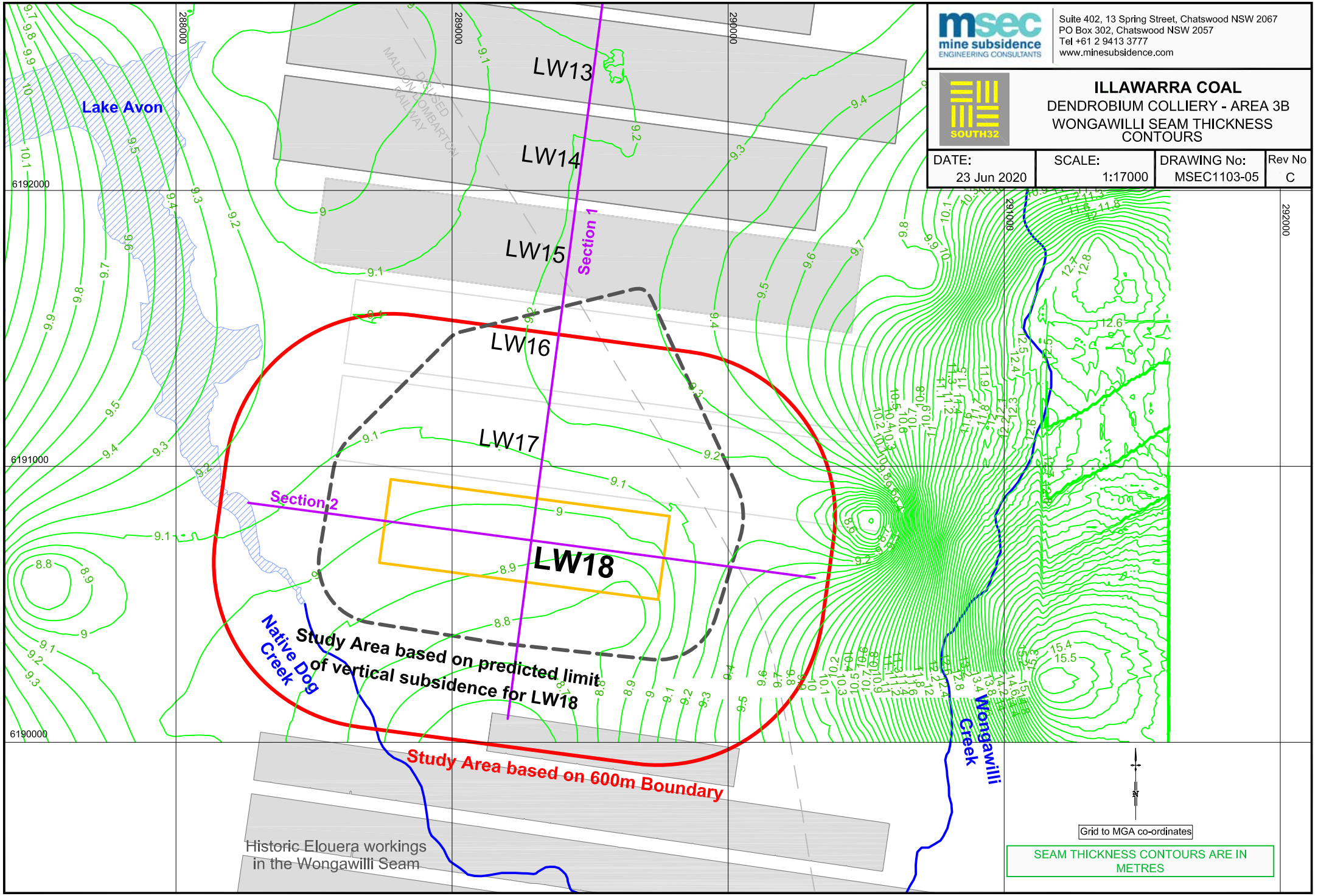
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DENDROBIUM COLLIERY - AREA 3B

WONGAWILLI SEAM FLOOR CONTOURS

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WONGAWILLI SEAM THICKNESS CONTOURS

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Grid to MGA co-ordinates

SEAM THICKNESS CONTOURS ARE IN METRES

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WONGAWILLI DEPTH OF COVER CONTOURS

DATE:	SCALE:	DRAWING No:	Rev No
23 Jun 2020	1:17000	MSEC1103-06	C

Lake Avon

LW13

LW14

LW15

LW16

LW17

LW18

Native Dog Creek

Wongawilli Creek

Study Area based on predicted limit of vertical subsidence for LW18

Study Area based on 600m Boundary

Historic Elouera workings in the Wongawilli Seam

Grid to MGA co-ordinates

DEPTH OF COVER CONTOURS ARE IN METRES

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DENDROBIUM COLLIERY - AREA 3B
GEOLOGICAL STRUCTURES

DATE:	SCALE:	DRAWING No:	Rev No
23 Jun 2020	1:17000	MSEC1103-07	C

288000 289000 290000 291000 292000

6192000 6191000 6190000

Lake Avon

DISUSED MALDON-DOMBARTON RAILWAY

LW13 LW14 LW15 LW16 LW17 **LW18**

Native Dog Creek

Wongawilli Creek

Avon Dam Notification Zone

Study Area based on predicted limit of vertical subsidence for LW18

Study Area based on 600m Boundary

Historic Elouera workings in the Wongawilli Seam

LEGEND
- Faults
- Dykes
- Lineaments
- Cinder Zone

N

Grid to MGA co-ordinates

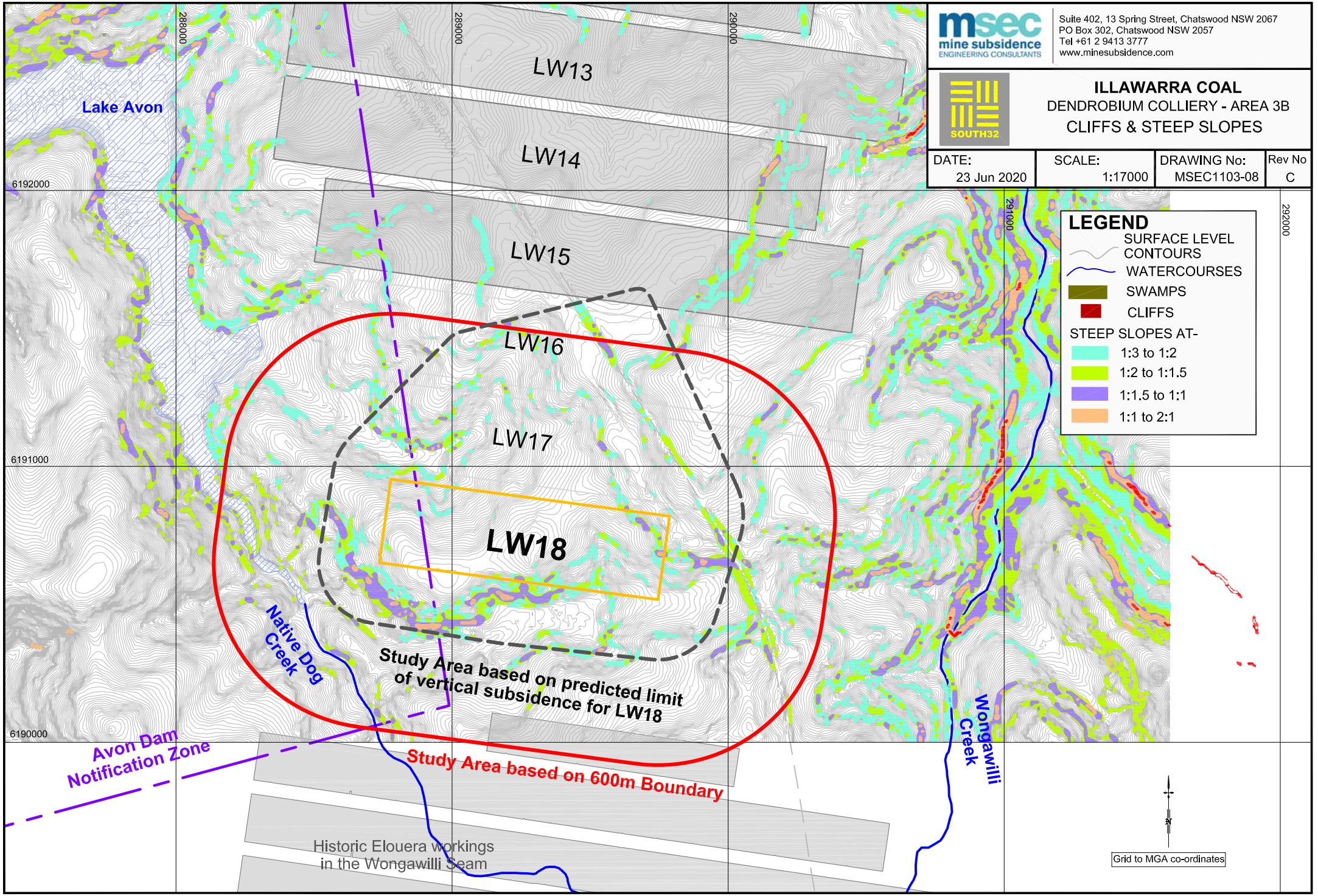
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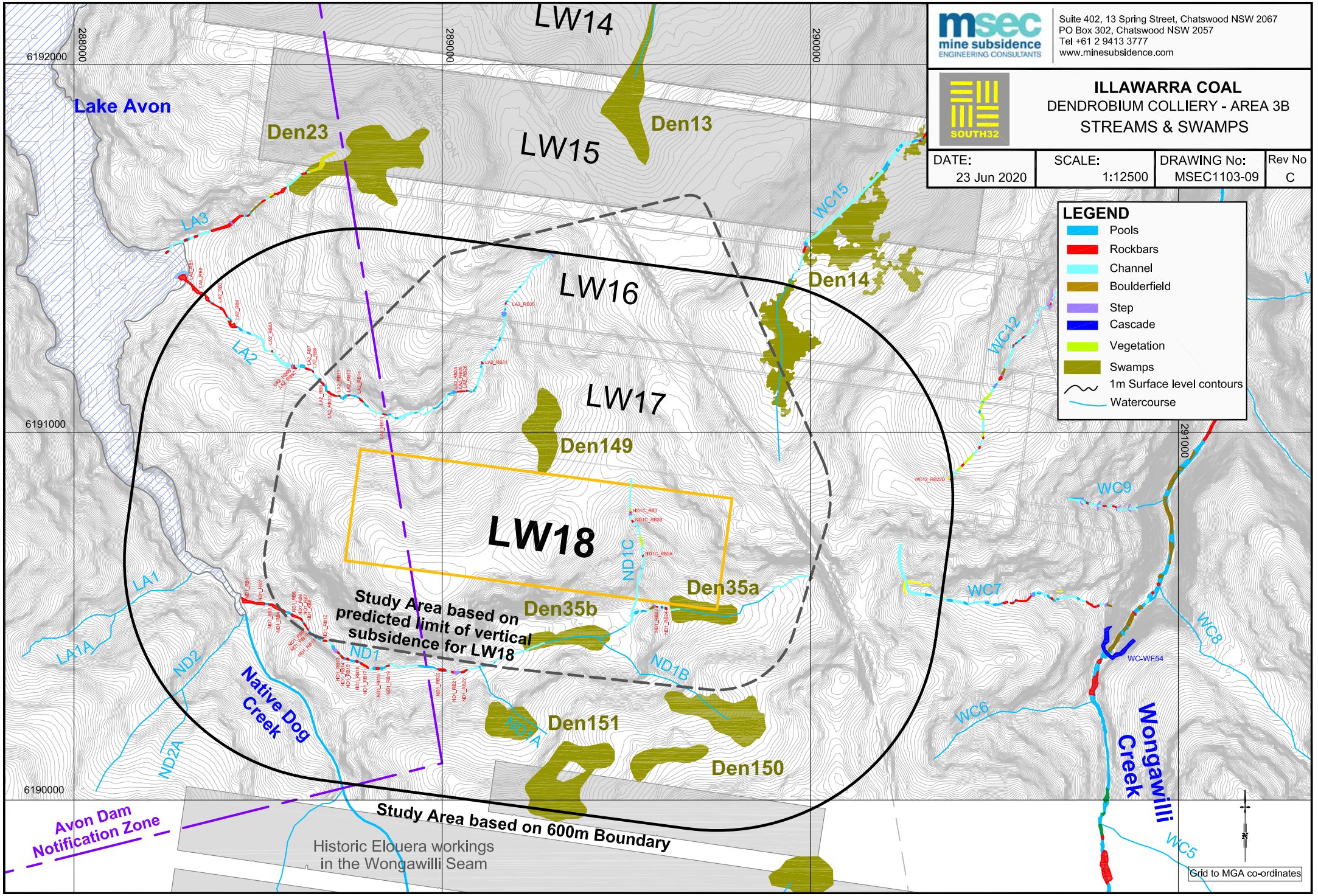
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ILLAWARRA COAL
DENDROBIUM COLLIERY - AREA 3B
CLIFFS & STEEP SLOPES

DATE:	SCALE:	DRAWING No:	Rev No
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ILLAWARRA COAL
DENDROBIUM COLLIERY - AREA 3B
STREAMS & SWAMPS

DATE:	SCALE:	DRAWING No:	Rev No
23 Jun 2020	1:12500	MSEC1103-09	C

LEGEND

- Pools
- Rockbars
- Channel
- Boulderfield
- Step
- Cascade
- Vegetation
- Swamps
- 1m Surface level contours
- Watercourse

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DENDROBIUM COLLIERY - AREA 3B
BUILT FEATURES

DATE:	SCALE:	DRAWING No:	Rev No
23 Jun 2020	1:17000	MSEC1103-10	C

LEGEND
- FIRE ROADS
- DISUSED RAILWAY CORRIDOR
- CUTTINGS
- EMBANKMENT
- DRILLHOLES
- SURVEY MARKS
- ARCHEOLOGICAL SITES

LW13
LW14
LW15
LW16
LW17
LW18

Study Area based on predicted limit of vertical subsidence for LW18

Study Area based on 600m Boundary

Historic Elouera workings in the Wongawilli Seam

Lake Avon
Native Dog Creek
Wongawilli Creek
Fire Road No6n
Fire Road No6q
Fire Road No6A
MALDON-DOMBARTON RAILWAY CORRIDOR
DISUSED

MDB-F5
MDB-F6
MDB-F7
MDB-F8
MDB-F9
MDB-F10
MDB-F11
MDB-F12
MDB-F13

288000
289000
290000
291000
292000
6192000
6191000
6190000

Grid to MGA co-ordinates

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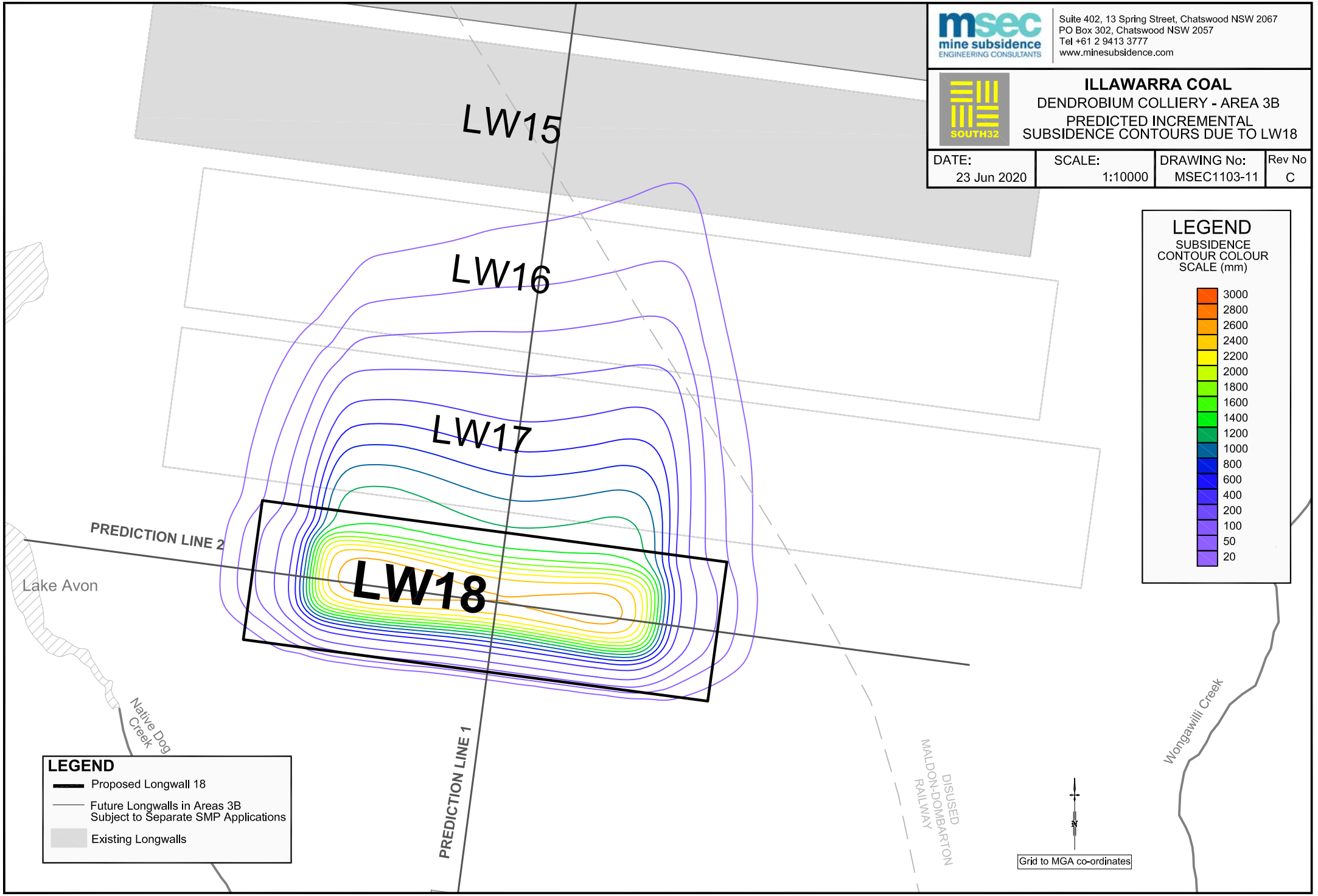
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ILLAWARRA COAL

DENDROBIUM COLLIERY - AREA 3B

PREDICTED INCREMENTAL SUBSIDENCE CONTOURS DUE TO LW18

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23 Jun 2020	1:10000	MSEC1103-11	C



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DENDROBIUM COLLIERY - AREA 3B

PREDICTED TOTAL SUBSIDENCE CONTOURS DUE TO LW9 TO LW18

DATE:	SCALE:	DRAWING No:	Rev No
23 Jun 2020	1:10000	MSEC1103-12	C

LW15

LW16

LW17

LW18

PREDICTION LINE 2

PREDICTION LINE 1

Lake Avon

Native Dog Creek

Wongawilli Creek

DISUSED MALDON-DOMBARTON RAILWAY

LEGEND

SUBSIDENCE CONTOUR COLOUR SCALE (mm)

3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
100
50
20

LEGEND

Proposed Longwall 18

Future Longwalls in Areas 3B Subject to Separate SMP Applications

Existing Longwalls

Grid to MGA co-ordinates

Attachment D – Risk Assessment

South32 - Illawarra Metallurgical Coal

Review of Dendrobium Longwall 18 Subsidence Management Plan

Risk Assessment Report

AR2944

Revision E

Tuesday, 4 August 2020

Assessment and report completed by;
AXYS Consulting Pty Ltd
PO Box 1011, Wilton, 2571
NSW, Australia
+61417281115

1. Revisions

Rev No	Date	Description
A	03 July 2020	Initial Release
B	12 July 2020	Review by Cody Brady
C	23 July 2020	Review by IMC
D	24 July 2020	Review by IMC
E	4 August 2020	Document reviewed by Professor Bruce Hebblewhite

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2. Participants

Name	Position	Relevant Years' Experience
Daniel Pygas	Cardno Principal Aquatic Ecology	14 Years
Will Minchin	Watershed HydroGeo Hydrogeologist	16 Years
Simon Tweed	Niche Environment and Heritage Team Leader (Ecology)	12 Years
Dr Stuart Brown	HydroGeo Principal Hydrogeologist	25 Years
James Barbato	Mine Subsidence Engineering Consultants (MSEC) Subsidence Engineer	16 Years
Ken Mills	SCT Operations Principal Geotechnical Engineer	40+ Years
Hugo Kaag	South32 Principal Geologist	26 Years
Richard Walsh	South32 Superintendent Exploration	30+ Years
Gary Brassington	South32 Manager Approvals	25 Years
Cody Brady	South32 Principal Approvals	4 Years

The following participants were not in attendance at the risk assessment held on 3 July though have reviewed this risk assessment report and provided feedback which has been incorporated. Professor Bruce Hebblewhite was engaged by Illawarra Metallurgical Coal (IMC) to provide a peer review of the document. Professor Hebblewhite reviewed Revision D of the document. Revision E has been updated to incorporate the feedback of the peer review.

Name	Position	Relevant Years' Experience
Prof. Bruce Hebblewhite	B K Hebblewhite Consulting Peer Reviewer	45+ Years

3. Introduction

IMC carried out a risk assessment for the Dendrobium Longwall 18 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 Panel regarding risk assessments undertaken to support recent SMP applications, this risk assessment has incorporated the 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 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 18 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 provides for a more detailed 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 18 - Background

IMC commenced longwall extraction in Dendrobium Area 3B in 2013 with Longwall 9 the first in the series. Longwall 16 is currently being extracted. IMC proposes to extract Longwall 18 within the Wongawilli Seam, which is the final longwall in the Area 3B series. The longwall will be extracted towards the main headings (i.e. retreat mining from the west towards the east) with a maximum cutting height of 3.9m. Longwall 18 will be extracted after Longwall 17 in Area 3B and prior to the extraction of Longwall 19 in Area 3A.

The Study Area (Drawing 1103-07 MSEC2020 [Attachment 6]) has been defined, as a minimum, as the surface area enclosed by the: 35° angle of draw line from the extents of Longwall 18; and the predicted incremental 20 mm subsidence contour due to the extraction of the proposed longwall. The natural features located within 600 m of the extent of the longwall mining area have also been included in the assessments, 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 18 SMP application should be read in conjunction with this risk assessment.

Natural and built features considered in the risk assessment:

- Wongawilli Creek is located 1 km east of Longwall 18, at its closest point. At this distance, the predicted incremental vertical subsidence, upsidence and closure for the creek, due to the mining of Longwall 18, 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 Wongawilli Creek due to the mining of Longwall 18 (MSEC 2020).
- Wongawilli Creek Waterfall 54 (WC-WF54) along Wongawilli Creek is located 1 km from the finishing (i.e. eastern) end of Longwall 18. At this distance, the waterfall is not expected to experience measurable conventional or valley related effects. It is unlikely, therefore, that adverse impacts would occur at the waterfall due to the mining of Longwall 18 (MSEC 2020).
- Native Dog Creek is located 310 m south-west of the proposed Longwall 18, at its closest point. The upper reaches of Native Dog Creek is located directly above the existing longwalls at Elouera Colliery. Fracturing could develop along Native Dog Creek where it is located within approximately 400 m of Longwall 18. Type 3 impacts are possible, but are considered unlikely, as only two cases have been observed at similar distances from Dendrobium Longwall 9 to 15 (MSEC 2020).
- Drainage lines ND1, ND1C and their tributaries are located directly above and adjacent to Longwall 18. Drainage lines LA1, LA2, ND1A, ND1B, ND2, ND2A, WC7 and WC12 are also located within the Study Area based on the 600 m boundary. These drainage lines are first and second order streams that form tributaries to Lake Avon and Wongawilli Creek.

  The drainage lines located directly above the mining area could experience the full range of predicted subsidence effects. Localised ponding due to mining-induced tilt 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 and adjacent to Longwall 18. 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 Longwall 18.
- There are six swamps that have been identified partially or wholly within the Study Area based on the 600m boundary. Swamp Den35a is partially located above Longwall 18 and Swamps Den14 and Den149 are located above the previous Longwall 16 and 17. Swamps Den35b, Den150 and Den151 are located at

minimum distances of 85 m to 325 m south of Longwall 18 . (Drawing 1103-09 MSEC2020 [Attachment 6]).

- Lake Avon, or the Avon Reservoir, is located 300 m west of Longwall 18, at its closest point. The maximum predicted valley related effects at Lake Avon, due to the mining in Area 3B, are 50 mm upsidence and 100 mm closure. Whilst the predicted valley related effects are small, it is possible that minor cracking could occur in the bedrock, as has been observed in the Southern Coalfield up to 400 m from previously extracted longwalls. It is not expected that this minor cracking in the lakebed would result in adverse physical impacts on the reservoir.
- The Avon Dam Wall is located at the northern end of the reservoir and it is at a distance of approximately 8 km from Longwall 18. The Cordeaux Dam Wall and the Upper Cordeaux No. 2 Dam Wall are located approximately 7 km north and 6 km east, respectively, from the proposed longwall. At these distances, the predicted vertical and horizontal movements at the dam walls are very small and are unlikely to be measurable (MSEC 2020).
- Geological features at both inseam and surface levels were considered as part of the risk assessment and are shown on (Drawing 1103-07 MSEC2020 [Attachment 6]). IMC (2020) includes a description of the expected geological conditions to be experienced during mining. This memorandum states the key conclusion that geological conditions predicted for Longwall 18 are similar to conditions IMC have experienced previously in Area 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 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 DPIE in relation to advice received from the Panel, the management of IMC have conducted a formal risk assessment [BC1]to address the concerns of mining in the catchment that may be affected by the extraction of Longwall 18.

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 18.

6. Objectives and Scope

The objective of this risk assessment was to support the Longwall 18 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 18.

A scoping session was carried out with the assessment team and the following items were agreed to be assessed:

- Avon Reservoir
- Groundwater
- Wongawilli Creek including the waterfall (WWC-WF54)
- Native Dog Creek
- Swamps, tributaries to Avon Reservoir, Wongawilli Creek and Native Dog Creek

For each of the items above the following concerns (where relevant) were reviewed and assessed:

- Surface subsidence
- Sub-surface ground movements
- Valley closure and upsidence
- Lineaments
- Faults
- Dykes
- Groundwater drawdown
- The Elouera Fault

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 potential impact from Longwall 18
- Reliable 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 and referenced 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
- Doyle J, 2007. Review of Permeability of Geological Structures in the Dendrobium Area.
- HGEO, 2020. Dendrobium Mine Spatial analysis of mine inflow chemistry, Dendrobium Areas 1, 2 and 3. April 2020. Report D20357.
- Independent Expert Panel for Mining in the Catchment (IEPMC), 2019, Independent Expert Panel for Mining in the Catchment Report: Part 2. Coal Mining Impacts in the Special Areas of the Greater Sydney Water Catchment, Prepared for the NSW Department of Planning, Industry and Environment
- B K Hebblewhite Consulting, 2020. Dendrobium Mine – Longwalls 14-18 Independent Review – Height of Fracturing (Stage 3). File Name: 170803.3. 4 February 2020.
- 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.
- Mine Subsidence Engineering Consulting, 2020. Subsidence Predictions and Impact Assessments for the Natural and Built Features due to the Extraction of the Proposed Longwall 18 in Area 3B at Dendrobium Mine. Report No. MSEC1103, dated 23 June 2020.
- SCT, 2020. Review of HGEO Report D19341: Investigation Into the Height of Fracturing above extracted longwalls in Area 3, Dendrobium. DEN4968A.
- SRK Consulting, 2020. Geological Structure Comparison Investigation. STH055.
- 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.
- Watershed HydroGeo, 2019. Dendrobium Area 3B Discussion of Surface Water Flow TARPs. December 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”.

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 18 Subsidence Management Plan	A	Avon Reservoir
		B	Groundwater
		C	Wongawilli Creek including the waterfall (WWC-WF54)
		D	Native Dog Creek
		E	Swamps, tributaries to Avon Reservoir, Wongawilli Creek and Native Dog 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.

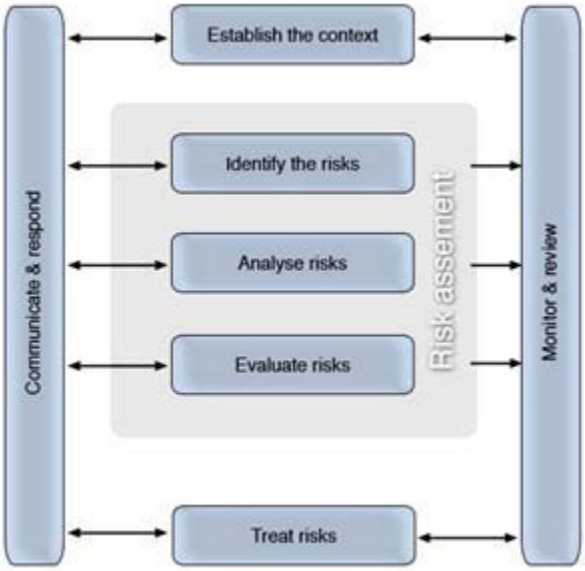
The qualitative approach succeeds by using local expert knowledge and relevant historical data.

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.

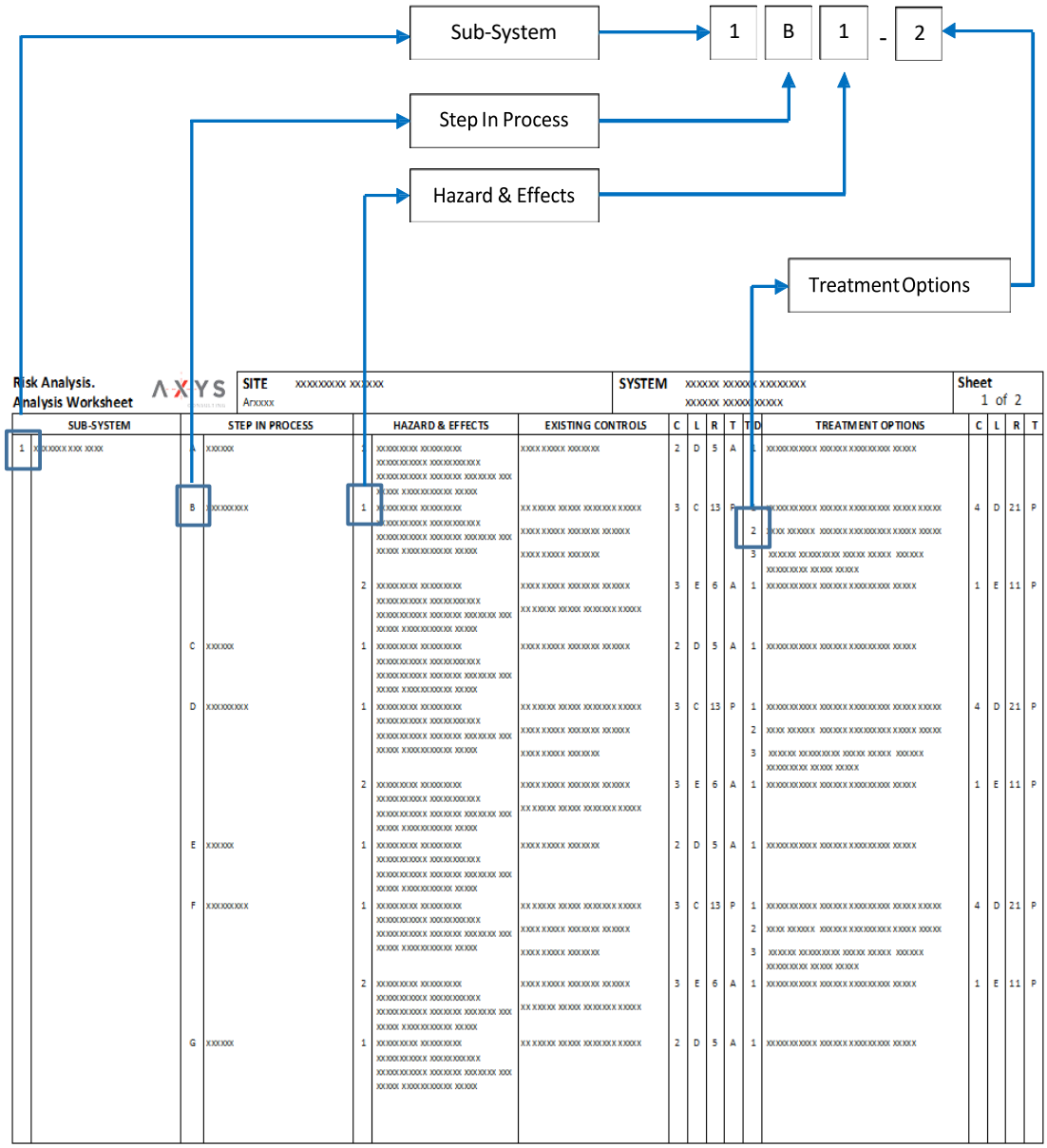
12. Risk Assessment Numbering

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. 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 Could be incurred 1 - 2 Years	3	9	30	90	300	900
1 Possible	Incurred in a minority of similar studies or projects. 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. 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 Could be incurred 20 – 50 years	0.1	0.3	1	3	10	30
0,03 Very Rare	Conceivable, but only in extreme circumstances. 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	C	L	R	T
1	Review Dendrobium Longwall 18 Subsidence Management Plan	A	Avon Reservoir	1	Surface subsidence and sub-surface ground movements results in impacts in excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licences, Aquifer Interference Policy and minimal harm criteria	Groundwater Licence with sufficient groundwater allocation Groundwater and surface water monitoring (piezometers, mine water balance and water chemistry) data are 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. Mine design set back from Avon Reservoir Mine design limiting extraction height to 3.9 metres Local groundwater model is used to design mine setbacks from Avon Reservoir to limit groundwater impacts/interactions. Groundwater monitoring data are analysed and interrogated against predictions to verify modelling and inform the model. Height of Fracturing Investigation (HGEO 2020 and Hebblewhite 2020)	10	0.3	3	L	1	Continue to periodically review and constrain the model using new field data (e.g. permeability data, defect logging) 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	C	L	R	T
1	Review Dendrobium Longwall 18 Subsidence Management Plan	A	Avon Reservoir	2	The Elouera Fault transmits water from Avon Reservoir in excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licences, Aquifer Interference Policy and minimal harm criteria	The Elouera Fault has been extensively drilled and characterised (including location, orientation and permeability) Mining is planned to avoid the Elouera Fault in the vicinity of the Avon Reservoir (minimum offset of 320 metres at seam level and 150 metres at the surface) Mining through the Elouera Fault in Elouera and Nebo workings did not result in inflow Elouera Mine has undertaken first workings and longwall extraction for greater than 4000 metres adjacent to the Elouera Fault (within 0-300 metres, typically 150 metres) at seam level Surface inspections have been undertaken along the inferred surface trace of the Elouera Fault without identifying the feature Drilling from both surface and underground targeting known and inferred geology completed Extensive geological and hydrogeological testing of surface boreholes through the Elouera Fault including lithology, defect logging, geophysical logging, Lugeon testing and geotechnical analysis Extensive underground drilling of the Elouera Fault without identifying any inflow, this includes consideration that the Elouera Mine workings are flooded to 60 metres of water head Extensive underground drilling of the Longwall 18 block has not identified geological structures	10	0.3	3	L	1 2 3 4	Assess any correlation between piezometers response and the Elouera Fault. Outcomes of this investigation may influence future exploration drilling and assessments Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals Undertake sensitivity analysis of the Elouera Fault conductance using the local and/or regional groundwater models to assess whether the Dams Safety NSW 1ML per day seepage limit could plausibly be exceeded Review the experience of groundwater inflows adjacent to lineaments and fault structures in the context of stress relief at Springvale and Wongawilli Mines				

SUB-SYSTEM	STEP IN PROCESS	HAZARD & EFFECTS	EXISTING CONTROLS	C	L	R	T	TID	TREATMENT OPTIONS	C	L	R	T
			Extensive underground drilling beyond the Longwall 18 block has intersected structures and no inflow has been identified into the drilled holes Overcoring stress measurements indicate that stress changes at the Elouera Fault, associated with Longwall 18, are expected to be small by comparison to the stress changes caused by the mining at Elouera (which has had no apparent associated inflow) Overcoring stress measurements indicate that the Elouera Fault is not actively influencing the stress. The stress relief behaviour of the Elouera longwalls is consistent with behaviour measured elsewhere HBSS groundwater levels in boreholes that intersect the Elouera Fault are well above (30+ metres) the average water level of Avon Reservoir, indicating a hydraulic gradient towards the reservoir. This indicates that, currently, HBSS groundwater is not being drained into the Elouera Mine via the fault The IEP Part 1 Report has been reviewed with the key recommendations of Section 3.6 [Recommendation 1] implemented to determine mine design constraints to achieve compliance with consent conditions Groundwater licence with sufficient groundwater allocation									

SUB-SYSTEM	STEP IN PROCESS	HAZARD & EFFECTS	EXISTING CONTROLS	C	L	R	T	TID	TREATMENT OPTIONS	C	L	R	T
			Ground and surface water monitoring (e.g. piezometers, mine water balance and water chemistry) data are 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 Mine design limiting extraction height to 3.9 metres Measured subsidence has been reviewed in locations of mapped lineaments and other geological structures (MSEC Report MSEC1034 - 2019 and SRK Report STH055 - 2020) No correlation has been found between mine inflow chemistry and lineaments (HGEO 2020) Local groundwater modelling indicates that 1 ML per day additional seepage from Dams Safety NSW is not likely to be exceeded										

SUB-SYSTEM		STEP IN PROCESS		HAZARD & EFFECTS		EXISTING CONTROLS	C	L	R	T	TID	TREATMENT OPTIONS	C	L	R	T
1	Review Dendrobium Longwall 18 Subsidence Management Plan	A	Avon Reservoir	3	Lineaments concentrate subsidence or groundwater in excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licences, Aquifer Interference Policy and minimal harm criteria	Lineaments are mapped and recorded Lineaments are assessed for correlation with known geological conditions Surface mapping around lineaments to understand if there is an associated geological feature Drilling from both surface and underground targeting known and inferred geology completed The IEP Part 1 Report has been reviewed with the key recommendations of Section 3.6 [Recommendation 1] implemented to determine mine design constraints to achieve compliance with consent conditions Groundwater licence with sufficient groundwater allocation Ground and surface water monitoring (e.g. piezometers, mine water balance and water chemistry) data are 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. Mine design set back from significant geological features Mine design limiting extraction height to 3.9 metres Measured subsidence has been reviewed in locations of mapped lineaments and other geological structures (MSEC Report MSEC1034 - 2019 and SRK Report STH055 - 2020)	10	0.3	3	L	1 2 3	Assess any correlation between piezometers response and lineaments. Outcomes of this investigation may influence future exploration drilling and assessments. Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 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	C	L	R	T
						Overcore stress measurements conducted in close vicinity to the Elouera Fault indicate the stress realignment from background is more consistent with the extracted Elouera longwall panels than the plane of the Elouera Fault. This observation implies that the Elouera Fault is not actively moving or at limiting equilibrium; if it were it would be modifying the in situ stress field. No correlation has been found between mine inflow chemistry and lineaments (HGEO 2020)										
1		A		4	Unnamed faults and dykes result in impacts in excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licences, Aquifer Interference Policy and minimal harm criteria	Faults and dykes are mapped and recorded Surface geological mapping around faults and dykes Drilling from both surface and underground targeting known and inferred geology completed Extensive exploration program undertaken to identify location of faults and dykes Review of Permeability of Geological Structures in the Dendrobium Area J DOYLE 2007 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 Mine design set back from significant geological features No correlation has been found between mine inflow chemistry and lineaments (HGEO 2020)	10	0.3	3	L	1 2 3	Review geological features relevant to Longwall 18 to determine if further investigatory actions such as inseam and or surface drilling are required Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 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	C	L	R	T
1	Review Dendrobium Longwall 18 Subsidence Management Plan	A	Avon Reservoir	5	Shear planes (including basal shear planes) transmits groundwater in excess of Development Consent Conditions (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licence, Aquifer Interference Policy and minimal harm criteria.	Shear planes (including basal shear planes) have been extensively drilled and characterised (including extent, depth and permeability) (SCT Reports 2015-2019) Mining is planned to avoid the Avon Reservoir Full Supply Level (FSL) by a minimum of 300 metres Extensive geological and hydrogeological testing of surface boreholes through the basal shear horizons including lithology, defect logging, geophysical logging, Lugeon testing and geotechnical analysis Standing water levels in boreholes that intersect basal shear planes provide an indication of hydraulic gradient towards the mine, which is a key input to the local model used to calculate inflow rates The IEP Part 1 Report has been reviewed with the key recommendations of Section 3.6 [Recommendation 1] implemented to determine mine design constraints to achieve compliance with consent conditions Groundwater licence with sufficient groundwater allocation Ground and surface water monitoring (e.g. piezometers, mine water balance and water chemistry) data are 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.	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	C	L	R	T
						Local groundwater modelling indicates that the maximum of 1 ML per day additional seepage from Dams Safety NSW is not likely to be exceeded										
1		B	Groundwater	1	Surface subsidence and sub-surface ground movements results in impacts excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licence, Aquifer Interference Policy and minimal harm criteria.	Groundwater Licence with sufficient Groundwater allocation Ground and surface water monitoring (piezometers, mine water balance and water chemistry) data are 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 Mine design set back from Avon Reservoir Mine design limiting extraction height to 3.9 metres Local groundwater model is used to design mine setbacks from Avon Reservoir to limit groundwater impacts/interactions. Groundwater monitoring data are analysed and interrogated against predictions to verify modelling and inform the model. Height of Fracturing Investigation (HGEO 2020 and Hebblewhite 2020)	10	0.3	3	L	1	Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals				

Risk Analysis. Analysis Worksheet	SITE South32 - Illawarra Metallurgical Coal AR2944	SYSTEM Review of Dendrobium Longwall 18 Subsidence Management Plan	Sheet Page 27

SUB-SYSTEM		STEP IN PROCESS		HAZARD & EFFECTS		EXISTING CONTROLS	C	L	R	T	TID	TREATMENT OPTIONS	C	L	R	T
1	Review Dendrobium Longwall 18 Subsidence Management Plan	B	Groundwater	2	The Elouera Fault transmits groundwater in excess of Development Consent Conditions (no more than negligible impacts as defined by the regional groundwater model) and Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licence, Aquifer Interference Policy and minimal harm criteria.	The Elouera Fault has been extensively drilled and characterised (including location, orientation and permeability) Mining is planned to avoid the Elouera Fault in the vicinity of the Avon Reservoir (minimum offset of 320 metres at seam level and 150 metres at the surface) Mining through the Elouera Fault in Elouera and Nebo workings did not result in inflow Elouera Mine has undertaken first workings and longwall extraction for greater than 4000 metres adjacent to the Elouera Fault (within 0-300 metres, typically 150 metres) at seam level Surface inspections have been undertaken along the inferred surface trace of the Elouera Fault without identifying the feature Drilling from both surface and underground targeting known and inferred geology completed Extensive geological and hydrogeological testing of surface boreholes through the Elouera Fault including lithology, defect logging, geophysical logging, Lugeon testing and geotechnical analysis Extensive underground drilling of the Elouera Fault without identifying any inflow, this includes consideration that the Elouera Mine workings are flooded to 60 metres of water head Extensive underground drilling of the Longwall 18 block has not identified geological structures	10	0.3	3	L	1 2 3 4	Assess any correlation between piezometers response and the Elouera Fault. Outcomes of this investigation may influence future exploration drilling and assessments. Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals Undertake sensitivity analysis of the Elouera Fault conductance using the local and/or regional groundwater models to assess whether the Dams Safety NSW 1ML per day seepage limit could plausibly be exceeded Review the experience of groundwater inflows adjacent to lineaments and fault structures in the context of stress relief at Springvale and Wongawilli Mines				

SUB-SYSTEM	STEP IN PROCESS	HAZARD & EFFECTS	EXISTING CONTROLS	C	L	R	T	TID	TREATMENT OPTIONS	C	L	R	T
			Extensive underground drilling beyond the Longwall 18 block has intersected structures and no inflow has been identified into the drilled holes Overcoring stress measurements indicate that stress changes at the Elouera Fault, associated with Longwall 18, are expected to be small by comparison to the stress changes caused by the mining at Elouera (which has had no apparent associated inflow) Overcoring stress measurements indicate that the Elouera Fault is not actively influencing the stress. The stress relief behaviour of the Elouera longwalls is consistent with behaviour measured elsewhere. HBSS groundwater levels in boreholes that intersect the Elouera Fault are well above (30+ metres) the average water level of Avon Reservoir, indicating a hydraulic gradient towards the reservoir. This indicates that, currently, HBSS groundwater is not being drained into the Elouera Mine via the fault The IEP Part 1 Report has been reviewed with the key recommendations of Section 3.6 [Recommendation 1] implemented to determine mine design constraints to achieve compliance with consent conditions Groundwater licence with sufficient groundwater allocation									

SUB-SYSTEM	STEP IN PROCESS	HAZARD & EFFECTS	EXISTING CONTROLS	C	L	R	T	TID	TREATMENT OPTIONS	C	L	R	T
			Ground and surface water monitoring (e.g. piezometers, mine water balance and water chemistry) data are 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 Mine design limiting extraction height to 3.9 metres Measured subsidence has been reviewed in locations of mapped lineaments and other geological structures (MSEC Report MSEC1034 - 2019 and SRK Report STH055 - 2020) No correlation has been found between mine inflow chemistry and lineaments. (HGEO 2020) Local groundwater modelling indicates that 1 ML per day additional seepage from Dams Safety NSW is not likely to be exceeded									

SUB-SYSTEM		STEP IN PROCESS		HAZARD & EFFECTS		EXISTING CONTROLS	C	L	R	T	TID	TREATMENT OPTIONS	C	L	R	T
1	Review Dendrobium Longwall 18 Subsidence Management Plan	B	Groundwater	3	Lineaments concentrate subsidence or groundwater impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference policy, minimal harm criteria).	Lineaments are mapped and recorded Lineaments are assessed for correlation with known geological conditions Surface mapping around lineaments to understand if there is an associated geological feature Drilling from both surface and underground targeting known and inferred geology completed The IEP Part 1 Report has been reviewed with the key recommendations of Section 3.6 [Recommendation 1] implemented to determine mine design constraints to achieve compliance with consent conditions Groundwater licence with sufficient groundwater allocation Ground and surface water monitoring (e.g. piezometers, mine water balance and water chemistry) data are 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. Mine design set back from significant geological features Mine design limiting extraction height to 3.9 metres Measured subsidence has been reviewed in locations of mapped lineaments and other geological structures (MSEC Report MSEC1034 - 2019 and SRK Report STH055 - 2020)	10	0.3	3	L	1 2 3	Assess any correlation between piezometers response and lineaments. Outcomes of this investigation may influence future exploration drilling and assessments. Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 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	C	L	R	T
						Overcore stress measurements conducted in close vicinity to the Elouera Fault indicate the stress realignment from background is more consistent with the extracted Elouera longwall panels than the plane of the Elouera Fault. This observation implies that the Elouera Fault is not actively moving or at limiting equilibrium; if it were it would be modifying the in situ stress field. No correlation has been found between mine inflow chemistry and lineaments (HGEO 2020)										
1		B		4	Unnamed faults and dykes result in impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference Policy and associated minimal harm criteria) on groundwater quantity	Faults and dykes are mapped and recorded Surface geological mapping around faults and dykes Drilling from both surface and underground targeting known and inferred geology completed Extensive exploration program undertaken to identify location of faults and dykes Review of Permeability of Geological Structures in the Dendrobium Area J DOYLE 2007 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. Mine design set back from significant geological features No correlation has been found between mine inflow chemistry and lineaments (HGEO 2020)	10	0.3	3	L	1 2 3	Review geological features relevant to Longwall 18 to determine if further investigatory actions such as inseam and or surface drilling are required Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 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	C	L	R	T
1	Review Dendrobium Longwall 18 Subsidence Management Plan	B	Groundwater	5	Shear planes (including basal shear planes) transmits groundwater in excess of Development Consent Conditions (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licence, Aquifer Interference Policy and minimal harm criteria.	Shear planes (including basal shear planes) have been extensively drilled and characterised (including extent, depth and permeability) (SCT Reports 2015-2019) Mining is planned to avoid the Avon Reservoir FSL by a minimum of 300 metres Extensive geological and hydrogeological testing of surface boreholes through the basal shear horizons including lithology, defect logging, geophysical logging, Lugeon testing and geotechnical analysis Standing water levels in boreholes that intersect basal shear planes provide an indication of hydraulic gradient towards the mine, which is a key input to the local model used to calculate inflow rates The IEP Part 1 Report has been reviewed with the key recommendations of Section 3.6 [Recommendation 1] implemented to determine mine design constraints to achieve compliance with consent conditions Groundwater licence with sufficient groundwater allocation Ground and surface water monitoring (e.g. piezometers, mine water balance and water chemistry) data are 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.	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	C	L	R	T
						Local groundwater modelling indicates that 1 ML per day additional seepage from Dams Safety NSW is not likely to be exceeded										
1		C	Wongawilli Creek including the waterfall (WWC-WF54)	1	Valley closure results in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences)	Longwall 18 is 1000 metres remote from Wongawilli Creek Calibrated subsidence model has assessed the impact of Longwall 18 upon Wongawilli Creek as being very small and within Performance Measures. Ground and surface water monitoring (surface water gauging, piezometers, mine water balance and water chemistry) data are 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. Environmental monitoring including visual inspections and aquatic ecology monitoring 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 Subsidence Management Plan - including End of Panel reporting and auditing against Performance Measures Revised WIMMCP including surface water flow TARPS for Wongawilli Creek (Watershed Hydrogeo 2019) (IMC 2020) Wongawilli Creek Waterfall Management Strategy includes specific monitoring of impacts to the waterfall, including visual inspections of the waterfall.	10	0.1	1	F	1	Submit the Subsidence Management Plan for Longwall 18				

SUB-SYSTEM		STEP IN PROCESS		HAZARD & EFFECTS		EXISTING CONTROLS	C	L	R	T	TID	TREATMENT OPTIONS	C	L	R	T
1	Review Dendrobium Longwall 18 Subsidence Management Plan	C	Wongawilli Creek including the waterfall (WWC-WF54)	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 Lineaments are assessed for correlation with known geological conditions Surface mapping around lineaments to understand if there is a geological feature associated Targeted exploration drilling from both surface and underground Subsidence Management Plan - including end of panel reporting and auditing against Performance Measures Review of Permeability of Geological Structures in the Dendrobium Area J DOYLE 2007	10	0.1	1	F	1	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure				
1		C		3	Groundwater drawdown results in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences)	Longwall 18 is 1000 metres remote from Wongawilli Creek Revised WIMMCP including surface water flow TARPS for Wongawilli Creek (Watershed Hydrogeo 2019) (IMC 2020) Subsidence Management Plan - including end of panel reporting and auditing against Performance Measures	10	0.1	1	F	1	Nil Required				

SUB-SYSTEM		STEP IN PROCESS		HAZARD & EFFECTS		EXISTING CONTROLS	C	L	R	T	TID	TREATMENT OPTIONS	C	L	R	T
1	Review Dendrobium Longwall 18 Subsidence Management Plan	D	Native Dog Creek	1	Valley closure results in impacts in excess of development consent conditions for Native Dog Creek (including no more than predictions)	Longwall 18 is 320 metres remote from Native Dog Creek Calibrated subsidence model has assessed the impact of Longwall 18 upon Native Dog Creek as being small Ground and surface water monitoring (surface water observations, piezometers, mine water balance and water chemistry) data are 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 Environmental monitoring including visual inspections of aquatic ecology Experience with mining next to watercourses. Impacts to date have been in-line with modelling Subsidence Management Plan - including end of panel reporting and auditing against Performance Measures Revised WIMMCP including surface water flow TARPS for Native Dog Creek (Watershed Hydrogeo 2019) (IMC 2020)	10	0.1	1	F	1	Submit the Subsidence Management Plan for Longwall 18				

SUB-SYSTEM		STEP IN PROCESS		HAZARD & EFFECTS		EXISTING CONTROLS	C	L	R	T	TID	TREATMENT OPTIONS	C	L	R	T
1	Review Dendrobium Longwall 18 Subsidence Management Plan	D	Native Dog Creek	2	Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Native Dog Creek (including no more than predictions)	Lineaments are mapped and recorded Lineaments are assessed for correlation with known geological conditions Surface mapping around lineaments to understand if there is a geological feature associated Targeted exploration drilling from both surface and underground Subsidence Management Plan - including end of panel reporting and auditing against Performance Measures Review of Permeability of Geological Structures in the Dendrobium Area J DOYLE 2007	10	0.1	1	F	1	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure				
1		D		3	Groundwater drawdown results in impacts in excess of development consent conditions for Native Dog Creek (including no more than predictions)	Longwall 18 is 320 metres remote from Native Dog Creek Subsidence Management Plan - including end of panel reporting and auditing against Performance Measures Revised WIMMCP including surface water flow TARPS for Native Dog Creek (Watershed Hydrogeo 2019) (IMC 2020)	10	0.3	3	L	1	Submit the Subsidence Management Plan for Longwall 18				

SUB-SYSTEM		STEP IN PROCESS		HAZARD & EFFECTS		EXISTING CONTROLS	C	L	R	T	TID	TREATMENT OPTIONS	C	L	R	T
1	Review Dendrobium Longwall 18 Subsidence Management Plan	E	Swamps, Tributaries to Avon Reservoir, Wongawilli Creek and Native Dog Creek	1	Surface subsidence, sub-surface movements or valley closure result in impacts to swamps, tributaries to Avon Reservoir, Wongawilli Creek and Native Dog Creek. Ranking has considered the loss of an individual small swamp (i.e. Den35a and/or Den35b) or a section of ephemeral drainage line habitat. The effect is considered low due to the abundant comparable habitat available in the Avon Catchment area.	Subsidence monitoring data are analysed and interrogated against predictions to verify modelling Ground and surface water monitoring (e.g. piezometers, mine water balance and water chemistry) data are analysed in independent studies, results inform surface and groundwater models. The analysis is used to assess impacts and demonstrate compliance Mine design avoids major geological structures Subsidence Management Plan - including end of panel reporting and auditing against Performance Measures Environmental monitoring including terrestrial and aquatic ecology monitoring programs - (e.g. LiDAR or other methods for the mapping of swamp boundaries, floristic monitoring of swamps) Research programs e.g. Littlejohns Tree Frog, Giant Dragon Fly and Swamp Research Plans Maddens Plains biodiversity offset	10	0.3	3	L	1	Submit the Subsidence Management Plan for Longwall 18				

Risk Analysis. Analysis Worksheet	SITE South32 - Illawarra Metallurgical Coal AR2944	SYSTEM Review of Dendrobium Longwall 18 Subsidence Management Plan	Sheet Page 38

SUB-SYSTEM		STEP IN PROCESS		HAZARD & EFFECTS		EXISTING CONTROLS	C	L	R	T	TID	TREATMENT OPTIONS	C	L	R	T
1	Review Dendrobium Longwall 18 Subsidence Management Plan	E	Swamps, Tributaries to Avon Reservoir, Wongawilli Creek and Native Dog Creek	2	Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for swamps, tributaries to Avon Reservoir, Wongawilli Creek and Native Dog Creek. Ranking has considered the loss of an individual small swamp (i.e. Den35a and/or Den35b) or a section of ephemeral drainage line habitat. The effect is considered low due to the abundant comparable habitat available in the Avon Catchment area.	Lineaments are mapped and recorded Lineaments are assessed for correlation with know geological conditions Surface mapping around lineaments to understand if there is an associated geological feature Targeted exploration drilling from both surface and underground Ground and surface water monitoring (e.g. piezometers, mine water balance and water chemistry) data are analysed in independent studies, results inform surface and groundwater models. The analysis is used to assess impacts and demonstrate compliance Mine design avoids major geological structures Subsidence Management Plan - including end of panel reporting and auditing against Performance Measures Environmental monitoring including terrestrial and aquatic ecology monitoring programs - (e.g. LiDAR or other methods for the mapping of swamp boundaries, floristic monitoring of swamps) Subsidence monitoring - (closure lines, vertical subsidence, 3D far-field, ALS, visual inspection) data are analysed in independent studies, results inform the calibrated subsidence model and mine planning decisions	10	0.3	3	L	1 2	Carry out a spatial correlation analysis between piezometers response and lineaments for swamps, tributaries to Avon Reservoir, Wongawilli Creek and Native Dog Creek. Outcomes of this investigation may influence future exploration drilling and assessment to improve the understand of any potential interactions between lineaments and swamps. In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling 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	C	L	R	T
1		E		3	Cumulative impacts, including the impacts of cracking of first and second order watercourses. Leading to changes to water supply quality.	Investigation completed comparing the impacts on lineaments from mining in the Western Coalfield (Springvale) and the Southern Coalfield. Outcomes of this investigation informed lineament consideration in mine planning Surface water monitoring data are analysed in independent studies, results inform surface data analysis and TARPs. These are used to ensure compliance with approval conditions and to demonstrate compliance Longwall 18 is 1000 metres remote from Wongawilli Creek Longwall 18 is 320 metres remote from Native Dog Creek Existing monitoring at numerous sites on Avon Reservoir tributaries, Wongawilli Creek and its tributaries and Native Dog Creek and its tributaries. Monitoring frequency at these sites would be increased during and after extraction of LW18 in line with existing management plans	10	1	10	R	1	Nil Required				

SUB-SYSTEM		STEP IN PROCESS		HAZARD & EFFECTS		EXISTING CONTROLS	C	L	R	T	TID	TREATMENT OPTIONS	C	L	R	T
1	Review Dendrobium Longwall 18 Subsidence Management Plan	E	Swamps, Tributaries to Avon Reservoir, Wongawilli Creek and Native Dog Creek	4	Cumulative impacts, including the impacts of cracking of first and second order watercourses. Leading to effects on aquatic and terrestrial ecology greater than those predicted in the EIS, WIMMCP and SMP (Schedule 2, Condition 2 and Schedule 3, Conditions 4 and 7 of the Development Consent)	Surface water monitoring data are analysed in independent studies, results inform surface data analysis and TARPs. These are used to ensure compliance with approval conditions and to demonstrate compliance. Environmental monitoring including terrestrial and aquatic ecology monitoring programs - (e.g. Littlejohns Tree Frog Monitoring Programme and other aquatic flora and fauna monitoring) Longwall 18 is 1000 metres remote from Wongawilli Creek Longwall 18 is 320 metres remote from Native Dog Creek Existing monitoring at numerous sites on Avon Reservoir tributaries, Wongawilli Creek and its tributaries and Native Dog Creek and its tributaries. Monitoring frequency at these sites would be increased during and after extraction of LW18 in line with existing management plans.	10	1	10	E	1 2	Update the terrestrial ecology monitoring programme to incorporate detailed water quality analysis in relation to Littlejohns Tree Frog monitoring sites Continue to consider cumulative impacts to aquatic ecology due to any reductions in availability of habitat in first and second order watercourses.				

Attachment 2

Assessment Worksheets
(Risk Rank Order)

Risk Analysis Risk Order

REF	Risk	HAZARD	TID	TREATMENT OPTIONS
1E3	10	Cumulative impacts, including the impacts of cracking of first and second order watercourses. Leading to changes to water supply quality.	1	Nil Required
1E4	10	Cumulative impacts, including the impacts of cracking of first and second order watercourses. Leading to effects on aquatic and terrestrial ecology greater than those predicted in the EIS, WIMMCP and SMP (Schedule 2, Condition 2 and Schedule 3, Conditions 4 and 7 of the Development Consent)	1	Update the terrestrial ecology monitoring programme to incorporate detailed water quality analysis in relation to Littlejohns Tree Frog Monitoring sites
			2	Continue to consider cumulative impacts to aquatic ecology due to any reductions in availability of habitat in first and second order watercourses.
1A1	3	Surface subsidence and sub-surface ground movements results in impacts in excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licences, Aquifer Interference Policy and minimal harm criteria	1	Continue to periodically review and constrain the model using new field data (e.g. permeability data, defect logging) and calibrate the groundwater model against monitoring results including peer review at appropriate intervals
1A2	3	The Elouera Fault transmits water from Avon Reservoir in excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licences, Aquifer Interference Policy and minimal harm criteria	1	Assess any correlation between piezometers response and Elouera Fault. Outcomes of this investigation may influence future exploration drilling and assessments.
			2	Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals
			3	Undertake sensitivity analysis of Elouera Fault conductance using the local and/or regional groundwater models to assess whether the Dams Safety NSW 1ML per day seepage limit could plausibly be exceeded
			4	Review the experience of groundwater inflows adjacent to lineaments and fault structures in the context of stress relief at Springvale and Wongawilli Mines
1A3	3	Lineaments concentrate subsidence or groundwater in excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licences, Aquifer Interference Policy and minimal harm criteria	1	Assess any correlation between piezometers response and lineaments. Outcomes of this investigation may influence future exploration drilling and assessments.
			2	Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals
			3	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure
1A4	3	Unnamed faults and dykes result in impacts in excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licences, Aquifer Interference Policy and minimal harm criteria	1	Review geological features relevant to Longwall 18 to determine if further investigatory actions such as inseam and or surface drilling are required
			2	Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals
			3	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure
1A5	3	Shear planes (including basal shear planes) transmits groundwater in excess of Development Consent Conditions (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licence, Aquifer Interference Policy and minimal harm criteria.	1	Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals

REF	Risk	HAZARD	TID	TREATMENT OPTIONS
1B1	3	Surface subsidence and sub-surface ground movements results in impacts excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licence, Aquifer Interference Policy and minimal harm criteria.	1	Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals
1B2	3	The Elouera Fault transmits groundwater in excess of Development Consent Conditions (no more than negligible impacts as defined by the regional groundwater model) and Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licence, Aquifer Interference Policy and minimal harm criteria.	1	Assess any correlation between piezometers response and Elouera Fault. Outcomes of this investigation may influence future exploration drilling and assessments.
			2	Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals
			3	Undertake sensitivity analysis of Elouera Fault conductance using the local and/or regional groundwater models to assess whether the Dams Safety NSW 1ML per day seepage limit could plausibly be exceeded
			4	Review the experience of groundwater inflows adjacent to lineaments and fault structures in the context of stress relief at Springvale and Wongawilli Mines
1B3	3	Lineaments concentrate subsidence or groundwater impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference policy, minimal harm criteria).	1	Assess any correlation between piezometers response and lineaments. Outcomes of this investigation may influence future exploration drilling and assessments.
			2	Continue to periodically review and calibrate the groundwater model against
			3	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure
1B4	3	Unnamed faults and dykes result in impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference Policy and associated minimal harm criteria) on groundwater quantity	1	Review geological features relevant to Longwall 18 to determine if further investigatory actions such as inseam and or surface drilling are required
			2	Continue to periodically review and calibrate the groundwater model against
			3	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure
1B5	3	Shear planes (including basal shear planes) transmits groundwater in excess of Development Consent Conditions (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licence, Aquifer Interference Policy and minimal harm criteria.	1	Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals
1D3	3	Groundwater drawdown results in impacts in excess of development consent conditions for Native Dog Creek (including no more than predictions)	1	Submit the Subsidence Management Plan for Longwall 18
1E1	3	Surface subsidence, sub-surface movements or valley closure result in impacts to swamps, tributaries to Avon Reservoir, Wongawilli Creek and Native Dog Creek. Ranking has considered the loss of an individual small swamp (i.e. Den35a and/or Den35b) or a section of ephemeral drainage line habitat. The effect is considered low due to the abundant comparable habitat available in the Avon Catchment area.	1	Submit the Subsidence Management Plan for Longwall 18
1E2	3	Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for swamps, tributaries to Avon Reservoir, Wongawilli Creek and Native Dog Creek.	1 .	Assess any correlation between piezometers response and lineaments for swamps, tributaries to Avon Reservoir, Wongawilli Creek and Native Dog Creek. Outcomes of this investigation may influence future exploration drilling and assessment.

REF	Risk	HAZARD	TID	TREATMENT OPTIONS
		Ranking has considered the loss of an individual small swamp (i.e. Den35a and/or Den35b) or a section of ephemeral drainage line habitat. The effect is considered low due to the abundant comparable habitat available in the Avon Catchment area.	2	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure
1C1	1	Valley closure results in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences)	1	Submit the Subsidence Management Plan for Longwall 18
1C2	1	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: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure
1C3	1	Groundwater drawdown results in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences)	1	Nil Required
1D1	1	Valley closure results in impacts in excess of development consent conditions for Native Dog Creek (including no more than predictions)	1	Submit the Subsidence Management Plan for Longwall 18
1D2	1	Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Native Dog Creek (including no more than predictions)	1	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure

Attachment 3

Assessment Worksheets
(Consequence Order)

Risk Analysis Consequence Order

REF	Con	HAZARD	TID	TREATMENT OPTIONS
1A1	10	Surface subsidence and sub-surface ground movements results in impacts in excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licences, Aquifer Interference Policy and minimal harm criteria	1	Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals
1A2	10	The Elouera Fault transmits water from Avon Reservoir in excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licences, Aquifer Interference Policy and minimal harm criteria	1	Assess any correlation between piezometers response and Elouera Fault. Outcomes of this investigation may influence future exploration drilling and assessments.
			2	Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals
			3	Undertake sensitivity analysis of Elouera Fault conductance using the local and/or regional groundwater models to assess whether the Dams Safety NSW 1ML per day seepage limit could plausibly be exceeded
			4	Review the experience of groundwater inflows adjacent to lineaments and fault structures in the context of stress relief at Springvale and Wongawilli Mines
1A3	10	Lineaments concentrate subsidence or groundwater in excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licences, Aquifer Interference Policy and minimal harm criteria	1	Assess any correlation between piezometers response and lineaments. Outcomes of this investigation may influence future exploration drilling and assessments.
			2	Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals
			3	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure
1A4	10	Unnamed faults and dykes result in impacts in excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licences, Aquifer Interference Policy and minimal harm criteria	1	Review geological features relevant to Longwall 18 to determine if further investigatory actions such as inseam and or surface drilling are required
			2	Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals
			3	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure
1A5	10	Shear planes (including basal shear planes) transmits groundwater in excess of Development Consent Conditions (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licence, Aquifer Interference Policy and minimal harm criteria.	1	Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals
1B1	10	Surface subsidence and sub-surface ground movements results in impacts excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licence, Aquifer Interference Policy and minimal harm criteria.	1	Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals
1B2	10	The Elouera Fault transmits groundwater in excess of Development Consent Conditions (no more than negligible impacts as defined by the regional	1	Assess any correlation between piezometers response and Elouera Fault. Outcomes of this investigation may influence future exploration drilling and assessments.

REF	Con	HAZARD	TID	TREATMENT OPTIONS
		groundwater model) and Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licence, Aquifer Interference Policy and minimal harm criteria.	2	Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals
			3	Undertake sensitivity analysis of Elouera Fault conductance using the local and/or regional groundwater models to assess whether the Dams Safety NSW 1ML per day seepage limit could plausibly be exceeded
			4	Review the experience of groundwater inflows adjacent to lineaments and fault structures in the context of stress relief at Springvale and Wongawilli Mines
1B3	10	Lineaments concentrate subsidence or groundwater impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference policy, minimal harm criteria).	1	Assess any correlation between piezometers response and lineaments. Outcomes of this investigation may influence future exploration drilling and assessments.
			2	Continue to periodically review and calibrate the groundwater model against
			3	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure
1B4	10	Unnamed faults and dykes result in impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference Policy and associated minimal harm criteria) on groundwater quantity	1	Review geological features relevant to Longwall 18 to determine if further investigatory actions such as inseam and or surface drilling are required
			2	Continue to periodically review and calibrate the groundwater model against
			3	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure
1B5	10	Shear planes (including basal shear planes) transmits groundwater in excess of Development Consent Conditions (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licence, Aquifer Interference Policy and minimal harm criteria.	1	Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals
1C1	10	Valley closure results in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences)	1	Submit the Subsidence Management Plan for Longwall 18
1C2	10	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: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure
1C3	10	Groundwater drawdown results in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences)	1	Nil Required
1D1	10	Valley closure results in impacts in excess of development consent conditions for Native Dog Creek (including no more than predictions)	1	Submit the Subsidence Management Plan for Longwall 18
1D2	10	Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Native Dog Creek (including no more than predictions)	1	In the event that an anomalous, unmapped geological structure is encountered: 3. Assess the significance of the structure to increase understanding 4. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure

REF	Con	HAZARD	TID	TREATMENT OPTIONS
1D3	10	Groundwater drawdown results in impacts in excess of development consent conditions for Native Dog Creek (including no more than predictions)	1	Submit the Subsidence Management Plan for Longwall 18
1E1	10	Surface subsidence, sub-surface movements or valley closure result in impacts to swamps, tributaries to Avon Reservoir, Wongawilli Creek and Native Dog Creek. Ranking has considered the loss of an individual small swamp (i.e. Den35a and/or Den35b) or a section of ephemeral drainage line habitat. The effect is considered low due to the abundant comparable habitat available in the Avon Catchment area.	1	Submit the Subsidence Management Plan for Longwall 18
1E2	10	Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for swamps, tributaries to Avon Reservoir, Wongawilli Creek and Native Dog Creek. Ranking has considered the loss of an individual small swamp (i.e. Den35a and/or Den35b) or a section of ephemeral drainage line habitat. The effect is considered low due to the abundant comparable habitat available in the Avon Catchment area.	1.	Carry out a spatial correlation analysis between piezometers response and lineaments for swamps, tributaries to Avon Reservoir, Wongawilli Creek and Native Dog Creek. Outcomes of this investigation may influence future exploration drilling and assessment to improve the understand of any potential interactions between lineaments and swamps.
			2	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure
1E3	10	Cumulative impacts, including the impacts of cracking of first and second order watercourses. Leading to changes to water supply quality.	1	Nil Required
1E4	10	Cumulative impacts, including the impacts of cracking of first and second order watercourses. Leading to effects on aquatic and terrestrial ecology greater than those predicted in the EIS, WIMMCP and SMP (Schedule 2, Condition 2 and Schedule 3, Conditions 4 and 7 of the Development Consent)	1	Update the terrestrial ecology monitoring programme to incorporate detailed water quality analysis in relation to Littlejohns Tree Frog Monitoring sites
			2	Continue to consider cumulative impacts to aquatic ecology due to any reductions in availability of habitat in first and second order watercourses.

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 results in impacts in excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licences, Aquifer Interference Policy and minimal harm criteria	1	Continue to periodically review and constrain the model using new field data (e.g. permeability data, defect logging) and calibrate the groundwater model against monitoring results including peer review at appropriate intervals	Cody Brady	Friday, 31 July 2020		
1A2	The Elouera Fault transmits water from Avon Reservoir in excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licences, Aquifer Interference Policy and minimal harm criteria	1	Assess any correlation between piezometers response and the Elouera Fault. Outcomes of this investigation may influence future exploration drilling and assessments	Cody Brady (Assessment by HGEO)	Friday, 18 December 2020		
		2	Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals	Cody Brady (Assessment by Watershed Hydrogeo)	Friday, 31 July 2020		
		3	Undertake sensitivity analysis of the Elouera Fault conductance using the local and/or regional groundwater models to assess whether the Dams Safety NSW 1ML per day seepage limit could plausibly be exceeded	Cody Brady (Assessment by Watershed Hydrogeo)	Friday, 31 July 2020		
		4	Review the experience of groundwater inflows adjacent to lineaments and fault structures in the context of stress relief at Springvale and Wongawilli Mines	Cody Brady (Assessment by SCT)	Friday, 31 July 2020		

ID	HAZARD	TID	TREATMENT OPTIONS	RESPONSIBILITY	IMPLEMENTATION	COMMENTS	COMPLETED (Sign Off)
1A3	Lineaments concentrate subsidence or groundwater in excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licences, Aquifer Interference Policy and minimal harm criteria	1	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, 18 December 2020		
		2	Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals	Cody Brady (Assessment by Watershed Hydrogeo)	Friday, 31 July 2020		
		3	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure	Cody Brady (IMC Technical Services)	Friday, 25 June 2021		
1A4	Unnamed faults and dykes result in impacts in excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licences, Aquifer Interference Policy and minimal harm criteria	1	Review geological features relevant to Longwall 18 to determine if further investigatory actions such as inseam and or surface drilling are required	Cody Brady (IMC Technical Services)	Friday, 25 June 2021		
		2	Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals	Cody Brady (Assessment by Watershed Hydrogeo)	Friday, 31 July 2020		
		3	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure	Cody Brady (IMC Technical Services)	Friday, 25 June 2021		

ID	HAZARD	TID	TREATMENT OPTIONS	RESPONSIBILITY	IMPLEMENTATION	COMMENTS	COMPLETED (Sign Off)
1A5	Shear planes (including basal shear planes) transmits groundwater in excess of Development Consent Conditions (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licence, Aquifer Interference Policy and minimal harm criteria.	1	Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals	Cody Brady (Assessment by Watershed Hydrogeo)	Friday, 31 July 2020		
1B1	Surface subsidence and sub-surface ground movements results in impacts excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licence, Aquifer Interference Policy and minimal harm criteria.	1	Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals	Cody Brady	Friday, 31 July 2020		
1B2	The Elouera Fault transmits groundwater in excess of Development Consent Conditions (no more than negligible impacts as defined by the regional groundwater model) and Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licence, Aquifer Interference Policy and minimal harm criteria.	1	Assess any correlation between piezometers response and the Elouera Fault. Outcomes of this investigation may influence future exploration drilling and assessments.	Cody Brady (Assessment by HGEO)	Friday, 18 December 2020		
		2	Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals	Cody Brady (Assessment by Watershed Hydrogeo)	Friday, 31 July 2020		
		3	Undertake sensitivity analysis of the Elouera Fault conductance using the local and/or regional groundwater models to assess whether the Dams Safety NSW 1ML per day seepage limit could plausibly be exceeded	Cody Brady (Assessment by Watershed Hydrogeo)	Friday, 31 July 2020		
		4	Review the experience of groundwater inflows adjacent to lineaments and fault structures in the context of stress relief at Springvale and Wongawilli Mines	Cody Brady (Assessment by SCT)	Friday, 31 July 2020		

ID	HAZARD	TID	TREATMENT OPTIONS	RESPONSIBILITY	IMPLEMENTATION	COMMENTS	COMPLETED (Sign Off)
1B3	Lineaments concentrate subsidence or groundwater impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference policy, minimal harm criteria).	1	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, 18 December 2020		
		2	Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals	Cody Brady (Assessment by Watershed Hydrogeo)	Friday, 31 July 2020		
		3	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure	Cody Brady (IMC Technical Services)	Friday, 25 June 2021		
1B4	Unnamed faults and dykes result in impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference Policy and associated minimal harm criteria) on groundwater quantity	1	Review geological features relevant to Longwall 18 to determine if further investigatory actions such as inseam and or surface drilling are required	Cody Brady (IMC Technical Services)	Friday, 25 June 2021		
		2	Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals	Cody Brady (Assessment by Watershed Hydrogeo)	Friday, 31 July 2020		
		3	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure	Cody Brady (IMC Technical Services)	Friday, 25 June 2021		

ID	HAZARD	TID	TREATMENT OPTIONS	RESPONSIBILITY	IMPLEMENTATION	COMMENTS	COMPLETED (Sign Off)
1B5	Shear planes (including basal shear planes) transmits groundwater in excess of Development Consent Conditions (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licence, Aquifer Interference Policy and minimal harm criteria.	1	Continue to periodically review and calibrate the groundwater model against monitoring results including peer review at appropriate intervals	Cody Brady (Assessment by Watershed Hydrogeo)	Friday, 31 July 2020		
1C1	Valley closure results in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences)	1	Submit the Subsidence Management Plan for Longwall 18	Cody Brady	Friday, 31 July 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: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure	Cody Brady (IMC Technical Services)	Friday, 25 June 2021		
1C3	Groundwater drawdown results in impacts in excess of development consent conditions for Wongawilli Creek (including no more than minor environmental consequences)	1	Nil Required				
1D1	Valley closure results in impacts in excess of development consent conditions for Native Dog Creek (including no more than predictions)	1	Submit the Subsidence Management Plan for Longwall 18	Cody Brady	Friday, 31 July 2020		

ID	HAZARD	TID	TREATMENT OPTIONS	RESPONSIBILITY	IMPLEMENTATION	COMMENTS	COMPLETED (Sign Off)
1D2	Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Native Dog Creek (including no more than predictions)	1	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure	Cody Brady (IMC Technical Services)	Friday, 25 June 2021		
1D3	Groundwater drawdown results in impacts in excess of development consent conditions for Native Dog Creek (including no more than predictions)	1	Submit the Subsidence Management Plan for Longwall 18	Cody Brady	Friday, 31 July 2020		
1E1	Surface subsidence, sub-surface movements or valley closure result in impacts to swamps, tributaries to Avon Reservoir, Wongawilli Creek and Native Dog Creek. Ranking has considered the loss of an individual small swamp (i.e. Den35a and/or Den35b) or a section of ephemeral drainage line habitat. The effect is considered low due to the abundant comparable habitat available in the Avon Catchment area.	1	Submit the Subsidence Management Plan for Longwall 18	Cody Brady	Friday, 31 July 2020		

ID	HAZARD	TID	TREATMENT OPTIONS	RESPONSIBILITY	IMPLEMENTATION	COMMENTS	COMPLETED (Sign Off)
1E2	Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for swamps, tributaries to Avon Reservoir, Wongawilli Creek and Native Dog Creek. Ranking has considered the loss of an individual small swamp (i.e. Den35a and/or Den35b) or a section of ephemeral drainage line habitat. The effect is considered low due to the abundant comparable habitat available in the Avon Catchment area.	1	Carry out a spatial correlation analysis between piezometers response and lineaments for swamps, tributaries to Avon Reservoir, Wongawilli Creek and Native Dog Creek. Outcomes of this investigation may influence future exploration drilling and assessment to improve the understand of any potential interactions between lineaments and swamps.	Cody Brady (Assessment by HGEO)	Friday, 18 December 2020		
		2	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure	Cody Brady (IMC Technical Services)	Friday, 25 June 2021		
1E3	Cumulative impacts, including the impacts of cracking of first and second order watercourses. Leading to changes to water supply quality.	1	Nil Required				
1E4	Cumulative impacts, including the impacts of cracking of first and second order watercourses. Leading to effects on aquatic and terrestrial ecology greater than those predicted in the EIS, WIMMCP and SMP (Schedule 2, Condition 2 and Schedule 3, Conditions 4 and 7 of the Development Consent)	1	Update the terrestrial ecology monitoring programme to incorporate detailed water quality analysis in relation to Littlejohns Tree Frog monitoring sites	Cody Brady (Assessment by Niche)	Friday, 31 July 2020		
		2	Continue to consider cumulative impacts to aquatic ecology due to any reductions in availability of habitat in first and second order watercourses.	Cody Brady (Assessment by Cardno)	Friday, 25 June 2021		

Attachment 5

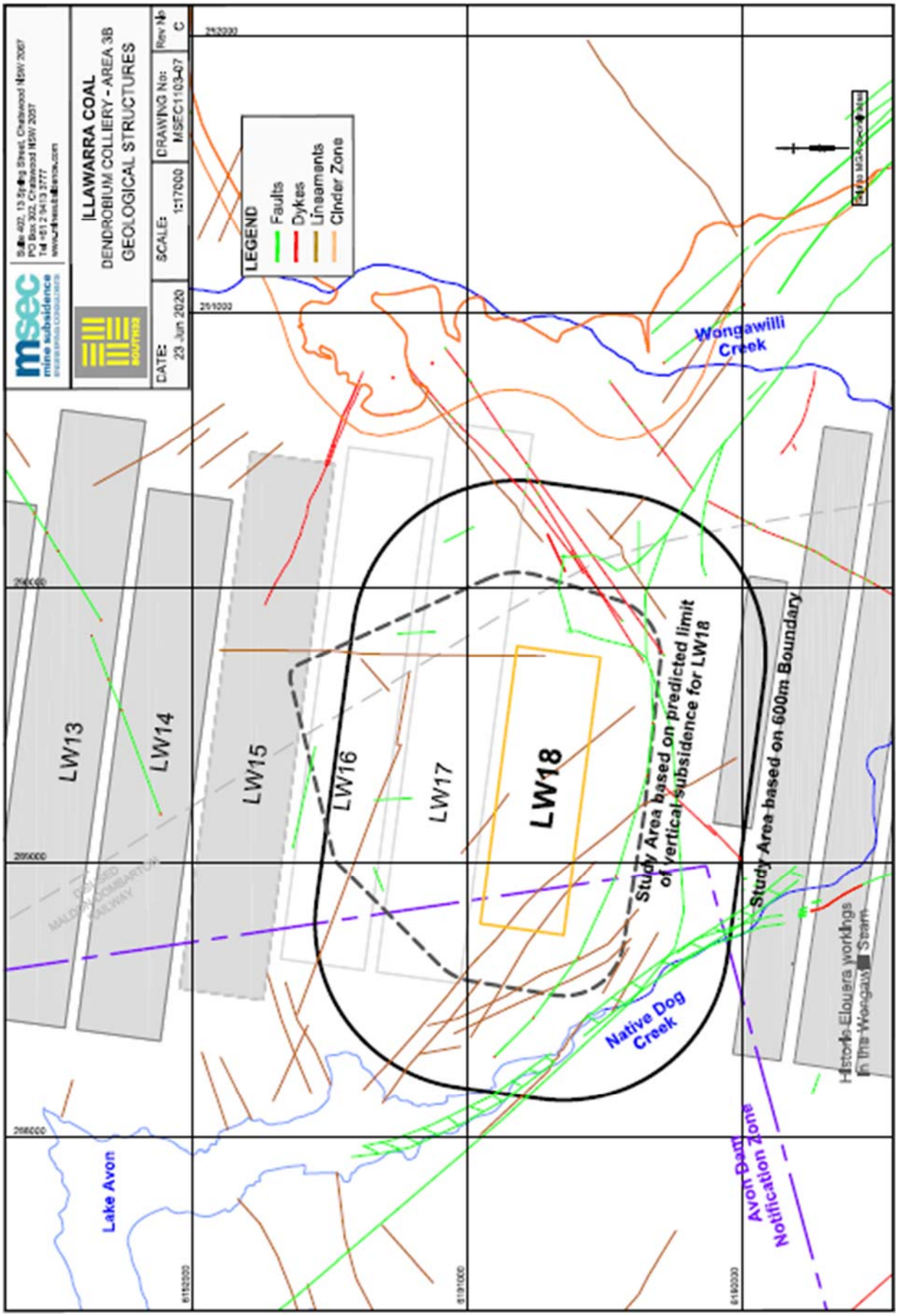
Risk Rank Order
Associated with Lineaments

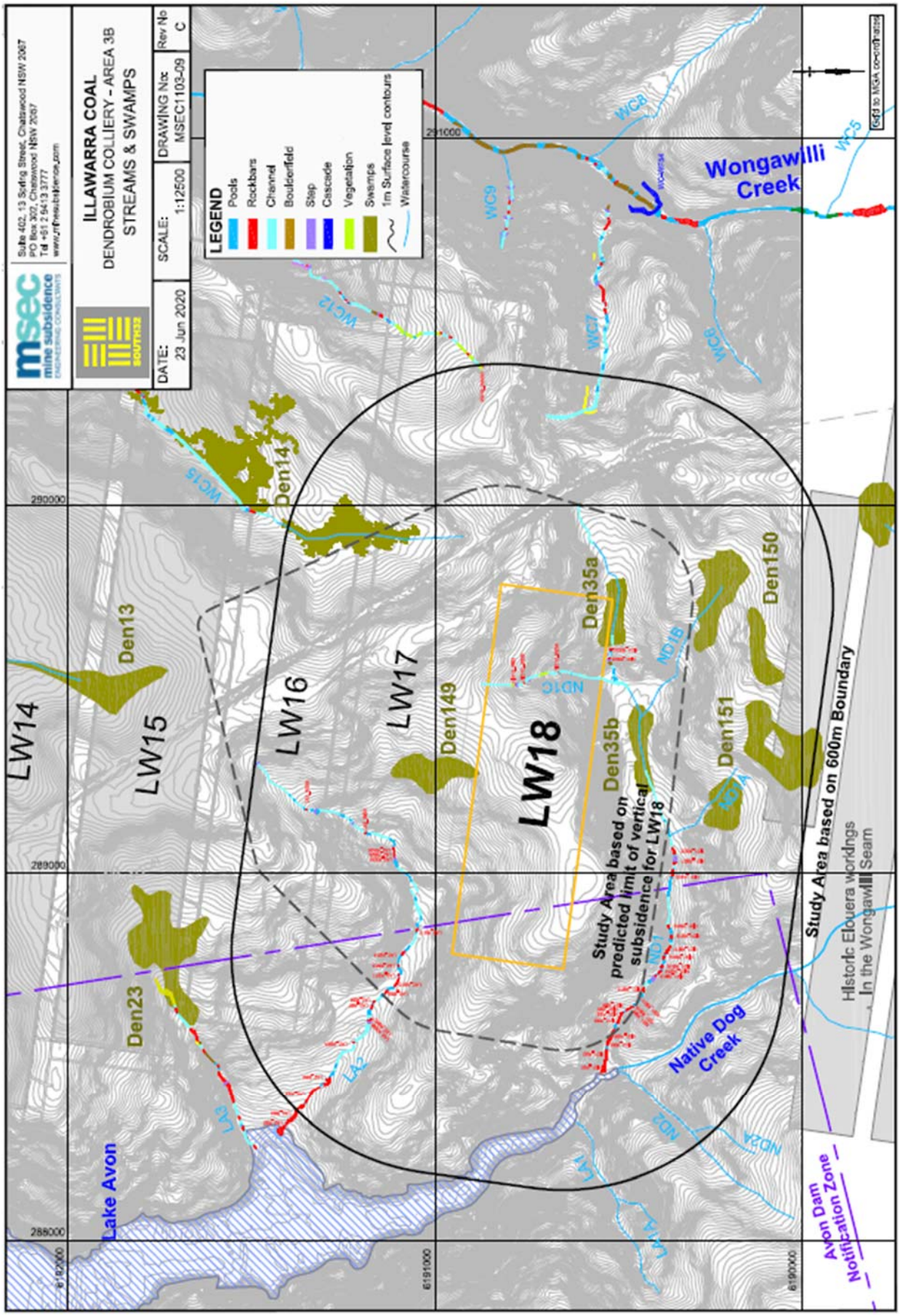
Risk Analysis Risk Order (Associated with Lineaments)

REF	Risk	HAZARD	TID	TREATMENT OPTIONS
1A3	3	Lineaments concentrate subsidence or groundwater in excess of Development Consent (no more than negligible impacts as defined by the regional groundwater model) and/or Dams Safety NSW conditions (policy of no more than 1ML per day cumulative leakage from Avon Reservoir) in addition to Groundwater Licences, Aquifer Interference Policy and minimal harm criteria	1	Assess any correlation between piezometers response and lineaments. Outcomes of this investigation may influence future exploration drilling and assessments.
			2	Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals
			3	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure
1B3	3	Lineaments concentrate subsidence or groundwater impacts in excess of development consent conditions (and Groundwater Licence, Aquifer Interference policy, minimal harm criteria).	1	Assess any correlation between piezometers response and lineaments. Outcomes of this investigation may influence future exploration drilling and assessments.
			2	Continue to periodically review and calibrate the groundwater model against monitoring results including Peer Review at appropriate intervals
			3	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure
1C2	1	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: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure
1D2	1	Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for Native Dog Creek (including no more than predictions)	1	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. radio imaging method, seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure
1E2	3	Lineaments, faults, dykes and intrusions result in impacts in excess of development consent conditions for swamps, tributaries to Avon Reservoir, Wongawilli Creek and Native Dog Creek. Ranking has considered the loss of an individual small swamp (i.e. Den35a and/or Den35b) or a section of ephemeral drainage line habitat. The effect is considered low due to the abundant comparable habitat available in the Avon Catchment area.	1	Carry out a spatial correlation analysis between piezometers response and lineaments for swamps, tributaries to Avon Reservoir, Wongawilli Creek and Native Dog Creek. Outcomes of this investigation may influence future exploration drilling and assessment to improve the understand of any potential interactions between lineaments and swamps.
			2	In the event that an anomalous, unmapped geological structure is encountered: 1. Assess the significance of the structure to increase understanding 2. If necessary, conduct surveys and testing e.g. Radio Imaging Method, Seismic, inseam and/or surface drilling 3. If the structure is deemed significant, revise mine plan accordingly to avoid/manage the geological structure

Attachment 6

Area 3B – Longwall 18 Plan


LLAWARRA COAL
DENDROBIUM COLLIERY - AREA 3B
GEOLOGICAL STRUCTURES
SCALE: 1:17000
DRAWING No: MSEC1103-07
DATE: 23 Jun 2020
LEGEND
Faults
Dykes
Lineaments
Cinder Zone
Wongawilli Creek
LW13
LW14
LW15
LW16
LW17
LW18
Study Area based on predicted limit of Vertical Subsidence for LW18
Study Area based on 600m Boundary
Native Dog Creek
Lake Avon
Avon Dam Notification Zone
Historic Elouera workings in the Wongawilli Seam


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www.minesubsidence.com
SOUTH32
ILLAWARRA COAL
DENDROBIUM COLLIERY - AREA 3B
STREAMS & SWAMPS
DATE: 23 Jun 2020
SCALE: 1:12500
DRAWING No: MSEC1103-09
Rev No C
LEGEND
Pools
Rockbars
Channel
Boulderfield
Step
Cascade
Vegetation
Swamps
1m Surface level contours
Watercourse
GDA to MGA coordinates
Wongawilli Creek
Native Dog Creek
Lake Avon
Avon Dam Notification Zone
Study Area based on 600m Boundary
Study Area based on predicted limit of vertical subsidence for LW18
Historic Eloura workings In the Wongawilli Seam
LW14
LW15
LW16
LW17
LW18
Den13
Den14
Den23
Den35a
Den35b
Den149
Den150
Den151
WC5
WC6
WC7
WC8
WC9
WC12
WC15
ND1
ND1A
ND1B
ND1C
ND2
ND2A
LA1
LA2
LA3
290000
289000
288000
6192000
6191000
6190000
291000

Attachment E – Surface Water Assessment

Illawarra Metallurgical Coal

Dendrobium Mine

Assessment of surface water and shallow groundwater effects of proposed Longwall 18, Area 3B



HGEO Pty Ltd
Date: August 2020
Project number: J21498
Report: D20363

Hgeo
hgeo.com.au

DOCUMENT REGISTER

Revision	Description	Date	Comments
01	1st Draft	5/8/2020	MS Word
05	Final report	12/8/2020	pdf

FILE

C:\OneDrive\HGEO\Projects\Dendrobium\04_Projects\J21498_LW18_SMP_SW\Report\D20363_Dendrobium_LW18_SW_Impact_Assessment_V05.docx

Cover photo: Wongawilli Creek, looking upstream from Waterfall 54 on 27/02/2019

QUALITY CONTROL

Process	Staff	Signature	Date
Authors	Stuart Brown, Will Minchin		
Approved	Stuart Brown		12/8/2020

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ABBREVIATIONS

Abbreviation/Term	Meaning
AHD	Australian Height Datum (Mean Sea Level 1966-1968)
BACS	Bald Hill Claystone
bgl	Below ground level
CVSS	Colo Vale Sandstone
DPIE	Department of Planning, Industry and Environment
EOP	End of Panel (monitoring review report)
HBBS	Hawkesbury Sandstone
IEPMC	Independent Expert Panel for Mining in the Catchment
IESC	Independent Expert Scientific Committee
IMC	Illawarra Metallurgical Coal
IMCEFT	Illawarra Metallurgical Coal Environmental Field Team
NDC	Native Dog Creek (tributary to Lake Avon)
SIMMCP	Swamp Impact Monitoring Management and Contingency Plan
SMP	Subsidence Management Plan
TARP	Trigger Action Response Plan
WIMMCP	Watercourse Impact Monitoring Management and Contingency Plan

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 18, located immediately to the south of Longwall 17 in mining Area 3B.

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 Lakes Cordeaux and Avon 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 Longwall 18. Within the study area, surface runoff drains into Wongawilli Creek and Lake Avon via a number of tributaries.

The main third-order channel of Wongawilli Creek is approximately 1050 m from Longwall 18 at its closest approach and is well outside the study area as defined by the 600 m buffer. The Waterfall along Wongawilli Creek, Waterfall 54 is located at a similar distance (1060 m) from the proposed longwall. Adverse effects associated with Longwall 18 such as creek bed fracturing and flow diversion are unlikely in Wongawilli Creek and its tributaries. Lake Avon tributary LA2 crosses directly above Longwalls 16 and 17 and will likely be affected by subsidence associated with those longwalls, with possible additional effects associated with Longwall 18. Native Dog Creek, a third order tributary to Lake Avon, was previously impacted as a result of subsidence associated with the Elouera Mine. Minor additional impacts are possible in the lower reaches of Native Dog Creek that are within 400 m of Longwall 18. Native Dog Creek tributary ND1 flows parallel to, and within 400 m of, Longwall 18. Valley-related closure is likely to result in minor and localised fracturing of the ND1 creek bed and potential 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 regional groundwater modelling indicate that the incremental effect on stream flow due to extraction of Longwall 18 will be 0.03 ML/day along Wongawilli Creek and 0.1 ML/day along ND1. The cumulative effect on flows due to the extraction of Longwall 6 to 19 is estimated to be approximately 1.0 ML/day along Wongawilli Creek and 0.15 ML/day along ND1 (~30% and 22% of mean flow, respectively), with the effects peaking around 2031-2035. The cumulative effects are likely to result in an increase in cease-to-flow days during dry conditions in Wongawilli Creek at gauging station WWL. Groundwater modelling indicates that Longwall 18 may result in an incremental seepage loss from Lake Avon of between 0.01 and 0.13 ML/day.

Water quality influence due to mining is expected to be minor or undetectable in stream reaches within subsidence affected areas. Impacts such as temporary changes in water salinity, pH and iron content with local discolouration of streambeds may be observed in the first order tributary ND1C which crosses Longwall 18; however, those impacts are not expected to significantly influence water quality at the ND1 outlet. Effects may include staining of bed rock and rock faces by iron hydroxide. Water quality effects on stored waters of the reservoirs are expected to be negligible and undetectable.

There are six areas of Coastal Upland Swamp vegetation located entirely or partially within the study area. Based on previous experience at Area 3B and subsidence predictions, it is likely that shallow groundwater levels will be affected in Swamp 35a and Swamp 149 which partially overlap the longwall footprint, noting that Swamp 149 will likely be impacted by the preceding Longwall 17. It is possible that impacts to shallow groundwater may occur in Swamp 35b, located 90 m from Longwall 18 and in the base of the ND1 valley. The remaining swamps are unlikely to be impacted.

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 Longwall 18, the final and southern-most of ten longwalls in Area 3B (Figure 1).

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 Longwall 18. 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 (Development Consent Schedule 3, Condition 8(d)), being the minimum extent of the assessments for the valley related subsidence effects (MSEC, 2020a). MSEC (2020a) 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 that extend upstream and downstream of the 600 m envelope, as appropriate for the definition of baseline characteristics and impact monitoring.

1.3 Scope

The scope of this assessment is to provide supporting information for the SMP for Area 3B 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 Longwall 18, 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 Longwall 18.
- 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

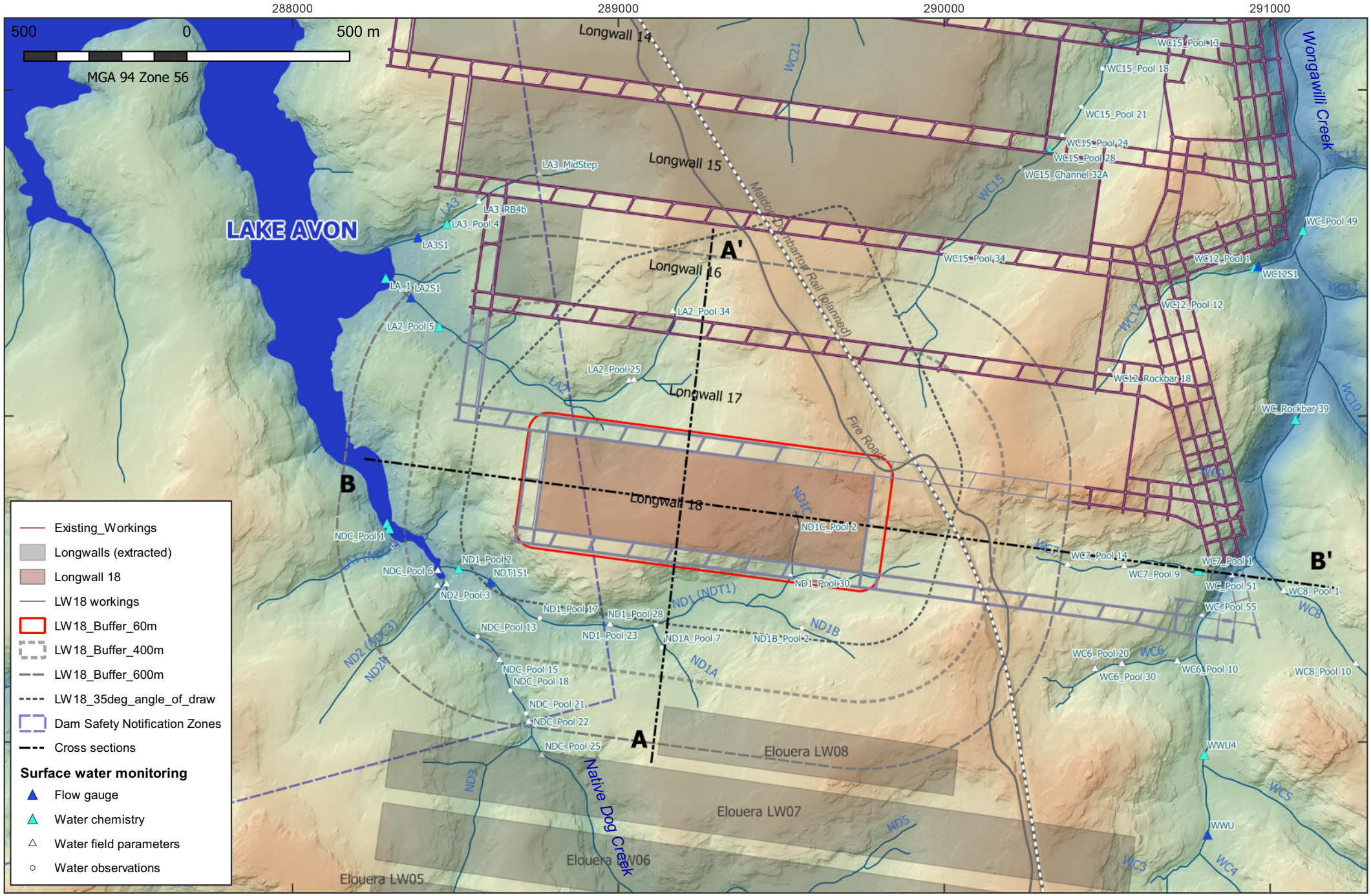
Condition		Where addressed
Schedule 3 – Specific Environmental Conditions		
2	The Applicant shall ensure that underground mining operations do not cause subsidence impacts at Sandy Creek and Wongawilli Creek other than "minor impacts" (such as minor fracturing, gas release, iron staining and minor impacts 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)

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 Longwall 21 (IEPMC, 2019c). Recommendations from the IEPMC reports are referred to throughout this assessment.

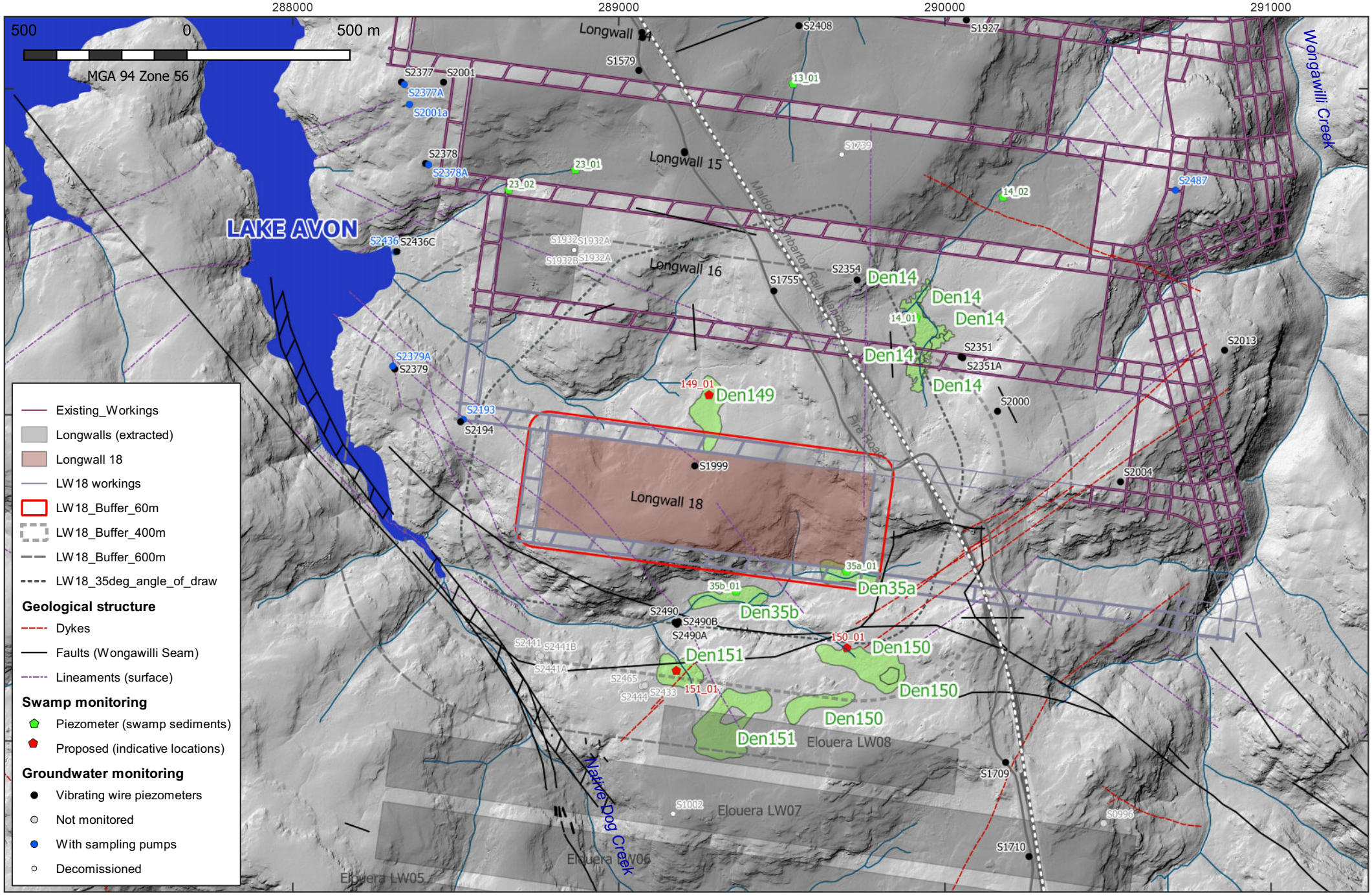


Dendrobium Longwall 18 Surface water assessment

Location map and surface water monitoring sites

Figure 1

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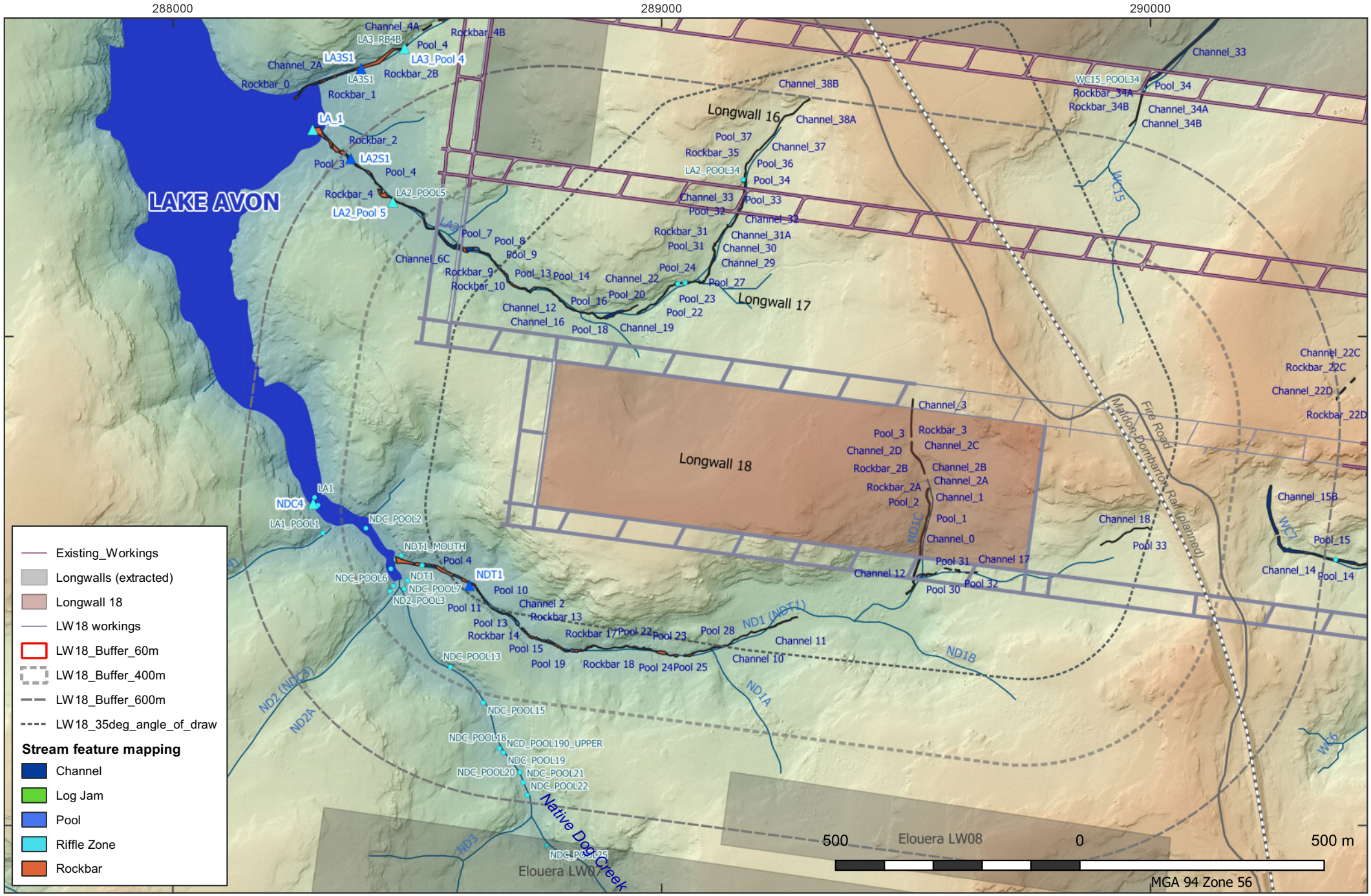


Dendrobium Longwall 18 Surface water assessment

Coastal Upland Swamp vegetation within Study Area

Figure 2

file: Dendrobium_2019.qgs.qgz



Dendrobium Longwall 18 Surface water assessment

Stream morphological mapping within Study Area

Figure 3

file: Dendrobium_2019.qgs.qgz

1.6 Mining geometry

The layout of the proposed Longwall 18 is shown in Figure 1. Longwall 18 will be extracted from the Wongawilli seam, with mining dimensions as follows:

- Void length: 1018 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: 300 – 370 m.

Longwall 18 will be extracted towards the main headings (from west to east). The extent of Longwall 18 within the Wongawilli Coal Seam is shown in an east-west geological cross-section B-B' in Figure 4 and in a north-south cross section A-A' in Figure 5. The ground surface ranges between 358 m above Australian Height Datum (mAHD) within the channel of tributary ND1C to 437 mAHD at the north-east corner of the longwall. The coal seam dips towards the north-west resulting in a depth of cover between 288 m and 374 m.

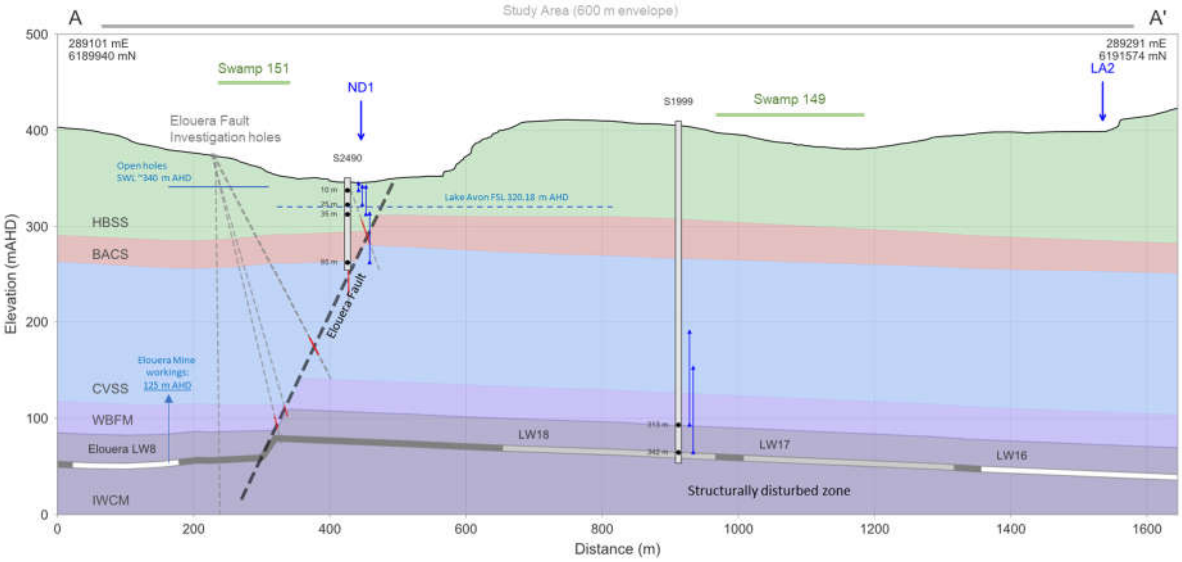


Figure 4. Geological cross section A-A' through Longwall 18 (North-South)

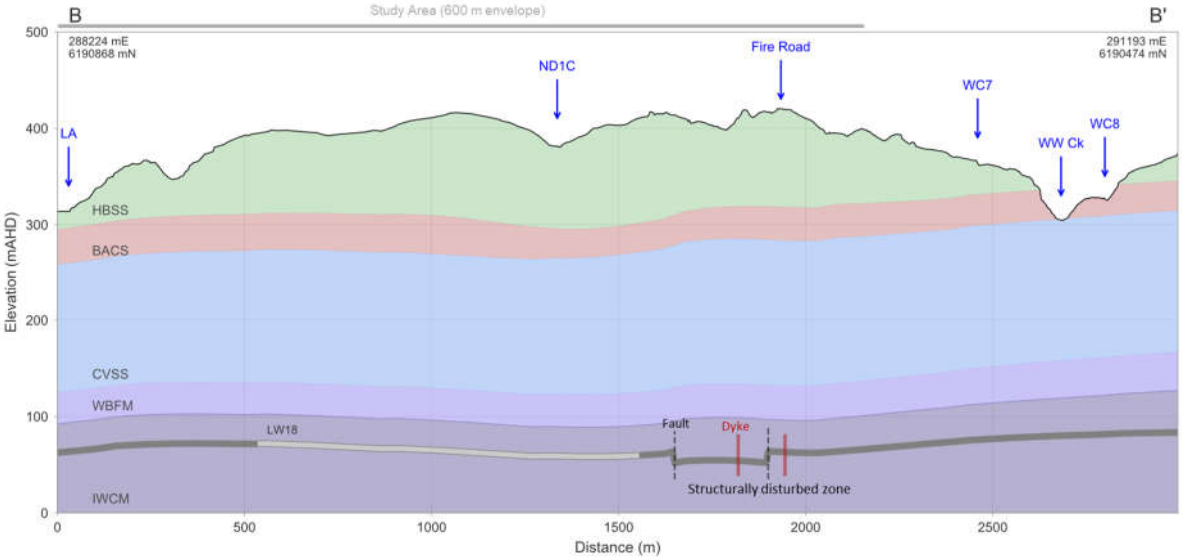


Figure 5. Geological cross section B-B' through Longwall 18 (East-West)

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 Longwall 18 is aligned approximately west-east and located immediately west of the ridgeline between Lake Avon and Wongawilli 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. Picton, located 20 km to the northwest of Dendrobium, records an average annual rainfall of 814 mm (1886-2020). 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 to early 2020. Since then, rainfall has been higher than average, with 2020 likely to be one of the wettest years on record.

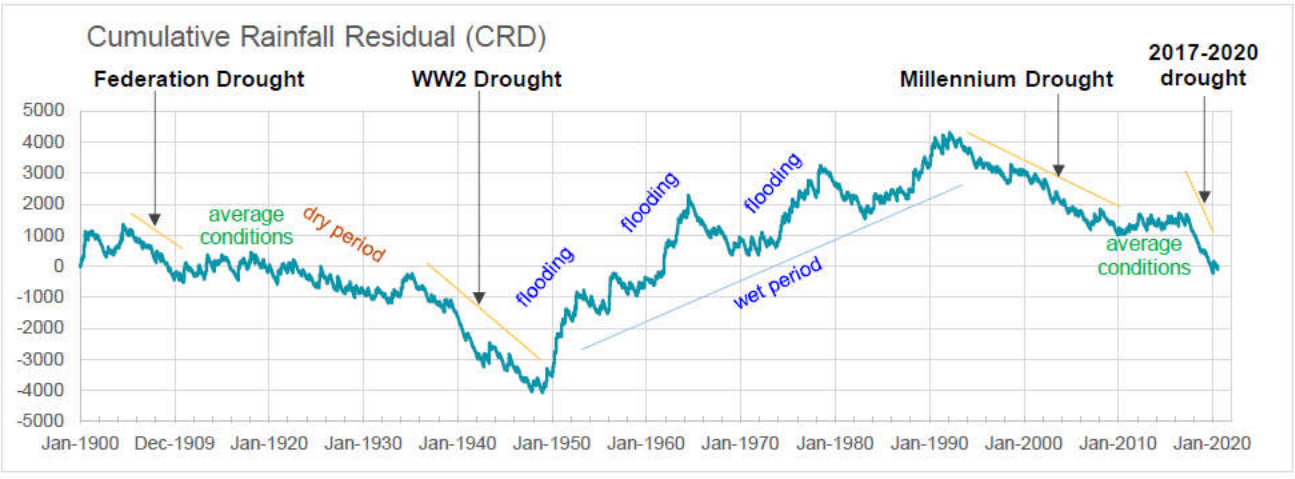


Figure 6. Long-term rainfall trends at Dendrobium Mine (from SILO daily data)

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 18 lies entirely within the catchment of Lake Avon (LA2 and ND1 sub-catchments), being located immediately west of the divide between the catchments of Lake Avon and Wongawilli Creek. The study area as defined by the 600 m distance buffer overlaps with a number of sub-catchments of Lake Avon and Wongawilli Creek as listed in Table 2.

Table 2. Sub-catchments overlapping the Longwall 18 study area

Catchment	Sub-catchment	Area (Ha)	Area over LW	% Area within 600 m	% Area within 400 m	2nd Order creeks <400m
Lake Avon	Native Dog Creek (ND3-9)	392.7	-	4	1	290 of 2400 m
	ND1	121.2	15.4	92	70	1025 m (all)
	ND2	24.3	-	16	1	
	LA1	26.3	-	17	-	
	LA2	82.4	14.6	96	72	648 of 927 m
	LA3	47.6	-	13	-	
	LA4	88.4	-	1	-	
Wongawilli Creek	WC6	22.2	-	7	-	
	WC7	27.6	-	47	10	
	WC12	42.2	-	12	-	
	WC15	128.0	-	30	17	
	WC21	239.5	-	-	-	

2.3.1 Wongawilli Creek

Wongawilli Creek is a third-order perennial stream that flows north to join the Cordeaux River approximately 4 km north of Area 3B (Longwall 9). 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 recent drought, Wongawilli Creek (WWL) typically recorded flow on more than 95% of days. 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 [BACS]) and upstream of the study area (Colo Vale Sandstone [CVSS]).

The main third-order channel of Wongawilli Creek is approximately 1050 m from Longwall 18 at its closest approach and is well out of the study area as defined by the 600 m buffer. The Waterfall along

Wongawilli Creek, Waterfall 54 is located at a similar distance (1060 m) from the proposed longwall. The upper reaches of tributaries WC15 and WC7 cross within the study area; only the uppermost headwaters of WC15 pass within 400 m of the longwall (within Swamp 14).

2.3.2 Lake Avon

Lake Avon is located to the west of Area 3B workings with Longwalls 12 to 17 being offset from the Full Supply Level (FSL) by 300 m. Longwall 18 is similarly offset with the southwest corner of the panel located 300 m from the Native Dog Creek arm of Lake Avon. Major tributaries to Lake Avon with catchments that overlap with the Longwall 18 study area as defined by the 600 m buffer include LA1, LA2, LA3 and LA4 and Native Dog Creek

- LA1 is a first order tributary draining to the western side of the Native Dog arm of Lake Avon. Field observations are taken at one site, LA1_Pool1 near the confluence with Lake Avon. The confluence of LA1 is 430 m from the western end of Longwall 18.

- LA2 is a second order tributary that flows west to join Lake Avon west of Longwall 16. The upper reaches of the tributary crosses Longwalls 16 and 17. There are five field observation sites on LA2 and a flow gauge at LA2S1. Longwall 18 will pass 100 m from the main LA2 channel at its closest point.

- The catchments of LA3 and LA4 cross within the Longwall 18 study area as defined by the 600 m buffer; however, both watercourses are outside the study area.

2.3.3 Native Dog Creek

Native Dog Creek (NDC) is a third-order tributary to Lake Avon. The main tributary system which includes ND3 to ND9 flows in a north-north-easterly direction, meeting tributaries ND1 and ND2 at the lake edge. The main tributary system of Native Dog Creek was previously mined under by longwall panels of the Elouera Mine which ceased operations on June 2007. The Elouera Mine workings underlie some 293 ha of the 393 ha catchment (75 %). Most of the first, second and third order channels of ND3 to ND9 were directly mined under by Eloura longwalls, giving rise to impacts including fracturing of the creek beds, diversion of flows and iron staining, most notably above and downstream of Elouera Longwall 7. The lower 290 m of Native Dog Creek is within 400 m of the proposed Longwall 18.

Tributary ND1 is a second order tributary which flows from east to west, roughly parallel to and south of Longwall 18. The longwall directly mines under the upper-most reaches of the first order tributary ND1C but not the main second order channel. Most of the ND1 tributary system is located within 400 m of Longwall 18. The tributary has a gauging station (NDT1S1) located 150 m upstream of Lake Avon FSL.

Tributary ND2 is a first order tributary that flows north-east to meet the main channel at the lake edge (at FSL). The lower 75 m of the first order channel is within 400 m of Longwall 18.

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 Longwall 18.

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 (BACS, Narrabeen Group) are exposed in deeply incised parts of Wongawilli Creek and along the south-eastern shores of Lake Cordeaux.

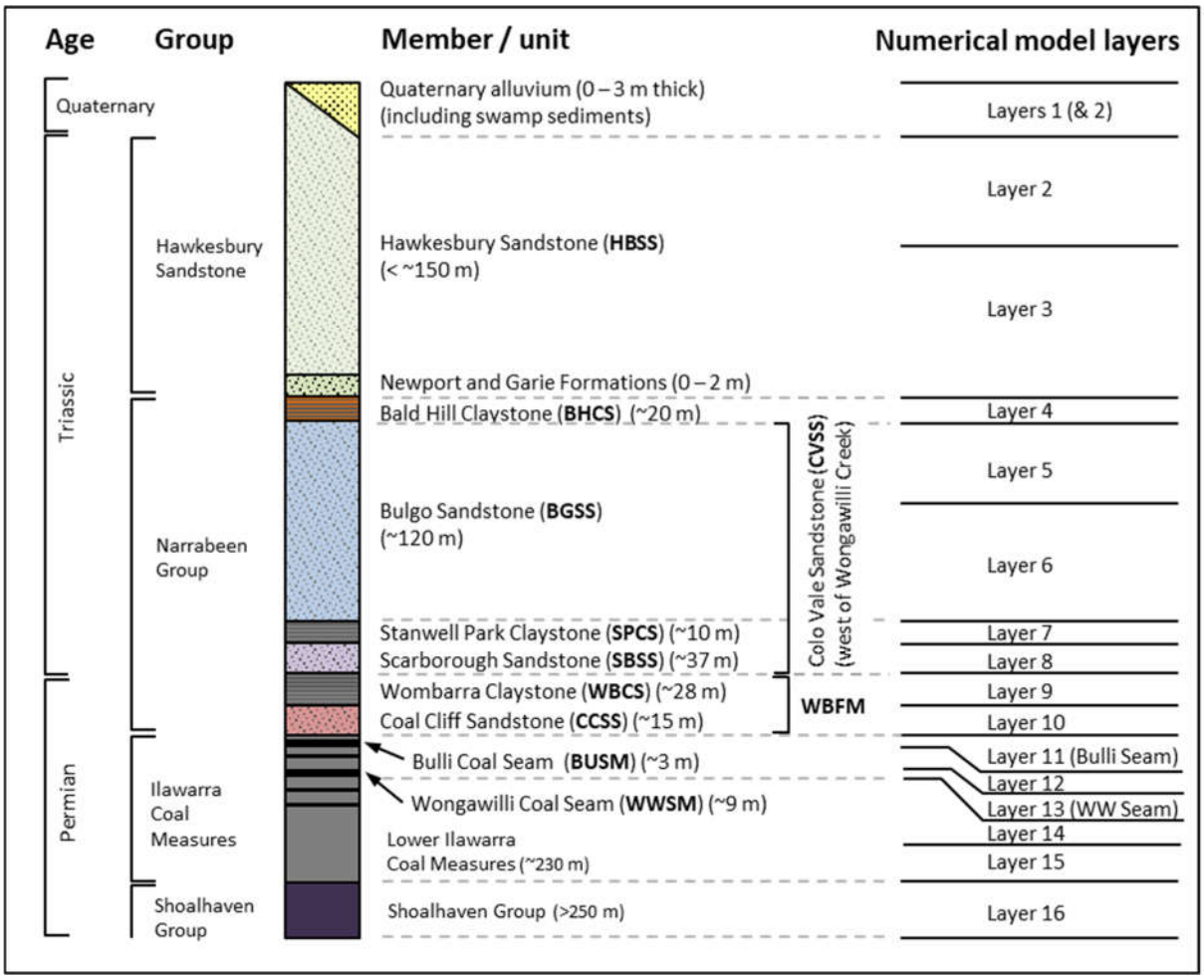


Figure 7. Stratigraphy of the Southern Coalfield and numerical model layers

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 CVSS.

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 monitoring bores located near the cross section, including water level observations in the recently drilled Elouera Fault investigation holes, and estimates of the water level within the abandoned Elouera Mine workings.

2.4.1 Faults and lineaments

Major faults and lineaments that cross the study area are shown in Figure 1. Most mapped faults are known from underground workings and therefore relate to the Wongawilli coal seam. Lineaments (shown in purple) are linear features identified from aerial photography, Lidar or geophysics. Lineaments typically relate to prominent rock joints, fracture zones, faults or dykes that are preferentially eroded or which control the course of a creek or river. Such geological features may represent linear or planar zones of enhanced permeability and therefore have the potential to propagate groundwater drawdown impacts to a greater distance from the mine footprint than otherwise would have been the case.

SRK (2020) assessed the presence of surface structures, including lineaments, and the role these might play in enhancing subsidence and environmental impacts around mining areas at Dendrobium. SRK noted that the conditions at Dendrobium (Southern Coalfield) are different to those in the Western Coalfield (e.g. at Springvale Mine) where lineaments around mining areas enhanced subsidence effects to significant distances, leading the transmission of effects out to hundreds of metres or a kilometre or so from Springvale workings. Based on analysis of repeated Lidar surveys, SRK concluded that "*longwall mining activities to date at Dendrobium appear to have had little or no effect in the reactivation of surface lineaments*" and "*minor [apparent] movement is mostly restricted to areas above individual longwall panels*. The potential for reactivation of surface lineaments extending outside the planned longwall areas was assessed as low.

Four mapped lineaments cross the footprint of Longwall 18 and two of the lineaments also cross the ND1 watercourse and /or the Lake Avon shoreline. Underground geological mapping and drilling has not identified structures of the same orientation that intersect Longwall 18.

Elouera Fault

In 2018 IMC commenced investigations to assess the structural and hydrogeological characteristics of the Elouera Fault in the vicinity of proposed mine workings at Area 3B. The main outcomes of the study are presented in HGEO (2020a) and summarised below:

- The Elouera Fault lies between the Dendrobium Area 3B (proposed Longwall 18) and the Elouera Mine workings adjacent to Lake Avon. The Elouera Fault zone dips to the south at approximately 60° from horizontal with an average vertical displacement within the CVSS of 39 m (the southern Elouera block is downthrown relative to the northern block). Displacement decreases up through the stratigraphy and is approximately 13 m at the BACS at drill Site 3. The fault zone likely

extends to the surface. The projected fault trace appears to correspond to a prominent break in slope and several topographic lineaments in the northern slopes of ND1 valley.

- The BACS, a regionally important aquitard, is not completely offset and maintains continuity across the fault. The major stratigraphic units (HBSS and CVSS) are largely continuous across the fault with minor displacement relative to their thickness. Minor offsets of lithology would result in the fault representing a weak barrier to transverse (north-south) groundwater flow.

- Narrow-spaced packer testing across the Elouera Fault shows a highly variable permeability structure (and overall average permeability) between drill sites and between closely adjacent holes at the same site. The data indicate that permeable zones are discontinuous on a scale of tens of metres and the fault does not form a continuous conduit to groundwater flow (along the fault).

- The highest average permeability was observed at the shallowest fault intersection (upper CVSS) and therefore the fault may form a zone of enhanced permeability near the surface associated with increased fracturing of the HBSS. However, the fault does not form a continuous conduit or connection to deeper stratigraphic levels. Groundwater levels within the HBSS beneath Swamp 35b are within metres of the ground surface despite the projected fault trace sub-cropping beneath the swamp and significant depressurisation of the lower CVSS (which is also intersected by the fault).

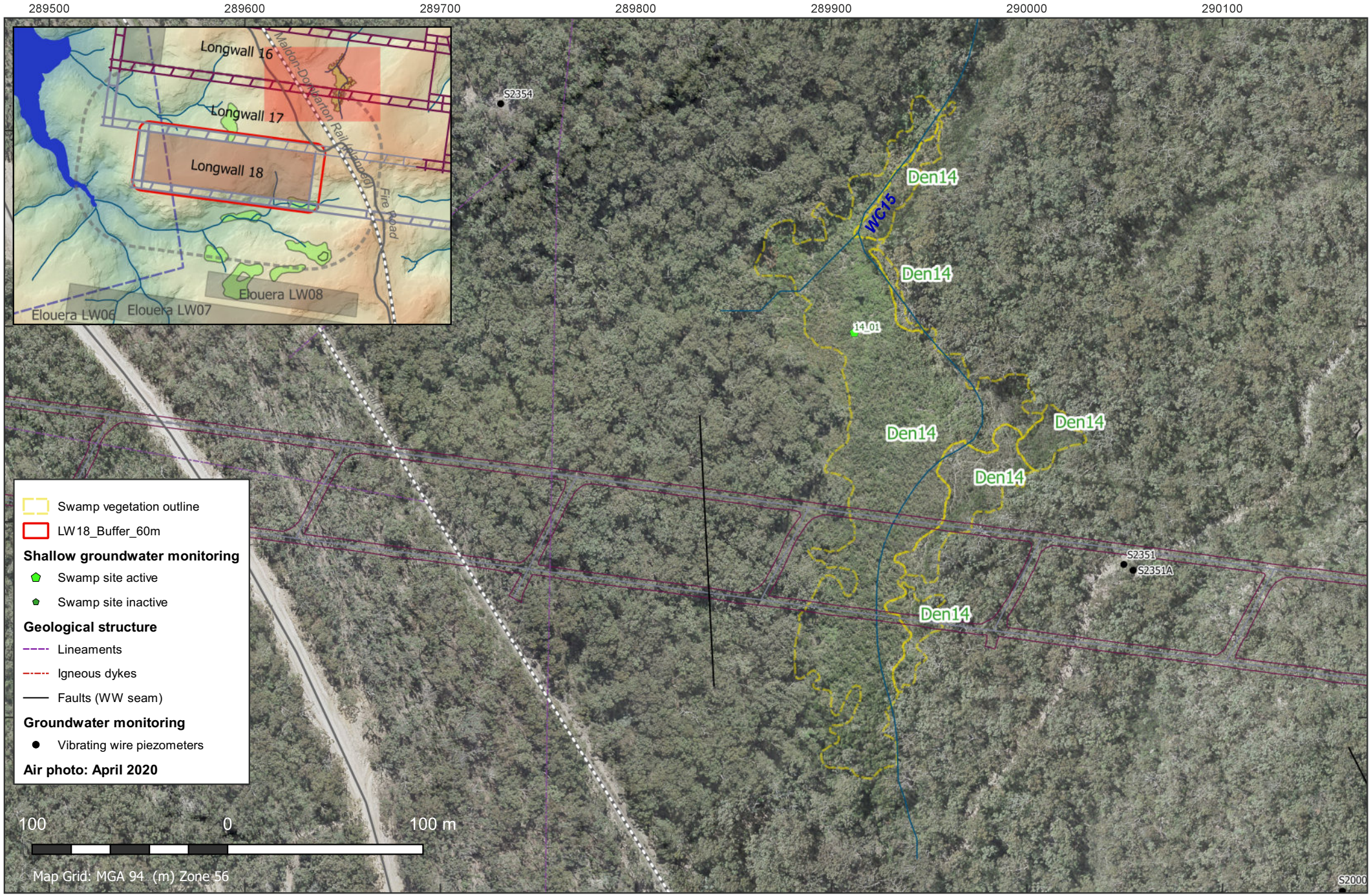
2.5 Upland Swamps

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 located entirely or partially within the study area based on the 600 m buffer and the 35° angle of draw line (Swamp 14, 35a, 35b, 149, 150 and 151). Swamp 14 was previously mined under by Longwalls 15 and 16; and Swamp 149 will be mined under by Longwall 17.

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.

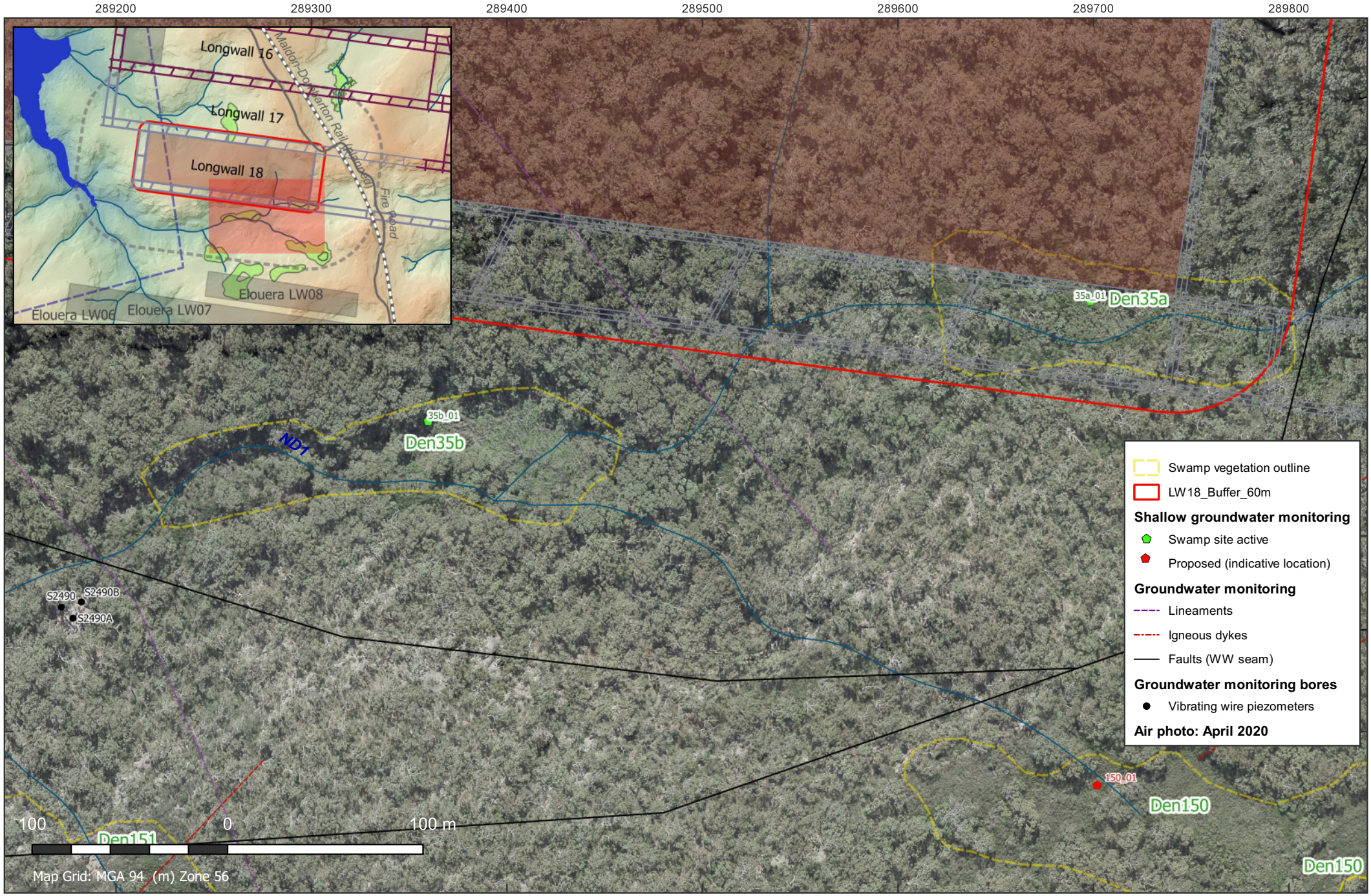


Dendrobium Longwall 18 Surface water assessment

Swamp 14 (upper)

Figure 8

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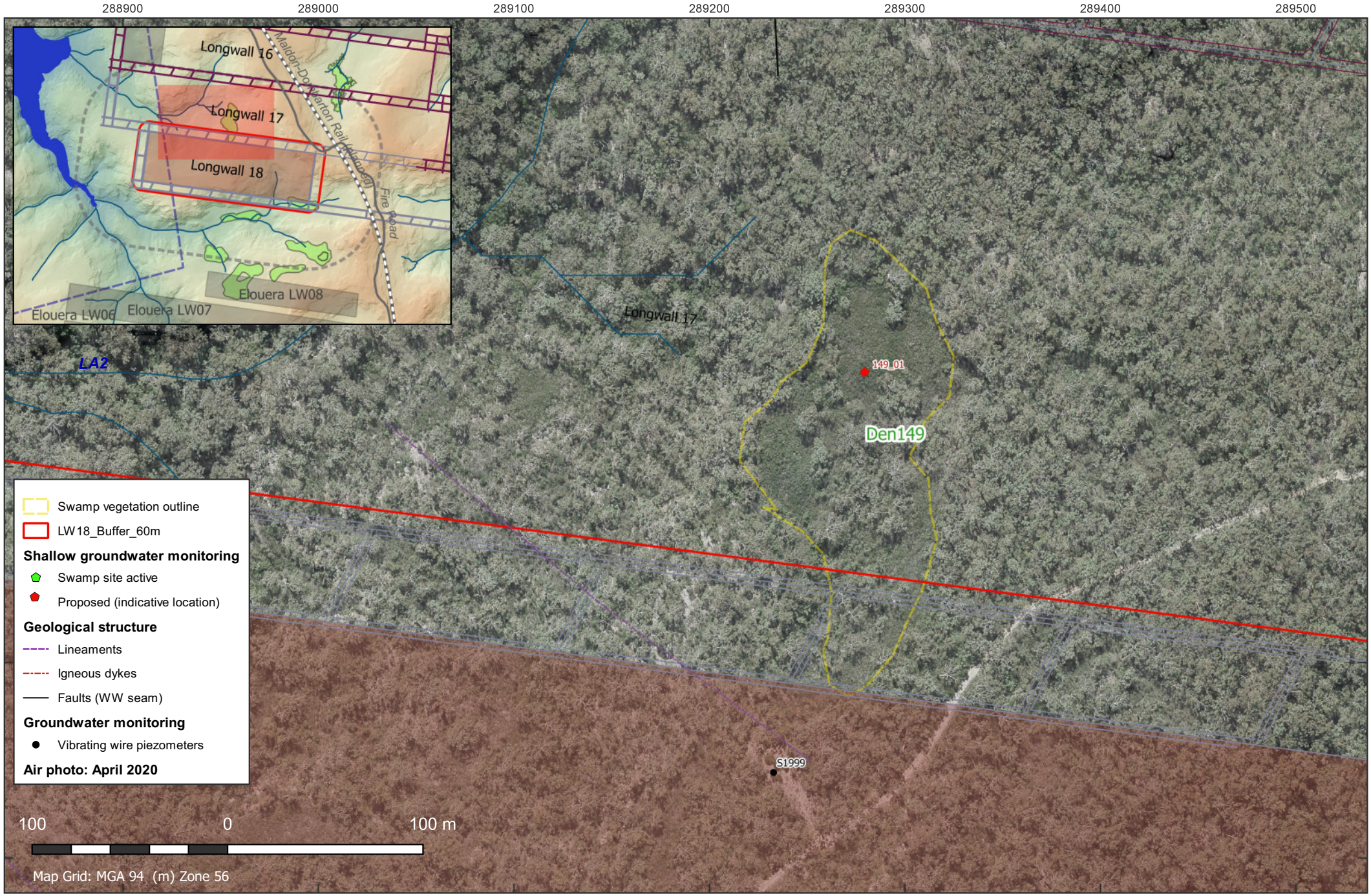


Dendrobium Longwall 18 Surface water assessment

Swamp 35 A and B

Figure 9

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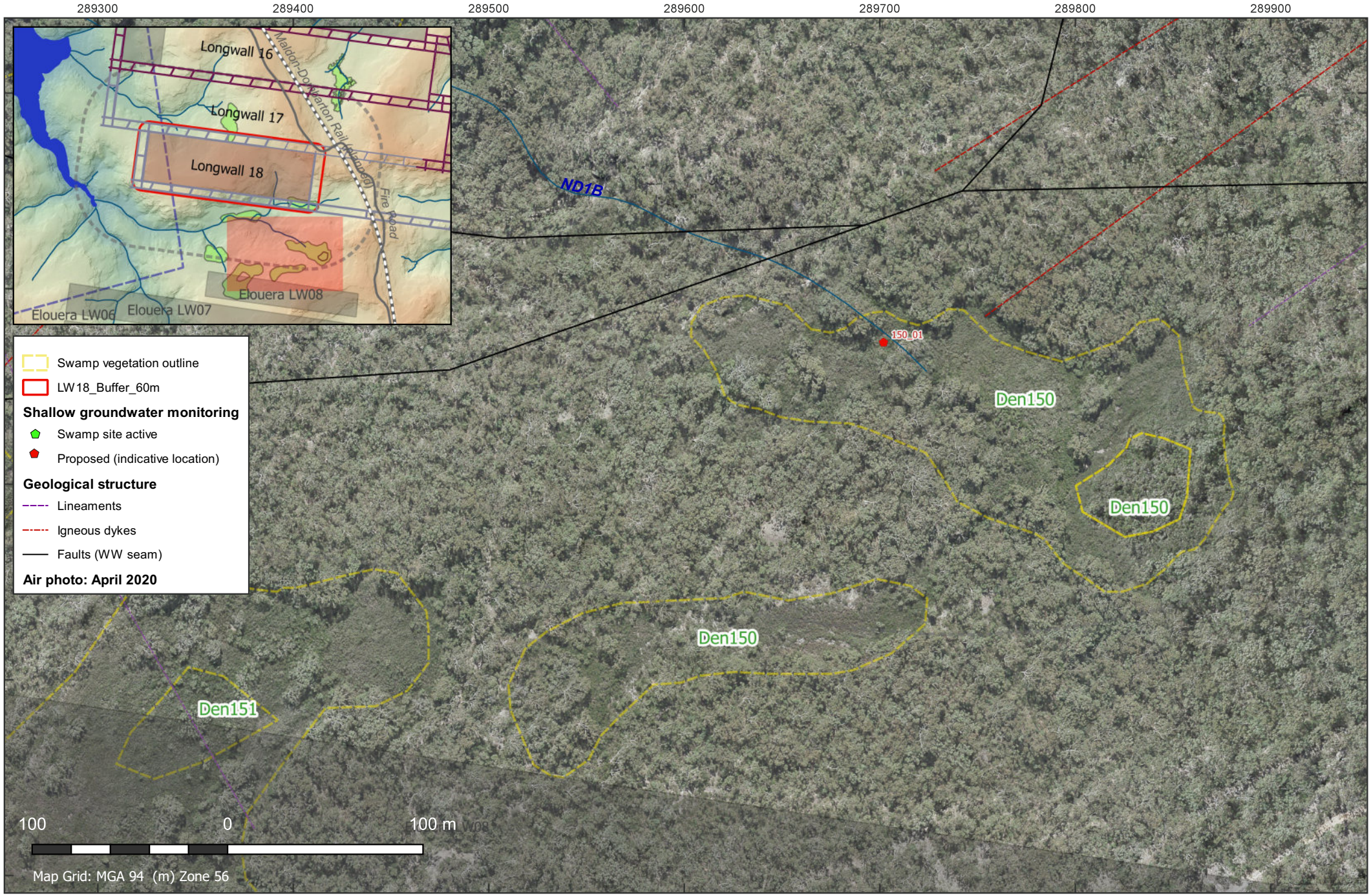


Dendrobium Longwall 18 Surface water assessment

Swamp 149

Figure 10

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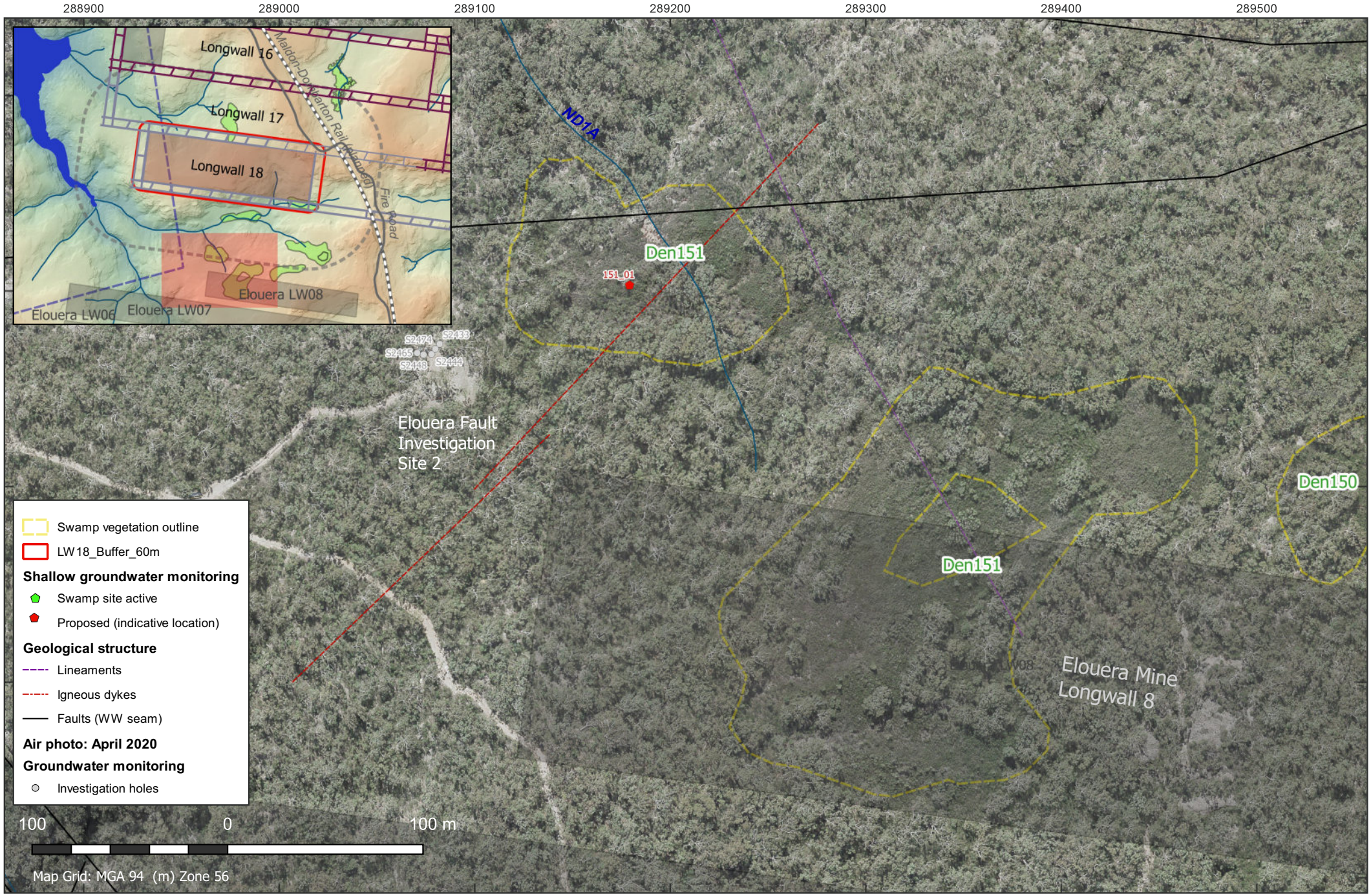


Dendrobium Longwall 18 Surface water assessment

Swamp 150

Figure 11

file: Dendrobium_2019.qgs.qgz



Dendrobium Longwall 18 Surface water assessment

Swamp 151

Figure 12

file: Dendrobium_2019.qgs.qgz

3. BASELINE ASSESSMENT

3.1 Monitoring

This section outlines the network of monitoring infrastructure and sites operated by IMC that are relevant to the Longwall 18 study area. Further details of monitoring sites and procedures are outlined in the Dendrobium Area 3B 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 to Lake Avon and Wongawilli Creek adjacent to proposed Longwall 18 have been mapped as part of previous assessments for mining at Dendrobium Mine (Figure 3). Each feature is photographed, and changes noted during regular monitoring events.

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 3B WIMMCP (South32, 2020a). There are 25 active monitoring tributaries to Lake Avon and Wongawilli Creek (and their sub-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 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 3. Surface water monitoring sites relevant to Longwall 18

Catchment	Site	East (MGA94)	North (MGA94)	Field obs. from	Chemistry sampling	Flow gauge
Lake Avon	LA1	288290	6190671	21/01/2002	Y	
	LA2_POOL5	288450	6191275	23/07/2012	Y	LA2S1
	LA2_POOL24	289033	6191108	10/12/2018		
	LA2_POOL25	289048	6191110	11/06/2019		
	LA2_POOL34	289167	6191321	3/03/2020		
Lake Avon (NDC)	NDC_POOL1	288297	6190655	21/01/2002	Y	
	NDC_POOL2	288395	6190608	12/01/2018		
	NDC_POOL6	288446	6190525	4/04/2002		
	NDC_POOL7	288473	6190484	10/04/2002		
	NDC_POOL13	288568	6190324	20/12/2001		
	NDC_POOL15	288635	6190251	30/05/2019		
	NDC_POOL18	288668	6190158	1/04/2003		
	NDC_POOL19	288676	6190149	17/01/2018		

Catchment	Site	East (MGA94)	North (MGA94)	Field obs. from	Chemistry sampling	Flow gauge
	NDC_POOL20	288710	6190109	20/12/2001		
	NDC_POOL21	288717	6190088	17/01/2018		
	NDC_POOL22	288725	6190062	30/10/2001		
	NDC1	289619	6189187	6/05/2002	Y	
	NDT1	288510	6190532	20/12/2001	Y	NDT1S1
	ND1_Pool 28	289116	6190360	7/08/2020		
	ND1_Pool 23	288974	6190360	7/08/2020		
	ND1_Pool 17	288759	6190380	7/08/2020		
	ND1_Pool 30	289528	6190510	7/08/2020		
	ND1C_Pool 2	289547	6190660	7/08/2020		
	ND1B_Pool 2	289564	6190350	7/08/2020		
	ND1A_Pool 7	289134	6190290	7/08/2020		
	ND2_POOL3	288444	6190479	25/03/2003		
Wongawilli Creek	WWU1	291131	6188146	15/08/2001	Y	
	WWU4	290798	6189962	17/07/2002	Y	
	WC_FR6	290960	6197376	15/05/2001	Y	WWL
	WC15_POOL34	289985	6191507	10/10/2010		WC15S1
	WC12_POOL1	290951	6191455	9/05/2018	Y	WC12S1
	WC7_POOL1	290780	6190527	25/08/2016	Y	

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 as mapped by ecological consultants Niche 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 Longwall 18.

The Trigger Action Response Plan (TARP) related assessments carried out as part of the SMP relate to those piezometers located within Upland Swamp sub-community 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 conditions

3.2.1 Stream flow and catchment yield

Table 4 lists stream flow gauging stations relevant to the study area, including those located outside the study area that will be used as downstream monitoring sites. The baseline period to 2020 includes data collected over the severe drought of 2018-2019. The last column of Table 4 summarises the effects on stream flow that are attributed to mining in previous reports.

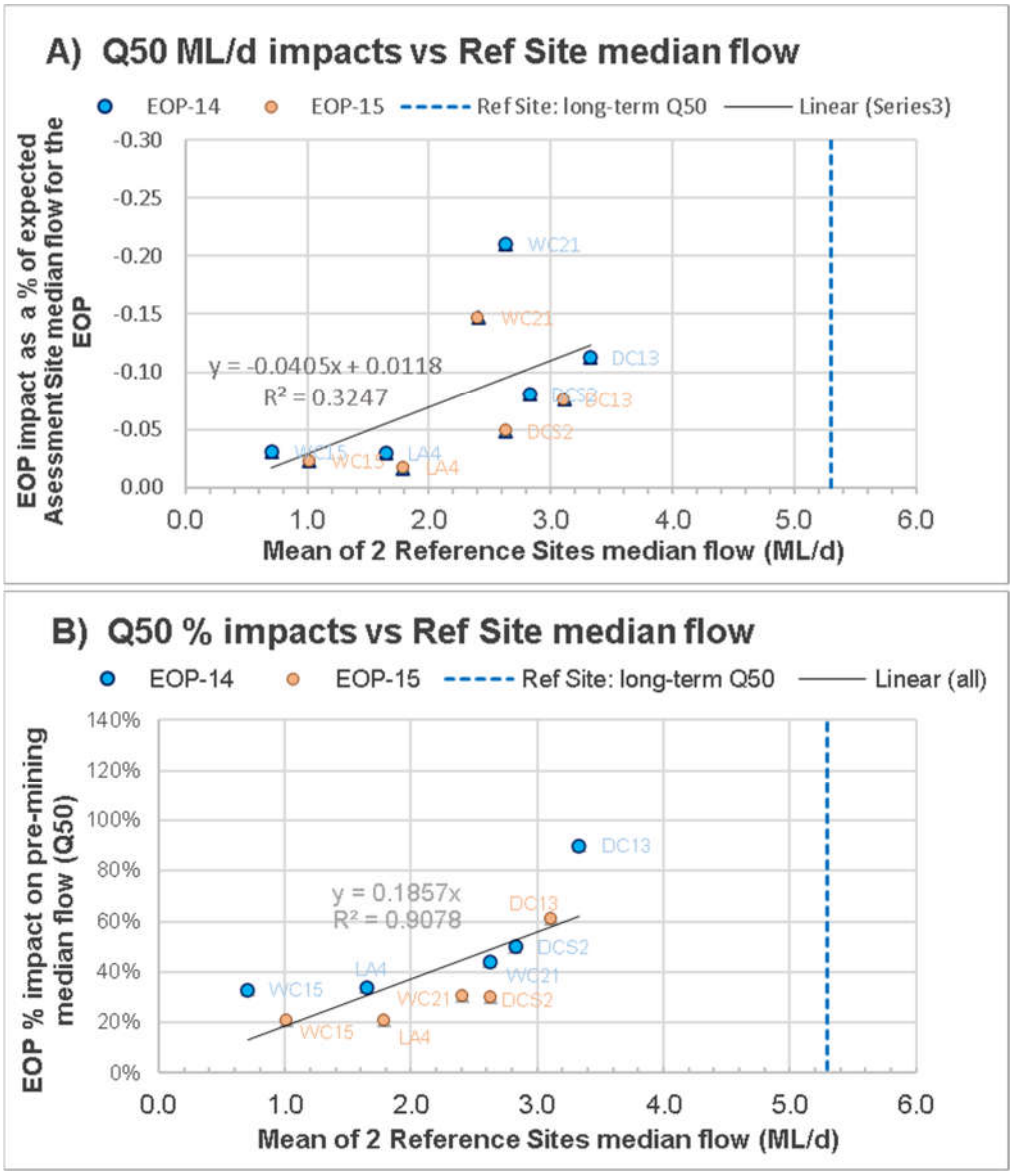
The assessment of mining effects on surface water flow or yield around Area 3B is carried out for End of Panel reports using recently agreed TARP methods (Watershed HydroGeo, 2019a and South 32, 2020). The new assessment analyses changes on median flow (Q50), cease-to-flow frequency, and general hydrological behaviour, using a comparison against flow at two Reference Sites for the corresponding pre- and post-mining periods. A trial of these assessments was conducted for the Longwall 14 assessment period (Watershed Hydrogeo, 2019a) and then the first formal assessment using the new TARP methods was carried out in HGEO (2020b). A summary of the mining effects based on the most recent End of Panel (EOP) report for Longwall 15 is in Table 5.

Effects on surface flow were evident at all headwater subcatchments that have been mined under, e.g. DC13, DCS2, WC21, WC15, LA4. The impacts are evident in all three assessments relevant to these sites, most significantly an increase in the frequency of cease-to-flow conditions and a reduction in Q50. As reported in HGEO (2020b), impacts on Q50 at the sites listed here, when compared to gauged pre-mining Q50, were equivalent to reductions of 20-60% of median flow.

The results of the assessment of impacts on Q50 from the two recent assessments is summarised on the following charts. The x-axis shows the average of the median at the two Reference Sites for the relevant post-mining periods (these periods are different for different 'Assessment Sites due to their position above or near different longwalls). This Reference Site median flow is a measure of the 'wetness' or availability of flow in each period.

- On Figure 13A, this is compared to the estimated surface water loss, expressed as a percentage of the pre-mining median flow at each site.
- On Figure 13B, this is compared to estimated surface water loss, expressed as a percentage of the estimated 'expected flow' at each site during that period. The expected flow is based on the 'un-impacted' Reference Sites.

In both Figures, the trend is that the impact increases (on the Y-axis) with increasing Reference Site flow (x-axis). Reference Site flow or 'wetness' is not the only factor that will affect the magnitude of impact; that will be influenced by the fraction of the sub-catchment that is affected by mining, the period for which mining has occurred in that catchment, as well as depth of cover, topographic effects.



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Figure 13. Historical flow impacts compared to Reference Site flows

Between End of Panel 14 (EOP14) and EOP15, the mined area of catchment for DC13, DCS2, and LA4 did not change, and barely changed in WC21. The other parameters (depth of cover and topographic effects) were also constant, and the assessed impacts generally declined from EOP14 to EOP15. As a result, the data does suggest that 'wetness' leads to greater impact, i.e. the concept that if there is more rainfall and flow, then there is more surface water flow that can be lost to fracturing and drawdown. If there is no rainfall and no flow or little flow, then there is less flow that can be lost.

The estimated losses (Watershed 2019a and HGEO, 2020d) appear reliable and consistent with field observations. However, both these periods are limited to periods dominated by drought conditions. This is shown by comparing the Reference Site median flow for the End of Panel periods shown on the x-axis of these charts against the long-term Reference Site median flow (the dashed blue line on

Figure 13). This confirms that flow in recent years is low (30-50%) compared to long-term average conditions.

The implication is that if rainfall and flow revert to average conditions (and conditions thus far in 2020 point to higher than average rainfall and flow), then impacts to stream flow may rise – not because of changes to the physical mining effects (fracturing and drawdown), but due to the increased availability of surface water flow. There is not historical data to indicate how much the impact may rise, but the trends on Figure 13 and the ratio of recent Reference Site median flow compared to the long-term average suggests that an increase in impact by 2-3 times, and potentially more, compared to that assessed in the recent End of Panel reports is plausible.

Table 4. Stream flow gauging stations relevant to the study area

Water-course	Gauge	Catch-ment Area (km^2)	Pre-mining gauged record			Representative* pre-mining baseline 2008-2020			Post-mining record		Annual no-flow days	Observed mining effects
			Period	Median flow (ML/day)	Mean flow (ML/day)	Median flow (ML/day)	Mean flow (ML/day)	Yield (%rain)	Median flow (ML/day)	Mean flow (ML/day)		
Wongawilli Creek	WWU	3.211	02/11/2007-12/06/2020	0.27	3.29	0.27	3.29	33%	n/a	n/a	20 (5.5%)	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	20/06/2012-28/01/2017	0.11	1.11	*0.06*	*0.65*	*27%*	0.002	0.54	Pre→ Post 44 → 110 (12→30%)	There is clear evidence that flow in WC15 has been affected by recent Area 3B longwalls.
Wongawilli Creek	WWL	20.08	02/11/2007-09/02/2010	3.66	11.70	3.08	14.78	26%	2.92	15.45	Pre→ Post 30 → 17 (8→4%)	No evidence for change of flow characteristics at downstream gauge compared to reference sites**
LA2	LA2S1	0.824	4/02/2019-12/06/2020	0.015	1.53	*0.23*	*1.1*	*45%*	n/a	n/a	*22*	Not yet mined under (would be first mined under by Longwall 17)
ND1	ND1S1	1.13	03/03/2019-15/06/2020	0.013	0.37	*0.14*	*0.66*	*21%*	n/a	n/a	*26*	Not yet mined under (would be first mined under by Longwall 18)
Native Dog Creek	n/a	5.28	n/a	n/a	n/a	*0.43*	*5.3*	*35%*	n/a	n/a	*18*	Elouera Colliery did mine in this catchment and is known to have affected hydrology in Native Dog Creek. There is no impact from Dendrobium mining.

Statistics are based on the full flow record, accounting for QA assessment by ALS hydrographers. Pre-mining and post-mining are in reference to Dendrobium mining (not Elouera).
**Representative pre-mining* flow statistics based on synthetic series via comparison against reference site (WWU). These are used for subsequent impact assessment, and are used so as not to skew predictions to recent drought conditions (Mar-2017 to Feb-2020).
** 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.

Table 5. Summary of historical effects on stream flow from Longwall 15 EOP report

Site	Watercourse	Area	Date mining occurred under sub-catchment	A) Low flow Q%ile outside Reference Site Q%ile		B) Change in cease-to-flow frequency (beyond natural)		C) Change in Q50 (beyond natural)			Comment
				Change %	TARP Level	Change %	TARP Level	Change ML/d	Change %	TARP Level	
DC13S1	DC13	A3B	9/02/2013	59%	Level 3	22%	Level 3	-0.091	-61%	Level 3	Effects are similar to those in LW14
DCS2	Donalds Castle Creek	A3B	10/07/2013	41%	Level 3	41%	Level 3	-0.059	-29%	Level 3	Effects are similar to those in LW14
DCU	Donalds Castle Creek	A3B	9/02/2013	-8%	Not triggered	9%	Level 1	+0.096	33%	Not triggered	Effects are similar to those in LW14
WC21S1	WC21	A3B	5/10/2013	33%	Level 3	14%	Level 2	-0.166	-30%	Level 3	Effects are similar to those in LW14
WC15S1	WC15	A3B	28/01/2017	38%	Level 3	15%	Level 2	-0.019	-21%	Level 3	Effects have increased since LW14
WC12S1	WC12	A3B	Not yet (LW16)								To be assessed in future EoP report.
WWL	Wongawilli Creek	d/s A3B	9/02/2010	0%	Not triggered	-1%	Not triggered	+0.083	11%	Not triggered	Effects are similar to those in LW14
WWLA	Wongawilli Creek	d/s A3B	9/02/2010								No pre-mining baseline record. To be assessed in future EoP report.
LA4S1	LA4	A3B	1/04/2015	14%	Level 1	0%	Not triggered* **(Level 3)**	-0.016	-21%	Level 3	Effects appear to have reduced slightly since LW14. However, low flows are reported to greater accuracy in post-mining period, so Method B assessment should not be treated as completely reliable. Level 3 is more likely for this.
LA3S1	LA3	A3B	28/04/2019	13%	Level 1	19%	Level 2	-0.006	-34%	Level 3	New site, not assessed in LW14.Very short baseline period (2 months), so statistics are unreliable.
LA2S1	LA2	A3B	Not yet (LW16)								To be assessed in future EoP report.
NDTS1	NDT1	A3B	Not yet (LW17 or LW18)								To be assessed in future EoP report.
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3.2.2 Surface water quality

Water chemistry is monitored at sites on watercourses LA1, LA2, NDC, ND1 and Wongawilli Creek providing baseline data for those watercourses in relation to Longwall 18 (Table 3; Figure 1). Regular sampling and analysis have been carried out at the furthest downstream sites (Wongawilli Creek at FR6, NDT1 and NDC_Pool1) since 2001 / 2002. Therefore, there are eleven years of baseline water quality data prior to the development of Area 3B. Water chemistry at LA2_Pool5 has been monitored since 2012, seven years prior to the catchment being mined under by Longwalls 15 and 16.

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-Longwall 9) are summarised and compared against guideline levels for the protection of 95% of freshwater aquatic species (Table 6).

Table 6. Baseline water quality field parameters

Median values (mg/L)	Wongawilli Creek catchment			Lake Avon catchment			ANZECC (2000)# Freshwater 95%
	WWU4	WC7_Pool1	WC12_Pool1	NDC_Pool1	NDT1	LA2_Pool5	
Samples	178	19	23	222	117	40	
Start date	17/07/2002	25/08/2016	9/05/2018	21/01/2002	20/12/2001	23/07/2012	
EC (µs/cm)	85	94	116	91	82	92	30-350[a]
pH (pH units)	**5.4**	**4.9**	**4.9**	**5.8**	**4.9**	**5.1**	6.5-7.5 [a]
DO (%)	93	**78**	**44**	90	**69**	**82**	90-110
Temp (°C)	17.4	11.7	13.0	18.2	15.5	14.0	
TDS (mg/L)	64	60	71	68	68	64	
TSS (mg/L)	5	6	5	2	5	5	
Total Alk	1	1	1	1	1	1	-
Cl	19	25	28	22	20	21	-
SO4	5	2	2	5	4	2	-
Na	10	13	14	11	11	12	-
K	0.5	1	1	1	1	1	-
Ca	0.5	1	1	1	1	1	-
Mg	2	2	2	2	2	2	-
Al	0.05	**0.19**	**0.16**	0.04	**0.3**	**0.15**	0.055[b]
Fe	0.07	0.12	0.1	0.09	0.365	0.06	-
Mn	0.0645	0.029	0.059	0.108	0.0825	0.014	1.9
Ni	0.005	0.001	0.001	0.004	0.002	0.001	0.011
Si	1.78	2.48	1.82	2.325	1.73	1.86	-
Zn	**0.024**	0.005	0.006	**0.029**	**0.0175**	0.005	0.008
Total N	0.1	0.1	0.1	0.1		0.2	0.25 [a]
Total P	0.01	0.01	0.01	0.01	0.02	0.01	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.

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 3B (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 4.9 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 and zinc in some locations. Elevated concentrations of zinc in WWU4 and NDC may be related to previous mining at Elouera (1994 – 2007) which passed beneath those watercourses (see Section 4.6). The slightly elevated aluminium concentrations are to be expected since aluminium (and most metals) are more soluble in waters of low pH, with aluminium being derived from the weathering of aluminosilicate minerals. Median DO levels are variable and typically between 80 and 95% saturation, but as low as 44 % in some frequently isolated pools. Time series plots of field parameters and selected dissolved metals for stream sampling sites relevant to this assessment are shown in Appendix 1.

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 3B SIMMCP (South32, 2020b).

Hydrographs for shallow piezometers located at swamps within 600 m of Longwall 18 are presented in Appendix 2. 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 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.
- 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.

The relationship between the swamp shallow groundwater system and the regional (e.g. HBSS) groundwater system is determined through comparison of swamp groundwater levels with piezometric data from the deeper groundwater monitoring network. Swamps that display continuous or near continuous saturation typically have a connection with the regional groundwater table and are therefore partially dependent on groundwater (e.g. Swamps 35a and 35b). Other swamps are saturated for periods of weeks or months following large rainfall events but remain largely unsaturated during dry periods. Such swamps are typically associated with perching above the interface between the sandstone or claystone substrate and therefore disconnected from the regional groundwater system (e.g. Swamps 150 and 151).

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 Longwall 18 the most likely effects are:

1. **Altered drainage and flooding**. Mine subsidence can lead to changes in gradient within watercourses and the general landscape 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 is 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 Longwall 18 by mine subsidence consultants MSEC (2020a). 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 7. The reader is referred to the subsidence assessment by MSEC (2020b) for further detail.

Table 7. Summary of predicted subsidence effects (from MSEC 2020)

Location / feature	Predicted subsidence effects
Within longwall footprint	**Incremental movement due to Longwall 18**: Up to 2750 mm subsidence, 35 mm/m incremental tilt, 0.8 km^{-1} incremental hogging and sagging curvatures. The maximum predicted strains are 8 mm/m tensile and compressive based on the 95 %confidence levels. **Cumulative movement** (Longwalls 9 to 18): 3200 mm subsidence; 40 m/m tilt; 1.0 km^{-1} curvature
Wongawilli Creek	Wongawilli Creek is located ~1 km east of the proposed Longwall 18, at its closest point. At this distance, the predicted incremental vertical subsidence, upsidence and closure for the creek, due to the mining of Longwall 18, are all less than 20 mm.

Location / feature	Predicted subsidence effects
	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 that adverse impacts would occur along Wongawilli Creek due to the mining of Longwall 18. **Waterfall 54** on Wongawilli Creek is located 1 km from Longwall 18 and is not expected to experience measurable conventional or valley related effects due to the longwall extraction. Adverse impacts are unlikely at the waterfall.
Native Dog Creek	Native Dog Creek is located 310 m south-west of Longwall 18 at its closest point. Fracturing could develop along Native Dog Creek where it is located within approximately 400 m of the proposed longwall. Type 3 impacts are possible, but are considered unlikely, as only two cases have been observed at similar distances from previous longwalls in Area 3B.
Tributaries	Native Dog Creek tributary ND1 is located adjacent to Longwall 18 with its 2nd order reach entirely within 400 m of the longwall. ND1 will experience valley closure of up to 200 mm which may result in fracturing and/or dilation of strata bedding planes and flow diversions. Drainage Lines LA1, LA2, ND1, ND1A, ND1B, ND2, ND2A, WC7 and WC12 are predicted to experience incremental vertical subsidence of 30 mm or less. While these drainage lines could experience low levels of vertical subsidence, they are not expected to experience measurable tilts, curvatures or strains. Tributary LA2 will experience cumulative subsidence of up to 3150 mm, with approximately 850 mm incremental subsidence associated with Longwall 18. Drainage lines located directly above the mining area (ND1C) are likely to experience the full range of predicted subsidence effects including fracturing and flow diversion. Localised ponding due to mining-induced tilt could develop along some sections of the drainage lines where the natural stream gradients are relatively low.
Swamps	Six upland swamps are located within 600 m of Longwall 18. Swamp 35a is partially located above Longwall 18; Swamps 14 and 149 are located above preceding longwalls. Swamps 35b, 150 and 151 are located at minimum distances of 85 m to 325 m south of Longwall 18. Fracturing of the bedrock could occur beneath the swamps that are located above and adjacent to Longwall 18 (35a, 35b). Fracturing and dilation of strata beneath the drainage lines could result in the diversion of some surface water flows beneath parts of the swamps. 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.

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 (2020c). 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 Longwall 18. It is expected that fracturing associated with Longwall 18 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 (2020a). The main conclusions in relation to the MSEC assessment of changes in stream-bed gradient are as follows:

- LA2 is predicted to experience reversals in grade associated with Longwall 17 subsidence rather than Longwall 18. The grade reversals may result in localised increased ponding upstream of these locations
- There are no predicted reversals of stream grade along the remaining drainage lines within the study area. There are slight reductions in grades along drainage lines ND1C and WC12, upstream of the chain pillars and the edges of the mining area, with potential for minor and localised increased ponding upstream of these locations. The majority of those effects are due to preceding longwalls rather than the proposed Longwall 18.

- The predicted post-mining gradients within the swamps are similar to the natural grades. There are small reductions in grades along the drainage lines near these swamps; however, adverse changes in the levels of ponding or scouring within the swamps are not anticipated due to the mining-induced vertical subsidence or tilt.

4.4 Changes in stream flow characteristics

4.4.1 Fracturing and 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.

Based on the subsidence assessment by MSEC (2020a), summarised in Table 7, and previous experience at Dendrobium summarised in Section 3.2.1, the following effects are expected as a result of Longwall 18 extraction:

- Wongawilli Creek: At a distance of 1 km from the proposed longwall, the main channel of Wongawilli Creek, including Waterfall 54 is unlikely to experience adverse impacts such as stream bed fracturing and significant flow diversion.
- LA2 will be partially mined under by the preceding Longwall 17 and will likely experience stream bed fracturing and flow diversions associated with that longwall. Flow reductions will likely be observed at the downstream gauge LA2S1. Additional fracturing and flow diversions may result from subsidence associated with Longwall 18; however, those effects are likely to be minor compared with those of Longwall 17.
- The main 2nd order channel of ND1 and the lower reaches of NDC (including ND2) are within 400 m of Longwall 18. Valley-related closure is likely to result in minor and localised fracturing of the ND1 creek bed and potential flow diversion. Minor fracturing is possible in NDC and ND2 although effects will be minor compared with those associated with the Elouera Mine.
- Other watercourses (WC6, WC7, WC12, WC15 and LA1) are located more than 400 m from the proposed longwall. It is unlikely that those watercourses will experience significant fracturing and flow diversion.

4.4.2 Baseflow loss due to groundwater depressurisation

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 (Watershed Hydrogeo, 2020). A summary of the estimated incremental loss of baseflow due to Longwall 19 is shown in Table 8 and the reader is referred to the groundwater assessment 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 Watershed HydroGeo (2020) has taken the latter approach by applying conservative assumptions in deriving the estimates in Table 8. Estimates are presented as the "**most likely**' value followed by the possible uncertainty range (again conservative). The most likely estimate for 2016-2020 is consistent with estimates of observed cumulative impacts as of Longwalls 14 and 15.

Table 8. Estimated cumulative and incremental change in surface water flow

5-year period	Wongawilli Creek and tributaries (ML/day)		Native Dog Creek catchment including the ND1 tributary	
	Whole Mine	Longwall 18 Increment	Whole Mine	Longwall 18 Increment
2016-20	-0.40 (-0.27 - -0.94)	0	-0.002 (-0.001 - -0.005)	0
2021-25	-0.82 (-0.54 - -1.90)	-0.004 (-0.002 - -0.011)	-0.07 (-0.043 - -0.15)	-0.05 (-0.031 - -0.11)
2026-30	-0.93 (-0.62 - -2.18)	-0.007 (-0.005 - -0.017)	-0.15 (-0.097 - -0.33)	-0.10 (-0.065 - -0.23)
2031-35	-0.96 (-0.64 - -2.23)	-0.01 (-0.005 - -0.019)	-0.15 (-0.099 - -0.34)	-0.09 (-0.063 - -0.23)
2036-40	-0.84 (-0.56 - -2.23)	-0.03 (-0.017 - -0.059)	-0.13 (-0.090 - -0.35)	-0.08 (-0.055 - -0.23)
2041-45	-0.61 (-0.41 - -2.23)	-0.03 (-0.020 - -0.069)	-0.11 (-0.073 - -0.35)	-0.07 (-0.044 - -0.23)
2046-50	-0.43 (-0.29 - -2.23)	-0.03 (-0.021 - -0.072)	-0.09 (-0.059 - -0.35)	-0.06 (-0.039 - -0.23)
Results are provided as: predicted 'most likely' (predicted range)				

* Incremental flow reductions as ML/d converted from ML/yr shown in Tables 7-4 and 7-5 of Watershed HydroGeo, 2020)

The potential incremental decrease in stream baseflow as a result of Longwall 18 extraction equates to approximately 1% and 66% of the whole of mine losses over the period 2020-2035 for Wongawilli Creek (including all tributaries) and Native Dog Creek (including ND1 tributaries) respectively. At the time of the maximum expected loss (5 years post extraction) the peak cumulative losses are estimated at 20-70% and 20-80% of the median flow (<1% and 15-53% incremental). After 2035 both the cumulative and incremental losses are expected to decline, although the conservative predictions in Table 8 account for potential permanency of effects.

Decreases in baseflow will be most apparent during periods of low rainfall and low-flow in the catchments and are likely to manifest as an increase in no-flow days compared with baseline conditions, as illustrated in Section 4.4.3.

4.4.3 Predicted effects on stream flow characteristics

Predicted reduction in surface water flow is an output of the groundwater modelling. Longwall 18 incremental losses and losses due to all of Dendrobium are presented in Section 7 of Watershed HydroGeo (2020).

Maximum predicted incremental Longwall 18 effects for watercourses within the study area are:

- LA2: up to 0.01 ML/d (relatively low because it lies directly above Longwall 17).
- LA3: <0.001 ML/d.
- WC12: up to 0.002 ML/d.
- WC15: up to 0.007 ML/d.
- ND1: 0.043-0.015 ML/d.
- Native Dog Creek: 0.06-0.23 ML/d.
- mid-Wongawilli Creek, including WC7: 0.01-0.04 ML/d.

Detailed assessment of the two watercourses most likely to be impacted by Longwall 18 (Native Dog Creek (including ND1) and Wongawilli Creek) is provided below.

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. Flow duration curves for the gauged site ND1S1 on ND1 and estimated flows on Native Dog Creek (which is not gauged) are presented on Figure 14 and Figure 15 respectively. A flow duration curve is presented in Figure 16 for WWL on Wongawilli Creek.

On each plot, the baseline flow duration curve is presented. The flow duration curves and associated discussion are based on gauged data, rather than on rainfall-runoff modelling as was used in previous SMP assessments. Where possible, the baseline is derived from data from 2008-2020 to provide a representative assessment. This baseline is presented as a heavy green line.

The range in predicted impacts from the groundwater modelling (Tables 7-4 and 7-5 of Watershed HydroGeo, 2020) for selected sites has then been applied for two cases:

- the predicted impacts as for Dendrobium Mine, simulated as all 'approved/proposed' longwalls [all historical Longwalls 1-16 plus Longwalls 17-23 and Longwall 18] (blue lines) and
- the simulated incremental effects of proposed Longwall 18 (orange-red lines).

The difference between one of the blue or red lines and the solid green line indicates the predicted impact or flow depletion at each site, based on the range in the groundwater modelling predictions.

Tributary ND1 (ND1S1)

Flow gauging has occurred at ND1 (also referred to as NDT1) since March-2019, with currently available data until June-2020. The pre-mining data record is 15-months long. The flow duration curve for this period is shown on Figure 14A (blue series). In order to make subsequent impact assessment more representative of long-term conditions, a synthetic series has been calculated from a reference site for the longer period 2008-2020 (green series). This synthetic series is less skewed towards the severe drought conditions that persisted for much of the ND1 gauged record.

Impact assessment for this tributary has been conducted by using the synthetic series to represent 'baseline' conditions (Figure 14B). The groundwater model predictions (Watershed Hydrogeo, 2020) of flow reduction for this watercourse are then applied to the baseline to illustrate potential effects of Longwall 18 (incremental) and Dendrobium as a whole.

The flow duration curves for ND1 (Figure 14B) indicate that:

- The groundwater model predicts that the effect of Longwall 18 (light and dark blue lines) would result in a decline in low-flows of between 0.04 and 0.15 ML/d. This would lead to an increase in the number of days with no-flows at ND1 (from approximately 8-10% of the time to approximately 30-52%), which is an additional 20-40% of the time. Based on recent analysis for End of Panel assessments, the increase in cease-to-flow frequency by 20% is considered more likely than a 40% increase.

- The predicted effects of Dendrobium as a whole (specifically of Area 3B) is approximately 0.06-0.22 ML/d (orange-red lines on Figure 14B). This could result in cease-to-flow conditions up to 33-61% of the time at ND1S1. An increase of approximately 22-25% (to about 33% of the time) is considered more likely based on analysis of field data in End of Panel assessments. The discrepancy is related to the conservatism imposed in the groundwater model configuration and predictions, as described in Section 3.2.

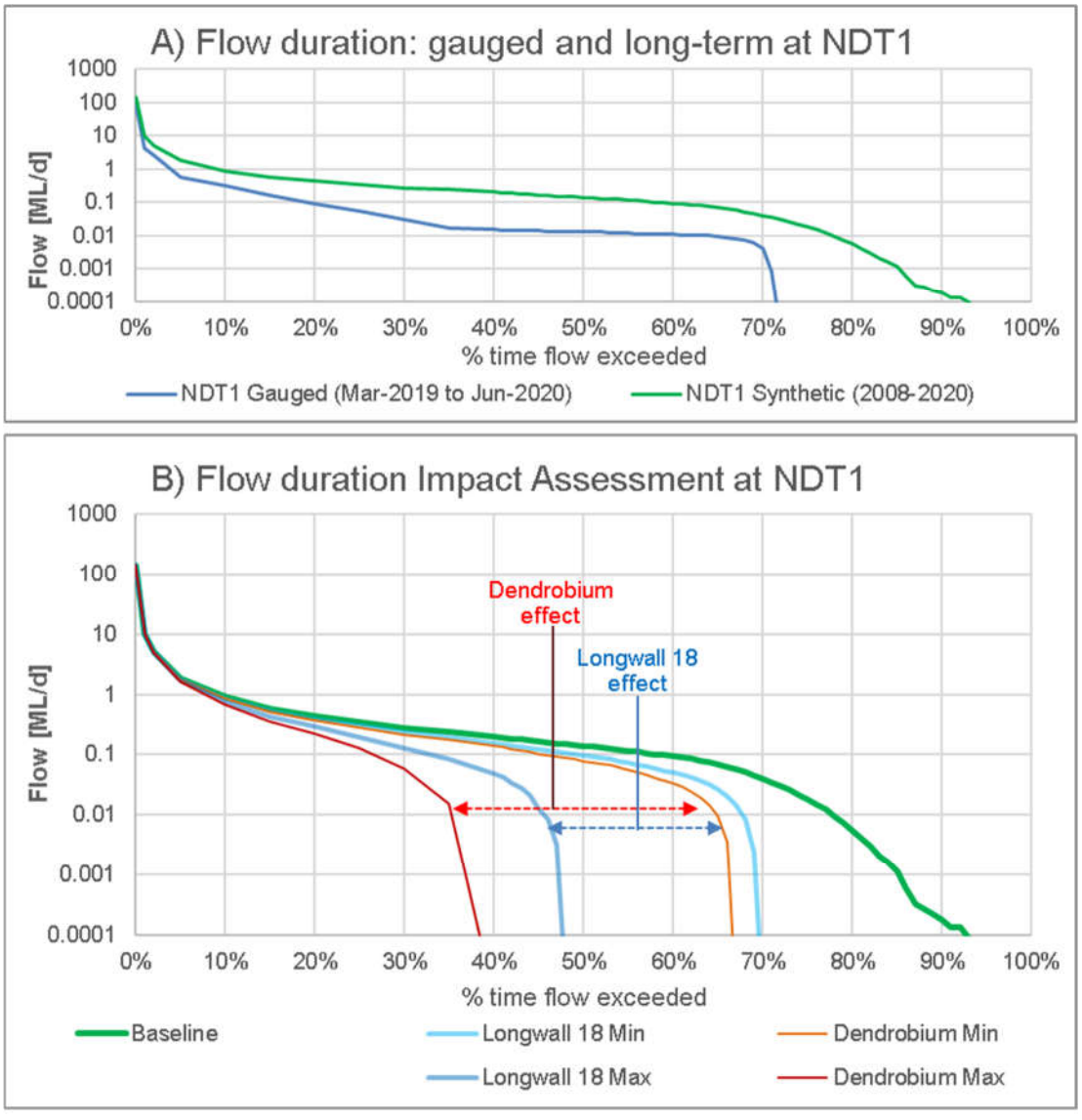


Figure 14 Flow duration curve for A) ND1S1 on Tributary ND1 and B) with predicted mining effects

Native Dog Creek at Lake Avon

There is no flow gauging undertaken on Native Dog Creek. It is known, based on field inspection, that historical longwall extraction at Elouera has affected the hydrology of Native Dog Creek, although the magnitude of that effect has not been quantified. In order to estimate the potential effects of Dendrobium and specifically of Longwall 18 on this watercourse, a synthetic series has been calculated from the gauged WWU (upper Wongawilli Creek) record and based on a comparison of catchment area (Figure 15A). The two creeks are comparable in terms of their hydrology, catchment size and likely historical effects of Elouera. The estimated flow series is calculated at or below the confluence with ND1, which meets Native Dog Creek just above the Lake Avon FSL.

Impact assessment for this tributary has been conducted by using the synthetic series to represent 'baseline' conditions. Noting that there is no gauging on this watercourse on which to accurately describe historical flow conditions, the flow duration curves for Native Dog Creek (Figure 15B) indicate that:

- The groundwater model predicts that the effect of Longwall 18 (light and dark blue lines on Figure 15B) would result in a decline in low-flows of between 0.06 and 0.23 ML/d. This would lead to an increase in the number of days with no-flows in Native Dog Creek from approximately 6% of the time to 20-39%), which is an additional 14-33% of the time. Based on recent analysis for End of Panel assessments, the increase in cease-to-flow frequency by 14% is considered more likely than a 33% increase.
- The predicted effect of Dendrobium as a whole (primarily Area 3B) is approximately 0.1-0.35 ML/d (orange-red lines on Figure 15B). This could result in cease-to-flow conditions up to 26-46% of the time at ND1S1, although an increase of approximately 20% (to about 26% of the time) is considered more likely based on analysis of field data at impacted sites.

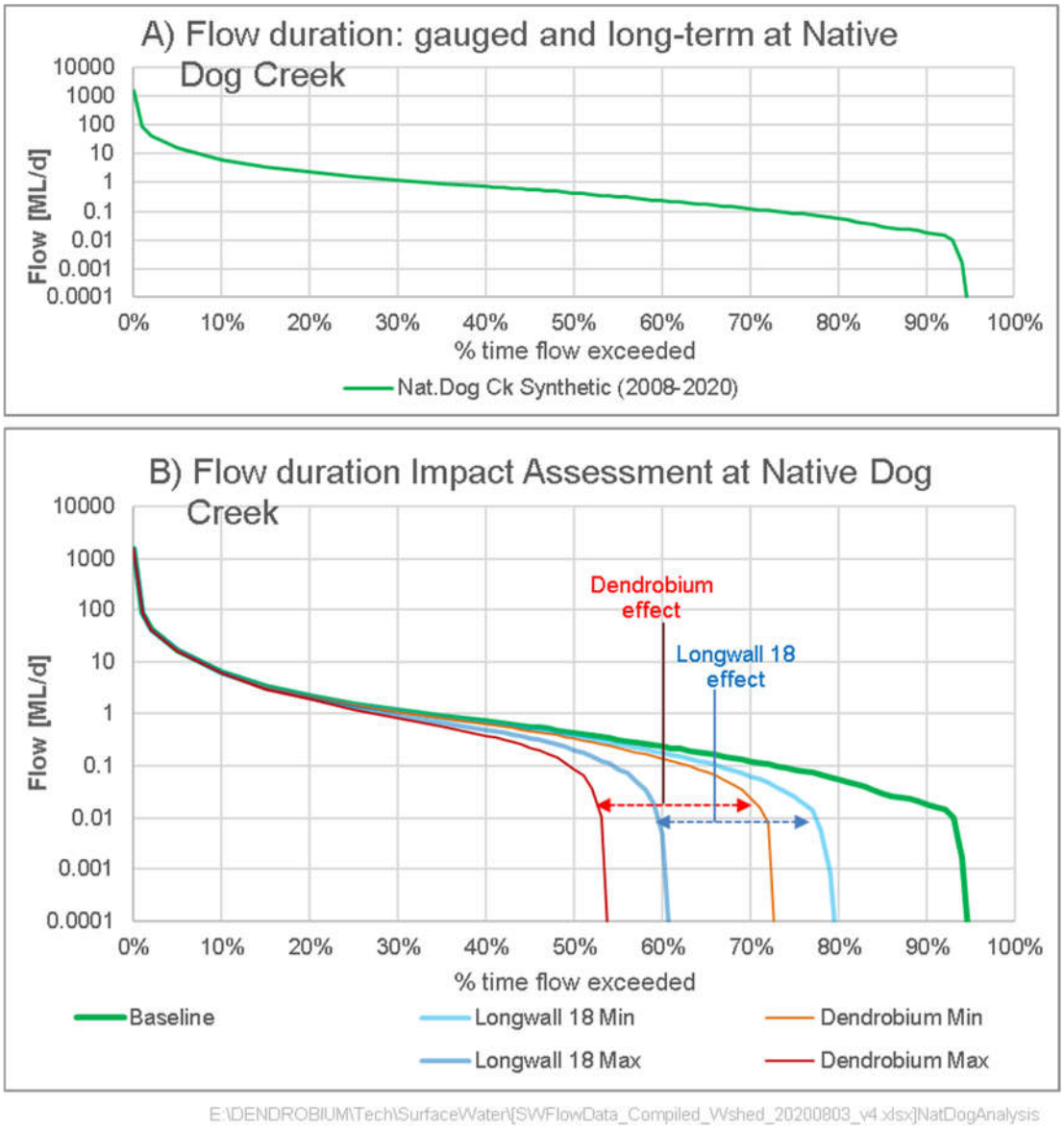


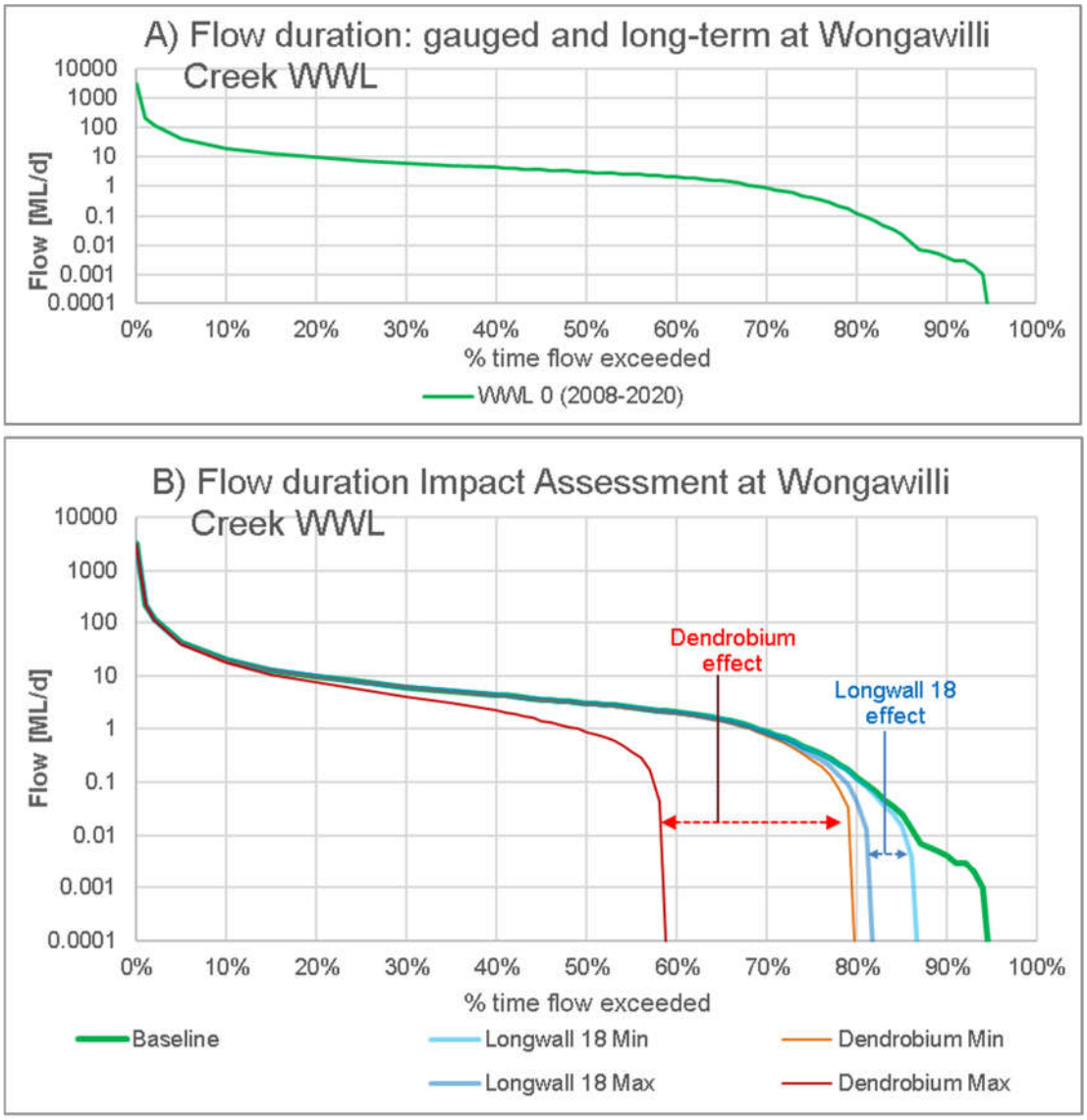
Figure 15 Flow duration curve for A) Native Dog Creek and B) with predicted mining effects

Wongawilli Creek (WWL)

The flow duration curves for WWL (Figure 16) indicate that:

- Baseline cease-to-flow frequency is approximately 6%, based on the green line on Figure 16 and the statistics in Table 4. Based on the analysis presented using recently-updated TARP assessments (Watershed HydroGeo, 2019; HGEO, 2020d), the effects of the historical Dendrobium mining at WWL have been less than predicted in previous groundwater modelling studies, and are within the scale of natural variability.
- The groundwater model predicts that the effect of Areas 3A and 3B longwalls would result in a significant decline in low-flows (blue lines on Figure 16B) and a significant increase in the number of days with no-flows at WWL (from about 5% of the time to 20-40%). As noted above, such a decline has not been observed to date.

- The predicted maximum incremental effect of Longwall 18 is up to 0.08 ML/d . This alone would result in cease-to-flow conditions occurring 14-18% of the time, although such an increase is again considered highly unlikely based on analysis of historical field data.



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Figure 16. 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 (HGEO, 2020b; 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 the position of Area 3A and 3B longwalls along each side of the 'middle' reach of Wongawilli Creek, where reductions in baseflow due to groundwater drawdown in the

near-surface strata (HBSS and CVSS 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 into early 2020.

Figure 17 shows a comparison of distance from each longwall to Wongawilli Creek and the 'frontage', which is a measure of the length of the nearest longwall edge to the creek. Comparing these two parameters, Longwall 18 has the lowest risk of effects on Wongawilli Creek compared to all other Area 3A, 3B and 3C longwalls. A comparison of the panel width/depth of cover (W/D) relationship indicates that same concept.

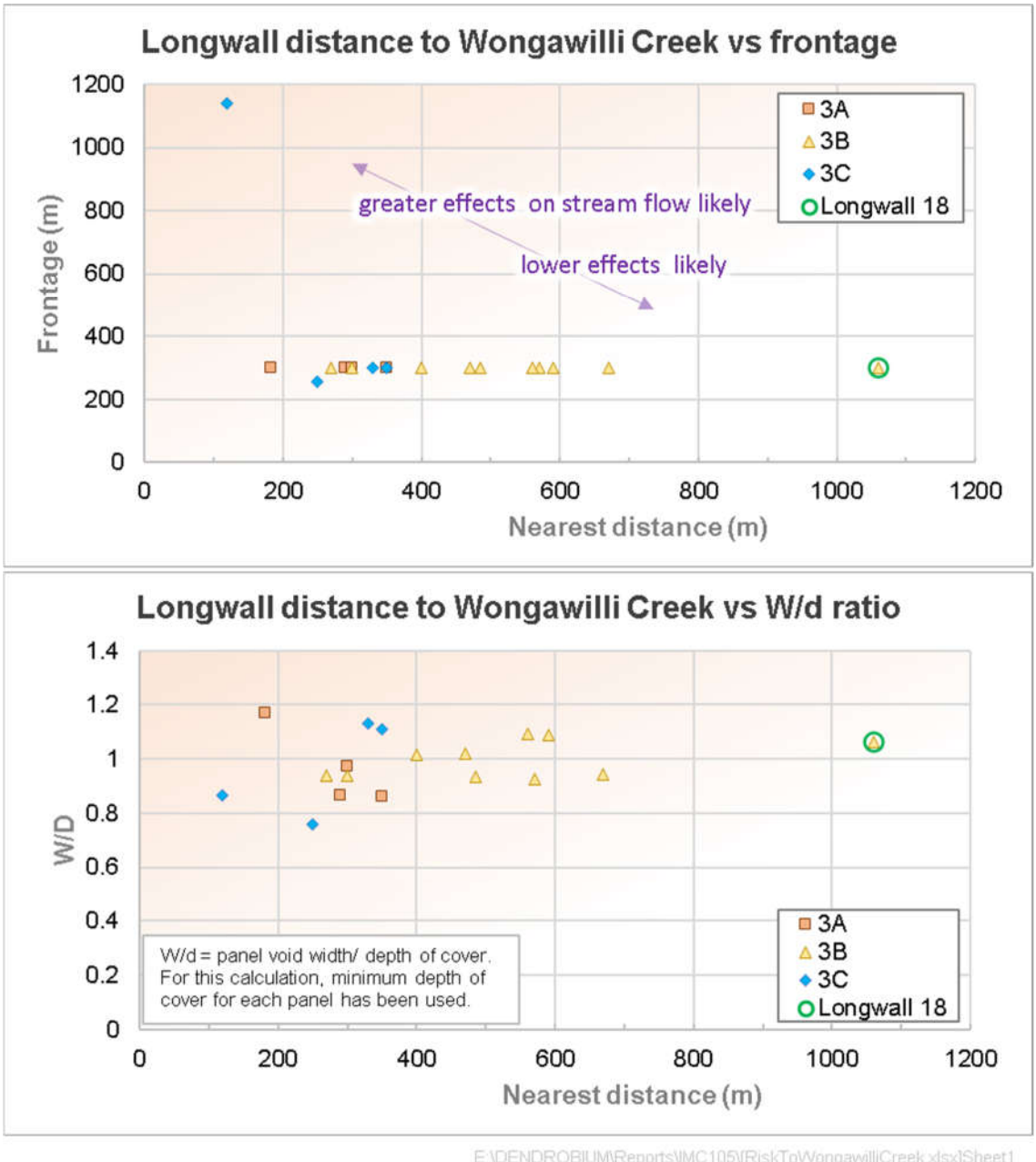


Figure 17. Relative impact risk to Wongawilli Creek

Groundwater modelling suggests that the cumulative flow reduction due to all Dendrobium longwalls in this reach would be in the order of 0.2-0.7 ML/d (moderate estimate of 0.3 ML/d) (more detail presented in Watershed HydroGeo, 2020). The predicted incremental effect of Longwall 18 is 0.01-

0.04 ML/d. Through time, the effect of Longwall 18 is only 2% of the cumulative effect of all Dendrobium longwalls. The groundwater model results are consistent with the analysis of depth and frontage and W/D presented above.

As a result, it is expected that Longwall 18 would cause an effectively negligible increase in the duration and length over which cease-to-flow conditions can occur in Wongawilli Creek during drought periods. The effect of this longwall would not be discernible from natural variability or from the effects of other historical, approved and proposed longwalls. The cumulative effect of Dendrobium longwalls, based on the groundwater modelling, could result in an increase in cease-to-flow days from approximately 10 % of the time (baseline, on average) to 27 % of the time at WWL. This is considered very conservative based on comparison of modelled and observed losses along Wongawilli Creek (Watershed Hydrogeo, 2020). Based on observed losses since the start of mining (HGEO, 2020d), it is considered more likely that cease to flow days may increase from 10 % (baseline) to ~13 % at WWL as a result of the cumulative effects of mining at Areas 3A and 3B.

4.5 Leakage from reservoirs

Watershed HydroGeo (2020) carried out several numerical modelling scenarios in which the permeability of strata between Area 3B and Lake Avon (and other incised valleys) were 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 Longwall 18 are shown in Table 9.

The estimated incremental leakage losses from Cordeaux Reservoir as a result of extraction of Longwall 18 is estimated to be nil, due to the distance from Longwall 18 to that reservoir. The incremental effect of Longwall 18 on leakage from Lake Avon is up to 0.13 ML/d (Table 9).

Table 9. Estimated leakage from reservoirs (Watershed HydroGeo, 2020)

Reservoir	Whole mine cumulative loss (ML/day)	Incremental loss due to Longwall 18 (ML/day)
Lake Avon	0.09 – 0.45 (mean 0.18)	0.01 – 0.13 (mean 0.04)
Lake Cordeaux	0.09 – 0.32 (mean 0.14)	<0.001

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.

Observed impacts to water quality from previous mining are summarised in Table 10, based on end of panel monitoring reports.

Table 10. 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.
	WWU4	Site is upstream of Dendrobium operations but downstream of Elouera Mine longwalls. Elouera Longwalls mined directly under the upper reaches of Wongawilli Creek from 1994 to 2001, and in 2007.	Increase in sulfate, Mn and Zn during 2007 following extraction of Elouera longwall Delta Longwall 17 (end 5/4/2007). Concentrations declined over following 10 years but remain slightly elevated as of 2020
WC15	WC15 Pool 2 and 9	WC15 mined under by Longwall 15 in late 2019 and approached within 35 m by Longwall 13 and 14 in April 2018, and Feb 2019. Resulted in reduction in stream flow and pool water levels	No obvious change in EC in downstream pools 2 and 9; Slight increase in Zn during Longwalls 14 and 15.
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 Longwall 7 from ~pH 5 to pH ~6 to 7. Fluctuating EC in some pools.
WC21	WC21 Pool 5	Watercourse and catchment mined under by Longwalls 9 to 15 (2013-2019). Reduction in stream low and drying of reaches directly mined under.	Increase in water pH and gradually increasing EC trend in downstream Pool 5 following Longwall 10 extraction. Transient increase in sulfate, Fe, Mn and Zn (longwalls 10 - 13)
Donalds Castle Creek	DCC Pool 19	Upper reaches of Donalds Castle Creek including Swamps 1b and 5 mined under by Longwalls 9, 10 and 11. Reduction in flow at DCS2 and DC13S1; reduction in pool levels.	Elevated EC conditions were observed in the upper tributaries of Donalds Castle Creek during 2018 and 2019. Accompanied by low DO and elevated sulfate, Zn and Mn.
SC10C	Pools 0, 1, 3, 4, 5, 7, 8, 9, 10, 11	Tributary crosses previously extracted Longwall 8. Decline in pool levels and/or drying of pool during or following Longwall 8.	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 Longwall 8. 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.
Native Dog Creek	NDC; several pools	Elouera Longwalls mined directly under NDC from 1994 to 2003 resulting in watercourse fracturing and flow diversion.	Iron staining in the creek bed and pools, most evident from above Elouera Longwall 7 (NDC_Pool25). Sharp transient increase in EC accompanied by low pH and DO in Pools 13, 20, 22 and 25 following Elouera Longwall 7 extraction. Effects including low pH (<4) appear to have recovered as of 2018 when monitoring resumed.

In summary, watercourses that have been directly mined under typically show one or more of the following water quality effects compared with baseline conditions:

- A transient increase in EC, evident at one or more monitoring sites, but not always detectable at downstream locations.
- An increase in water pH from baseline mildly acidic conditions to near neutral conditions. By contrast mining under Native Dog Creek by Elouera Longwalls resulted in a decrease in water pH which lasted several years.
- Transient increases in dissolved Fe and Mn (+/- Zn and Al) at sampling locations immediately down-stream of the affected area.

Water quality impacts have not been detected in watercourses that are not directly mined under.

Based on previous observations, it is expected that water quality influence due to the extraction of Longwall 18 would be minor or undetectable in stream reaches within subsidence affected areas (LA2, ND1 and NDC). Impacts may be observed in the first order tributary ND1C which crosses Longwall 18; however, those impacts are not expected to significantly influence water quality at the ND1 outlet. 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:

- 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.

Hydrological changes at swamps 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 (and increase in recession rate). 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.

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 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 11, with a qualitative assessment of the likelihood that the shallow groundwater regime will be affected by subsidence related ground movements associated with Longwall 18 (as described above). The likelihood is based on observations at swamps in Area 3B during and after longwall extraction (HGEO, 2020e; Watershed Hydrogeo, 2019b) and predictions of subsidence related to longwall extraction and other ground movement related to valley closure (MSEC, 2020a).

Table 11. Summary of predicted impacts to Upland Swamps

Swamp	Area (ha)	Distance from LW18 goaf (m)	% Area within 60 m of Longwall	Maximum predicted vertical ground movement (mm; MSEC, 2020)			Likelihood of shallow groundwater effects
				Subsidence	Valley related closure	Tilt (mm/m)	
14	1.93	280	-	2850	400	25	Previously impacted
35a	1.09	0	98%	225	200	8	Likely
35b	1.02	90	-	20	425	<0.5	Possible
149	1.42	0	15%	3000	N/A	25	Likely will be impacted by Longwall 17
150	3.15	235	-	<20	50	<0.5	Unlikely
151	3.98	330	-	<20	40	<0.5	Unlikely

Given their proximity to the proposed longwall panel, it is likely that shallow groundwater levels will be affected at Swamp 35a and Swamp 149 (15% within 60 m of the goaf footprint). Swamp 14 directly overlies previously extracted Longwall 15 and currently active Longwall 16. Shallow groundwater at Swamp 14 was impacted following the passage of Longwall 15 triggering a level 2 TARP (HGEO,

2020b). It is possible that impacts to shallow groundwater may occur in Swamp 35b, located 90 m from Longwall 18 and in the base of the ND1 valley. 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, 2020a).

A NW-trending surface lineament intersects both Longwall 18 and Swamp 150. The lineament is derived from air photo and/or digital elevation analysis and is one of several NW-trending lineaments that cross or pass to the west of Longwall 18. Given the distance of Swamp 150 from Longwall 18 (235+ m) and its location on the ridge opposite the longwall impact is considered unlikely.

5. PERFORMANCE MEASURES

The performance measures and monitoring of surface water and shallow groundwater in relation to mining at Area 3B are defined in the Area 3B SMP (South32, 2020). The TARP (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 3B SMP, including sites upstream and downstream of the proposed Longwall 18. Therefore, the existing TARPs are considered generally applicable to future monitoring and management of mining effects related to Longwall 18. 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 current SMP for Area 3B. Monitoring should continue at existing sites as specified in the Area 3B SMP.

The monitoring network was recently extended to include additional monitoring locations along ND1 which flows adjacent to and within 400 m of the proposed Longwall 18. Those locations are included in Figure 1.

5.2 Swamp monitoring

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. Shallow groundwater and soil moisture within Swamps 35a, 35b and 14 are currently monitored at three sites within the study area for Longwall 18, forming part of the existing Area 3B SMP.

In addition to the existing active monitoring sites, it is recommended that IMC consider installation of additional shallow piezometers and paired soil moisture sensor arrays within **Swamps 149, 150 and 151** (see Figure 2). All three areas of swamp vegetation are located on the upper slopes within the headwaters of minor tributaries. Based on groundwater levels in nearby piezometers, they are not dependent on the regional water table within the HBSS and are likely sustained by shallow perched groundwater at the soil-sandstone interface.

Due to the small size and disconnected nature of the swamps it is recommended that a single monitoring piezometer should be installed at each swamp. The piezometers should be located as close as possible to the down-stream outlet of the swamp and close to the main channel within the thickest accumulation of sediments. The exact location and construction details of the installation will need to be confirmed in the field by an appropriately qualified and experienced specialist. 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.

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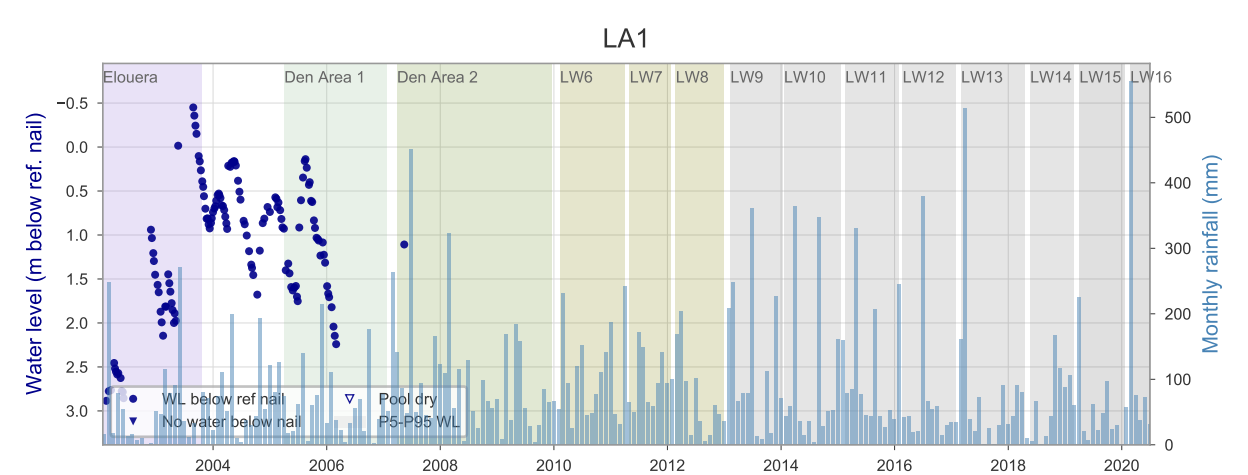
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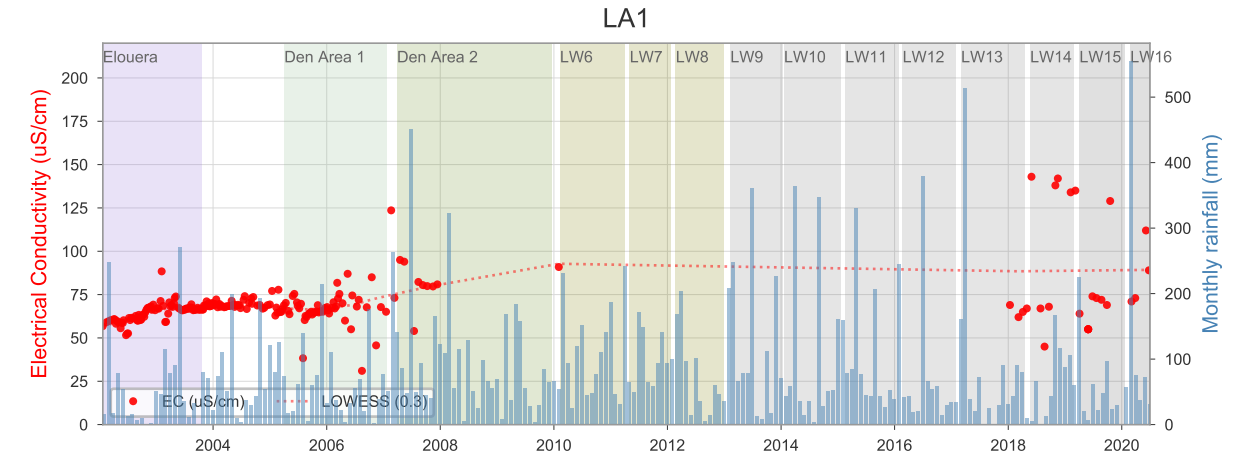
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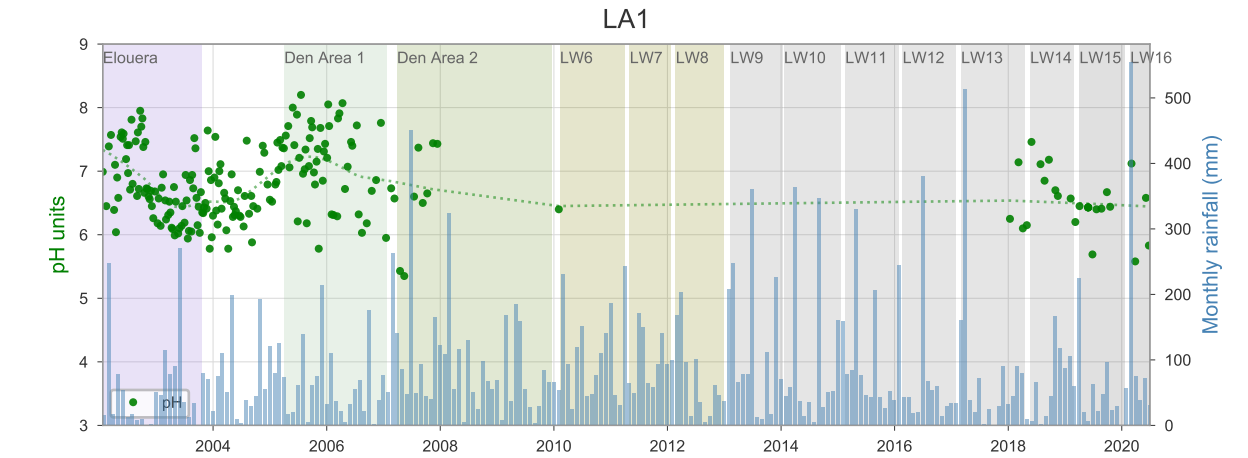
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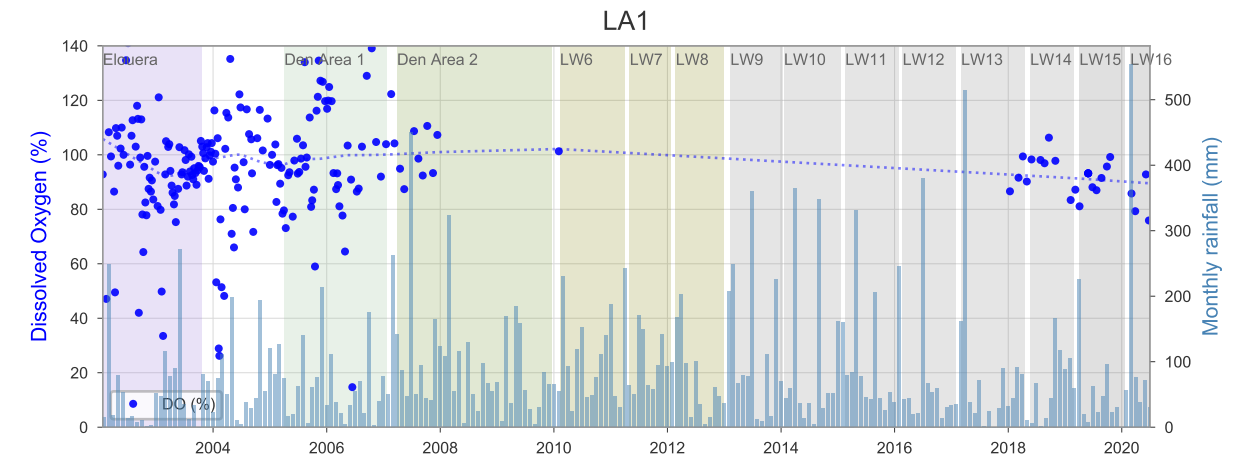
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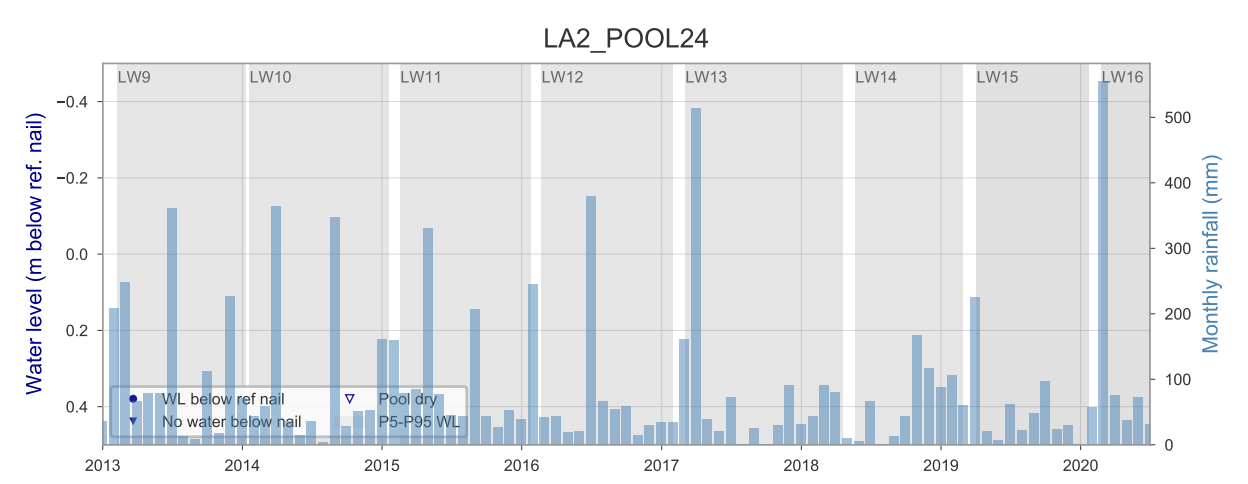
APPENDIX I – Surface water chemistry time-series

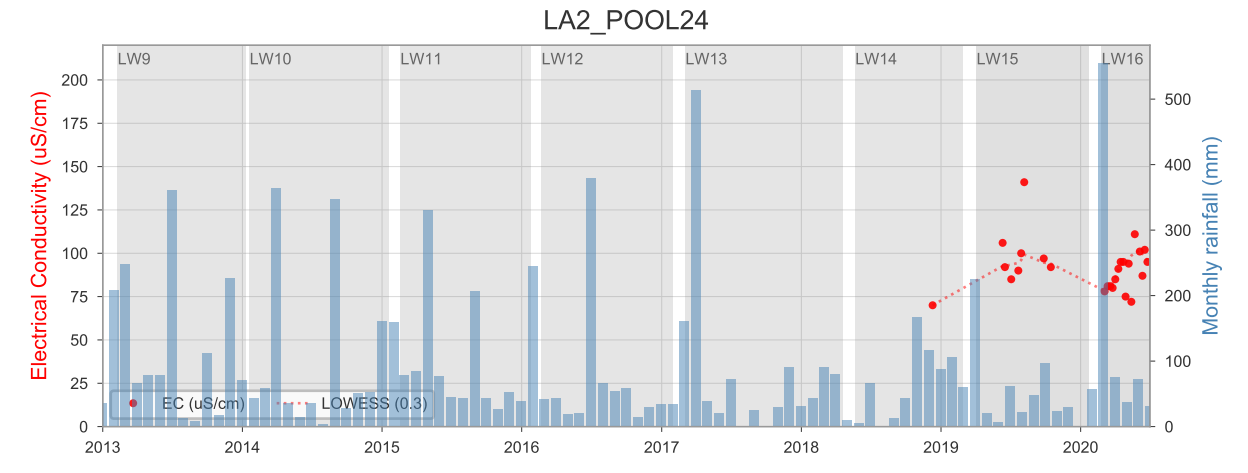

LA1
Water level (m below ref. nail)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
WL below ref nail
No water below nail
Pool dry
P5-P95 WL

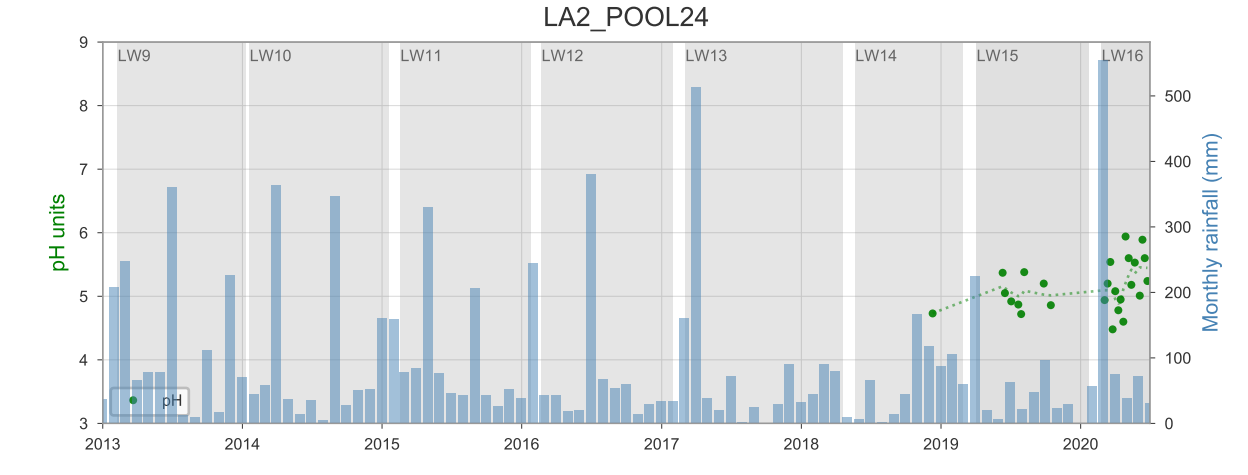

LA1
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
EC (uS/cm)
LOWESS (0.3)

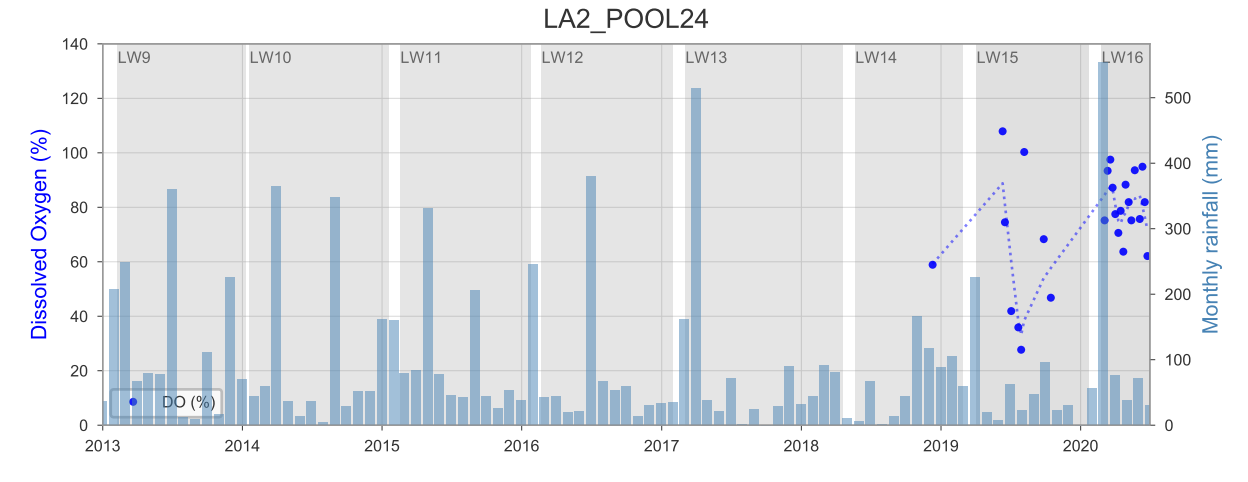

LA1
pH units
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH

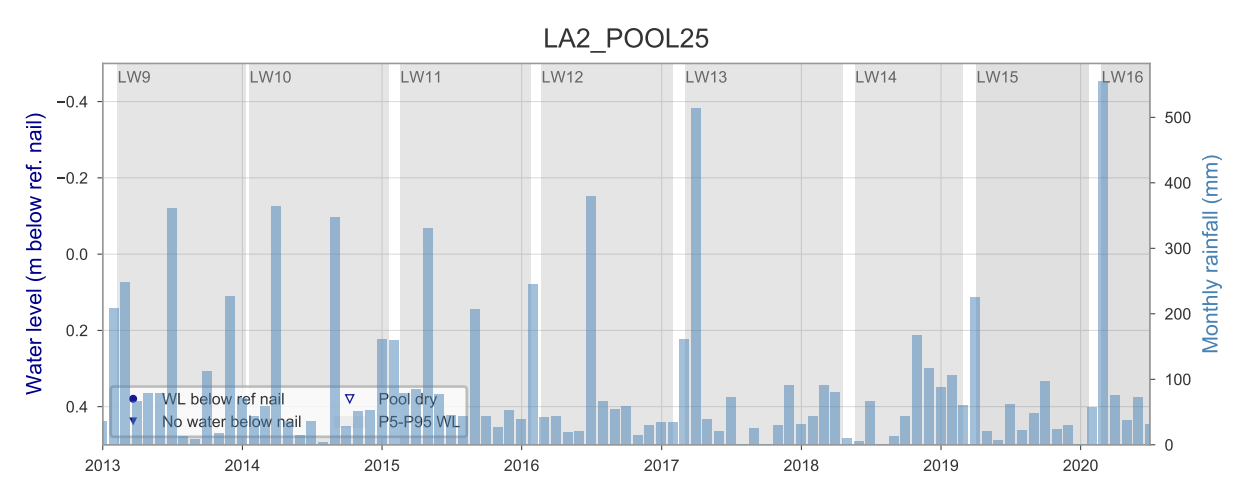

LA1
Dissolved Oxygen (%)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
DO (%)

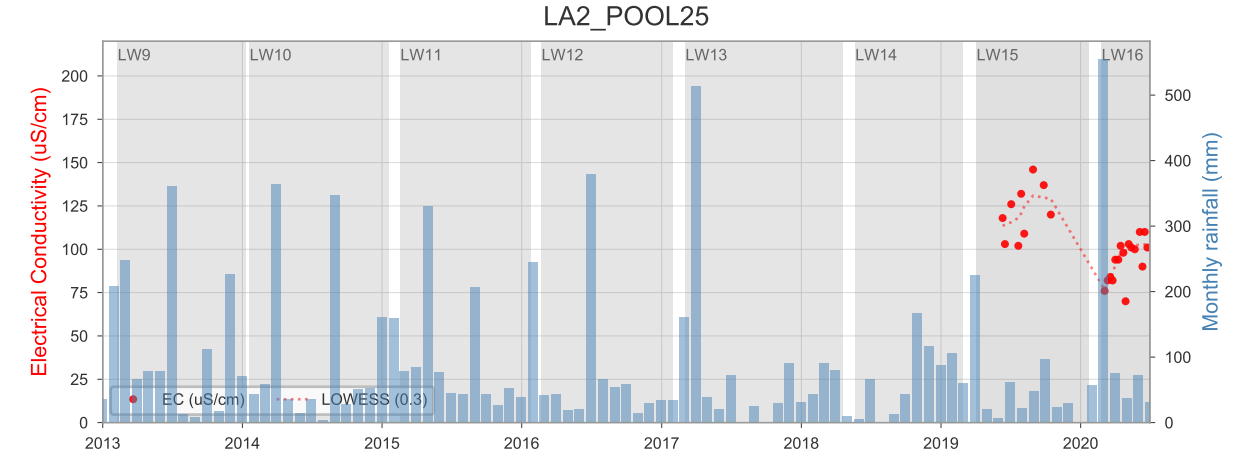

LA2_POOL24
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2013
2014
2015
2016
2017
2018
2019
2020

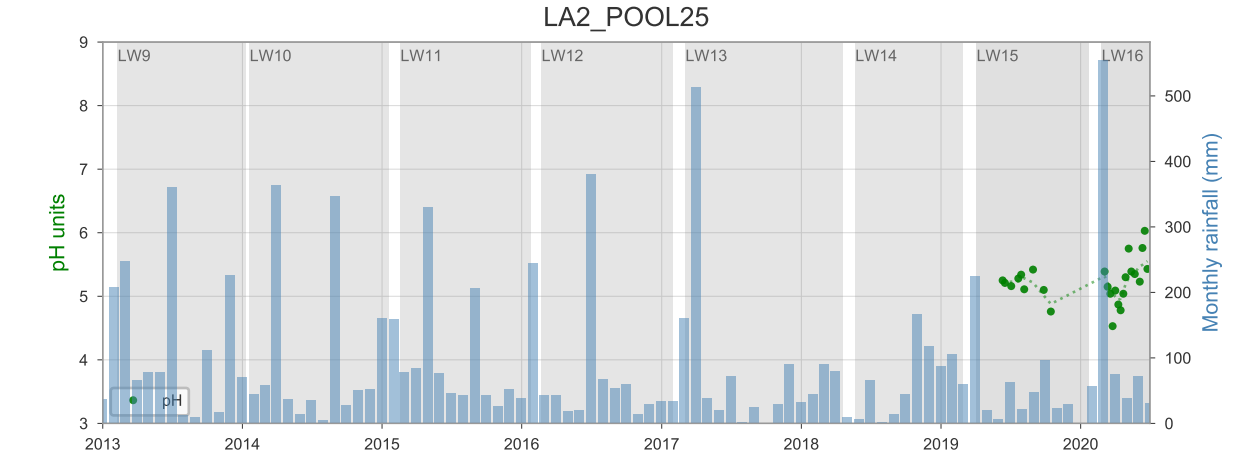

LA2_POOL24
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
2013
2014
2015
2016
2017
2018
2019
2020

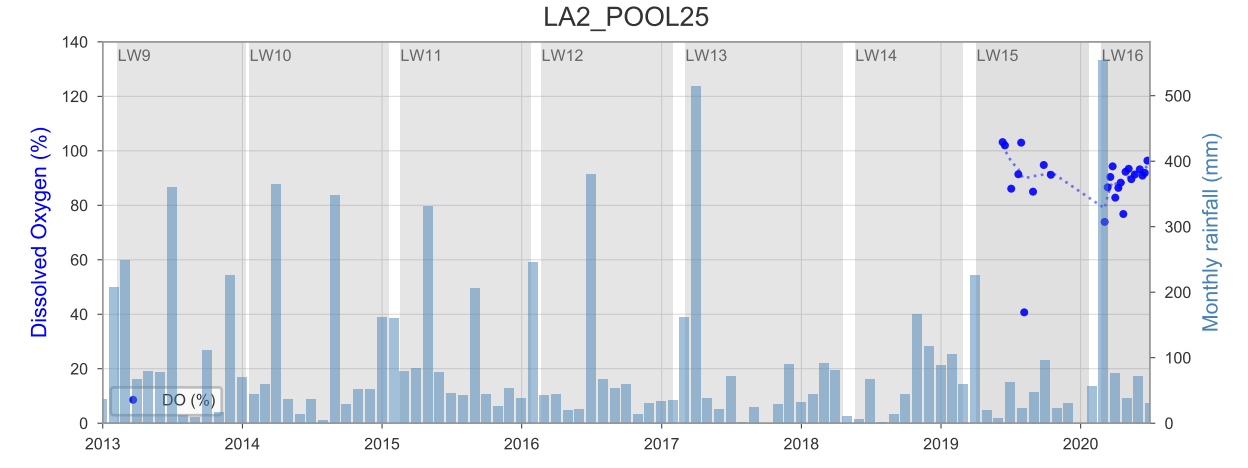

LA2_POOL24
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH
2013
2014
2015
2016
2017
2018
2019
2020

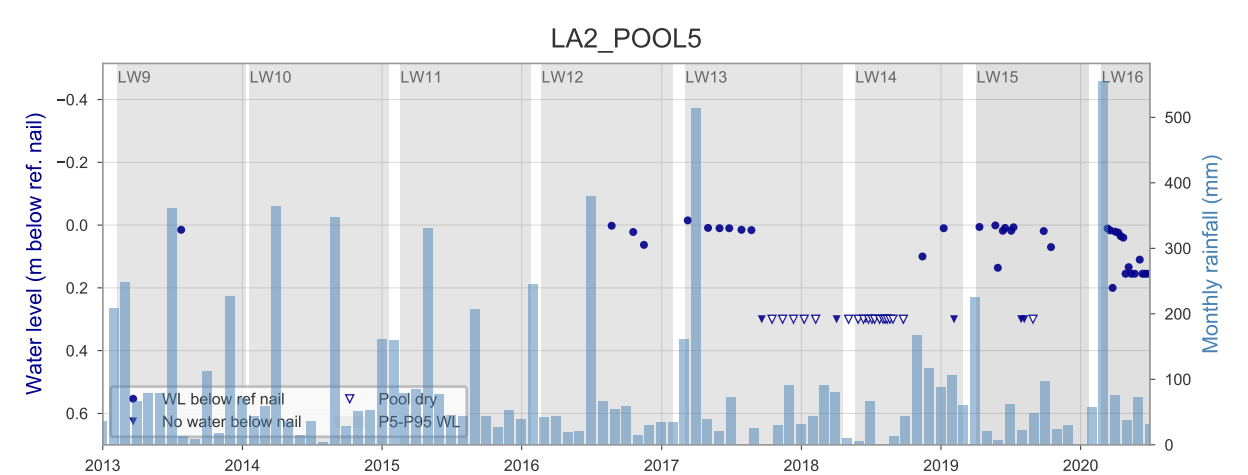

LA2_POOL24
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
2013
2014
2015
2016
2017
2018
2019
2020

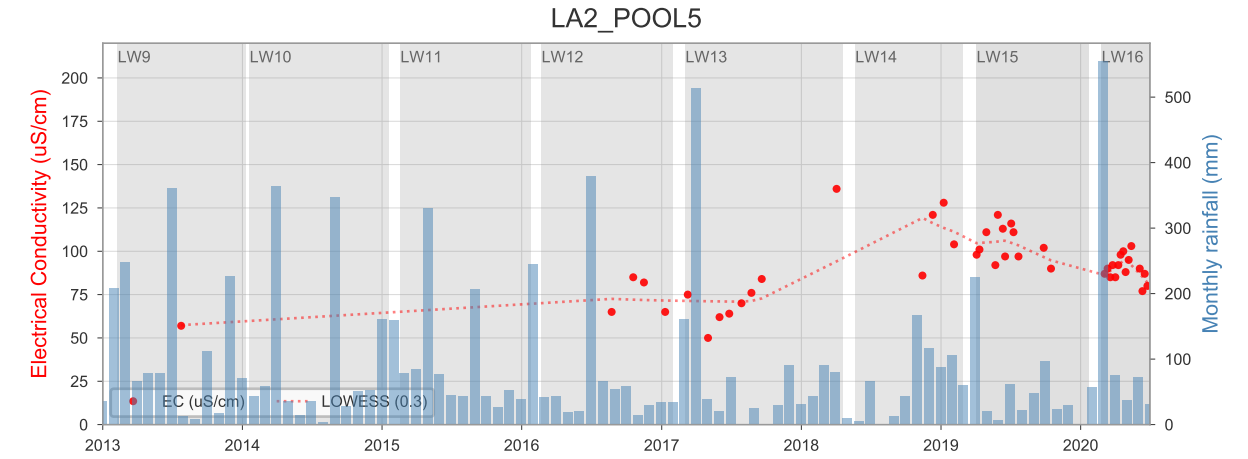

LA2_POOL25
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2013
2014
2015
2016
2017
2018
2019
2020

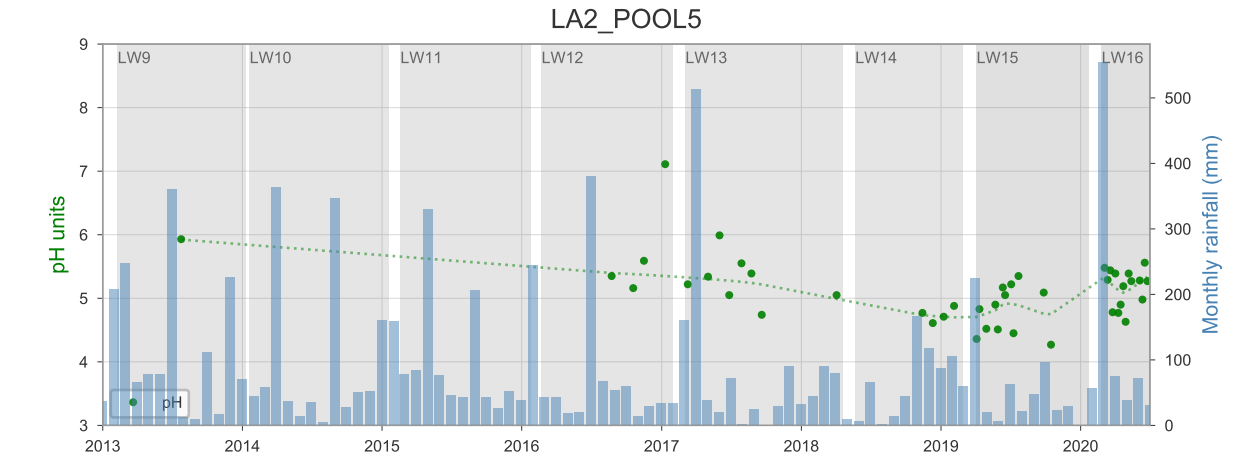

LA2_POOL25
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
2013
2014
2015
2016
2017
2018
2019
2020

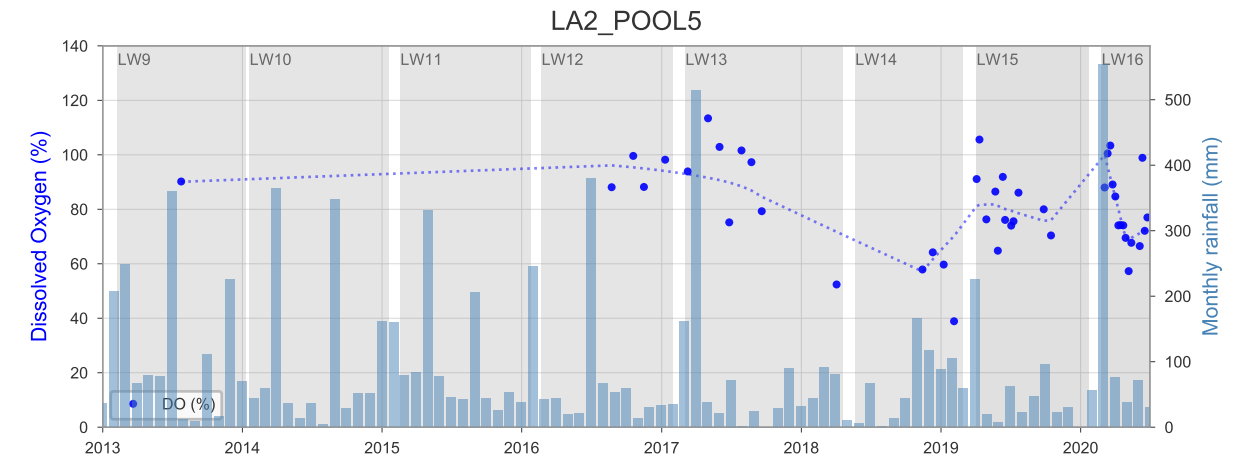

LA2_POOL25
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH
2013
2014
2015
2016
2017
2018
2019
2020

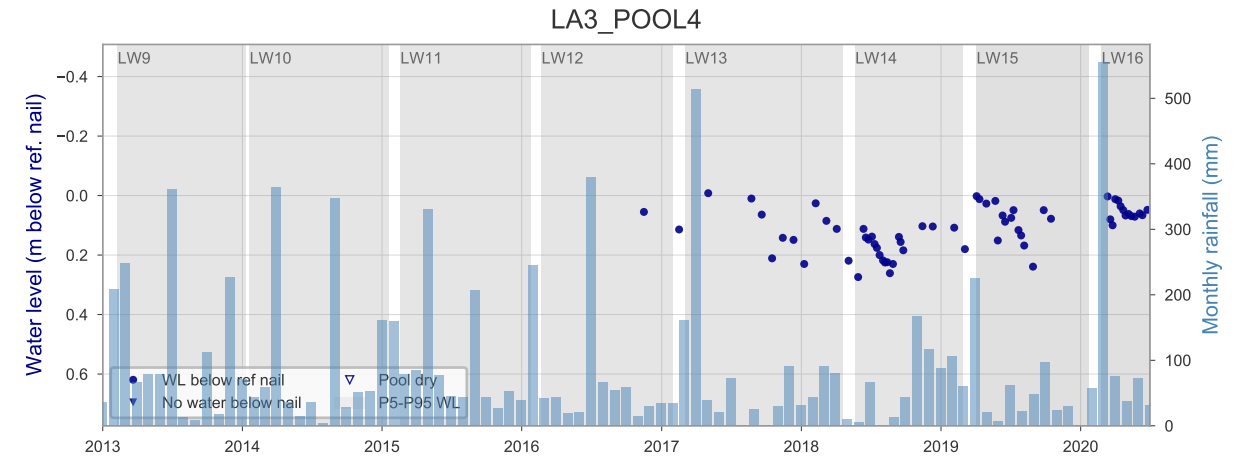

LA2_POOL25
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
2013
2014
2015
2016
2017
2018
2019
2020

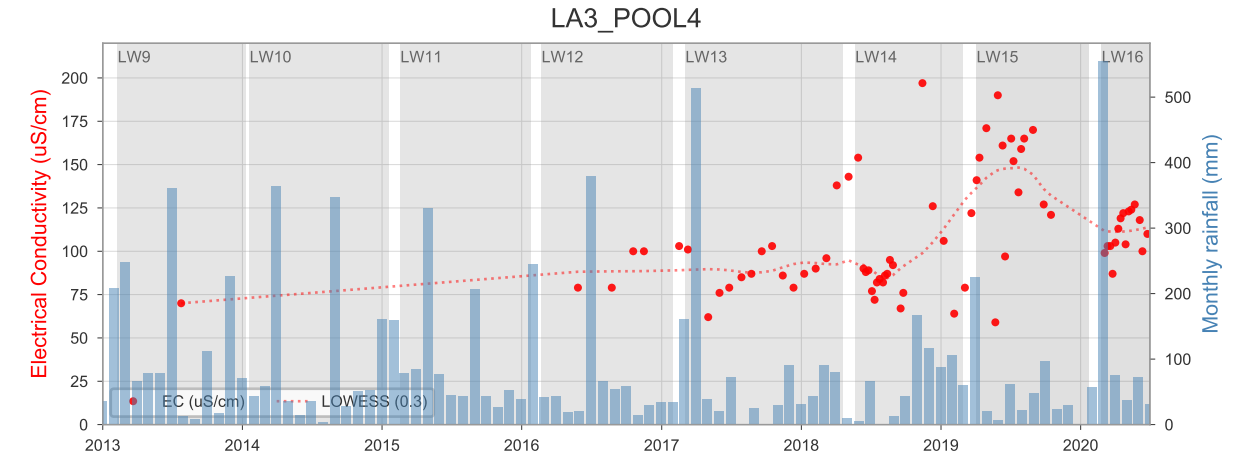

LA2_POOL5
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2013
2014
2015
2016
2017
2018
2019
2020

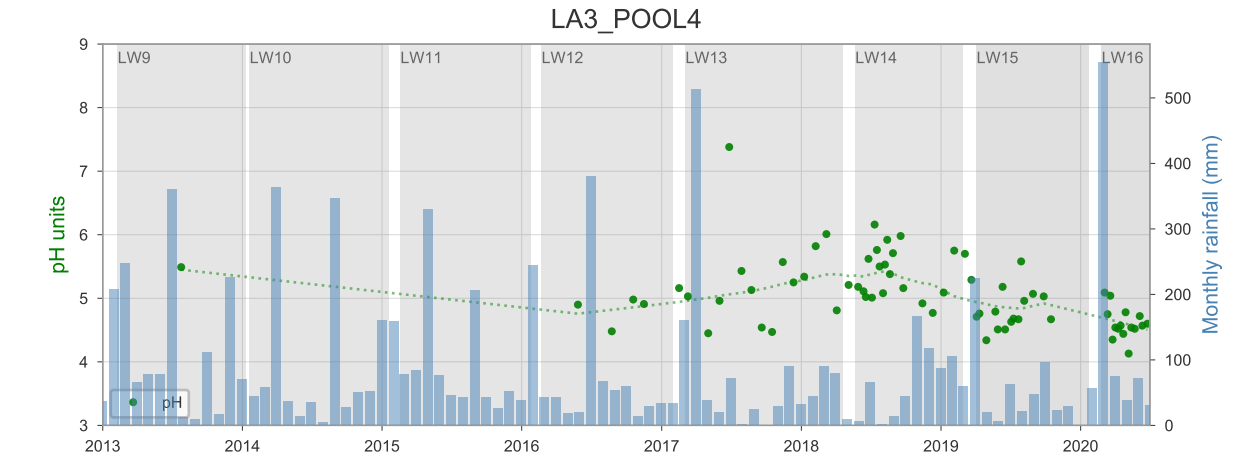

LA2_POOL5
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
2013
2014
2015
2016
2017
2018
2019
2020

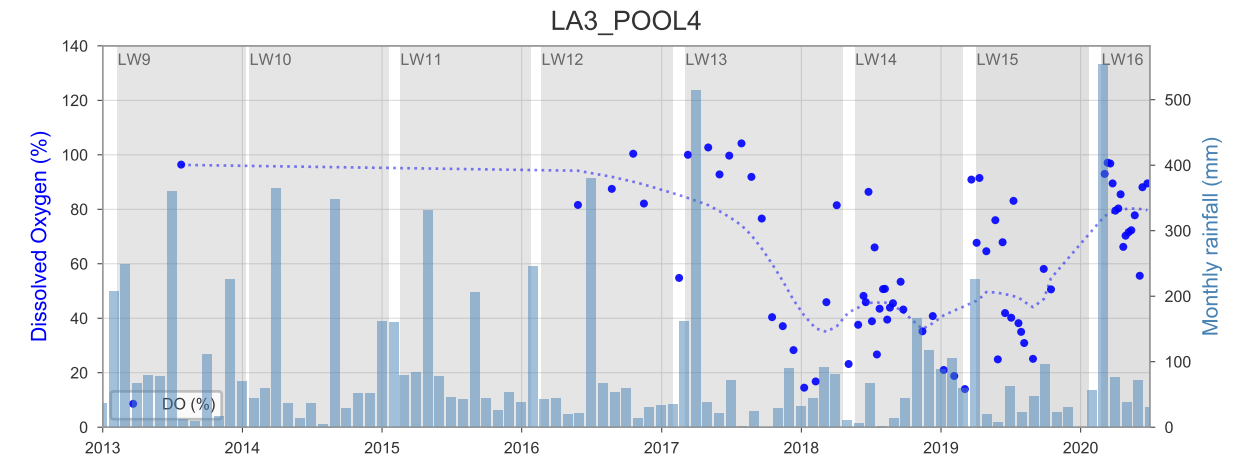

LA2_POOL5
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH
2013
2014
2015
2016
2017
2018
2019
2020

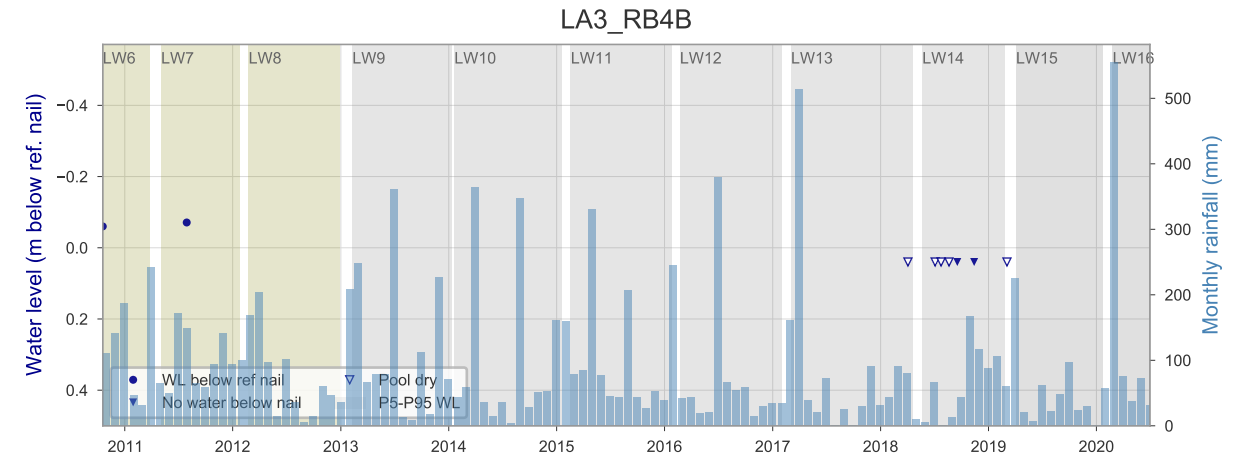

LA2_POOL5
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
2013
2014
2015
2016
2017
2018
2019
2020

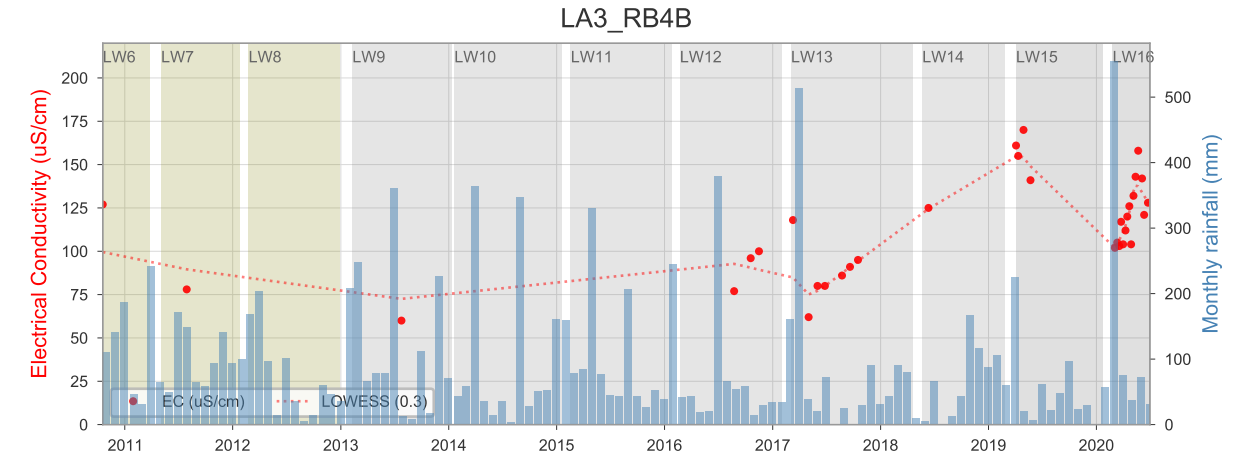

LA3_POOL4
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2013
2014
2015
2016
2017
2018
2019
2020

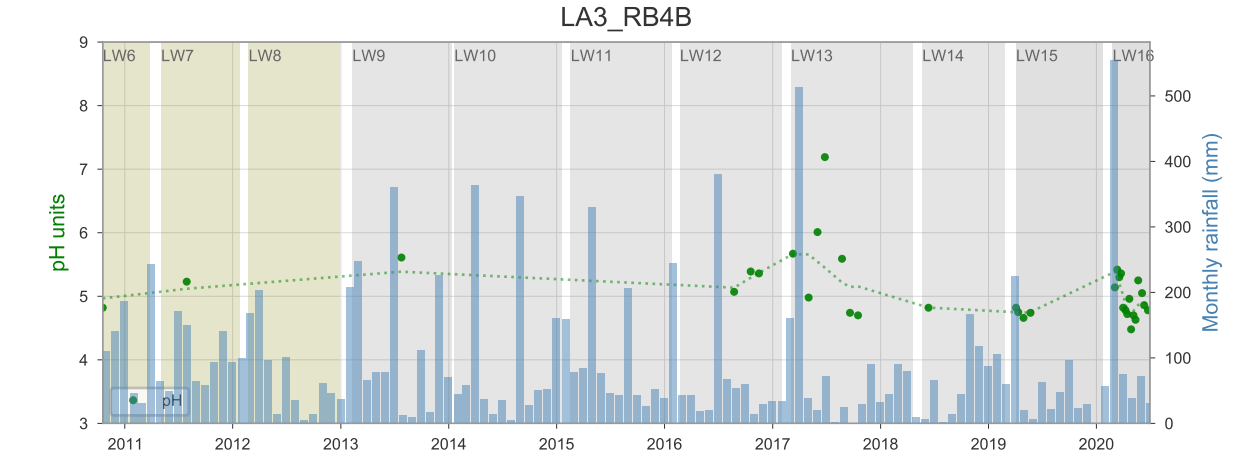

LA3_POOL4
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
2013
2014
2015
2016
2017
2018
2019
2020

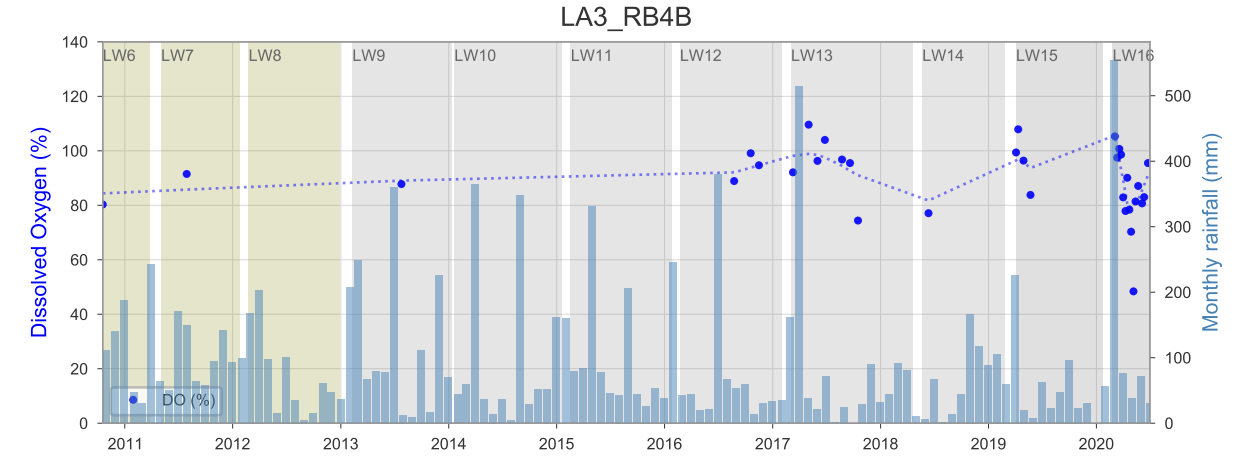

LA3_POOL4
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH
2013
2014
2015
2016
2017
2018
2019
2020

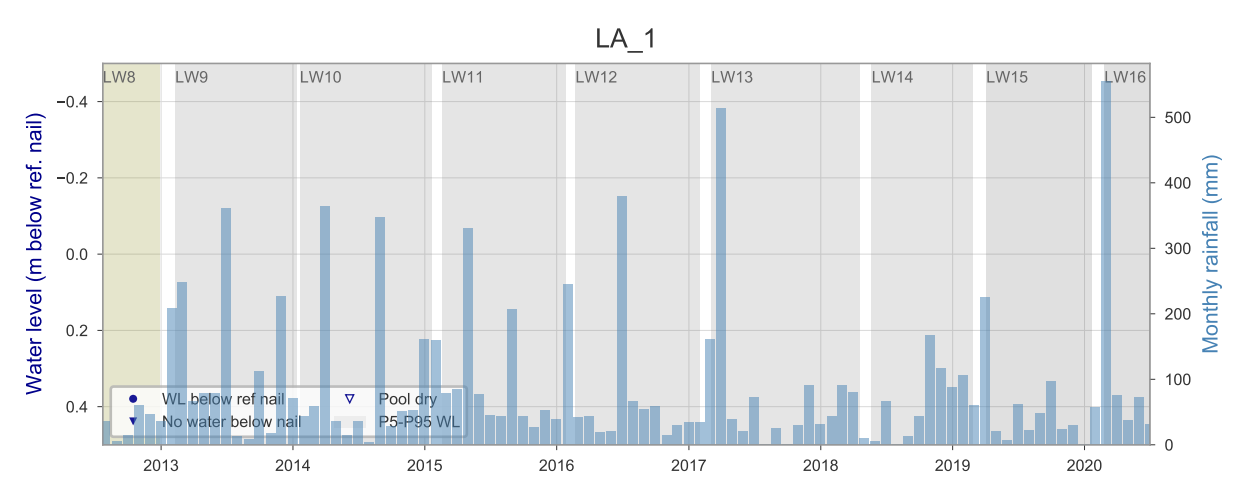

LA3_POOL4
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
2013
2014
2015
2016
2017
2018
2019
2020

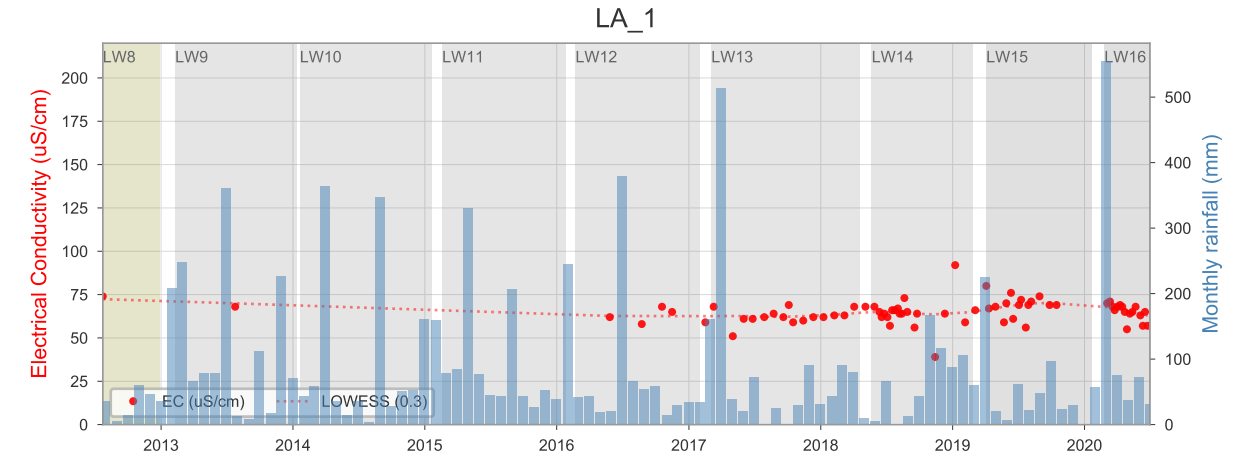

LA3_RB4B
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

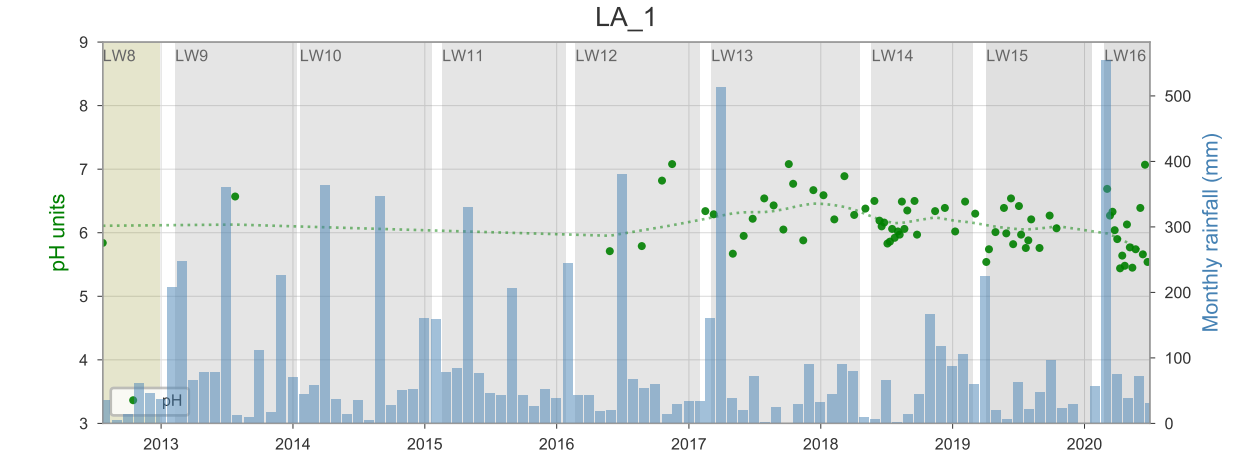

LA3_RB4B
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

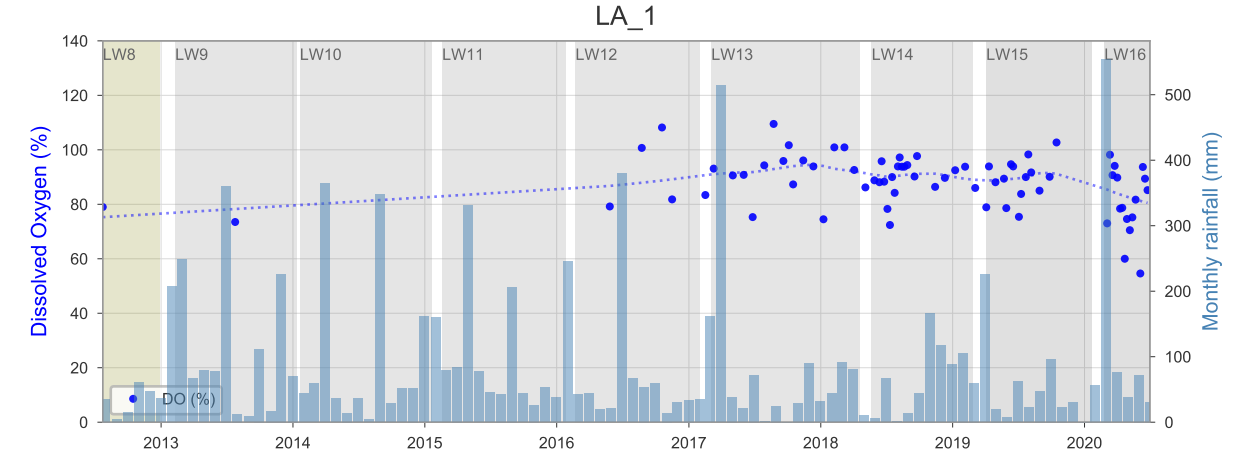

LA3_RB4B
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

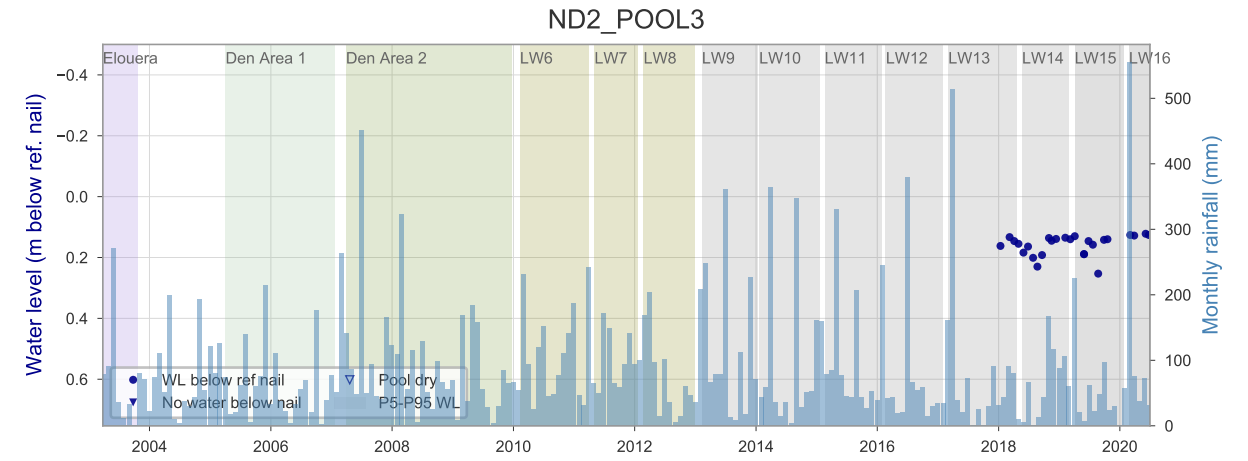

LA3_RB4B
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

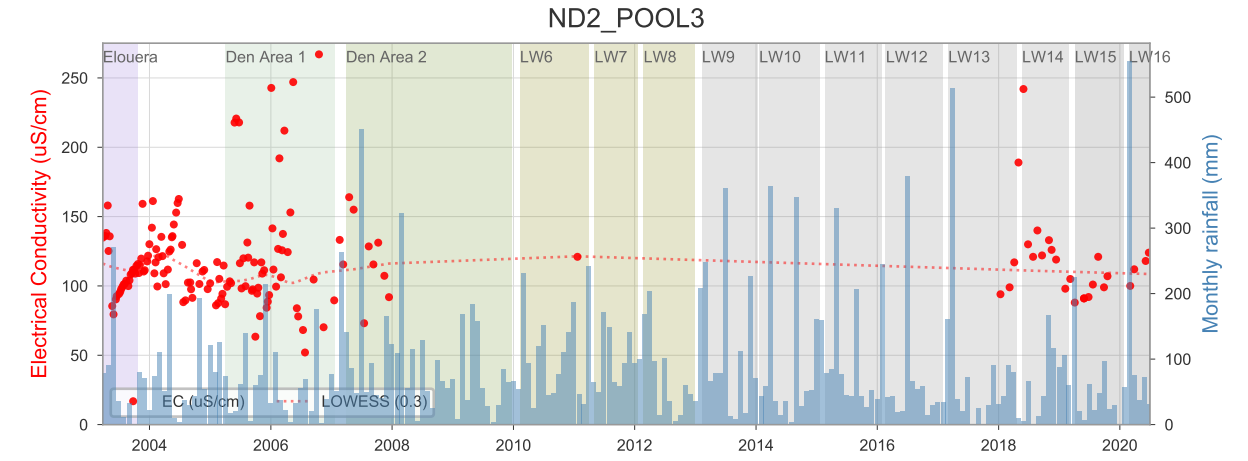

LA_1
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2013
2014
2015
2016
2017
2018
2019
2020

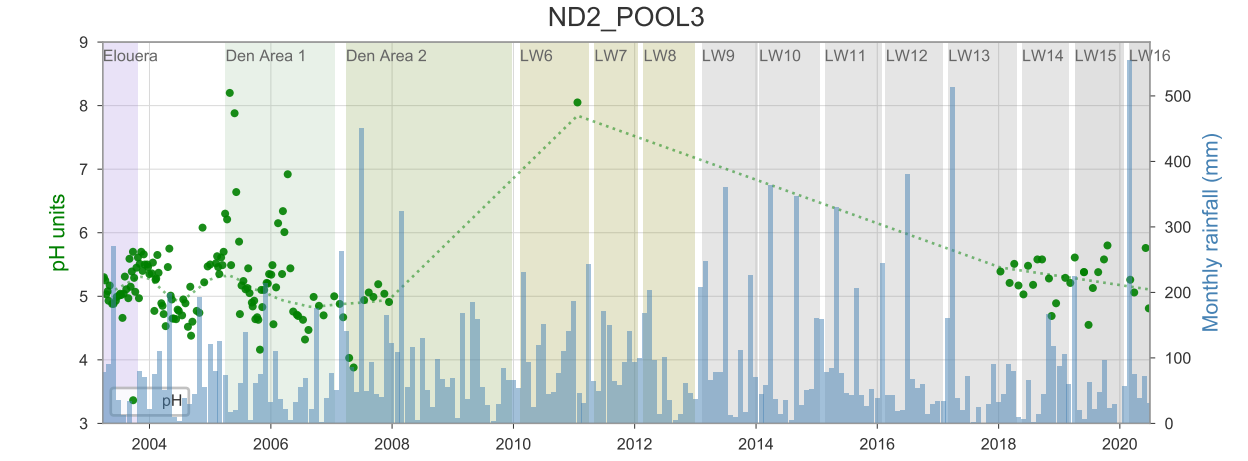

LA_1
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
2013
2014
2015
2016
2017
2018
2019
2020

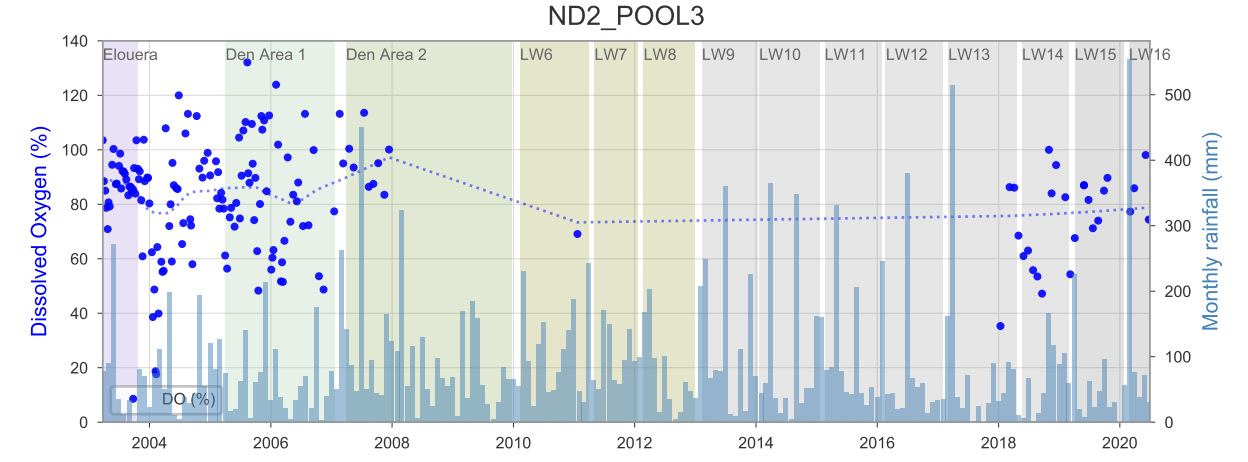

LA_1
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH
2013
2014
2015
2016
2017
2018
2019
2020

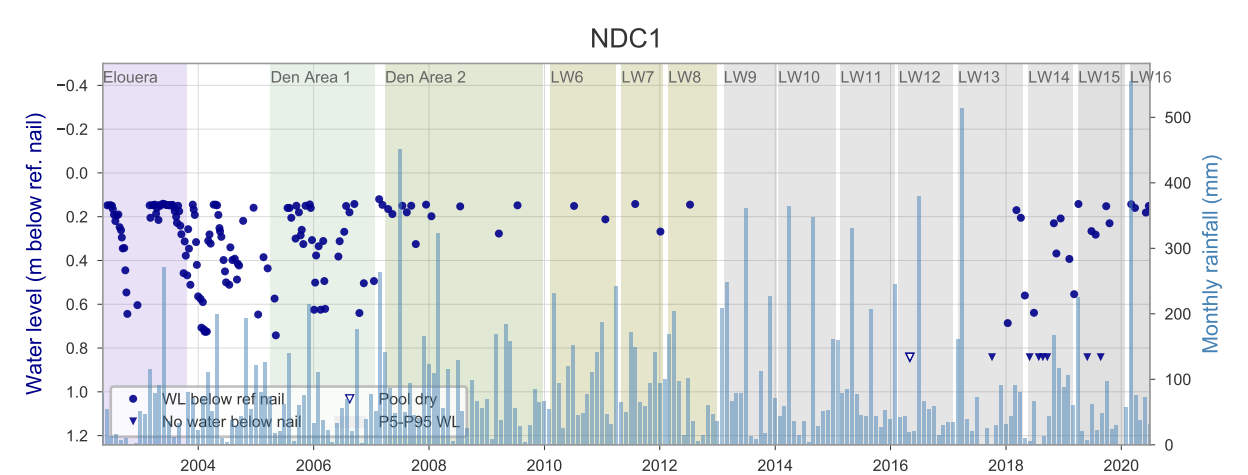

LA_1
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
2013
2014
2015
2016
2017
2018
2019
2020

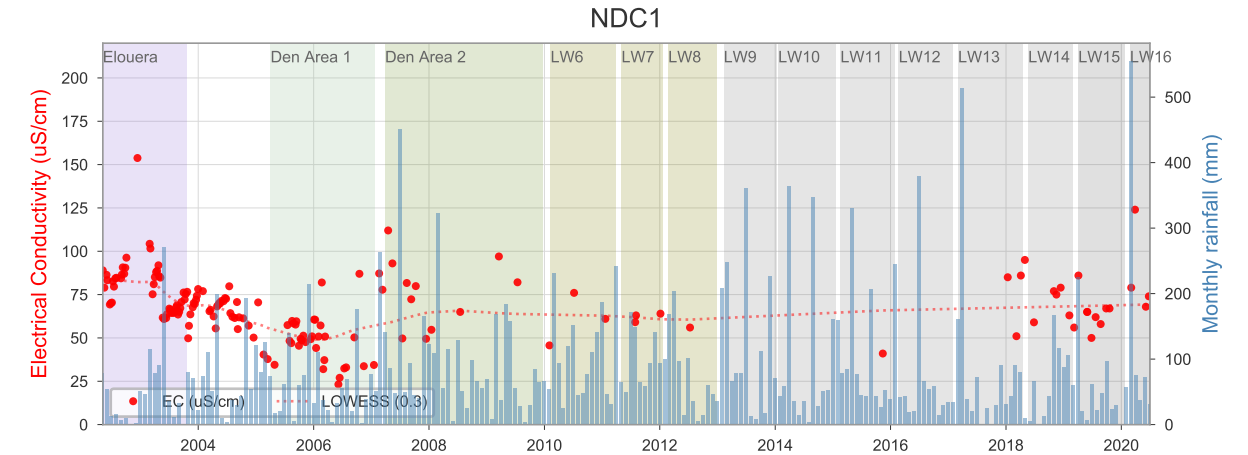

ND2_POOL3
Water level (m below ref. nail)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2004
2006
2008
2010
2012
2014
2016
2018
2020

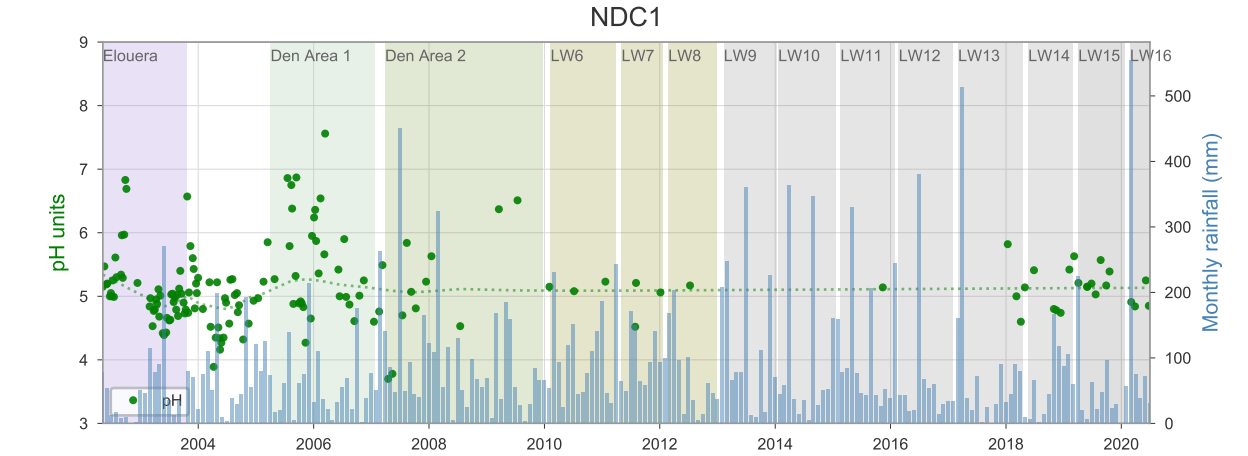

ND2_POOL3
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
EC (uS/cm)
LOWESS (0.3)
2004
2006
2008
2010
2012
2014
2016
2018
2020

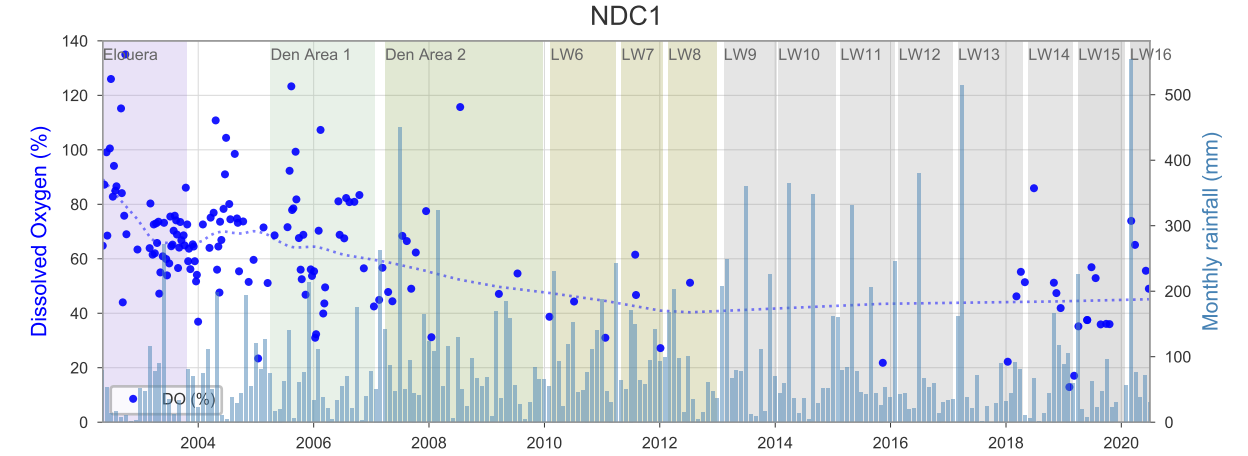

ND2_POOL3
pH units
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH
2004
2006
2008
2010
2012
2014
2016
2018
2020

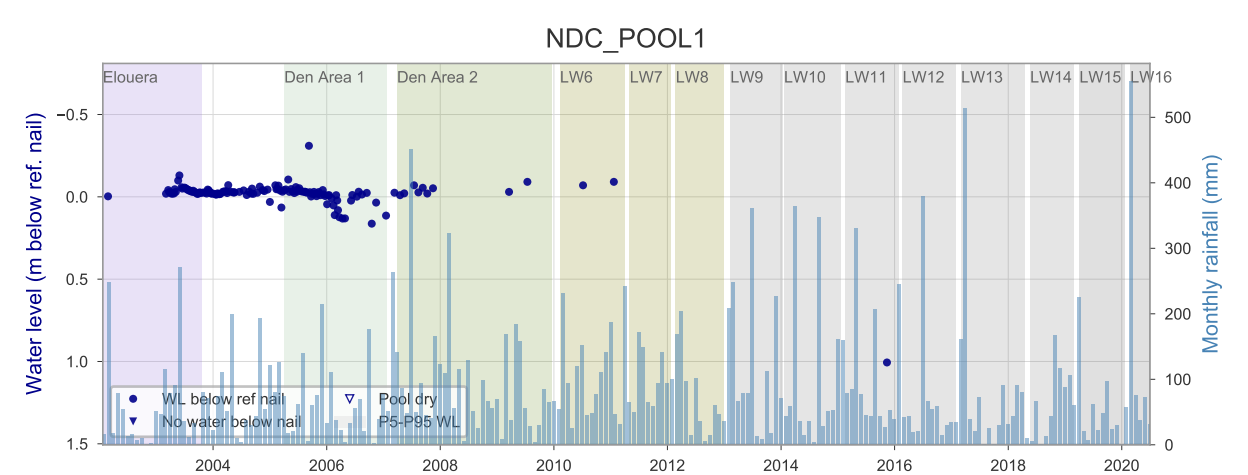

ND2_POOL3
Dissolved Oxygen (%)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
DO (%)
2004
2006
2008
2010
2012
2014
2016
2018
2020

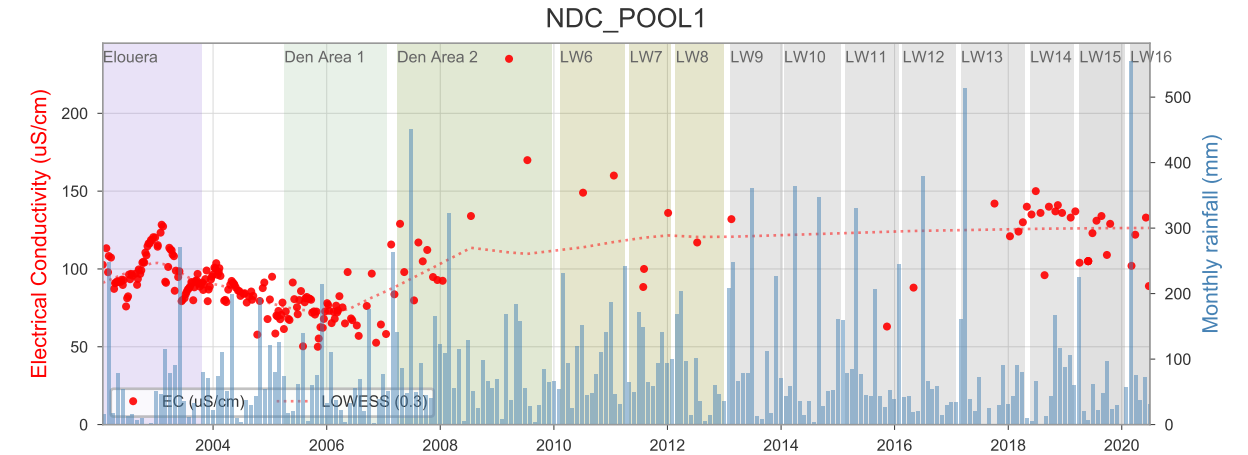

NDC1
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL

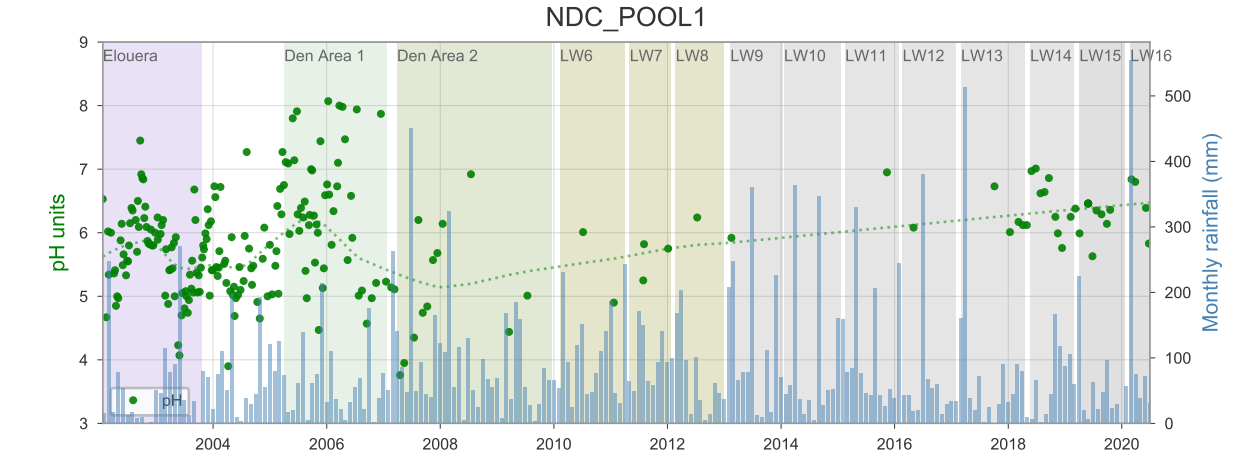

NDC1
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)

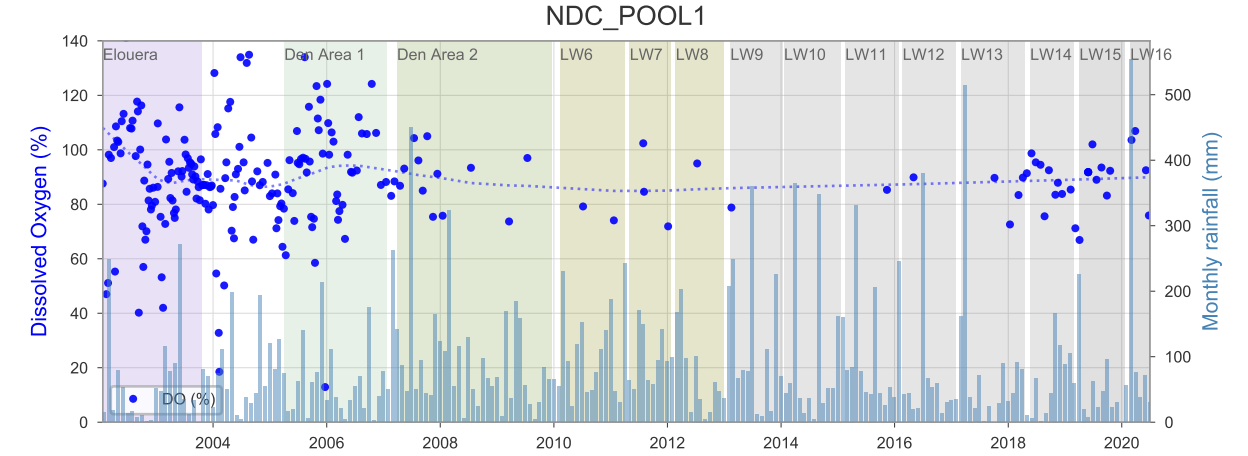

NDC1
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH

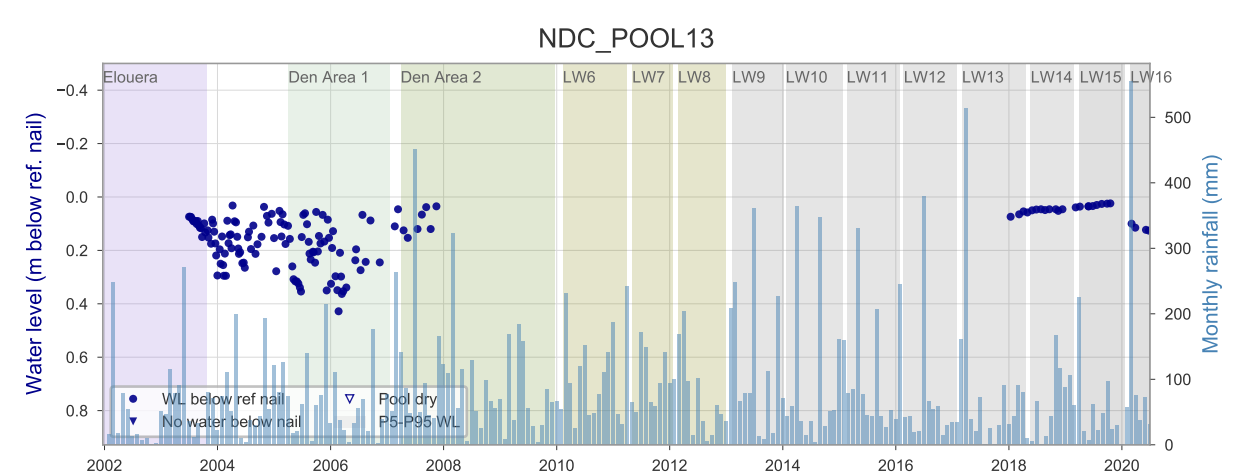

NDC1
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)

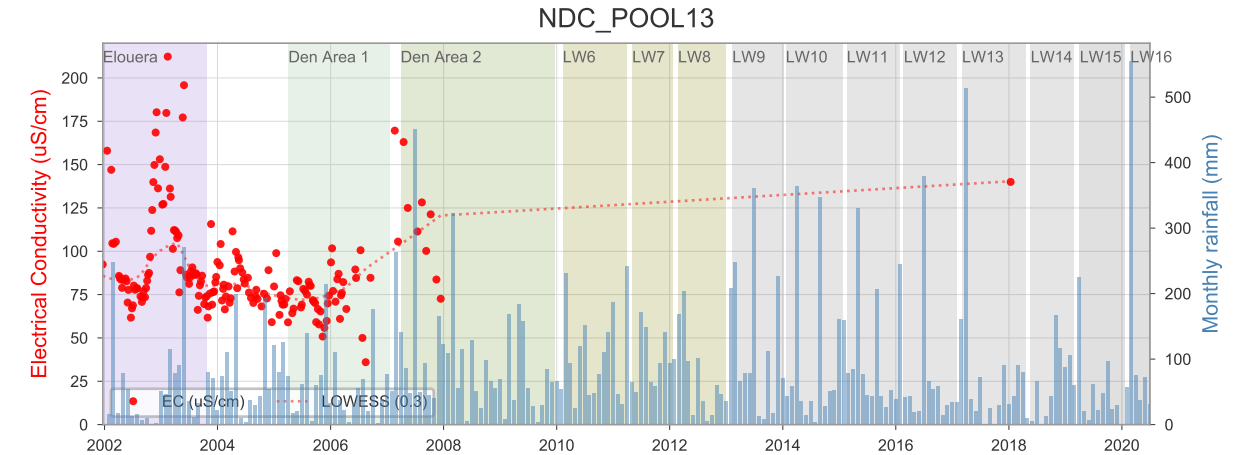

NDC_POOL1
Water level (m below ref. nail)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
WL below ref nail
No water below nail
Pool dry
P5-P95 WL

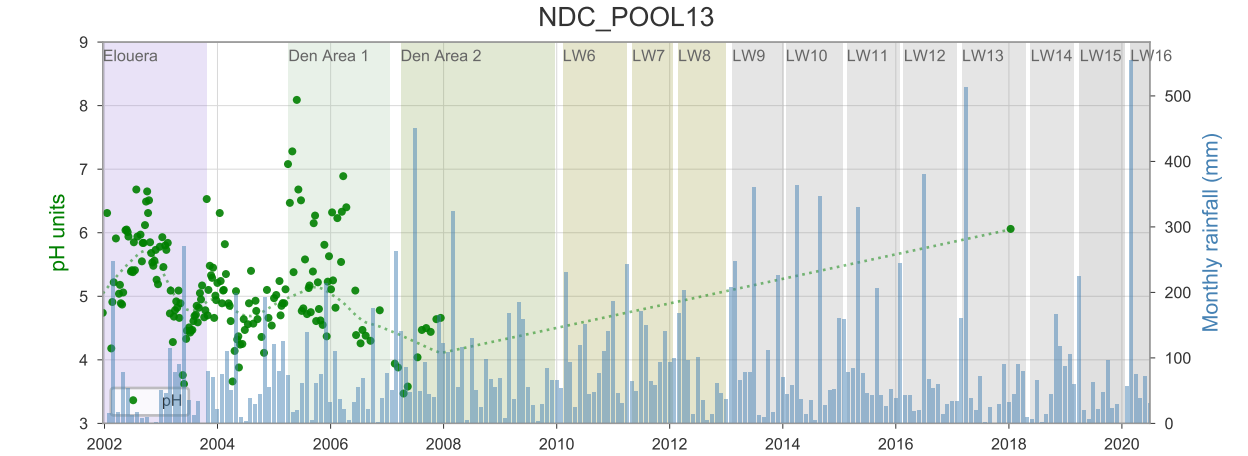

NDC_POOL1
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
EC (uS/cm)
LOWESS (0.3)

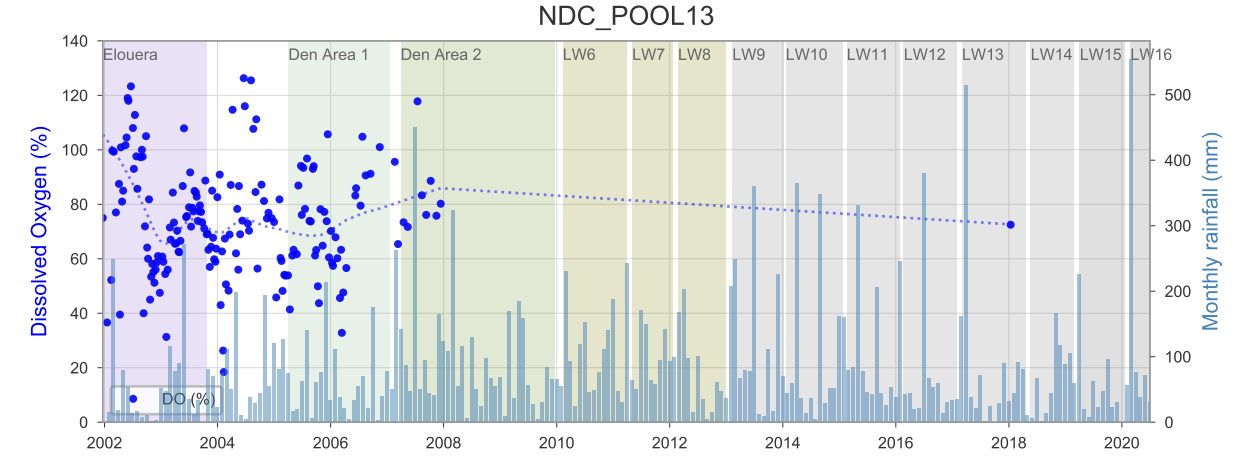

NDC_POOL1
pH units
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH

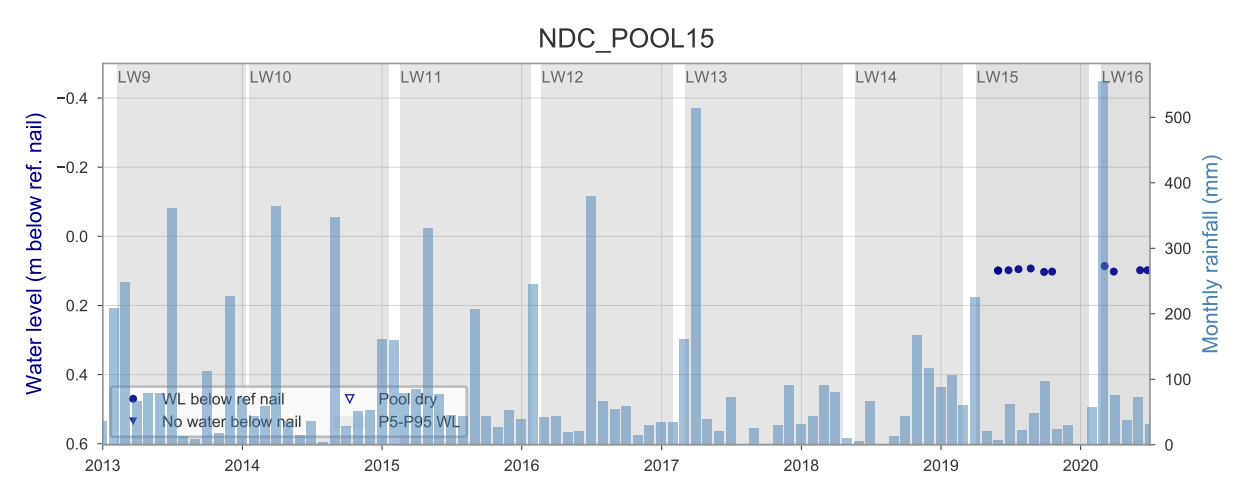

NDC_POOL1
Dissolved Oxygen (%)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
DO (%)

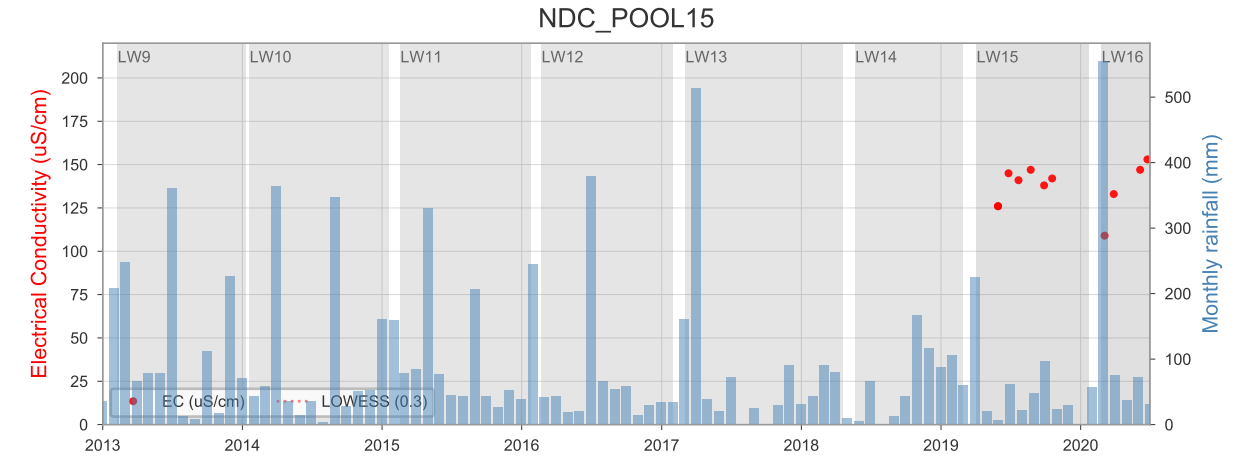

NDC_POOL13
Water level (m below ref. nail)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
WL below ref nail
No water below nail
Pool dry
P5-P95 WL

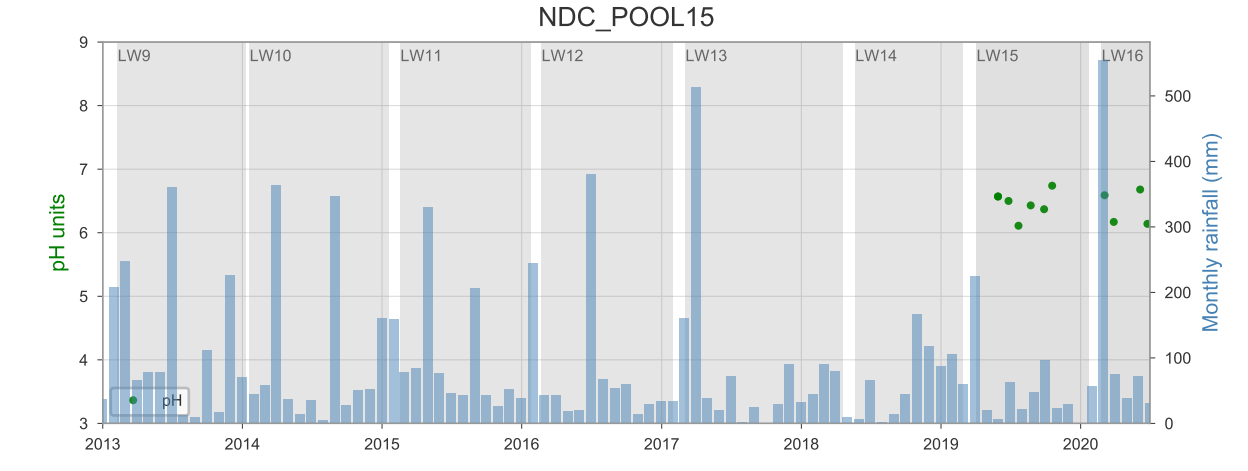

NDC_POOL13
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
EC (uS/cm)
LOWESS (0.3)

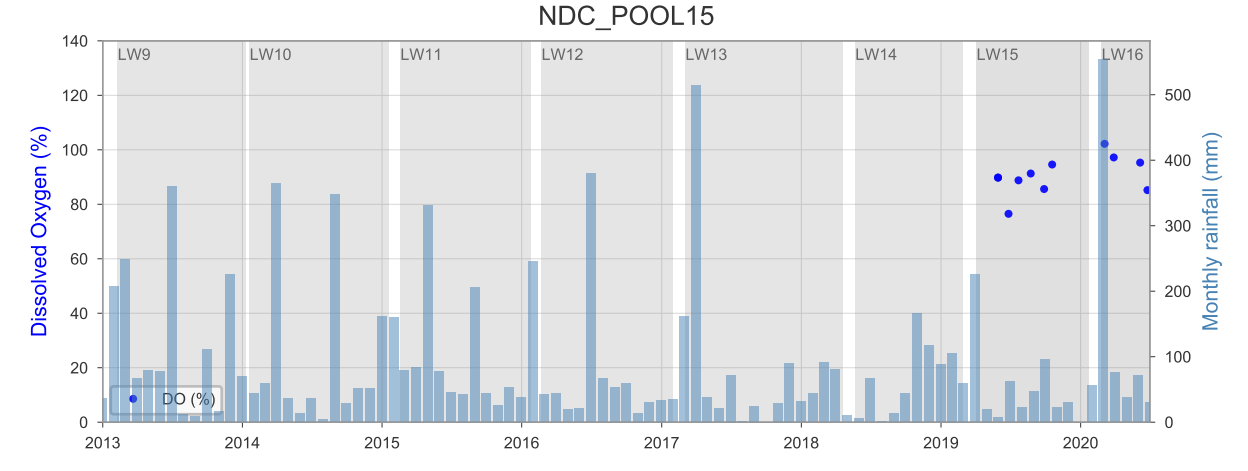

NDC_POOL13
pH units
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH

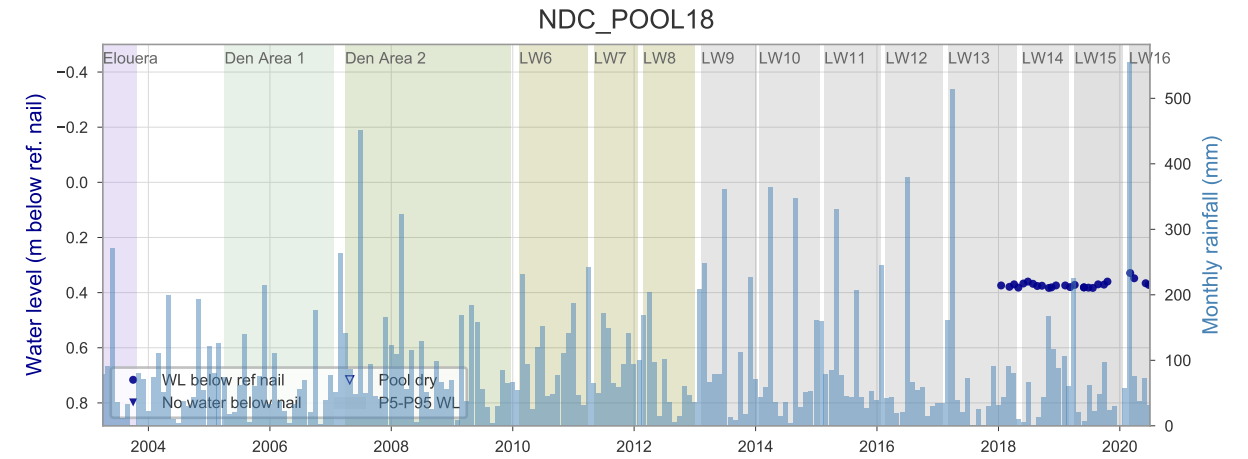

NDC_POOL13
Dissolved Oxygen (%)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
DO (%)

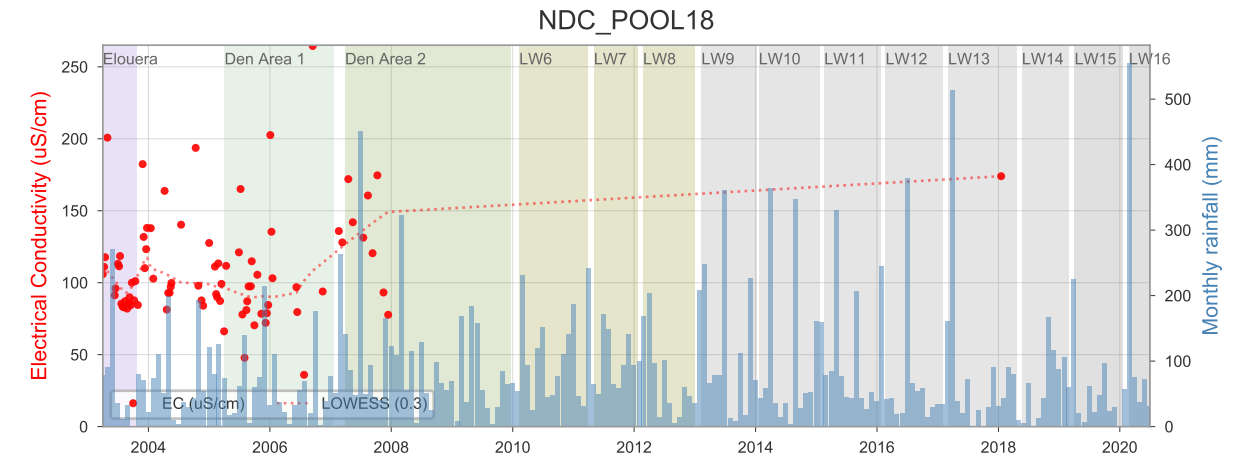

NDC_POOL15
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2013
2014
2015
2016
2017
2018
2019
2020

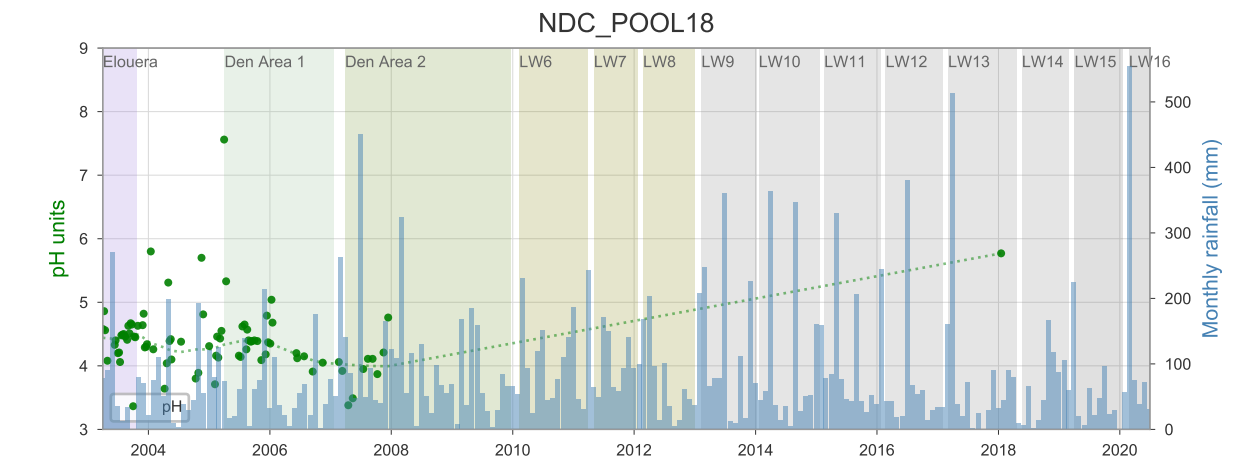

NDC_POOL15
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
2013
2014
2015
2016
2017
2018
2019
2020

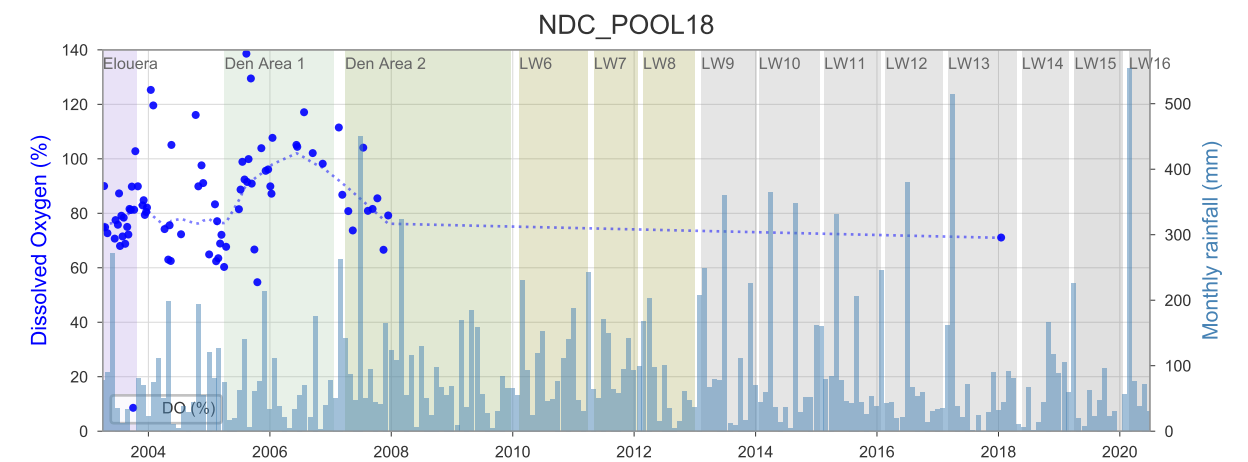

NDC_POOL15
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH
2013
2014
2015
2016
2017
2018
2019
2020

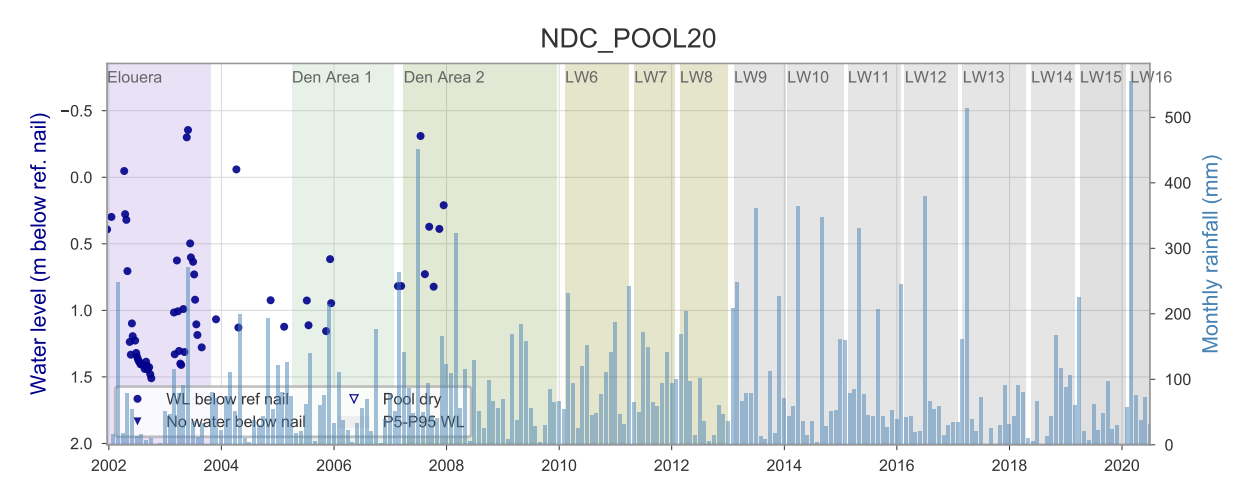

NDC_POOL15
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
2013
2014
2015
2016
2017
2018
2019
2020

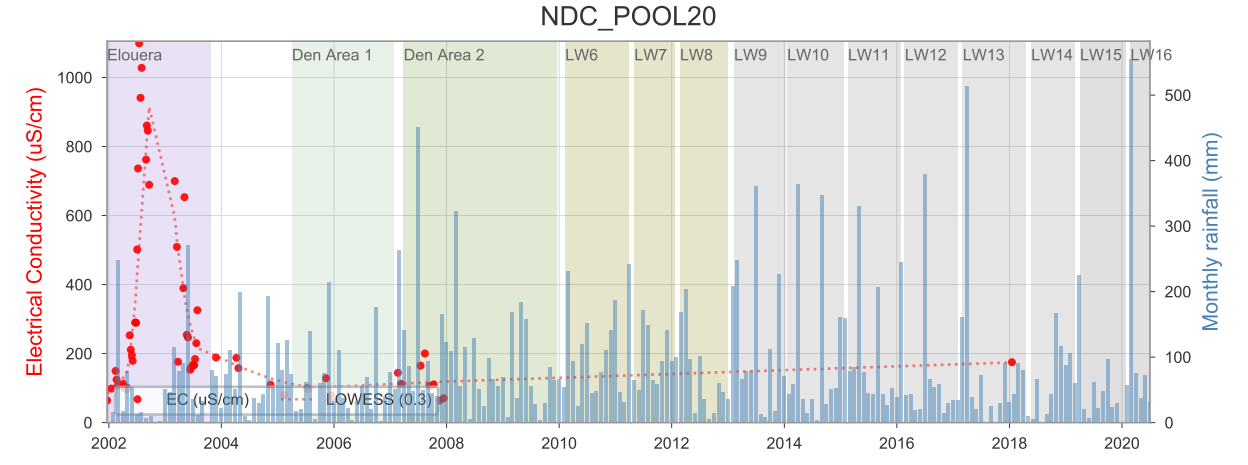

NDC_POOL18
Water level (m below ref. nail)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
WL below ref nail
No water below nail
Pool dry
P5-P95 WL

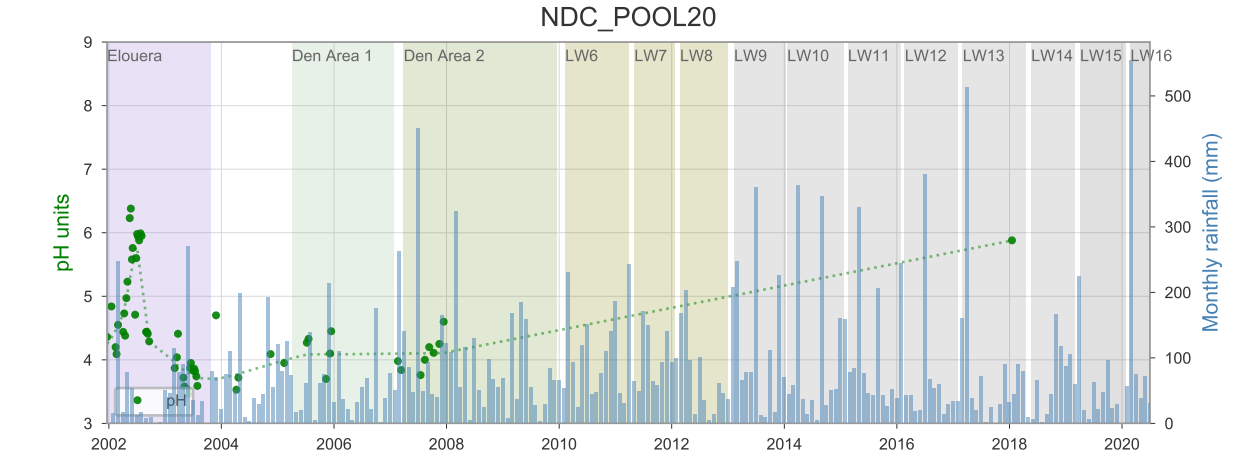

NDC_POOL18
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
EC (uS/cm)
LOWESS (0.3)

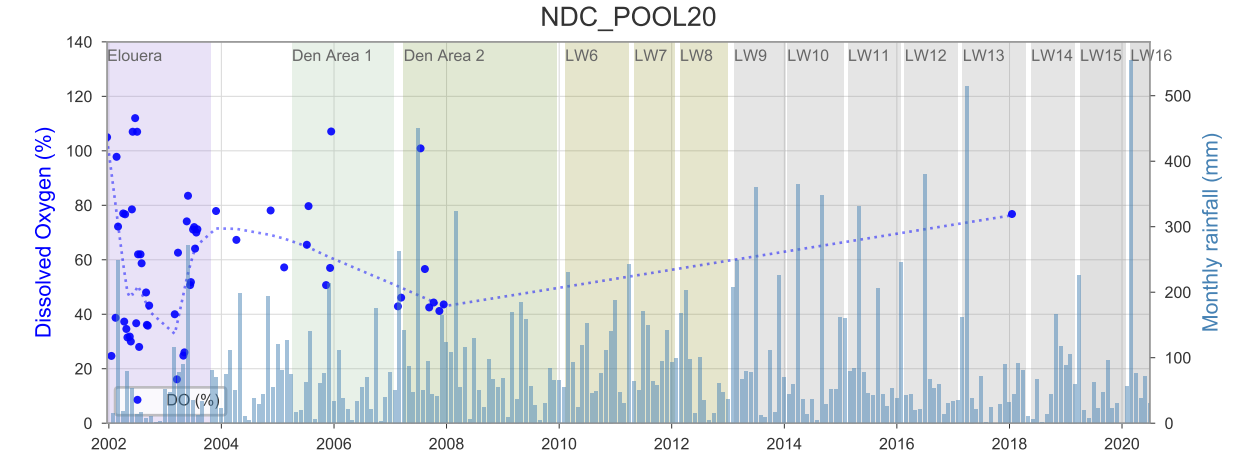

NDC_POOL18
pH units
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH

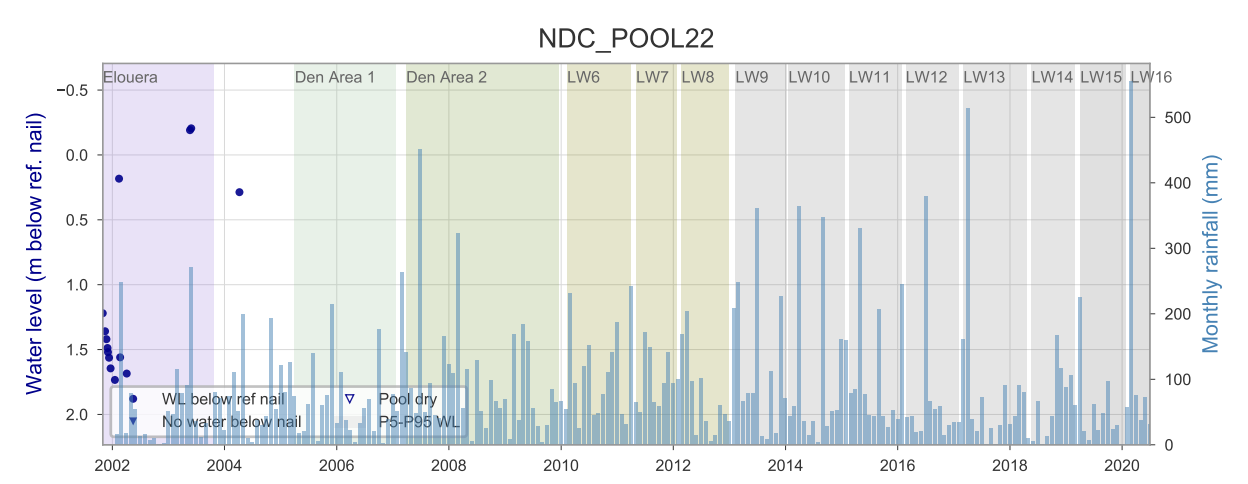

NDC_POOL18
Dissolved Oxygen (%)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
DO (%)

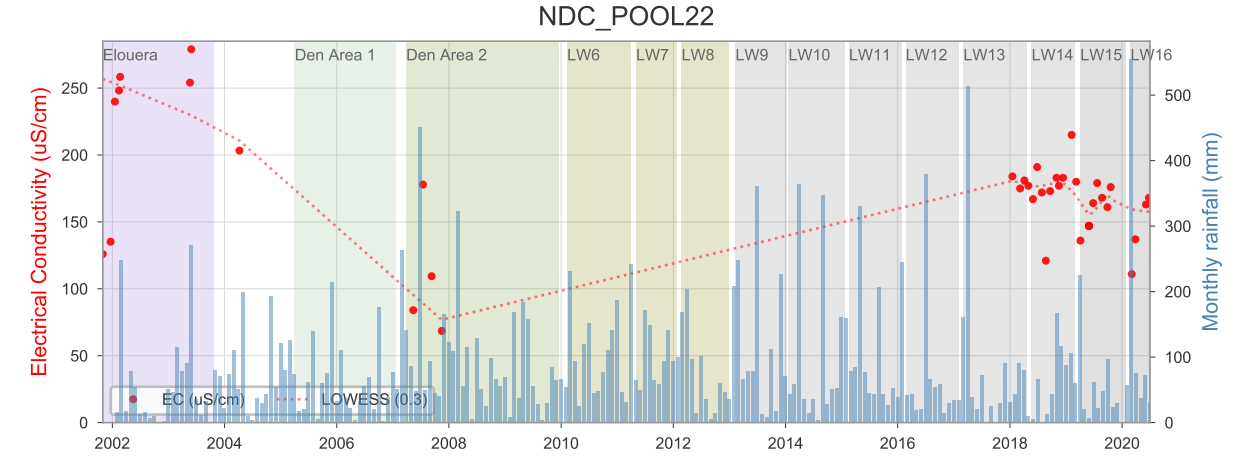

NDC_POOL20
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL

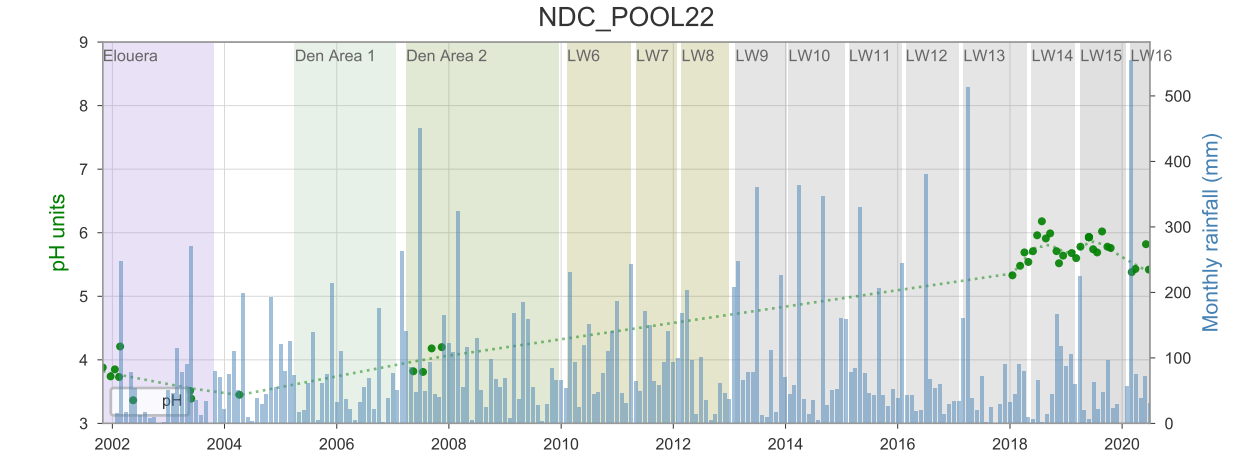

NDC_POOL20
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)

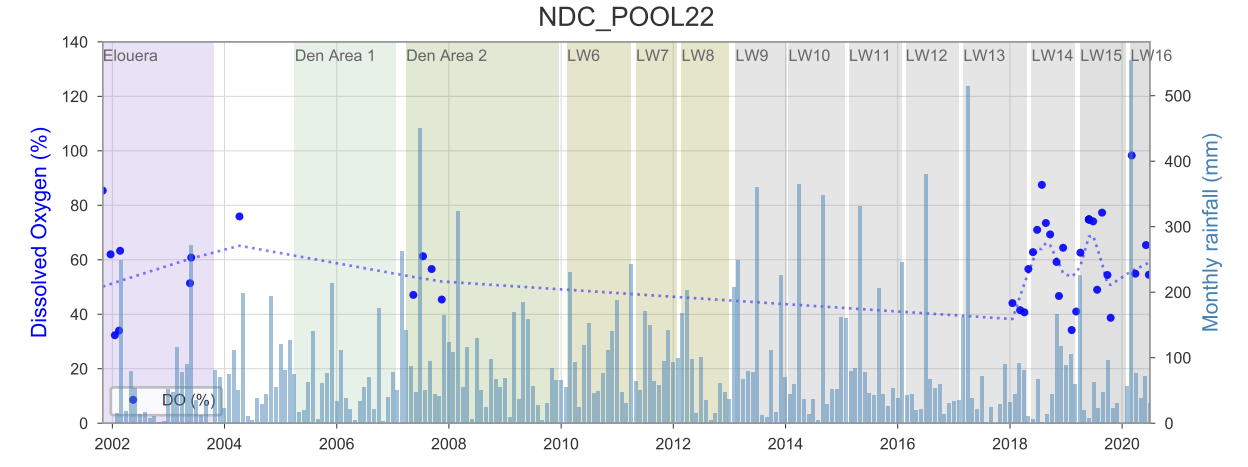

NDC_POOL20
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH

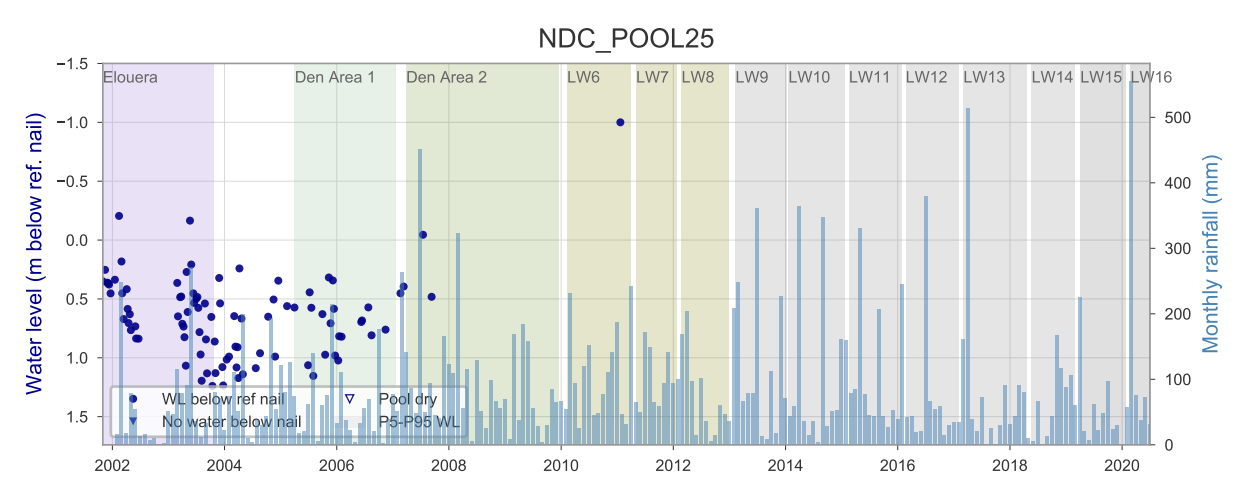

NDC_POOL20
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)

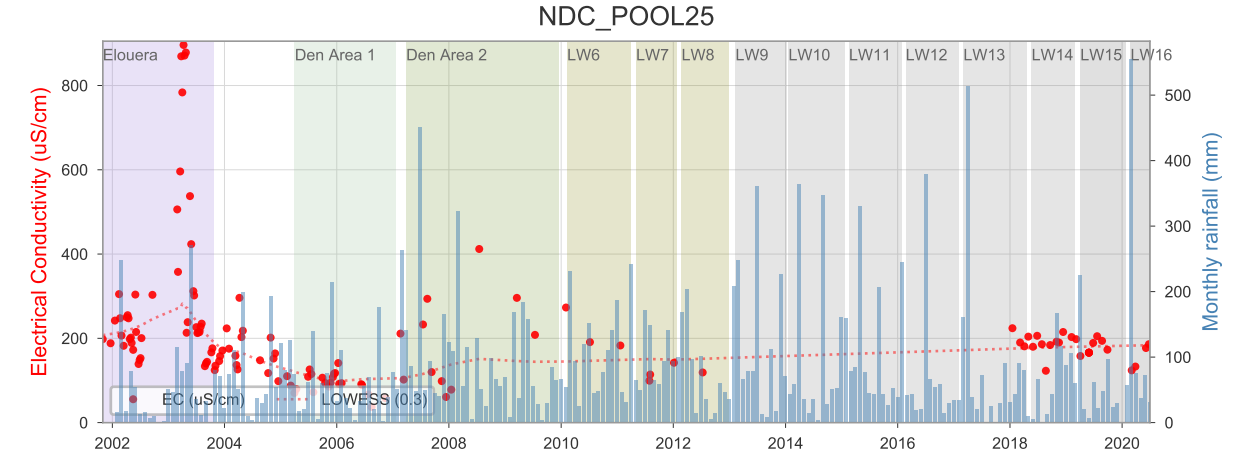

NDC_POOL22
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL

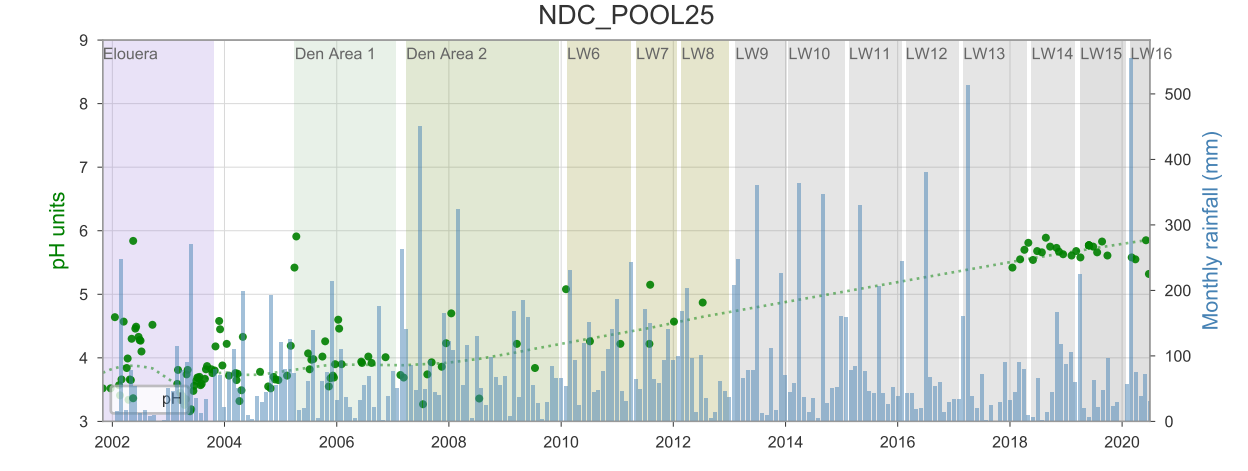

NDC_POOL22
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)

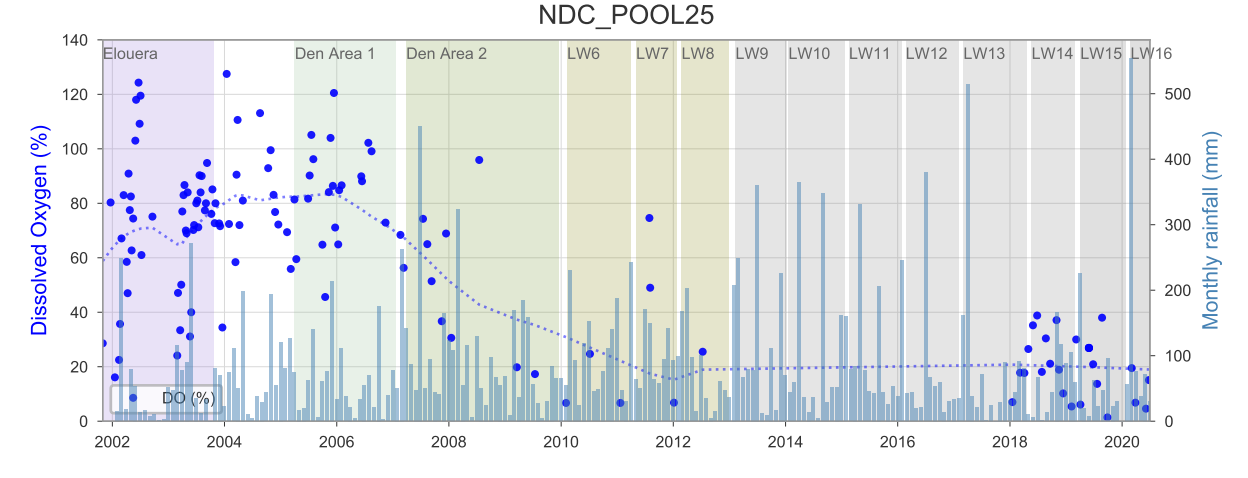

NDC_POOL22
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH

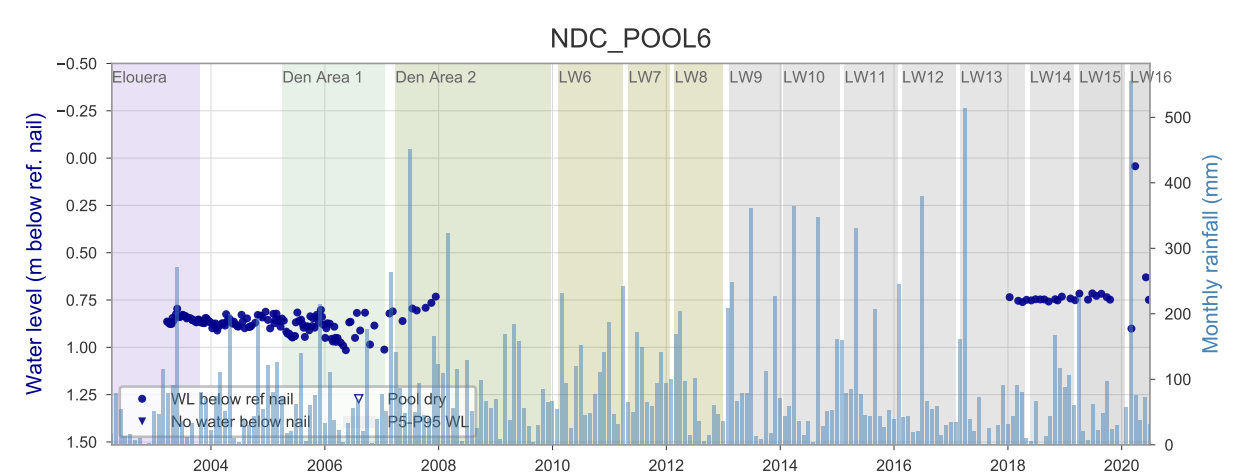

NDC_POOL22
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)

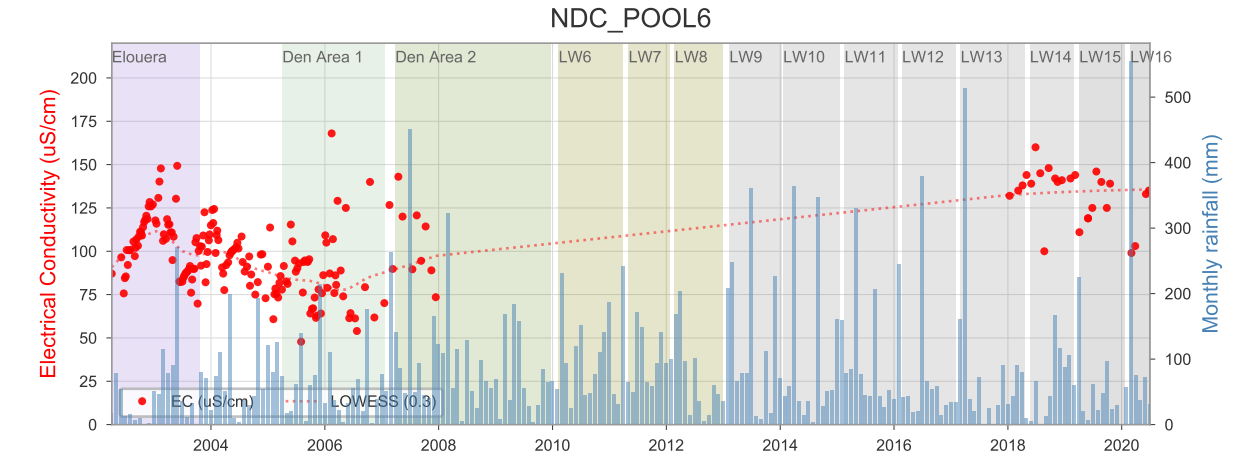

NDC_POOL25
Water level (m below ref. nail)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
WL below ref nail
No water below nail
Pool dry
P5-P95 WL

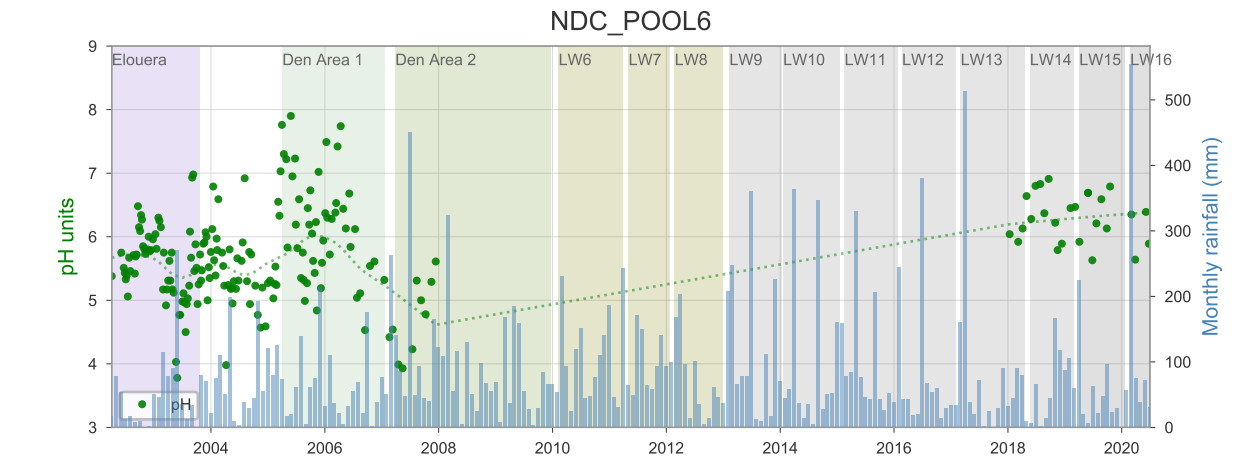

NDC_POOL25
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
EC (uS/cm)
LOWESS (0.3)

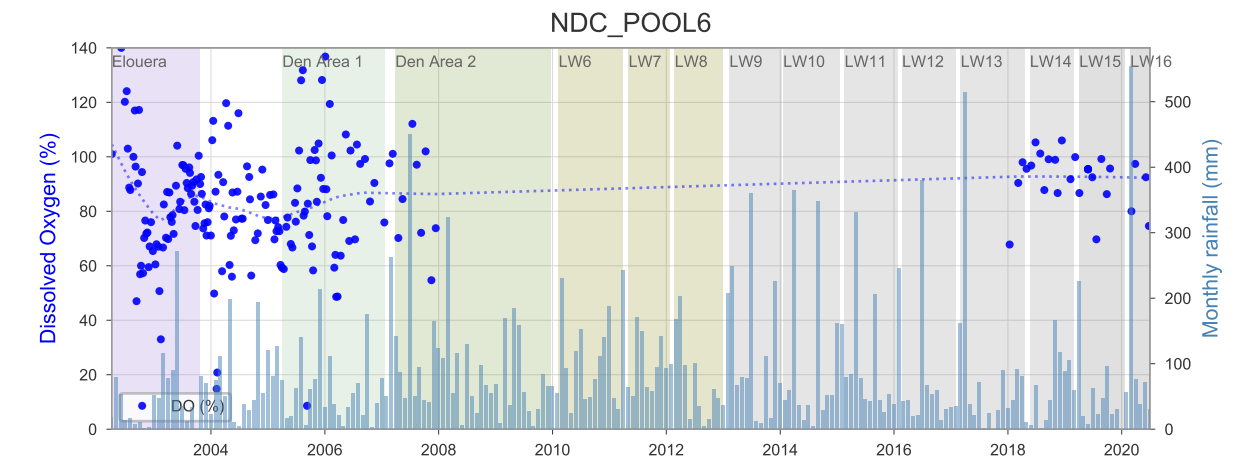

NDC_POOL25
pH units
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH

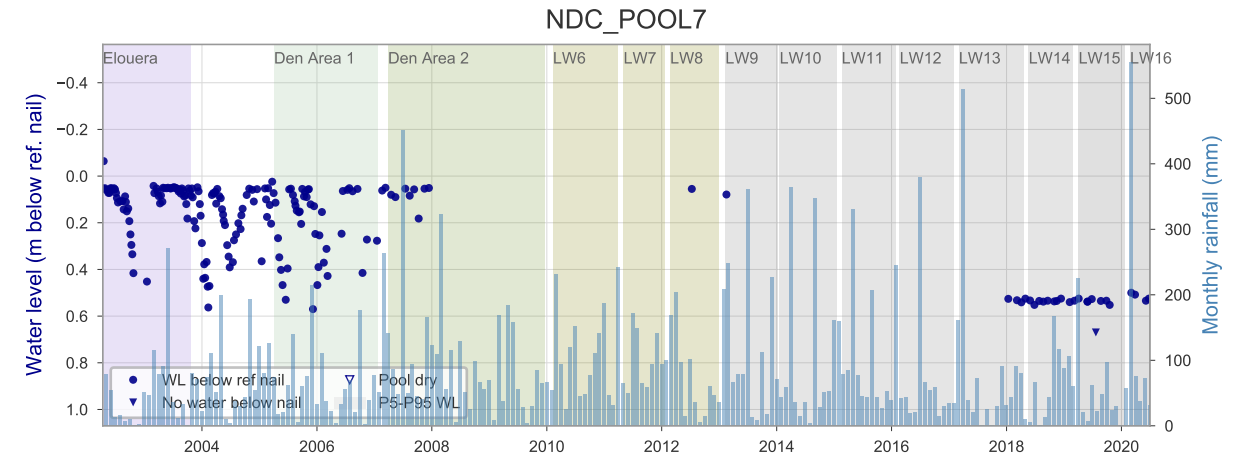

NDC_POOL25
Dissolved Oxygen (%)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
DO (%)

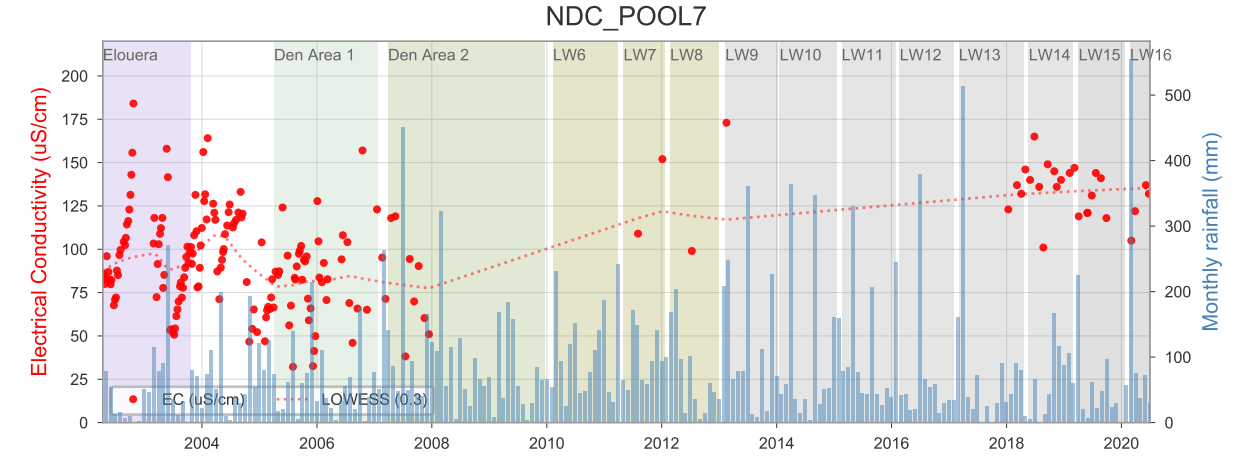

NDC_POOL6
Water level (m below ref. nail)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
WL below ref nail
Pool dry
No water below nail
P5-P95 WL

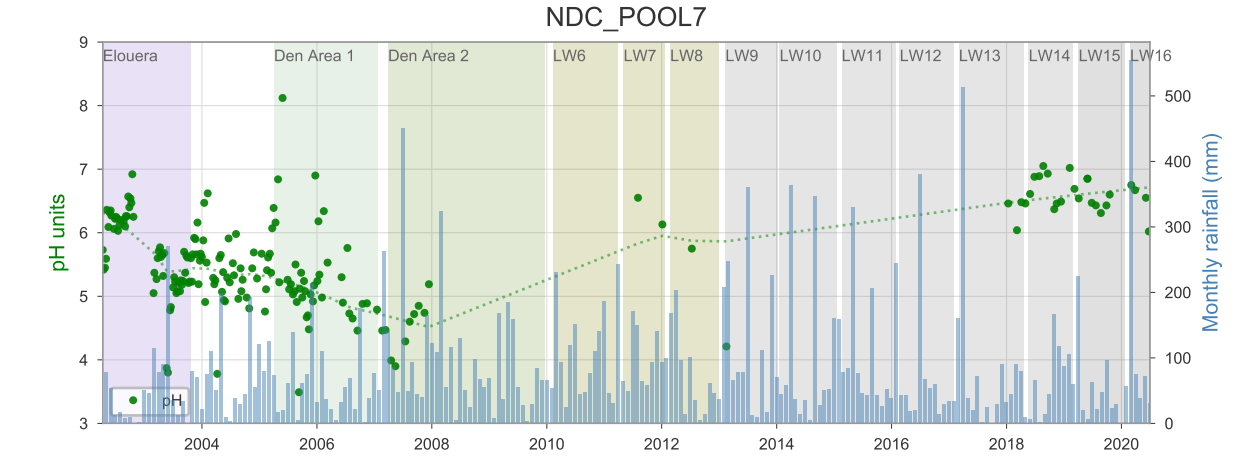

NDC_POOL6
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
EC (uS/cm)
LOWESS (0.3)

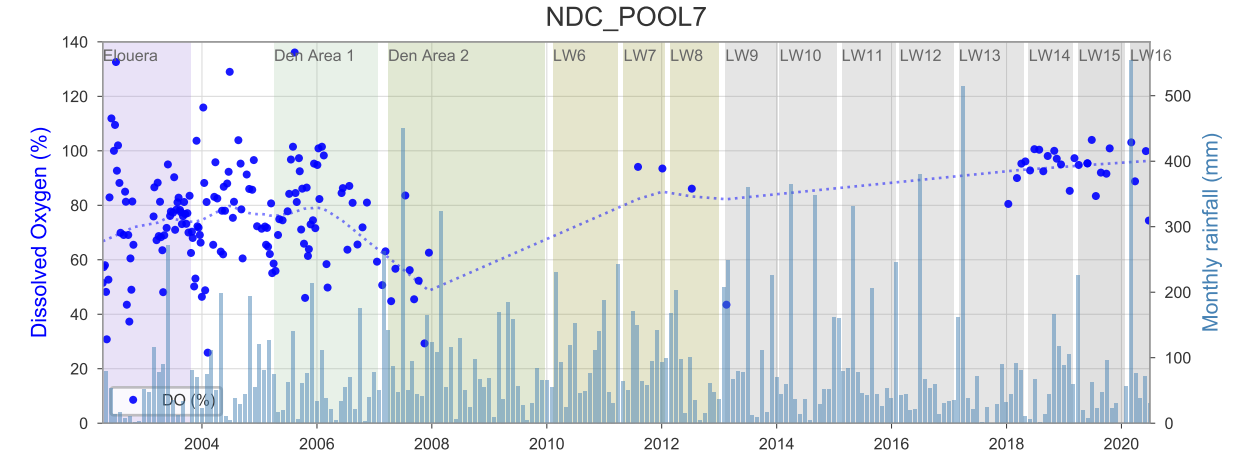

NDC_POOL6
pH units
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH

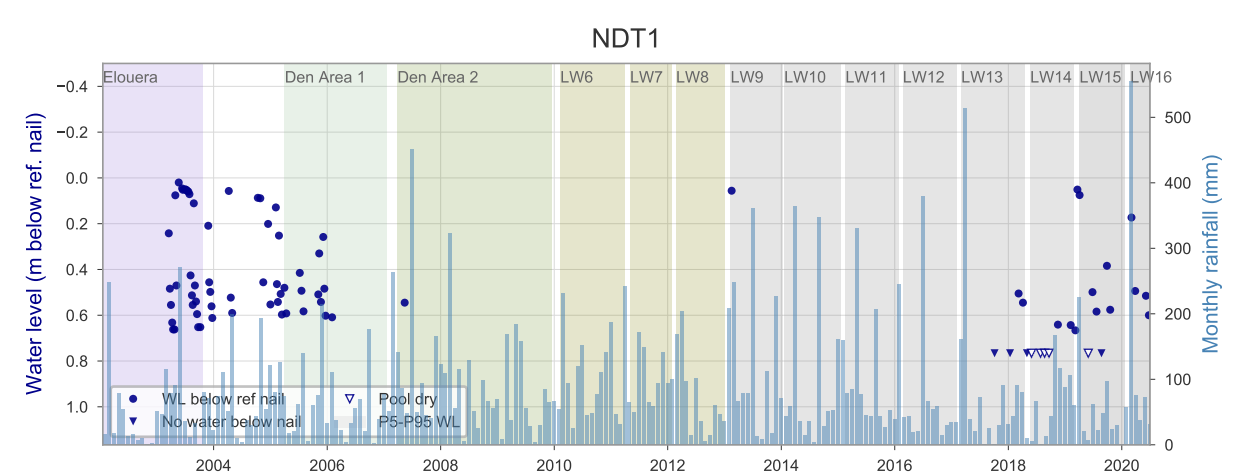

NDC_POOL6
Dissolved Oxygen (%)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
DO (%)

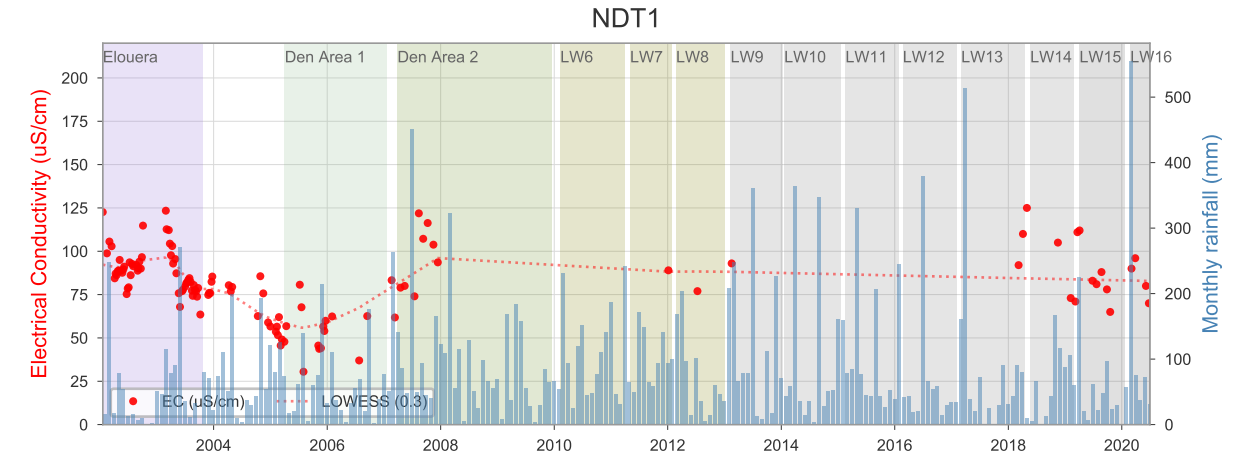

NDC_POOL7
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL

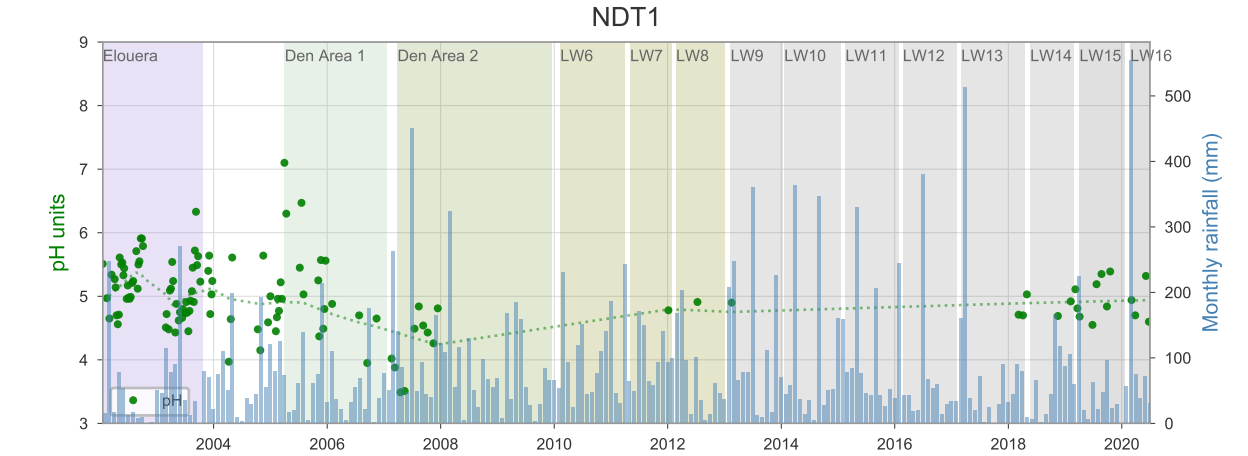

NDC_POOL7
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)

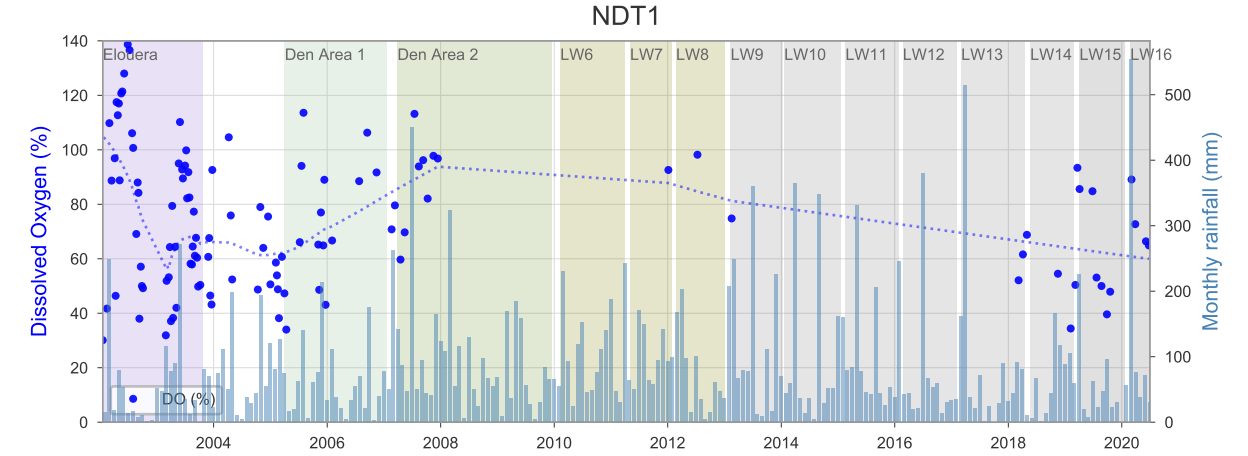

NDC_POOL7
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH

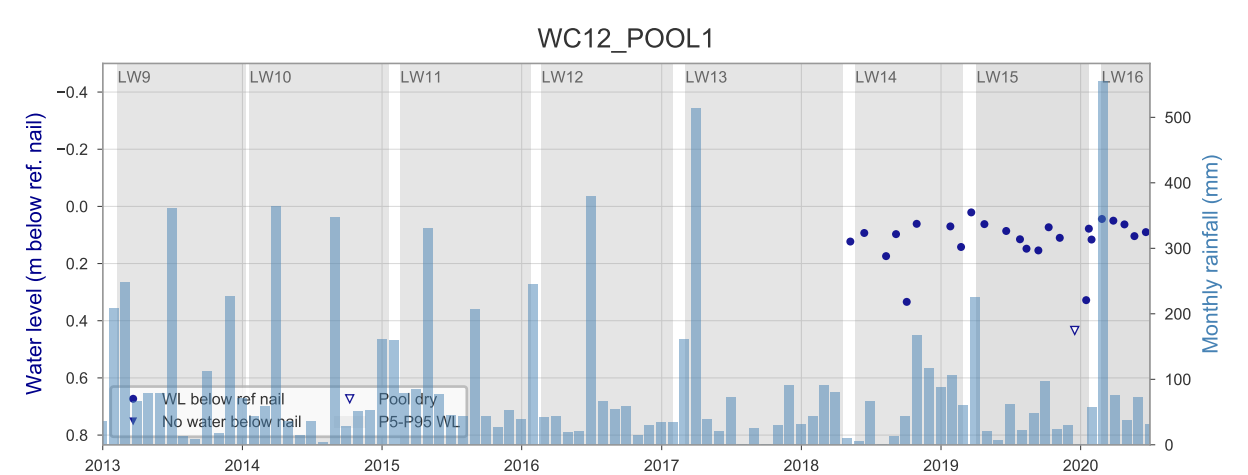

NDC_POOL7
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)

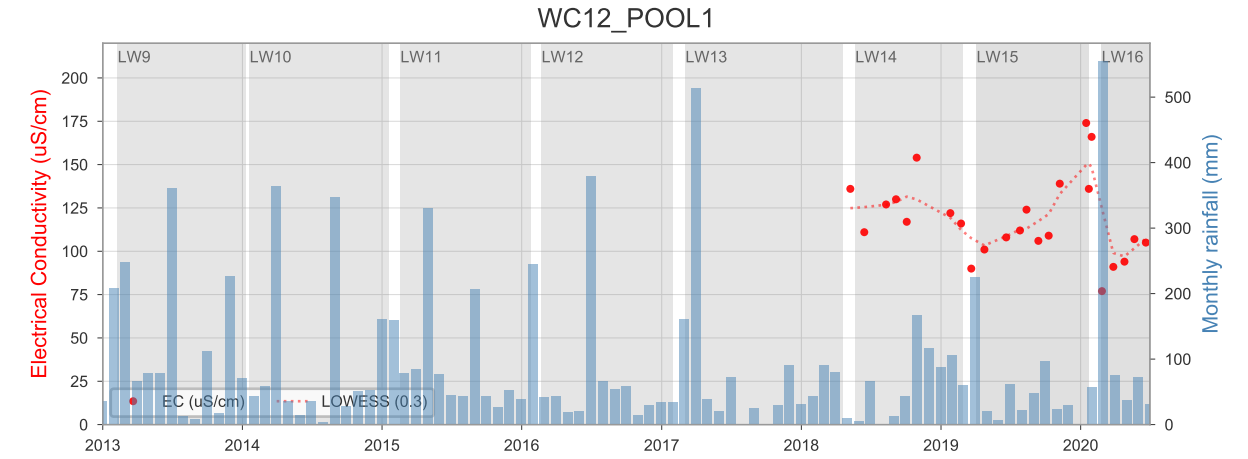

NDT1
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL

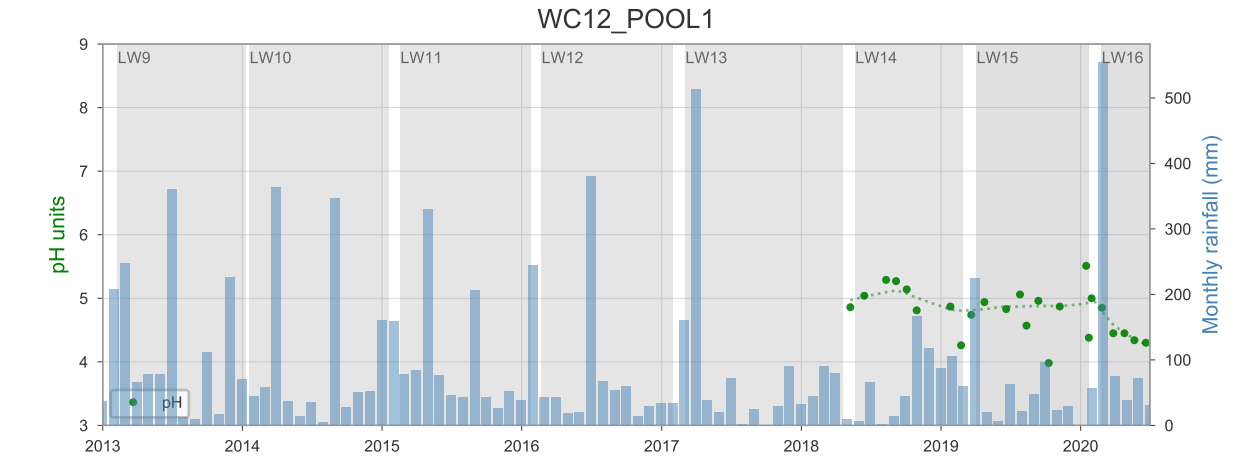

NDT1
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)

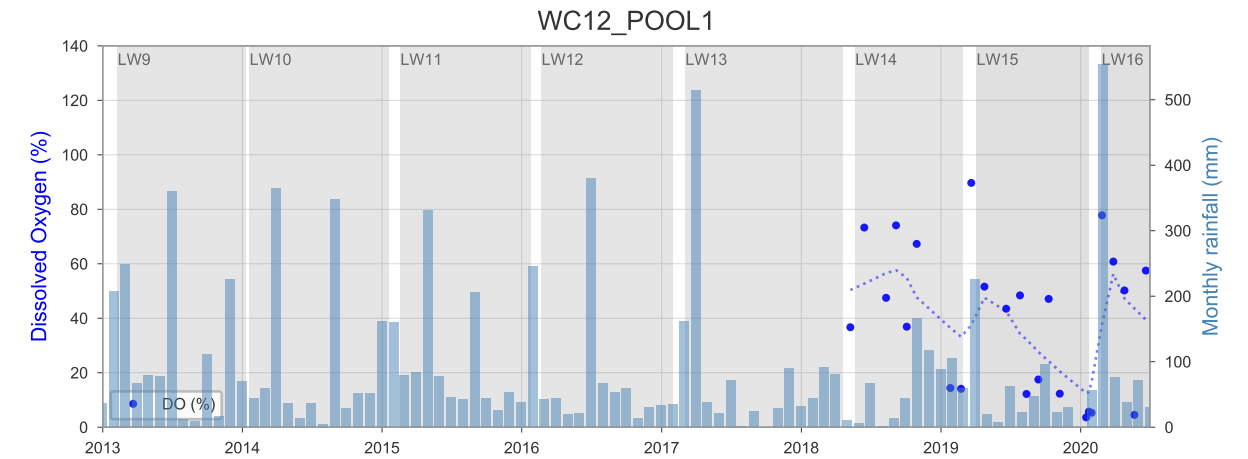

NDT1
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH

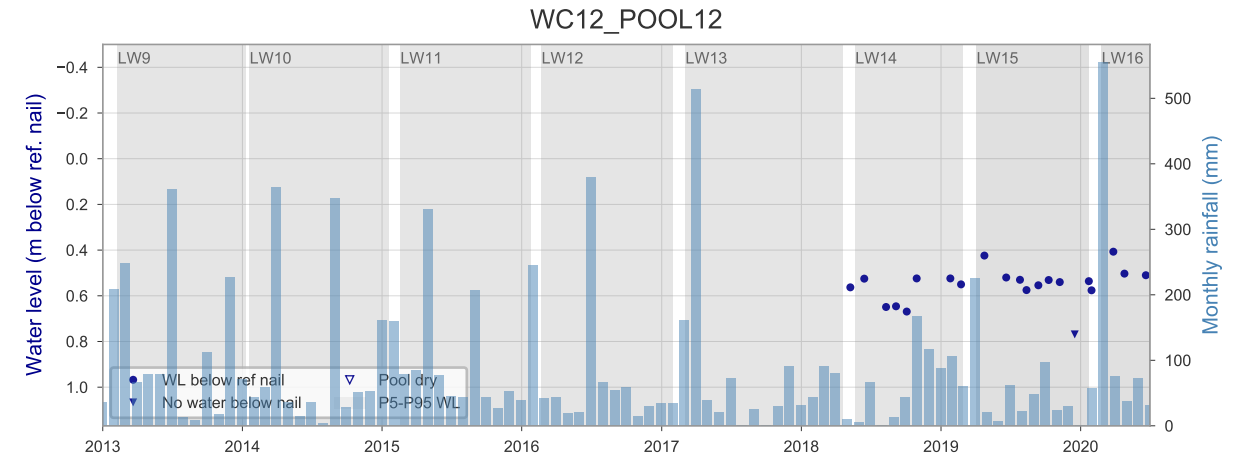

NDT1
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)

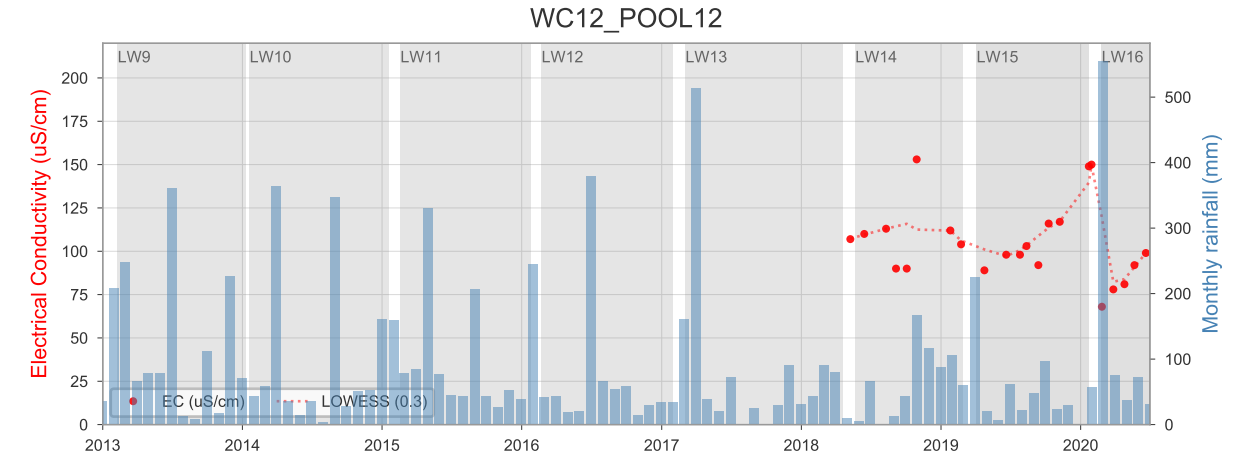

WC12_POOL1
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2013
2014
2015
2016
2017
2018
2019
2020

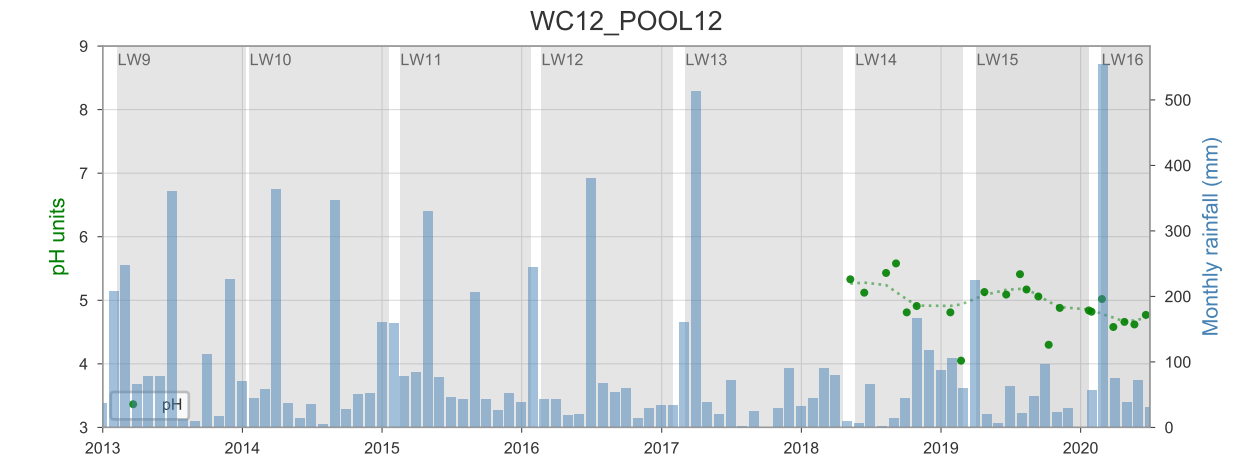

WC12_POOL1
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
2013
2014
2015
2016
2017
2018
2019
2020

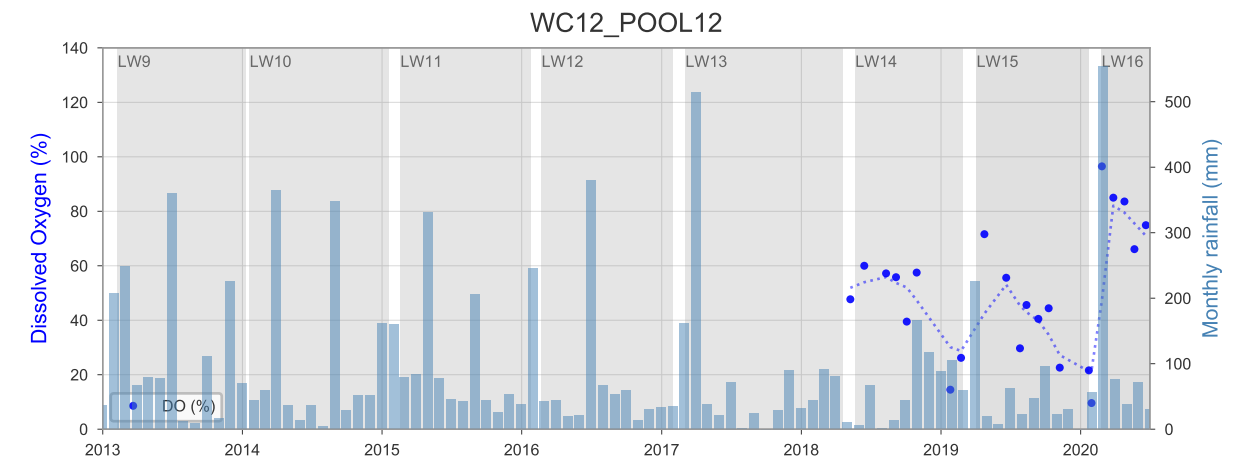

WC12_POOL1
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH
2013
2014
2015
2016
2017
2018
2019
2020

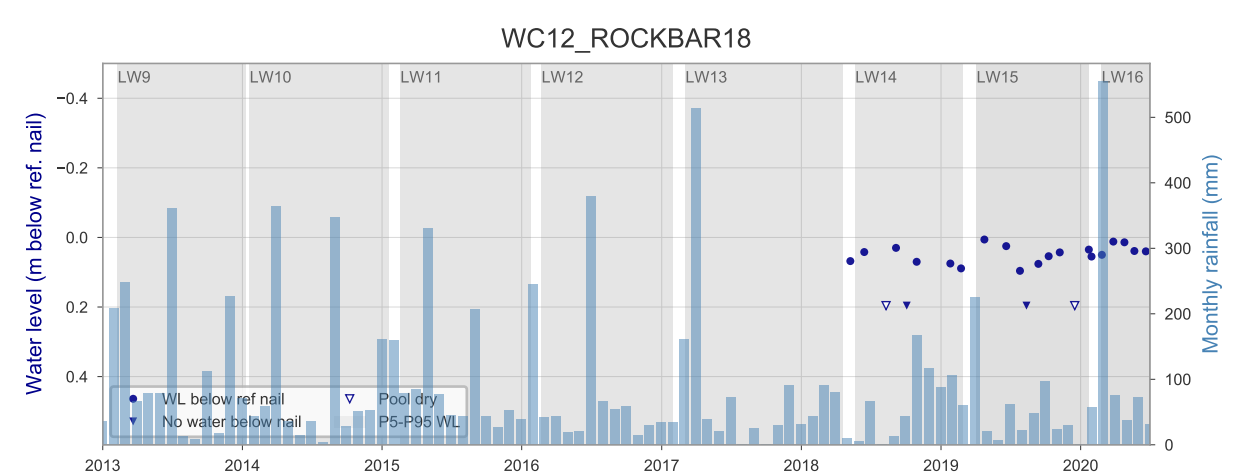

WC12_POOL1
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
2013
2014
2015
2016
2017
2018
2019
2020

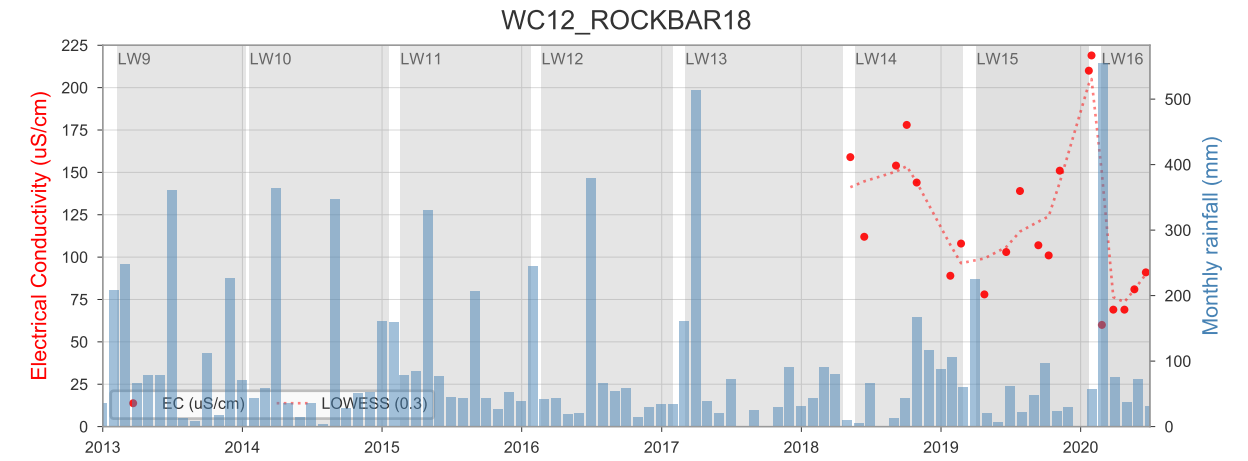

WC12_POOL12
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2013
2014
2015
2016
2017
2018
2019
2020

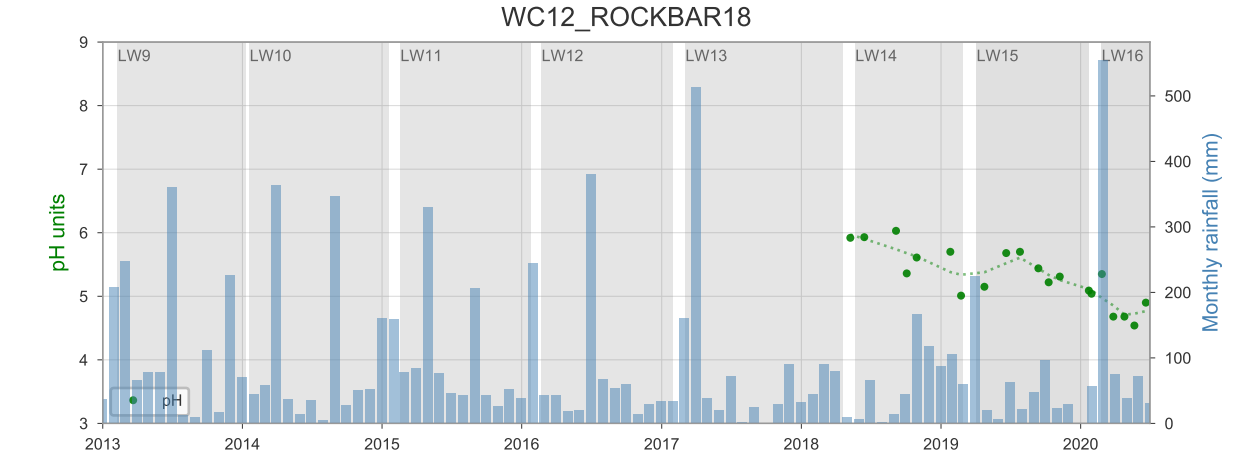

WC12_POOL12
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
2013
2014
2015
2016
2017
2018
2019
2020

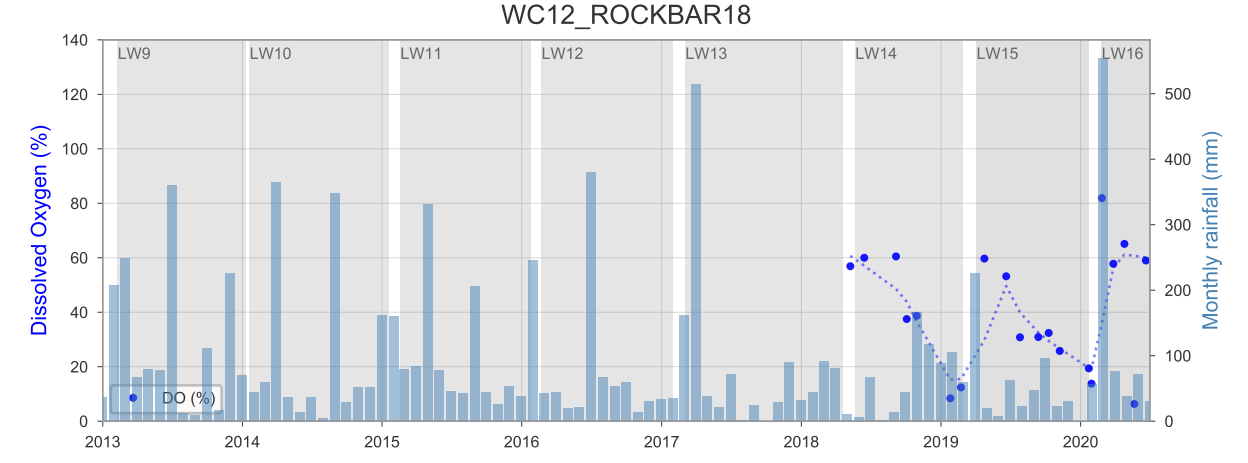

WC12_POOL12
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH
2013
2014
2015
2016
2017
2018
2019
2020

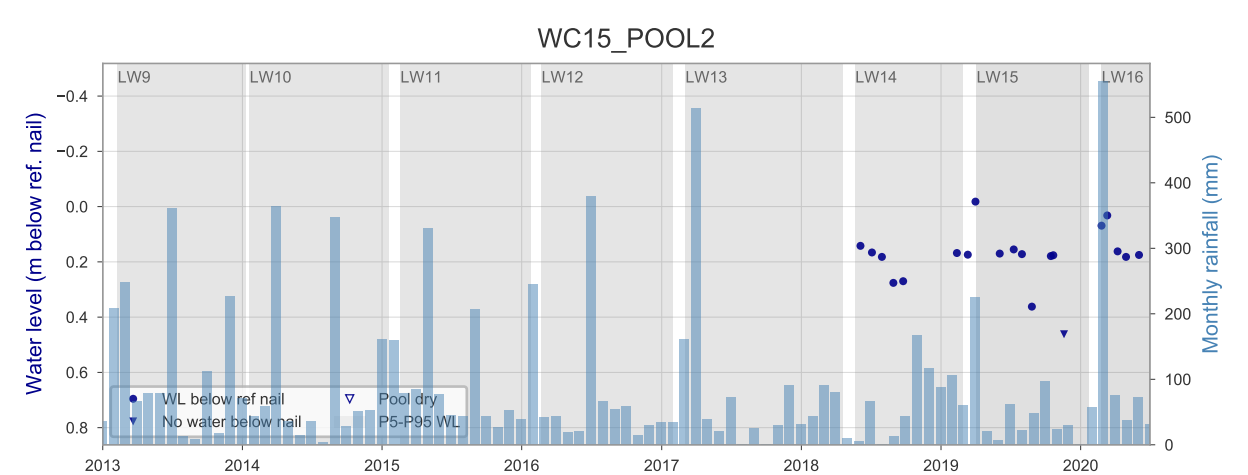

WC12_POOL12
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
2013
2014
2015
2016
2017
2018
2019
2020

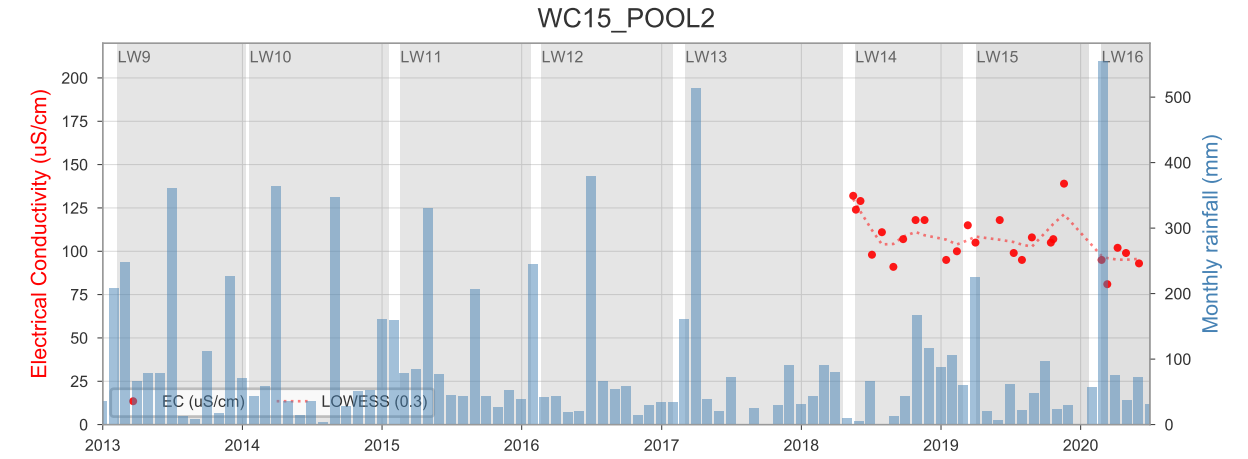

WC12_ROCKBAR18
Water level (m below ref. nail)
Monthly rainfall (mm)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2013
2014
2015
2016
2017
2018
2019
2020

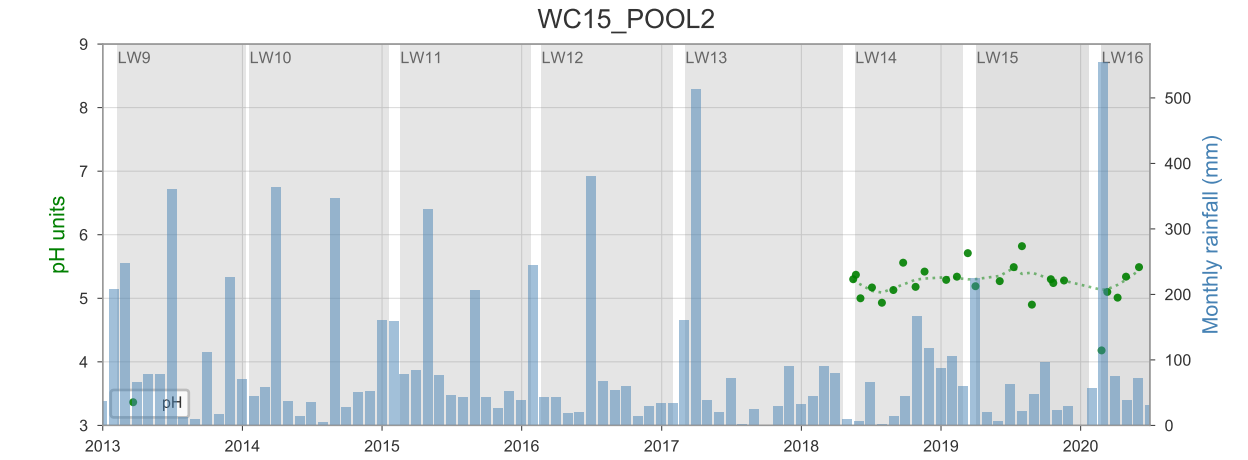

WC12_ROCKBAR18
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
EC (uS/cm)
LOWESS (0.3)
2013
2014
2015
2016
2017
2018
2019
2020

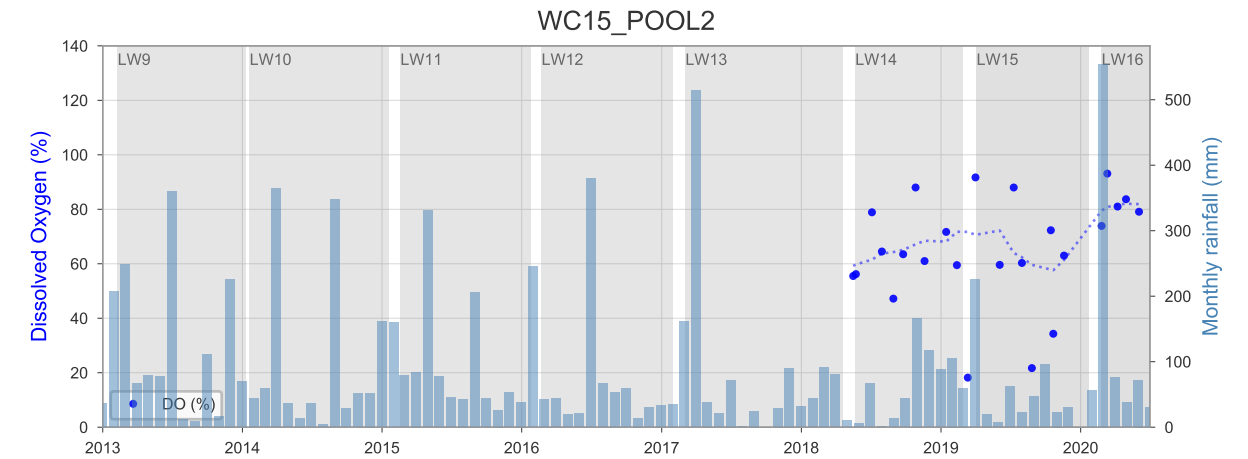

WC12_ROCKBAR18
pH units
Monthly rainfall (mm)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH
2013
2014
2015
2016
2017
2018
2019
2020

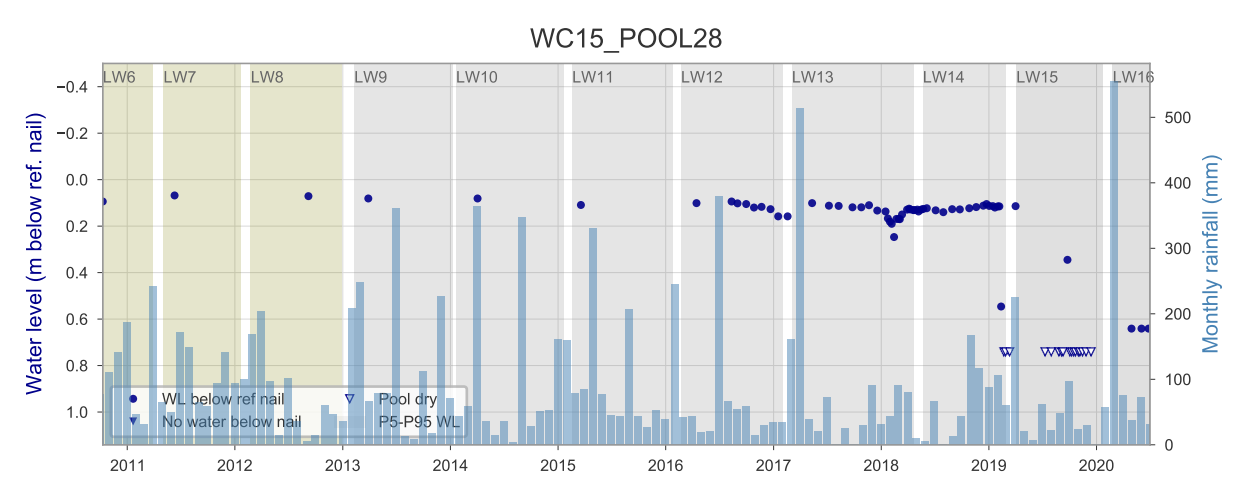

WC12_ROCKBAR18
Dissolved Oxygen (%)
Monthly rainfall (mm)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
DO (%)
2013
2014
2015
2016
2017
2018
2019
2020

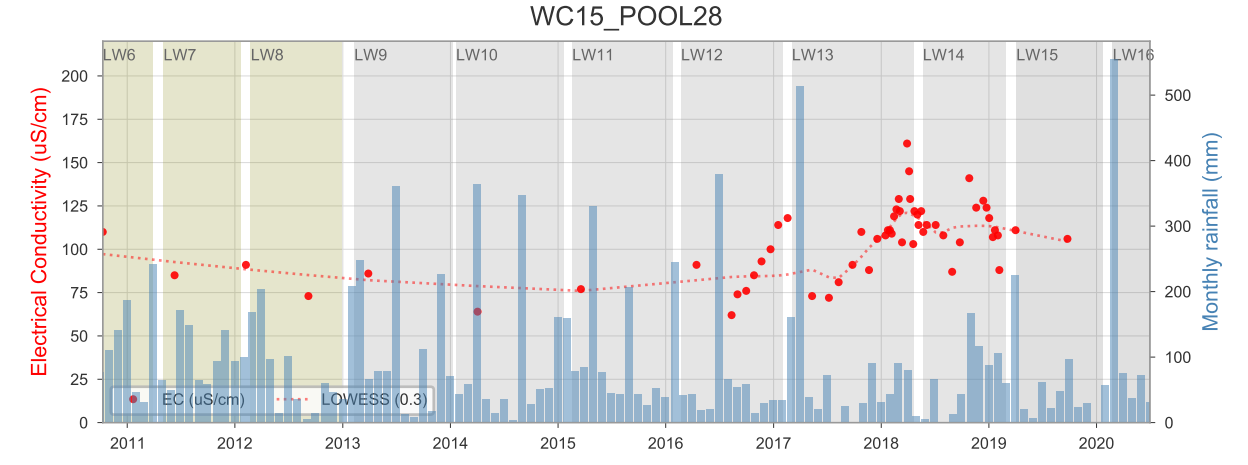

WC15_POOL2
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2013
2014
2015
2016
2017
2018
2019
2020

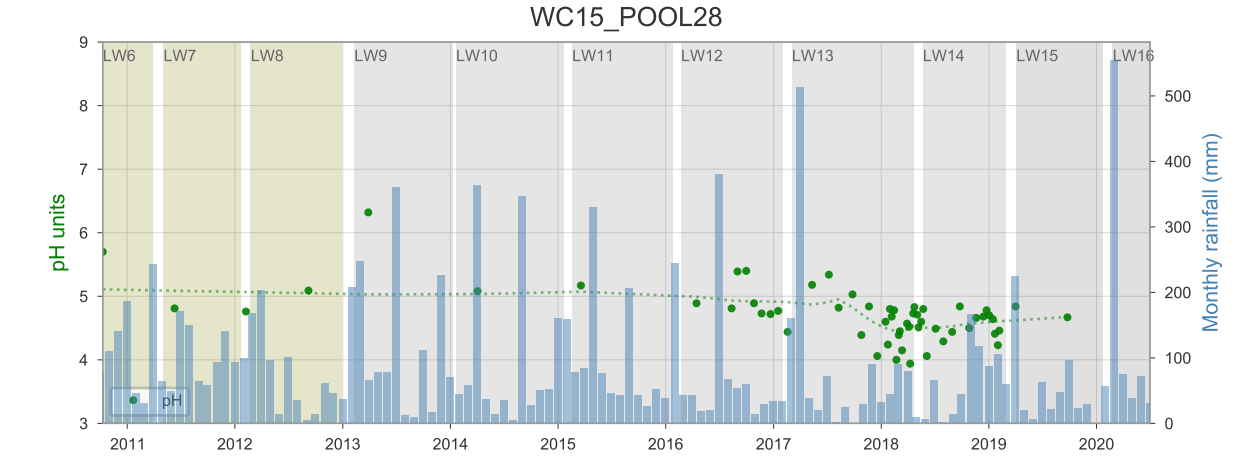

WC15_POOL2
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
2013
2014
2015
2016
2017
2018
2019
2020

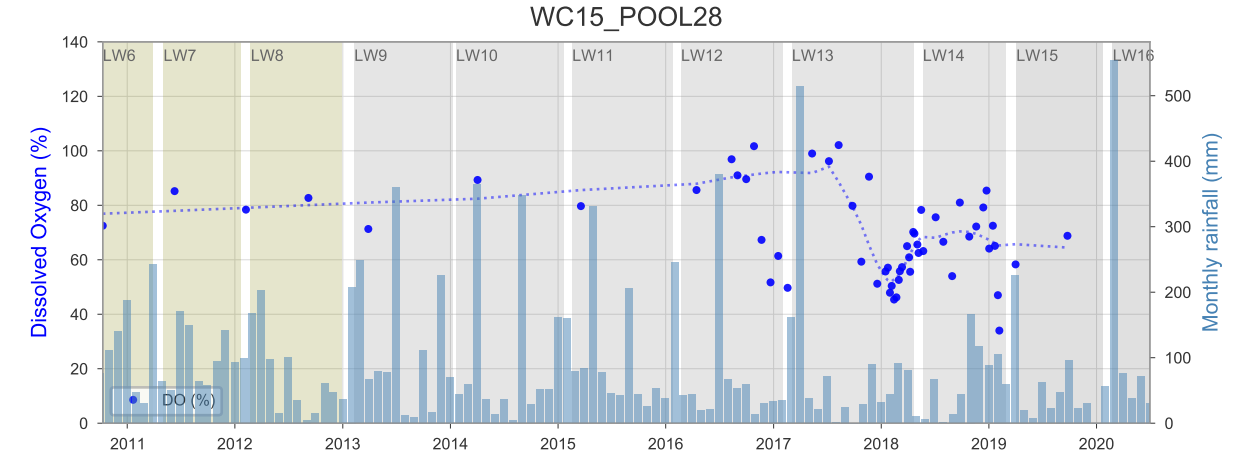

WC15_POOL2
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH
2013
2014
2015
2016
2017
2018
2019
2020

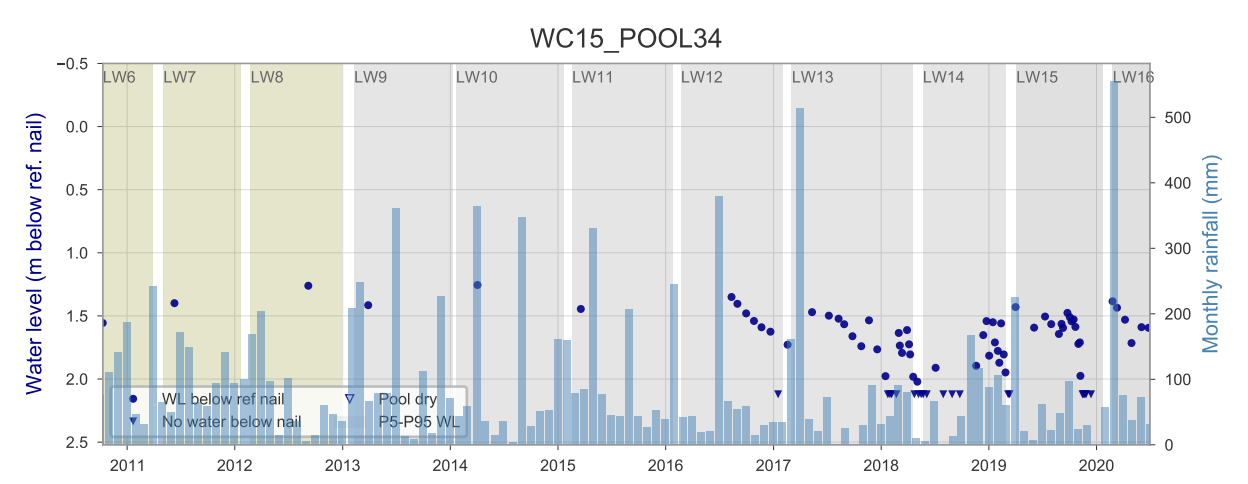

WC15_POOL2
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
2013
2014
2015
2016
2017
2018
2019
2020

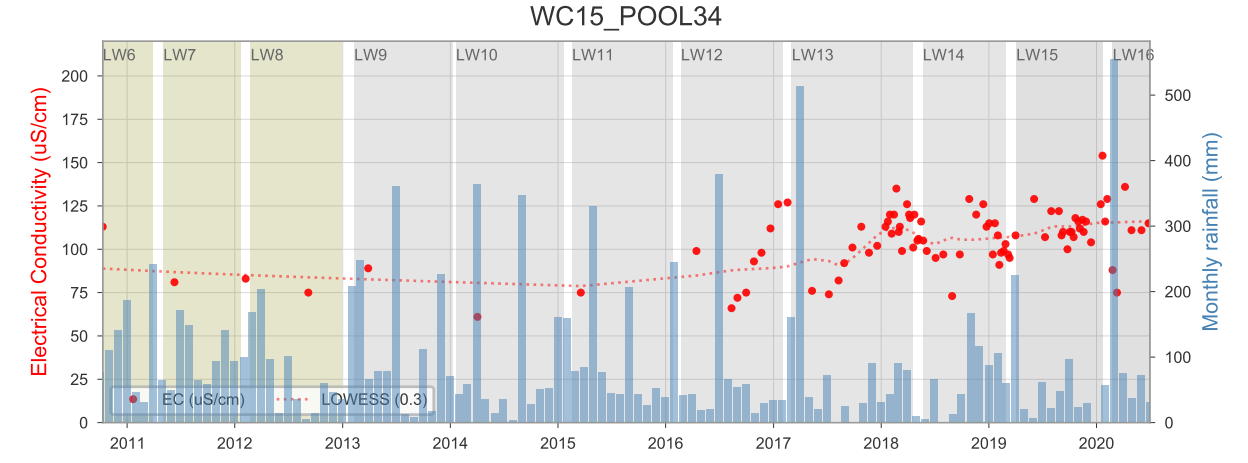

WC15_POOL28
Water level (m below ref. nail)
Monthly rainfall (mm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
WL below ref nail
No water below nail
Pool dry
P5-P95 WL

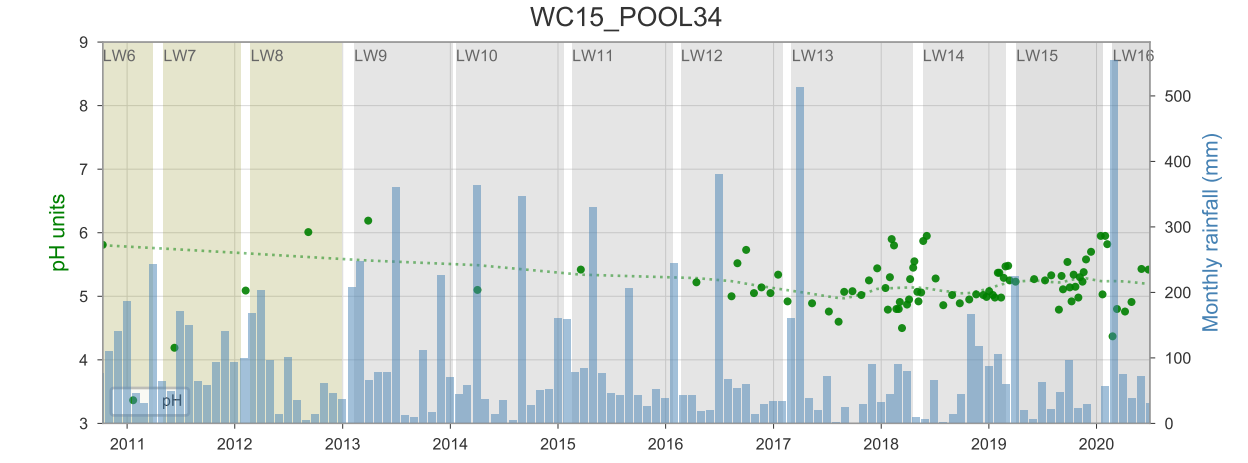

WC15_POOL28
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
EC (uS/cm)
LOWESS (0.3)

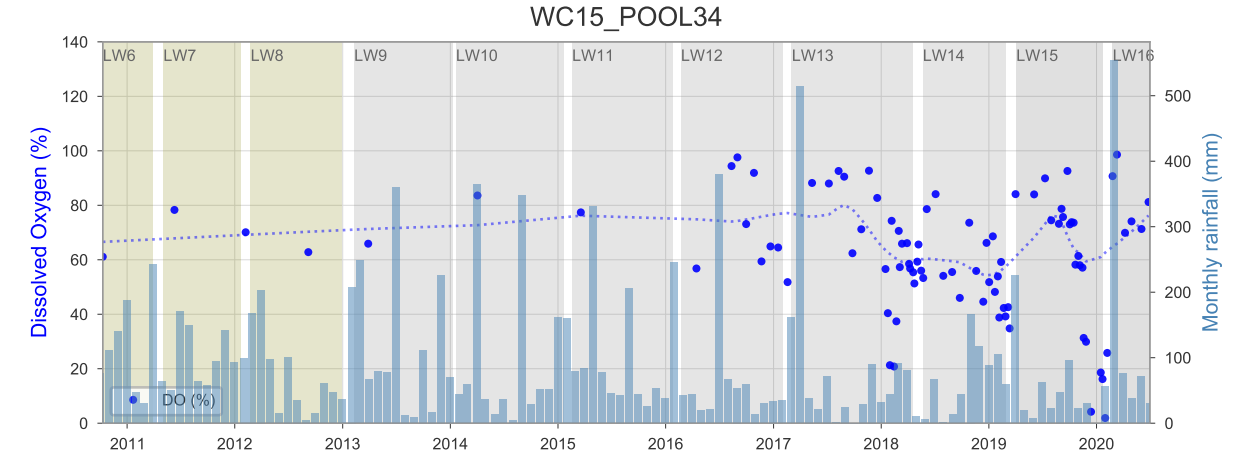

WC15_POOL28
pH units
Monthly rainfall (mm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH

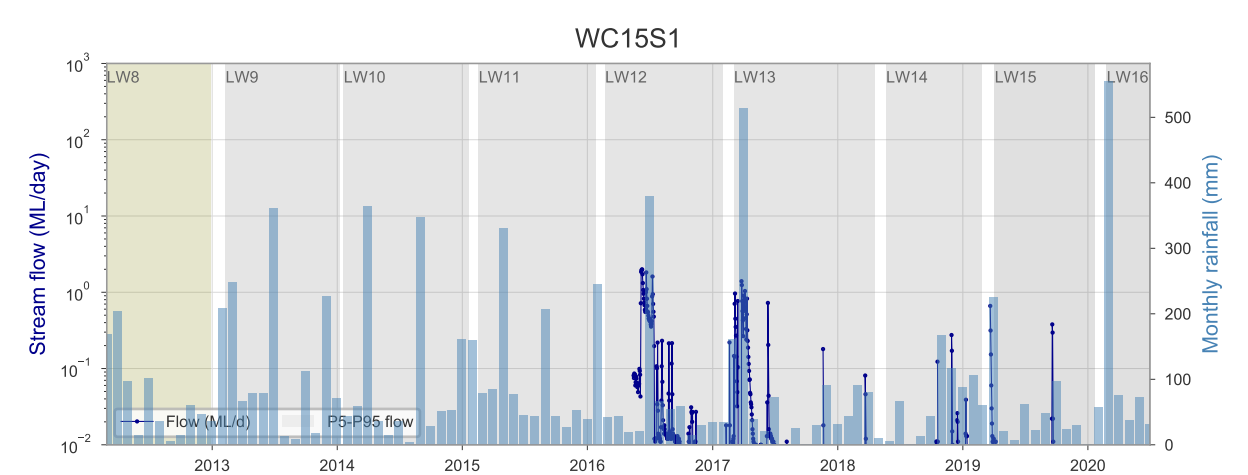

WC15_POOL28
Dissolved Oxygen (%)
Monthly rainfall (mm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
DO (%)

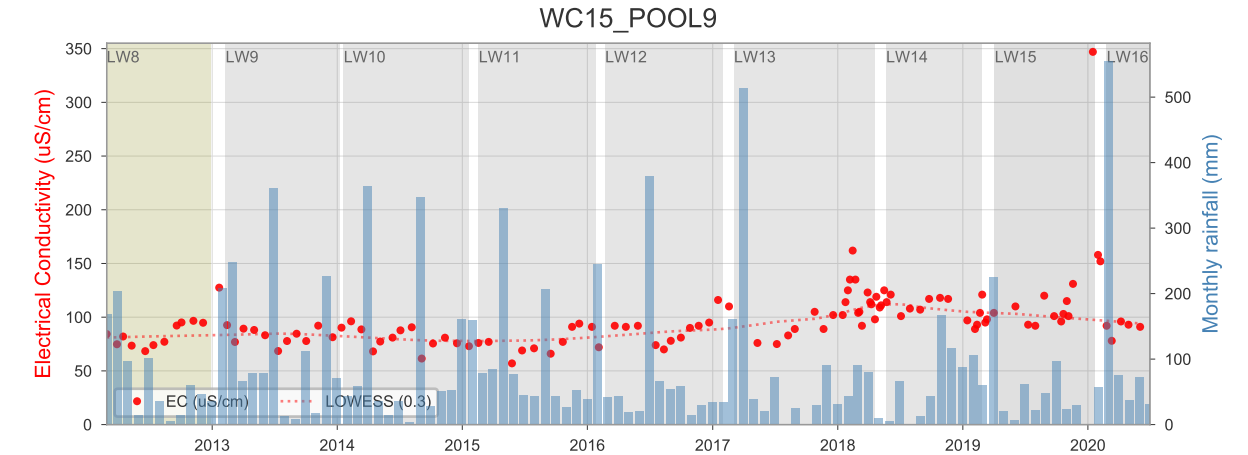

WC15_POOL34
Water level (m below ref. nail)
Monthly rainfall (mm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
WL below ref nail
No water below nail
Pool dry
P5-P95 WL

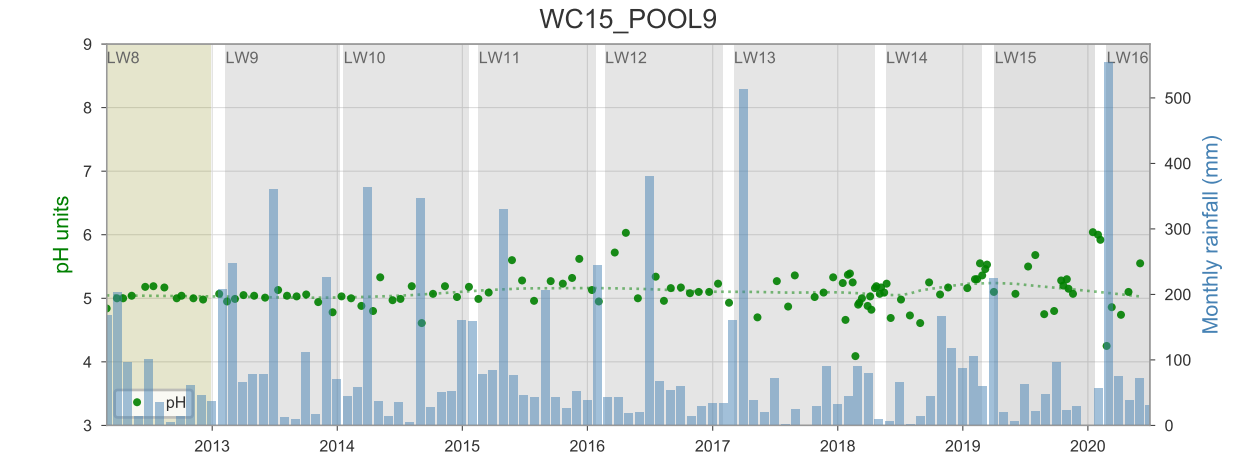

WC15_POOL34
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
EC (uS/cm)
LOWESS (0.3)

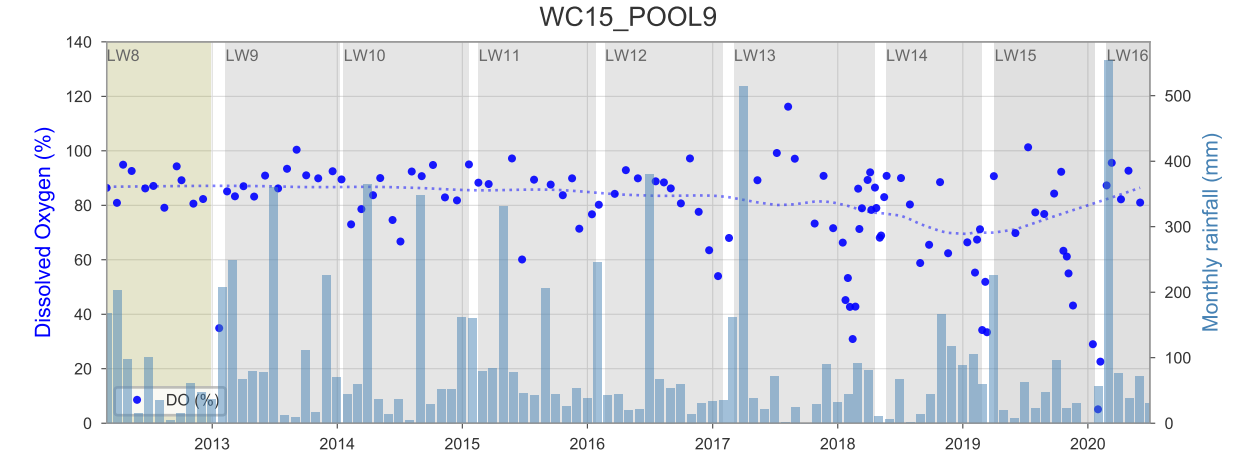

WC15_POOL34
pH units
Monthly rainfall (mm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH

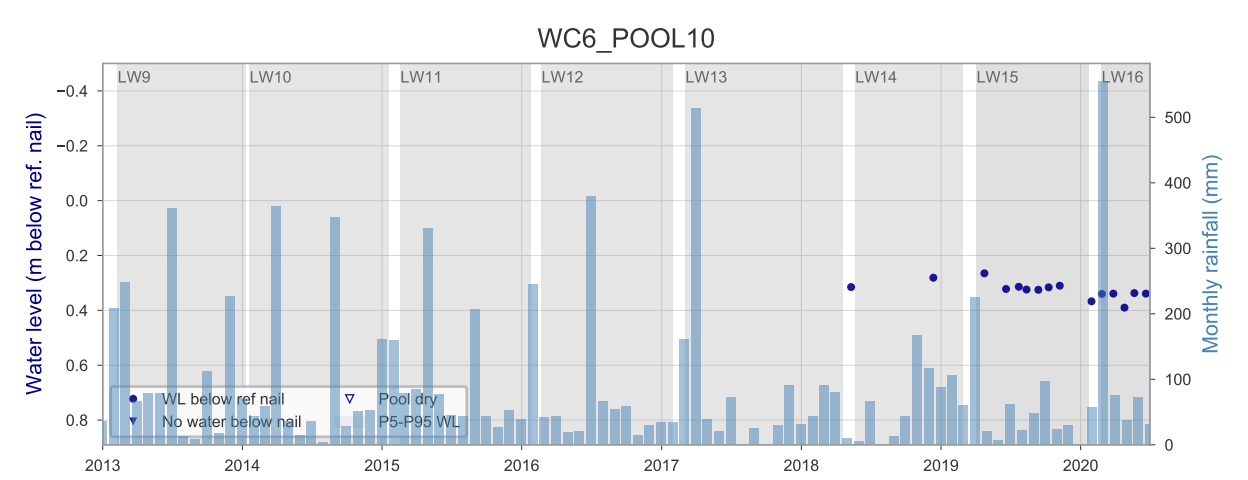

WC15_POOL34
Dissolved Oxygen (%)
Monthly rainfall (mm)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
DO (%)

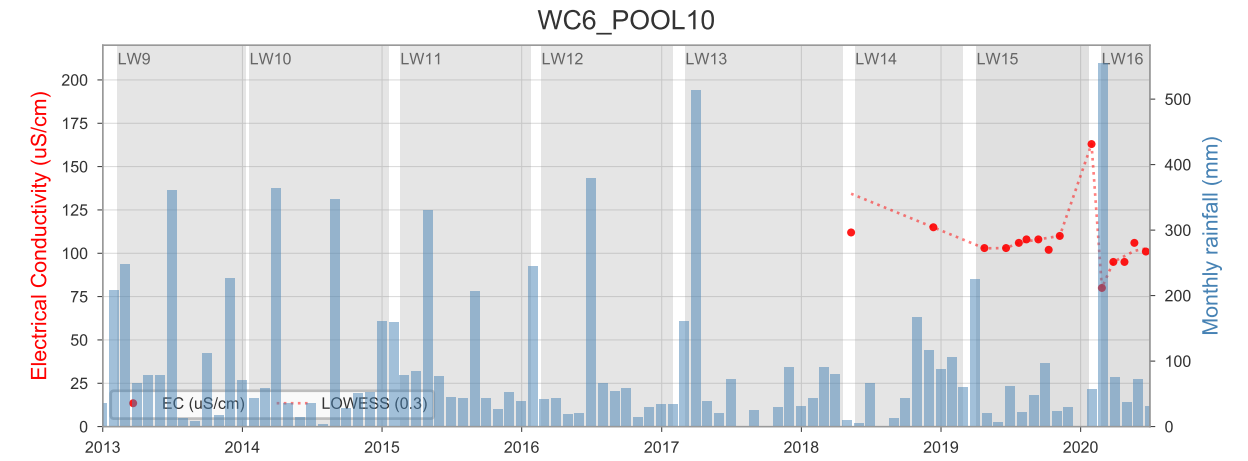

WC15S1
Stream flow (ML/day)
Monthly rainfall (mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Flow (ML/d)
P5-P95 flow
2013
2014
2015
2016
2017
2018
2019
2020

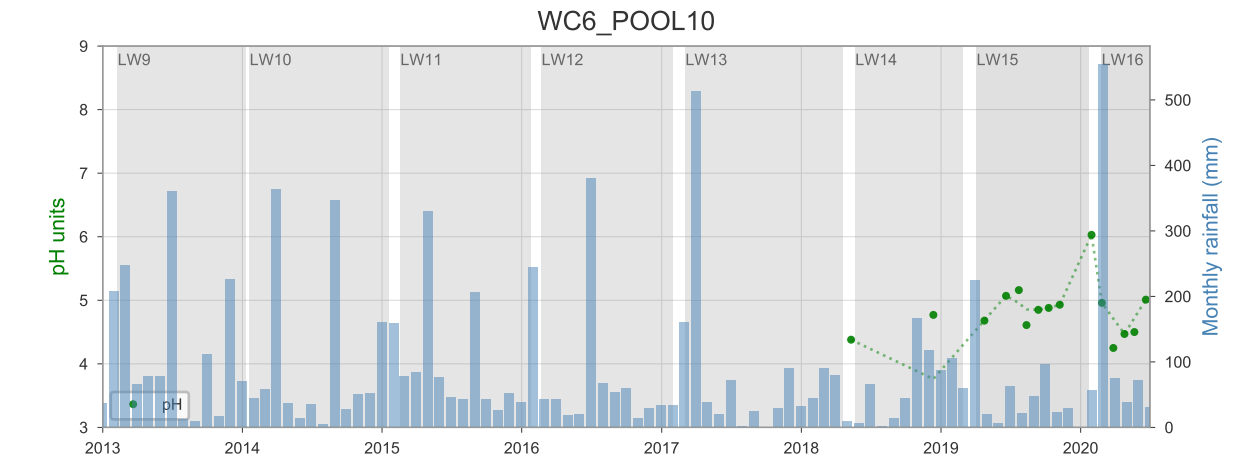

WC15_POOL9
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
EC (uS/cm)
LOWESS (0.3)
2013
2014
2015
2016
2017
2018
2019
2020

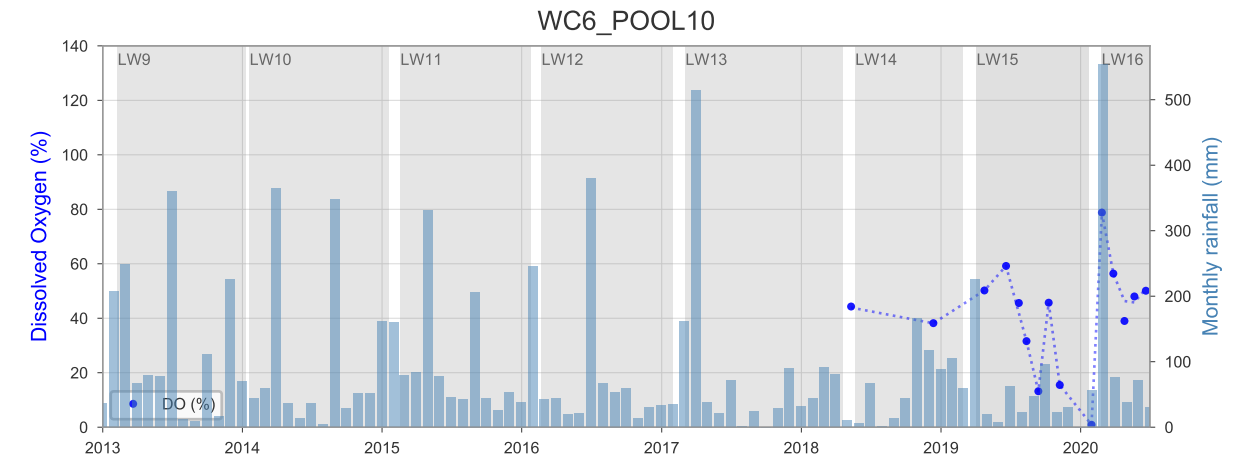

WC15_POOL9
pH units
Monthly rainfall (mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH
2013
2014
2015
2016
2017
2018
2019
2020

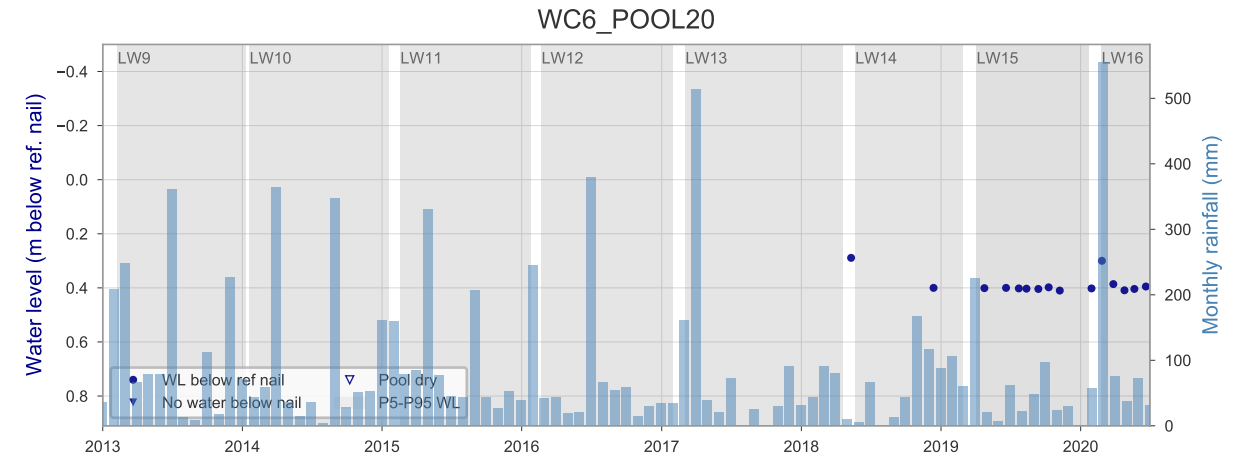

WC15_POOL9
Dissolved Oxygen (%)
Monthly rainfall (mm)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
DO (%)
2013
2014
2015
2016
2017
2018
2019
2020

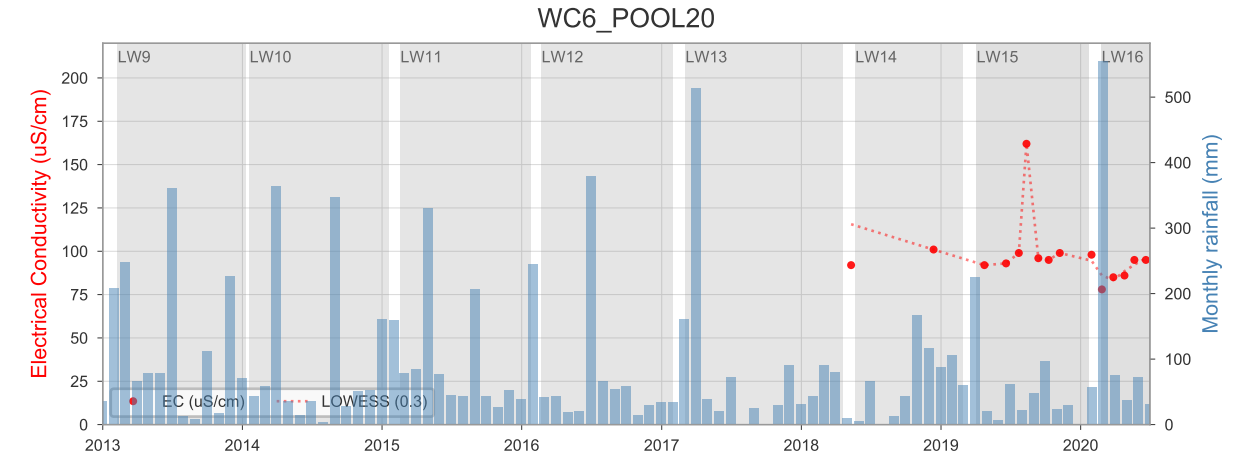

WC6_POOL10
Water level (m below ref. nail)
Monthly rainfall (mm)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2013
2014
2015
2016
2017
2018
2019
2020

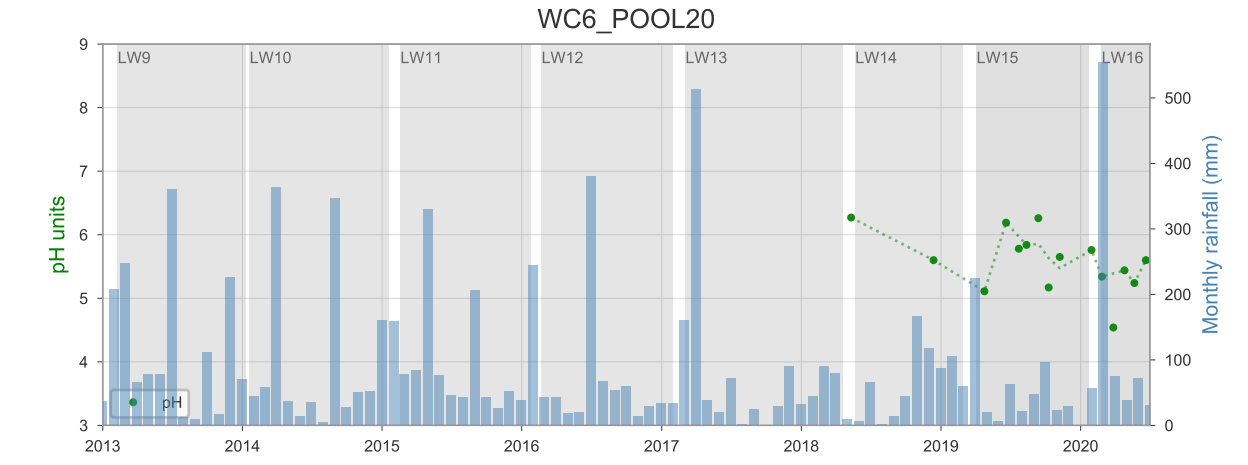

WC6_POOL10
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
EC (uS/cm)
LOWESS (0.3)
2013
2014
2015
2016
2017
2018
2019
2020

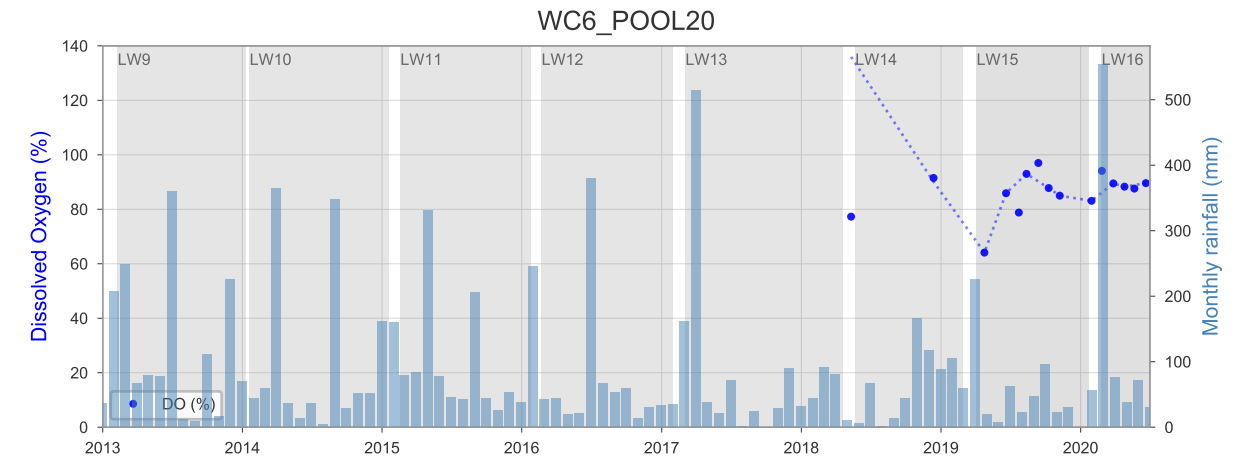

WC6_POOL10
pH units
Monthly rainfall (mm)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH
2013
2014
2015
2016
2017
2018
2019
2020

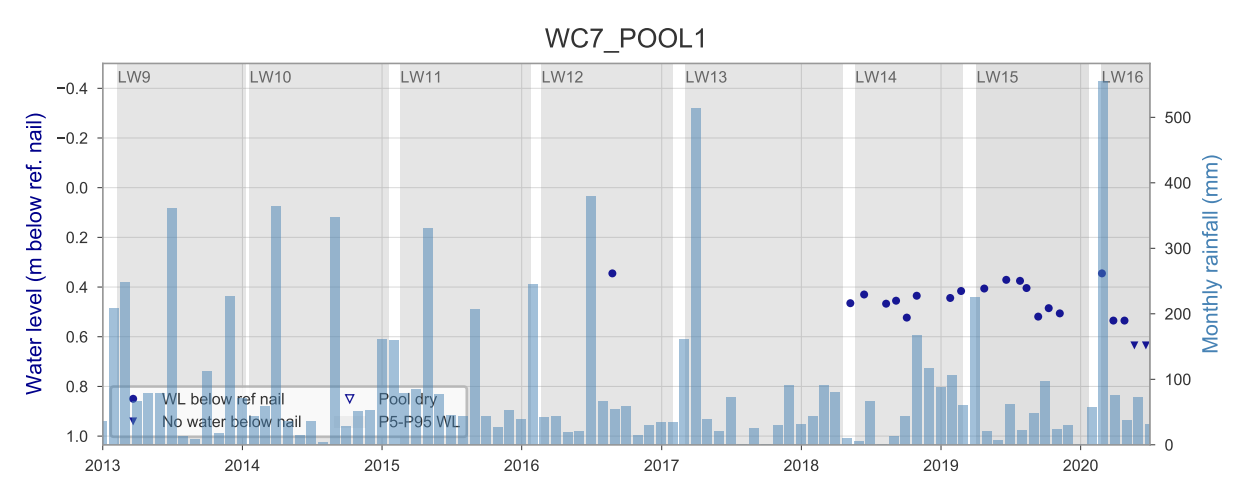

WC6_POOL10
Dissolved Oxygen (%)
Monthly rainfall (mm)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
DO (%)
2013
2014
2015
2016
2017
2018
2019
2020

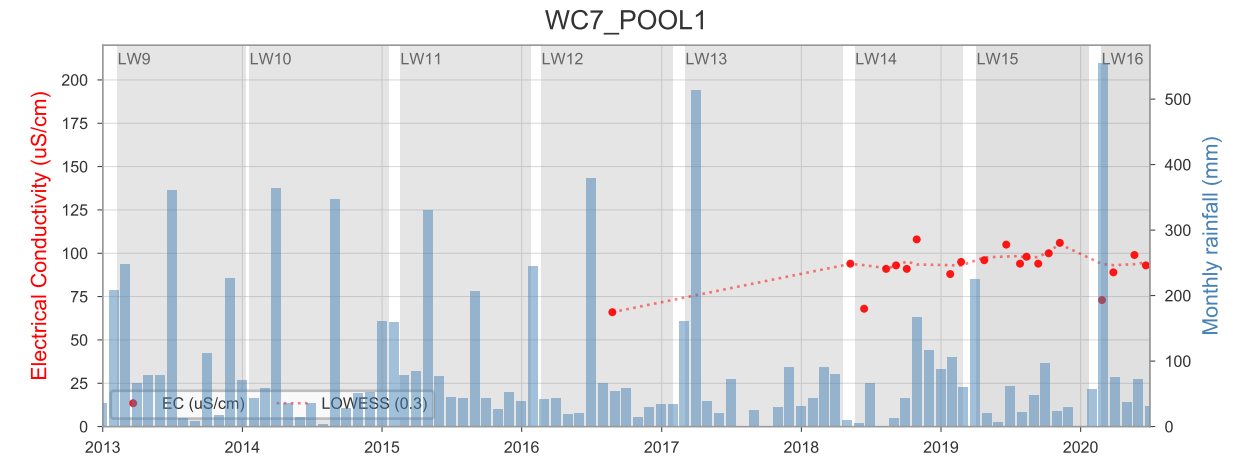

WC6_POOL20
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2013
2014
2015
2016
2017
2018
2019
2020

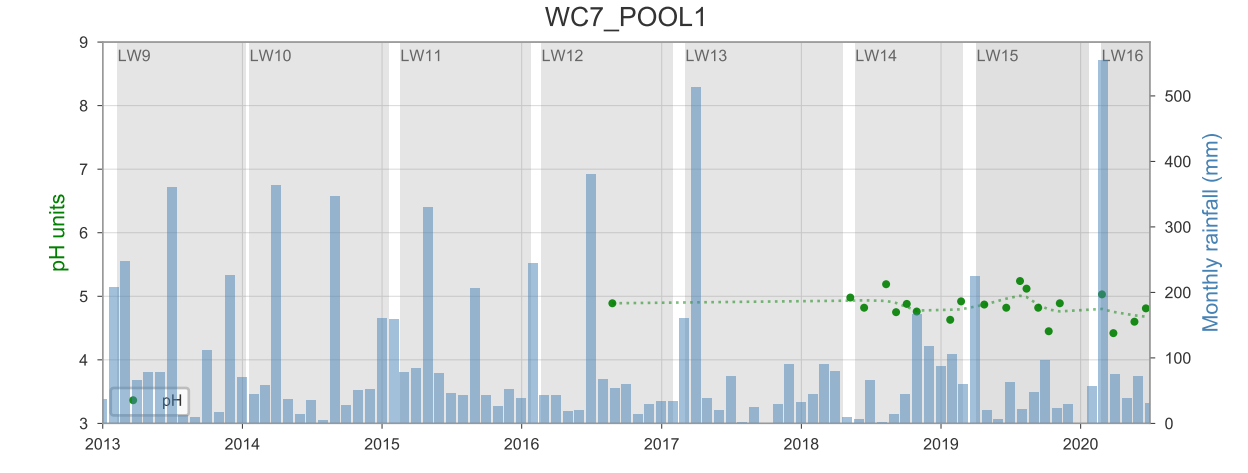

WC6_POOL20
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
2013
2014
2015
2016
2017
2018
2019
2020

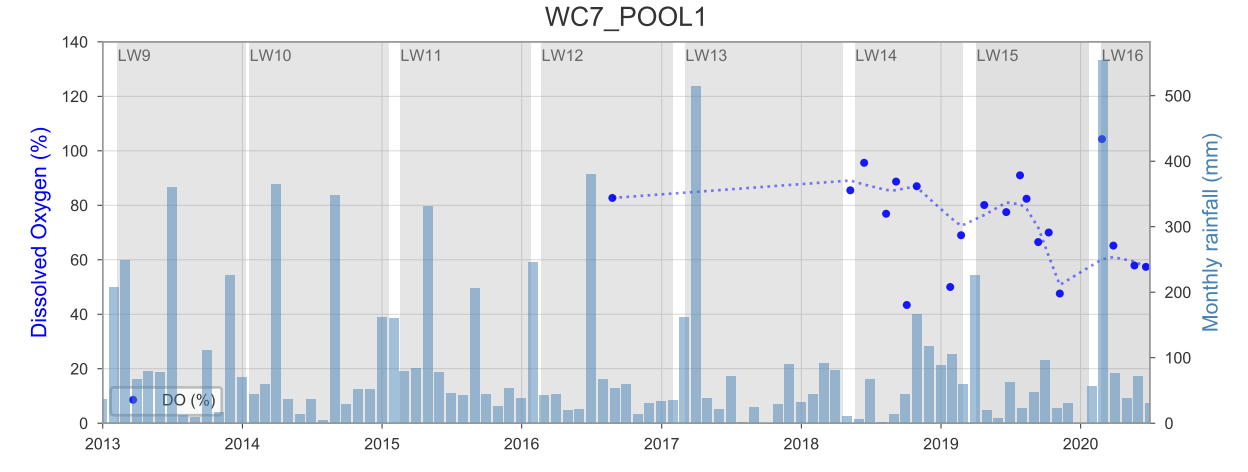

WC6_POOL20
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH
2013
2014
2015
2016
2017
2018
2019
2020

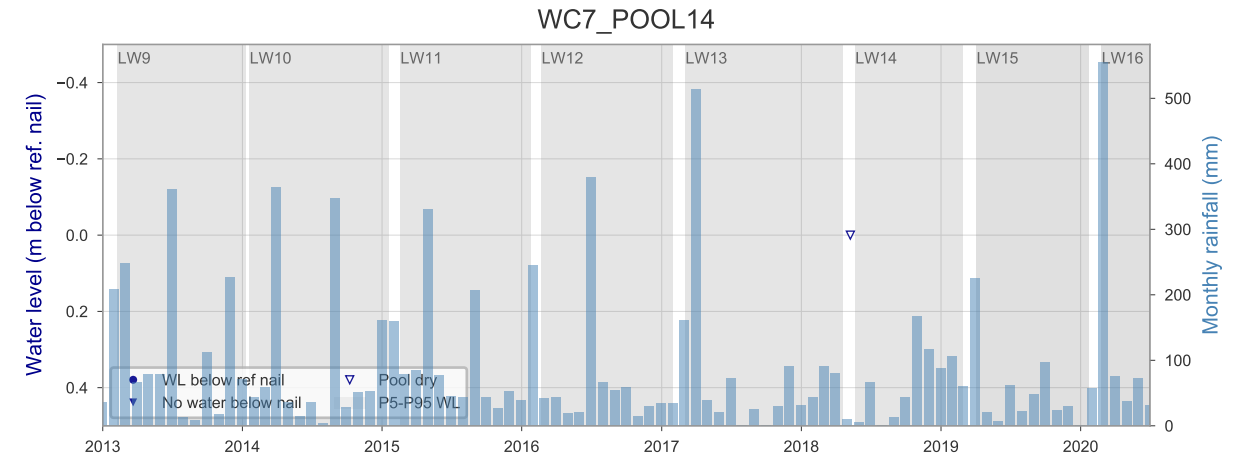

WC6_POOL20
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
2013
2014
2015
2016
2017
2018
2019
2020

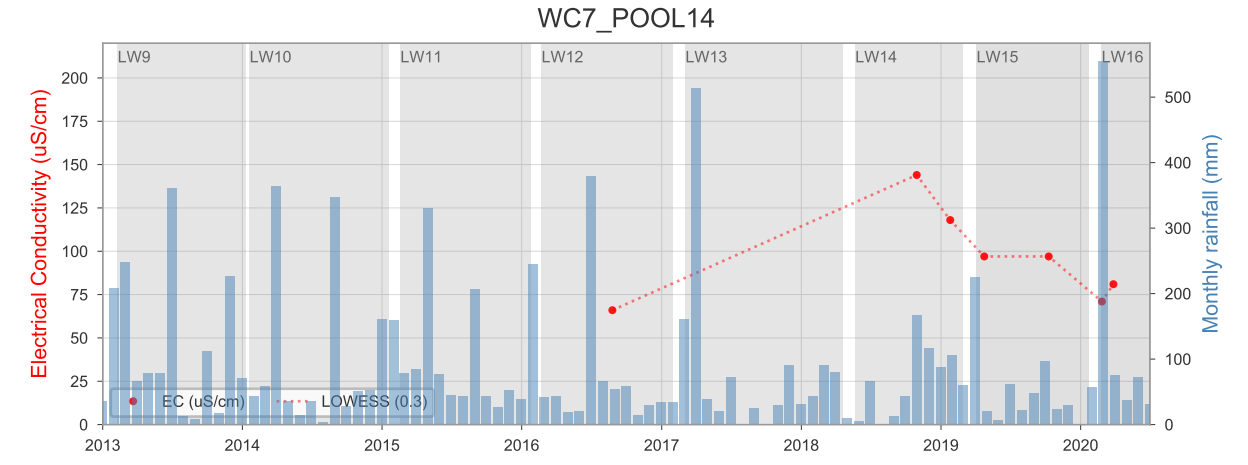

WC7_POOL1
Water level (m below ref. nail)
Monthly rainfall (mm)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2013
2014
2015
2016
2017
2018
2019
2020

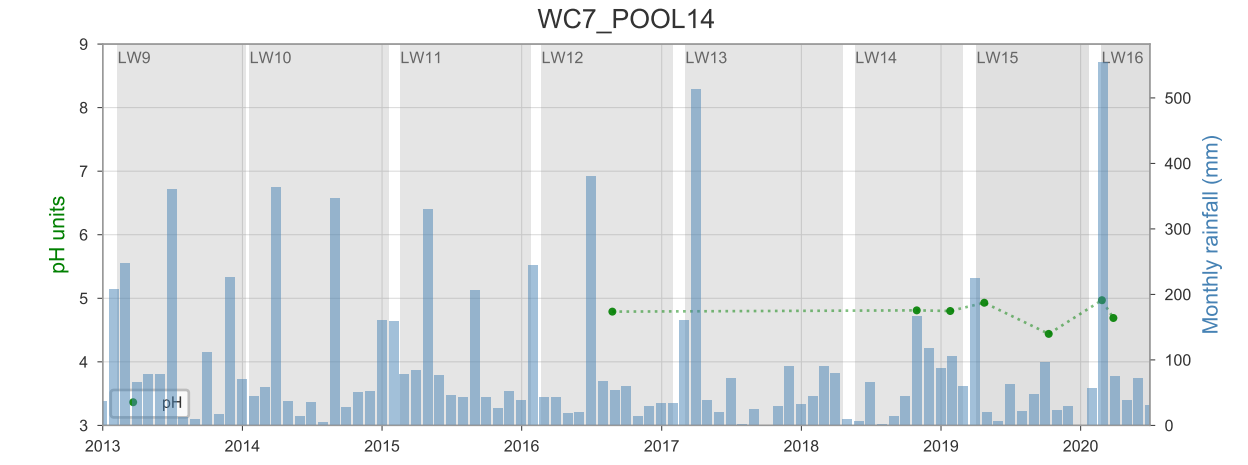

WC7_POOL1
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
EC (uS/cm)
LOWESS (0.3)
2013
2014
2015
2016
2017
2018
2019
2020

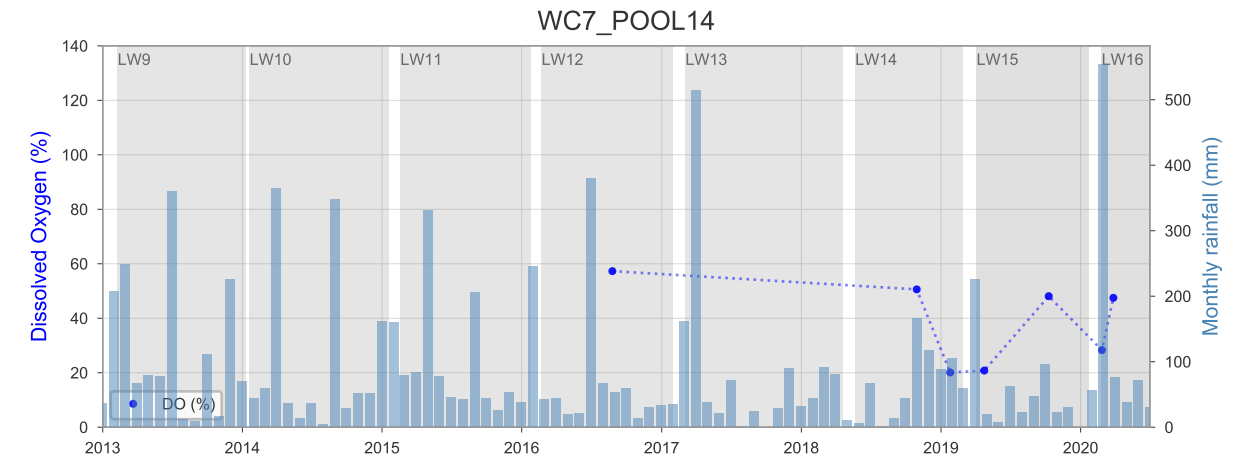

WC7_POOL1
pH units
Monthly rainfall (mm)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH
2013
2014
2015
2016
2017
2018
2019
2020

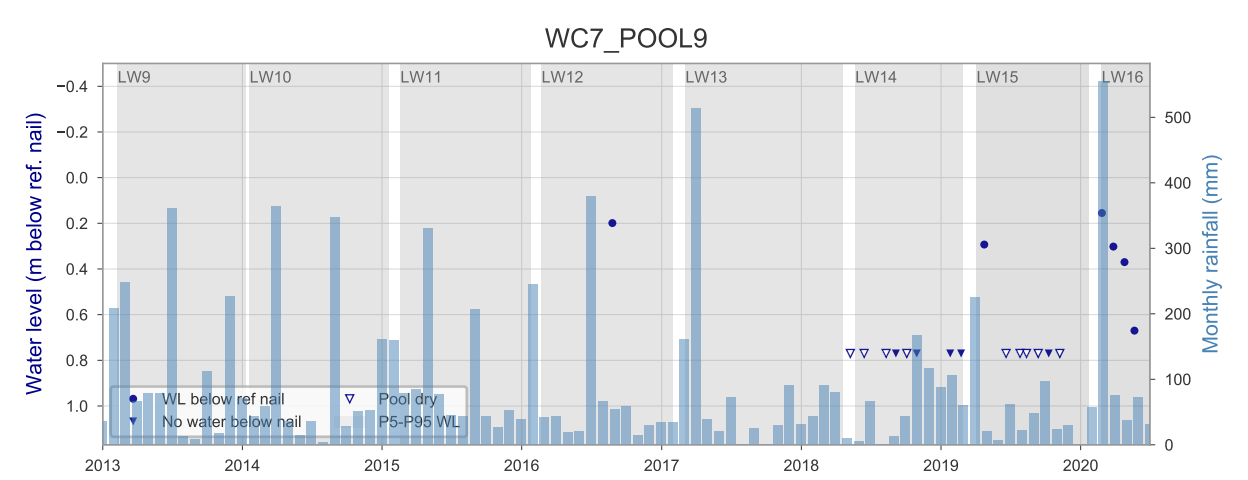

WC7_POOL1
Dissolved Oxygen (%)
Monthly rainfall (mm)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
DO (%)
2013
2014
2015
2016
2017
2018
2019
2020

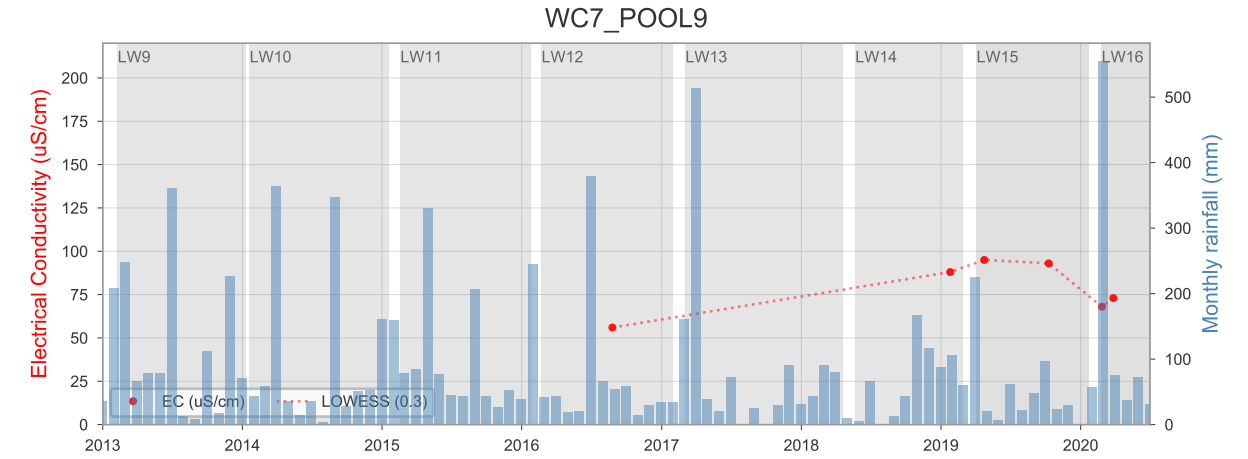

WC7_POOL14
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2013
2014
2015
2016
2017
2018
2019
2020

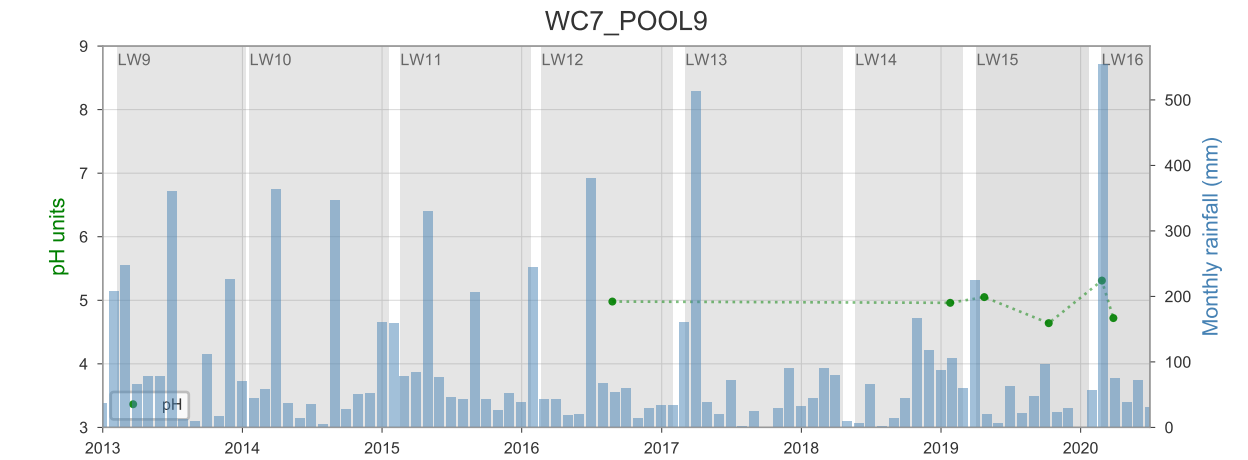

WC7_POOL14
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
2013
2014
2015
2016
2017
2018
2019
2020

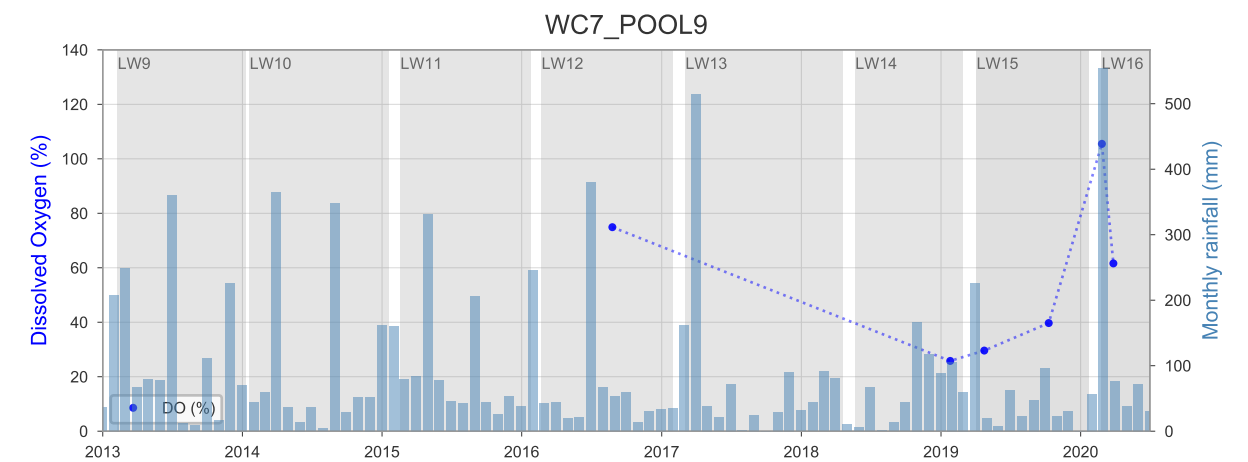

WC7_POOL14
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH
2013
2014
2015
2016
2017
2018
2019
2020

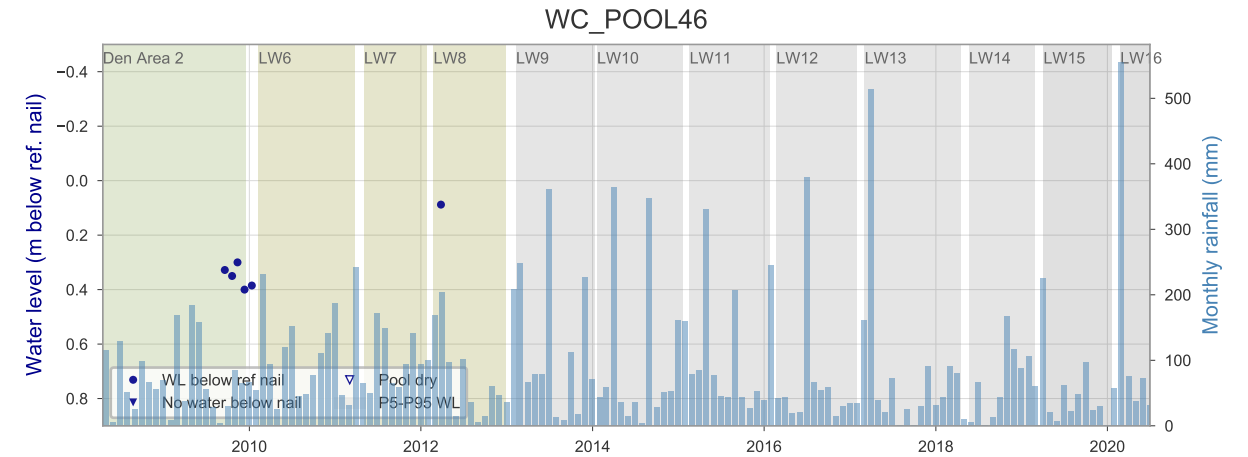

WC7_POOL14
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
2013
2014
2015
2016
2017
2018
2019
2020

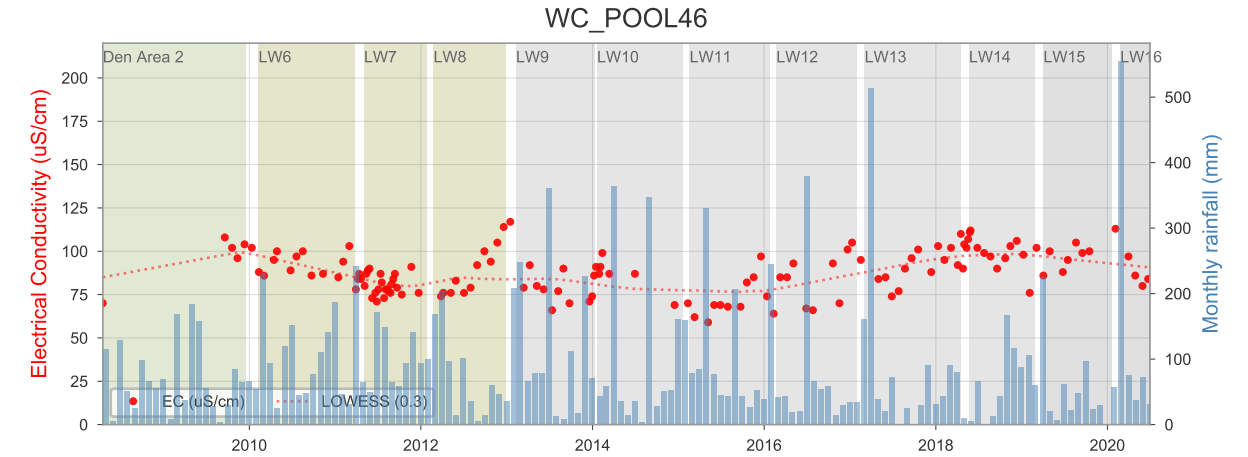

WC7_POOL9
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2013
2014
2015
2016
2017
2018
2019
2020

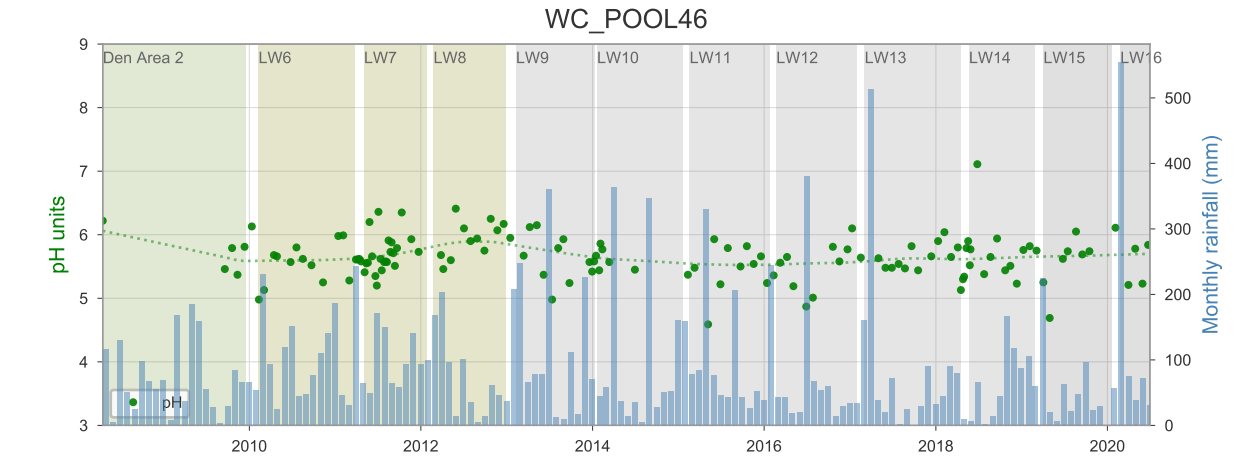

WC7_POOL9
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
2013
2014
2015
2016
2017
2018
2019
2020

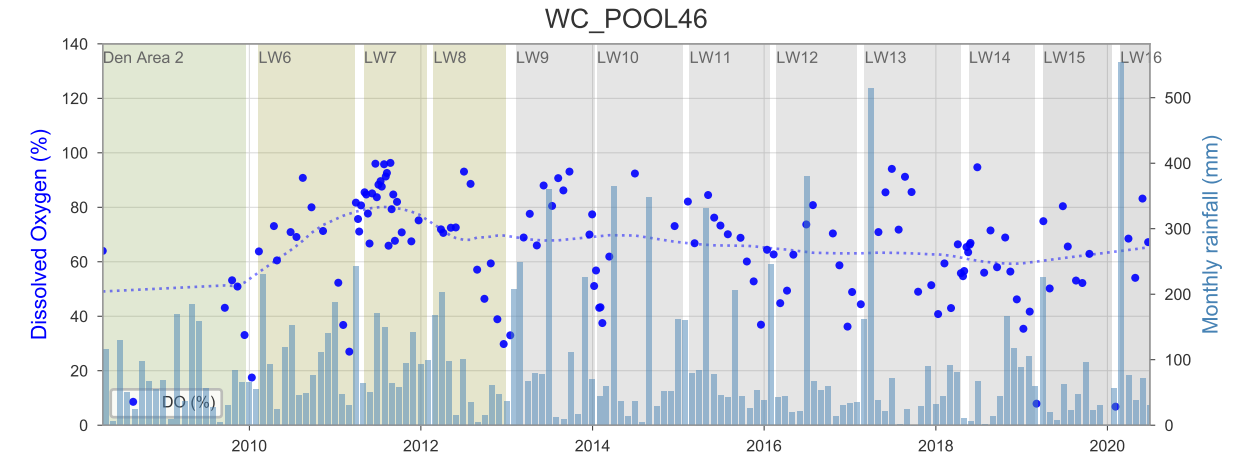

WC7_POOL9
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH
2013
2014
2015
2016
2017
2018
2019
2020

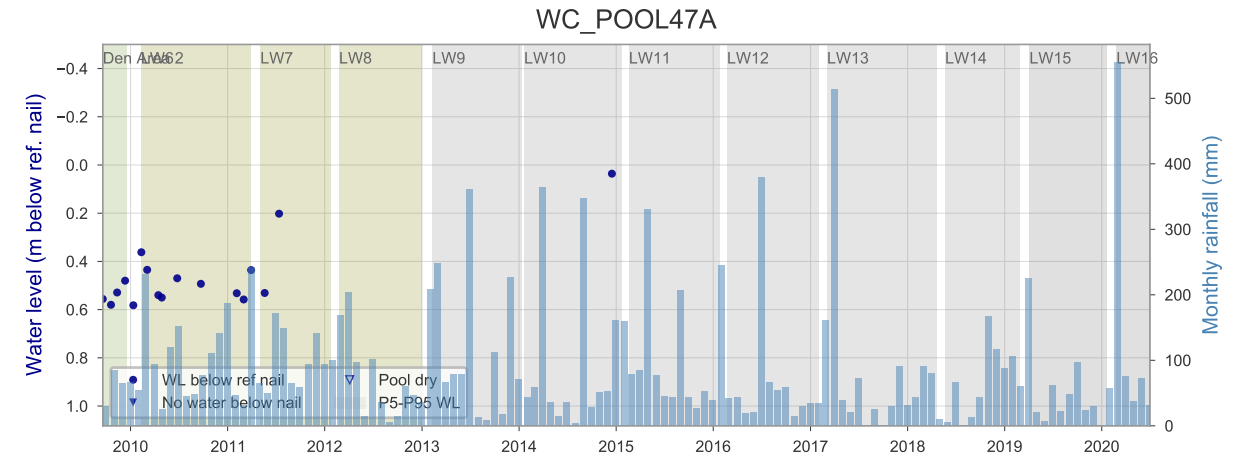

WC7_POOL9
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
2013
2014
2015
2016
2017
2018
2019
2020

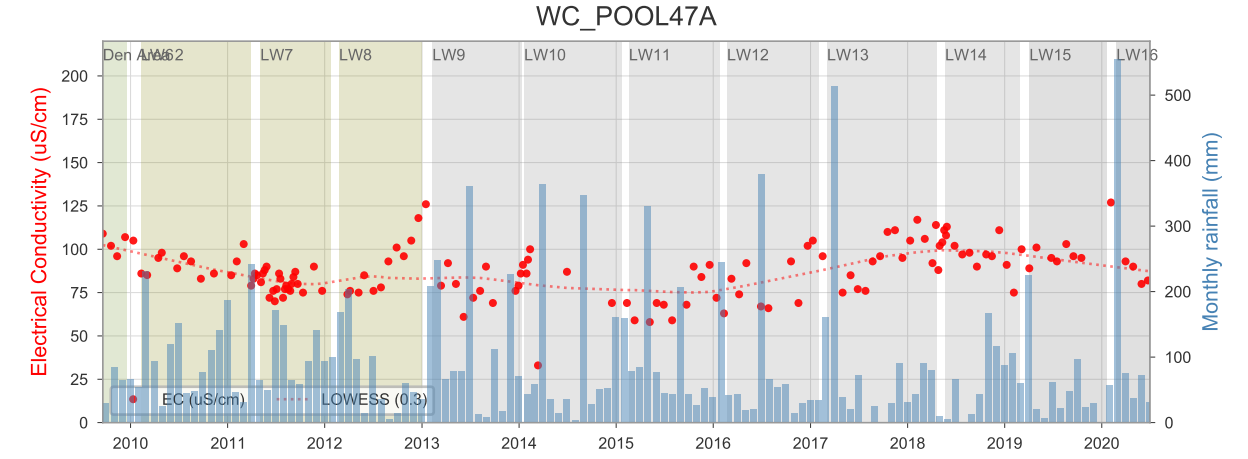

WC_POOL46
Water level (m below ref. nail)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2010
2012
2014
2016
2018
2020

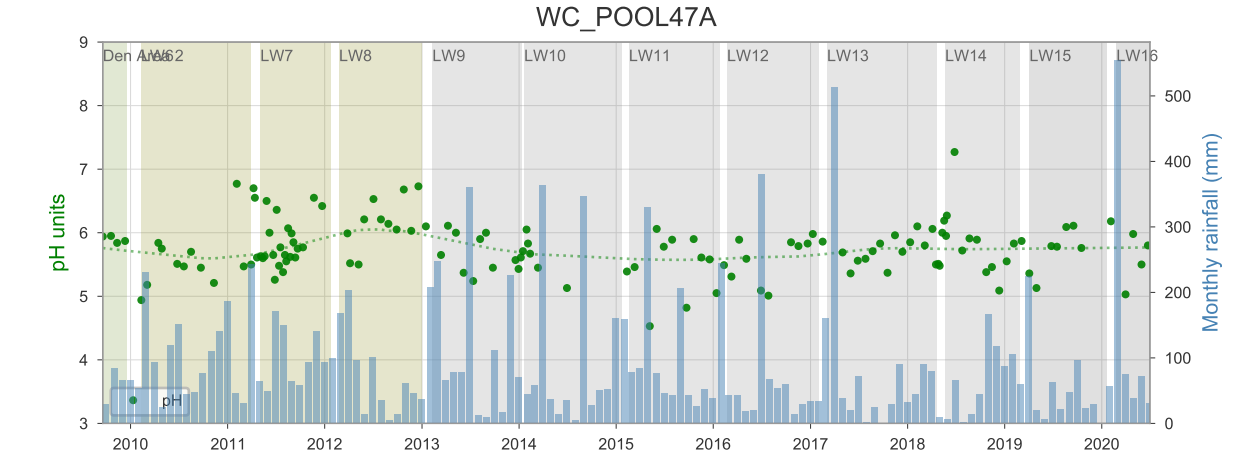

WC_POOL46
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
EC (uS/cm)
LOWESS (0.3)
2010
2012
2014
2016
2018
2020

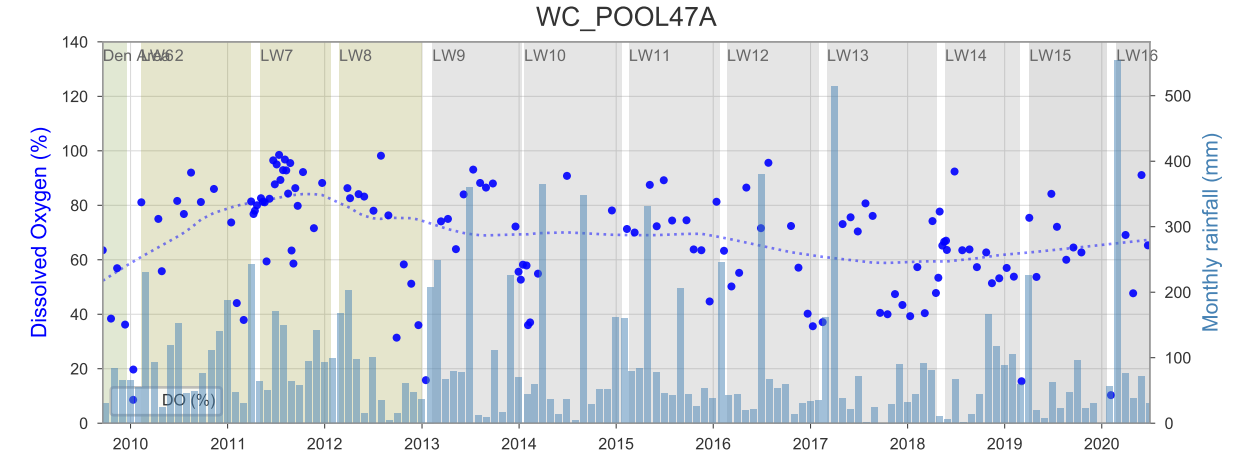

WC_POOL46
pH units
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH
2010
2012
2014
2016
2018
2020

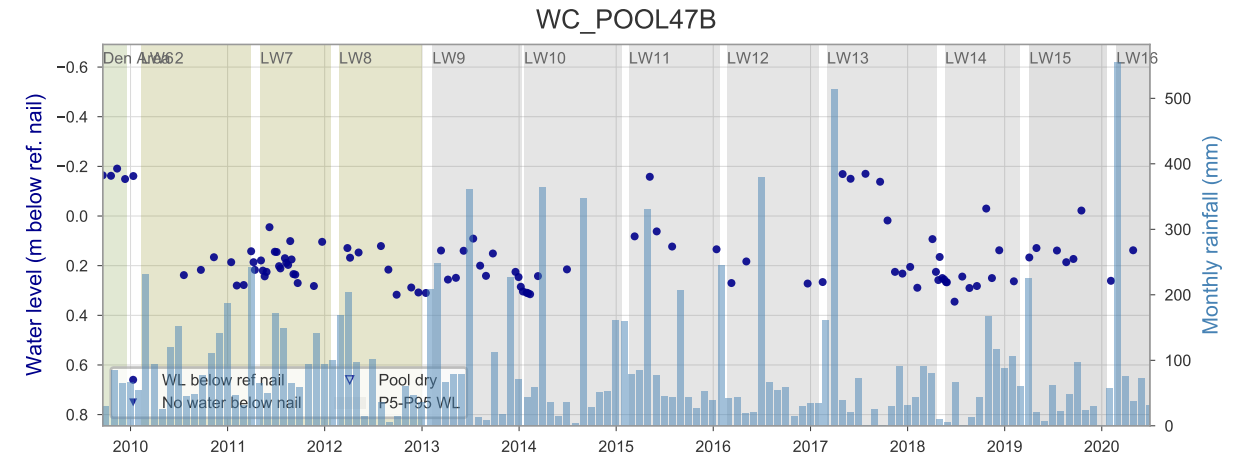

WC_POOL46
Dissolved Oxygen (%)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
DO (%)
2010
2012
2014
2016
2018
2020

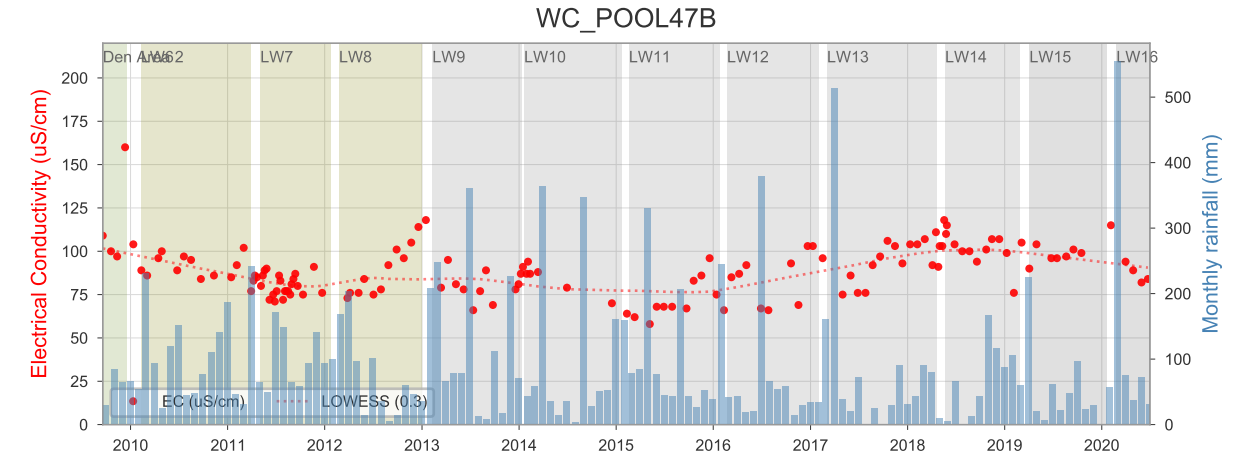

WC_POOL47A
Water level (m below ref. nail)
Monthly rainfall (mm)
Den Ana
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
WL below ref nail
No water below nail
Pool dry
P5-P95 WL

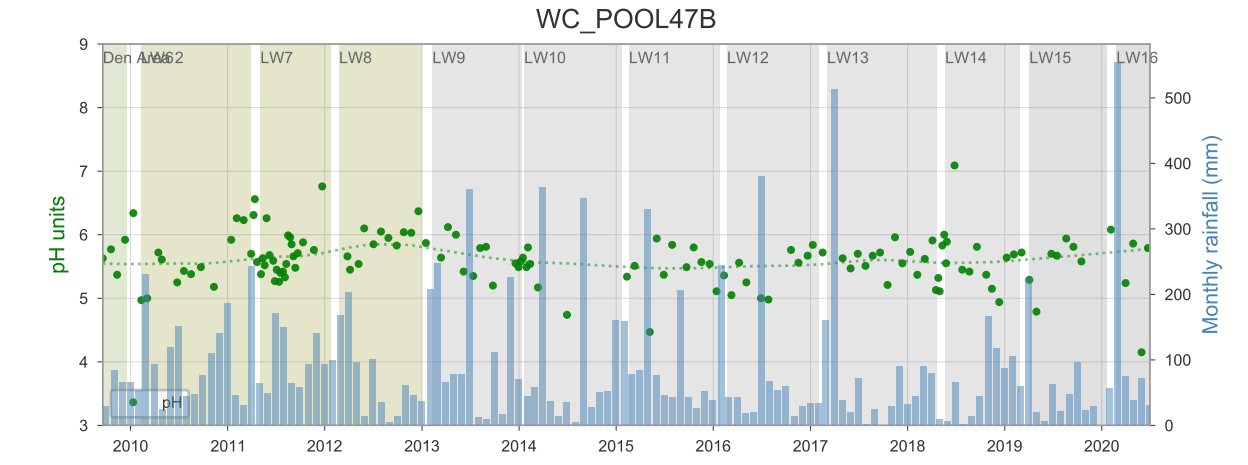

WC_POOL47A
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)

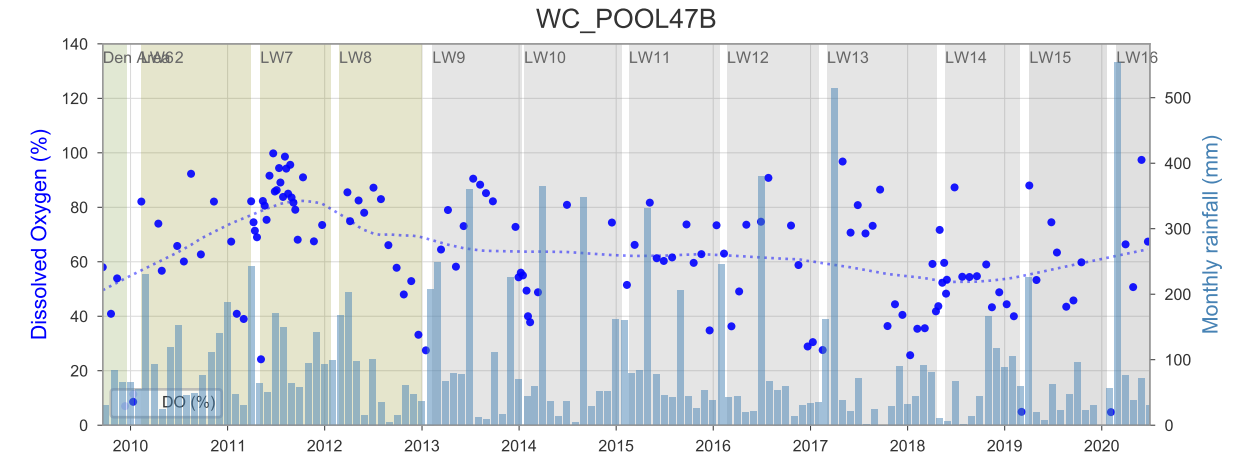

WC_POOL47A
pH units
Monthly rainfall (mm)
pH

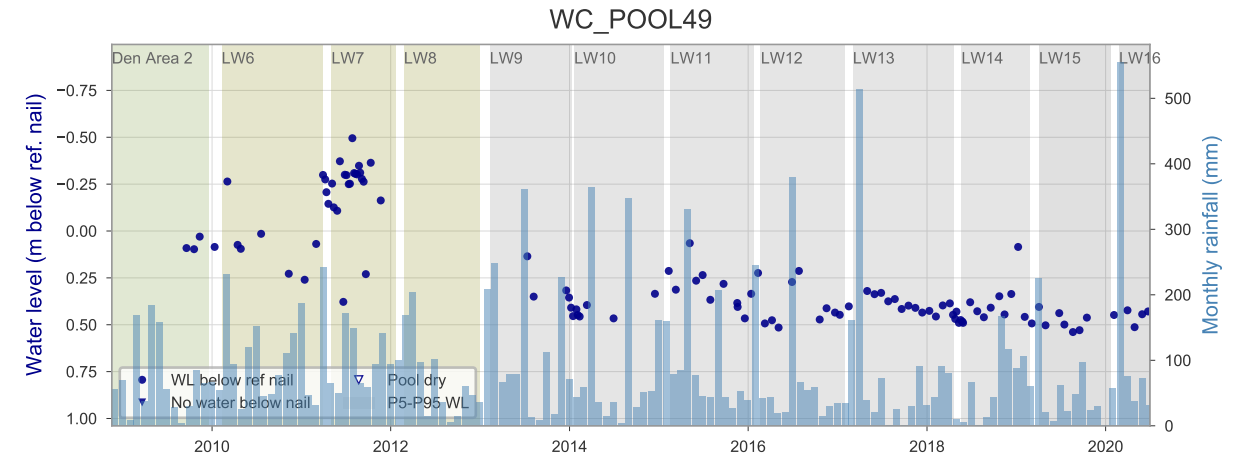

WC_POOL47A
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)

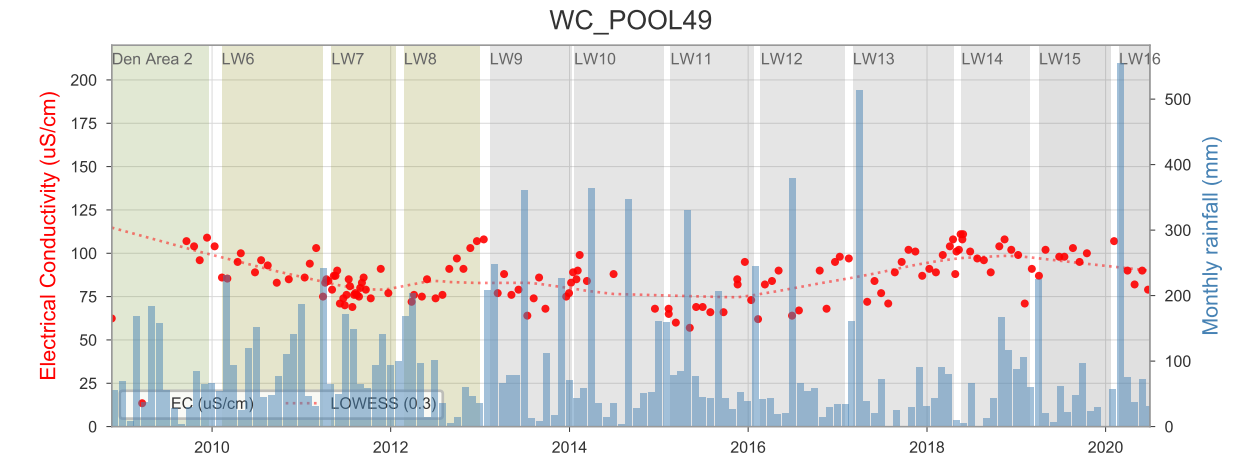

WC_POOL47B
Water level (m below ref. nail)
Monthly rainfall (mm)
Den Ana
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
WL below ref nail
No water below nail
Pool dry
P5-P95 WL

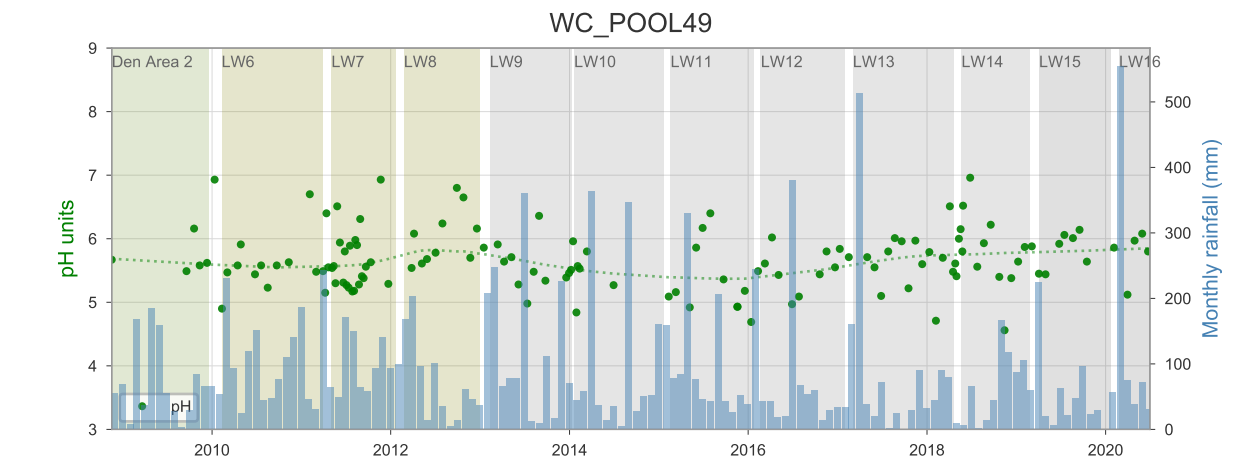

WC_POOL47B
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)

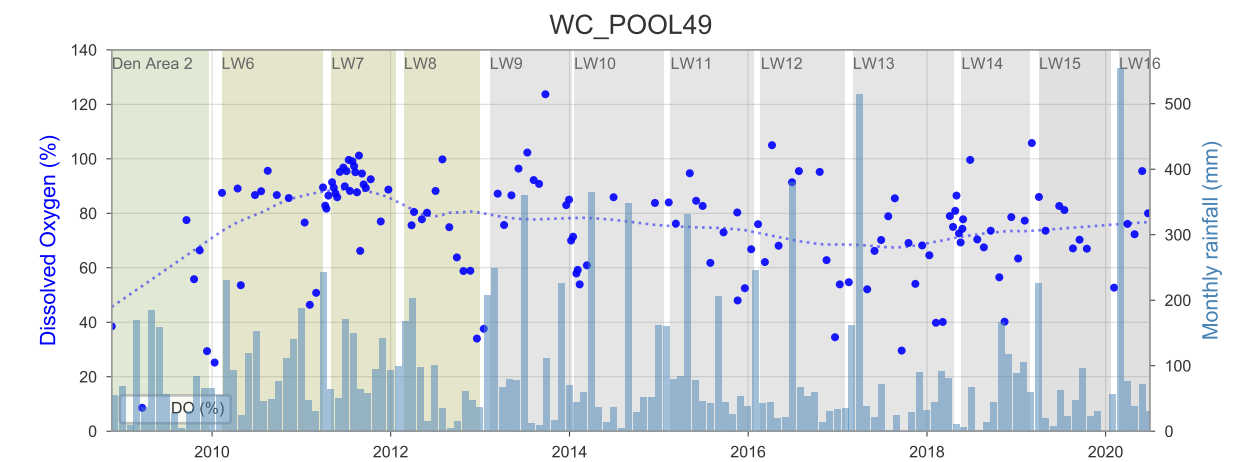

WC_POOL47B
pH units
Monthly rainfall (mm)
pH

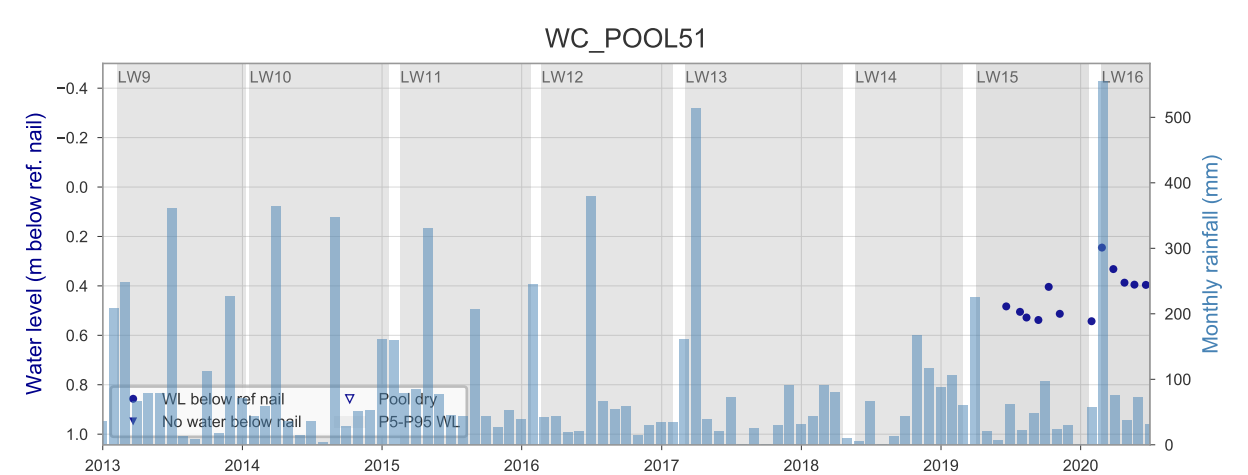

WC_POOL47B
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)

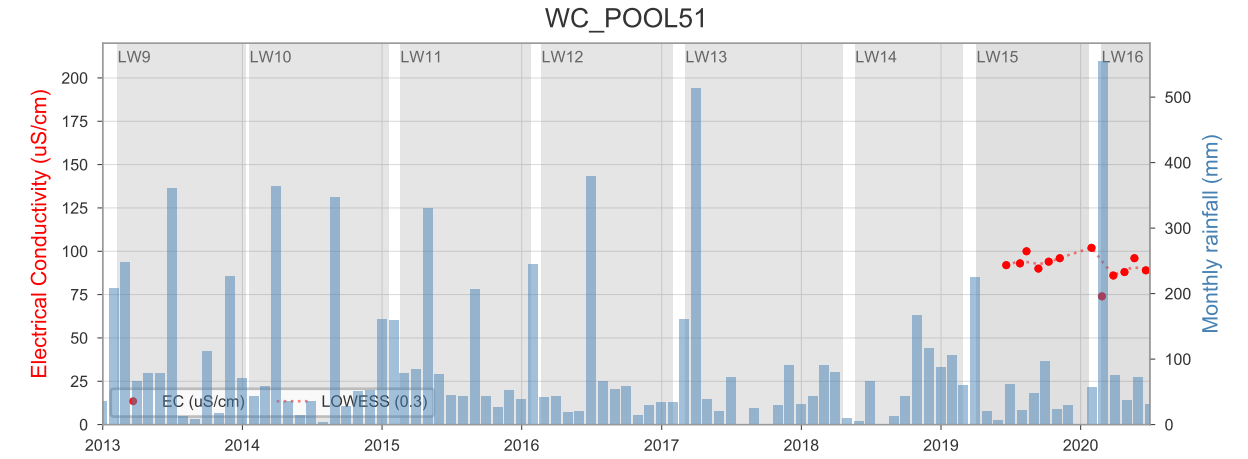

WC_POOL49
Water level (m below ref. nail)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2010
2012
2014
2016
2018
2020

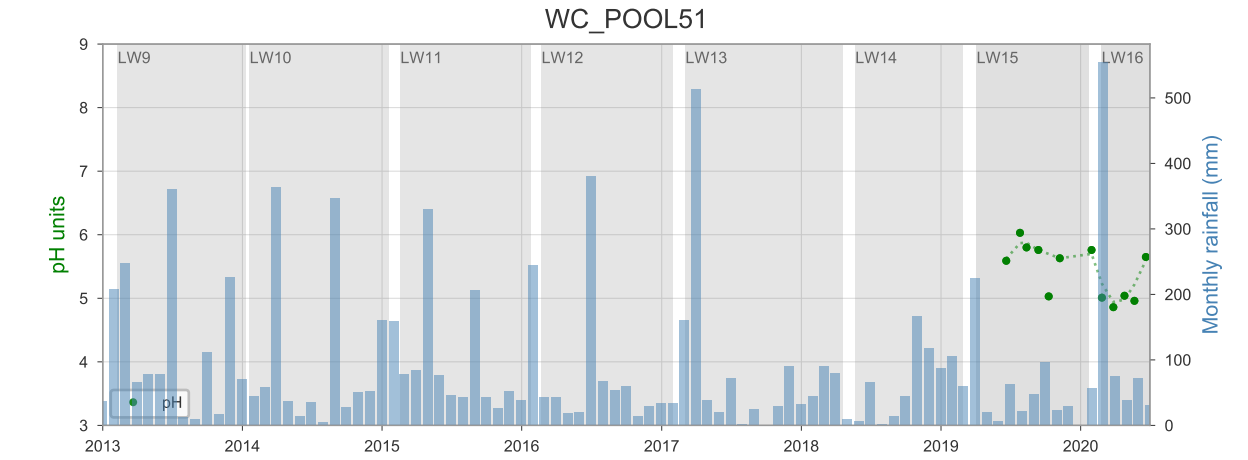

WC_POOL49
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
EC (uS/cm)
LOWESS (0.3)
2010
2012
2014
2016
2018
2020

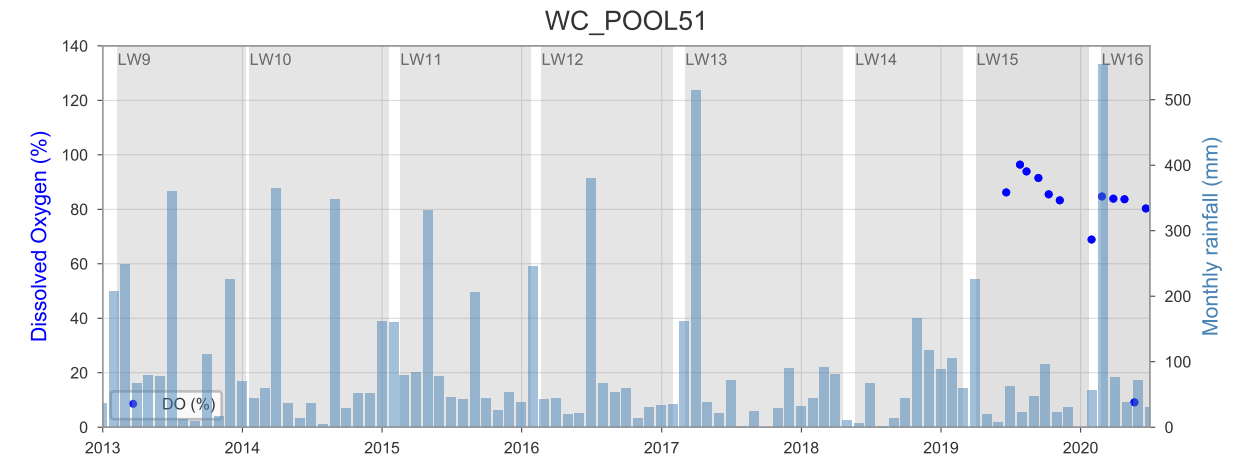

WC_POOL49
pH units
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH
2010
2012
2014
2016
2018
2020

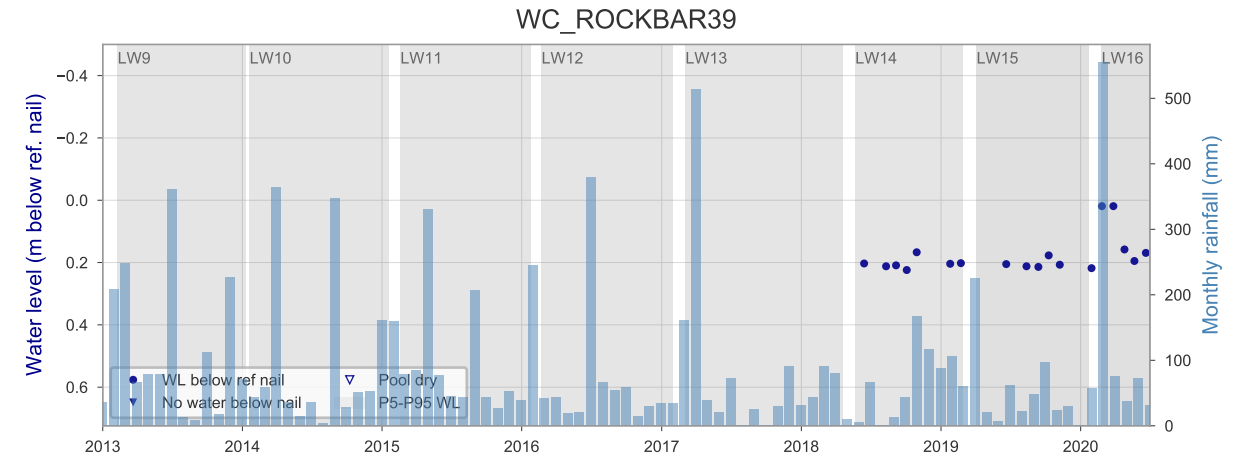

WC_POOL49
Dissolved Oxygen (%)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
DO (%)
2010
2012
2014
2016
2018
2020

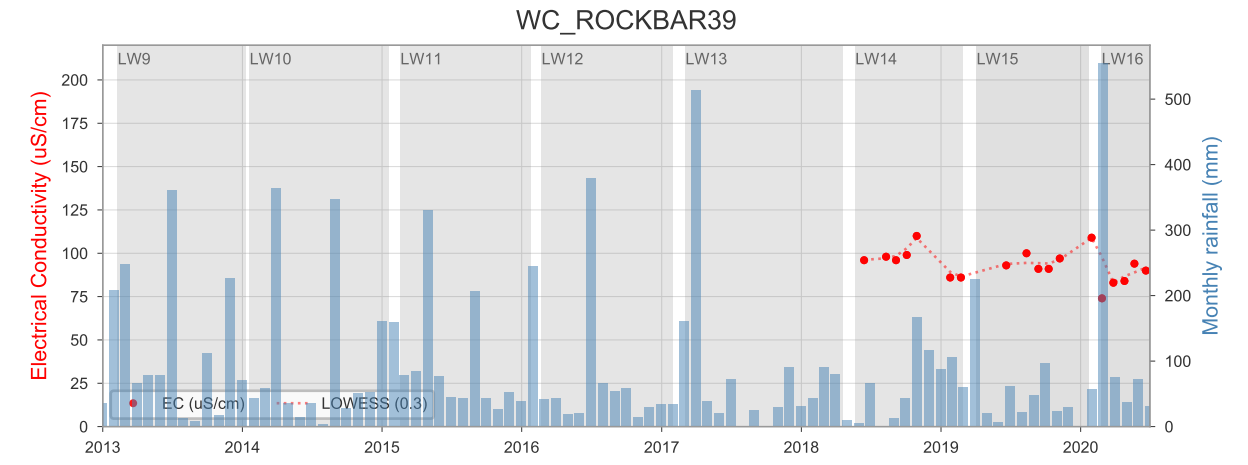

WC_POOL51
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2013
2014
2015
2016
2017
2018
2019
2020

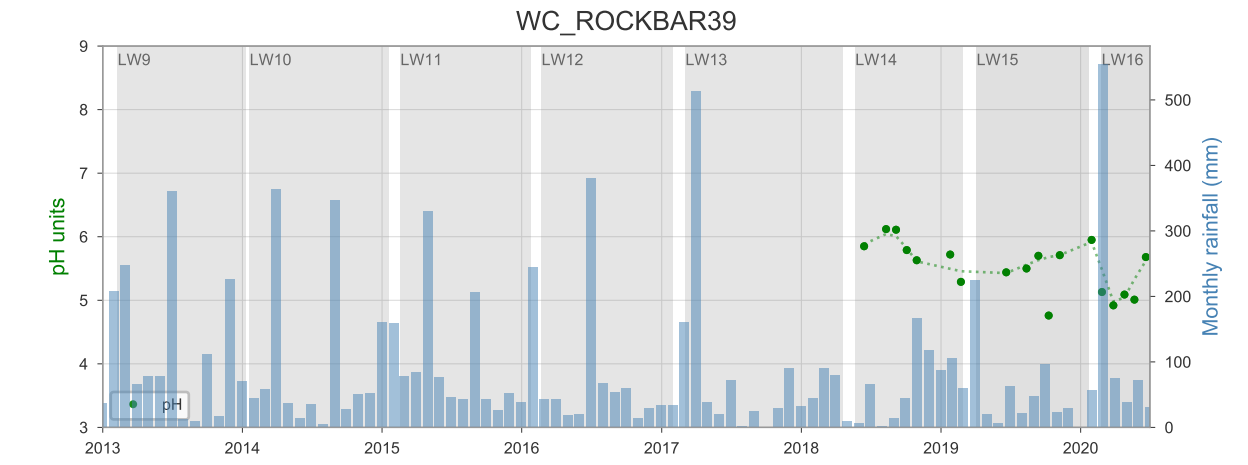

WC_POOL51
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
2013
2014
2015
2016
2017
2018
2019
2020

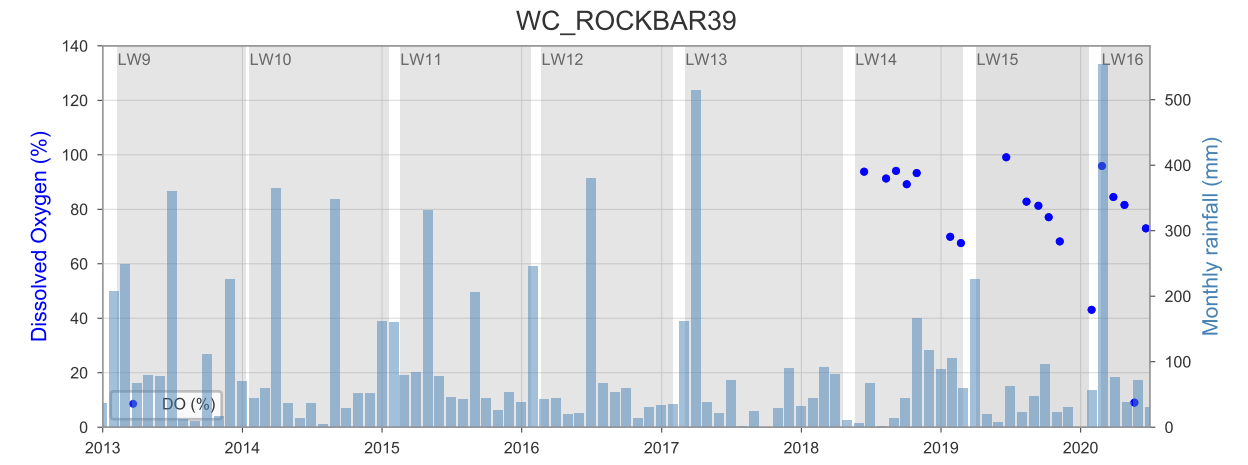

WC_POOL51
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH
2013
2014
2015
2016
2017
2018
2019
2020

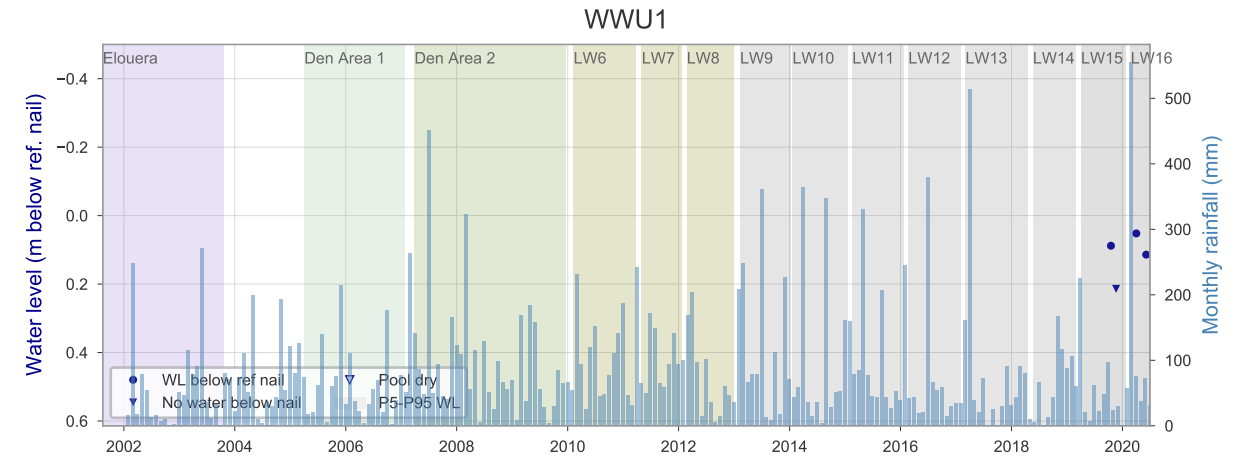

WC_POOL51
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
2013
2014
2015
2016
2017
2018
2019
2020

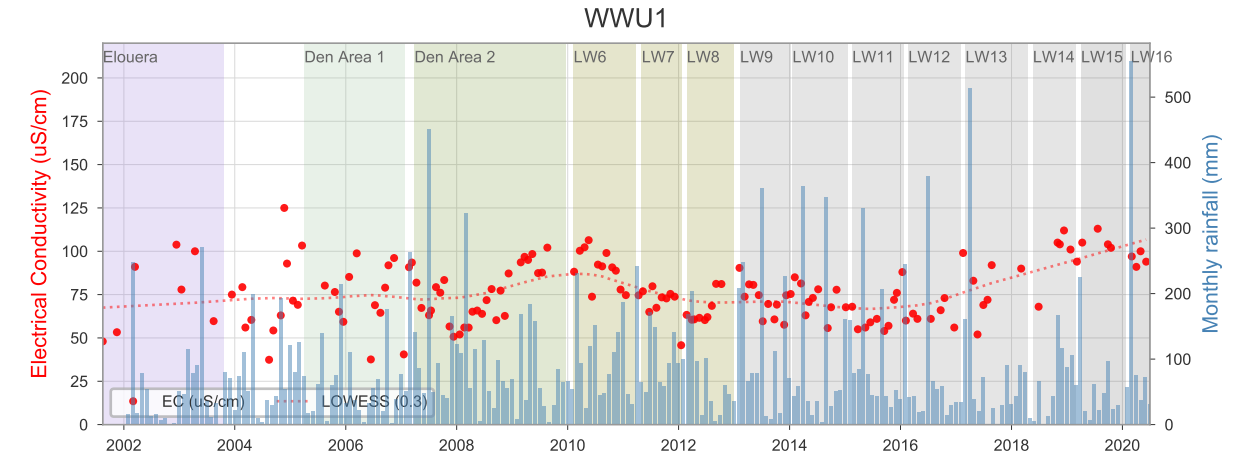

WC_ROCKBAR39
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
2013
2014
2015
2016
2017
2018
2019
2020

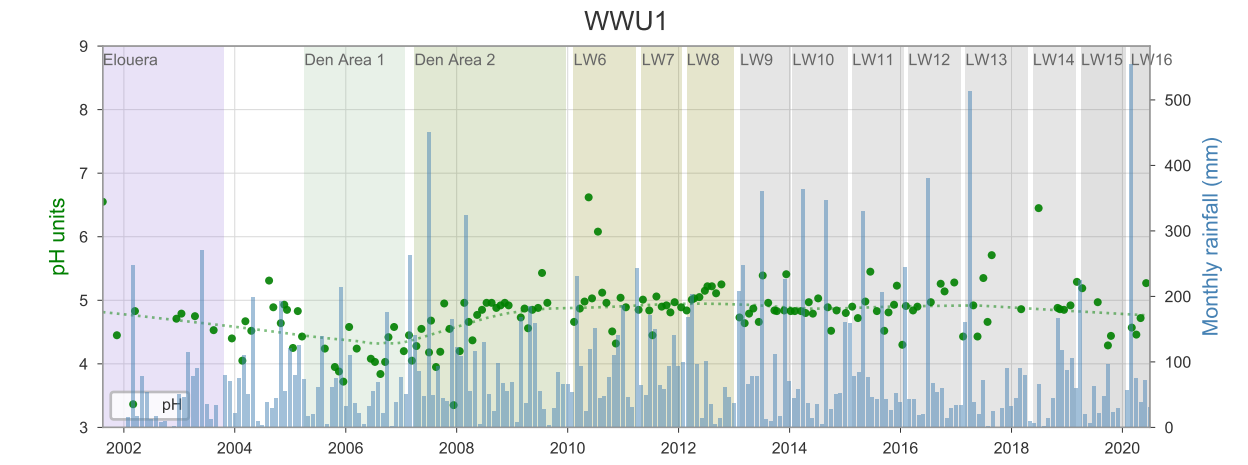

WC_ROCKBAR39
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
2013
2014
2015
2016
2017
2018
2019
2020

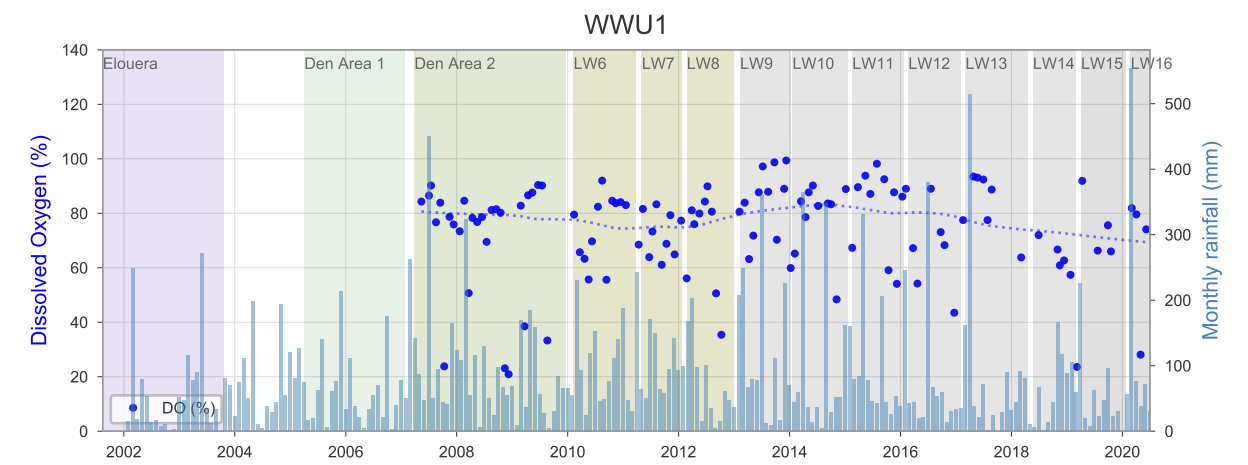

WC_ROCKBAR39
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH
2013
2014
2015
2016
2017
2018
2019
2020

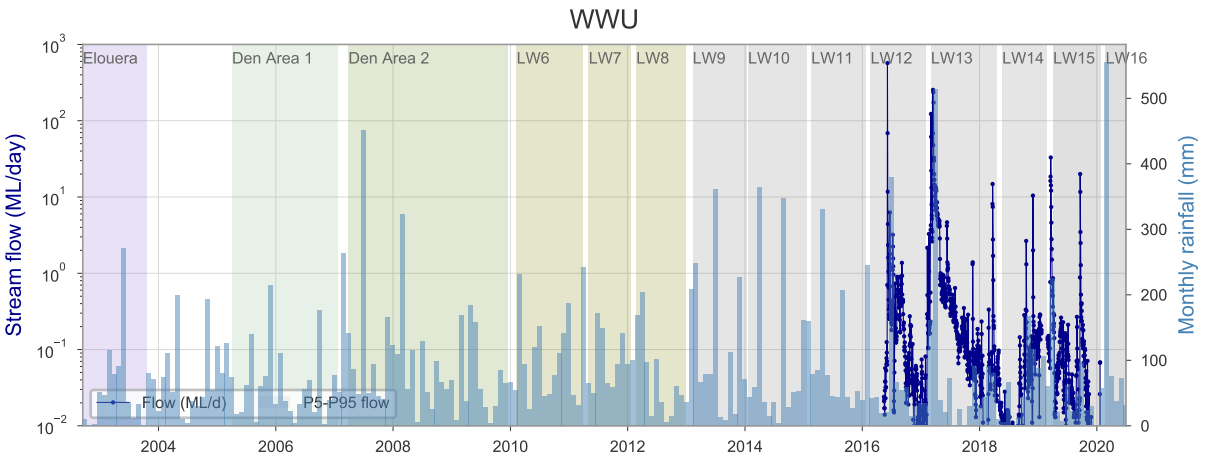

WC_ROCKBAR39
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
2013
2014
2015
2016
2017
2018
2019
2020

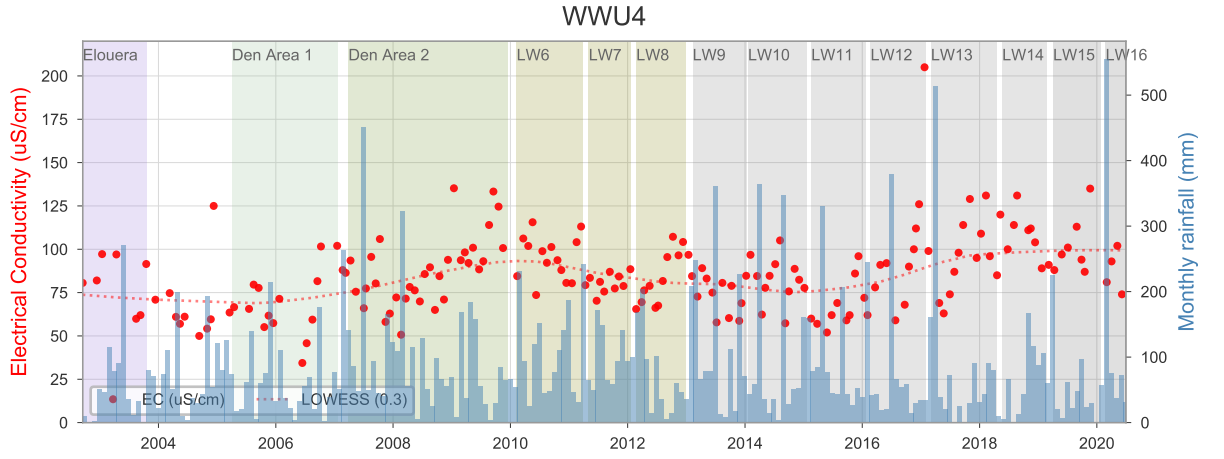

WWU1
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
Pool dry
P5-P95 WL

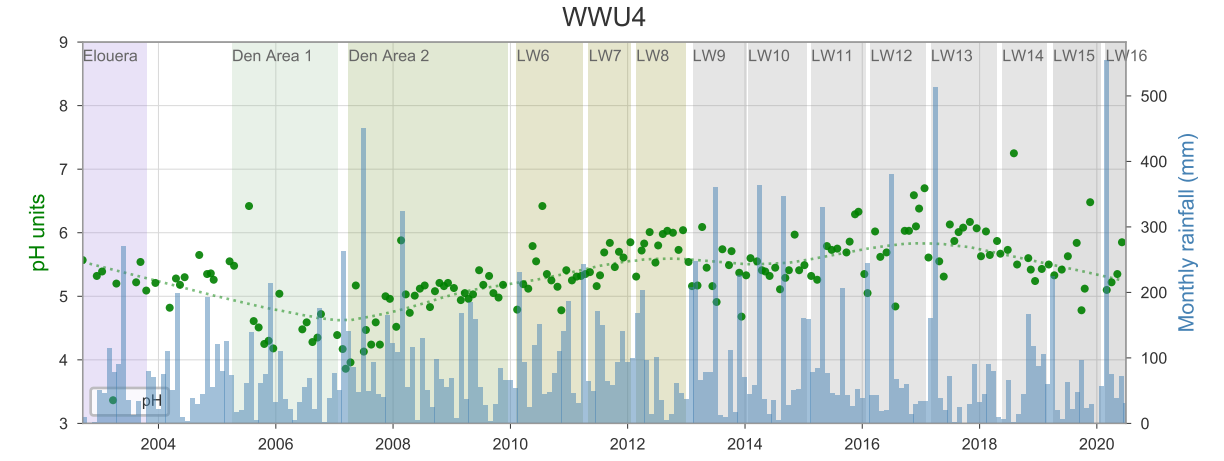

WWU1
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)

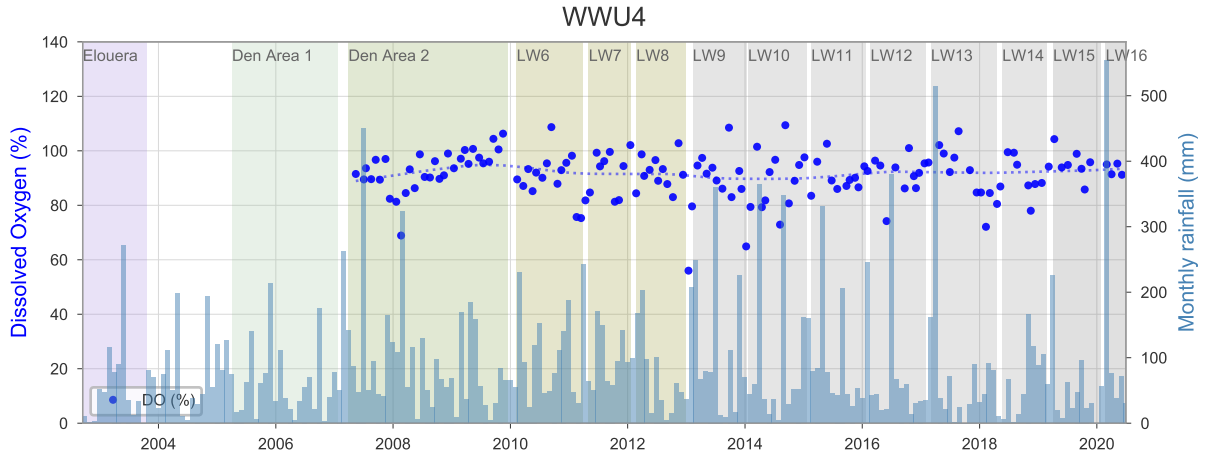

WWU1
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH units
Monthly rainfall (mm)
pH

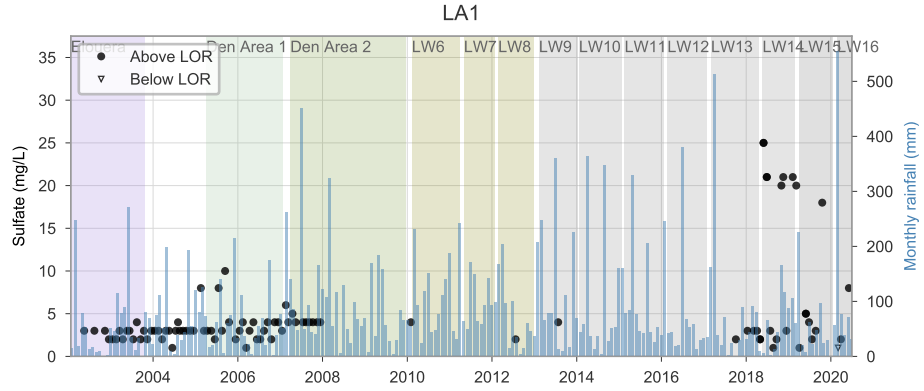

WWU1
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)

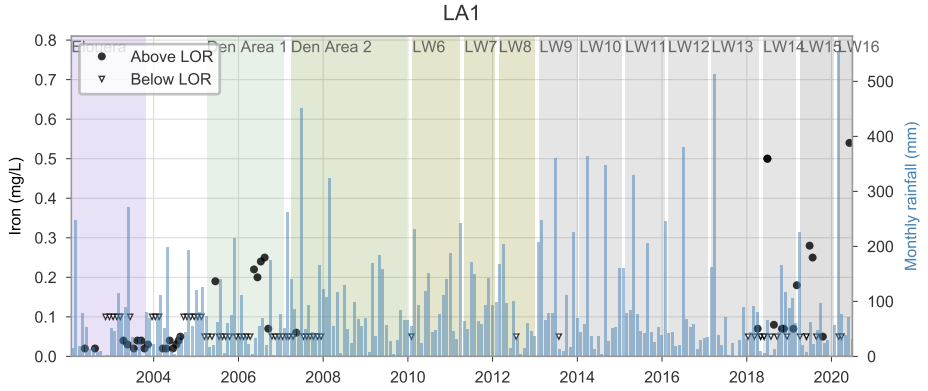

WWU
Stream flow (ML/day)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Flow (ML/d)
P5-P95 flow

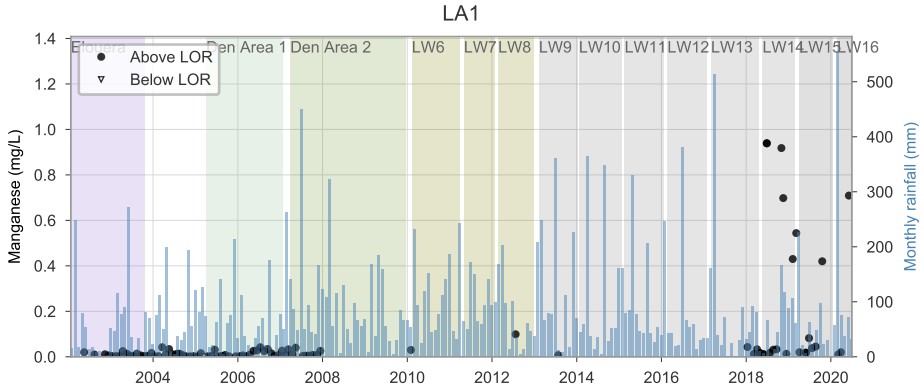

WWU4
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
EC (uS/cm)
LOWESS (0.3)

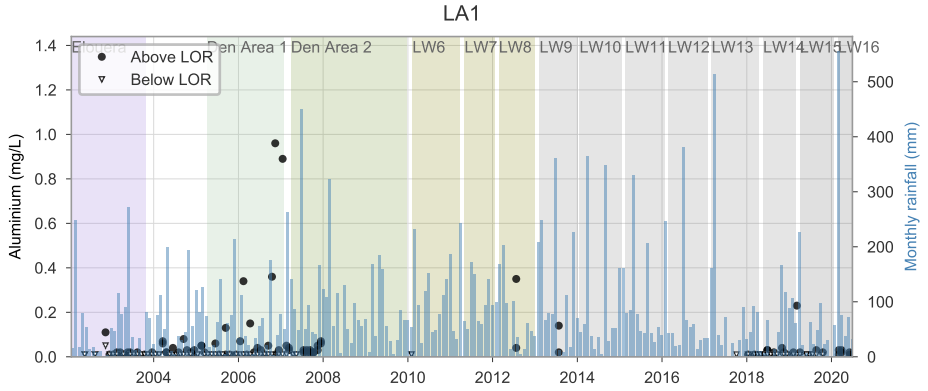

WWU4
pH units
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
pH

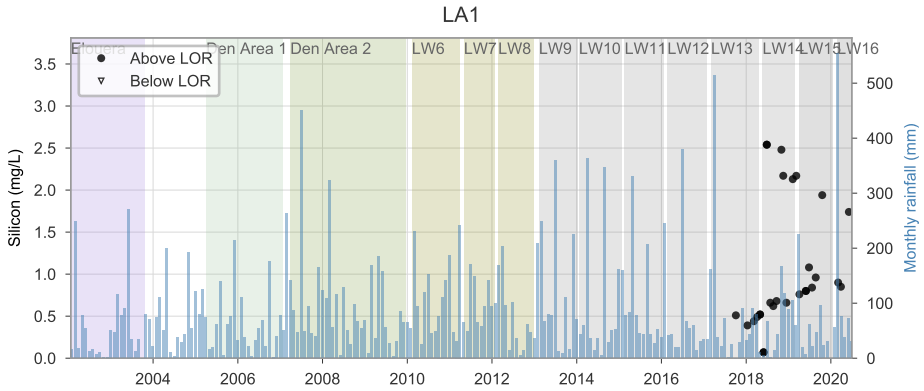

WWU4
Dissolved Oxygen (%)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
DO (%)

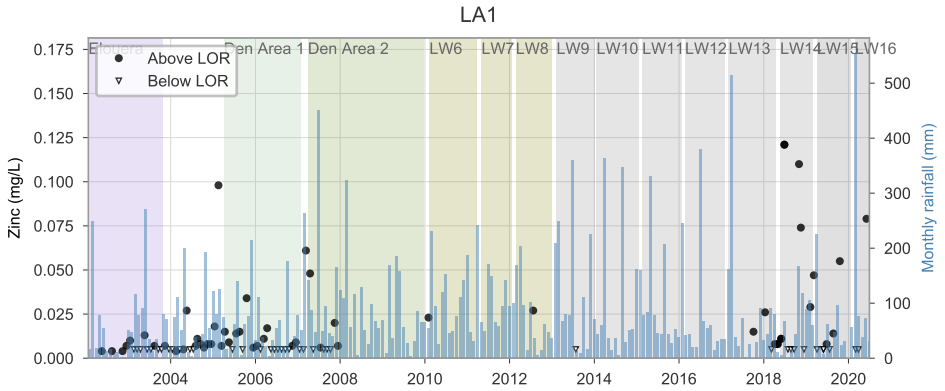

LA1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Sulfate (mg/L)
Monthly rainfall (mm)

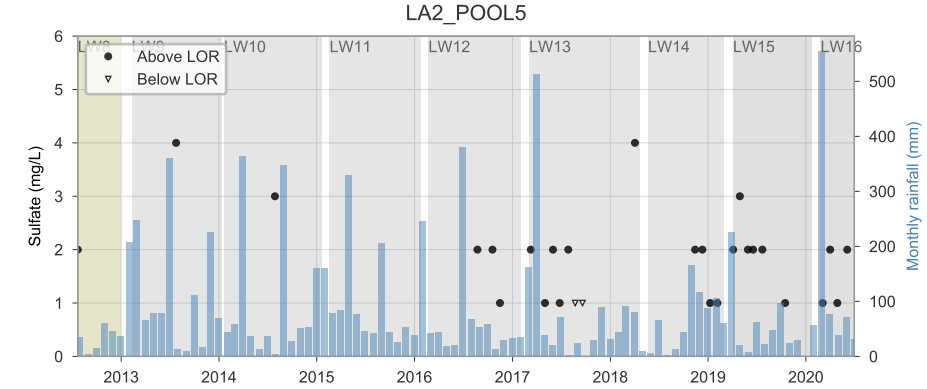

LA1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Iron (mg/L)
Monthly rainfall (mm)

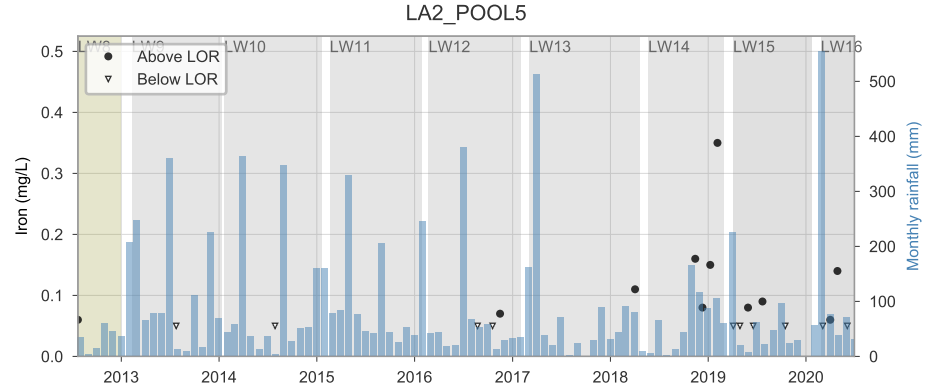

LA1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Manganese (mg/L)
Monthly rainfall (mm)

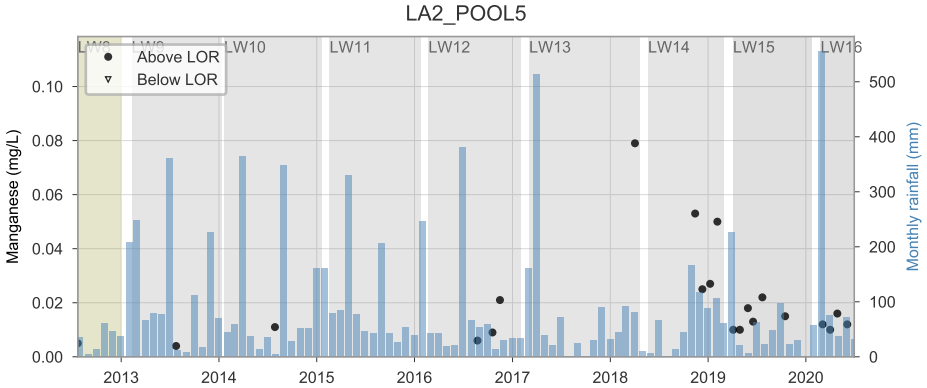

LA1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Aluminium (mg/L)
Monthly rainfall (mm)

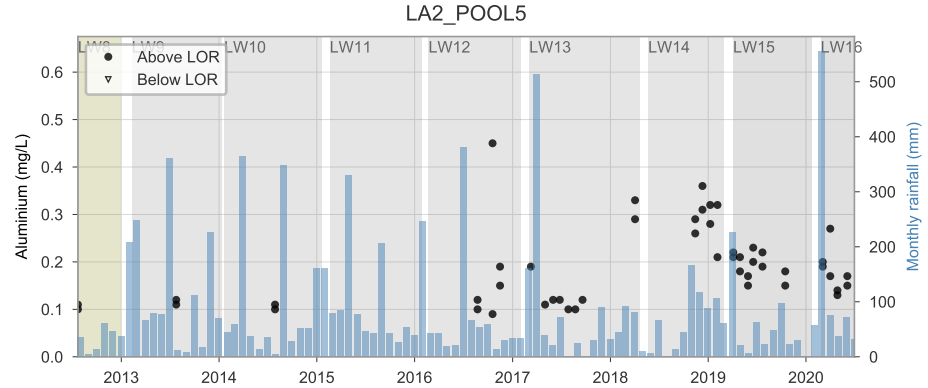

LA1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Silicon (mg/L)
Monthly rainfall (mm)

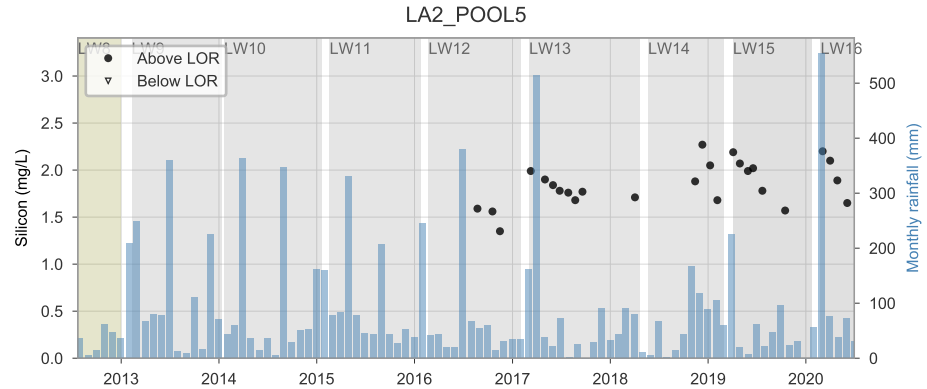

LA1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Zinc (mg/L)
Monthly rainfall (mm)

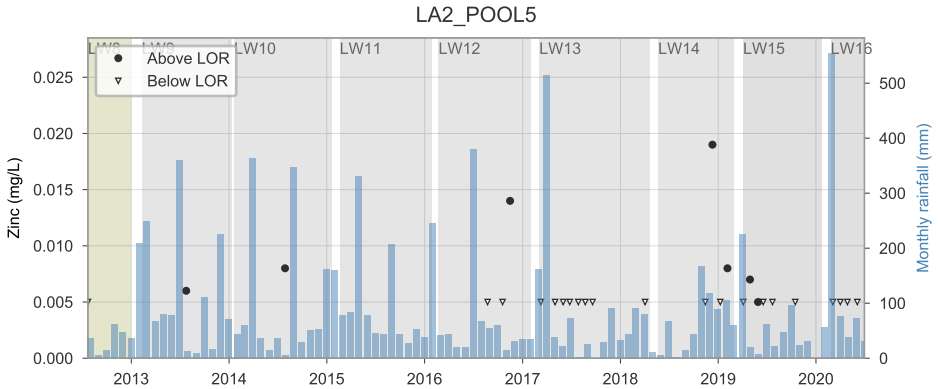

LA2_POOL5
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Sulfate (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

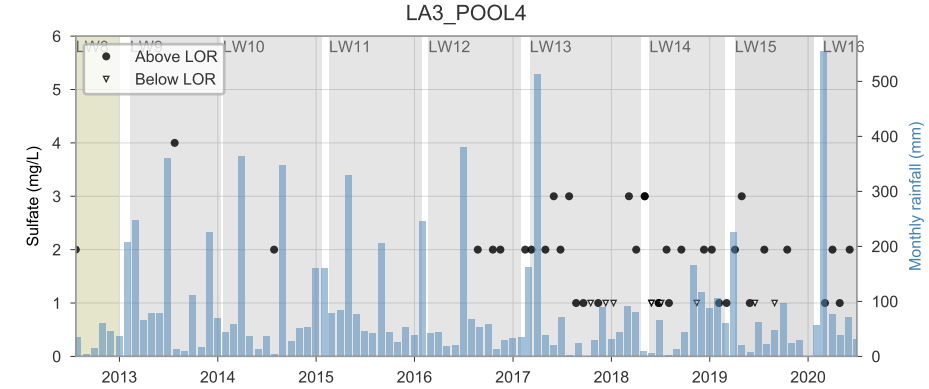

LA2_POOL5
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Iron (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

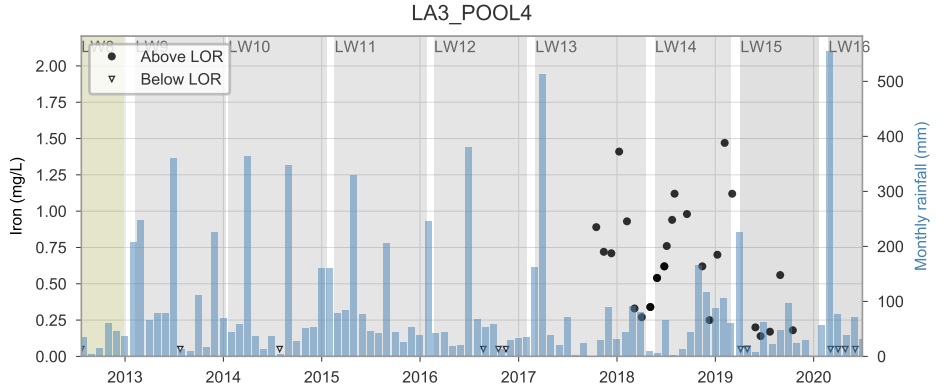

LA2_POOL5
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Manganese (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

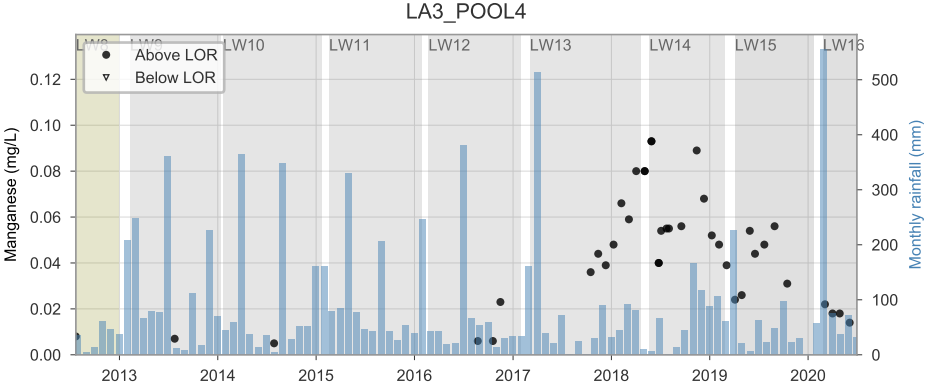

LA2_POOL5
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Aluminium (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

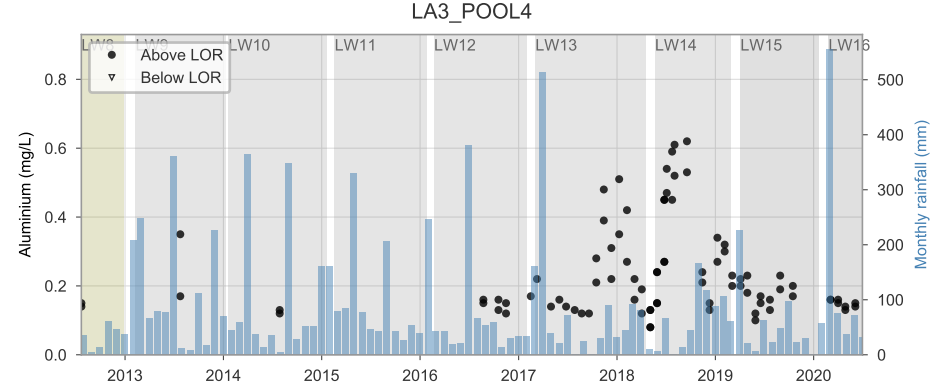

LA2_POOL5
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Silicon (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

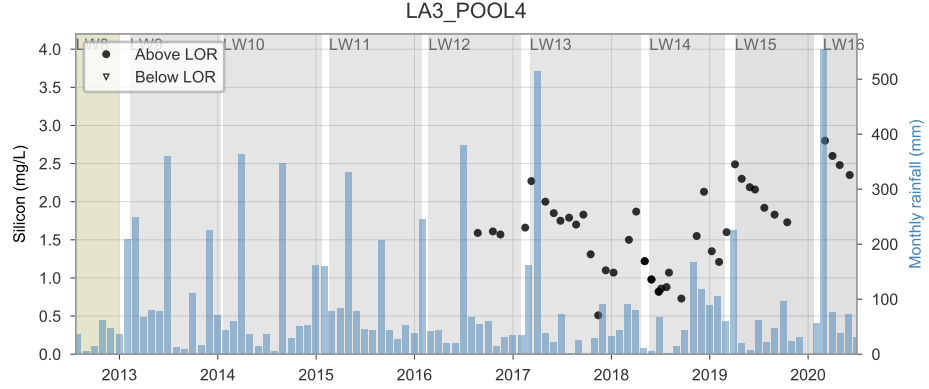

LA2_POOL5
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Zinc (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

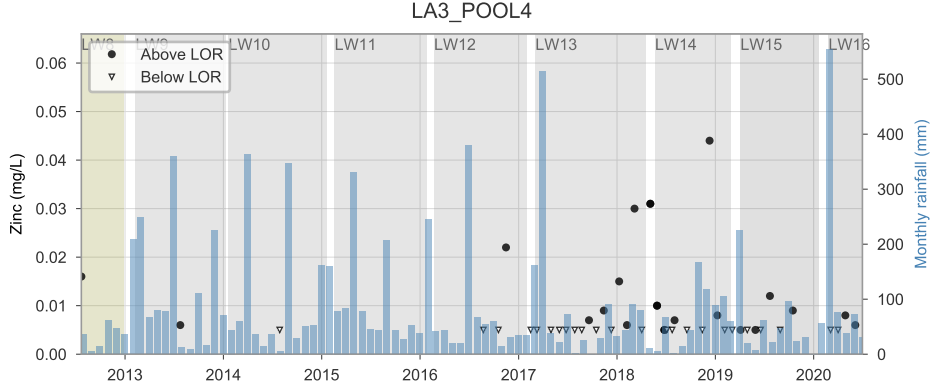

LA3_POOL4
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Sulfate (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

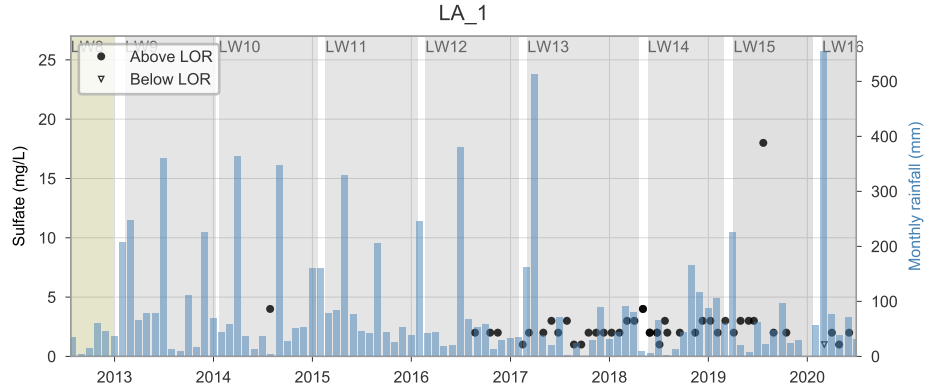

LA3_POOL4
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Iron (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

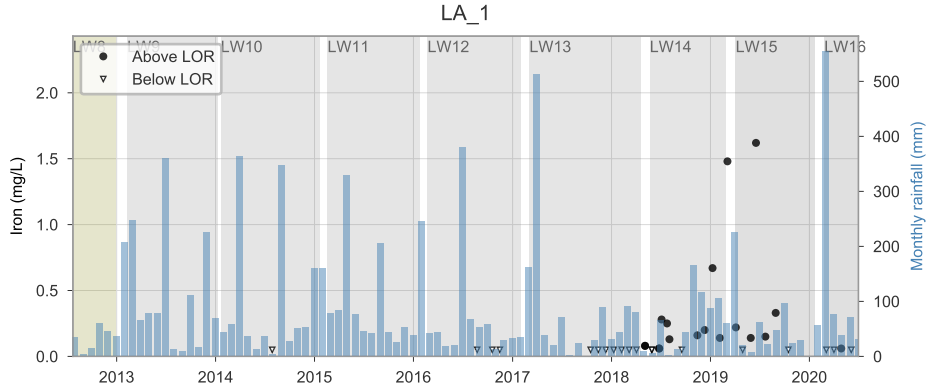

LA3_POOL4
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Manganese (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

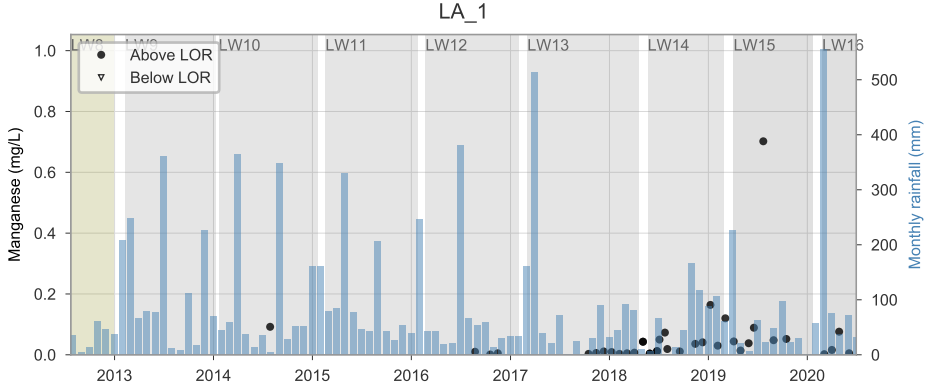

LA3_POOL4
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Aluminium (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

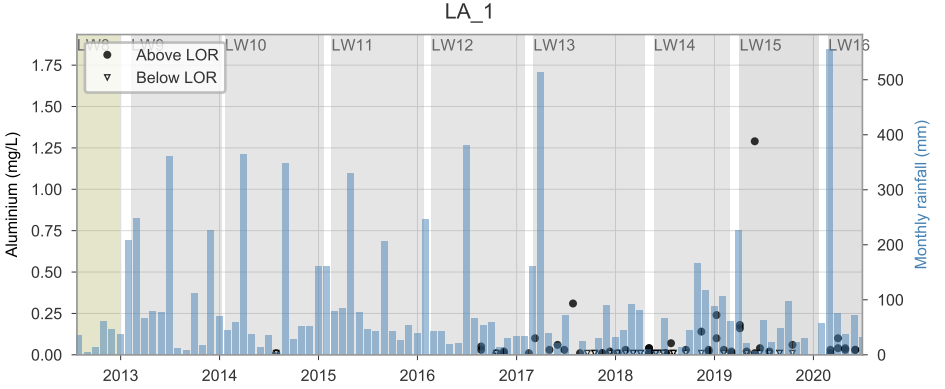

LA3_POOL4
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Silicon (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

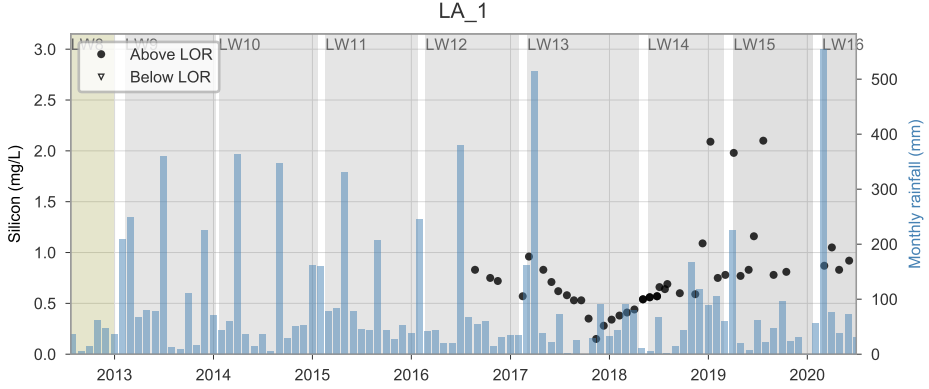

LA3_POOL4
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Zinc (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

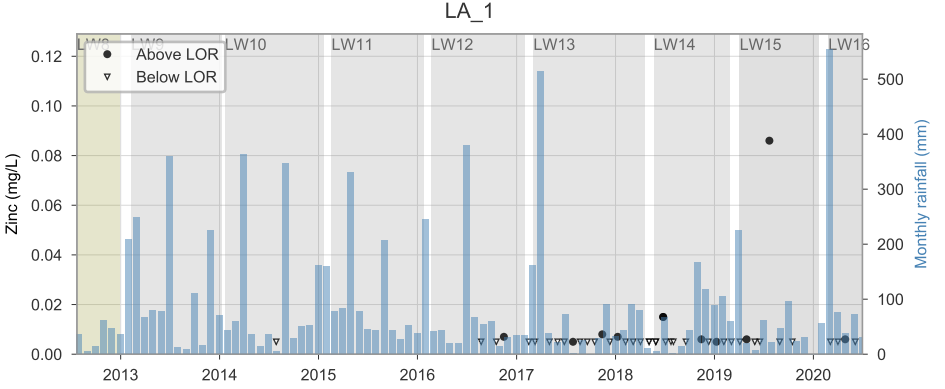

LA_1
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Sulfate (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

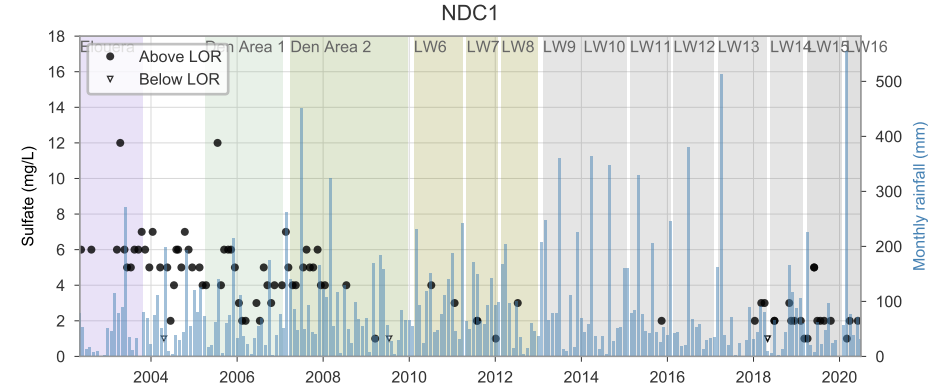

LA_1
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Iron (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

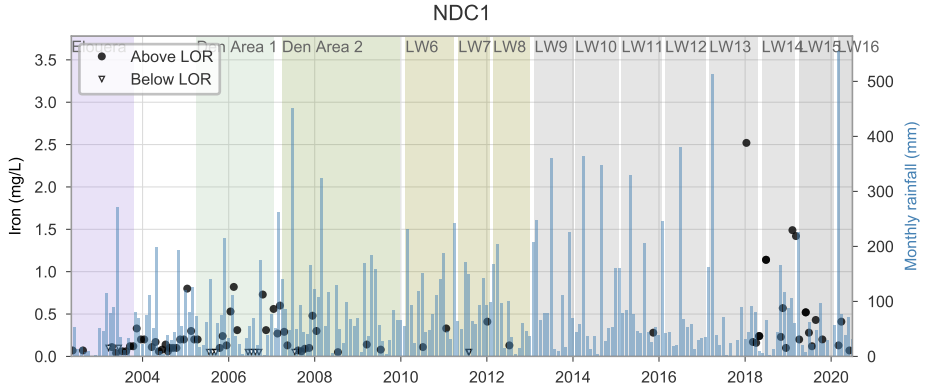

LA_1
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Manganese (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

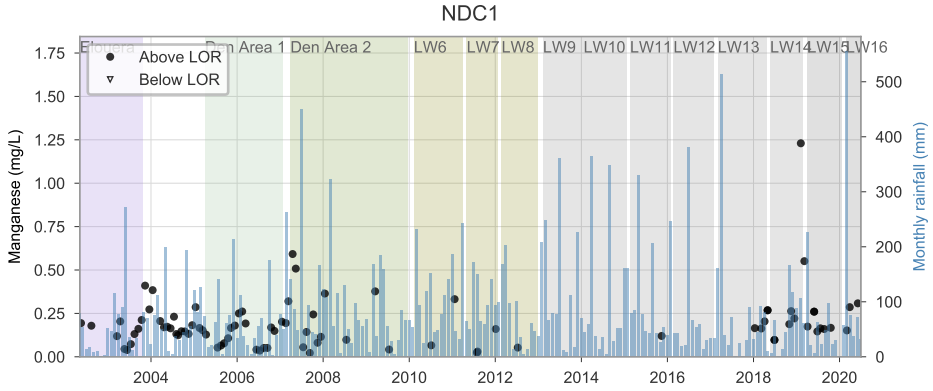

LA_1
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Aluminium (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

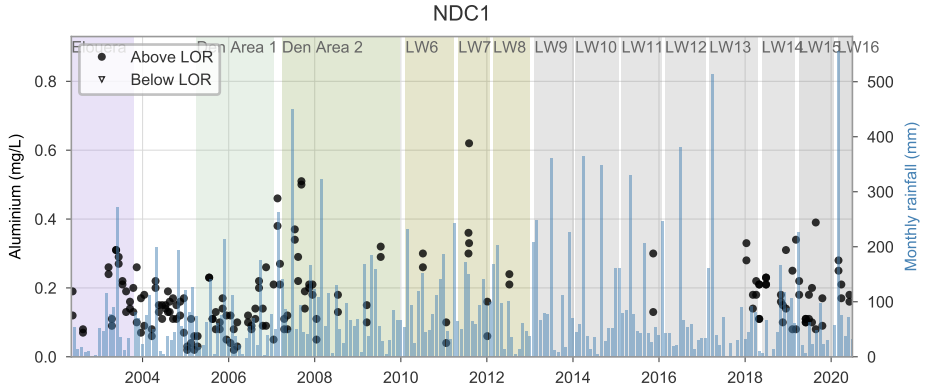

LA_1
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Silicon (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

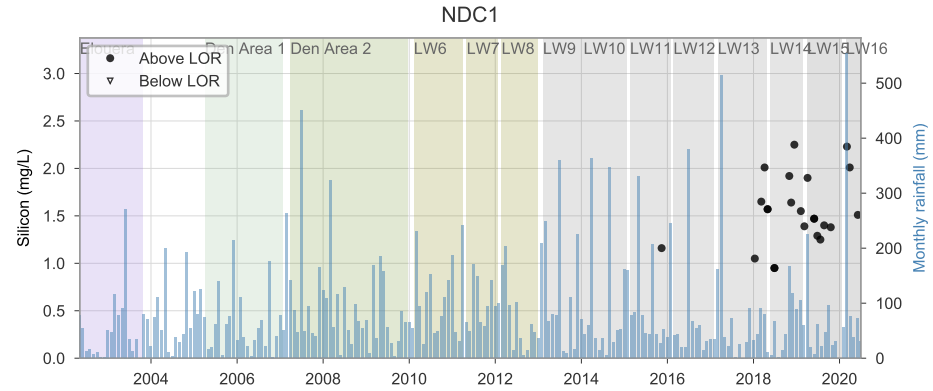

LA_1
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Zinc (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

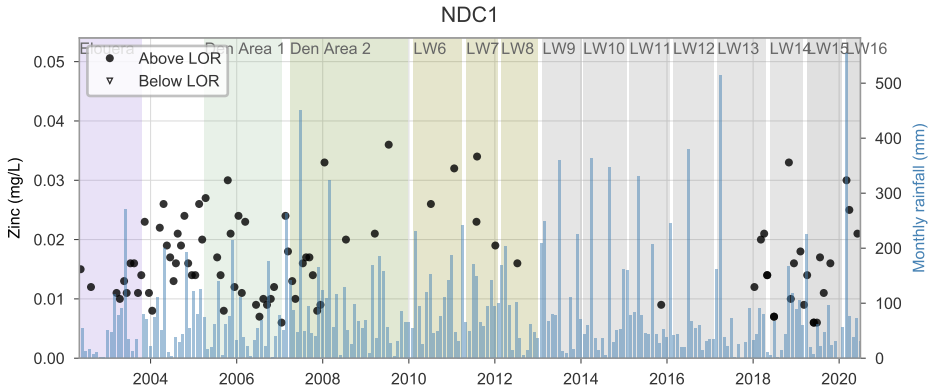

NDC1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Sulfate (mg/L)
Monthly rainfall (mm)

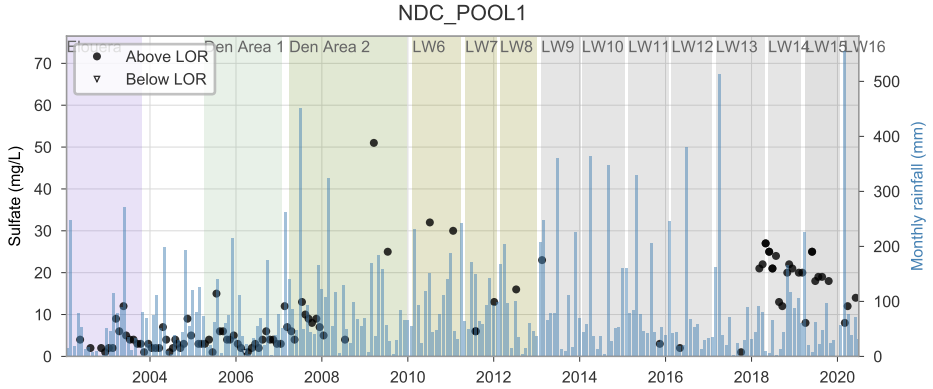

NDC1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Iron (mg/L)
Monthly rainfall (mm)

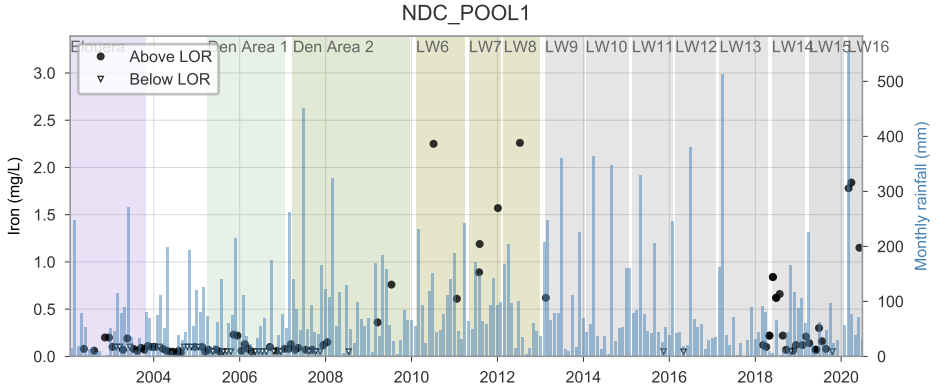

NDC1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Manganese (mg/L)
Monthly rainfall (mm)

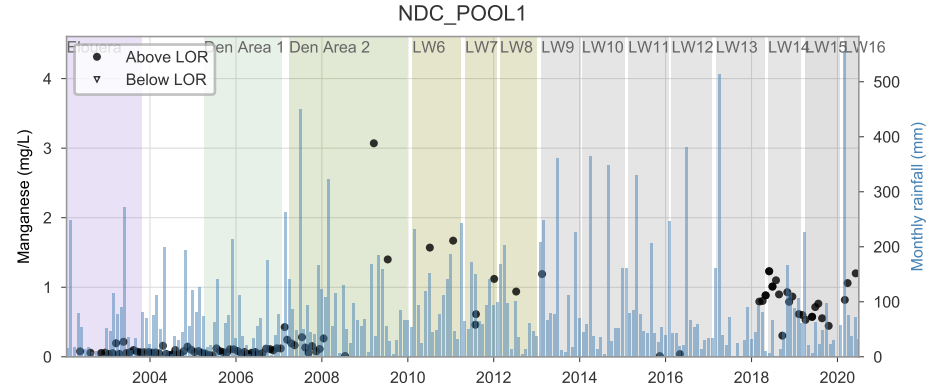

NDC1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Aluminium (mg/L)
Monthly rainfall (mm)

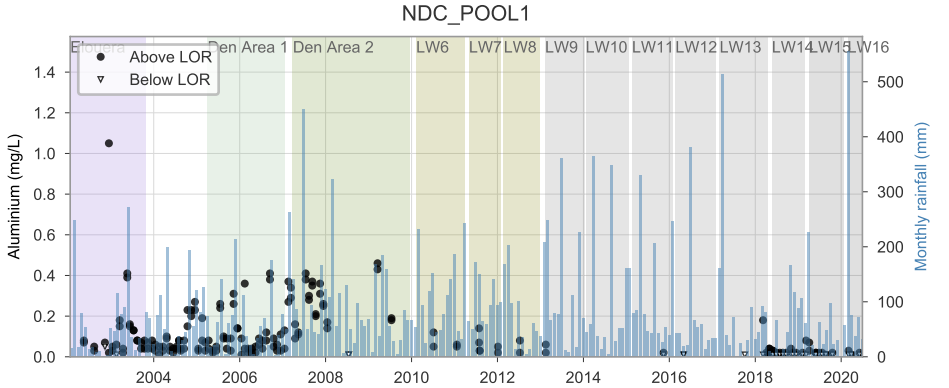

NDC1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Silicon (mg/L)
Monthly rainfall (mm)

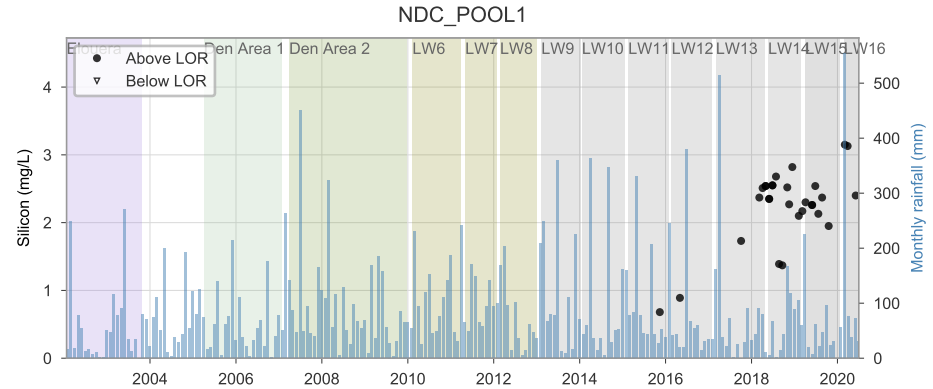

NDC1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Zinc (mg/L)
Monthly rainfall (mm)

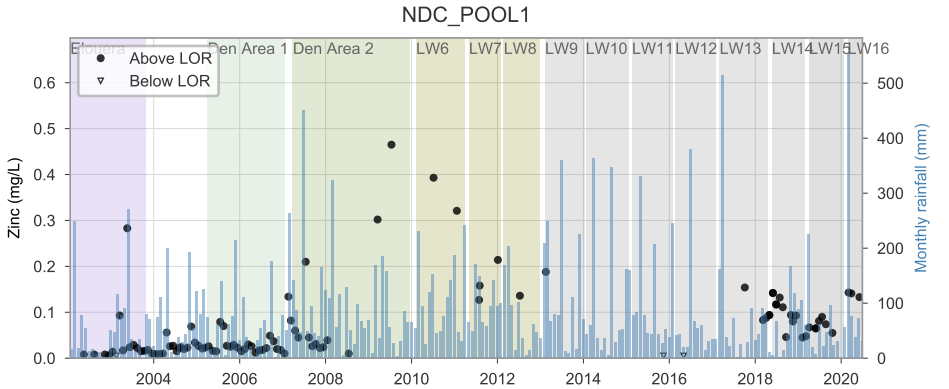

NDC_POOL1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Sulfate (mg/L)
Monthly rainfall (mm)

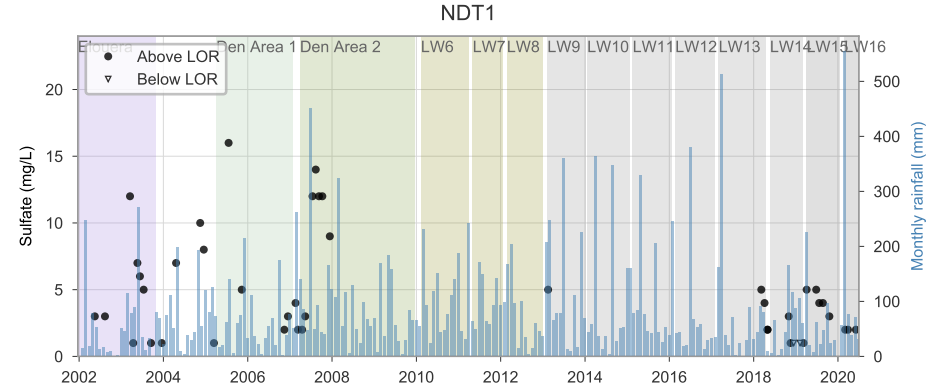

NDC_POOL1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Iron (mg/L)
Monthly rainfall (mm)

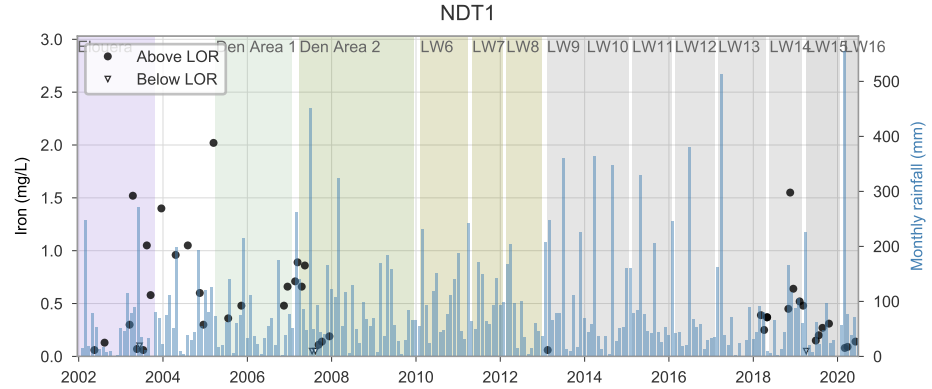

NDC_POOL1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Manganese (mg/L)
Monthly rainfall (mm)

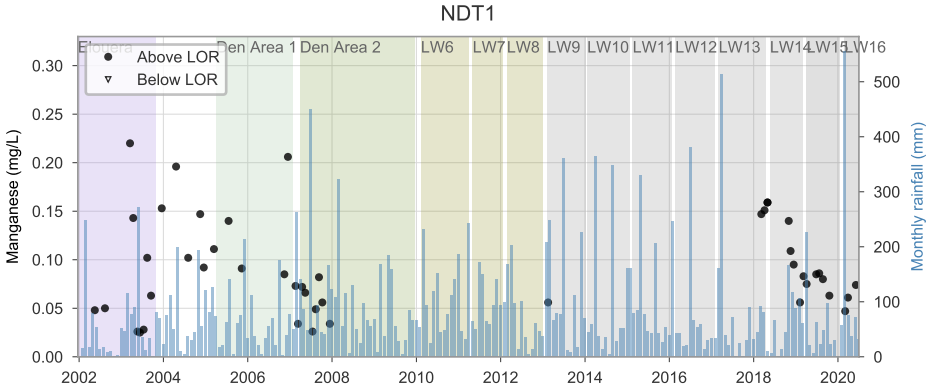

NDC_POOL1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Aluminium (mg/L)
Monthly rainfall (mm)

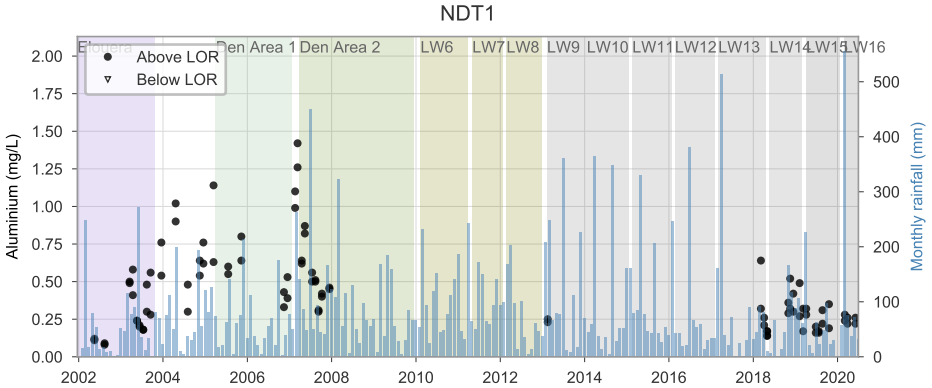

NDC_POOL1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Silicon (mg/L)
Monthly rainfall (mm)

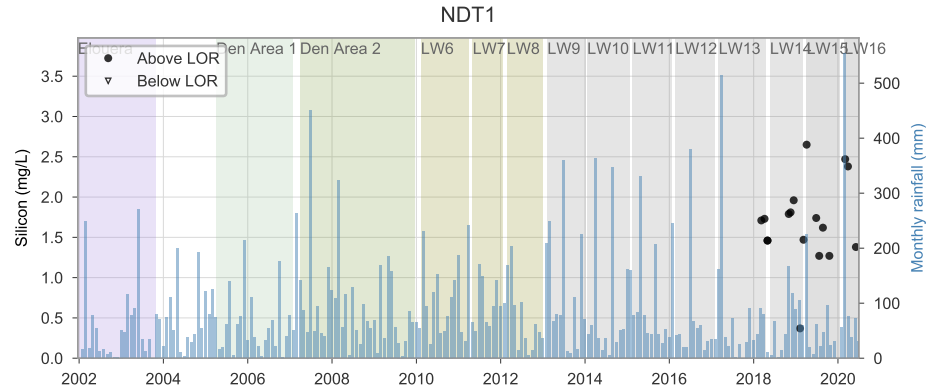

NDC_POOL1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Zinc (mg/L)
Monthly rainfall (mm)

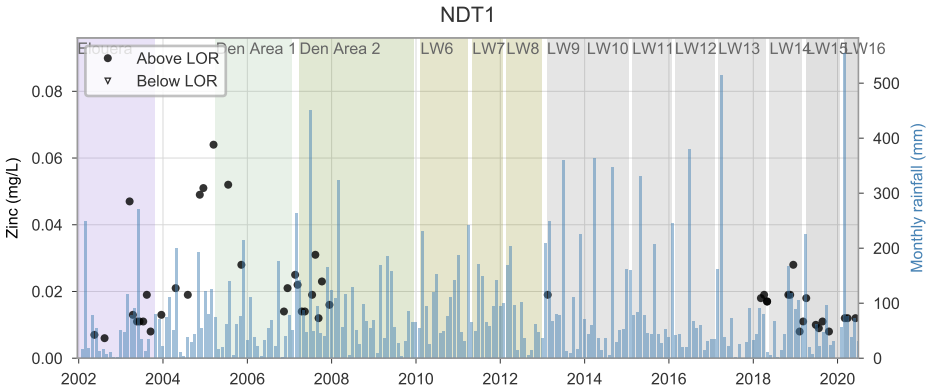

NDT1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Sulfate (mg/L)
Monthly rainfall (mm)

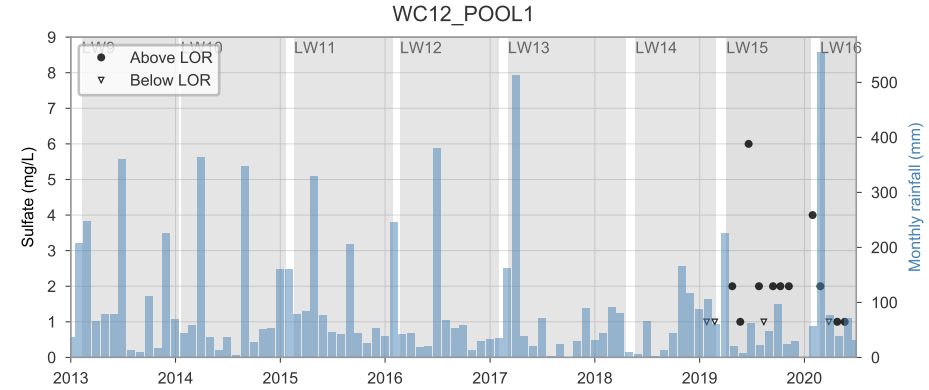

NDT1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Iron (mg/L)
Monthly rainfall (mm)

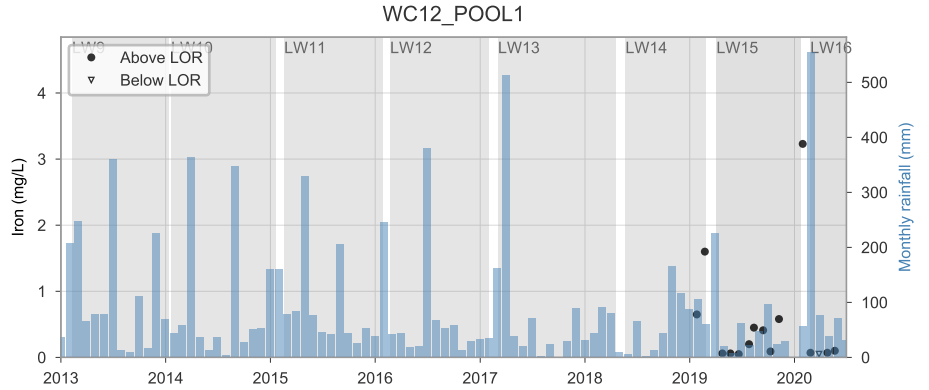

NDT1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Manganese (mg/L)
Monthly rainfall (mm)

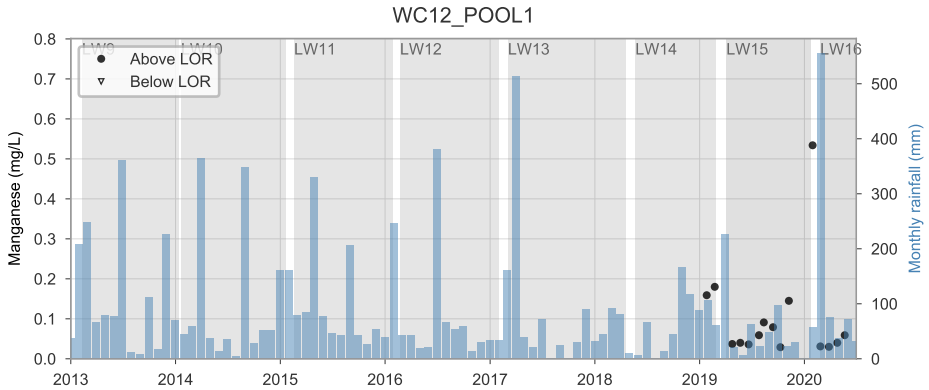

NDT1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Aluminium (mg/L)
Monthly rainfall (mm)

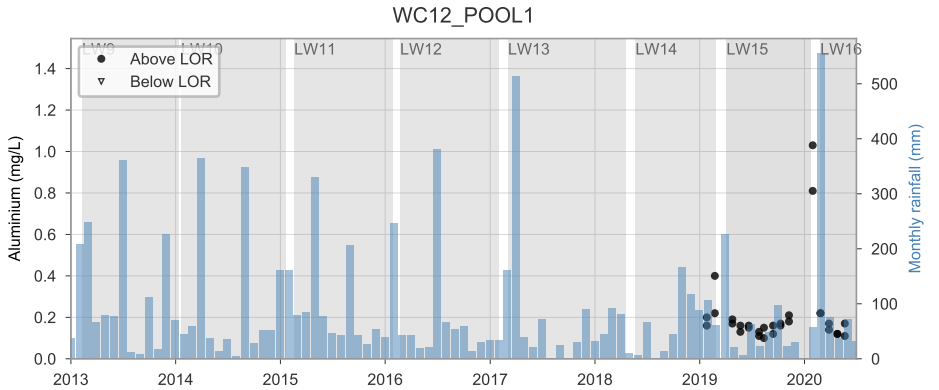

NDT1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Silicon (mg/L)
Monthly rainfall (mm)

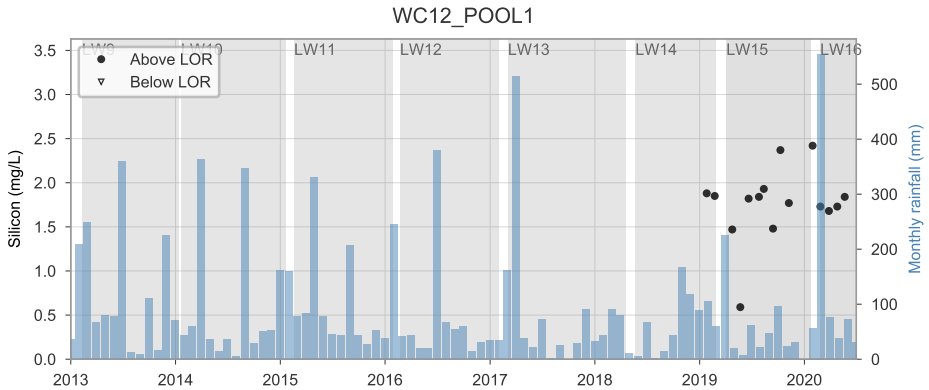

NDT1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Zinc (mg/L)
Monthly rainfall (mm)

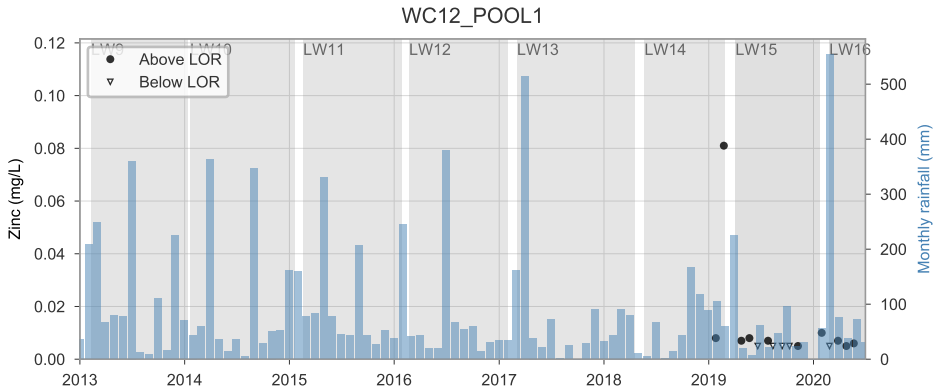

WC12_POOL1
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Sulfate (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

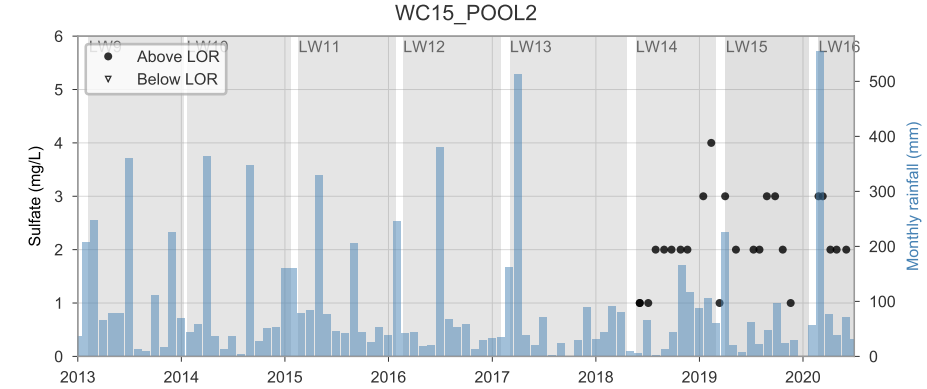

WC12_POOL1
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Iron (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

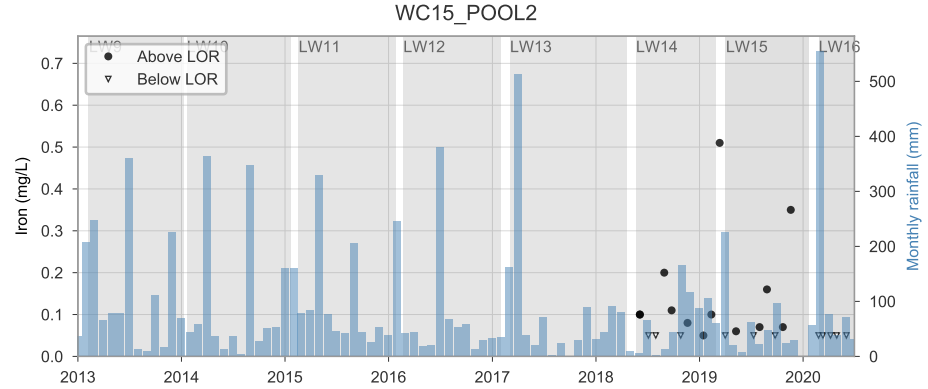

WC12_POOL1
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Manganese (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

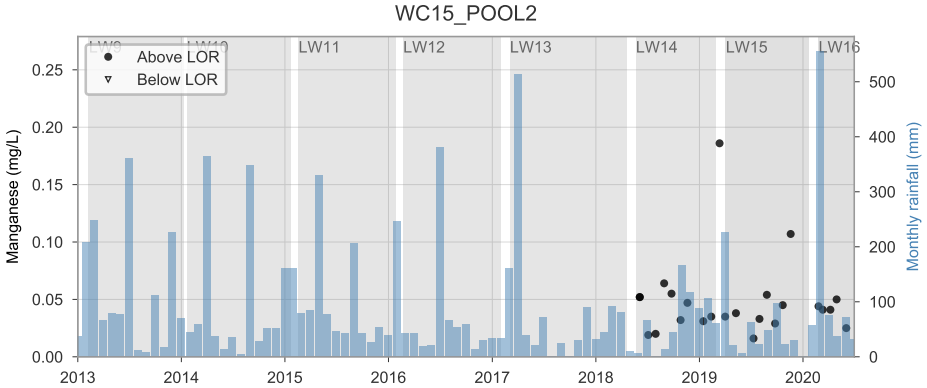

WC12_POOL1
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Aluminium (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

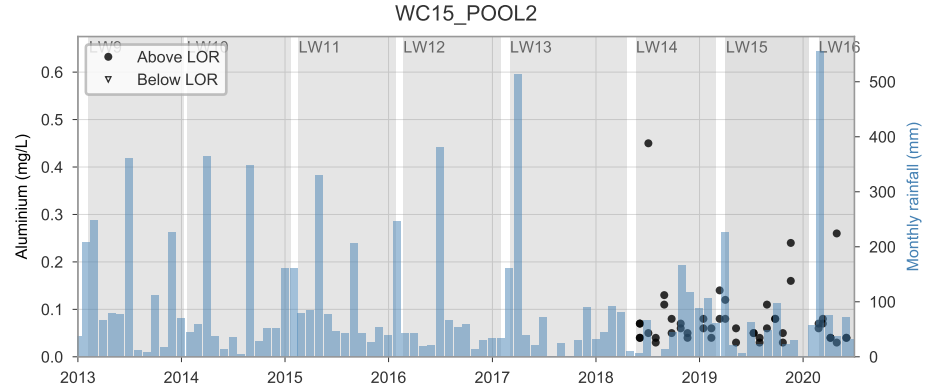

WC12_POOL1
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Silicon (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

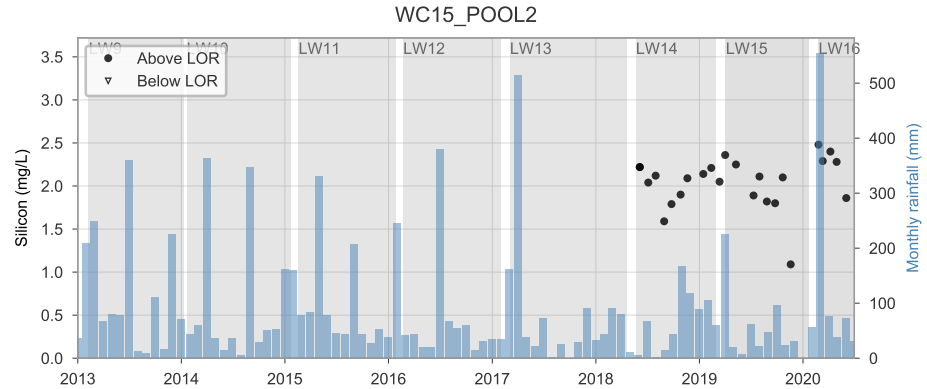

WC12_POOL1
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Zinc (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

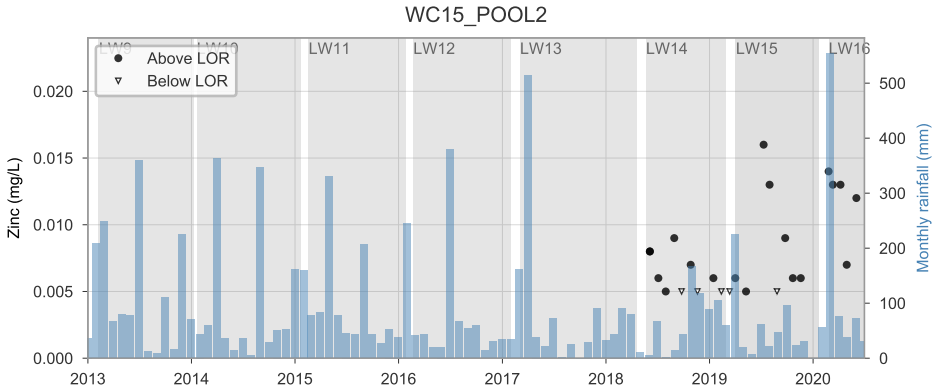

WC15_POOL2
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Sulfate (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

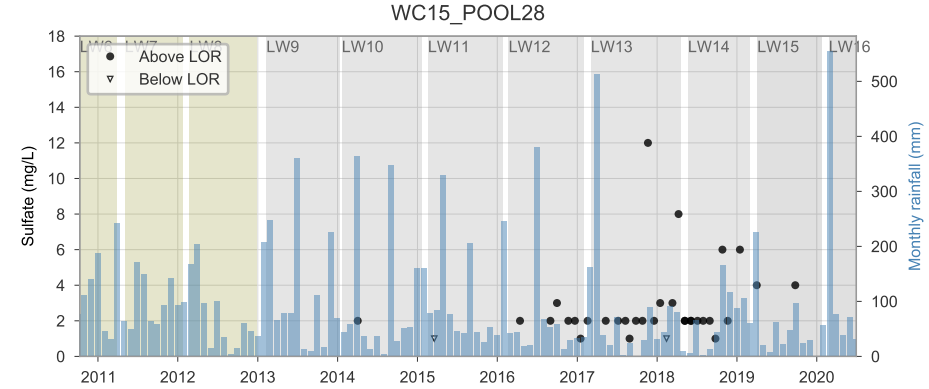

WC15_POOL2
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Iron (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

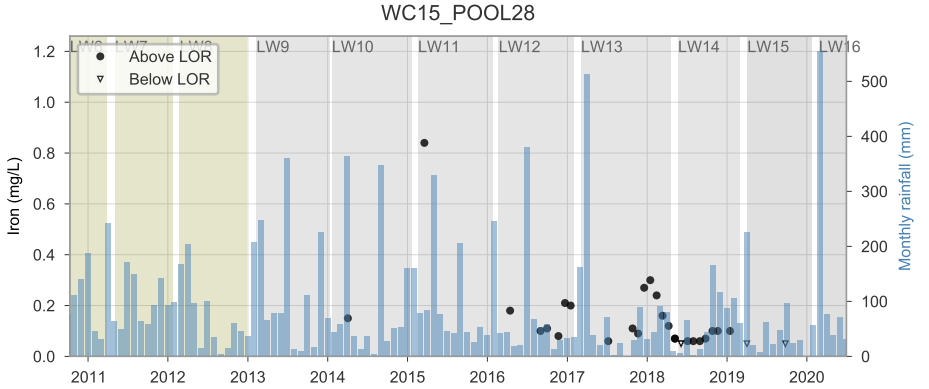

WC15_POOL2
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Manganese (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

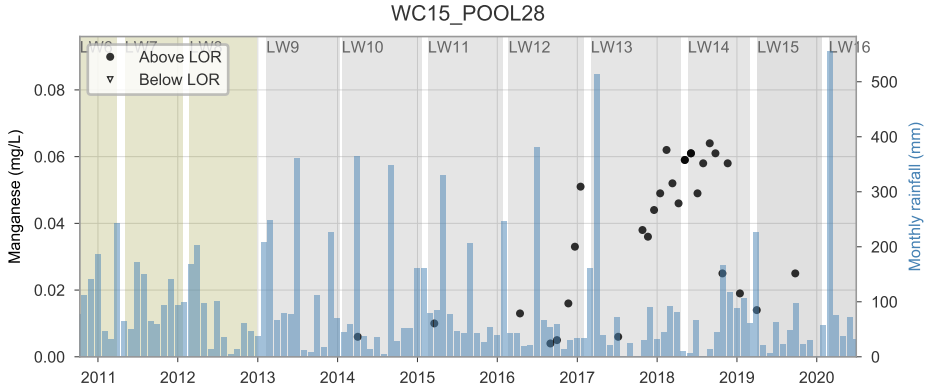

WC15_POOL2
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Aluminium (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

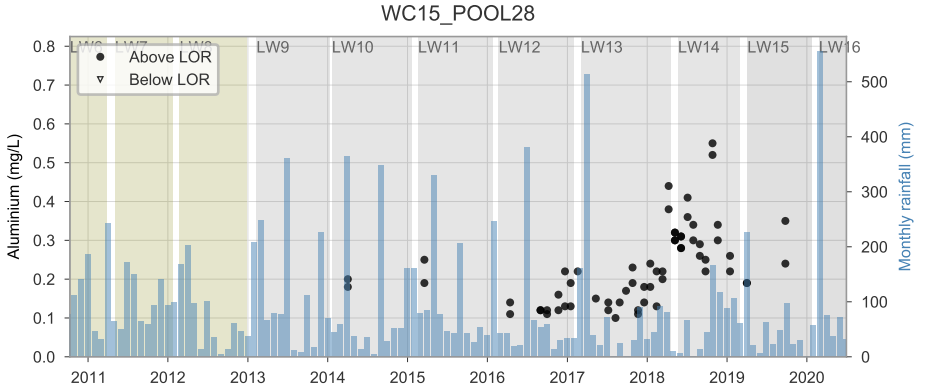

WC15_POOL2
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Silicon (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

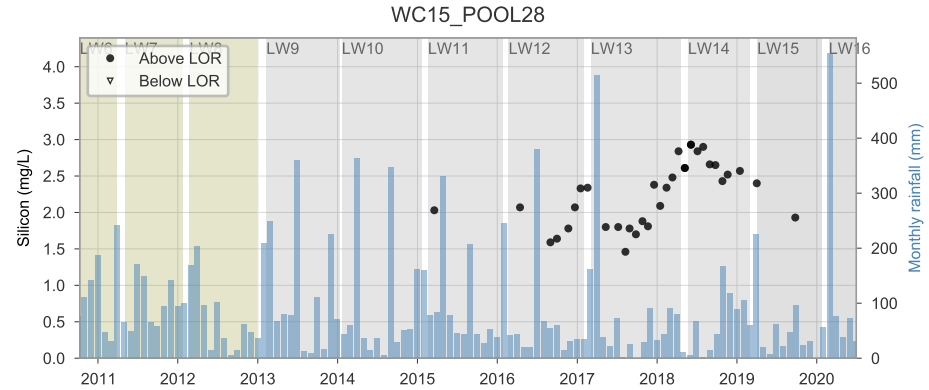

WC15_POOL2
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Zinc (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

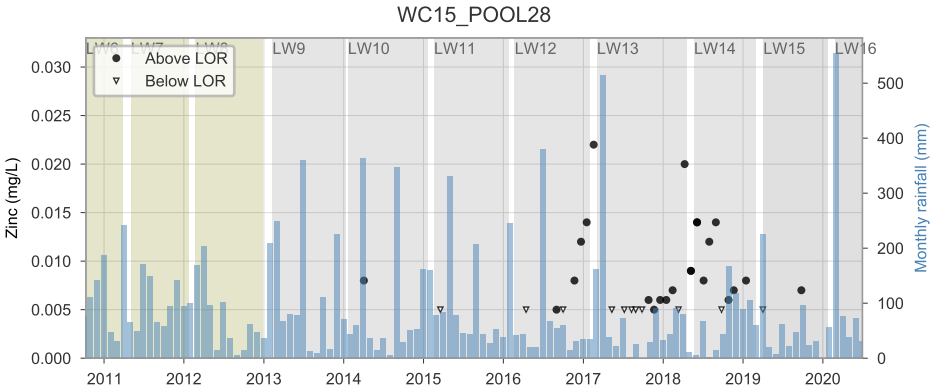

WC15_POOL28
Above LOR
Below LOR
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Sulfate (mg/L)
Monthly rainfall (mm)
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

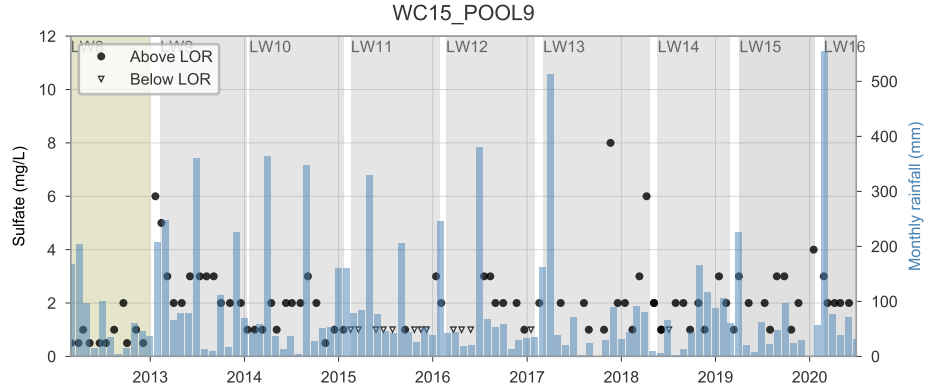

WC15_POOL28
Above LOR
Below LOR
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Iron (mg/L)
Monthly rainfall (mm)
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

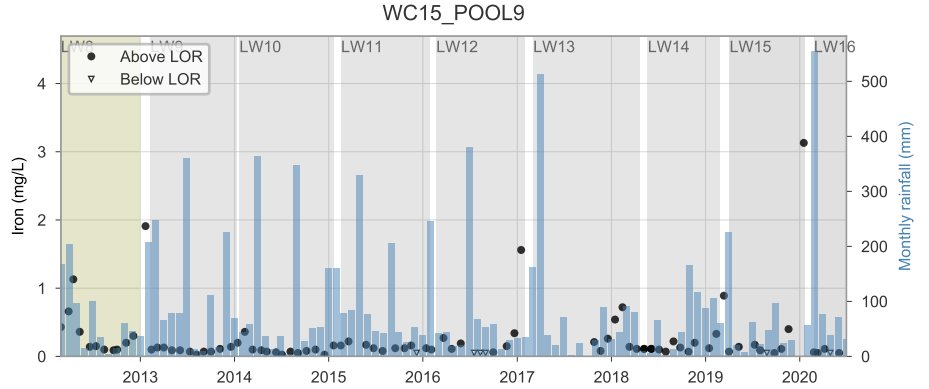

WC15_POOL28
Above LOR
Below LOR
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Manganese (mg/L)
Monthly rainfall (mm)
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

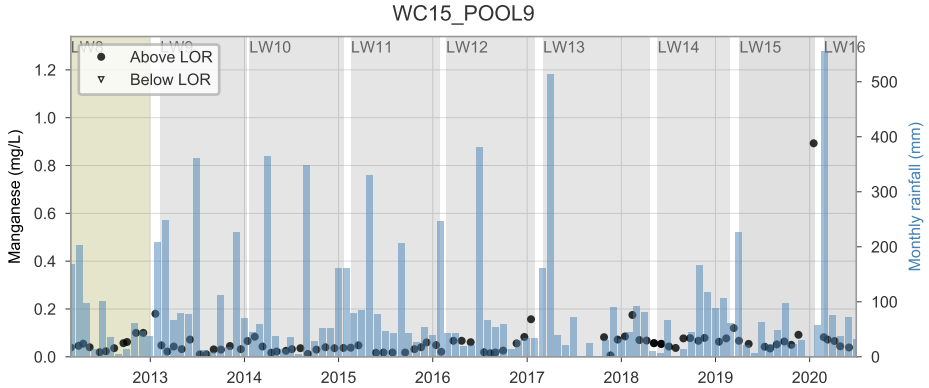

WC15_POOL28
Above LOR
Below LOR
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Aluminium (mg/L)
Monthly rainfall (mm)
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

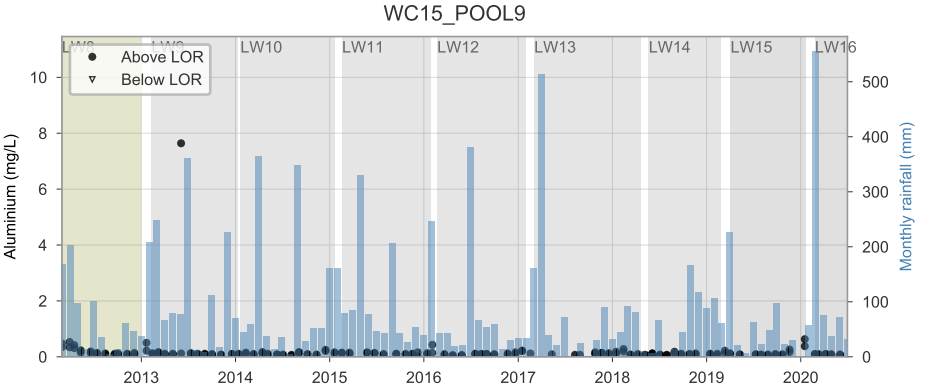

WC15_POOL28
Above LOR
Below LOR
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Silicon (mg/L)
Monthly rainfall (mm)
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

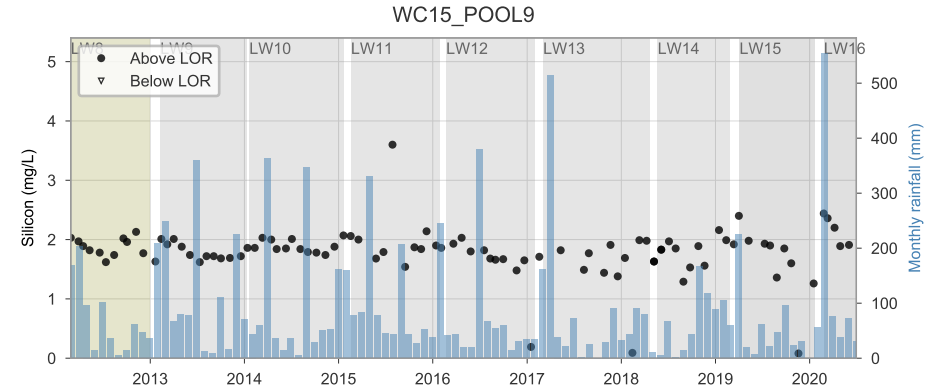

WC15_POOL28
Above LOR
Below LOR
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Zinc (mg/L)
Monthly rainfall (mm)
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

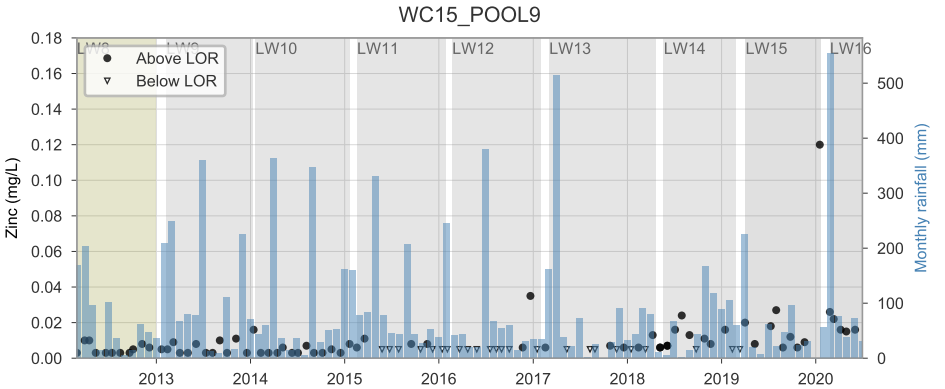

WC15_POOL9
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Sulfate (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

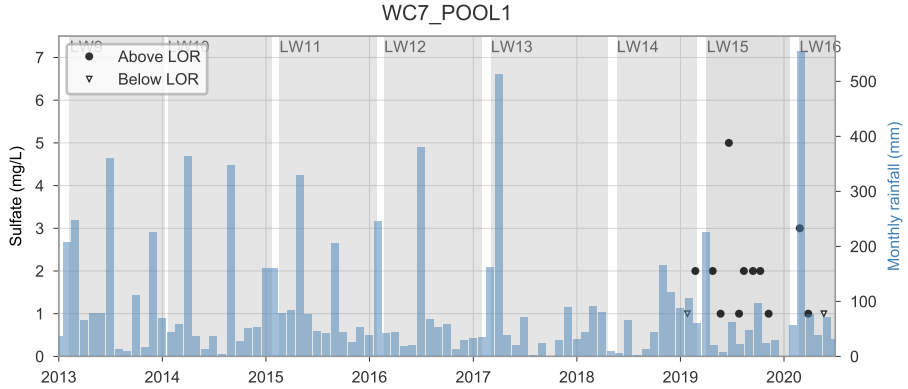

WC15_POOL9
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Iron (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

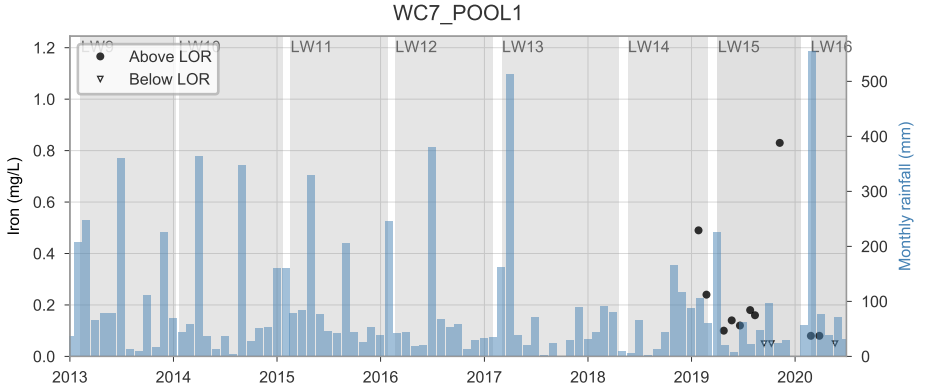

WC15_POOL9
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Manganese (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

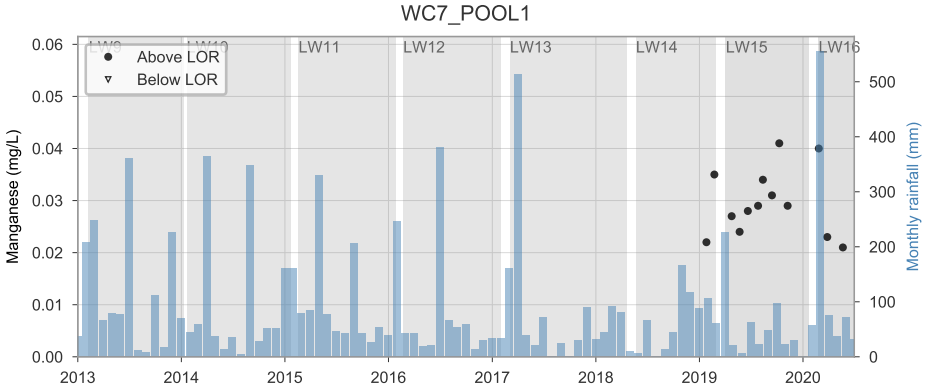

WC15_POOL9
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Aluminium (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

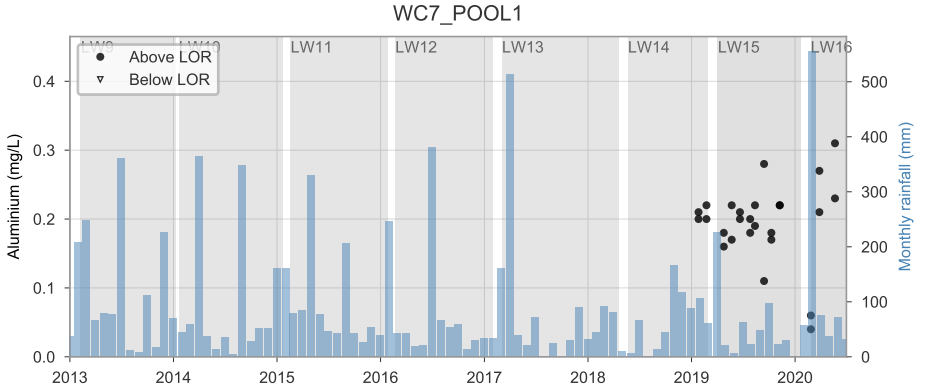

WC15_POOL9
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Silicon (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

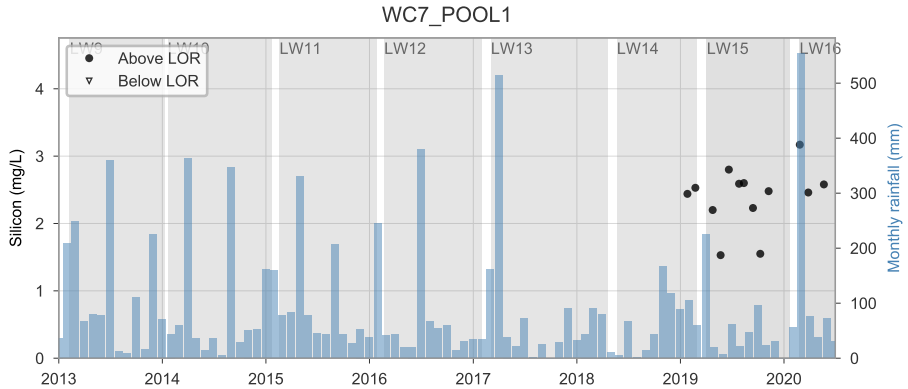

WC15_POOL9
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Zinc (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

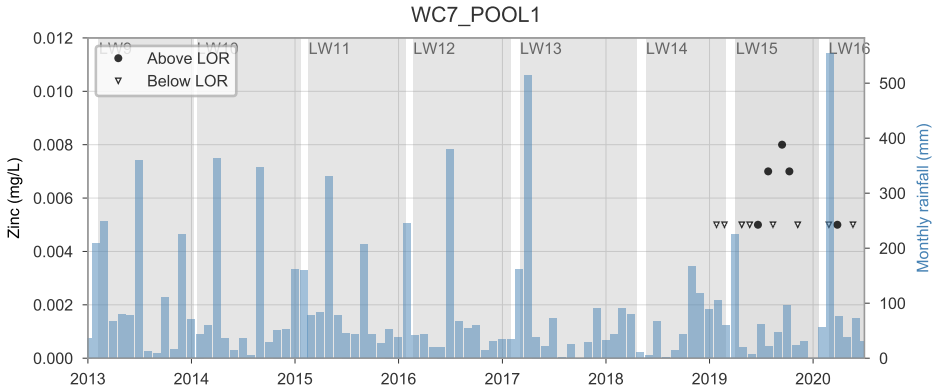

WC7_POOL1
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Sulfate (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

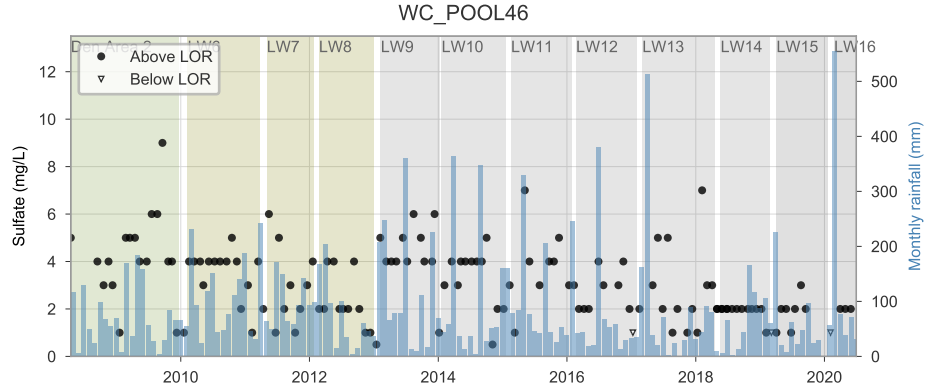

WC7_POOL1
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Iron (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

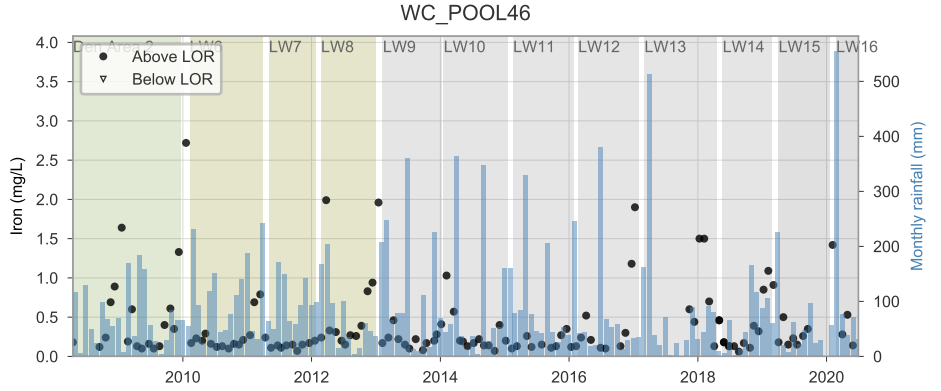

WC7_POOL1
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Manganese (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

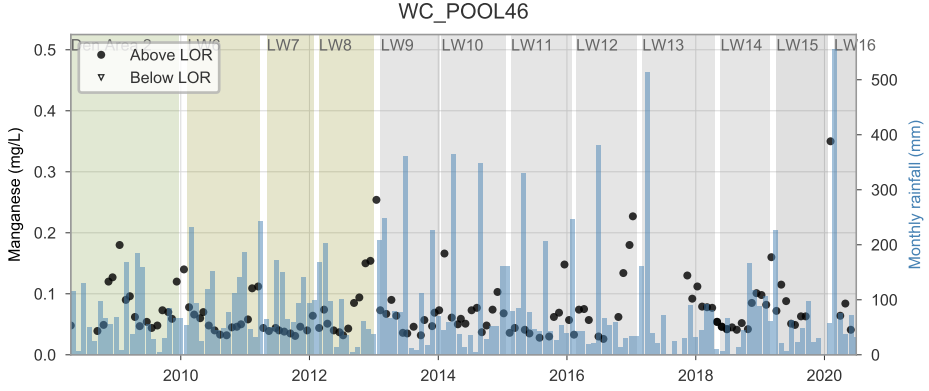

WC7_POOL1
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Aluminium (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

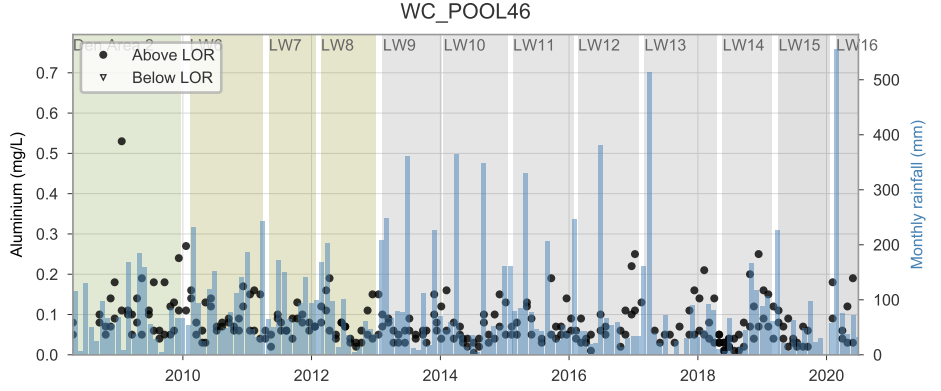

WC7_POOL1
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Silicon (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

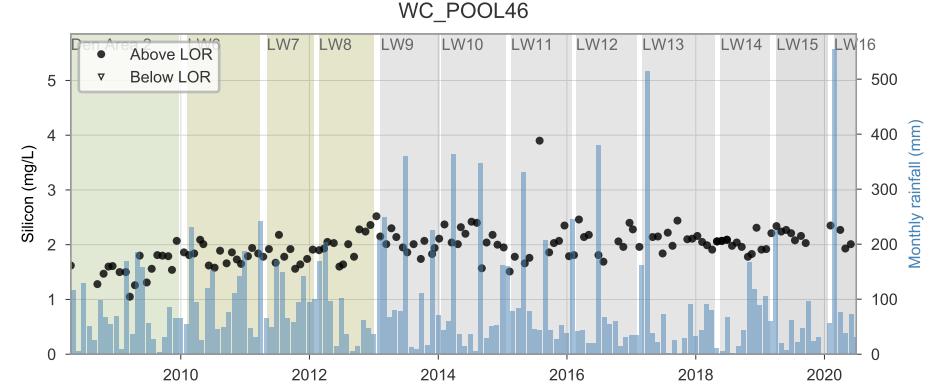

WC7_POOL1
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Zinc (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

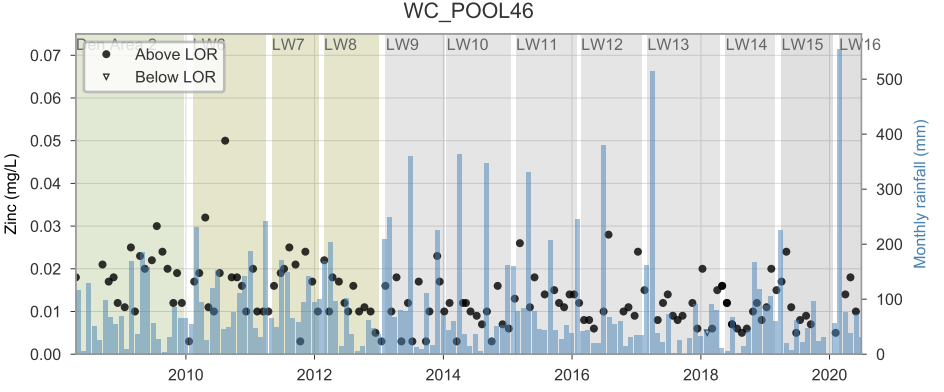

WC_POOL46
Above LOR
Below LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Sulfate (mg/L)
Monthly rainfall (mm)
2010
2012
2014
2016
2018
2020

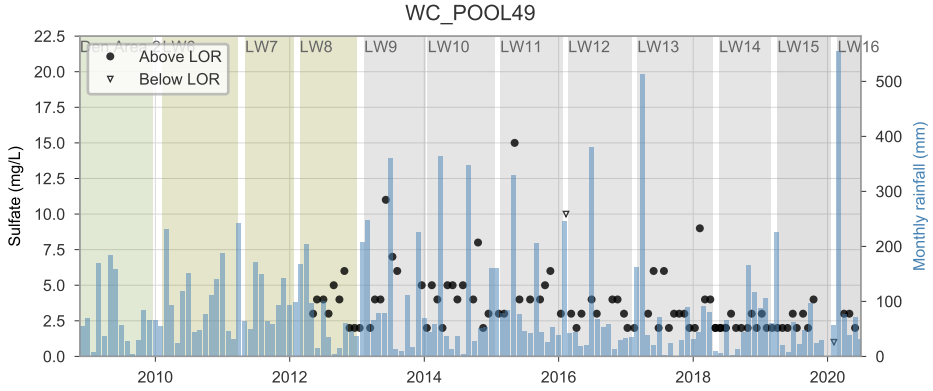

WC_POOL46
Above LOR
Below LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Iron (mg/L)
Monthly rainfall (mm)
2010
2012
2014
2016
2018
2020

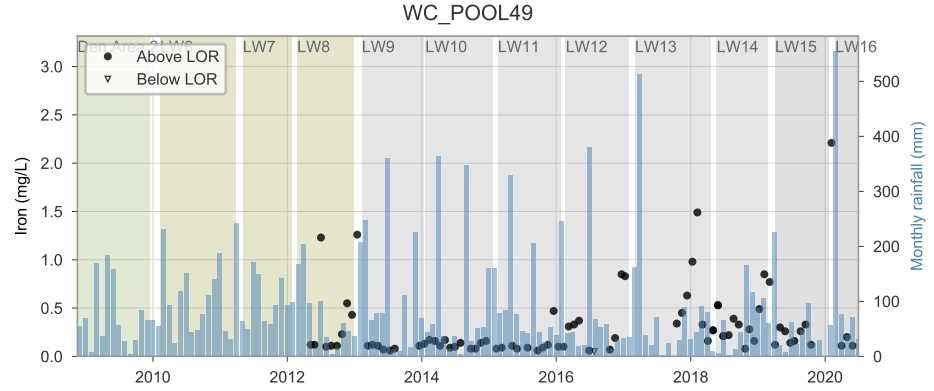

WC_POOL46
Above LOR
Below LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Manganese (mg/L)
Monthly rainfall (mm)
2010
2012
2014
2016
2018
2020

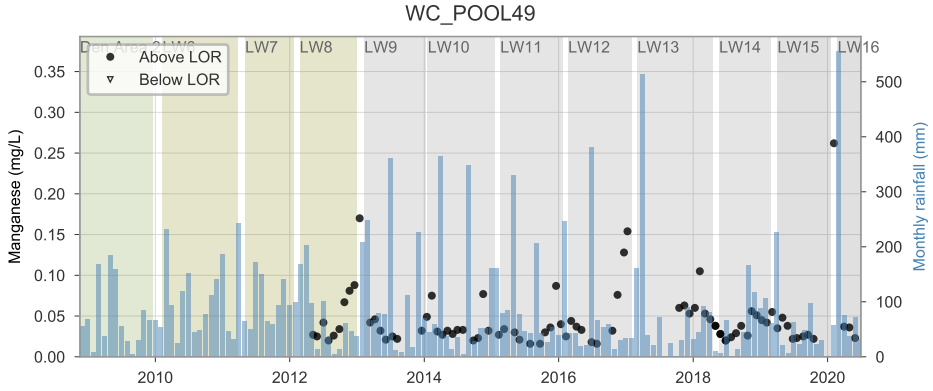

WC_POOL46
Above LOR
Below LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Aluminium (mg/L)
Monthly rainfall (mm)
2010
2012
2014
2016
2018
2020

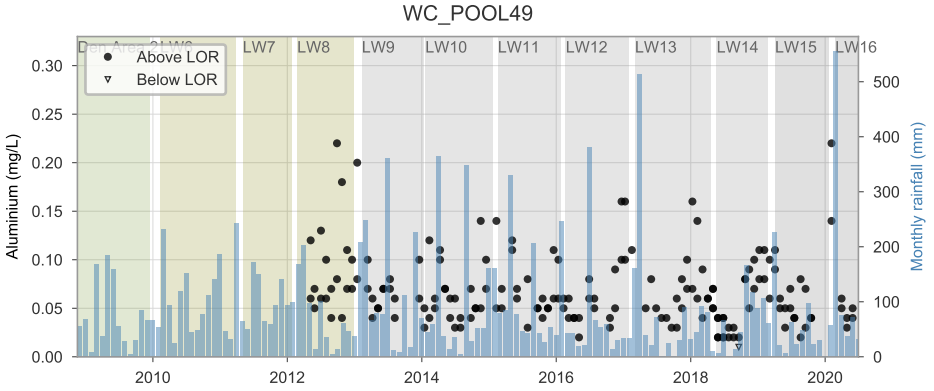

WC_POOL46
Above LOR
Below LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Silicon (mg/L)
Monthly rainfall (mm)
2010
2012
2014
2016
2018
2020

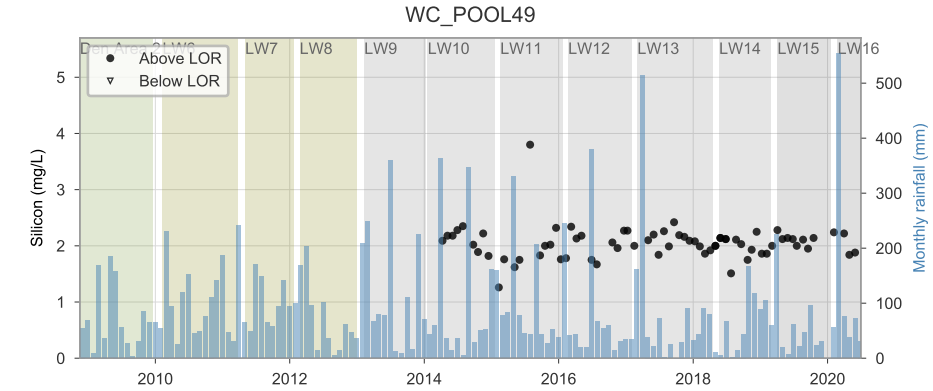

WC_POOL46
Above LOR
Below LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Zinc (mg/L)
Monthly rainfall (mm)
2010
2012
2014
2016
2018
2020

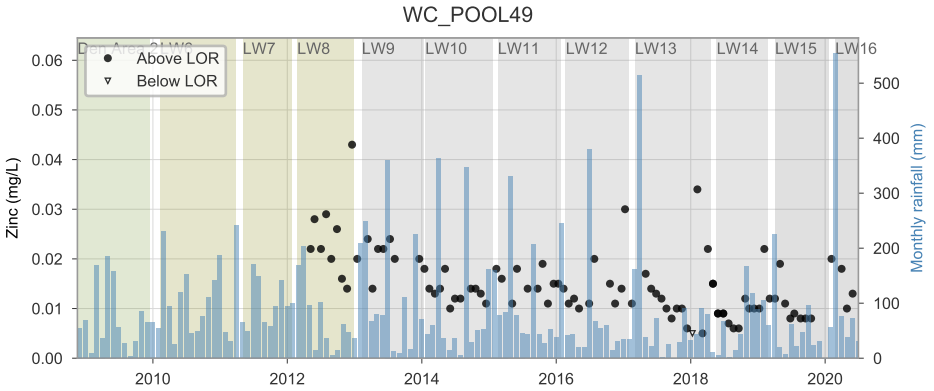

WC_POOL49
Above LOR
Below LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Sulfate (mg/L)
Monthly rainfall (mm)
2010
2012
2014
2016
2018
2020

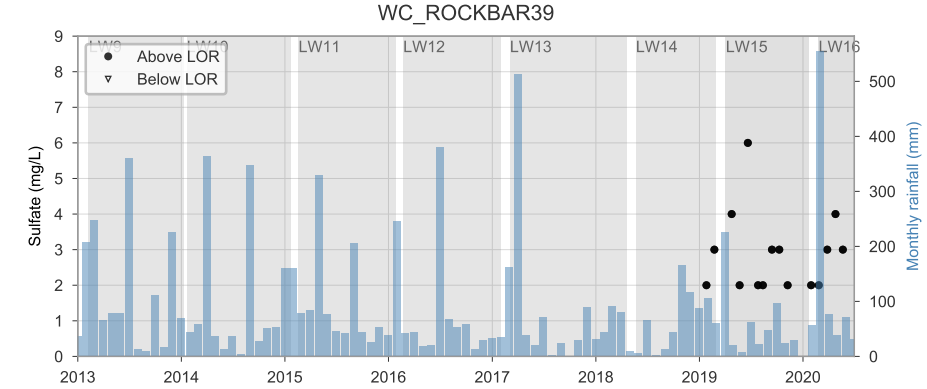

WC_POOL49
Above LOR
Below LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Iron (mg/L)
Monthly rainfall (mm)
2010
2012
2014
2016
2018
2020

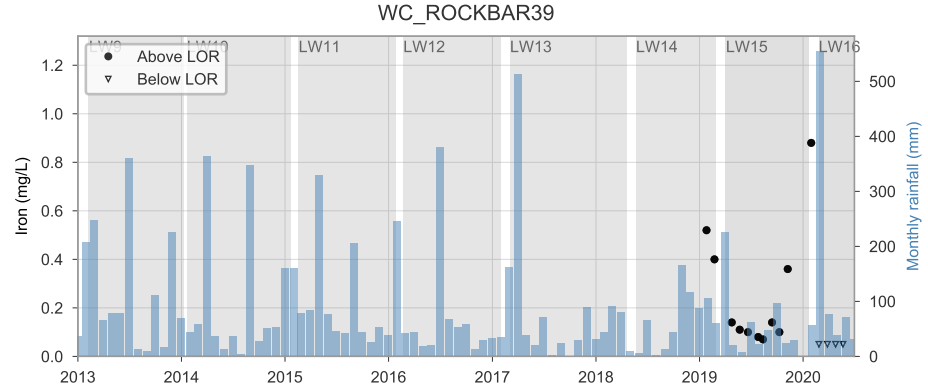

WC_POOL49
Above LOR
Below LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Manganese (mg/L)
Monthly rainfall (mm)
2010
2012
2014
2016
2018
2020

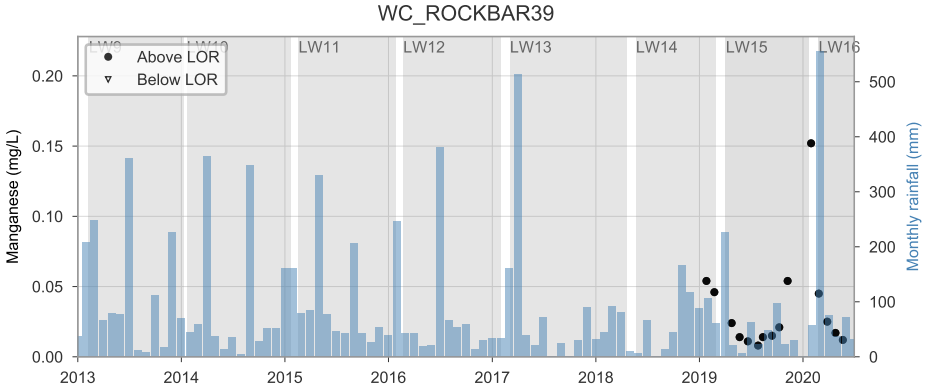

WC_POOL49
Above LOR
Below LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Aluminium (mg/L)
Monthly rainfall (mm)
2010
2012
2014
2016
2018
2020

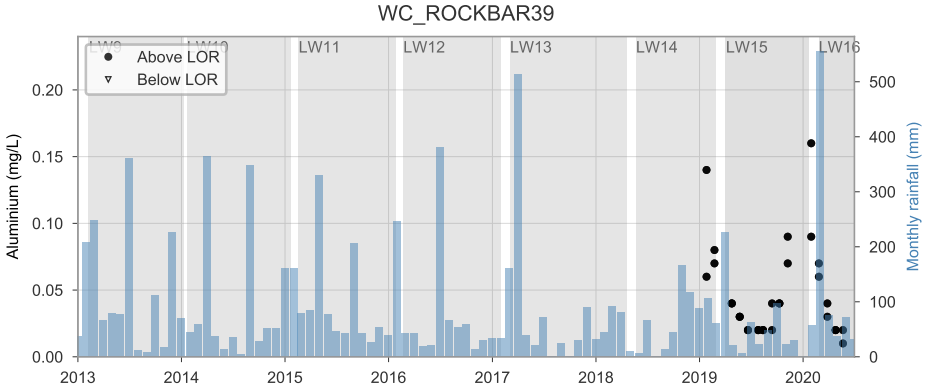

WC_POOL49
Above LOR
Below LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Silicon (mg/L)
Monthly rainfall (mm)
2010
2012
2014
2016
2018
2020

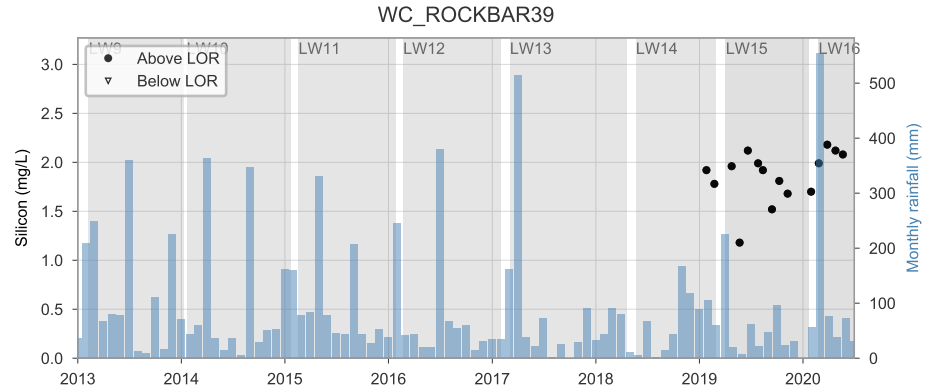

WC_POOL49
Above LOR
Below LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Zinc (mg/L)
Monthly rainfall (mm)
2010
2012
2014
2016
2018
2020

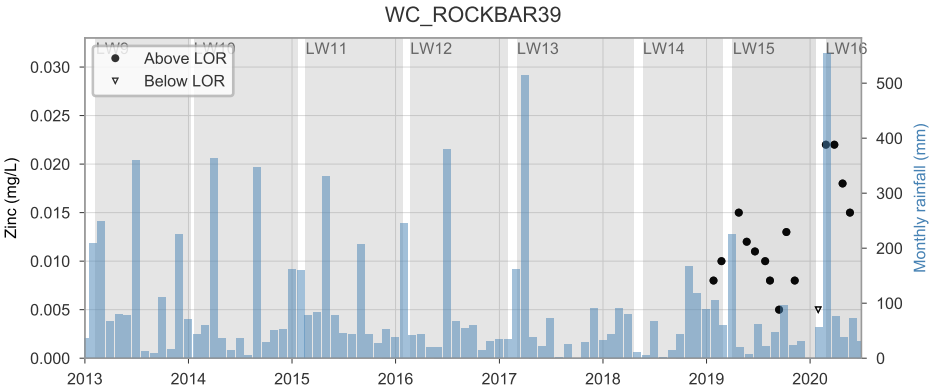

WC_ROCKBAR39
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Sulfate (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

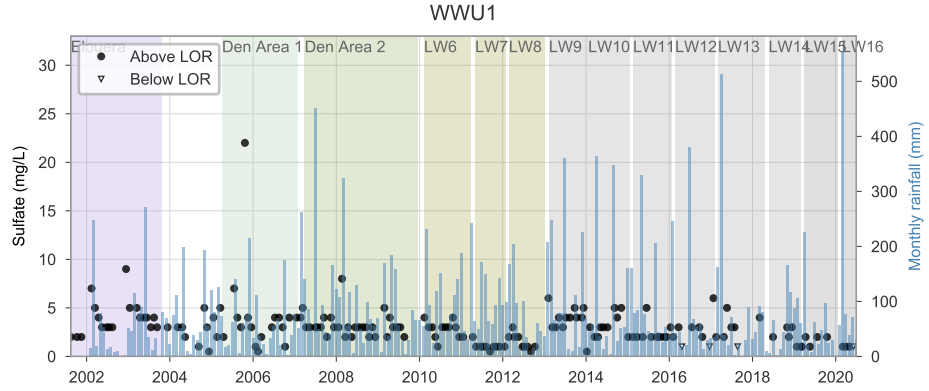

WC_ROCKBAR39
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Iron (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

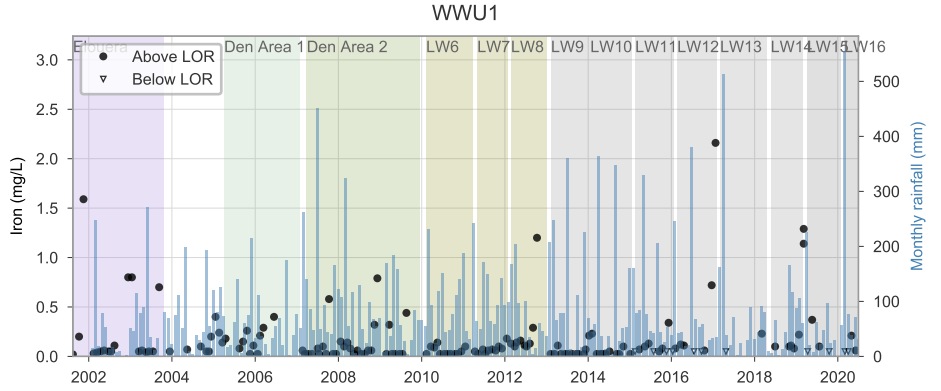

WC_ROCKBAR39
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Manganese (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

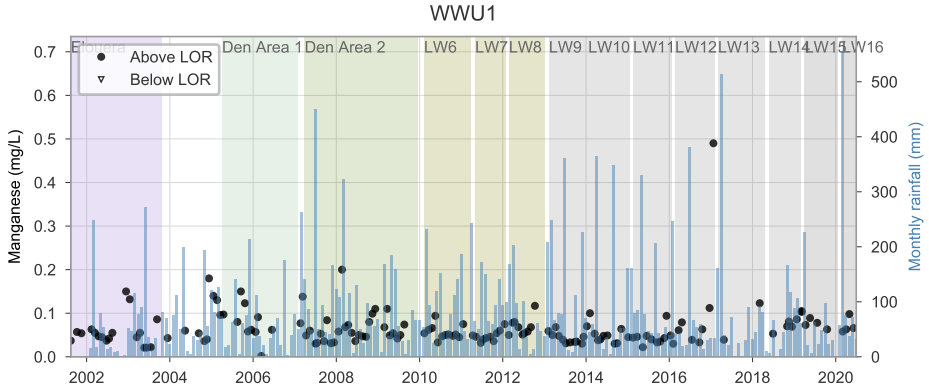

WC_ROCKBAR39
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Aluminium (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

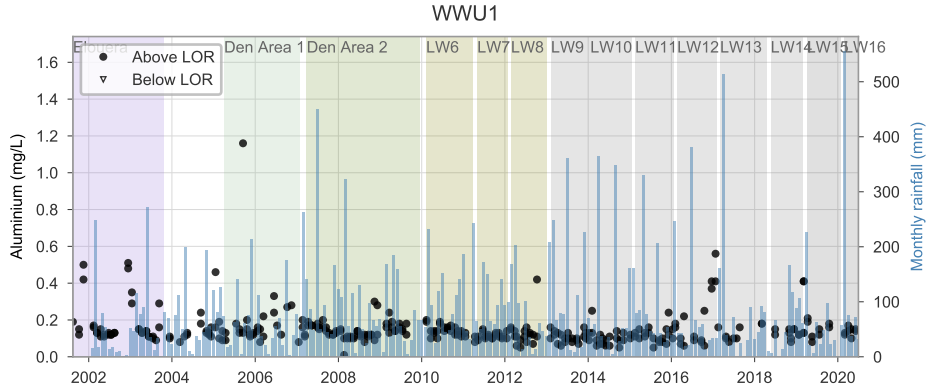

WC_ROCKBAR39
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Silicon (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

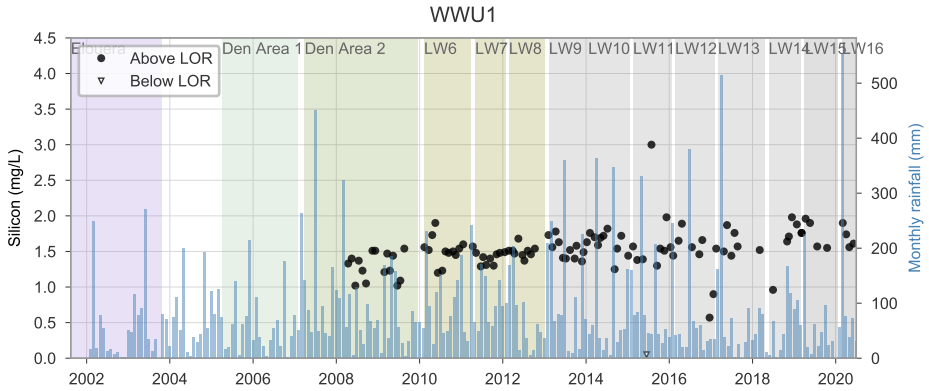

WC_ROCKBAR39
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
Zinc (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019
2020

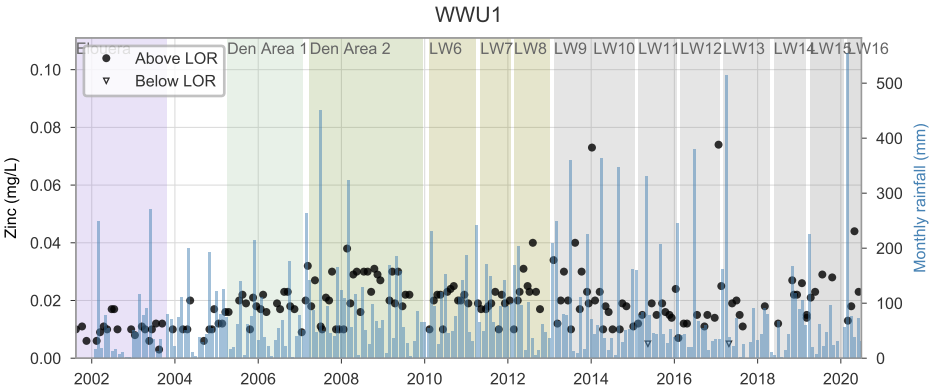

WWU1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Sulfate (mg/L)
Monthly rainfall (mm)

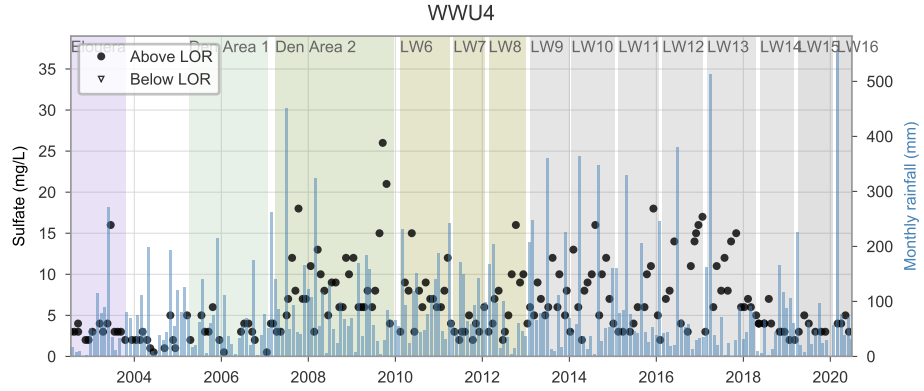

WWU1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Iron (mg/L)
Monthly rainfall (mm)

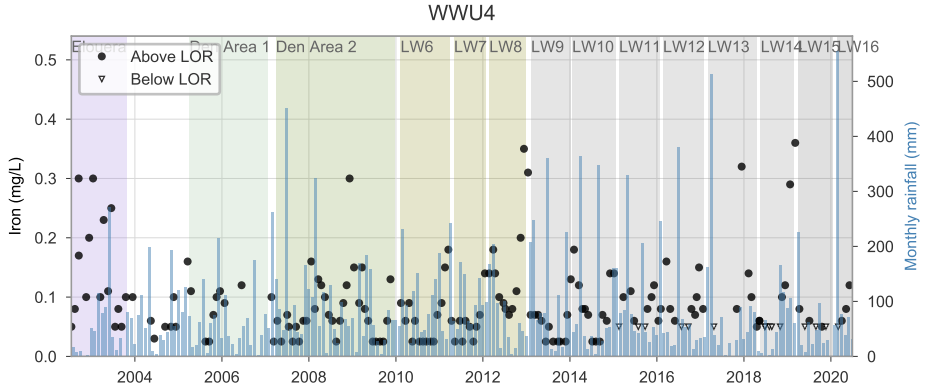

WWU1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Manganese (mg/L)
Monthly rainfall (mm)

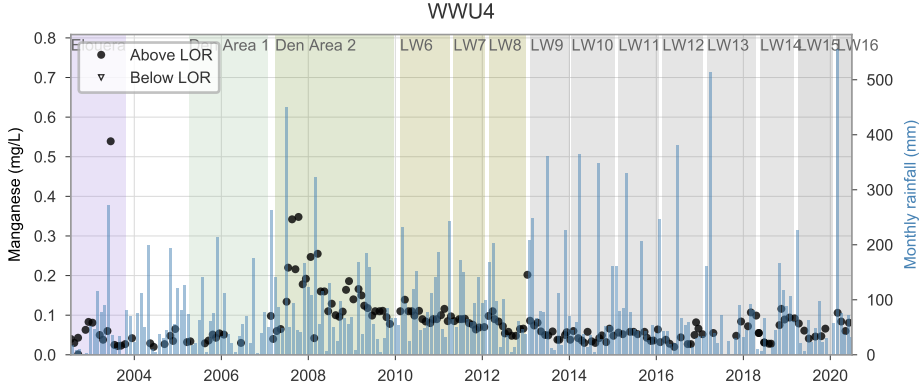

WWU1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Aluminium (mg/L)
Monthly rainfall (mm)

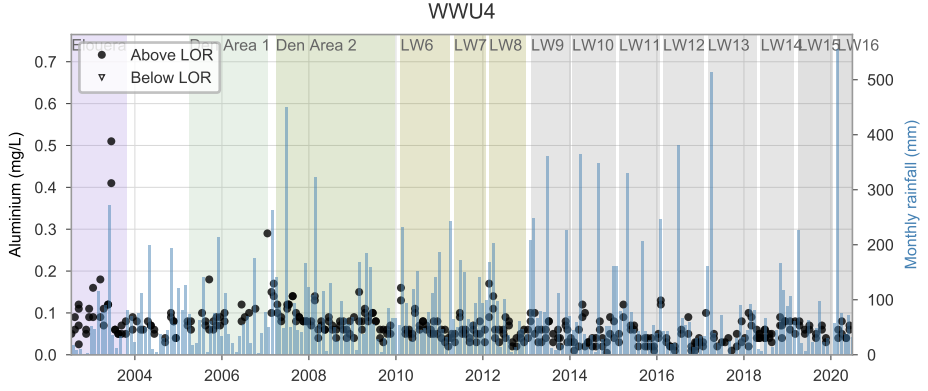

WWU1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Silicon (mg/L)
Monthly rainfall (mm)

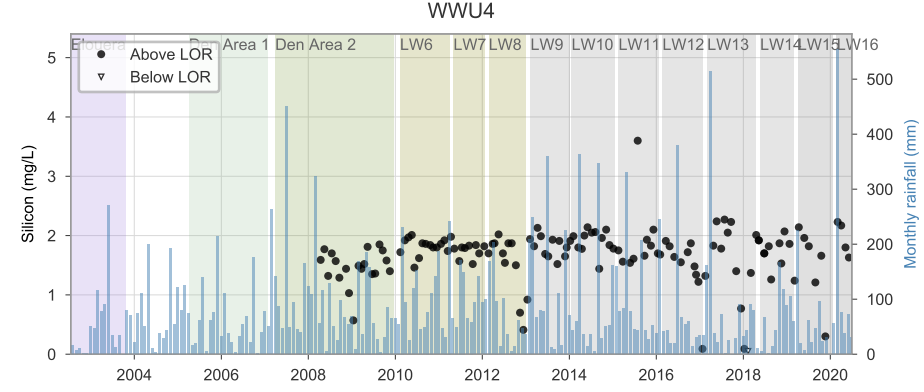

WWU1
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Zinc (mg/L)
Monthly rainfall (mm)

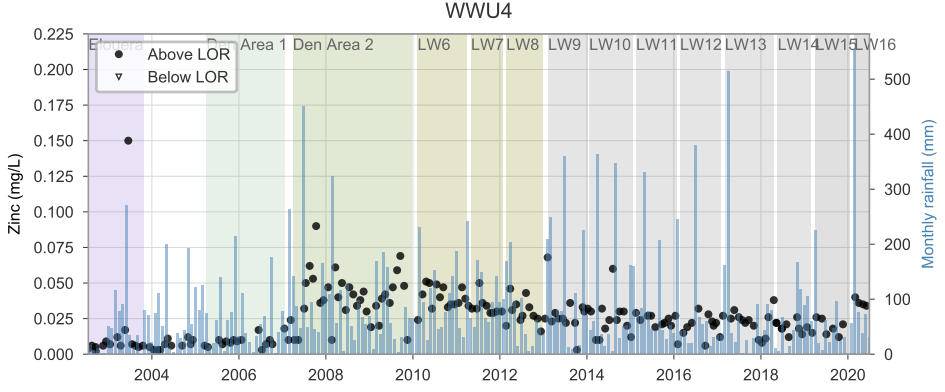

WWU4
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Sulfate (mg/L)
Monthly rainfall (mm)


WWU4
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Iron (mg/L)
Monthly rainfall (mm)


WWU4
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Manganese (mg/L)
Monthly rainfall (mm)


WWU4
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Aluminium (mg/L)
Monthly rainfall (mm)


WWU4
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Silicon (mg/L)
Monthly rainfall (mm)


WWU4
Above LOR
Below LOR
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
Zinc (mg/L)
Monthly rainfall (mm)

APPENDIX 2 – Surface flow observations on Wongawilli Ck

Figure A2-1

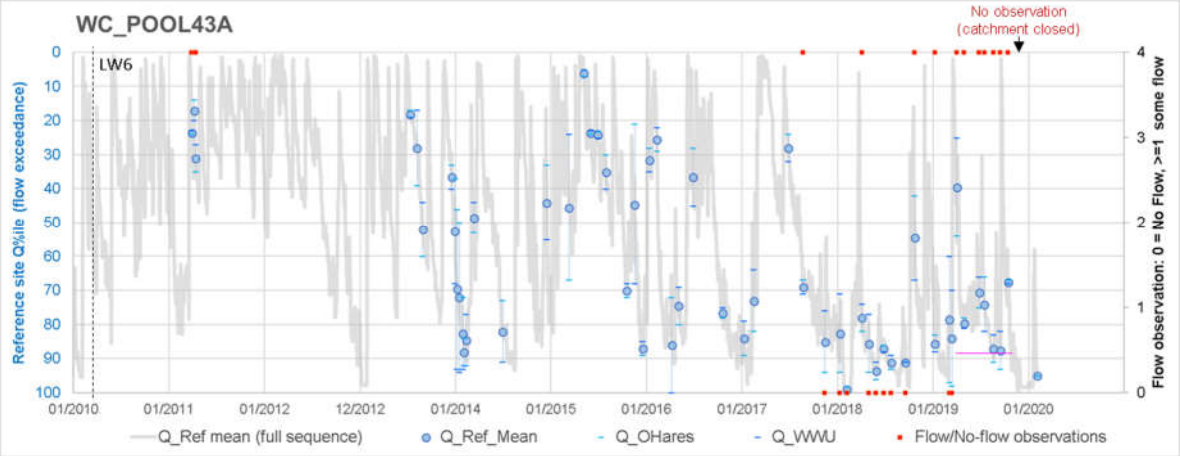


Figure A2-2

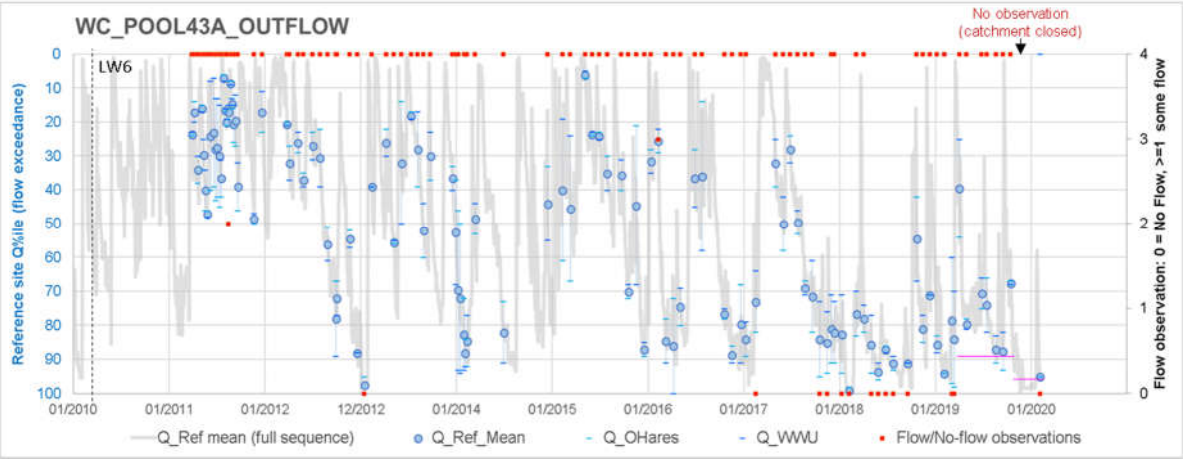
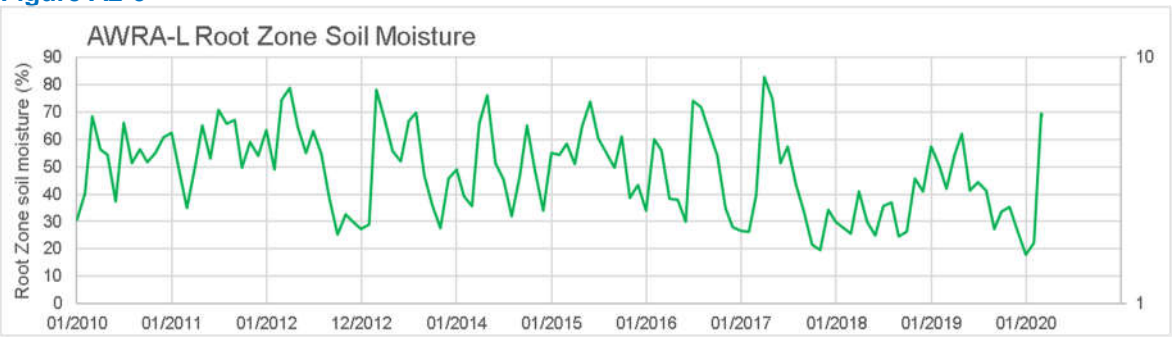


Figure A2-3



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

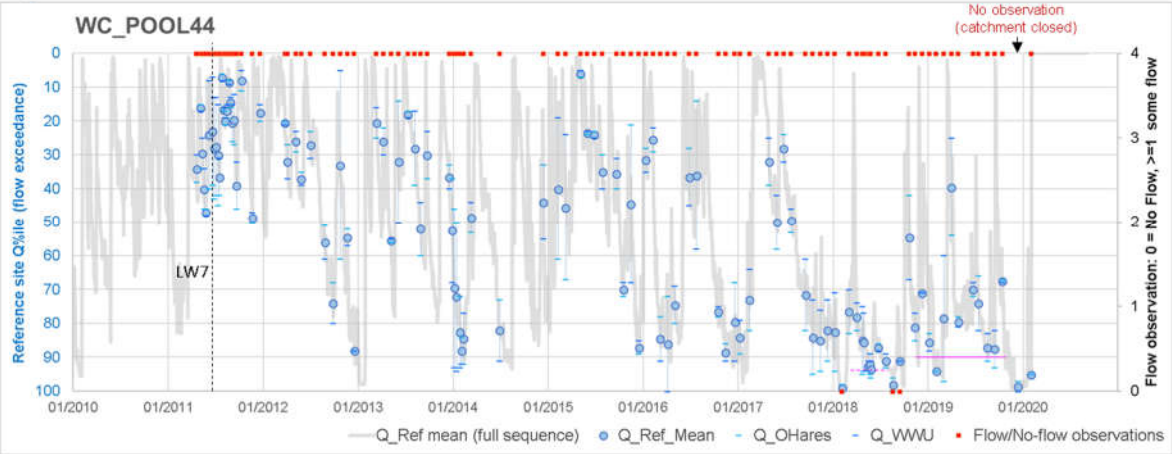


Figure A2-5

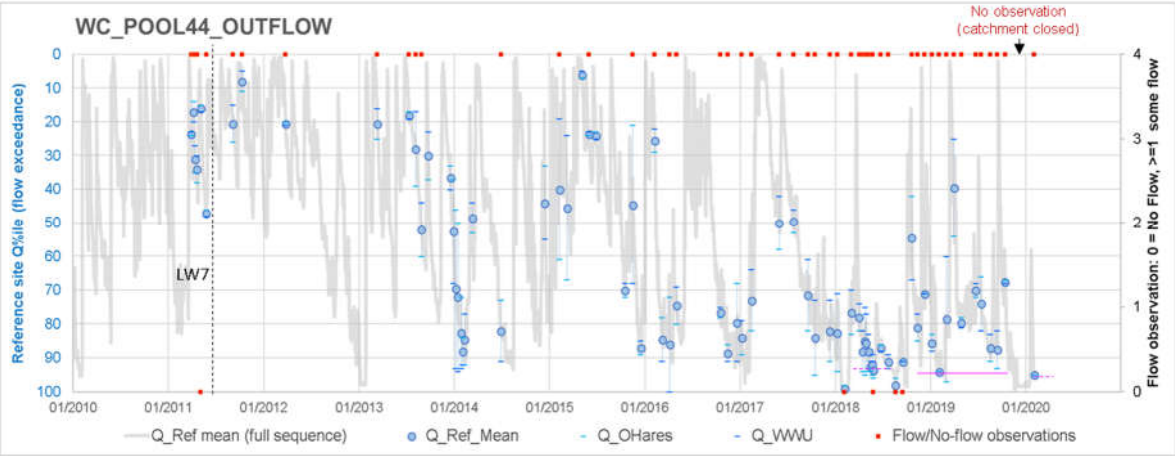
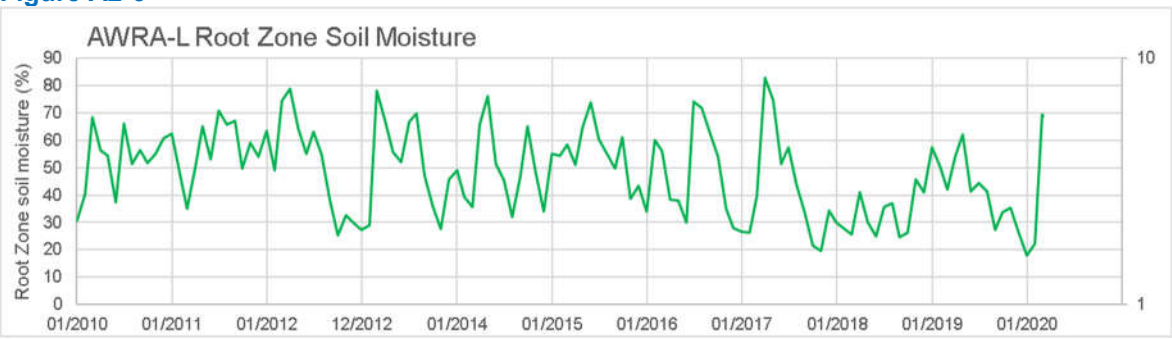


Figure A2-6



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

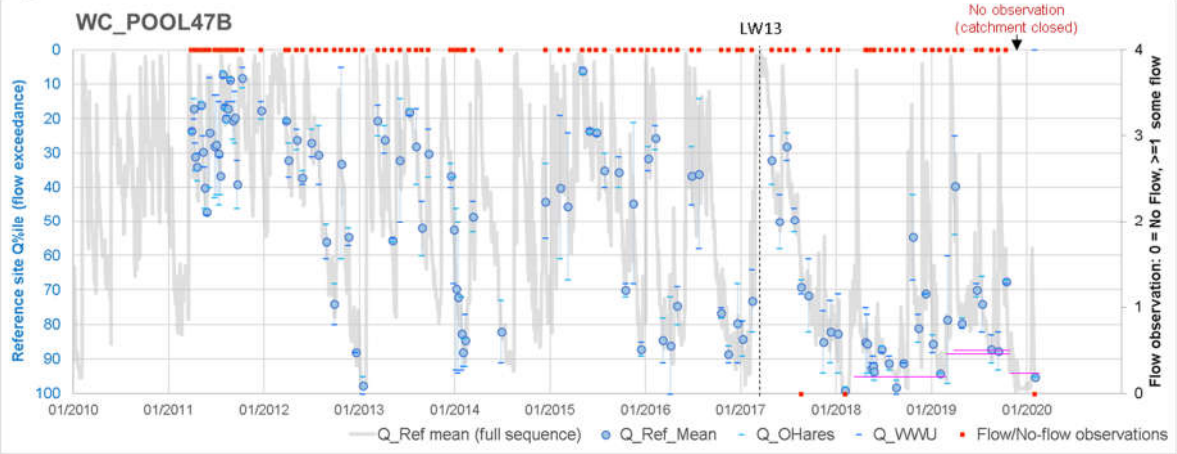


Figure A2-8

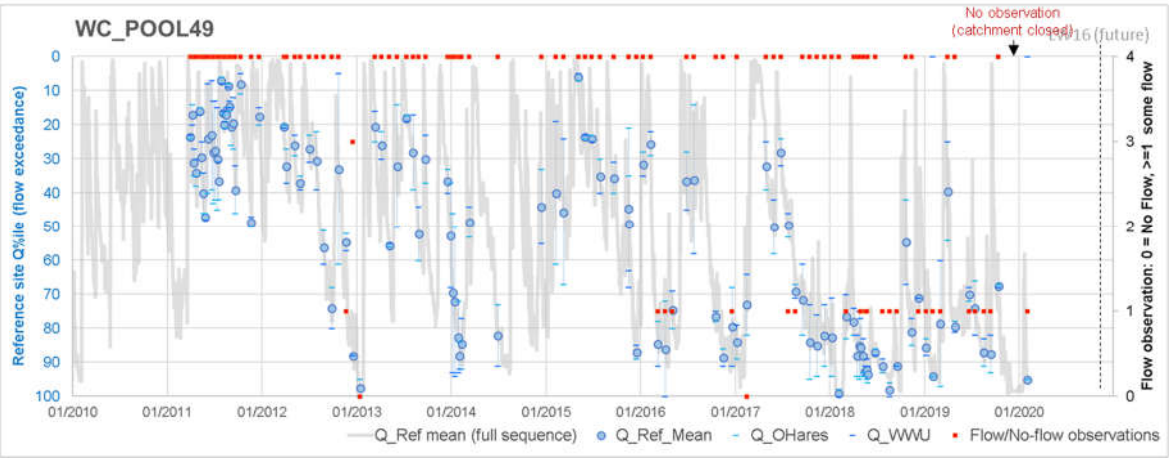
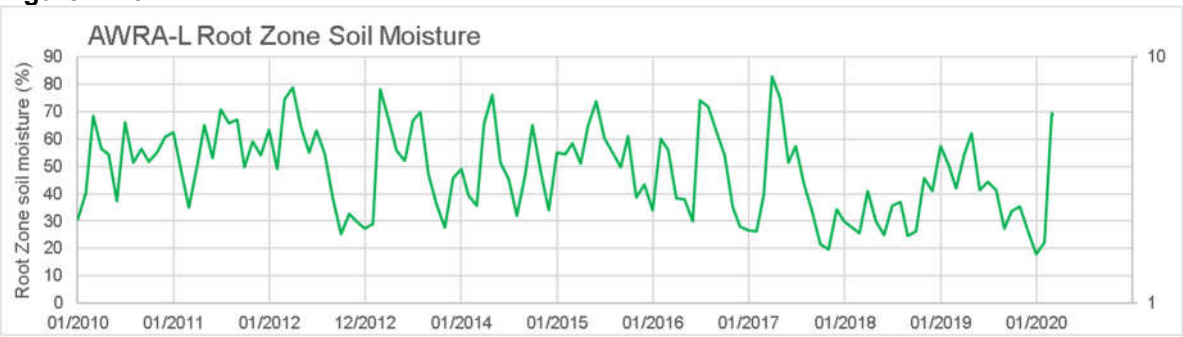
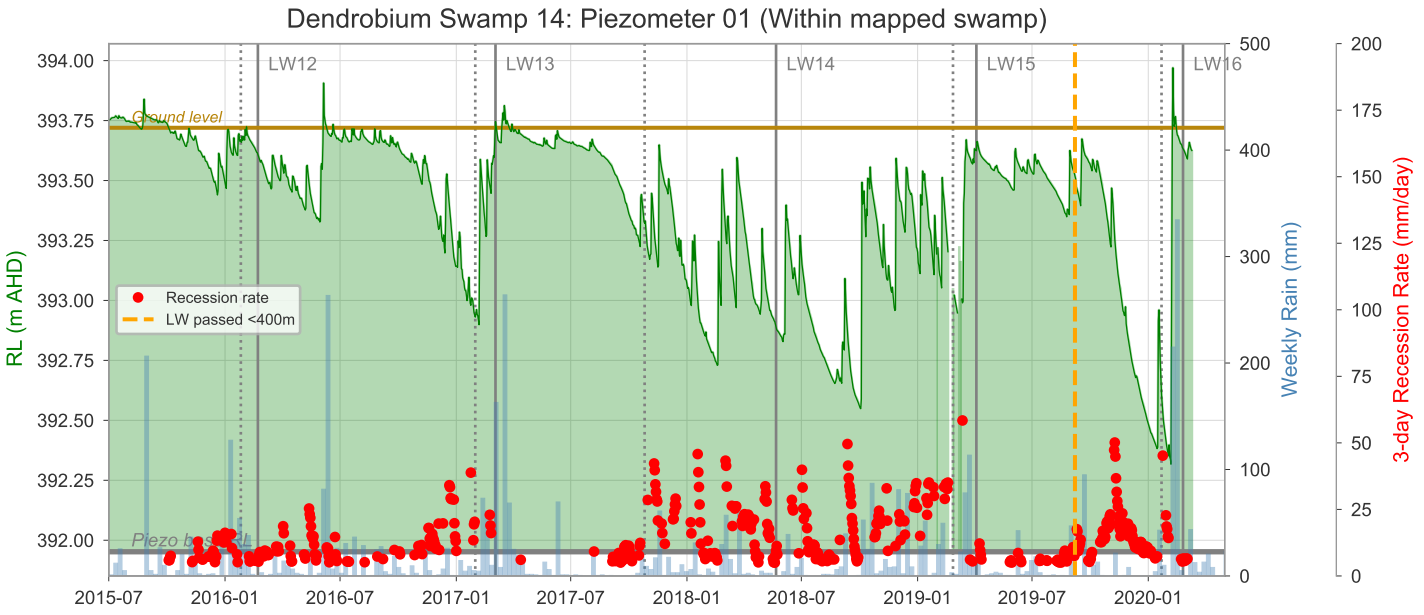


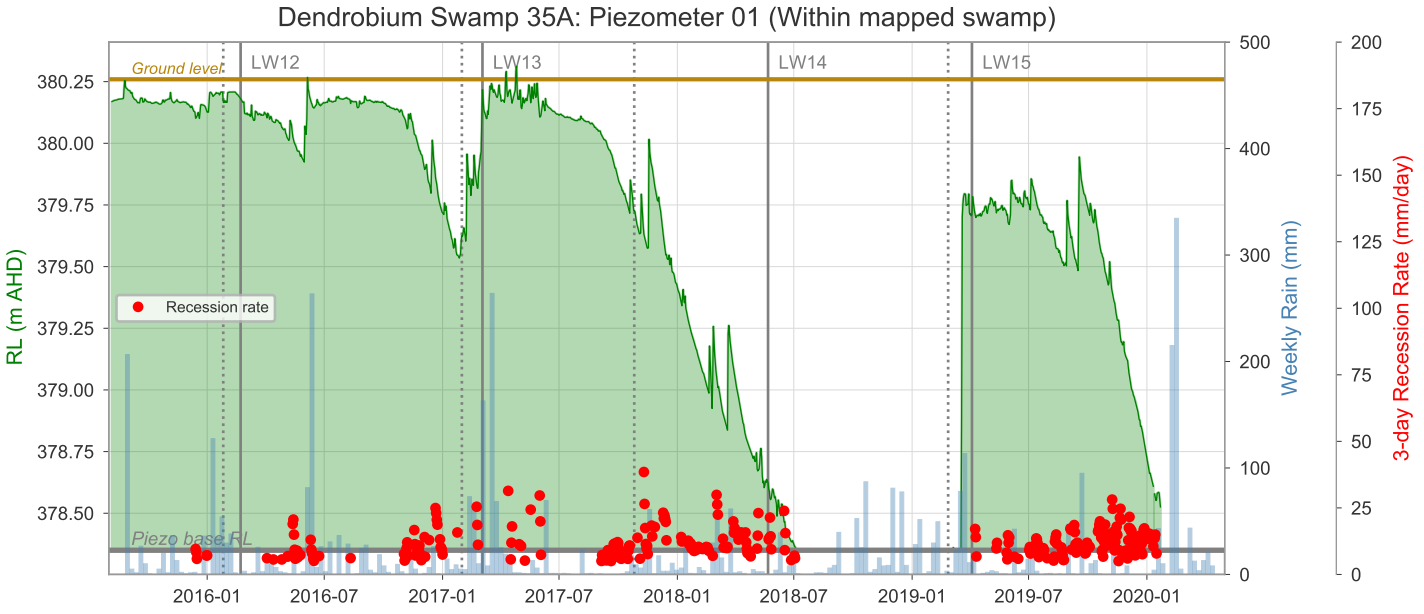
Figure A2-9

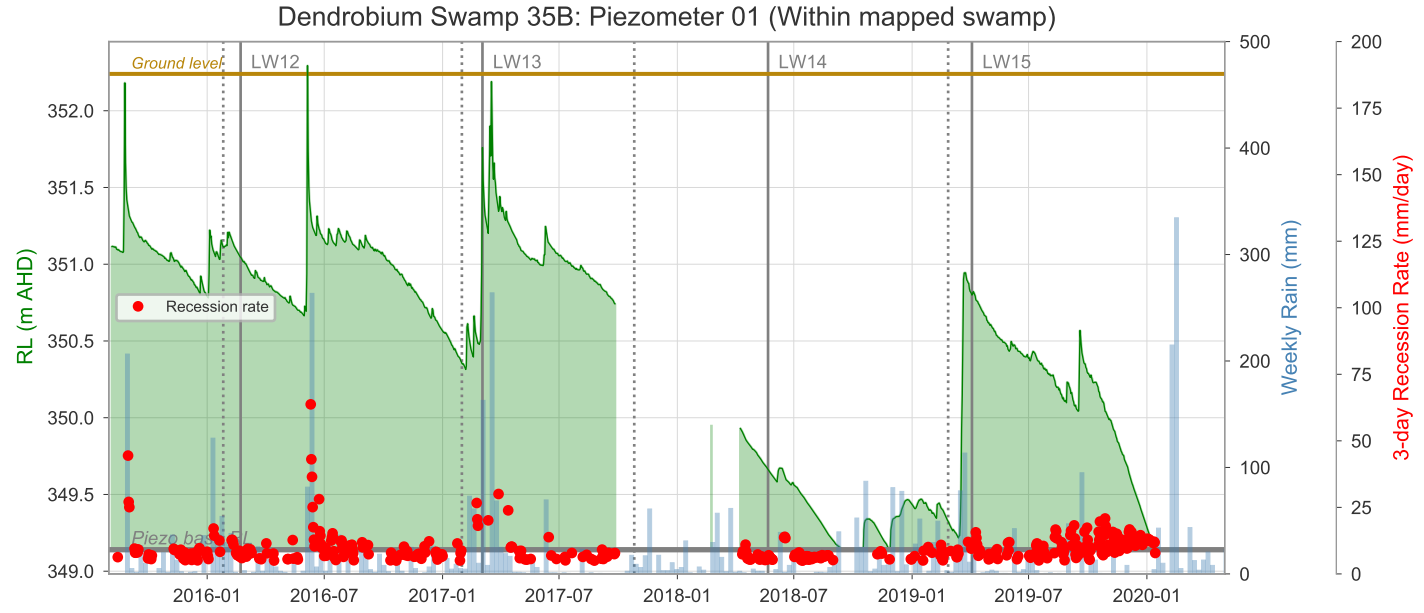


These two sites (Pool 47B and Pool 49) are further upgradient along Wongawilli Creek, near to Longwalls 13 and 16 (which is yet to be extracted). They have relatively longer pre-mining records than the other sites (Pools 43A and 44).

APPENDIX 3 – Swamp shallow groundwater hydrographs


Dendrobium Swamp 14: Piezometer 01 (Within mapped swamp)
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)
Ground level
LW12
LW13
LW14
LW15
LW16
Recession rate
LW passed <400m
Piezo base RL
394.00
393.75
393.50
393.25
393.00
392.75
392.50
392.25
392.00
500
400
300
200
100
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
2019-07
2020-01


Dendrobium Swamp 35A: Piezometer 01 (Within mapped swamp)
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)
Ground level
LW12
LW13
LW14
LW15
Recession rate
Piezo base RL
380.25
380.00
379.75
379.50
379.25
379.00
378.75
378.50
500
400
300
200
100
0
200
175
150
125
100
75
50
25
0
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01
2019-07
2020-01


Dendrobium Swamp 35B: Piezometer 01 (Within mapped swamp)
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)
Ground level
LW12
LW13
LW14
LW15
Recession rate
Piezo base RL
352.0
351.5
351.0
350.5
350.0
349.5
349.0
500
400
300
200
100
0
200
175
150
125
100
75
50
25
0
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01
2019-07
2020-01

APPENDIX 4 – Trigger Action Response Plan (Area 3B)

Appendix A – Watercourse Monitoring and Trigger Action Response Plan

Watercourse monitoring within Dendrobium Area 3 will be installed ahead of mining to achieve 2 years baseline data (subject to timing and approval timeframes of any request to install additional monitoring). Monitoring will be conducted throughout the mining period and for at least 2 years following active subsidence or until the consequences of mining have stabilised. A review of post mining monitoring will be carried out in consultation with DPIE, WaterNSW and other relevant agencies where required. Where impacts are observed, the monitoring period will be extended and this will be reported in Impact Assessment Reports and End of Panel Reports. For Level 2 and 3 Triggers and for impacts exceeding prediction this review will be conducted in consultation with key agencies. The location of monitoring sites is indicated on the figures of the relevant areas WIMMCP.

Table 1.1 – Dendrobium Area 3 Watercourse Monitoring

	Monitoring Site	Site Type	Monitoring Frequency	Parameters
OBSERVATIONAL MONITORING				
AREA 3A	Sandy Creek and tributaries (including SC7 and SC10) Wongawilli Creek and tributaries *Refer to Figure 3-1 of 3A WIMMCP*	Observation and photo point monitoring: • Sites based on an assessment of risk • Streams and swamps • Pools and rockbars • Previously observed impacts that warrant follow-up inspection	• Monthly 2 years pre- and post-mining, weekly when longwall is within 400 m of monitoring site • Reference sites 6 monthly	Visual signs of impacts to creeks and drainage lines (i.e. cracking, vegetation changes, increased erosion, changes in water colour, soil moisture etc.) determined by comparing baseline photos with photos during the mining period Manual Field Testing: Key water quality parameters in pools analysed to identify any changes resulting from mining including pH, Temp, EC, DO and ORP Pool water levels to identify any changes resulting from mining. At suitable sites, pool water levels will be measured with a pressure transducer and continuous logger. A benchmark for manual readings will be installed at sites that are not suitable for a logger
AREA 3B	**Impact Sites** Native Dog, Wongawilli and Donalds Castle Creeks, WC21, WC18, WC16, WC15, WC12, WC9, WC7, LA5, LA4, LA3, LA2, LA1, ND1, ND2 and DC13 Swamps 5, 10, 11, 13, 14, 23, 35a, 35b, 1a, 1b, 8, 3 and 4 *Refer to Figures 2-2 to 2-11 and 2-25 to 2-32 of 3B WIMMCP* **Reference Sites** Wongawilli Creek, Sandy Creek, Gallaghers Creek, LC5[(1)], WC11, DC10, SC9A, CR36 and D10 Swamps 2[(1)], 7[(1)], 15a, 22, 24, 25, 33, 84, 85, 86, 87 and 88 *Refer to Figures 2-12 to 2-25, 2-28 to 2-30 and 2-33 to 2-35*			
AREA 3C	**Impact Sites** [(2, 3)] Wongawilli Creek, , WC20, WC21, WC22, WC23, WC24, , LC5[(1)] Swamps), ,), 9, , , 144 and 145 **Reference Sites** CR36 (Cordeaux River tributary)			
WATER CHEMISTRY				
AREA 3A	**Wongawilli Creek** WWU1, WWU4, WC_Pool 46, WWM2, WC_Pool 43b and Wongawilli Creek (FR6) WC17_S1 (Wongawilli Creek tributary) WC14_S1 (Wongawilli Creek tributary) WC13_S1 (Wongawilli Creek tributary) **Sandy Creek** SCk_Rockbar 5 (Sandy Creek adjacent to LW7) SC10_Rockbar 3 (Sandy Creek tributary) SC10C_Pool 1 (SC10 tributary) SC7_S1 (Sandy Creek tributary)	• Collect sample • Field water quality	• Monthly monitoring pre, during and post mining for two years	Lab. Analytes: • (incl. lab checks of pH, lab. check of EC, DOC, Na, K, Ca, Mg, Filt. SO4, Cl, T. Alk., Total Fe, Mn, Al, Filt. Cu, Ni, Zn, Si)

	Lake Cordeaux Sandy Creek Arm (lake site) *Refer to Figure 3-2 of 3A WIMMCP*			
AREA 3B	**Wongawilli Creek** WWU1 (Wongawilli Creek headwaters) WWU4 (Wongawilli Creek upstream) WC_Rockbar 39 (Wongawilli Creek adjacent to LW17) WC Pool 49 (Wongawilli Creek adjacent to LW15) WC_Pool 46 (Wongawilli Creek adjacent to LW12) WWM2 (Wongawilli Creek adjacent to LW11) WC_Pool 43b (Wongawilli Creek downstream of LW9) Wongawilli Creek (FR6) (Wongawilli Creek downstream) WC21_Pool 5 (Wongawilli Creek tributary downstream of mining) WC21 Pools 30 and 53 (Wongawilli Creek tributaries over mining) WC15_Pool 28 (Wongawilli Creek tributary downstream of mining) WC15_Pool 9 (Wongawilli Creek tributary downstream of mining) WC15_Pool 2 (Wongawilli Creek tributary downstream of mining) WC7_Pool 1(Wongawilli Creek tributary downstream of mining) WC12_Pool 1 (Wongawilli Creek tributary downstream of mining) **Lake Avon** LA4_S1, LA4_S2, LA5_S1, LA5_S2, LA3 Pool 4, LA2 Pool 5, LA1 and LA_1 (Lake Avon tributaries downstream of mining) NDC_Pool 1 (Native Dog Creek downstream of mining) NDC_Pool 3 (Native Dog Creek downstream of mining) ND1_Pool 2 (tributary to Native Dog Creek downstream of mining) **Donalds Castle Creek** Donalds Castle Creek (FR6) (Donalds Castle Creek lower) DCL3 (Donalds Castle Creek Upstream approx. 1km from Cordeaux River) DC_Pool 22 (Donalds Castle Creek downstream of mining) DC13_Pool 2b (Donalds Castle Creek tributary downstream of mining) **Lake Cordeaux** *LC5_S1 (Reference Site)* *Refer to Figure 2-35* **Cordeaux River** CR36_S1 (Cordeaux River tributary Reference Site)			

AREA 3C	**Wongawilli Creek** WWU1 (headwaters; upstream of Area 3C) WWU4 (upstream of Area 3C) WC_S3 (adjacent to Longwall 20) Wongawilli Creek (FR6) (Wongawilli Creek downstream) WC_Pool 43b (adjacent to Longwall 20) WC_S1 (downstream of Longwall 21) WC20_S1 (downstream of Longwall 20) (4) WC24_S1 (downstream of Longwall 20) (4) WC26_S1 (downstream of Longwall 20) (4) WC21_Pool 5 (Wongawilli Creek tributary within the study area) **Donalds Castle Creek** Donalds Castle Creek (FR6) (Donalds Castle Creek lower) DCL3 (Donalds Castle Creek upstream of Cordeaux River confluence) **Lake Cordeaux** LC5_S1[1] (downstream of Longwall 20) **Cordeaux River** CR36_S1 (Reference site northeast of Area 3C)			
WATER FLOW				
Ref Sites	**O'Hares Creek** [NSW govt site] 213200 (O'Hares Creek @ Wedderburn) **Wongawilli Creek** WWU (Wongawilli Creek upstream)	• Some data (for reference sites) is provided by Water NSW		Other reference sites may be used depending on data availability and quality (e.g. Woronora River 2132101 and Bomaderry Creek 215016)
AREA 3A	**Wongawilli Creek** WWU (Wongawilli Creek upstream) WWL_A (Wongawilli Creek downstream) WC14S1 (Wongawilli Creek tributary) **Sandy Creek** SCL2(Sandy Creek at downstream) SC10S1 and SC10CS1 (Sandy Creek tributary) *Refer to Figures 3-5 of 3A WIMMCP*	• Pressure transducer with data logger • Flow gauging site (volumetric or flow meter). Low-profile weir or suitable natural rockbar control	• Continuous 1-hour logging intervals	Automatic pool water level measurements which are converted to flows by calculation of rating curves using measured creek cross sections/measured flows at the monitoring point. Hydrological changes are assessed by comparing pre- and post-mining observed flows from impact or assessment sites to flow data from similar reference sites (that are not impacted by mining).
AREA 3B	**Wongawilli Creek** WWU (Wongawilli Creek upstream) WWL_A (Wongawilli Creek downstream) WC21S1 (Wongawilli Creek tributary downstream of mining) WC15S1 (Wongawilli Creek tributary downstream of mining) WC12S1 (Wongawilli Creek tributary downstream of mining) **Donalds Castle Creek** DCU (Donalds Castle Creek @ FR6) DC13S1 (Donalds Castle Creek tributary downstream of mining) DCS2 (Donalds Castle Creek downstream of mining)			

	Lake Avon LA4S1 (Lake Avon tributary downstream of mining) LA3S1 (Lake Avon tributary downstream of mining) LA2S1 (Native Dog Creek tributary downstream of mining) NDCS1 (Lake Avon tributary downstream of mining) NDTS1 (Native Dog Tributary downstream of mining) **Lake Cordeaux** LC5S1 (Reference Site) **Cordeaux River** CR36S1 (Cordeaux River tributary Reference Site) *Refer to Figure 2-36 of 3B WIMMCP*			
AREA 3C	**Wongawilli Creek** WWU (Wongawilli Creek upstream) WWL_A (Wongawilli Creek downstream) WWL (Wongawilli Creek downstream) WCS1 (Wongawilli Creek downstream) WC20S1 (Wongawilli Creek tributary downstream of mining) WC24S1 (Wongawilli Creek tributary downstream of mining) WC26S1 (Wongawilli Creek tributary within the study area) WC21S1 (Wongawilli Creek tributary within the study area) **Donalds Castle Creek** DCU (Donalds Castle Creek downstream of mining) DCS2 (Donalds Castle Creek within study area) **Lake Cordeaux** LC5S1[1] (Downstream of LW20) **Cordeaux River** CR36S1 (Cordeaux River tributary Reference Site)			
AQUATIC ECOLOGY				
AREAS 3A, 3B and 3C	**Impact Sites:** Sites 2, 3, 4, X4, X5 and X6 (Wongawilli Creek) Sites X2 and X3 (WC21) Site X1 (Donalds Castle Creek) Sites 8, 9, 11, 12 and 13 (Sandy Creek Catchment) *Refer to Figure 2-57 of 3B WIMMCP* **Reference Sites:** Site 1 (Wongawilli Creek – until LW15) Site 5 (Wongawilli Creek) Site 14 (Donalds Castle Creek) Site 6 (WC21) Site 7 (Sandy Creek)	• Quantitative and observational monitoring	• Two baseline monitoring campaigns prior to mining during autumn and spring • Biennial monitoring during mining in autumn and spring • Biennial monitoring post mining for two years or as otherwise required • Biennial monitoring targets sites as mining progresses through the domain	Macroinvertebrate sampling and assessment using the AUSRIVAS protocol and quantitative sampling using artificial collectors In consideration of Adams Emerald Dragonfly, Giant Dragonfly and Sydney Hawk Dragonfly, individuals of the genus Austrocorduliidae and Gomphomacromiidae, Petalura are identified to species level if possible

	Sites 15 and 16 (Kentish Creek) *Refer to Figure 2-57 of 3B WIMMCP*			Fish are sampled by visual observations and dip netting in Area 3A, and sampled using baited traps in Area 3B
TERRESTRIAL ECOLOGY				
AREAS 3A, 3B and 3C	**Impact Sites:** DC13 (Donalds Castle Creek tributary) DC(1) (Donalds Castle Creek) WC15 and 21 (Wongawilli Creek tributaries) LA4A (Lake Avon tributary) ND1 (Native Dog Creek tributary) **Reference Sites:** WC10 and 11 (Wongawilli Creek tributaries) SC6, SC7-1, SC7-2, SC7A and SC8 (Sandy Creek tributaries) DC8 (Donalds Castle Creek tributary) NDC (Native Dog Creek)	• Standardised transects in potential breeding habitat for two threatened frog species, Littlejohn's Tree Frog and Giant Burrowing Frog	• Surveys are undertaken in optimal periods over the season (i.e. when frogs are calling and/or active at known sites)	Frog surveys are conducted along creeks with a focus on features susceptible to impacts e.g. breeding pools. Potential breeding habitat for Littlejohn's Tree Frog and Giant Burrowing Frog will be targeted. Standardised transects have been established to record numbers of individuals at each site from one year to the next. Tadpole counts will also be undertaken as part of the breeding habitat monitoring transects. These transects are surveyed by walking down the creekline and counting all amphibians seen or heard on either side of the line

(1) *Reference site for Area 3B; impact site when mining commences in Area 3C.*

(2) *The proposed sites are designed to monitor each mapped pool/rockbar complex within the Study Area reach of Wongawilli Creek. Based on site inspections (August 2019), continuous monitoring will be implemented at suitable sites. A benchmark for manual readings will be installed at sites that are not suitable for continuous monitoring.*

(3) *Proposed sites within the Wongawilli Creek tributaries are subject to change based on further field inspections. The sites will target pool/rockbar complexes and steps.*

(4) *The proposed water chemistry monitoring sites are designed to detect changes to water quality, due to mining in Area 3C, within Wongawilli Creek. The proposed tributary sites (WC26, WC24 and WC20) aim to detect surface water inputs into Wongawilli Creek. Based on field observations, the Wongawilli Creek tributaries WC28, WC27, WC25, WC23 and WC22 were deemed as unsuitable for water chemistry sites due to a lack of site flows and the morphology of the tributaries.*

Table 1.2 – Dendrobium Area 3B Watercourse Impacts, Triggers and Response

OBSERVATIONAL-MONITORING		
Wongawilli Creek, Donalds Castle Creek and WC-WF54 **Relevant Performance Measure(s):** • Wongawilli Creek - minor environmental consequences • Donalds Castle Creek - minor environmental consequences • Waterfall WC-WF54 – negligible environmental consequences General observation of streams in active mining areas when longwall is within 400m	***Level 1*** • Crack or fracture up to 100mm width at its widest point with no observable loss of surface water or erosion • Crack or fracture up to 10m length with no observable loss of surface water or erosion • 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 • Observable release of strata gas at the surface • Observable increase in iron staining within the mining area • Observation that a pool on a subject Creek is dry • Observation that the subject Creek has ceased to flow	• Continue monitoring program • Submit an Impact Report to BCD, DPIE, MEG, Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2 • Observation that a single pool on a subject Creek is dry in consecutive monitoring events • Observation that two or more pools on a subject Creek are dry in a single monitoring event • Observation that the subject Creek has ceased to flow in consecutive monitoring event	• *Actions as stated for Level 1* • Carry out Water Flow Assessment Method D • Review monitoring frequency • Submit letter report to DPIE, MEG and Water NSW and seek advice on any CMA required • 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 • Crack or fracture between 10 and 50m length • Soil surface crack that causes erosion that is likely to stabilise within the monitoring period without intervention • 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* • Review monitoring frequency • Submit letter report to DPIE, MEG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)
	Level 3 • Crack or fracture over 300mm width at its widest point • Crack or fracture over 50m length • Fracturing observed in the bedrock base of any significant permanent pool which results in observable loss of surface water • Soil surface crack that causes erosion that is unlikely to stabilise within the monitoring period without intervention	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, MEG, Water NSW • Implement additional monitoring or increase frequency if required • 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, MEG, Water NSW • Completion of works following approvals and at a time agreed between S32, DPIE, MEG and Water NSW (i.e. may be after mining induced

	• Gas release results in vegetation dieback, mortality or loss of aquatic habitat • 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 • Review relevant TARP and Management Plan in consultation with key agencies
	Exceeding Prediction • 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 • Gas release results in vegetation dieback that does not revegetate • Gas release results in mortality of threatened species or ongoing loss of aquatic habitat • 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) • Iron staining and associated increases in dissolved iron resulting from the mining is observed in water at the Donalds Castle Creek downstream monitoring site Donalds Castle Creek (FR6) • Rock fall at WC-WF54 or its overhang • Impacts on the structural integrity of WC-WF54, its overhang or its pool	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent
Native Dog Creek, ND1, ND2, WC15, WC12, WC7, LA1 and LA2 General observation of streams in active mining areas when longwall is within 400m	***Level 1*** • Crack or fracture up to 100mm width at its widest point with no observable loss of surface water or erosion • Crack or fracture up to 10m length with no observable loss of surface water or erosion • 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 • Observable release of strata gas at the surface • Observable increase in iron staining within the mining area	• Continue monitoring program • Submit an Impact Report to BCD, DPIE, MEG, Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR

	Level 2 • 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 • Crack or fracture between 10 and 50m length • Soil surface crack that causes erosion that is likely to stabilise within the monitoring period without intervention • 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* • Review monitoring frequency • Submit letter report to DPIE, MEG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)
	Level 3 • Crack or fracture over 300mm width at its widest point • Crack or fracture over 50m length • Fracturing observed in the bedrock base of any significant permanent pool which results in observable loss of surface water • Soil surface crack that causes erosion that is unlikely to stabilise within the monitoring period without intervention • Gas release results in vegetation dieback, mortality or loss of aquatic habitat • Observable increase in iron staining within the mining area continues more than 600m from the longwall	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, MEG, Water NSW • Implement additional monitoring or increase frequency if required • 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, MEG, Water NSW • Completion of works following approvals and at a time agreed between S32, DPIE, MEG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success • Review relevant TARP and Management Plan in consultation with key agencies
WATER QUALITY		
Wongawilli Creek **Relevant Performance Measure(s):** • Wongawilli Creek - minor environmental consequences Wongawilli Creek (FR6) Baseline means: • pH 5.98 • EC 98.8 uS/cm • DO 89.5%	***Level 1*** • One exceedance of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 4.45 – EC 154.1 uS/cm – DO 50.5%	• Continue monitoring program • Submit an Impact Report to BCD, DPIE, MEG, Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2 • 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: – pH 4.45 – EC 154.1 uS/cm – DO 50.5%	• *Actions as stated for Level 1* • Review monitoring frequency • Submit letter report to DPIE, MEG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)

	Level 3 • Three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 4.45 – EC 154.1 uS/cm – DO 50.5%	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, MEG, Water NSW • Implement additional monitoring or increase frequency if required • Review relevant TARP and Management Plan in consultation with key agencies • Develop site CMA (subject to agency feedback). This may include: – Limestone emplacement to raise pH where it is appropriate to do so • Completion of works following approvals and at a time agreed between S32, DPIE, MEG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success
	Exceeding Prediction • 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: – pH 4.45 – EC 154.1 uS/cm – DO 50.5%	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent
Donalds Castle Creek **Relevant Performance Measure(s):** • Donalds Castle Creek - minor environmental consequences Donalds Castle Creek (FR6) Baseline means: • pH 5.41 • EC 116.0 uS/cm • DO 85.6%	***Level 1*** • One exceedance of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 3.60 – EC 185.8 uS/cm – DO 40.1%	• Continue monitoring program • Submit an Impact Report to BCD, DPIE, MEG Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2 • 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: – pH 3.60 – EC 185.8 uS/cm – DO 40.1%	• *Actions as stated for Level 1* • Review monitoring frequency • Submit letter report to DPIE, MEG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)
	Level 3	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, MEG, Water NSW • 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: – pH 3.60 – EC 185.8 uS/cm – DO 40.1%	• Review relevant TARP and Management Plan in consultation with key agencies • Collect laboratory samples and analyse for: – pH, EC, major cations, major anions, Total Fe, Mn & Al – Filterable suite of metals • Develop site CMA (subject to agency feedback). This may include: – Limestone emplacement to raise pH where it is appropriate to do so • Completion of works following approvals and at a time agreed between S32, DPIE, MEG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success
	Exceeding Prediction • 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: – pH 3.60 – EC 185.8 uS/cm – DO 40.1%	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent
Lake Avon **Relevant Performance Measure(s):** • Lake Avon - negligible reduction in the quality of surface water inflows to Lake Avon Lake Avon tributary (LA4_S1) Baseline means: • pH 5.38 • EC 90.8 uS/cm • DO 89.9%	***Level 1*** • One exceedance of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 4.90 – EC 129.8 uS/cm – DO 69.5%	• Continue monitoring program • Submit an Impact Report to BCD, DPIE, MEG, Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2 • 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: – pH 4.90 – EC 129.8 uS/cm – DO 69.5%	• *Actions as stated for Level 1* • Review monitoring frequency • Submit letter report to DPIE, MEG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)
	Level 3	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, MEG, Water NSW • 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: – pH 4.90 – EC 129.8 uS/cm – DO 69.5%	• Review relevant TARP and Management Plan in consultation with key agencies • Collect laboratory samples and analyse for: – pH, EC, major cations, major anions, Total Fe, Mn & Al – Filterable suite of metals • Develop site CMA (subject to agency feedback). This may include: – Limestone emplacement to raise pH where it is appropriate to do so – Grouting of fractures in rockbar and bedrock base of any significant pool where flow diversion results in pool water level lower than baseline period • Completion of works following approvals and at a time agreed between S32, DPIE, MEG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success
	Exceeding Prediction • 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: – pH 4.90 – EC 129.8 uS/cm – DO 69.5%	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • 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 Donalds Castle Creek **Relevant Performance Measure(s):** • Wongawilli Creek - minor environmental consequences • Donalds Castle Creek - minor environmental consequences	***Level 1*** • Single pool on a subject Creek is observed as dry	• Continue monitoring program • Carry out Water Flow Assessment Method D. • Submit letter report to DPIE, MEG and Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2 • Single pool on a subject Creek is observed as dry in consecutive monitoring events • Two or more pools on a subject Creek are observed as dry in a single monitoring event	• *Actions as stated for Level 1* • Review monitoring frequency • Submit letter report to DPIE, MEG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)

	Level 3 • 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* • Offer site visit with BCD, DPIE, MEG, Water NSW • Implement additional monitoring or increase frequency if required • Review relevant TARP and Management Plan in consultation with key agencies • 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, MEG, Water NSW • Completion of works following approvals and at a time agreed between S32, DPIE, MEG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success
	Exceeding Prediction • 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* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • 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 **Relevant Performance Measure(s):** • Waterfall WC-WF54 – negligible environmental consequences	***Exceeding Prediction*** • Fracturing in Wongawilli Creek within 30m of the waterfall which results in observable flow diversion • Fracturing in Wongawilli Creek which results in observable flow diversion from the lip of the waterfall	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • 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 Donalds Castle Creek **Lake Avon and Cordeaux River** **Relevant Performance Measure(s):**	***Level 1*** • A) Lower flow than expected (additional 10-15% of days where Q% lower than Reference Q%) • B) 5-10% increase in cease-to-flow frequency beyond natural) • C) Reduction in Q50 (10-15% beyond natural)	• Continue monitoring program. • Submit an Impact Report to BCD, DPIE, MEG, WaterNSW. • Report in the End of Panel Report. • Summarise actions and monitoring in AEMR.

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Wongawilli Creek - minor environmental consequences
Donalds Castle Creek - minor environmental consequences
Lake Avon - negligible reduction in the quantity of surface water inflows to Lake Avon[1]
Cordeaux River - negligible reduction in the quantity of surface water inflow to the Cordeaux River at its confluence with Wongawilli Creek[2]

Surface water flow Reference sites (as in Table 1.1):

<u>Wongawilli Creek - WWU</u> (Wongawilli Creek upstream);
<u>O’Hares Creek at Wedderburn (213200);</u>
(other such sites, if necessary, include Woronora River 2132101 and Bomaderry Creek 215016)

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).
Hydrological changes are assessed by comparing pre- and post-mining observed flows from impact or assessment sites to flow data from the reference sites.
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.
</td>
<td>Level 2

A) Lower flow than expected (additional 15-20% of days where Q% lower than Reference Q%).
B) 10-20% increase in cease-to-flow frequency (beyond natural)
C) 15-20% reduction in Q50 (beyond natural)
D) Observation that the subject Creek has ceased to flow at spatially consecutive monitoring sites.

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Actions as stated for Level 1
Review monitoring frequency.
D) → carry out Water Flow Assessment Method D.
Submit letter report to DPIE, MEG and WaterNSW and seek advice on any CMA required.
Implement agreed CMAs as approved (subject to agency feedback).

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<td>Level 3

A) Lower flow than expected (additional >20% of days where Q% lower than Reference Q%)
B) >20% increase in cease-to-flow frequency (beyond natural)
C) >20% reduction in Q50 (beyond natural)

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Actions as stated for Level 2
Offer site visit with BCD, DPIE, MEG, WaterNSW.
Implement additional monitoring or increase frequency if required.
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, MEG, WaterNSW.
Completion of works following approvals and at a time agreed between S32, DPIE, MEG and WaterNSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success.
Review relevant TARP and Management Plan in consultation with key agencies.

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<td>Exceeding Prediction
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".
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Actions as stated for Level 3
Investigate reasons for the exceedance.
Update future predictions based on the outcomes of the investigation.
Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent.

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[1] Surface water inflows calculation = [Impacts at gauged catchments (LA1 + LA2 + LA3 + LA4 + LA6+ NDT1 + ND2) + estimated impacts at ungauged but undermined catchments (e.g. LA5)] / [total inflow to LA].
[2] Flow reduction as determined from measured at flow gauging station WWL_A.

Tributaries of Wongawilli Creek and Donalds Castle Creek and other affected watercourses not subject to performance measures **Surface water flow Reference sites** (as in Table 1.1)**:** • Wongawilli Creek - WWU (Wongawilli Creek upstream); • O'Hares Creek and Wedderburn (213200); • (other such sites, if necessary, include Woronora River 2132101 and Bomaderry Creek 215016) 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). Hydrological changes are assessed by comparing pre- and post-mining observed flows from impact or assessment sites to flow data from the reference sites. *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*** • A) Lower flow than expected (additional 10-20% of days where Q% lower than Reference Q%) • B) 5-10% increase in cease-to-flow frequency (beyond natural) • C) 10-20% reduction in Q50 (beyond natural)	• Continue monitoring program. • Submit an Impact Report to BCD, DPIE, MEG, WaterNSW. • Report in the End of Panel Report. • Summarise actions and monitoring in AEMR.
	Level 2 • A) Lower flow than expected (additional 20-30% of days where Q% lower than Reference Q%) • B) 10-20% increase in cease-to-flow frequency (beyond natural) • C) 20-30% reduction in Q50 (beyond natural)	• *Actions as stated for Level 1* • Review monitoring frequency. • Submit letter report to DPIE, MEG and WaterNSW and seek advice on any CMA required. • Implement agreed CMAs as approved (subject to agency feedback).
	Level 3 • A) Lower flow than expected (additional >30% of days where Q% lower than Reference Q%) • B) >20% increase in cease-to-flow frequency (beyond natural) • C) >30% reduction in Q50 (beyond natural)	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, MEG, WaterNSW. • Implement additional monitoring or increase frequency if required • 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, MEG, WaterNSW. • Completion of works following approvals and at a time agreed between S32, DPIE, MEG and WaterNSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success. • 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 • Wongawilli Creek catchment – 8 sites • Donalds Castle Creek catchment – 1 site	***Level 1*** • Reduction in aquatic habitat for 1 year	• Continue monitoring program • Submit an Impact Report to BCD, DPIE, MEG, Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2	• *Actions as stated for Level 1*

Relevant Performance Measure(s): • Wongawilli Creek - minor environmental consequences • Donalds Castle Creek - minor environmental consequences	• Reduction in aquatic habitat for 2 years following the active subsidence period	• Review monitoring frequency • Submit letter report to DPIE, BCD, MEG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)
	Level 3 • Reduction in aquatic habitat for >2 years following the active subsidence period	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, MEG, Water NSW • Implement additional monitoring or increase frequency if required • Review relevant TARP and Management Plan in consultation with key agencies • 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, MEG, Water NSW • Completion of works following approvals and at a time agreed between S32, DPIE, MEG 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 • Wongawilli Creek catchment – 2 sites • Donalds Castle Creek catchment – 2 sites • Lake Avon tributary – 1 site • Native Dog tributary – 1 site **Relevant Performance Measure(s):** • Wongawilli Creek - minor environmental consequences • Donalds Castle Creek - minor environmental consequences	***Level 1*** • Reduction in habitat for 1 year	• Continue monitoring program • Submit an Impact Report to BCD, DPIE, MEG, Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2 • Reduction in habitat for 2 years following the active subsidence period	• *Actions as stated for Level 1* • Review monitoring frequency • Submit letter report to DPIE, BCD, MEG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)
	Level 3 • Reduction in habitat for > 2 years following the active subsidence period	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, MEG, Water NSW • Implement additional monitoring or increase frequency if required • Review relevant TARP and Management Plan in consultation with key agencies • 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, MEG, Water NSW • Completion of works following approvals and at a time agreed between S32, DPIE, MEG 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)

Department of Mining, Exploration and Geosciences (MEG)

WaterNSW

Attachment F – Terrestrial Ecology Assessment

Excellence in your environment

niche Environment and Heritage

DENDROBIUM LONGWALL 18 TERRESTRIAL ECOLOGICAL ASSESSMENT

ACCOMPANYING DOCUMENT TO DENDROBIUM LONGWALL 18 SUBSIDENCE MANAGEMENT PLAN

Prepared for SOUTH32 ILLAWARRA METALLURGICAL COAL | 12 August 2020



niche-eh.com

Excellence in your environment

Document control

Project number	Client	Project manager	LGA
5804	South32 Illawarra Metallurgical Coal (IMC)	Sian Griffiths	Wollongong

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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 (LW) 18 within Dendrobium Area 3B (DA3B). 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.

In accordance with the Development Consent, a Subsidence Management Plan (SMP), specific to LW18 within DA3B is required to be approved by the New South Wales Department of Planning, Industry and Environment (DPIE) prior to any mining of the proposed LW18. 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 LW18 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 terrestrial ecological assessment involved flora and fauna surveys within DA3B 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 a 600 m buffer area from the proposed LW18 as well as any predicted subsidence areas outside of that boundary.

Natural areas and features sensitive to subsidence within the DA3B study area include: watercourses, cliffs, rock outcrops, steep slopes and upland swamps. Significant conclusions from the MSEC (2020) report, relevant to this study include the following:

- It is unlikely that adverse impacts would occur along Wongawilli Creek due to the mining of LW18. It is unlikely that adverse impacts would occur at the Wongawilli Creek waterfall due to the mining of LW18.
- Fracturing could develop along Native Dog Creek where it is located within approximately 400 m of the proposed LW18.
- The drainage lines located directly above the mining area could experience the full range of predicted subsidence effects. Localised ponding due to mining-induced tilt 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 and adjacent to the proposed LW18. 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.
- It is unlikely that adverse impacts would occur at the cliffs due to the mining of LW18.
- Rock outcrops and steep slopes 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 LW18, and where the rock is marginally stable, this could then result in instabilities. 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 less than 50 mm up to 150 mm in width. The steep slopes are heavily

vegetated and erosion due to soil instability (i.e. downslope movements) was not readily apparent. If tension cracks were to develop, due to the extraction of LW18, it is possible that soil erosion could occur and require treatment.

- The predicted post-mining grades within the swamps are similar to the natural grades. There are small reductions in grades along the drainage lines near these swamps; however, adverse changes in the levels of ponding or scouring within the swamps are not anticipated due to the mining-induced vertical subsidence or tilt.
- Fracturing of the bedrock could occur beneath the swamps that are located above and adjacent to the mining area. 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 mining area. 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 Den14 and Den149 are located above the previous LW16 and LW17 and, therefore, the predicted subsidence effects are predominately due to these previous longwalls.
- Baseflow components of Wongawilli Creek and Native Dog Creek tributaries (ND1) are predicted to decline following longwall extraction. These reductions in base flow can result in an increased number of cease to flow days during dry conditions in Wongawilli Creek.
- 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 possibly observed in the first order tributary ND1C, which crosses Longwall 18; however, those impacts are not expected to significantly influence water quality at the ND1 outlet.
- Water quality effects on stored waters of the reservoirs are expected to be negligible and undetectable.
- Shallow groundwater levels will likely be affected in Swamp Den35a and Swamp Den149 which partially overlap the longwall footprint, noting that Swamp Den149 will likely be impacted by the preceding LW17. It is possible that impacts to shallow groundwater may occur in Swamp Den35b, located 90 m from LW18 and in the base of the ND1 valley. The remaining swamps are unlikely to be impacted.

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 DA3B and DA3B was reviewed as part of this report with major reports listed below:

- SIS completed for the 2008 modification (Biosis 2007).
- Dendrobium Area 3A Terrestrial Ecology Assessment (Niche 2020).
- Dendrobium Area 3C Terrestrial Ecology Assessment (Niche 2019).
- Dendrobium DA3B 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 2020; HGeo 2017).
- Statutory reviews and policy guidelines including.
    - Southern Coalfields Inquiry (DOP 2008).

- Upland Swamps Environmental Assessment Guidelines – Draft (OEH 2012).
- 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 April and May 2020.

Survey activities predominantly involved 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 vegetation communities. Six upland swamps, that meet the definition of the Threatened Ecological Community (TEC) under the *Biodiversity Conservation Act 2016* (BC Act) and *Environment Protection and Biodiversity Conservation Act* (EPBC Act), occur within the wider study area with complexity of swamps generally increasing with overall size. One complex larger swamp (Den14) partially occurs 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 3.94 hectares constituting the upland swamps or portion of swamp within or up to the 35 degree angle of draw study area.

Habitats such as pools which are potential breeding or nursery habitat for threatened frogs 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.

One threatened plant species was recorded within upland swamps of the study area: *Pultenaea aristata.* Three additional threatened plant species (*Epacris purpurascens var. purpurascens, 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 significant cumulative impacts (due to mining of LW18 and other longwalls within area DA3B) 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
DA3B	Dendrobium DA3B
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: LW18
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 18 (LW18) within Dendrobium DA3B (DA3B) (Figure 1, Figure 2). 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) for LW18 within DA3B (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 LW18. 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 LW18 in DA3B 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

LW18 is scheduled to be extracted between October 2021 – March 2022.

Mine layouts for DA3B 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 DA3B 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.

- Gas drainage, geological and geotechnical issues.

Several layout alternatives for DA3B 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 DA3B was achieved. DA3B 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 DA3B including major surface water features such as Lake Avon, Wongawilli Creek and Native Dog Creek; and a number of geological constraints such as dykes and faults. The process of developing the layout for DA3B 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 DA3B 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 Area 3 SMPs.

2 Description of the study area and subsidence predictions

2.1 Study area

One longwall (LW18) (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 LW18 consisting of:

- The 35° angle of draw line from the extents of the proposed LW18;
- The predicted limit of vertical subsidence, taken as the 20 millimetres (mm) subsidence contour, resulting from the extraction of the proposed longwall; 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 hectares (ha) of largely undisturbed bushland and watercourses of the Avon River Catchment inside the WaterNSW Metropolitan Special Area. The Avon 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 Rivers, creeks and drainage lines

There are no rivers within the study area. The closest rivers are the Avon River and Cordeaux River downstream of the Avon Dam and Cordeaux Dam, respectively. These rivers are located more than 6 km from LW18, at their closest points (MSEC 2020).

Wongawilli Creek, flows northwards to the east of LW18 in DA3B. Wongawilli Creek is located outside the study area, based on the 600 m boundary (Figure 3). A waterfall (Ref. WC-WF54) is located along Wongawilli Creek to the east of LW18. The centreline of the waterfall is situated 1 km from the eastern end of LW18 (MSEC 2020). 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).

Native Dog Creek flows into Lake Avon to the south-west of LW18. Native Dog Creek is located outside the study area based on the 35° angle of draw line and predicted 20 mm subsidence contour for LW18, however, it is partially located within the study area based on the 600 m boundary (Figure 3). The total length of creek within the study area based on the 600 m boundary is 0.6 km. The bed of Native Dog Creek includes exposed bedrock containing rockbars with some standing pools.

The drainage lines that are located directly or partially above LW18 include ND1, ND1C and their tributaries (Figure 3) (MSEC 2020). Other drainage lines that are located within the study area based on the 600 m boundary include LA1, LA2, ND1A, ND1B, ND2, ND2A, WC7 and WC12 (MSEC 2020) (Figure 3). These drainage lines are first and second order streams that form tributaries to Lake Avon and Wongawilli Creek (MSEC 2020). The beds of the drainage lines generally comprise exposed bedrock containing rockbars with some standing pools (MSEC 2020). There are also steps and cascades along the steeper sections. Debris accumulations have formed along the flatter sections that include sand, loose rocks and tree branches (MSEC 2020).

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.

2.1.2 Cliffs

There are no cliffs that have been identified within the study area. The nearest cliffs are located along Wongawilli Creek around 1 km east of proposed LW18 (MSEC 2020).

2.1.3 Rock outcrops and steep slopes

The steep slopes within the study area have been identified within the valleys of Lake Avon, Wongawilli Creek and their 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 %) (MSEC 2020).

There are rock outcrops located across the study area, primarily within the valleys of the drainage lines (MSEC 2020).

2.1.4 Upland swamps

There are four upland swamps (Den14, Den35a, Den35b and Den149) constituting TECs 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 (MSEC 2020) (Figure 3, Figure 4). There are two additional upland swamps (Den150 and Den151) that are partly or wholly located within the study area based on the 600 m boundary (MSEC 2020) (Figure 3, Figure 4).

The swamps within the study area are typically valley infill swamps that have formed along the drainage lines. However, Swamp Den149 and parts of Swamps Den150 and Den151 are headwater swamps located further up the valley sides (MSEC 2020).

The term ‘upland swamp’ here refers to those that meet the NSW and Commonwealth final determination descriptions of Coastal Upland Swamps in the Sydney Basin Bioregion, which is listed as an Endangered Ecological Communities (EECs) under the NSW BC Act and the Commonwealth EPBC Act. Therefore, it excludes swamps mapped within the study area that fall outside this definition, such as Upland Swamps: Mallee-Heath (MU46).

2.2 Predicted mine subsidence for natural features

Subsidence predictions for LW18 within DA3B 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;
- Upland 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 LW18 (MSEC 2020; HGeo 2020)

Feature	Description of natural feature	Predicted subsidence or surface water impact LW18	Previously observed impacts in other areas
Wongawilli Creek and Wongawilli Creek waterfall (WC-WF54)	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. Pools in the creek are permanent (based on monitoring to date) and naturally develop behind the rockbars and at sediment and debris accumulations (MSEC 2020). Wongawilli Creek is situated on the eastern side of the longwalls in DA3B. The thalweg (i.e. base or centreline) of the creek is 1 km from the finishing (i.e. eastern) end of LW18, at its closest point. The creek is therefore located outside the study area based on the 600 m boundary (MSEC 2020). A waterfall (Ref. WC-WF54) is located along Wongawilli Creek to the east of LW18. The centreline of the waterfall is situated 1 km from the finishing (i.e. eastern) end of LW18 (MSEC 2020).	The maximum predicted incremental vertical subsidence, upsidence and closure for Wongawilli Creek, due to the mining of LW18, 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 Wongawilli Creek due to the mining of LW18 (MSEC 2020). The waterfall is not expected to experience measurable conventional or valley related effects. Impacts on cliffs or rock features have not been observed at this distance outside of previous longwall mining in the Southern Coalfield. It is unlikely, therefore, that adverse impacts would occur at the waterfall due to the mining of LW18 (MSEC 2020).	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. 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 DA3B and 410 m east of LW9 in DA3B. 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.
Native Dog Creek	Native Dog Creek flows into Lake Avon to the south-west of LW18. The thalweg of the creek is 310 m from the commencing (i.e. western) end of LW18, at its closest point. The upper reaches of the creek are located directly above the completed longwalls at Elouera Colliery to the south of LW18 and outside of the study area based on the 600 m boundary (MSEC 2020). Native Dog Creek is located outside the study area based on the 35° angle of draw line and predicted 20 mm subsidence contour for LW18. However, it is partially located within the study area based on the 600 m boundary. The total length of creek within the study area based on the 600 m boundary is 0.6 km (MSEC 2020). The bed of Native Dog Creek comprises exposed bedrock containing rockbars with some standing pools.	While Native Dog Creek could experience very low levels of vertical subsidence, it is not expected to experience measurable conventional tilts, curvatures or strains. The compressive strain due to valley closure could result in fracturing in the creek bed, where it is located within approximately 400 m of the proposed longwall. 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) are possible, but are considered unlikely, as only two cases have been observed at similar distances from Dendrobium LW9 to LW15 (MSEC 2020).	The mining of the existing longwalls beneath the upper reaches of Native Dog Creek resulted in fracturing of the creek bed and the draining of pools directly above and adjacent to the mining area. The furthest drained pool from Elouera Colliery was located approximately 75 m downstream of the mining area. That affected pool is located just inside the study area based on the 600 m boundary for LW18 (MSEC 2020). Fracturing has also been observed along streams up to 300 m from the extracted longwalls in DA3B and up to approximately 400 m elsewhere in the Southern Coalfield. Type 3 impacts have been observed at distances up to 290 m from the

			extracted longwalls at Dendrobium Mine (MSEC 2020).
Drainage Lines	The drainage lines that are located directly or partially above LW18 include ND1, ND1C and their tributaries. Other drainage lines that are located within the study area based on the 600 m boundary include LA1, LA2, ND1A, ND1B, ND2, ND2A, WC7 and WC12. These drainage lines are first and second order streams that form tributaries to Lake Avon and Wongawilli Creek. The beds of the drainage lines 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. Some sections of the drainage lines are confined within the swamps (MSEC 2020). The natural gradients of the drainage lines typically vary between 10 mm/m (i.e. 1 %, or 1 in 100) along the upper reaches and 300 mm/m (i.e. 30 %, or 1 in 3) along the lower reaches. The average natural gradients of the drainage lines, directly above the longwalls, typically vary between 25 mm/m (i.e. 2.5 %, or 1 in 40) and 100 mm/m (i.e. 1 %, or 1 in 10) (MSEC 2020).	The drainage lines located directly above the mining area could experience the full range of predicted subsidence effects (MSEC 2020). Localised ponding due to mining-induced tilt 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 (MSEC 2020). It is expected that fracturing would occur along the sections of the drainage lines that are located directly above and adjacent to the proposed LW18 (MSEC 2020). Fracturing can also occur outside the extents of the proposed longwall at distances up to approximately 400 m (MSEC 2020). 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 (MSEC 2020).	Impacts have been observed along the drainage lines above and adjacent to the previously extracted LW9 to LW14 in DA3B, 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 DA3B (MSEC 2020).
Cliffs	Cliffs are defined as '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 no cliffs that have been identified within the study area. The nearest cliffs are located along Wongawilli Creek around 1 km east of the proposed LW18 (MSEC 2020).	The cliffs are not predicted to experience measurable conventional or valley related effects. It is unlikely that adverse impacts would occur at the cliffs due to the mining of LW18 (MSEC 2020).	Impacts on cliffs have not been observed at this distance outside of previous longwall mining in the Southern Coalfield (MSEC 2020).
Rock outcrops/ steep slopes	The steep slopes within the study area have been identified within the valleys of Lake Avon, Wongawilli Creek and their tributaries (MSEC 2020). 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 %).	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, and where the rock is marginally stable, this could then result in instabilities.	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 (MSEC 2020).

	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 the drainage lines.	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 less than 50 mm up to 150 mm in width (MSEC 2020). 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 (MSEC 2020). If tension cracks were to develop, due to the extraction of the longwalls, it is possible that soil erosion could occur and require treatment (MSEC 2020).	Previous experience of mining beneath rock outcrops at the Mine indicates that the percentage of rock outcrops that experience adverse impacts is small, representing less than 3 % of the total surface area (MSEC 2020).
Upland swamps	There are four upland swamps (Den14, Den35a, Den35b and Den149) 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 are two additional upland swamps (Den150 and Den151) that are partly or wholly located within the study area based on the 600 m boundary. Upland Swamp Den35a is partially located above the proposed LW18 and upland swamps Den14 and Den149 are located above the previous LW16 and LW17. Upland swamps Den35b, Den150 and Den151 are located at minimum distances of 85 m to 325 m south of LW18 (MSEC 2020). The upland swamps within the study area are typically valley infill swamps that have formed along the drainage lines. However Swamp Den149 and parts of upland swamps Den150 and Den151 are headwater swamps located further up the valley sides (MSEC 2020).	The predicted post-mining grades within the upland swamps are similar to the natural grades. There are small reductions in grades along the drainage lines near these upland swamps; however, adverse changes in the levels of ponding or scouring within the swamps are not anticipated due to the mining-induced vertical subsidence or tilt. Fracturing of the bedrock could occur beneath the upland swamps that are located above and adjacent to the mining area. 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 mining area. 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 (MSEC 2020). Upland swamps Den14 and Den149 are located above the previous LW16 and LW17 and, therefore, the predicted subsidence effects are predominately due to these previous longwalls (MSEC 2020).	The mining of LW9 in DA3B, located directly above Swamp Den05, resulted in multiple fractures and uplifting at its basal step. Reduction in groundwater levels were also noted (MSEC 2020). The groundwater levels were lower than baseline and recession rates greater than baseline for Swamps Den03, Den05, Den10, Den11, Den13, Den14 and Den23. Soil moisture levels below baseline were also reported in Swamps Den05, Den11, Den14 and Den23 (MSEC 2020). 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. 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 (MSEC 2020). LW7 in DA3A 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. Piezometer data (one of four monitoring station) shows a reduction in groundwater levels (MSEC 2020).
Water quality and surface water	• Lake Avon • Wongawilli Creek • Native Dog Creek • Tributaries • Water quality • Swamps	The incremental effect on stream flow due to extraction of LW18 will be 0.03 ML/day along Wongawilli Creek and 0.1 ML/day along ND1. The cumulative effect on flows due to the extraction of Longwall 6 to 18 is estimated to be approximately 1.0 ML/day along Wongawilli Creek and 0.15 ML/day along ND1 (~30% and 22% of mean flow, respectively), with the effects peaking around 2031-2035. The cumulative effects are likely to result in an increase in cease-to-flow days during dry conditions in Wongawilli Creek at gauging station WWL. LW18 may result in an incremental seepage loss from Lake Avon of between 0.01 and 0.13 ML/day (HGEO 2020). These predictions are based on a conservative regional groundwater model and monitoring to date has indicated impacts to be less than predicted (LW15 End of Panel Report). Water quality influence due to mining is expected to be minor or undetectable in stream reaches within subsidence affected areas. Impacts such as temporary changes in water salinity, pH and iron content with local discolouration of streambeds may be observed in the first order tributary ND1C which crosses Longwall 18; however, those impacts are not expected to significantly influence water quality at the ND1 outlet. Effects may include staining of bed rock and rock faces by iron hydroxide. Water quality effects on stored waters of the reservoirs are expected to be negligible and undetectable (HGEO 2020). It is likely that shallow groundwater levels will be affected in Swamp Den35a and Swamp Den149 which partially overlap the longwall footprint, noting that Swamp Den149 will likely be impacted by the preceding LW17. It is possible that impacts to shallow groundwater may occur in Swamp Den35b, located 90 m from LW18 and in the base of the ND1 valley. The remaining swamps are unlikely to be impacted (HGEO 2020).	Watercourses that have been directly mined under typically show one or more of the following water quality effects compared with baseline conditions (HGEO 2020): • A transient increase in EC, evident at one or more monitoring sites, but not always detectable at downstream locations. • An increase in water pH from baseline mildly acidic conditions to near neutral conditions. By contrast mining under Native Dog Creek by Elouera Longwalls resulted in a decrease in water pH which lasted several years. • Transient increases in dissolved Fe and Mn (+/- Zn and Al) at sampling locations immediately down-stream of the affected area. Water quality impacts have not been detected in watercourses that are not directly mined under (HGEO 2020). 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 (HGEO 2020): • 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. 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 (HGEO 2020).

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 LW18 within DA3B, 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.

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 was reviewed as part of this SMP with details provided in proceeding sections of this report.

In addition, relevant statutory reviews and policy guidelines have been reviewed (see section 3.8) 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 Previous surveys and ongoing monitoring

The DA3 area has been subject to ecological assessments commissioned by IMC for over 15 years which have been used to support development applications and exploration activities within specific parts of the DA3 area. The results of select key relevant assessments have been referred to or summarised in this report (see sections 3.2 to 3.6 below). Threatened species previously recorded 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) and the SIS completed for the 2008 modification (Biosis 2007);
- 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 DA3B: Terrestrial Ecological Assessment (Niche 2012);
- Dendrobium Area 3C: Terrestrial Ecological Assessment (Niche 2019);
- Dendrobium Area 3A Terrestrial Ecology Assessment (Niche 2020);
- Monitoring as part of previous SMPs for longwalls within areas 3A and 3B, including annual and end of panel reporting;
- 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 the findings of the long-term monitoring up to 2019 is provided in Section 3.6.

3.2 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 DA3B 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 DA3B
Wongawilli Creek	Longwalls set back from Wongawilli Creek. 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.	LW18 set back from Wongawilli Creek. It is unlikely that adverse impacts would occur along Wongawilli Creek due to the mining of LW18 (MSEC 2020).
Drainage lines	No specific predictions for the drainage lines in the study area in the SIS.	The drainage lines located directly above the mining area could experience the full range of predicted subsidence effects (MSEC 2020). Localised ponding due to mining-induced tilt could develop along some sections of the drainage lines (MSEC 2020). It is expected that fracturing would occur along the sections of the drainage lines that are located directly above and adjacent to the proposed LW18 (MSEC 2020). Fracturing can also occur outside the extents of the proposed longwall at distances up to approximately 400 m (MSEC 2020). 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 (MSEC 2020).
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 be directly mined beneath are unlikely to exhibit any significant impacts.	It is unlikely that adverse impacts would occur at the cliffs due to the mining of LW18 (MSEC 2020).
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 these features are located directly above the proposed longwall, and where the rock is marginally stable, this could then result in instabilities. 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 less than 50 mm up to 150 mm in width (MSEC 2020).

Subsidence Parameters	MSEC (2007) report for Dendrobium Area 3 used in the SIS	MSEC (2020) report for DA3B
		Previous experience of mining beneath rock outcrops at the Mine indicates that the percentage of rock outcrops that experience adverse impacts is small, representing less than 3 % of the total surface area (MSEC 2020).
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.	The steep slopes are heavily vegetated and erosion due to soil instability (i.e. downslope movements) was not readily apparent (MSEC 2020). If tension cracks were to develop, due to the extraction of LW18, it is possible that soil erosion could occur and require treatment (MSEC 2020).
Upland Swamps	Swamps directly mined beneath are expected to experience the full range of predicted subsidence and valley related movements. It is unlikely that mine subsidence induced scour effects would affect the swamps in Area 3. 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 not anticipated that significant changes in water levels would occur as a result of subsidence induced tilt.	Adverse changes in the levels of ponding or scouring within the swamps are not anticipated due to the mining-induced tilt. Fracturing of the bedrock could occur beneath the swamps that are located above and adjacent to the mining area. 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 mining area. 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 (MSEC 2020).

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 then *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 Area 3 mining operations. 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 under the TSC/BC and EPBC Acts.

The survey effort and outcomes of the SIS have been summarised in Section 4.1.

3.3 Dendrobium Area 3C: 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 for LW20 - 21. Impacts on these species were assessed within the Area 3 mining operation's SIS (Biosis 2007) and were considered 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 proposed LW20 – 21 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; and
- 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 DA3C 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 TSC/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.

3.4 Dendrobium Area 3B: Longwalls 9 to 18 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.

A population of the threatened flora species, *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 9 to 18 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 DA3B 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 mining Longwalls 9 to 18.

Thirteen large upland swamps were recorded within the DA3B study area. The upland swamps in the study area fit the description of the TEC Coastal Upland Swamps in the Sydney Basin Bioregion. 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 Swamp Den35a 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.

It is noted that the *P.aristata* population referred to in the DA3B terrestrial ecology report were referenced from the project SIS, however no records of the species have been found to occur at Swamp Den35a within the Atlas of NSW Wildlife, mapping of literature reviewed or during recent field survey. Additionally, the reference states that the population occurs directly above Longwall 17. The reference is therefore considered to be incorrect. The closest known population of *P. aristata* is on the edge of Swamp Den149, which coincides with quadrat locations from the 2007 SIS and is above Longwall 17. Recommendations for monitoring of *P. aristata* have therefore been updated to reflect the actual location of the records.

3.5 Dendrobium Area 3A: Longwall 19 Terrestrial Ecological Assessment

Niche was commissioned by IMC in 2019 to prepare a Terrestrial Ecological Assessment for the extraction of Longwall 19 within DA3A.

Natural areas and features sensitive to subsidence within the DA3A study area include Wongawilli Creek, watercourses, cliffs, rock outcrops, steep slopes and upland swamps.

Nine upland swamps occur within the wider study area with complexity of swamps generally increasing with overall size. Based on previous subsidence monitoring, a maximum impact area for swamps was calculated at 18.12 ha 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; and
- 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. The same conclusion was reached in the Dendrobium Area 3 SIS impact assessments for these species.

Recommendations are focussed around swamp and frog monitoring along watercourses in concert with established programs for measuring physical impacts of subsidence.

3.6 Dendrobium Terrestrial Ecology Monitoring Program

Annual reporting (Biosis 2016, Biosis 2017, Biosis 2018, Biosis 2019, Biosis 2020) documents the ecological monitoring program undertaken within Dendrobium Areas 2 (11 years), 3A (10-16 years) and 3B (7 years-16 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 (Biosis 2020):

- Vegetation within upland swamps in Dendrobium Area 2, Area 3A and Area 3B; and

- Littlejohn's Tree Frog *Litoria littlejohni* along selected streams providing suitable habitat in Area 3A and Area 3B.

As part of the monitoring program, Biosis (2020) 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 upland swamp monitoring program to date (Biosis 2020, 2019, 2016):

- The results of the Total Species Richness (TSR) analysis demonstrate the response to mining at individual swamps is complex with the monitoring data likely confounded by non-mining related changes within swamps. The monitoring data indicated a decline and subsequent increase in TSR following mining and changes in shallow groundwater.
- Meanwhile Swamp Den1a Swamp Den1b and Swamp Den5 displayed no significant decline in TSR, despite observed changes in shallow groundwater availability.
- The total area of all upland swamps decreased in 2019, relative to the 2014 baseline. This trend was observed across all impact and control swamps assessed. This is a continuation of the same trend identified in 2017 (Biosis 2018). The total area of all upland swamps was also found to decrease between 2017 and 2019. The overall extent of the smaller control swamps (S89, S91, S92 and S93) remained relatively stable during the 2014 to 2017 period, but show small but more marked decreases in the 2019 data relative to the other years. The changes observed in impact swamp total areas appear to be comparable to those observed at the control swamps, indicating that catchment scale conditions, rather than mining impacts are driving the reduction in total swamp area.
- The change in extent of vegetation communities within upland swamp from the baseline is most notable at impact sites, with declines from the 2014 baseline identified for all vegetation communities in 2019. 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.
- 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 Den1B. These changes were observed immediately following undermining and have continued at Swamp Den15B for at least four years post-mining. At the remaining sites there is no statistical significance in floristic composition when compared to before and after mining and between control and impact sites. The species composition in Swamp Den15B is becoming dominated by species that prefer drier soils. The change in Swamp 1B does not indicate a definitive trend in vegetation composition change that can be attributable to impacts from mining and/or drying conditions. Given a statistically significant result has been detected for 2018-2019, continued analysis of species compositional change will be imperative to determining the most likely reason for a shift in species at this swamp.

The Littlejohn's Tree Frog monitoring (Biosis 2020) detailed the following results (Biosis 2020, 2019):

- The detection of Littlejohn's Tree Frog was low in 2019 in comparison to the high reproduction rate in the breeding year of 2016 and was comparable to that recorded in 2018, also part of the extended drought experienced in 2019.

- Variation between the years 2018 and 2019 was observed in terms of the relative abundance of different life stages. Variation was observed among sites generally, including paired control sites, during 2019. A combination of environment driven factors, such as survey timing coinciding or not coinciding with rainfall and habitat differentiation of sites based on landscape position in response to such stimuli, are likely contributors to the variation observed.

3.7 Geographic review of mining effects on Upland Swamps at Dendrobium Mine

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 DA3B. 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.

3.8 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; • 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 DA3B;
- 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 for LW18; and
- Additional management and mitigation measures have been recommended in this report and the SIS.

3.9 Databases

Databases used in the preparation of this report include:

- DPIE Bionet Atlas of NSW Wildlife (DPIE 2020) (accessed April 2020); and
- EPBC Act Protected Matters Search Tool (Department of the Environment and Energy (DoEE) 2020) (accessed April 2020).

Further records of threatened species were obtained from the SIS (Biosis 2007), and from the previous studies listed in Section 3.

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	280.8 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	29.9 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
Den14	Large complex swamp	Located within angle of draw of LW18. Located above the previous LW16 and LW17.	1 x vegetation surveys sites (vegetation validation and dominant species observations) (Biosis 2007, Niche 2012).	Scat collections and anabat (Biosis 2007). Nocturnal chorus and active search; remote listening device; diurnal habitat assessment and

Site	Swamp characteristics	Position of highest impact area	Previous vegetation survey	Previous fauna survey
				tadpole searches (Niche 2012).
Den35a	Small simple swamp	Swamp to be partially mined beneath.	1 x vegetation surveys sites (vegetation validation and dominant species observations) (Biosis 2007 and Niche 2012).	Nocturnal chorus and active search (2012).
Den35b	Small simple swamp	Located within angle of draw of LW18.	1 x vegetation surveys sites (vegetation validation and dominant species observations) (Biosis 2007 and Niche 2012).	-
Den149	Small simple swamp	Located within angle of draw of LW18. Located above the previous LW16 and LW17.	1 x vegetation surveys sites (vegetation validation and dominant species observations) (Biosis 2007).	-
Den150	Small simple swamp	Located within 600 m buffer area of LW18.	1 x vegetation surveys sites (vegetation validation and dominant species observations) (Biosis 2007).	-
Den151	Small simple swamp	Located within 600 m buffer area of LW18.	1 x vegetation surveys sites (vegetation validation and dominant species observations).	-

Table 6: Previous survey effort of natural features in study area

Stream	Stream order	Position of highest impact area (HGEO 2020)	Previous vegetation survey	Previous fauna survey
Native Dog Creek	3rd	Within 600 m buffer, 4% of catchment within 600 m of LW18 and 1% of catchment within 400 m of LW18).	-	Fixed frog monitoring sites (threatened frog breeding pool) (Biosis 2020). Monitoring undertaken for 8-14 years. Spotlighting (mammals, reptiles, birds), diurnal bird survey, scat collection, nocturnal watercourse search (frogs) (Biosis 2007).
LA1	1st	Within 600 m buffer, 17% of catchment within 600 m of LW18		
LA2	2nd	Within angle of draw, 96% of catchment	-	Fixed frog monitoring sites (threatened frog breeding pool) (Biosis 2020). Monitoring undertaken for 8-14 years.

Stream	Stream order	Position of highest impact area (HGEO 2020)	Previous vegetation survey	Previous fauna survey
		within 600 m of LW18 and 72% of catchment within 400 m of LW18.		Diurnal bird survey (Biosis 2007). Nocturnal chorus and active search, diurnal habitat assessment and tadpole searches; remote listening device (Niche 2012)
ND1	2nd	Mined beneath by LW18, 92% of catchment within 600 m of LW18 and 70% of catchment within 400 m of LW18.	3 x vegetation surveys sites (vegetation validation and dominant species observations) (Biosis 2007).	Fixed frog monitoring sites (threatened frog breeding pool) (Biosis 2020). Monitoring undertaken for 8-14 years.
ND1A	1st	Within 600 m buffer, less than 400 m from LW18.	1 x vegetation surveys sites (vegetation validation and dominant species observations) (Biosis 2007).	-
ND1B	1st	Within angle of draw, less than 400 m from LW18.	-	Nocturnal chorus and active search (Niche 2012).
ND1C	1st	Mined beneath by LW18.	-	-
ND2	1st	Within 600 m buffer of LW18, 16% of catchment within 600 m of LW18 and 1% of catchment within 400 m of LW18.		
WC7	1st	Within 600 m buffer, 47% of catchment within 600 m of LW18 and 10% of catchment within 400 m of LW18.	-	-
WC12	1st	Within 600 m buffer, 12% of catchment	-	-

Stream	Stream order	Position of highest impact area (HGEO 2020)	Previous vegetation survey	Previous fauna survey
		within 600 m of LW18		
WC15	1st	Within angle of draw, 30% of catchment within 600 m of LW18 and 17% of catchment within 400 m of LW18.	-	-

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 5 and Figure 6).

Survey was conducted throughout the study area over the following days: 22-24 April 2020, 14 May 2020). Field survey effort from previous nearby longwalls was also utilised to supplement the survey data from the current survey. 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 3, Figure 5). A sample of swamps mapped within the Woronora vegetation mapping project (NPWS 2003), Biosis (2019) 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 (Figure 5):

- 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 opportunistic 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 6). 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	Creek (LA 2, Native Dog Creek)	8.5	22/04/2020, 24/04/2020, 14/05/2020
Nocturnal frog searches	Creek (LA 2, Native Dog Creek)	4.5	12/12/2019, 14/05/2020

Note: Survey effort was limited due to extensive coverage already by Biosis (2020).

4.2.4 Limitations

Survey was conducted during April and May 2020 which is not ideal timing from all potentially impacted threatened species, however is preferable for species such as Littlejohn's Tree Frog which acts somewhat as an indicator species in terms of previous monitoring programs and impact assessment. Survey focused on biodiversity that could potentially be impacted by subsidence, such as swamps and frogs. Other biodiversity and habitat features of the study area were not included in this field assessment.

4.3 Likelihood of occurrence assessment for threatened species

A list of threatened species within the locality (5 km radius) 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/TEC Criteria	Threatened and Migratory Fauna Criteria
Known	The species/TEC was observed within the study area.	The species was observed within the study area.
High	It is likely that a species/TEC 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/TEC 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/TEC 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/TEC.	The habitat within the study area is unsuitable for the species.

5 Results

5.1 Vegetation communities

Nine 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, Figure 5).

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)	PCT	Keith Formation	Keith Class	Corresponding TEC	Area in study area * (ha)
MU26	Sandstone Gully Peppermint Forest (SGPF)	1250 Sydney Peppermint - Smooth-barked Apple - Red Bloodwood shrubby open forest on slopes of moist sandstone gullies, eastern Sydney Basin Bioregion	Dry Sclerophyll Forests (Shrubby sub-formation)	Sydney Coastal Dry Sclerophyll Forests	Not listed	88.11
MU29	Exposed Sandstone Scribbly Gum Woodland (ESSGW)	1083 Red Bloodwood - scribbly gum heathy woodland on sandstone plateaux, Sydney Basin Bioregion	Dry Sclerophyll Forests (Shrubby sub-formation)	Sydney Coastal Dry Sclerophyll Forests	Not listed	190.75
MU39	Rock Plate Heath Mallee	881 Hairpin Banksia - Kunzea ambigua - Allocasuarina distyla heath on coastal sandstone plateaux, Sydney Basin Bioregion	Heathlands	Sydney Coastal Heaths	Not listed	0.54
MU42	Upland Swamps: Banksia Thicket (USBT)	1803 Needlebush - banksia wet heath on sandstone plateaux of the Sydney Basin Bioregion	Freshwater Wetlands	Coastal Heath Swamps	Coastal Upland Swamps of the Sydney Basin Bioregion (BC Act and EPBC Act)	10.45

MU43	Upland Swamps: Tea-Tree Thicket (USTTT)	1804 Banksia - Needlebush - Tea-tree damp heath swamps on coastal sandstone plateaus of the Sydney basin	Freshwater Wetlands	Coastal Heath Swamps	Coastal Upland Swamps of the Sydney Basin Bioregion (BC Act and EPBC Act)	4.47
MU44a	Coastal Upland Swamps: Sedgeland-Heath Complex (Sedgeland)	978 Needlebush - banksia wet heath on sandstone plateaux of the Sydney Basin Bioregion	Freshwater Wetlands	Coastal Heath Swamps	Coastal Upland Swamps of the Sydney Basin Bioregion (BC Act and EPBC Act)	0.02
MU44c	Coastal Upland Swamps: Sedgeland-Heath Complex (Cyperoid Heath)	1804 Needlebush - banksia wet heath swamps on coastal sandstone plateaus of the Sydney Basin	Freshwater Wetlands	Coastal Heath Swamps	Coastal Upland Swamps of the Sydney Basin Bioregion (BC Act and EPBC Act)	0.87
MU46	Upland Swamps: Mallee-Heath	978 Needlebush - banksia wet heath on sandstone plateaux of the Sydney Basin Bioregion	Freshwater Wetlands	Coastal Heath Swamps	Not Listed	3.25

*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

Six upland swamps (meeting the definition of the Commonwealth and State listed TEC as in Table 9) occur within the study area based on the 600m boundary (Table 10) (Figures 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.

One complex large swamp within the study area (Den14) is located within the predicted area of subsidence impacts (35 degree angle of draw study area) (Figure 3 and 4). There are also three smaller 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 LW18
Den14	Upland Swamps: Banksia Thicket	2.11	0.061	-	
	Upland Swamps: Tea-tree Thicket	2.15	1.50	0.40	
	Upland Swamps: Sedgeland-Heath Complex (Cyperoid Heath)	0.87	0.35	0.01	
	Upland Swamps: Sedgeland-Heath Complex (Sedgeland)	0.02	-	-	
Den35a	Upland Swamps: Tea-tree Thicket	1.02	1.02	1.02	0.17
Den35b	Upland Swamps: Tea-tree Thicket	1.09	1.09	1.09	
Den149	Upland Swamps: Banksia Thicket	1.42	1.42	1.42	
Den150	Upland Swamps: Banksia Thicket	2.94	2.94	-	
	Upland Swamps: Tea-tree Thicket	0.21	0.21	-	
Den151	Upland Swamps: Banksia Thicket	3.98	3.70	-	
Total		**15.81**	**12.29**	**3.94**	**0.17**

* Excludes areas of Upland Swamp: Mallee Heath, as these are not included in the BC/EPBC Act listing of TEC Coastal Upland Swamps.

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 upland 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 occurs within minor depressions in Swamp Den14 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, usually occurs within minor depressions in upland swamps, though none was recorded 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 Swamp Den14 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 or small sections within 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 2012) 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 LW18 is 15.81 ha (Table 10).

5.5 Threatened flora

A total of 32 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 7). Of

the 32 threatened species obtained in the database searches, 11 species (*Acacia bynoeana, Callistemon linearifolius, 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.

Pultenaea aristata was observed at three Upland Swamps within the study area (Den149, Den150 and Den151) (Figure 4 and Figure 5). *Pultenaea aristata* was also recorded in an area of Upland Swamp: Mallee Heath in the study area (Figure 5). Small numbers of the species were recorded at each location (between one and five plants). The species is known to be associated with upland swamps and was recorded in the drier swamp types within the study area (Banksia Thicket and Mallee Heath). 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 59 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 8). Forty one of these species were determined to have a moderate or high likelihood of occurrence within the study area (Appendix 1).

The previous SIS survey recorded 139 fauna, including 32 threatened fauna within Dendrobium Area 3. Two threatened fauna were recorded during the current survey as detailed in Table 11 (Figure 6).

Table 11: Threatened fauna recorded during current survey

Threatened species	Observation details	Date
Littlejohn's Tree Frog	Observations of tadpoles and adults (heard call) were made from the following locations: • LA2 (approximately 394 tadpoles observed amongst multiple pools) with closest records 150 m from proposed longwall. • ND1A/Swamp Den151 (approximately 120 tadpoles at base of swamp within pools of bedrock). • ND1A downstream of Swamp Den151 – 150 tadpoles within medium sized pool. • ND1 (two adults heard) approximately 200 m from the proposed longwall. • ND1B (approximately 40 tadpoles observed). Littlejohn's Tree Frog was not observed from ND1C (a steeper stream with fewer pools) which occurs directly above the proposed longwall	22/04/2020 24/04/2020
Gang-gang Cockatoo	Heard call.	22/04/2020

In additional to those threatened species listed in Table 11, the following threatened fauna are known from the study area (Bionet records on Figure 6 and Figure 8):

- A large population of Littlejohns Tree Frog has been recorded along ND1.
- Numerous records of Giant Dragonfly in Swamp Den14.
- Two records of Scarlet Robin and one Little Eagle, along Fire Road 6A.
- Eastern Coastal Freetail Bat and Yellow-bellied Freetail Bat near Fire Road 6A.
- Rosenberg's Goanna on Fire Road 6A.

5.7 Fauna habitat

Fauna habitat within the study area considered prone to subsidence impacts is described below.

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 DA3B study area include Wongawilli Creek and Native Dog 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 KTP (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: *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 TSC Act have been replaced by AOBVs with the introduction of the 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) display 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 six swamp areas within and adjacent to the 600 m study area boundary are considered, 15.81 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 (0.17 ha of upland swamps). The severity and risk of impacts will reduce with distance from LW18 up to the 35° angle of draw study area, which includes the 20 mm subsidence contour (3.94 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.

Den35a is located partially above LW18, a total of 0.17 ha (Figure 3). Approximately 3.94 ha of upland swamps from Den14, Den35a, Den35b, Den149 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 8.35 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
Den14	Large complex swamp with pools within or on edges of swamp. Swamp follows alignment of watercourse WC15.	Within the angle of draw. Directly above LW16 and LW17.	There is potential for minor and localised increased ponding near to Swamp Den14. However, Den14 is located above the previous LW16 and LW17, therefore, the potential for increased ponding occurs due to these previous longwalls rather than the proposed LW18. It is considered unlikely 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. It is likely that fracturing would occur in the bedrock beneath Den14. The typical fracture widths in the bedrock beneath Swamp Den14, could be similar to the surface deformations previously observed at the Mine. The potential 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. Predicted total upsidence in Swamp Den14 (ranging between 175 mm and 275 mm) could result in the dilation of the strata beneath the swamp. 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. The dilated strata beneath the drainage lines upstream of Swamp Den14, could result in the diversion of some surface water flows beneath parts of the swamp. The drainage lines upstream of the swamp 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. Swamp Den14 is located directly above the previous LW16 and LW17 and, therefore, the potential impacts predominately occur due to these previous longwalls, rather than the proposed LW18.	Unlikely to be measurable additional impacts (after impacts from LW16 and LW17) to this swamp or associated species including threatened species from the current proposal. Monitoring of impacts likely to be confounded from previous direct undermining (LW16 and LW17). A known population of Giant Dragonfly occurs within Swamp Den14.

Site	Swamp characteristics	Position	Subsidence predictions (MSEC 2020)	Conclusion
Den35a	Small simple swamp. Swamp follows alignment of upper reaches of ND1	Directly above the maingate of LW18, within angle of draw.	There is potential for minor and localised increased ponding near to Swamp Den35a. Swamp Den35a is located above the maingate of LW18 and only low-level changes are predicted. It is considered unlikely that there would be adverse changes in the levels of ponding or scouring for Swamp Den35a within the study area based on the predicted vertical subsidence and tilt. It is likely that fracturing would occur in the bedrock beneath Den35a. The typical fracture widths in the bedrock beneath Swamp Den35a could be similar to the surface deformations previously observed at the Mine. 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 Den35a is predicted to experience total upsidence ranging between 175 mm and 275 mm. These valley related effects could result in the dilation of the strata beneath the swamp. 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. The dilated strata beneath the drainage lines upstream of Swamp Den35a could result in the diversion of some surface water flows beneath parts of the swamp. The drainage lines upstream of the swamp 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. Only a small area of Swamp Den35a is located directly above the proposed LW18.	Possible ecological impacts including changes in vegetation and threatened species habitat for the area of swamp directly above and adjacent the proposed longwall. Areas may trend towards Banksia Thicket or Fringing Eucalypt Forest if changes are long-term.

Site	Swamp characteristics	Position	Subsidence predictions (MSEC 2020)	Conclusion
			It is likely that shallow groundwater levels will be affected in Swamp Den35a which partially overlap the longwall footprint (HGEO 2020).	
Den35b	Small simple swamp. Swamp follows middle reaches of ND1.	Within angle of draw, 85 m south of the maingate of LW18.	It is considered unlikely 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. Swamp Den35b is located outside the mining area at a minimum distance of 85 m from the proposed LW18. However, this swamp is located in the more incised valley along the middle reaches of drainage line ND1 and, therefore, it could experience compressive strains due to valley related effects in the order of 10 mm/m to 20 mm/m. It is likely, therefore, that fracturing would occur in the bedrock beneath Den35b. Fracturing has been observed in the drainage lines at the Mine at distances of up to 290 m from the previously extracted longwalls in DA3B. Minor and isolated fractures have also been observed up to 400 m outside of longwalls extracted elsewhere in the Southern Coalfield. Fracture widths in the order of 20 mm to 50 mm have been observed due to valley closure effects at similar distances as Den35b from the proposed LW18. It is possible that a series of smaller fractures, rather than one single fracture, could develop in the bedrock. Swamp Den35b is predicted to experience total upsidence ranging between 175 mm and 275 mm. These valley related effects could result in the dilation of the strata beneath the swamp. 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. The dilated strata beneath the drainage lines upstream of Swamp Den35b could result in the diversion of some surface water flows beneath parts of the swamp. The drainage lines upstream of these swamps flow during and shortly after	Possible ecological impacts including changes in vegetation and threatened species habitat (predominantly for Littlejohn's Tree Frog, which is known to occur downstream of Swamp Den35b, along watercourse ND1). Potential breeding habitat for this population may be impacted through reductions in water retention from pools after fracturing. Areas may trend towards Banksia Thicket or Fringing Eucalypt Forest if changes are long-term.

Site	Swamp characteristics	Position	Subsidence predictions (MSEC 2020)	Conclusion
			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. Den35b is located outside the mining area. It is possible that impacts to shallow groundwater may occur in Swamp Den35b, located 90 m from LW18 and in the base of the ND1 valley (HGEO 2020).	
Den149	Small simple swamp. Valley side of LA2.	Directly above LW17 and within angle of draw.	It is considered unlikely that there would be adverse changes in the levels of ponding or scouring for the Swamp Den149 within the study area based on the predicted vertical subsidence and tilt. It is likely that fracturing would occur in the bedrock beneath Den149. The typical fracture widths in the bedrock beneath Swamp Den149 could be similar to the surface deformations previously observed at the Mine. 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. It is likely that shallow groundwater levels will be affected in Swamp Den149 which partially overlap the longwall footprint, noting that Swamp Den149 will likely be impacted by the preceding Longwall 17 (HGEO 2020).	Unlikely to be measurable additional impacts (after impacts from LW17) to this swamp or associated species including threatened species from the current proposal. Monitoring of impacts likely to be confounded from previous direct undermining (LW17). A population of *Pultenaea aristata* is associated with this swamp.
Den150	Small simple swamp along upper reaches of ND1B.	Within 600 m boundary, 225 m south of the maingate of LW18. Parts of Swamp Den150 previously mined beneath by LW8	It is considered unlikely that there would be adverse changes in the levels of ponding or scouring for Swamp Den150 within the study area based on the predicted vertical subsidence and tilt. Swamp Den150 is located outside the mining area at a minimum distance of 225 m from the proposed LW18. Fracturing could occur at this swamp, as has been observed at similar distances from the previously extracted longwalls	Possible ecological impacts including changes in vegetation and threatened species habitat (predominantly for Littlejohn's Tree Frog, which is known to occur downstream of Swamp Den150, along watercourse ND1B). Potential breeding habitat for this population may be impacted through reductions in water retention from pools after fracturing. Areas may trend towards Banksia Thicket or Fringing Eucalypt Forest if changes are long-term.

Site	Swamp characteristics	Position	Subsidence predictions (MSEC 2020)	Conclusion
		at Elouera Colliery.	in DA3B. Fracture widths in the order of 20 mm could develop at Den150.	Swamp Den150 likely already impacted by mining of LW8. Monitoring of impacts likely to be confounded from previous direct undermining (LW8).
Den151	Small simple swamp, along upper and lower reaches of ND1A.	Within 600 m boundary, 325 m south of the maingate of LW18. Parts of Swamp Den151 previously mined beneath by LW8 at Elouera Colliery.	It is considered unlikely that there would be adverse changes in the levels of ponding or scouring for Swamp Den151 within the study area based on the predicted vertical subsidence and tilt. Swamp Den151 is located outside the mining area at a minimum distance 325 m from the proposed LW18. Fracturing could occur at this swamp, as has been observed at similar distances from the previously extracted longwalls in DA3B. Fracture widths in the order of 20 mm could develop at Den151.	Possible ecological impacts including changes in vegetation and threatened species habitat (predominantly for Littlejohn's Tree Frog, which is known to occur downstream of Swamp Den151, along watercourse ND1A). Potential 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 Den151 likely already impacted by mining of LW8. Monitoring of impacts likely to be confounded from previous direct undermining (LW8).

The MSEC (2020) report has predicted potential subsidence impacts within upland swamps located within the 35° angle of draw study area constituting four swamps, with parts of Swamp Den35a being mined beneath by LW18. Fracturing is considered likely at four of the six swamps within the study area and could potentially occur at the two remaining swamps 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 1). 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.

One threatened plant species is known to occur in the study area, *Pultenaea aristata,* which was recorded at three locations within upland swamps of the study area. Three additional species (*Epacris purpurascens* var*. purpurascens, 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. Potential habitat includes upland swamps, creek lines and ridge lines.	Yes. Upland swamps and creek line habitat may be impacted by subsidence mechanisms.	Yes. No significant impact concluded.
Epacris purpurascens var. *purpurascens*	Not previously recorded in study area. Potential habitat includes upland swamps, creek lines and ridge lines.	Yes. Upland swamps and creek line habitat may be impacted by subsidence.	Yes. No significant impact concluded.
Leucopogon exolasius	Not previously recorded in the study area. Potential habitat includes creek lines. Vegetation communities include SGPF and SRS.	Yes. Creek line habitat may be impacted by subsidence mechanisms.	Yes. No significant impact concluded.
Pultenaea aristata	Known to occur in the study area including from the edge of Swamp Den149.	Yes. Upland swamps and creek line habitat may be impacted by subsidence mechanisms.	Yes.

Botanical Name	Potential Habitat in study area	Potential to be Impacted by subsidence	Seven-Part Test undertaken in SIS (Biosis 2007)
	Potential habitat includes upland swamps and creek lines.		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 Native Dog Creek, and as such, subsidence impacts within these areas are expected to 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. Secondary impacts on water quality due to the extraction of LW18 are expected to be minor in stream reaches outside of subsidence affected areas. Impacts such as temporary changes in water salinity, pH and iron content with local discolouration of streambeds may be observed in the first order tributary ND1C which crosses LW18 and ND1; however, those impacts are not expected to significantly influence water quality at the ND1 outlet (HGEO 2020) i.e. where it flows into Native Dog Creek.

Within the Dendrobium mining domain, the above-mentioned hydrological and water quality 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, though tension cracks may appear in steep slopes, resulting in erosion and requiring remediation. It is expected that the rock outcrops located directly above the proposed longwall would experience fracturing and, where the rock is marginally stable, this could then result in instabilities. Previous experience shows percentage of rock outcrops that experience adverse impacts is small, representing less than 3 % of the total surface area. 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 nine threatened fauna were considered during likelihood of occurrence assessment (Appendix 1). Forty one of these species were determined to have a moderate or high likelihood of occurrence within

the study area. Subsidence impacts from LW18 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 2020). 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 Giant Burrowing Frog	Species has been recorded during SIS and subsequent monitoring surveys in areas 3A and 3B (Biosis 2019; Figure 7). 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. 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. Impacts detected for Littlejohn's Tree Frog for permanent pools are likely relevant for Giant Burrowing Frog.
Litoria Littlejohni Littlejohn's Tree Frog	Recorded throughout Areas 3A-3C during SIS. Recorded within current study in several watercourses and downstream of upland swamps (Figure 6). Likely to be present in other watercourses throughout study area where appropriate breeding habitat is present. Within the study area, the species relies upon semi-permanent pools for tadpole development. Maturation times for tadpoles 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	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. 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. Monitoring within DA3B 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-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

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
	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.			(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). The 2019 results recorded marked increase in detection of adult and tadpole life stages of Littlejohn's Tree Frog, but a decrease in the detection of egg mass, despite the relatively similar environmental conditions between the 2018 and 2019 (Biosis 2020).
Pseudophryne australis 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. Recorded in DA3B in 2011 surveys (Niche 2012) and during follow-up monitoring (e.g. Biosis 2016). Recorded in Area 3C along WC20.	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 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	Yes. Significant impact determined.	Conservation listing status of species has not changed since original SIS. 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. Impacts detected for Littlejohn's Tree Frog along smaller streams are likely relevant for Red-crowned Toadlet.

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
		important role in providing appropriate breeding or sheltering habitat.		
Reptiles				
Hoplocephalus bungaroides Broad-headed Snake	Previously recorded in study area (Bionet records). Potential habitat includes ridgeline and creek lines. Vegetation communities include SGPF and ESSGW.	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 that deleterious impacts would need to then result, leads to a prediction of minimal impacts for this species.	Yes. No significant impact determined.	Conservation listing status of species has not changed since original SIS. 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. 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.
Varanus rosenbergi Rosenberg's Goanna	Previously recorded by Biosis (2007) within Area 3. Potential habitat includes upland swamps, ridgelines and creek lines. Vegetation communities include: SGPF and upland swamp communities.	Potential impacts include: death or injury resulting from rock fall or collapse. 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	Yes. No significant impact determined.	Conservation listing status of species has not changed since original SIS. Limited monitoring has been done for this species. 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.

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 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.		
Mammals				
Miniopterus schreibersii Eastern Bent-wing Bat	Recorded in study area with probable certainty during the SIS. 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. 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.	Yes. No significant impact determined.	Conservation listing status of species has not changed since original SIS. Monitoring has not been undertaken for this species. 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 Little Bent-wing Bat	Recorded in study area with probable certainty during the SIS. Potential habitat includes the entire study area, however only specific features likely to be impacted.	Potential impacts include: death or injury as result of rock fall or collapse, possible changes in availability of breeding and roosting habitat.	Yes. No significant impact determined.	Conservation listing status of species has not changed since original SIS. Monitoring has not been undertaken for this species. It is not known if this species has been impacted by subsidence from mining within the Dendrobium area, however given the limited

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
				extent of reported rock-falls and cliff failures, impacts are likely to be minimal and difficult to detect.
Myotis macropus Southern Myotis	Recorded in study area during the SIS. Potential habitat includes larger watercourses with pools and standing water and adjacent vegetation.	Potential impacts include: death or injury as result of rock fall or collapse and impacts on prey availability due to drying of pools.	Yes. No significant impact determined.	Conservation listing status of species has not changed since original SIS. Monitoring has not been undertaken for this species. 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 Native Dog Creek) are unlikely to be impacted by LW18.
Invertebrates				
Petalura gigantea Giant Dragonfly	Previous record in the study area, with sightings in Swamp Den14 (Invertebrate Identification Australasia 2019, Figure 6). No other swamps within the study area have known sightings of the species. Potential habitat includes upland swamps. Swamps that were recorded as being suitable	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 2019). Once the groundwater level drops below the depth of the larval burrows (> 70cm) and the	Yes. Significant impact determined.	Conservation listing status of species has not changed since original SIS. Swamps with preferred breeding habitat for this species, based on the presence of moist swamp subcommunities (Swamp Den14 identified as suitable habitat with sightings within Invertebrate Identification Australasia 2019, Figure 6) occur

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
	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).	peat dries the habitat, potentially a population in a specific swamp is lost (Invertebrate Identification Australasia 2019).		within the angle of draw and may be impacted by subsidence as a result of LW18. 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.

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 (2020) *Dendrobium Terrestrial Ecological Monitoring Program Annual Report for 2019*. 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 Swamp Impact Monitoring, Management and Contingency Plan and Watercourse Impact 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 DA3B should continue to be based on existing methodologies within Biosis (2020) 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 DA3B:

- Monitoring of upland swamps for any change associated with subsidence should continue. Consideration should be given to updating the swamp monitoring methodology to consider remote sensing methodologies that will likely lead to improvements in data collection over a broader area of swamp.
- Mapping of upland swamp boundaries within DA3B should be refined as part of 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 LW18 prior to baseline frog surveys.
- Frog monitoring in DA3B (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.
- Numbers of *P. aristsata* at Swamp Den149 should be confirmed during baseline monitoring, and a population census repeated should groundwater levels in the swamp be imacted by mining.
- 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 100 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 LW18 within DA3B are consistent with previous subsidence predictions for Area 3.

Monitoring of impacts to natural features such as swamps, watercourses and cliffs in DA3B 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, impacts 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.

Six upland swamps that meet the definition of the TEC listed under the TSC/BC and EPBC Acts occur within the 600 m study area boundary. A maximum of 3.94 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, 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 species 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.

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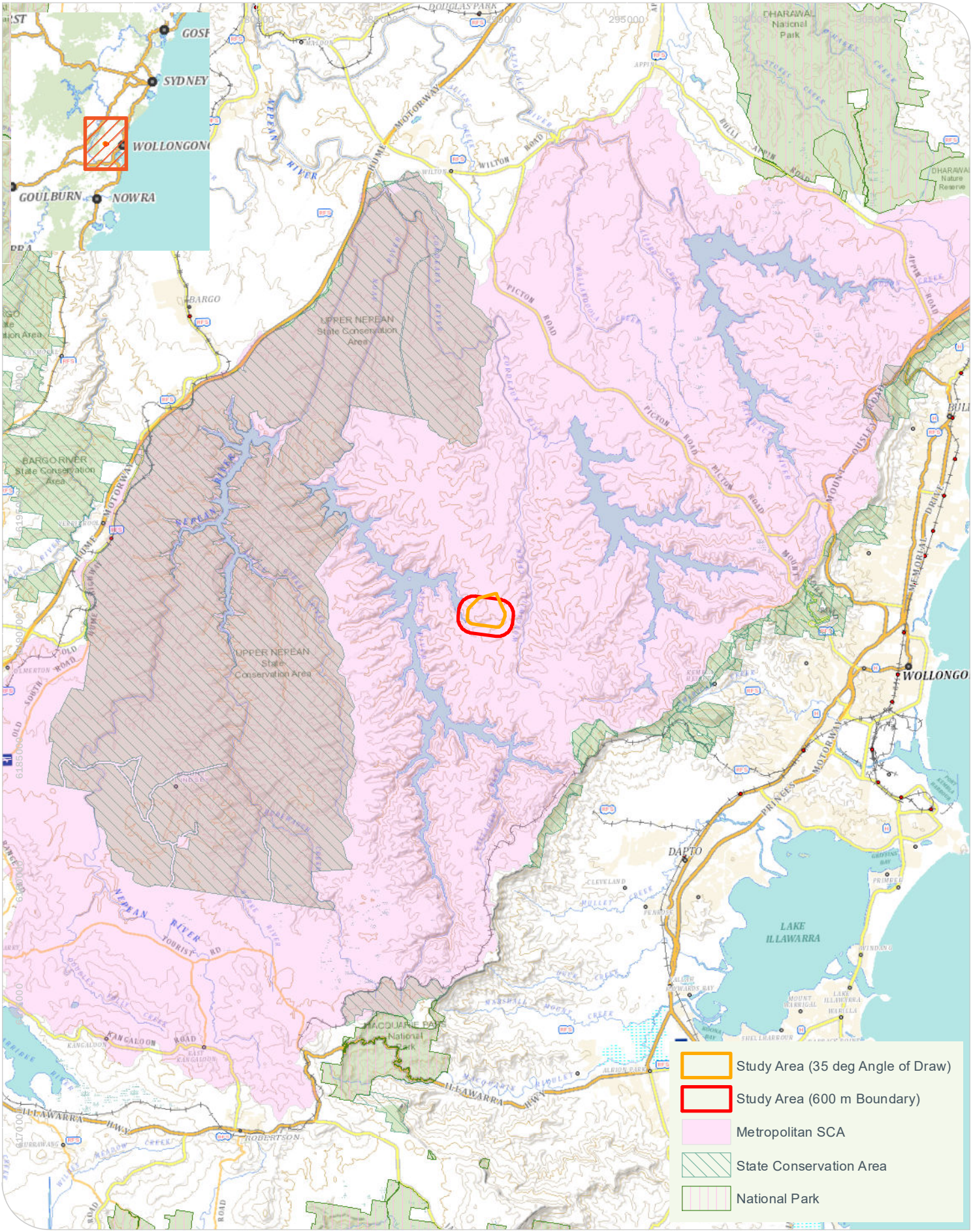
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Figures



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Location Map

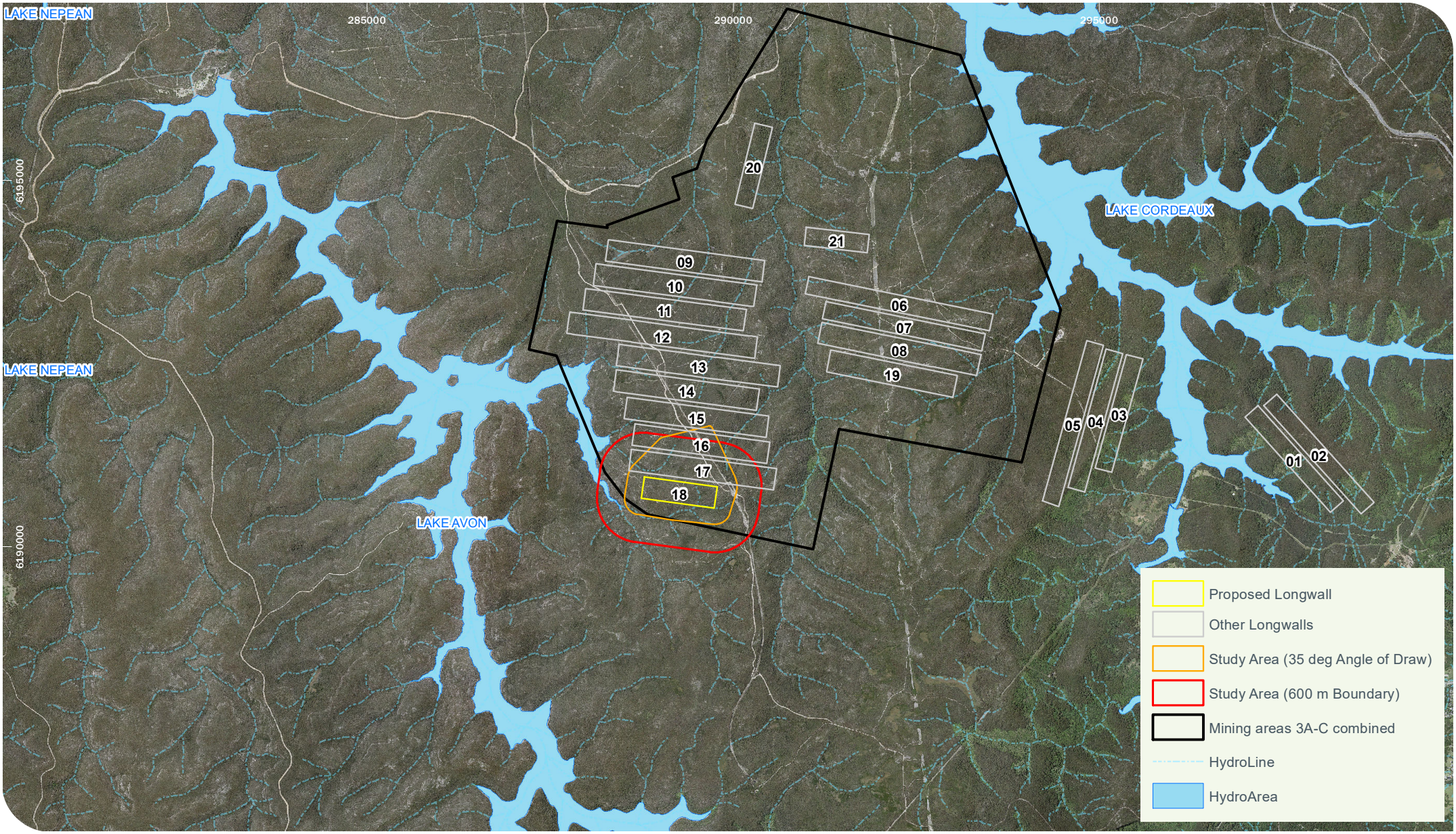
Dendrobium Area 3A Longwall 18 - Terrestrial Flora and Fauna Assessment

Niche PM: Sian Griffiths
Niche Proj. #: 5804
Client: South32 Illawarra Metallurgical Coal

Figure 1

public_NSW_Base_Map: © Department of Finance, Services & Innovation 2018

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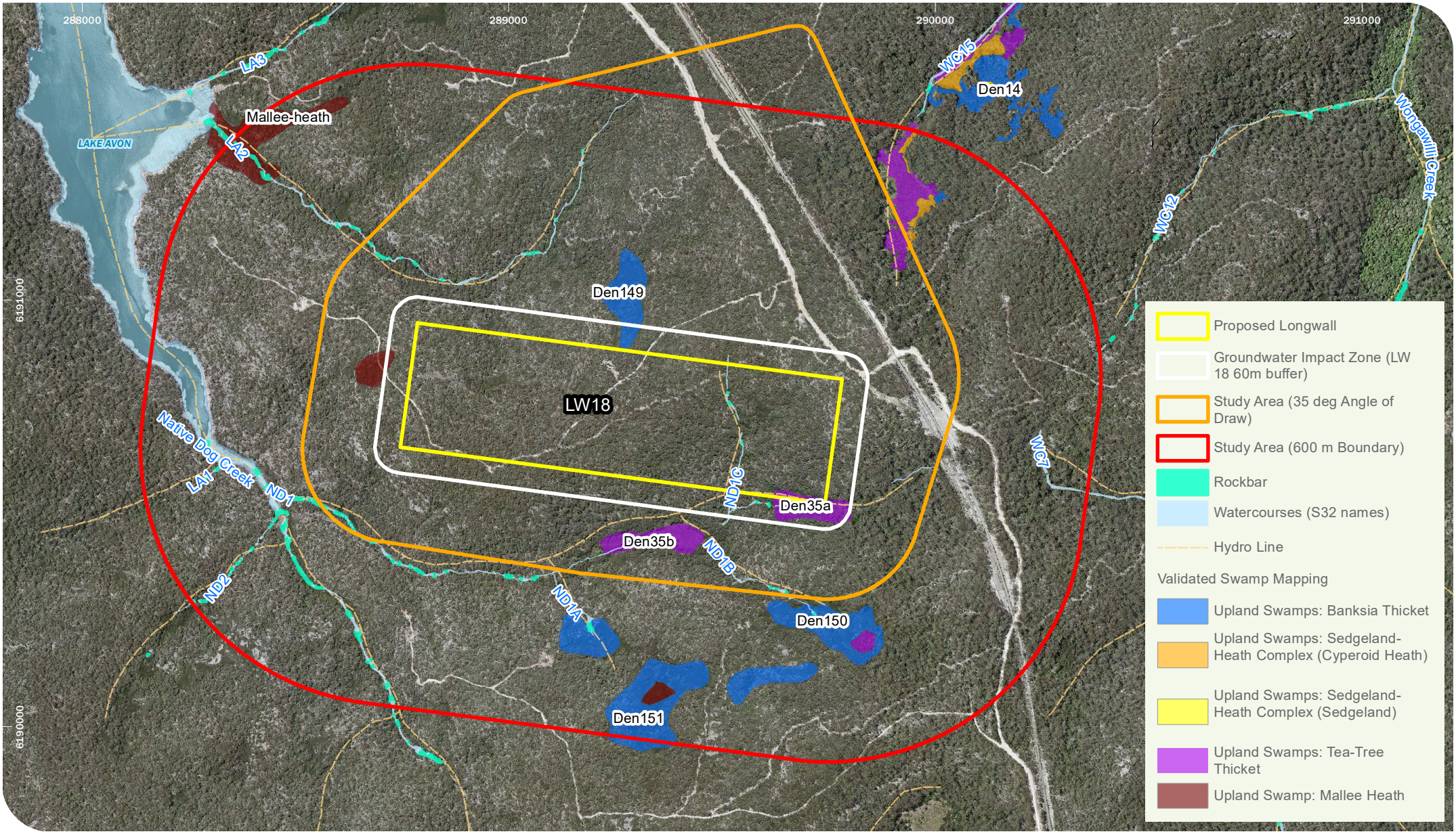
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GDA 1994 MGA Zone 56

Site map

Dendrobium Area 3A Longwall 18 - Terrestrial Flora and Fauna Assessment

Niche PM: Sian Griffiths
Niche Proj. #: 5804
Client: South32 Illawarra Metallurgical Coal

Figure 2



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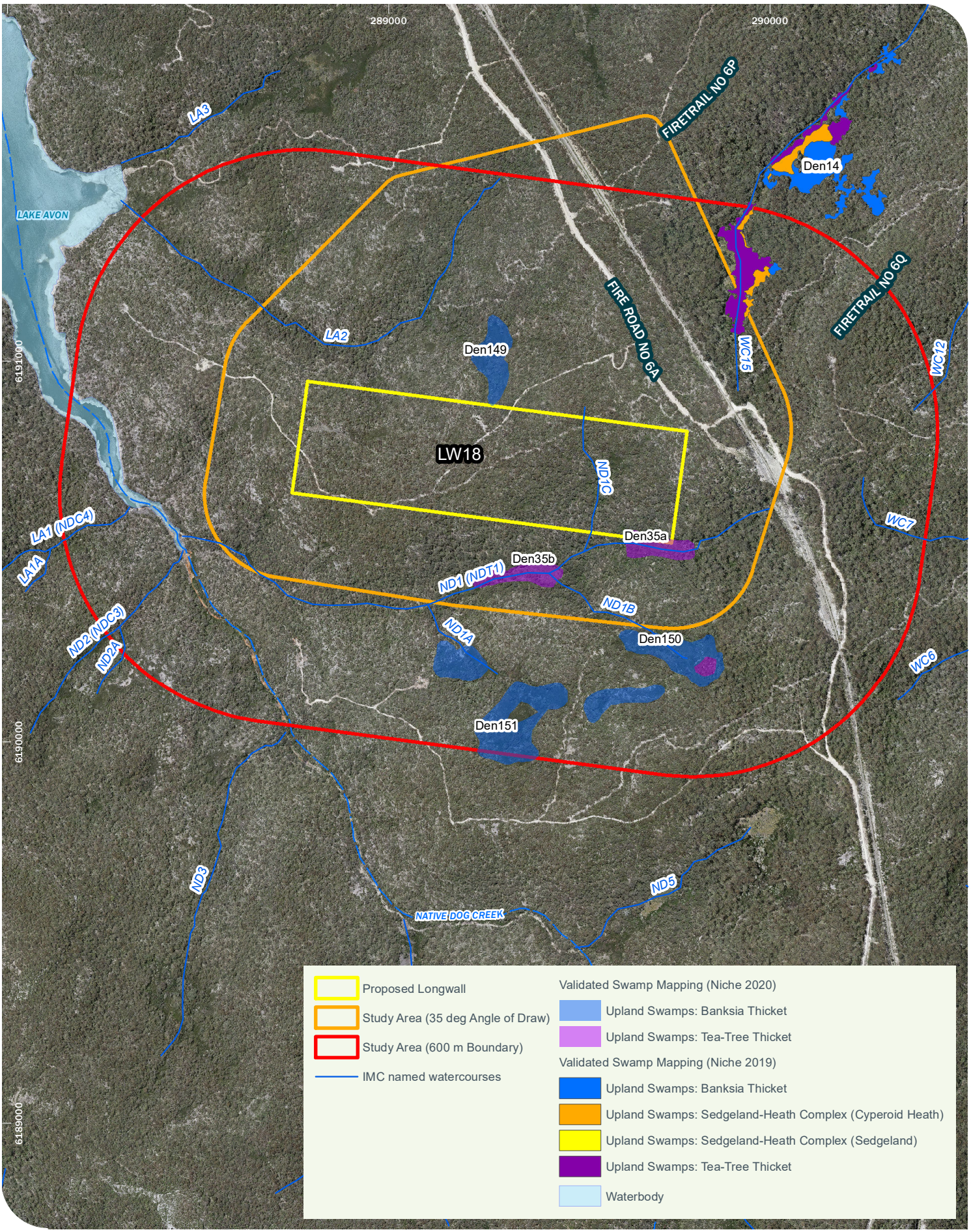
GDA 1994 MGA Zone 56

Watercourses and Confirmed Swamps within the Study Area and Surrounds

Dendrobium Area 3A Longwall 18 - Terrestrial Flora and Fauna Assessment

Niche PM: Sian Griffiths
Niche Proj. #: 5804
Client: South32 Illawarra Metallurgical Coal

Figure 3



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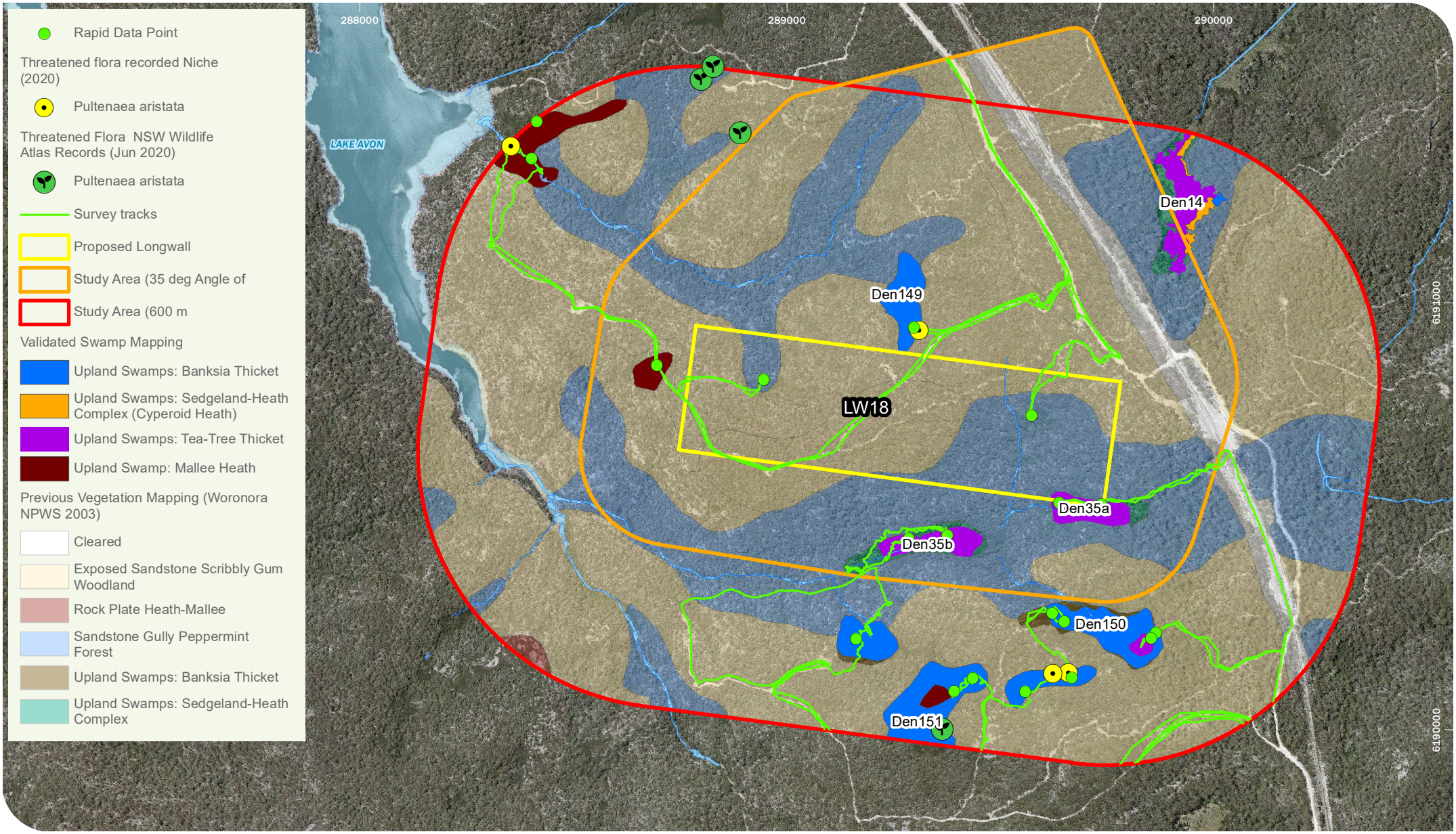
BC/EPBC Act listed Coastal Upland Swamp in the Sydney basin Bioregion in the study area

Dendrobium Area 3A Longwall 18 - Terrestrial Flora and Fauna Assessment

Niche PM: Sian Griffiths
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Client: South32 IMC

Figure 4

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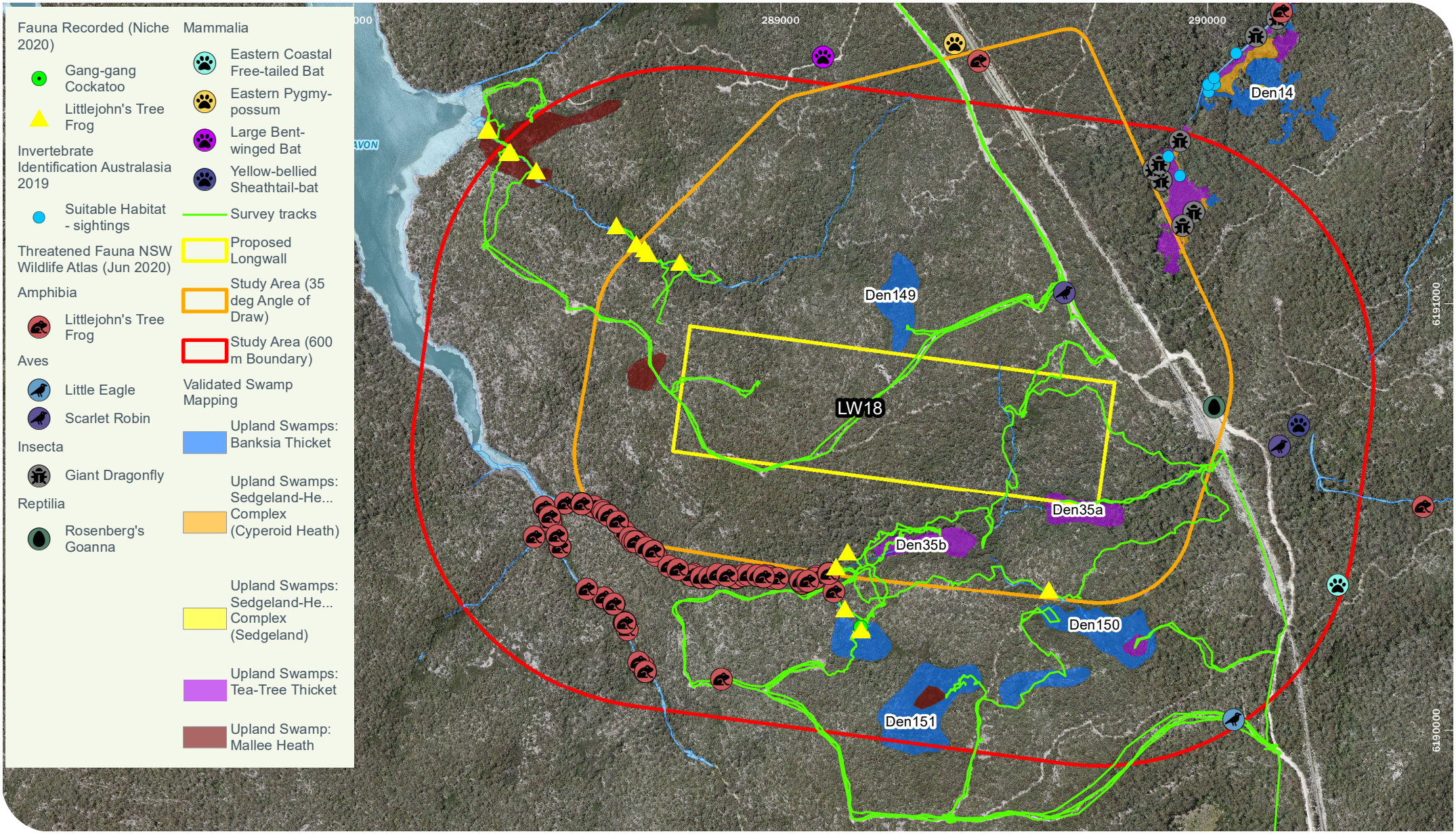
Flora Survey Effort, Vegetation Mapping and Threatened Flora Records

Dendrobium Area 3A Longwall 18 - Terrestrial Flora and Fauna Assessment

Niche PM: Sian Griffiths
Niche Proj. #: 5804
Client: South32 Illawarra Metallurgical Coal

Figure 5

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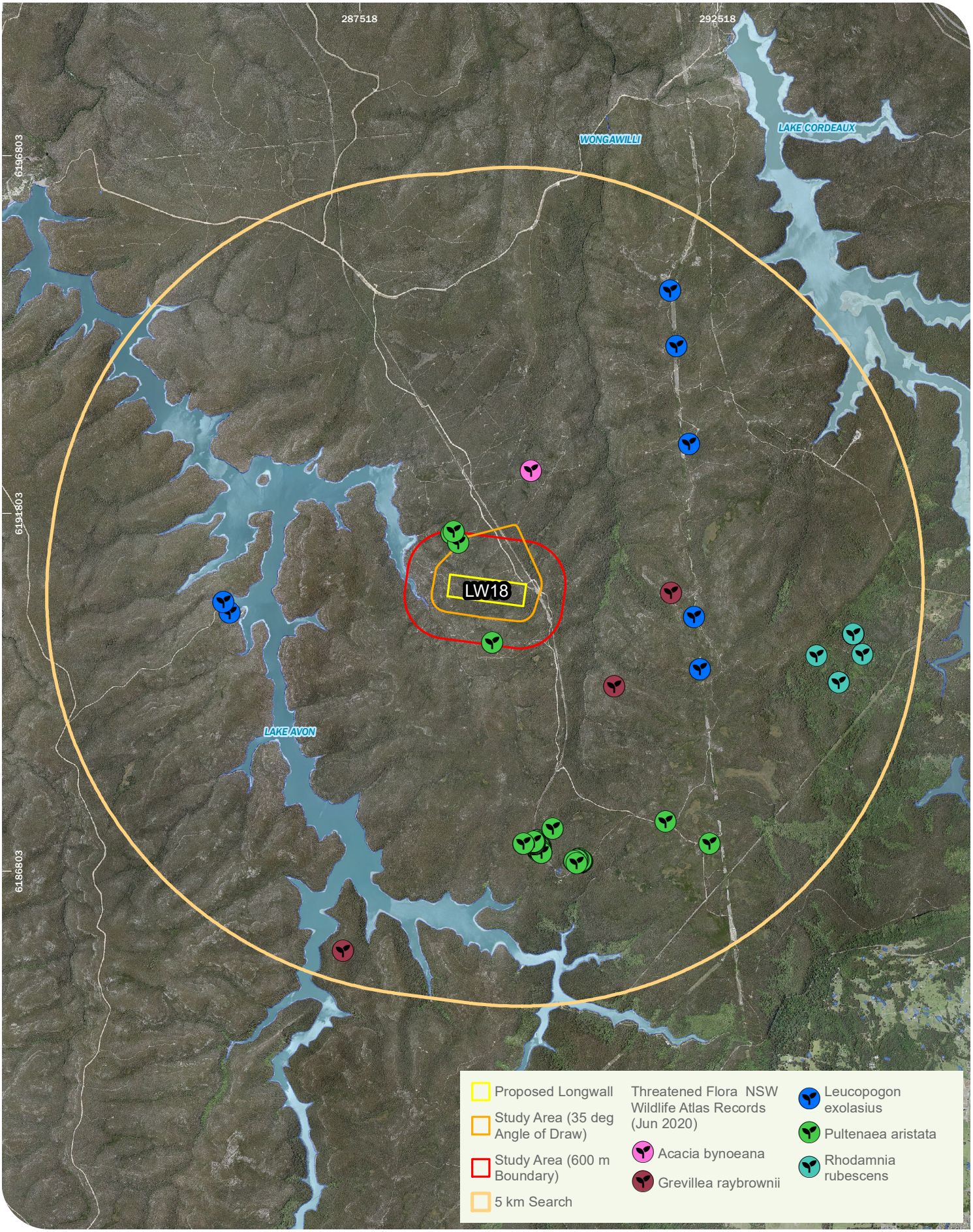
Fauna Survey Effort, Results and Threatened Fauna Records

Dendrobium Area 3A Longwall 18 - Terrestrial Flora and Fauna Assessment

Niche PM: Sian Griffiths
Niche Proj. #: 5804
Client: South32 Illawarra Metallurgical Coal

Figure 6

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NSW Bionet Atlas Threatened Species 5km Search – Flora

Dendrobium Area 3A Longwall 18 - Terrestrial Flora and Fauna Assessment

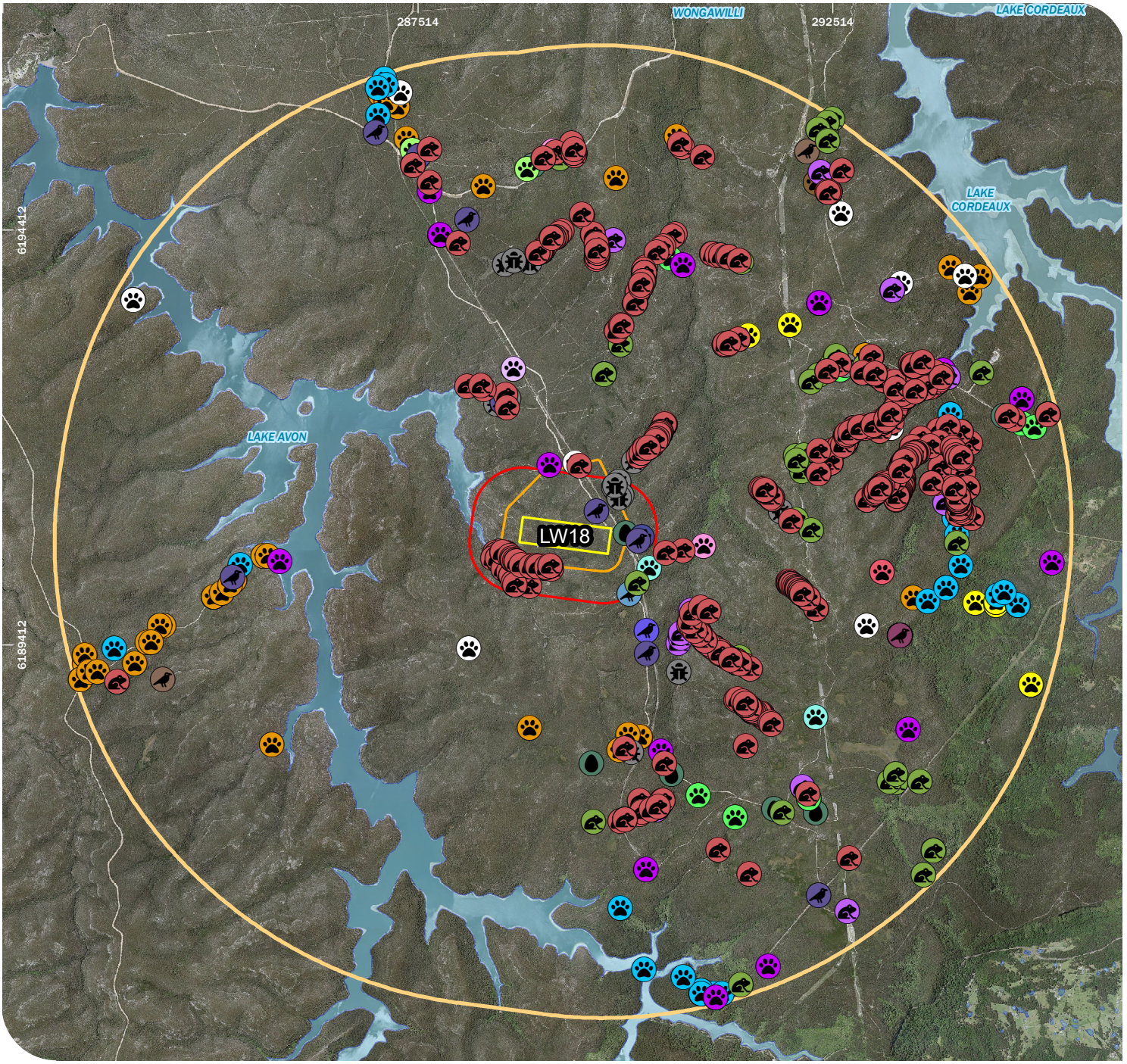
Niche PM: Sian Griffiths
Niche Proj. #: 5804
Client: South32 Illawarra Metallurgical Coal

Figure 7

NSW Office of Environment and Heritage's BioNet Atlas, which holds the data from a number of custodians. Data Obtained 05/06/2020.

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Threatened Fauna NSW Wildlife Atlas (Jun 2020)

- Giant Burrowing Frog
- Littlejohn's Tree Frog
- Red-crowned Toadlet

Aves

- Black Bittern
- Dusky Woodswallow
- Eastern Curlew
- Flame Robin
- Freckled Duck
- Little Eagle
- Little Lorikeet
- Scarlet Robin
- Varied Sittella
- White-bellied Sea-Eagle
- White-fronted Chat
- White-throated Needletail

Insecta

- Giant Dragonfly

Mammalia

- Brush-tailed Rock-wallaby
- Eastern Coastal Free-tailed Bat
- Eastern False Pipistrelle
- Eastern Pygmy-possum
- Greater Broad-nosed Bat
- Greater Glider
- Grey-headed Flying-fox
- Koala
- Large Bent-winged Bat
- Large-eared Pied Bat
- Little Bent-winged Bat
- Southern Brown Bandicoot (eastern)
- Southern Myotis
- Yellow-bellied Glider
- Yellow-bellied Sheathtail-bat

Reptilia

- Rosenberg's Goanna

- Proposed Longwall
- Study Area (35 deg Angle of Draw)
- Study Area (600 m Boundary)
- 5 km Search

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GDA 1994 MGA Zone 56

NSW Bionet Atlas Threatened Species 5km Search – Fauna

Dendrobium Area 3A Longwall 18 - Terrestrial Flora and Fauna Assessment

Niche PM: Sian Griffiths
Niche Proj. #: 5804
Client: South32 Illawarra Metallurgical Coal

Figure 8

NSW Office of Environment and Heritage's BioNet Atlas, which holds the data from a number of custodians. Data Obtained 05/06/2020.

v2.0

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. Recorded during current survey and previously recorded along LA2 and Native Dog Creek and its tributaries 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. Previous records in study area in Bionet Atlas.	High
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						

Scientific Name	Common Name	BC Act	EPBC Act	Habitat	Likelihood of Occurrence	Potential for Impact
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.	Moderate	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
Numenius madagascariensis	Eastern Curlew	-	CE, MA, M	A primarily coastal distribution. Found in all states, particularly the north, east, and south-east regions including Tasmania. Rarely recorded inland. Mainly forages on soft sheltered intertidal sand flats or mudflats, open and without vegetation or cover. Breeds in the northern hemisphere.	Low	Low
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. 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.	Moderate	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

Scientific Name	Common Name	BC Act	EPBC Act	Habitat	Likelihood of Occurrence	Potential for Impact
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.	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. Recorded in study area and previous records in study area in Bionet Atlas.	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).	High	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 recently logged areas. May nest in farmland, woodland and forest in tall trees.	High. Previous records in study area in Bionet Atlas.	Low
lossopsitta 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.	Moderate	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

Scientific Name	Common Name	BC Act	EPBC Act	Habitat	Likelihood of Occurrence	Potential for Impact
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
Grantiella picta	Painted Honeyeater	V	V	Inhabits Boree/ Weeping Myall (*Acacia pendula*), Brigalow (*A. harpophylla*) and Box-Gum Woodlands and Box-Ironbark Forests. A specialist feeder on the fruits of mistletoes growing on woodland eucalypts and acacias. Prefers mistletoes of the genus Amyema.	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 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).	High. Previous records in study area in Bionet Atlas.	Low
Merops ornatus	Rainbow bee-eater	-	M	Found throughout mainland Australia most often in open forests, woodlands and shrublands, and cleared areas, usually near water. It will be found on farmland with remnant vegetation and in orchards and vineyards. It will use disturbed sites such as quarries, cuttings and mines to build its nesting tunnels.	Low	Low
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	Moderate	Low

Scientific Name	Common Name	BC Act	EPBC Act	Habitat	Likelihood of Occurrence	Potential for Impact
				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.		
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.	High. Previous records in study area in Bionet Atlas.	Low
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.	Low	Low
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

Scientific Name	Common Name	BC Act	EPBC Act	Habitat	Likelihood of Occurrence	Potential for Impact
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 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.	Low	Low
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. Previous records in study area in Bionet Atlas.	High – previously recorded in Swamp Den14 in the study area. Numerous records within the locality and habitat present within most of the swamps of the study area.
Synemon plana	Golden Sun Moth	E	CE	The Golden Sun Moth's NSW populations are found in the area between Queanbeyan, Gunning, Young and Tumut. Occurs in natural temperate grasslands and grassy box-gum woodlands in which groundlayer is dominated by wallaby grasses Austrodanthonia spp.	Low	Low
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
Mormopterus norfolkensis	Eastern Coastal Freetailed-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. Previous records in study area in Bionet Atlas.	Low

Scientific Name	Common Name	BC Act	EPBC Act	Habitat	Likelihood of Occurrence	Potential for Impact
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
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
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

Scientific Name	Common Name	BC Act	EPBC Act	Habitat	Likelihood of Occurrence	Potential for Impact
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).	High	Low
Miniopterus orianae oceanensis	Large bent-winged 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.	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 impacts from subsidence of features such as cliffs are expected to occur given the limited propensity of roosting. No further assessment is considered required.
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 impacts from subsidence of features such as cliffs are expected to occur given the limited propensity of roosting. No further assessment 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

Scientific Name	Common Name	BC Act	EPBC Act	Habitat	Likelihood of Occurrence	Potential for Impact
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 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.	Low	Low
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. Previous records in study area in Bionet Atlas.	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 1998).	High.	Moderate

Scientific Name	Common Name	BC Act	EPBC Act	Habitat	Likelihood of Occurrence	Potential for Impact
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. Previous records in study area in Bionet Atlas.	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-	High. Previously recorded in Area 3C in the Biosis (2007) SIS along Fire Road 6.	Low
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
Callistemon linearifolius		V	-	Recorded from the Georges River to Hawkesbury River in the Sydney area, and north to the Nelson Bay area of NSW. Recorded in 2000 at Coalcliff in the northern Illawarra. For the Sydney area, recent records are limited to the Hornsby Plateau area near the Hawkesbury River. Grows in dry sclerophyll forest on the coast and adjacent ranges.	Moderate	Low
Commersonia prostrata	Dwarf Kerrawang	E	E	Occurs on sandy, sometimes peaty soils in a wide variety of habitats: snow gum woodland at Rose Lagoon; blue leaved stringybark open forest at Tallong; and in brittle gum low open woodland at Penrose; scribbly gum - swamp mahogany ecotonal forest at Tomago.	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-	Moderate	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

Scientific Name	Common Name	BC Act	EPBC Act	Habitat	Likelihood of Occurrence	Potential for Impact
Daphnandra johnsonii	Illawarra Socketwood	E	E	Restricted to the Illawarra region where it has been recorded from the local government areas of Shoalhaven, Kiama, Shellharbour and Wollongong. Occupies the rocky hillsides and gullies of the Illawarra lowlands, occasionally extending onto the upper escarpment slopes. Associated vegetation includes rainforest and moist eucalypt forest.	Low	Low
Epacris purpurascens var. purpurascens		V	-	Recorded from Gosford in the north, to Narrabeen in the east, Silverdale in the west and Avon Dam vicinity in the South. Found in a range of habitat types, most of which have a strong shale soil influence.	Moderate	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 Cordeaux Dam, with disjunct northern populations south of Putty and near Cessnock and Cooranbong, possibly also south of Moss Vale.	Moderate	Low
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
Irenepharsus trypherus	Illawarra Irene	E	E	Typically inhabits steep rocky slopes near cliff lines and ridge tops. The species is less typically found growing out of rock crevices or on narrow benches along cliff lines. Most sites are recorded from the upper slopes of the ridge systems	Low	Low

Scientific Name	Common Name	BC Act	EPBC Act	Habitat	Likelihood of Occurrence	Potential for Impact
				that extend south and east of the Illawarra escarpment, although the species has also been recorded from the deep sandstone gorges of the Shoalhaven River. Associated vegetation includes moist sclerophyll forest, ironwood thicket, and rainforest.		
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	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	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-	Moderate	Low
Persoonia bargoensis	Bargo Geebung	E	V	The Bargo Geebung occurs in woodland or dry sclerophyll forest on sandstone and on heavier, well drained, loamy, gravely soils.	Low	Low
Persoonia hirsuta	Hairy Geebung	E	E	The Hairy Geebung is found in sandy soils in dry sclerophyll open forest, woodland and heath on sandstone.	Moderate	Low
Pimelea spicata	Spiked Rice-flower	E	E	In both the Cumberland Plain and Illawarra environments this species is found on well-structured clay soils.	Low	Low
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
Prasophyllum fuscum	Tawny Leek Orchid	CE	V	Tawny Leek-orchid is confined to the Blue Mountains, Hawkesbury sandstone, and the Burrawang district, NSW. This species grows on the margins of swamps at moderate altitudes, about 500–700 m above sea level. Tawny Leek-orchid grows in wet low heathland on gentle slopes, in brown silty loam or in moist heath, often along seepage lines. The species can also be found in grasslands with scattered low Leptospermum and rushes, in silty peat loam, or	Low	Low

Scientific Name	Common Name	BC Act	EPBC Act	Habitat	Likelihood of Occurrence	Potential for Impact
				in boggy soils in open heath, sometimes in running water or at the ecotone between grassy woodland-forest and swamps.		
Pterostylis gibbosa	Illawarra Greenhood	E	E	Grows in open forest or woodland, on flat or gently sloping land with poor drainage. Known from a small number of populations in the Hunter region (Milbrodale), the Illawarra region (Albion Park and Yallah) and the Shoalhaven region (near Nowra)	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	Known. Recorded in study area during current survey and previously recorded in Biosis (2007) SIS in DA3. Four previous records in the study area in BioNet Atlas.	Moderate
Rhodamnia rubescens	Scrub Turpentine	CE	-	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 Commonwealth	Quantity	Latitude	Longitude
Amphibia	*Crinia signifera*	Common Eastern Froglet	P	-	-	-34.3971	150.6972
	Crinia signifera	Common Eastern Froglet	P	-	-	-34.3971	150.6972
	Crinia signifera	Common Eastern Froglet	P	-	-	-34.398	150.6984
	Litoria littlejohni	Littlejohn's Tree Frog	V	V	32 tadpoles	-34.4078	150.7064
	Litoria littlejohni	Littlejohn's Tree Frog	V	V	40 tadpoles	-34.3971	150.6972
	Litoria littlejohni	Littlejohn's Tree Frog	V	V	4 tadpoles	-34.3976	150.6977
	Litoria littlejohni	Littlejohn's Tree Frog	V	V	4 tadpoles	-34.3976	150.6977
	Litoria littlejohni	Littlejohn's Tree Frog	V	V	150 tadpoles	-34.4074	150.706
	Litoria littlejohni	Littlejohn's Tree Frog	V	V	120 tadpoles	-34.4078	150.7064
	Litoria littlejohni	Littlejohn's Tree Frog	V	V	40 tadpoles	-34.4071	150.7112
	Litoria littlejohni	Littlejohn's Tree Frog	V	V	1 adult	-34.4065	150.7058
	Litoria littlejohni	Littlejohn's Tree Frog	V	V	1 adult	-34.4062	150.7061
	Litoria littlejohni	Littlejohn's Tree Frog	V	V	5 tadpoles	-34.398	150.6984
	Litoria littlejohni	Littlejohn's Tree Frog	V	V	100 tadpoles	-34.3998	150.7012
	Litoria littlejohni	Littlejohn's Tree Frog	V	V	30 tadpoles	-34.3997	150.7011
	Litoria littlejohni	Littlejohn's Tree Frog	V	V	30 tadpoles	-34.3996	150.7009
	Litoria littlejohni	Littlejohn's Tree Frog	V	V	150 tadpoles	-34.3992	150.7004
	Litoria littlejohni	Littlejohn's Tree Frog	V	V	35 tadpoles	-34.4	150.702
	Limnodynastes peronii	Brown-striped Frog	P	-	-	-34.3972	150.6973
	Litoria fallax	Eastern Dwarf Tree Frog	P	-	-	-34.3976	150.6978
Aves	*Callocephalon fimbriatum*	Gang-gang Cockatoo	V	-	1	-34.4078	150.7064
Reptilia	*Amalosia lesueurii*	Lesueur's Velvet Gecko	P	-	-	-34.4075	150.7065
	Cryptophis nigrescens	Eastern Small-eyed Snake	P	-	1	-34.4037	150.7128

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

2020	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1st	30.6	*45.3*	31.9	*23.3*	16.6	22.5	*20.4*	*18.9*				
2nd	27.4	*38.2*	36.9	*22.6*	17.6	16.7	*23.2*	*21.1*				
3rd	34.4	*34.4*	20.6	*24.9*	20.0	18.7	*17.4*	*20.5*				
4th	45.5	*23.2*	22.4	*25.6*	20.0	17.9	*16.4*	*21.7*				
5th	27.4	*26.9*	21.8	*23.7*	21.4	18.5	*18.4*	*16.5*				
6th	25.3	*23.3*	27.5	*23.6*	22.3	18.6	*18.9*	*17.3*				
7th	34.6	*20.9*	25.0	*21.0*	22.5	18.1	*16.6*	*13.4*				
8th	27.4	*22.5*	23.1	*20.1*	26.6	17.8	*16.9*	*18.0*				
9th	26.1	*21.1*	23.2	*23.1*	26.2	20.3	*18.0*	*14.6*				
10th	36.1	*29.3*	24.2	*23.1*	17.9	16.6	*16.3*	*16.4*				
11th	22.2	*31.2*	25.4	*25.6*	19.5	21.6	*16.2*					
12th	20.2	*27.8*	25.9	*22.2*	20.0	17.0	*19.0*					
13th	26.5	*27.4*	26.8	*22.9*	17.7	19.3	*17.7*					
14th	30.2	*27.8*	16.3	*26.2*	18.3	19.8	*16.6*					
15th	30.8	*29.4*	21.5	*28.9*	18.2	20.0	*16.7*					
16th	29.7	*26.5*	21.8	*23.8*	20.6	20.8	*17.0*					
17th	21.9	*24.7*	22.7	*26.2*	20.4	16.0	*17.4*					
18th	24.0	*32.5*	27.0	*25.1*	21.3	19.1	*18.2*					
19th	24.5	*27.4*	32.1	*23.8*	21.4	19.1	*20.1*					
20th	31.2		34.9	*18.8*	24.3	18.7	*18.2*					
21st	32.8	*26.4*	25.6	*25.3*	18.3	18.1	*17.6*					
22nd	34.8	*24.0*	30.1	*25.1*	15.8	15.9	*18.7*					
23rd	40.9	*24.0*	22.8	*24.7*	17.3	16.3	*19.8*					
24th	26.9	*29.1*	23.3	*27.6*	18.2	18.9	*18.7*					
25th	30.5	*31.4*	25.6	*27.4*	17.9	18.1	*20.2*					
26th	37.7	*32.9*	22.4	*26.3*	19.8	19.3	*15.5*					
27th	33.0	*26.6*	21.7	*22.8*	20.9	16.3	*16.4*					
28th	34.2	*26.6*	24.4	*22.8*	22.7	17.6	*18.8*					
29th	29.9	*27.4*	25.4	*26.0*	18.8	17.2	*20.5*					
30th	33.3		24.6	*15.0*	20.1	17.9	*19.0*					
31st	37.9		27.6		20.7		*17.7*					
Highest daily	45.5	*45.3*	36.9	*28.9*	26.6	22.5	*23.2*	*21.7*				
Lowest daily	20.2	*20.9*	16.3	*15.0*	15.8	15.9	*15.5*	*13.4*				
Monthly mean	30.6	28.2	25.3	23.9	20.1	18.4						

Quality control: 12.3 Done & acceptable, *12.3* Not quality controlled or uncertain, or precise date unknown

Product code: IDCJAC0010 reference: 64777790

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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	28.6	27.1	24.1	21.2	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	16.3	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	14th 2020	30th 2020	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

2020	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1st	*0*	*0*	*0*	*0*	*10.0*	*0*	*0*	*0*				
2nd	*0*	*0*	*0*	*2.4*	*0.2*	*0.4*	*0.2*	*0*				
3rd	*0*	*6.6*	*0*	*6.2*	*0*	*0*	*0*	*0.2*				
4th	*0*	*0*	*5.6*	*3.0*	*0*	*0*	*0*	*0.2*				
5th	*0*	*0*	*8.2*	*0.2*	*0*	*0*	*0*	*0*				
6th	*0*	*1.2*	*22.8*	*0*	*0*	*0*	*0*	*0*				
7th	*1.2*	*35.8*	*0.2*	*0*	*0*	*0*	*0*	*0*				
8th	*11.0*	*46.2*	*1.6*	*0*	*0*	*2.6*	*0*	*25.0*				
9th	*0*	*43.6*	*0*	*0*	*0*	*0.8*	*0*	*0.4*				
10th	*0*	*172.4*	*0*	*1.6*	*0*	*1.0*	*0*	*52.6*				
11th	*0.2*	*0*	*0*	*9.6*	*0*	*0.6*	*5.2*	*1.4*				
12th	*0.4*	*0*	*1.2*	*0*	*0*	*1.8*	*0.2*					
13th	*7.6*	*6.8*	*0.2*	*0*	*0*	*0.6*	*0.4*					
14th	*0*	*1.6*	*0.4*	*0*	*0*	*9.0*	*3.0*					
15th	*0*	*0*	*8.0*	*0*	*0*	*0*	*0*					
16th	*10.4*	*0.8*	*3.2*	*0*	*2.6*	*0*	*0*					
17th	*32.0*	*0.8*	*9.4*	*0*	*0.2*	*0*	*0*					
18th	*7.6*	*0.6*	*0.8*	*0*	*0*	*0.4*	*0*					
19th	*3.2*		*0.2*	*0*	*1.0*	*0*	*0*					
20th	*1.8*		*0*	*0*	*0*	*0.2*	*0*					
21st	*16.6*		*0*	*0*	*0.6*	*11.0*	*0*					
22nd	*0*	*0*	*0*	*0*	*35.8*	*0*	*0*					
23rd	*0*	*1.4*	*0*	*0*	*0.8*	*0*	*0.2*					
24th	*2.4*	*0.4*	*0*	*0*	*0.6*	*0.2*	*0*					
25th	*5.6*	*0*	*0*	*0*	*0*	*0*	*0*					
26th	*0*	*0*	*13.2*	*0*	*0.2*	*0*	*5.2*					
27th	*0*	*0.4*	*1.6*	*0*	*2.0*	*0*	*51.6*					
28th	*0*	*0*	*0.2*	*0*	*0*	*0*	*17.4*					
29th	*0*	*0*	*2.8*	*0*	*0*	*0*	*0*					
30th	*0*		*2.6*	*17.4*	*0*	*3.0*	*0.2*					
31st	*0*		*0*		*0*		*0*					
Highest daily	*32.0*	*172.4*	*22.8*	*17.4*	*35.8*	*11.0*	*51.6*	*52.6*				
Monthly Total	*100.0*		*82.2*	*40.4*	*54.0*	*31.6*	*83.6*					

↓ This day is part of an accumulated total
Quality control: 12.3 Done & acceptable, *12.3* Not completed or unknown

Product code: IDCJAC0009 reference: 64777764

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Australian Government
Bureau of Meteorology

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*	*51.6*	*52.6*	*35.2*	*27.6*	*64.4*	*38.8*
Date of highest daily	29th 2013	10th 2020	8th 2012	21st 2015	24th 2013	6th 2016	27th 2020	10th 2020	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

http://www.bom.gov.au/climate/cdo/about/about-rain-data.shtml.

Australian Government
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Ecology and biodiversity
Terrestrial
Freshwater
Marine and coastal
Research and monitoring
Wildlife Schools and training

Heritage management
Aboriginal heritage
Historical heritage
Conservation management
Community consultation
Archaeological, built and landscape values

Environmental management and approvals
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 18

GEOLOGY OF LONGWALL 18

July 2020
Illawarra Metallurgical Coal: Technical Services

Summary

Longwall 18 is planned for future extraction which includes Maingate (MG)18 [1] roadways. Longwall 18 is located immediately south of Longwall 17 in Dendrobium Area 3B. As per all previous panels in Area 3B, MG18 will be developed from the Wongawilli Mains development panels in a westerly direction with longwall extraction towards the east. Development of MG18 has progressed to cut through (CT) 3 at the time of writing.

In general, the geology appears to be mostly benign apart from a significant structurally disturbed zone along MG18 between CT 9-11 which also extends into the Longwall 18 panel. To the south of MG18 is a regional fault zone known as the Elouera Fault which is downthrown some 20-40m to the south and separates the Dendrobium workings from Wollongong Coal's Wongawilli Colliery workings.

Extensive exploration activities have been undertaken to increase the understanding of geology in Dendrobium Area 3B. The Longwall 18 panel is covered by a significant amount of geological data including:

Surface Vertical/Angled boreholes		Underground Inseam (UIS) boreholes	
S0223	S1299	MG16-A9-IS2	MG16-A9-IS3
S1999	S2000	MG16-A9-IS4	MG16-A9-IS5
S2004	S2194	MG16-A9-IS6	WO3-D1-IS1
S2433	S2441	WO3-D1-IS2	MG17-A1-IS1
S2441A	S2441B	MG17-A1-IS1	WO3-C11-IS1
S2444	S2448		
S2476	S2476A		
S2478	S2478A		
S2484	S2484A		
S2484B			

[1] Refer to Longwall 18 Subsidence Management Plan – Plan 1 (DEN-01-6151) for mine layout detail.

- Numerous 2D seismic lines;
- Surface geological mapping;
- Underground geological mapping; and
- Aeromagnetic and related remote sensing surveys.

Some additional underground inseam drilling (UIS) is planned once MG18 development commences and will further define the structural zone in MG18.

STRUCTURE

Longwall 18 contains a significant structurally disturbed zone along MG18 between CT 7-8 which also extends into the longwall block. This zone appears to consist of a series of three faults with displacements 10 - 15m, downthrown to the south and middle and has been investigated via a variety of exploration methods; including UIS, vertical and angled drilling from the surface, 2D seismic and surface and underground mapping. This zone was first reported in 2012 as part of the "Geology & Mineral Resources - Dendrobium Area 3B" report when an area of poor seismic response was identified following an extensive phase of 2D seismic acquisition. The exact nature of the zone was unclear from the seismic data at the time, apart from being indicative of faulting (Section *2.3.4.1.1 Elouera Fault (DF11)* in the "Geology & Mineral Resources - Dendrobium Area 3B" report.

The report recommended further UIS drilling once workings were close enough which first occurred in 2018. Drilling of WO3-D1-IS2 hit stone in two branches, both in the middle of the Longwall 18 block. Further UIS drilling identified further stone consistent with a fault interpretation. A series of angled surface boreholes (S2476A, S2484A and S2484B) were then able to determine the throw of the faulting as being some 10-15m down to the south. The level of displacement of these faults is too large for the longwall to negotiate and resulted in a decision to shorten the length of Longwall 18 to just over 1000m in length (Figure 1).

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 at the eastern end of the panel and then the seam dip flattens in the center before gently rising again with dips towards the northeast. Seam elevations are 83 m above mean sea level (amsl) at MG18 panel entry from where the seam is expected to dip gently to a minimum of 57m amsl around the middle of the Longwall 18 block and then rise again to a maximum of 74m amsl.

Apart from the main fault zone described above there are several other features that may impact on mining conditions. A known dyke zone consisting of dykes DD26, DD36 and DD37 cuts through the structural zone described above, further complicating the interpretation of this area. The dykes have been intersected previously in Wongawilli Mains 3 and MG17 and while they did not have a significant impact on mining conditions, they have a thickening trend towards MG18. One of the angled surface boreholes (S2476A) in Longwall 18 intersected significant amounts of igneous material in and around the Wongawilli Seam and another (S2484B) encountered igneous material in the upper stratigraphy.

The Dendrobium Nepheline Syenite sill occurs in the far eastern portions around the Wongawilli Mains 3 panel but extends over the top of the Wongawilli working section in the upper parts of the seam. Impact on mining from this structure are expected to be relatively minor. 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.

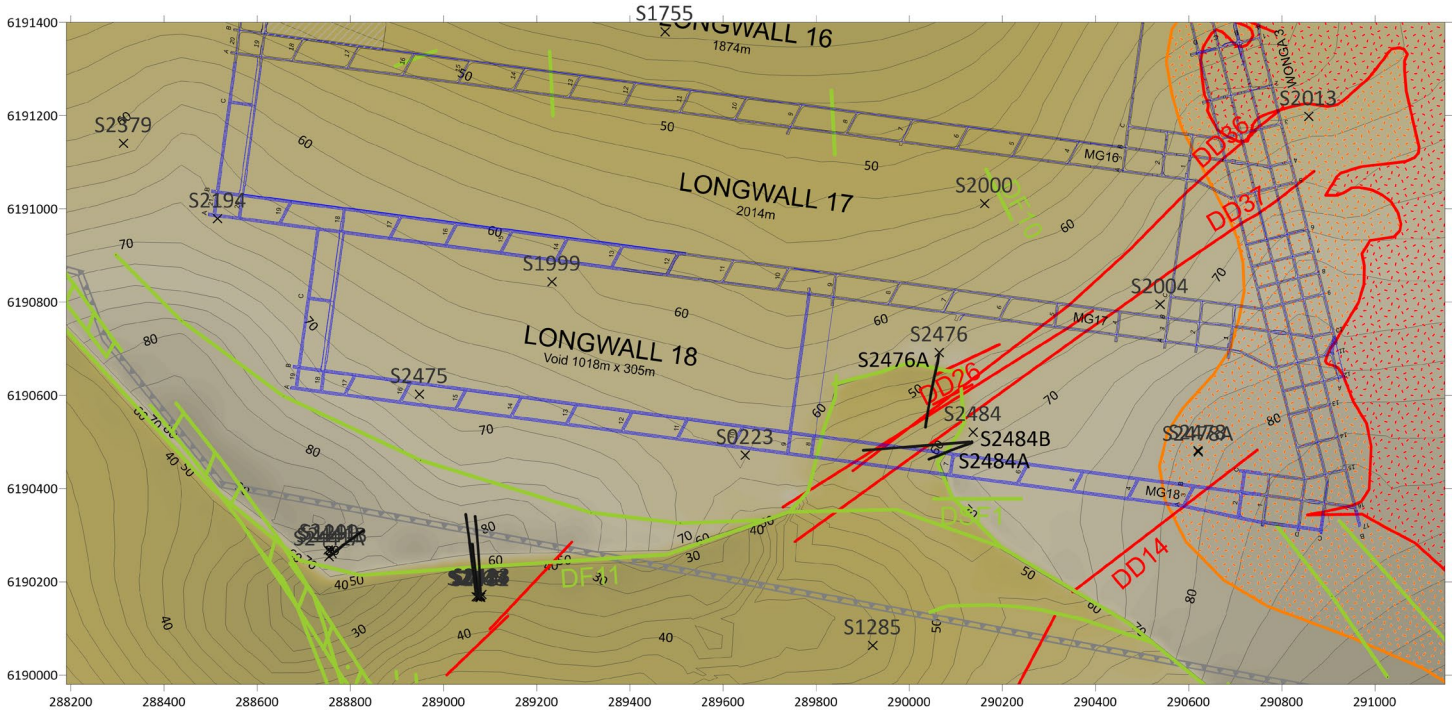


Figure 1 – Geological Structure and seam Floor Contours

Mining conditions in MG17 have been good with little roof deformations and no significant roof falls. Apart from the fault zone and dykes the mining conditions in MG18 are expected to be similar. 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 Longwall 18 ranges from 300 to 370m, with the highest values in the center of the longwall block (Figure 2).

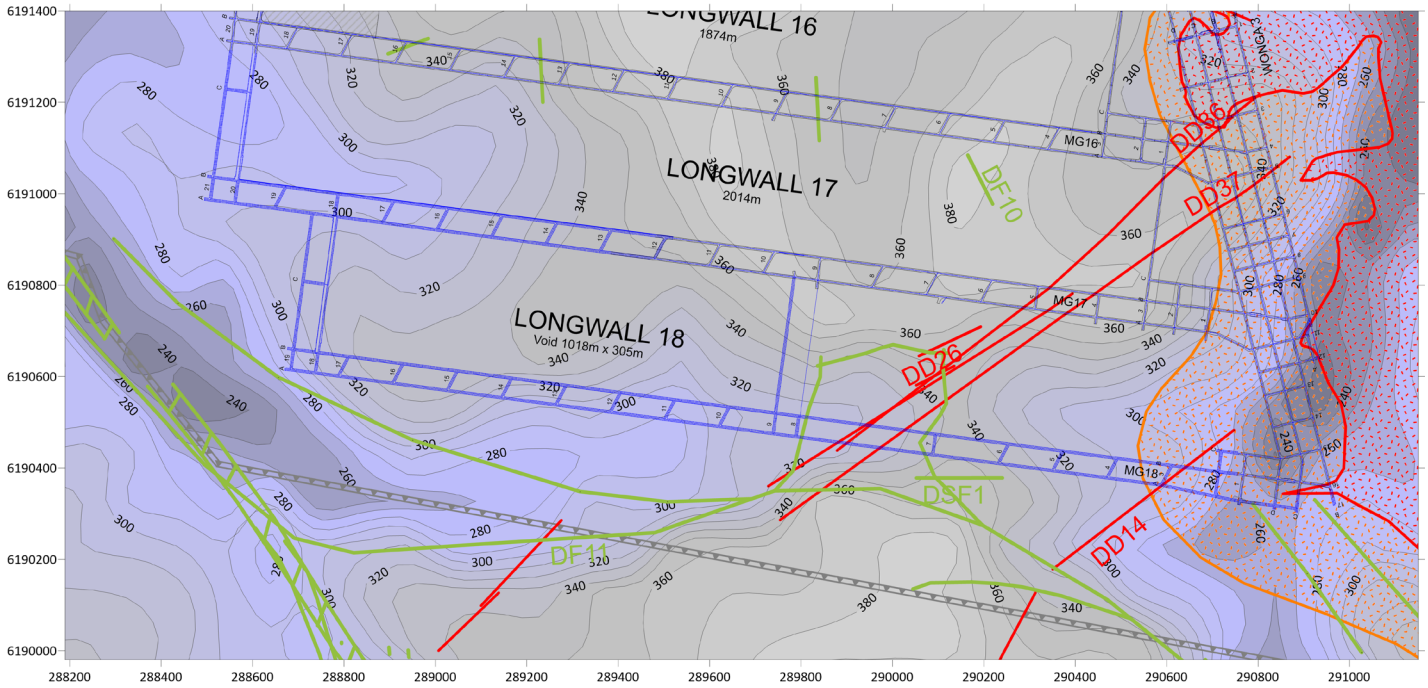


Figure 2 – Depth of Cover

SEAM THICKNESS

Seam thickness for the working section at the base of the Wongawilli Seam in the Longwall 18 area ranges from 3.6 to 4.1m, which is consistent with most of Area 3B (Figure 3). An extraction limit of 3.9m will be applied, consistent with previous subsidence management plans. There is a slight thinning of the working section towards the southeast corner of the area to 3.6m. Coal quality and coking yield is expected to be similar to previous longwalls in Area 3B.

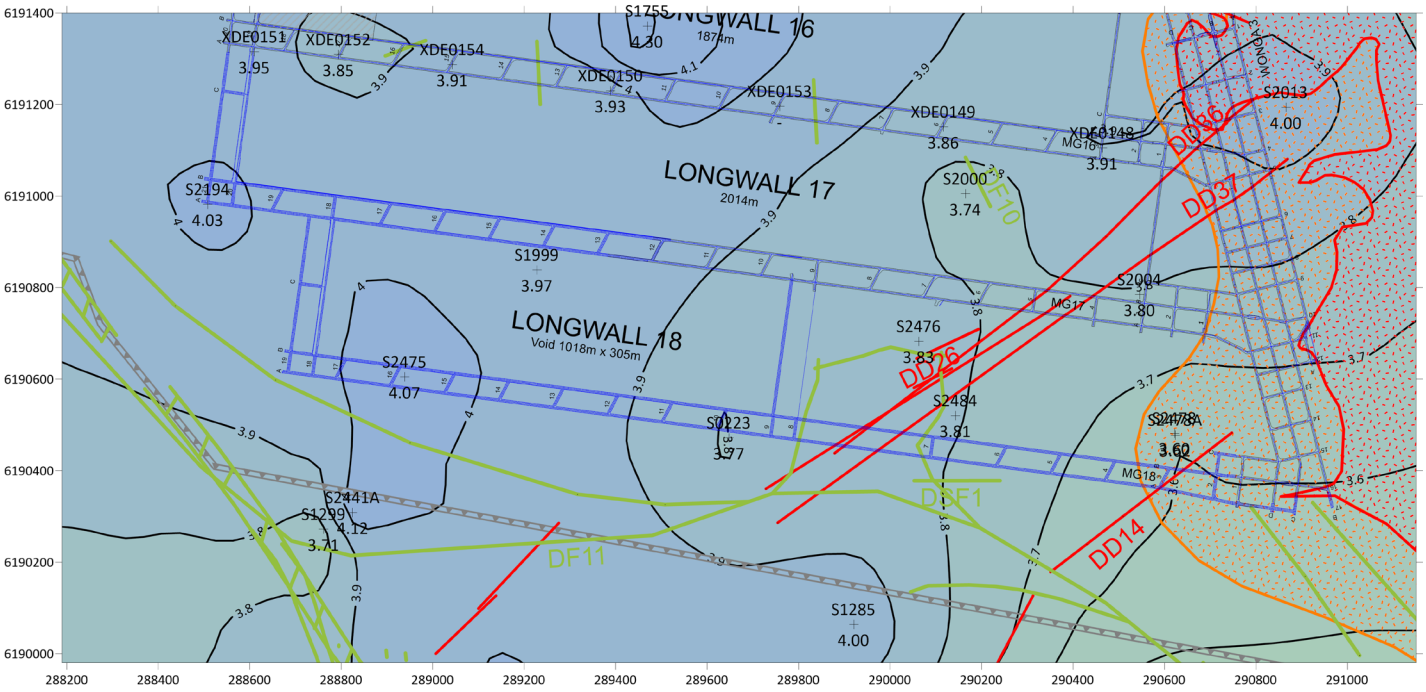


Figure 3 – Seam Thickness (Working Section)

CONCLUSION

The geological setting present within the Longwall 18 block is expected to be dominated by the faulted zone in MG18 between CT's 7-8. Considerable exploration data has been collected but mining conditions in this zone of MG18 will be challenging with two faults to be negotiated as well as several dykes and associated silling. Inseam drilling data from outside this zone suggests that conditions for the Longwall 18 block are likely similar to those previously experienced in Area 3B with only minor impacts from geological features expected. Further definition of the extent of the fault zone and sill will be confirmed by additional inseam drilling.