Illawarra Metallurgical Coal

Dendrobium Mine

Assessment of surface water flow and quality effects of proposed Dendrobium Longwall 19A

HGEO Pty Ltd
Date: September 2022
Project number: J21533
Report: D22175

DOCUMENT REGISTER

Revision	Description	Date	Comments
01	1st Draft	16/8/2022	MS Word
02	Final	5/9/2022	pdf
03	Update	29/9/2022	pdf

FILE

Https://hgeocomau.sharepoint.com/sites/HGEO/Shared Documents/Files/Client_Site/Dendrobium/04_Projects/J21533_LW19A_SMP_Surface_Water/D22175_Dendrobium_LW19A_SW_Impact_Assessment_V03.docx

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

Abbreviation/Term	Meaning
AHD	Australian Height Datum (Mean Sea Level 1966-1968)
bgl	Below ground level
IMC	Illawarra Metallurgical Coal
IMCEFT	Illawarra Metallurgical Coal Environmental Field Team
SMP	Subsidence Management Plan
VWP	Vibrating Wire Piezometer

EXECUTIVE SUMMARY

Illawarra Metallurgical Coal (IMC), a wholly owned subsidiary of South32 Limited (South32), operates the underground Dendrobium Mine in the Southern Coalfield of New South Wales (NSW). IMC proposes to extract Longwall 19A, located immediately to the south of the currently active Longwall 19 in Area 3A. This report describes surface water and swamp features within the expected zone of mining influence and provides an assessment of likely impacts from the proposed mining operations.

Dendrobium Mine is located within the catchment of the Upper Nepean River on the Woronora Plateau inland of the Illawarra Escarpment. Drainage is to the north-northwest, towards the Nepean River, with most of the local surface runoff initially captured in Cordeaux and Avon Reservoirs before eventually flowing into the Nepean River. The study area is defined by the area within 600 m of the proposed Longwall 19A. Longwall 19A spans the divide between the catchments of Wongawilli Creek and Sandy Creek, such that approximately half of the runoff from the study area reports to each catchment.

Wongawilli Creek is a third-order perennial stream that flows north to join the Cordeaux River approximately 5.8 km north of Longwall 19A. Longwall 19A does not directly underlie any third- or second-order tributaries of Wongawilli Creek, passing within 395 m at its closest point. Two first-order tributaries, WC13 and WC14 are within 400 m of Longwall 19A; the latter will be mined beneath by the current Longwall 19. The main Sandy Creek tributary and Sandy Creek waterfall are unlikely to be affected by subsidence. Tributary SC10B crosses the north-east corner of Longwall 19A. Predictions of mine subsidence related to Longwall 19A (MSEC, 2022) combined with previous experience and information from Dendrobium, indicate that fracturing and stream diversion is likely to occur in tributaries that cross the longwall footprint. Watercourses that pass within 400 m of the longwall may experience some fracturing and flow diversion.

Estimates based on a regional groundwater model by Watershed (2022) indicate that over the longer term (>40 years) the baseflow components of Wongawilli Creek and Sandy Creek may decline by up to 0.9 and 0.06 megalitres per day (ML/day) (cumulative / whole mine) and up to 0.01 ML/day ML/day (incrementally). This equates to approximately 6% and 1% of the mean flow at the downstream gauges (0.06% and 0.14% incremental). Baseflow reduction would manifest as an increase in low-flow (and no-flow) days during prolonged dry periods. Over the longer term, no-flow days may increase from 44 to 108 days per year in Wongawilli Creek and from 39 to 56 days per year in Sandy Creek (cumulative). However, it is noted that such flow effects at WWL have not been observed as a result of mining in Areas 3A and 3B to date and these predictions are likely conservative.

Water quality influence due to mining is expected to be minor in stream reaches within subsidence affected areas. Effects are likely to include temporary changes in water salinity, pH and iron content with local transient discolouration of streambeds and rock faces by iron hydroxide. Water quality effects on stored waters of the reservoirs are expected to be negligible and undetectable.

Seven areas of Coastal Upland Swamp vegetation are mapped wholly or partially within 600 m of the proposed longwall. Of those, Swamp 15c and Swamp 148 overlap with the proposed longwall footprint and Swamp 34 extends within 60 m of the longwall. Based on previous experience at Area 3B and subsidence predictions, it is likely that shallow groundwater levels will be affected in Swamp 15c and 54% of Swamp 34. Shallow groundwater impacts are possible in areas of Swamp 15b that are within 400 m of Longwall 19A. Areas of Swamps 12, 15b and 148 were previously mined under (or were within 60 m of) Longwalls 7, 8 and 19. The remaining swamps are unlikely to be impacted since they are located more than 400 m from the proposed goaf and/or are predicted to experience negligible ground movement related to subsidence and valley closure.

1. INTRODUCTION

1.1 Project background

Illawarra Metallurgical Coal (IMC), a wholly owned subsidiary of South32 Limited (South32), operates the underground Dendrobium Mine in the Southern Coalfield of New South Wales (NSW). The mine is located about 12 kilometres (km) west of Wollongong and within the Metropolitan Special Catchment Area managed by WaterNSW.

Since approval in 2001, underground mining has been carried out using longwall extraction within Areas 1, 2, 3A and 3B. Longwall mining is currently underway at Longwall 19 in Area 3A. Following completion of Longwall 19 in Area 3A, IMC proposes to extract one further longwall in Area 3A, Longwall 19A (Figure 1). This assessment relates to Longwall 19A located immediately to the south of Longwall 19 which was approved by DPE in 11 March 2021.

Previous workings in the Wongawilli Seam are located to the south of Dendrobium at Elouera and Nebo Mines, 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 19A. HGEO was engaged to carry out an assessment of the potential effects of mining on surface water and shallow groundwater systems. This assessment is to form part of the SMP and should be read in conjunction with that document and other specialist reports referred to in the SMP.

1.2 Study area

The study area is nominally defined by the area within 600 m of the edge of the longwall (Approval Condition 8(d)), being the minimum extent of the assessments for the valley related subsidence effects (MSEC, 2022). MSEC (2022) also considers a study area based on the 35° angle of draw and predicted 20 mm subsidence contour. Study areas defined by both criteria are shown in Figure 1. This assessment considers reaches of Wongawilli Creek and Sandy Creek that extend upstream and downstream of the 600 m envelope, as appropriate for the definition of baseline characteristics and long-term impact monitoring.

1.3 Scope

The scope of this assessment is to provide supporting information for the SMP for Area 3A which is required under Schedule 3 of the Dendrobium Development Consent. The assessment is to include:

- Description of surface water hydrology within the study area.
- Summary of existing monitoring sites.
- Summary of baseline monitoring data.
- Assessment of potential impacts to surface water systems as a result of subsidence related to Longwall 19A, 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 19A.
- 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

The proposed developments in Area 3A are subject to the following specific environmental conditions as listed in Schedule 3 of the Dendrobium Integrated State Significant Development consent (Mod 9), dated 8 July 2022 (Table 1).

Table 1. Dendrobium Development Consent conditions relevant to this surface water assessment

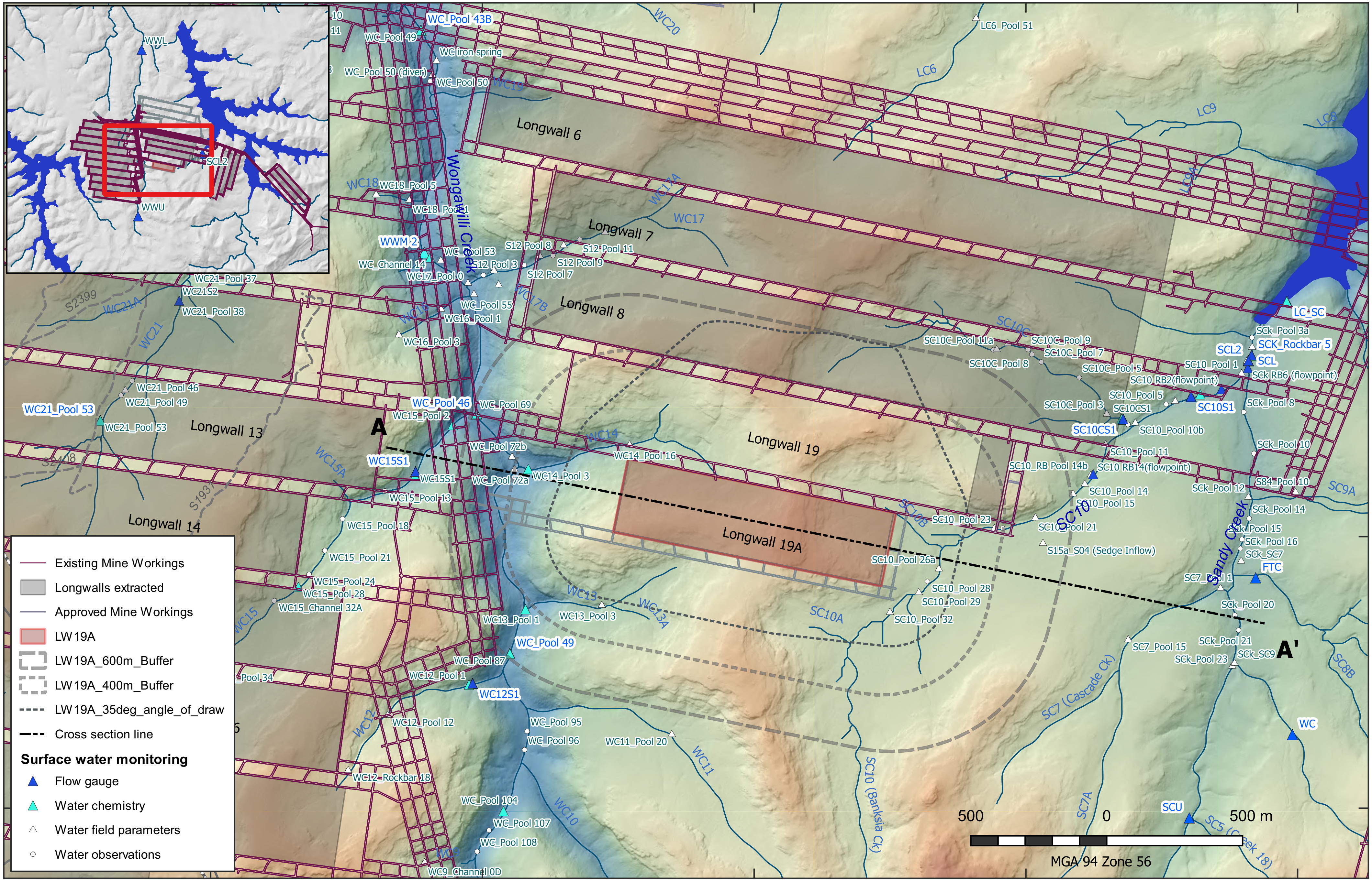
Condition		Where addressed
Schedule 3 – Specific Environmental Conditions		
2	The Applicant shall ensure that underground mining operations do not cause subsidence impacts at Sandy Creek and Wongawilli Creek other than "minor impacts" (such as minor fracturing, gas release, iron staining and minor impacts on water flows, water levels and water quality) to the satisfaction of the Secretary.	Section 4 (this report)
3	The Applicant shall ensure the development does not result in reduction (other than negligible reduction) in the quality or quantity of surface water or groundwater inflows to Lake Cordeaux or Lake Avon or surface water inflow to the Cordeaux River at its confluence with Wongawilli Creek, to the satisfaction of the Secretary.	Section 4 (this report)
5	The Applicant shall ensure that subsidence does not cause erosion of the surface or changes in ecosystem functionality of Swamp 15a and that the structural integrity of its controlling rockbar is maintained or restored, to the satisfaction of the Secretary.	Section 4 (this report) Accompanying report by Niche (2022)

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 DPE on the SMP for Dendrobium Mine Longwall 21 (IEPMC, 2019c). Recommendations from the IEPMC reports are referred to throughout this assessment.



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Dendrobium Longwall 19A Surface water assessment

Location map and surface water monitoring sites

Figure 1

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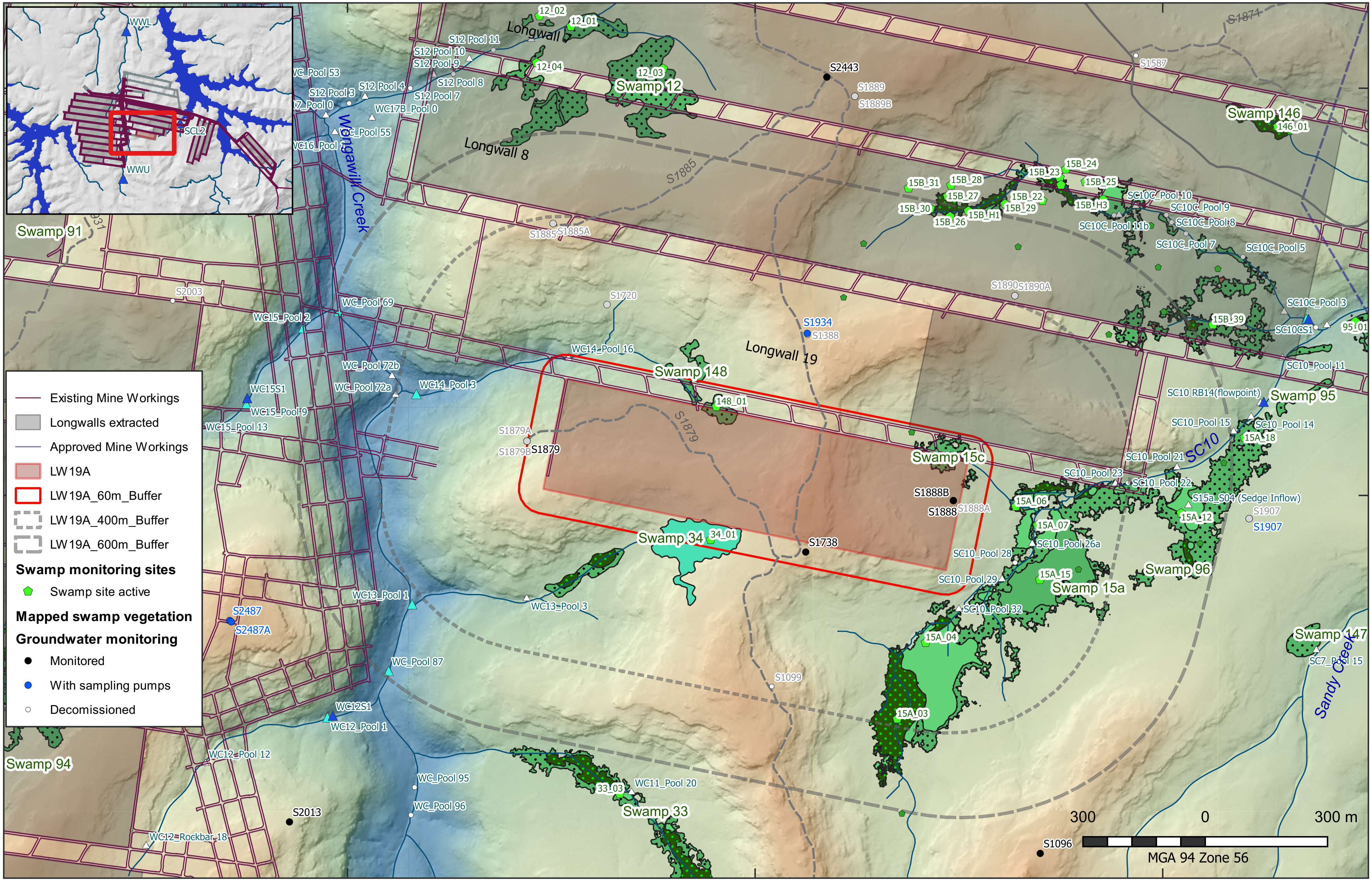

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Dendrobium Longwall 19A Surface water assessment

Coastal Upland Swamp vegetation and monitoring sites

Figure 2

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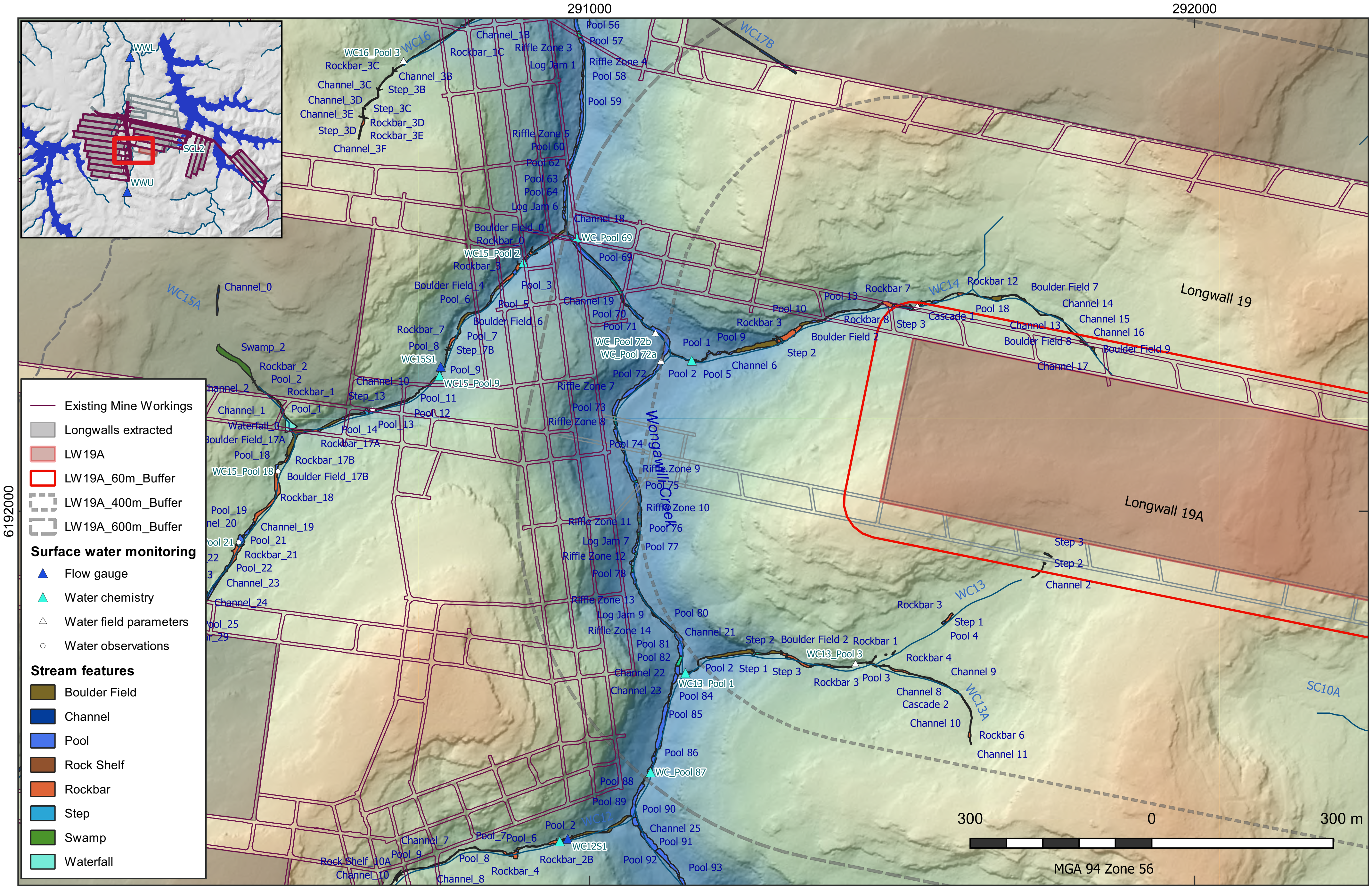

Dendrobium Longwall 19A Surface water assessment

Stream morphological mapping within Study Area (Wongawilli Creek)

Figure 3

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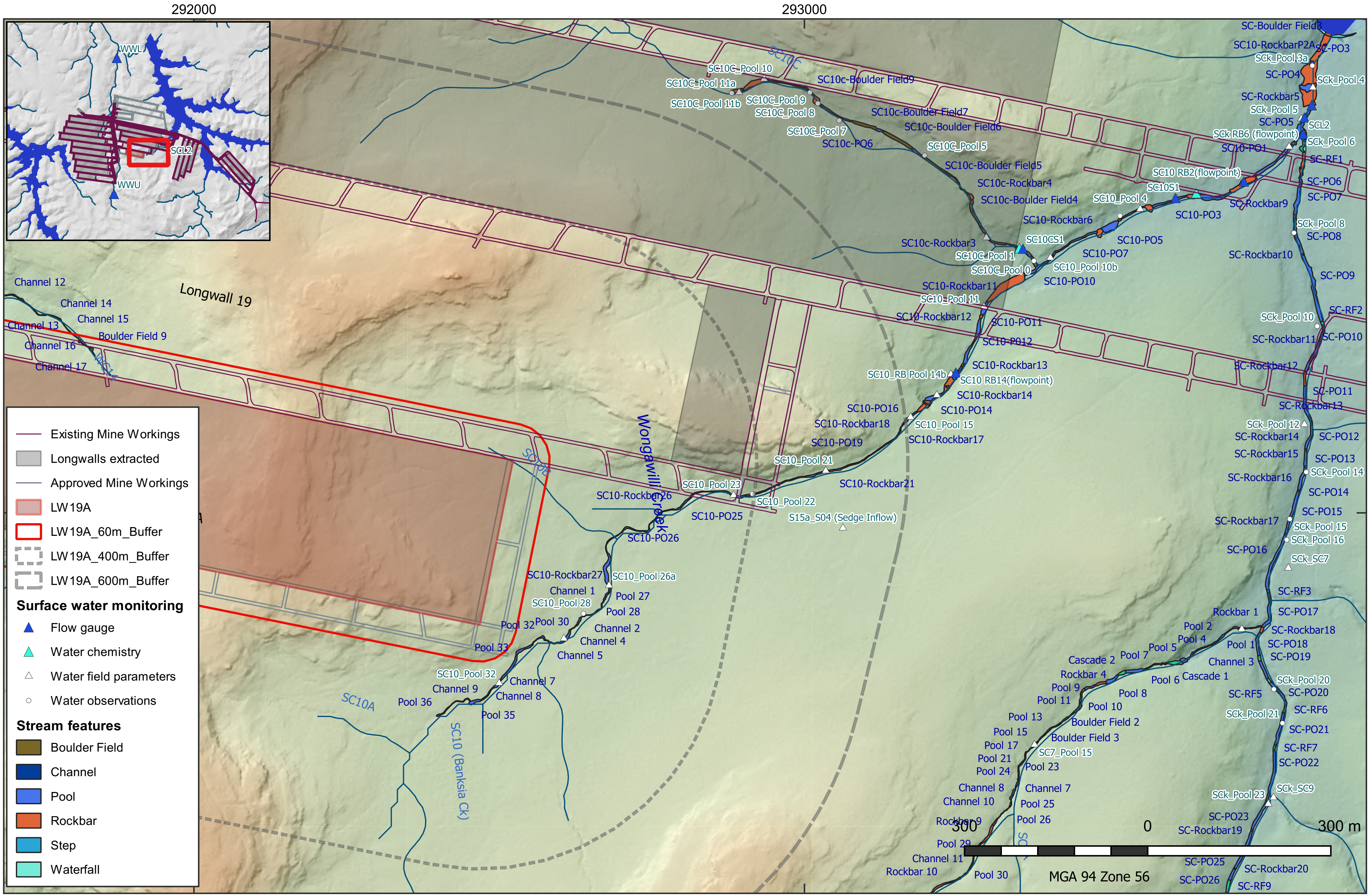

Dendrobium Longwall 19A Surface water assessment

Stream morphological mapping within Study Area (Sandy Creek)

Figure 4

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1.6 Mining geometry

The layout of the proposed Longwall 19A is shown in Figure 1. The longwall will be extracted from the Wongawilli seam, with mining dimensions as follows:

- Void length: 1009 m (including heading).
- Width (including first workings): 275 m.
- Extraction height: 3.5 to 3.9 m (maximum).
- Depth of cover: 290 – 360 m.

Longwall 19A will be extracted towards the main headings (from east to west). The extent of the longwall within the Wongawilli Coal Seam is shown in an east-west geological cross-section A-A' in Figure 5. The proposed longwall is located between Wongawilli Creek to the west and Sandy Creek to the east. The ground surface ranges between 350 m and 430 m above Australian Height Datum (mAHD). The coal seam dips from the south-east to the north-west. The depth of cover to the Wongawilli Seam directly above the proposed longwall ranges between 290 m and 360 m. The minimum depth of cover occurs along tributary WC14 near the western end and the maximum depth of cover occurs along the ridgeline towards the middle of the proposed longwall.

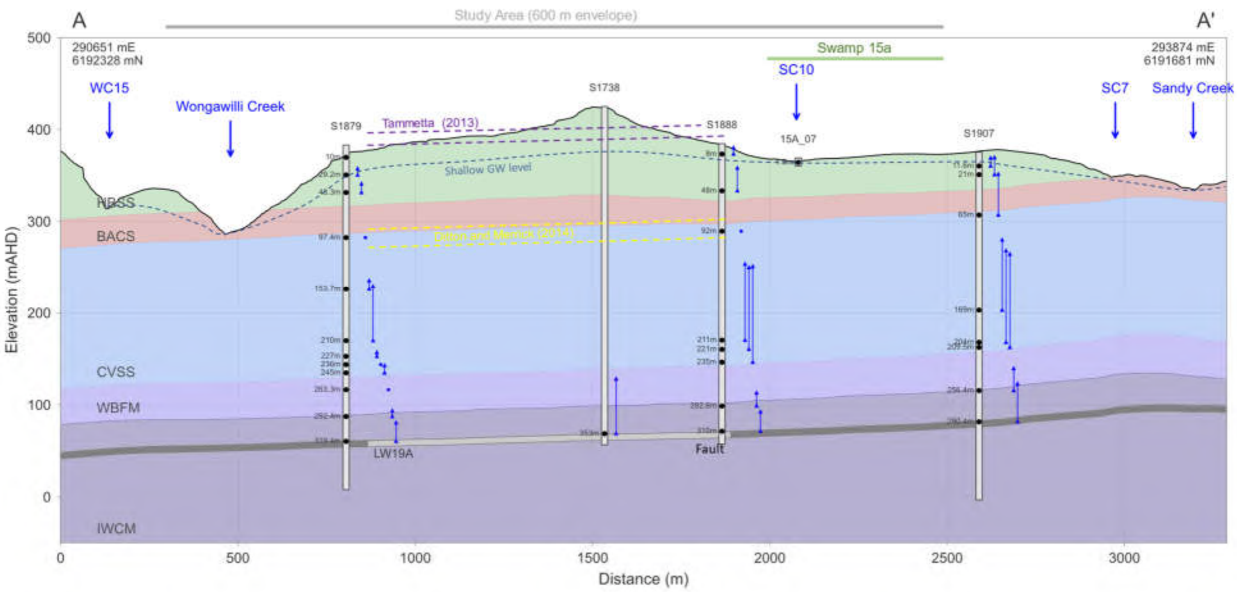

Figure 5. Geological cross section A-A' through Longwall 19A (West-East)

2. BACKGROUND

2.1 Topography

Dendrobium Mine is located on the Woronora Plateau inland of the Illawarra Escarpment. The escarpment rises from the coastal plain to elevations in excess of 400 mAHD around Dendrobium. The plateau generally slopes to the north or northwest, toward the centre of the Sydney Basin. Dendrobium Area 3 is characterised by broad sandstone ridges and plateaus rising to approximately 410 m AHD, incised by relatively steep and rugged gullies. Longwall 19A is aligned west-northwest across the ridgeline between the Wongawilli Creek and Sandy Creek catchments.

2.2 Climate

Weather data have been collected at the Dendrobium Mine since 2003. Mean annual rainfall between 2002 and 2021 was 1050 mm (2.87 mm per day on average). 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. Evapotranspiration 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. Severe drought conditions occurred across much of NSW during 2017-19 including Dendrobium. The drought was followed by very wet weather in 2020-2022 with the development of prolonged La Niña conditions.

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 19A lies across the divide between the catchments of Wongawilli Creek and Sandy Creek, such that approximately half of the runoff from the study area reports to each catchment.

2.3.1 Wongawilli Creek

Wongawilli Creek is a third-order perennial stream that flows north to join the Cordeaux River approximately 5.8 km north of Longwall 19A. 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. Since the start of monitoring in 2007, Wongawilli Creek (WWL) has recorded measurable flow on 88% 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]).

Longwall 19A does not directly underlie any third- or second-order tributaries of Wongawilli Creek. The broader 600 m study area overlaps with the following watercourses within the Wongawilli Creek catchment:

- Wongawilli Creek: 1.0 km of the third-order watercourse crosses the 600 m study area. The main channel passes just within 400 m of Longwall 19A at the confluence with WC14 with the closest approach being 395 m.

- WC14: The second order tributary is entirely within the 600 m study area. The second order section of the tributary passes within 50 m of Longwall 19A. No first or second-order channels cross the longwall footprint. The hydrology of WC14 is likely influenced by storage within, and drainage from, Swamp 148 which underlies the upper reaches of the tributary. Both the tributary and the swamp will be affected by subsidence associated with Longwall 19 which is currently underway. There is one field observation site and one chemistry sampling site on WC14 (WC14_Pool16 and WC14_Pool3).

- WC13: The second order tributary is entirely within the 600 m study area, with 320 m of the second order channel within 400 m of the longwall. The second-order channel passes 260 m from the longwall. No first or second-order channels cross the longwall footprint. The hydrology of WC14 is likely influenced by Swamp 34 which underlies the upper reaches of the tributary. There is one field observation site and one chemistry sampling site on WC14 (WC13_Pool3 and WC13_Pool1).

2.3.2 Sandy Creek

Sandy Creek is a third-order tributary to Lake Cordeaux. Sandy Creek flows from south to north, entering Lake Cordeaux at the Sandy Creek Waterfall. Sandy Creek passes to the east of previously extracted Longwalls 6 to 8 and Longwall 19 currently being mined in Area 3A and is entirely outside the 600 m study area for Longwall 19A.

A major second-order tributary of Sandy Creek, SC10, and several first-order tributaries pass within the 600 m study area:

- SC10. This second-order tributary has a relatively large sub catchment relative to the total Sandy Creek catchment (40%). The second-order channel of SC10 passes within 85 m of Longwall 19A, with a length of 910 m within 400 m of the longwall. Tributary SC10 flows through Swamp 15a for much of its length and it is likely that the swamp has a major influence on the hydrology and water quality in the tributary. Much of the tributary and swamp area within the Longwall 19A Study Area is also within 400 m of currently active Longwall 19. There are 14 field observation sites along SC10, including a flow gauging site (SC10S1).

- SC10C. The second-order channel of this tributary of SC10 is entirely outside the study area.

- Two first-order tributaries, SC10A and SC10B are entirely within the Study Area and within 400 m of Longwall 19A. Tributary SC10B crosses the north-east corner of Longwall 19A over a length of 10 m. The upper reaches of SC10 B pass within 35 m of the currently active Longwall 19.

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 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 19A (Figure 5).

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 and CVSS) are exposed in deeply incised parts of Wongawilli Creek and along the south-eastern shores of Lake Cordeaux.

Three main groundwater systems are recognised:

1. Perched groundwater systems associated with swamps and shallow sandstone. These may be ephemeral and/or disconnected from the deeper groundwater systems;
2. Shallow groundwater systems: layered water-bearing zones within the saturated HBSS; and
3. Deeper groundwater systems within the Narrabeen Group and the Illawarra Coal Measures.

Recharge to the aquifer systems comes primarily from rainfall infiltration through outcropping formations, generally the HBSS in the western half of the Dendrobium Mine area and the Bulgo Sandstone in the eastern half. There will be some recharge from the Reservoirs and streams to host formations at times of high water level and creek flooding. In the western part of Area 3B, the Stanwell Park Claystone pinches out such that the Bulgo and Scarborough Sandstones form a single unit, the Colo Vale Sandstone.

Strong topographic relief and recharge drive vertical groundwater flow near the ground surface, but at depth the alternation of aquifers and aquitards promotes horizontal groundwater flow at the base of permeable units. Regional groundwater flow in the deeper sandstone units (pre-development) is predominantly northwest, towards the Nepean River system and away from the Illawarra escarpment.

Discharge from the groundwater systems occurs naturally at the surface to creeks (contributing to stream baseflow) and to the reservoirs as baseflow and seeps, and as evapotranspiration. Along the escarpment to the south-east of Dendrobium Mine, groundwater discharge appears as seeps in cliff faces at the junction of formations with contrasting permeability.

Groundwater piezometric levels are shown on Figure 5 for three monitoring bores located near the Longwall 19A cross-section line. The data show that deeper strata are depressurised from previous mining at Area 3A and adjacent areas. Groundwater levels are maintained at between ~380 to 395 m AHD within the HBSS in the centre of Longwall 19A. There is a groundwater divide along the ridgeline and groundwater within the HBSS flows west towards Wongawilli Creek and east towards Sandy Creek (SC10) where it discharges as baseflow.

2.5 Upland Swamps

Coastal Upland Swamps are endemic to the eastern part of the Sydney Basin and have a significant role in catchment hydrology. They are listed as an endangered ecological community under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*, and the NSW *Biodiversity Conservation Act 2016*. Upland Swamps are typically located at the headwaters of low order streams, on low relief plateaus on low permeability HBSS. Swamp vegetation is highly variable, ranging from open graminoid (grassy) heaths and sedgelands to fernlands and scrub (Threatened Species Scientific Committee (TSSC), 2014).

The location and extent of known swamps is shown in Figure 2 and is derived from a combination of mapping by the then NSW Office of Environment and Heritage (OEH), ecological consultants and the Illawarra Metallurgical Coal Environmental Field Team (IMCEFT). There are seven swamps located entirely or partially within 600 m of Longwall 19A. Those swamps are listed in Table 2, which lists swamp position in relation to the landscape and the dominant vegetation communities. Two swamps (Den 15c and part of Den 148) partially or entirely overlie the longwall footprints; Swamp Den 34 extends within 60 m of the longwall. Swamp 15a is 475 m from Longwall 19A at its closest point and 68% of the swamp is within 400 m of the longwall 1footprint. The remaining three swamps are located beyond 400 m from the longwall footprint.

Table 2. Swamp vegetation communities within the study area

Swamp	Area (ha)	Position	Vegetation communities	Minimum Distance from LW (m)	Monitoring	
					Shallow GW	Soil Moisture
Den 12	5.37	Headwater	Banksia Thicket	590	4 sites	-
Den 15a	17.38	Valley infill	Banksia Thicket Tea-Tree Thicket Sedgeland-Heath	75	7 sites	-
Den 15b	4.96	Valley infill	Banksia Thicket Tea-Tree Thicket Sedgeland-Heath	470	14 sites	4 sites
Den 15c	0.65	Headwater	Banksia Thicket	0 (34% of swamp overlaps)	-	-
Den 34	2.58	Headwater / Valley infill	Banksia Thicket Tea-Tree Thicket Mallee Heath	0 (0.2% of swamp area overlaps)	1 site	-
Den 96	0.17	Headwater	Banksia Thicket	440	-	-
Den 148	0.86	Headwater	Banksia Thicket	0 (22% of swamp areas overlaps)	1 site	1 site

The structure and hydrological function of Coastal Upland Swamps has been well studied by Young (1982), Tomkins and Humphreys (2006), Cowley *et al*. (2016), Fryirs *et al*. (2014), and others. Upland Swamps form on accumulations of sandy and silty sediments on the broad and gently sloping headwater valleys. Measured cross-sections indicate a reasonably consistent structure: A basal layer of grey-brown, medium to coarse sand is overlain by increasingly organic rich sands and organic fines. There is commonly a lateral variation in facies caused by the fractionation of sediments during overland flow such that grey-brown sands accumulate at the swamp margins, whereas finer-grained sediments (silt, mud) and organic material accumulate towards the swamp axis (Young, 1982). Fibric mats of live and dead organic matter occur at the swamp surface, up to a depth of approximately 50 cm, providing some protection from erosion during runoff events. Episodes of scouring and erosion occur naturally with a periodicity of several thousand years (Tomkins and Humphreys, 2006) and are thought to be caused by high intensity rainfall-runoff events, possibly following wildfires.

Ground subsidence and near-surface fracturing related to longwall mining can impact swamp hydrology as has been observed during mining at Dendrobium Areas 3A and 3B. Those effects are discussed further in Section 4.

3. BASELINE ASSESSMENT

3.1 Monitoring

This section outlines the network of monitoring infrastructure and sites operated by IMC that are relevant to the Longwall 19A study area. Further details of monitoring sites and procedures are outlined in the Dendrobium Area 3A Longwall 19 WIMMCP (South32, 2020a).

3.1.1 Geomorphological mapping

Stream bed morphology has been mapped in detail by the IMCEFT to provide baseline observations in all active and proposed mining areas. Mapping involved characterisation of the watercourse in terms of its bed characteristics (e.g. channel, pool, riffle, rockbar, etc.), sediment type and vegetation. Key features are mapped and photographed for comparison during and after mining. Major streams and tributaries of Wongawilli Creek and Sandy Creek adjacent to proposed Longwall 19A have been mapped as part of previous assessments for mining at Dendrobium Mine (Figure 3 and Figure 4 respectively).

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 Longwall 19 WIMMCP and broader Area 3A WIMMCP (South32, 2020b). There are 21 active monitoring sites on Sandy Creek and Wongawilli Creek (and their tributaries) within 600 m of the proposed longwall. Stream monitoring sites within the study area are shown in Figure 1. Those sites at which flow conditions are recorded and/or water chemistry data is collected are listed in Table 3 and Table 4 (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 on Sandy Creek

Watercourse	Site	East (MGA94)	North (MGA94)	Flow gauge	Chemistry	Field parameters
Sandy Creek	SCL2* (Rockbar 5)	293819	6192648	2011 -	2007 -	2007 -
SC10	SC10S1** (Pool 1)	293609	6192519	2007 -	2008 -	2008 -
SC10	Pool 26a	292680	6191881			2016 -
SC10	Pool 29	292606	6191794			2016 -
SC10	Pool 32	292500	6191721			2016 -
SC10	RB Pool 14b	293240	6192227			2016 -
SC10C	SC10CS1 (Pool 1)	293358	6192433	2007 -	2008 -	2008 -
SC10C	Pool 0	293376	6192413			2009 - 2018

Note*: Gauge site SCL2 is known to have a leak which affects the flow measurements. Planned repairs to the site were delayed due to catchment closures and will now not be carried out until after Longwalls 19 and 19A to maintain consistent gauge rating characteristics. ** Site SC10CS1 is being upgraded to a flume site to improve low-flow measurements. A slot was cut in the rock bar for the flume installation but not completed prior to catchment closures. Therefore, pool levels and the gauge rating will be altered until installations can be completed.

Table 4. Surface water monitoring sites on Wongawilli Creek

Watercourse	Site	East (MGA94)	North (MGA94)	Flow gauge	Chemistry	Field parameters
Wongawilli Creek	WWU / WWU4	290808	6189716	2007 -	2002 -	2002 -
Wongawilli Creek	WWL Wongawilli Ck (FR6)	290960	6197376	2007 -	2001 -	2001 -
Wongawilli Creek	WC_Pool 69	290979	6192452		2008 -	2008 -
Wongawilli Creek	WC_Pool 72a	291118	6192247			2009 -
Wongawilli Creek	WC_Pool 72b	291109	6192293			2009 -
Wongawilli Creek	WC_Pool 87	291101	6191569		2012 -	2008 -
WC13	WC13_Pool 1	291159	6191733		2021 -	2020 -
WC13	WC13_Pool 3	291440	6191747			2021 -
WC14	WC14_Pool 3	291169	6192249		2021 -	2009 -
WC14	WC14_Pool 16	291542	6192337			2021 -

The monitoring of water quality parameters provides a means of detecting and assessing the effects of streambed fracturing or the emergence of ferruginous springs. Monitoring includes measurement of field parameters (pH, Electrical Conductivity (EC), Dissolved Oxygen (DO), Oxygen Reduction Potential (ORP) and laboratory tested analytes (DOC, Na, K, Ca, Mg, Filt. SO4, Cl, T. Alk., Total Fe, Mn, Al, Filt. Cu, Ni, Zn, Si).

3.1.3 Shallow Groundwater Monitoring

Figure 2 shows areas of swamp vegetation, broadly mapped by OEH and refined through site-scale mapping by ecological consultants and IMC. Hydrological baseline characteristics and mining effects at swamps are monitored using shallow (1 to 3 m) piezometers and soil moisture sensors. Figure 2 shows the locations of shallow groundwater monitoring sites in the vicinity of Longwall 19A.

The Trigger Action Response Plan (TARP) related assessments carried out as part of the SMP relate to those piezometers located within areas mapped as Banksia Thicket, Sedgeland-heath complex and Tea Tree Thicket; being listed as Costal Upland Swamp Endangered Ecological Community (EEC). Piezometers located within fringing Eucalypt Woodland are excluded from the TARP related assessment as per the advice from OEH (dated 17/01/2014).

3.1.4 Soil moisture monitoring

Soil moisture profiles are monitored at most swamps, with sensor arrays typically positioned near shallow piezometers (where possible). Where possible the monitoring arrays are numbered according to the corresponding piezometer (if present) with an ‘S’ prefix. At most locations, five sensors are installed at 20 cm depth intervals to a total depth of 1 m.

Soil moisture is measured using ‘Sentek’ sensors which monitor changes in the dielectric constant within a cylinder of soil extending to a radial distance of 10 cm from the access tube. Soil moisture is reported as mm water per 100 mm soil depth (or volumetric % water) at each monitored depth

(Sentek, 2017). The most recent installations are equipped with automated data loggers set to record moisture levels every hour, whereas previous installations are recorded manually during scheduled site visits.

3.2 Baseline monitoring

3.2.1 Stream flow and catchment yield

Stream flow is gauged at three sites in the Wongawilli Creek catchment and three sites in the Sandy Creek catchment that are relevant to monitoring of baseline conditions for Longwall 19A (Table 3; Figure 1). Table 5 summarises the baseline flow conditions for the gauging stations relevant to this assessment (late 2022). The last column of Table 5 summarises the effects on stream flow that are attributed to mining at Area 3A (and 3B) in previous reports.

Sites WWU, WWL, SC10S1 and SC10CS1 have been monitored since 2007, prior to the start of mining in Area 3A, whereas monitoring at SCL started in 2011. The available baseline for Longwall 19A as of the end of 2022 ranges from 11 years to approximately 15 years. There are >2 years of baseline data available for the longest active gauges prior to the start of mining in Area 3A (9/2/2010).

Table 5. Stream flow gauge sites relevant to the study area

Water-course	Gauge	Catchment Area (km^2)	Median flow (ML/day)	Mean flow (ML/day)	Yield (%rain)	Annual no-flow days	Observed mining effects
Wongawilli Creek	WWU	3.211	0.43	4.2	39%	21 (6%)	Although Elouera Colliery did mine in this catchment, it is considered to be an upstream control site. There is no impact from Dendrobium mining.
Wongawilli Creek	WWL	20.08	3.18	15.5	25%	44 (12%)	No evidence for change of flow at downstream gauge*
SC10	SC10S1	2.771	0.80	8.1	*94%***	39 (11%)	No clear evidence for change in flow due to previous Area 3A mining.
SC10C	SC10CS 1	0.817	0.23	1.2	46%	114 (31%)	Decrease in flow from September-2012 due to LW8 mining near and under the watercourse
Sandy Creek	SCL	7.029	1.31	5.7	28%	57 (16%)	No baseline data for the period before LW7.

Statistics are based on the full flow record, accounting for QA assessment by ALS hydrographers.
* Qualitative monitoring of flow condition by IMCEFT between WWU and WWL has shown that baseflow losses are evident at very low flows in reaches close to extracted Area 3A and 3B longwalls, even if effects are not clear at the WWL downstream gauge. ** SC10 mean flow data appears erroneously high (all other sub-catchments listed here indicate a yield of 25-46%).

Stream flow duration curves for the baseline period are shown in Figure 6. Limited or no baseline data are available for gauging stations SCL2 prior to the start of mining at Area 3A. Baseline conditions in the Study Area are summaries as follows:

- Headwater catchments overlapping the Study Area are almost entirely covered by native eucalypt forest and upland swamp vegetation.

- Gauges on third order reaches indicate average runoff yields of 25% to 28% of rainfall. The baseflow component is low and calculated to be in the order of 8% (HydroSimulations, 2016) at downstream gauges.

- Most streams cease to flow during prolonged dry periods, particularly during the summer months when potential evapotranspiration rates are high. During the baseline period, no-flow conditions occurred 12% to 16% of the monitored period for third-order watercourses and 6% to 31% for second order watercourses.

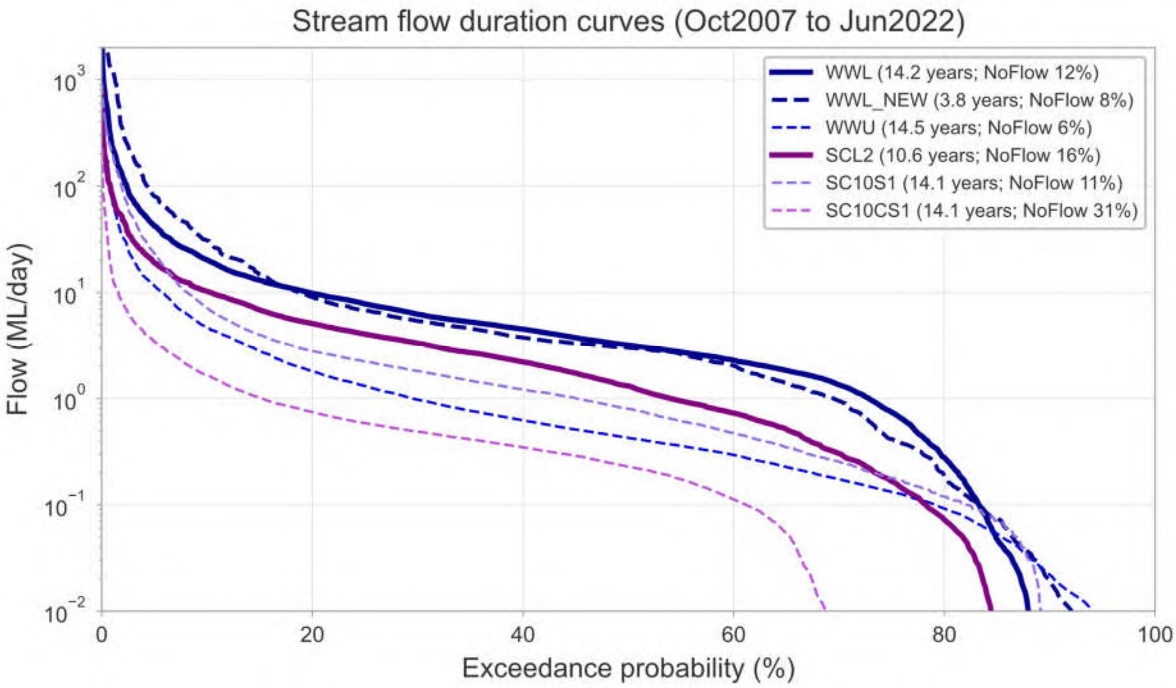

Figure 6. Stream flow duration curves for baseline period (2007 – 2019)

3.2.2 Surface water quality

Water chemistry is monitored at three sites on Wongawilli Creek and three sites on Sandy Creek that are relevant to monitoring of baseline conditions and potential impacts associated with proposed Longwall 19A (Table 3; Figure 1). Regular sampling and analysis have been carried out at the furthest downstream sites (Wongawilli Creek at FR6 and Sandy Creek Rockbar 5) since 2001 and 2007 respectively. Therefore, there are twelve years of baseline water quality data on Wongawilli Creek prior to the development of Area 3B and three years baseline at Sandy Creek prior to development at Area 3A.

ANZECC (2000) provides a framework for conserving the ambient water quality of streams and lakes through the development of Water Quality Objectives (WQO) based on their agreed environmental values. The approach has been adopted by the NSW Government in the management of the Hawkesbury-Nepean River system (HNCMA, 2008; HRC, 1998). Baseline water quality data (pre-LW9) are summarised and compared against guideline levels for the protection of 95% of freshwater aquatic species (Table 6).

While the ANZECC (2000) guideline provides default trigger values for the protection of aquatic species, its preferred approach is to use local (site) reference data when sufficient baseline data are available. Accordingly, the WIMMCP for Dendrobium Mine Area 3A (South32, 2020a) adopts location-specific trigger levels determined from baseline monitoring data. The TARP levels are set for key water quality parameters (pH, EC and DO; see Section 5).

Streams draining the Dendrobium area contain relatively fresh water (<150 µS/cm) dominated by sodium and chloride ions, reflecting mostly direct rainfall runoff. Water pH is typically mildly acidic (pH 5.0 to 6.5), likely due to drainage from swamps and organic-rich soils. Dissolved trace metals are present in very low concentrations, mostly below the ANZECC guidelines for protection of 95% of freshwater species (where trigger levels are set). An exception is dissolved aluminium in up-stream sites on Wongawilli Creek and Sandy Creek which is slightly above the guideline value for near neutral waters (pH >6.5), noting that there is no guideline value set for pH <6.5 more typical of these headwater streams. The slightly elevated aluminium concentrations are to be expected since aluminium (and most metals) are more soluble in waters of low pH. DO levels are variable and typically between 80 and 95% saturation. Time series plots of field parameters and selected dissolved metals for stream sampling sites relevant to this assessment are shown in Appendix 1.

Table 6. Baseline stream water chemistry (pre-Longwall 6 median values)

Median values (mg/L)	Wongawilli Creek (<2013)			Sandy Creek (<2010)			ANZECC (2000)[#] Freshwater 95%
	WWU4	**WCS1**	**Wongawilli Ck (FR6)**	**SCk Rockbar 5**	**SC10 Rockbar 3**	**SC10C Pool 1**	
Samples	*111*	*12*	*132*	*35*	*15*	*15*	
EC (µs/cm)	89	89	101	104	94	98	30-350[a]
pH (pH units)	**5.5**	**6.3**	**6.2**	**6.2**	**5.9**	**5.5**	6.5-7.5 [a]
DO (%)	93	**82.6**	92.5	n/a	n/a	n/a	90-110
Total Alk	<0.5	3	2	2	<0.5	<0.5	-
Cl	19	20	25	n/a	n/a	n/a	-
SO4	4	2	3	2	2	3	-
K	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-
Na	10	11	13	12	13	13	-
Ca	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-
Mg	<2	<2	<2	<2	<2	<2	-
Al	**0.06**	0.05	0.04		**0.12**	**0.12**	0.055[b]
Fe	0.08	0.20	0.22	0.17	0.18	0.25	-
Mn	0.09	0.07	0.04	0.043	0.035	0.046	1.9
Ni	0.006	0.0008	0.0005	<0.001	<0.001	<0.001	0.011
Si	1.73	2.04	1.745	1.46	1.17	1.35	-
Zn	0.03	**0.008**	0.006	<0.005	<0.005	<0.005	0.008
Fe (total)	0.13	0.95	0.5	n/a	0.27	0.41	-
Al (total)	0.08	0.085	0.07	n/a	0.17	0.16	-
Mn (total)	0.08	0.08	0.05	n/a	0.035	0.047	-
Total N	0.005	0.020	0.005	n/a	n/a	n/a	0.25 [a]
Total P	0.005	0.005	0.005	n/a	0.005	0.005	0.02 [a]

Guideline trigger vales for protection of 95% of species; (a) Default trigger levels for Upland river systems in south-east Australia. (b) Trigger for Al in water with pH >6.5.

Extraction of Longwalls 6, 7 and 8 in Area 3A resulted in localised effects on water quality in tributaries of Wongawilli Creek (WC17) and of Sandy Creek (SC10C). Those effects are summarised in Section 4.6.

3.2.3 Shallow groundwater

Swamp groundwater levels in the Dendrobium Mine area have been monitored since 2010, providing baseline data with which to assess the natural hydrological characteristics of swamps, and also the impacts of mine-related subsidence on swamp hydrology. Monitoring of shallow groundwater levels and soil moisture content in Coastal Upland Swamps is prescribed in the Area 3A SIMMCP (South32, 2020c).

Hydrographs for shallow piezometers located at swamps within 600 m of Longwall 19A are presented in Appendix 2. Hydrographs for other swamps overlying Dendrobium are included to illustrate typical swamp characteristics. Each hydrograph is plotted relative to ground elevation and the elevation of the piezometer base, longwall timing, rainfall, and the dates that previous longwalls pass under (or within 400 m of) a piezometer. Also plotted on the hydrographs in red is the groundwater level recession rate in mm/day.

Swamp hydrographs display a range of responses reflecting varying hydrological regimes at each swamp and at different locations within each swamp. At most locations, the shallow groundwater level rises sharply to within centimetres of the ground surface after a significant rainfall event (>75 mm in one day), particularly if the event is preceded by rainy days. The shape of the recession curve is characteristic of each swamp and location.

A review of shallow groundwater hydrographs for reference swamps indicates two main hydrological end-member types (HGEO, 2022):

1. Near-continuously saturated swamp sediments. Examples include Swamps 7, 22 and 25 (not located within the study area). Swamp sediments at these locations remain saturated during periods of prolonged drought. It is assumed that at these locations, groundwater levels within the swamp are sustained by discharge from adjacent and underlying sandstone substrate (groundwater-connected swamps).
2. Intermittently saturated swamp sediments. Examples include Swamps 33, 84, 85, 86 and 88. Swamp sediments at these locations saturate, typically to the ground surface, following large rainfall events and remain saturated for several weeks to months as shallow groundwater levels recede to below the base of the swamp. The duration of saturation and rate of recession vary between locations and likely depend on the characteristics of the swamp substrate, controlling rock-bar and contributions from adjacent or up-gradient perched sandstone aquifers. It is assumed that at these locations, the swamp sediments are likely perched above the water table in the sandstone substrate.

Near-continuously saturated swamps tend to be within deep valleys where adjacent ridges rise ≥ 50 m above the swamp level. Intermittently saturated swamp locations tend to reside in shallow valleys where the adjacent ridges rise ≤ 20 m above the swamp level (e.g. headwater swamps).

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 19A the most likely effects are:

1. **Altered drainage and flooding**. Mine subsidence can lead to changes in gradient within a watercourse which in turn may lead to a change in the likelihood of ponding, flooding and erosion.
2. **Flow diversions**. The development of fractures in a stream bed may result in diversion of flow from the stream channel to the sub-surface and a measurable reduction in stream flow at monitoring gauges. This effect has the potential to be long-lasting and possibly permanent.
3. **Groundwater drawdown and reduction in baseflow**. Where stream flow is partly sustained by the discharge of groundwater from adjacent aquifers (baseflow), groundwater drawdown or depressurisation due to mining can lead to a reduction in baseflow and additional cease to flow/pool dry days. This effect is likely to be long-lasting (i.e. decades), but not permanent.
4. **Altered surface water quality**. Fracturing of the stream substrate can result in the development of ferruginous springs (iron staining), alteration of water quality parameters and the mobilisation of trace metals which may in turn affect the health of aquatic ecosystems.
5. **Altered swamp hydrology**. Near-surface fracturing can result in a decline in shallow groundwater levels which may in turn affect soil moisture content, swamp vegetation and dependent ecosystems. Effects on swamp hydrology (water retention and groundwater drainage rates) can be long-lasting and possibly permanent. Potential effects on swamp vegetation will be described in the ecological assessment (Niche, 2020) accompanying this surface water assessment.

4.1 Mine subsidence

Most surface water and shallow groundwater impacts are associated with ground subsidence and near-surface fracturing. It is therefore relevant to review predictions of subsidence and surface cracking associated with the extraction of Longwall 19A by mine subsidence consultants MSEC (2022). 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 (2022) for further detail.

Table 7. Summary of predicted subsidence effects (from MSEC2022)

Location / feature	Predicted subsidence effects
Within longwall footprint	**Incremental movement**: Up to 2500 mm subsidence, 35 mm/m incremental tilt. **Total cumulative subsidence** above Longwall 19A as a result of Longwall 6 to 8, Longwall 19 and Longwall 19A is estimated at 3250 mm with 40 mm total tilt.
Wongawilli Creek	Wongawilli Creek is located outside the extents of Longwall 19A, at a minimum distance of 390 m. The maximum predicted total vertical subsidence along Wongawilli Creek is less than 20 mm; maximum 40 mm upsidence and 40 mm incremental valley closure.

Location / feature	Predicted subsidence effects
	Minor fracturing could occur along the creek within approximately 400 m of the proposed longwalls. The likelihood of significant fracturing resulting in surface water flow diversions at rockbars is considered low (may affect <10% of rockbars).
Sandy Creek and Sandy Creek waterfall	The maximum predicted incremental vertical subsidence, upsidence and closure for Sandy Creek, due to the mining of Longwall 19A, are all less than 5 mm. Therefore, it is unlikely that adverse impacts would occur along Sandy Creek due to the mining of Longwall 19A. It is unlikely that Sandy Creek Waterfall would experience adverse impacts due to the mining of Longwall 19A.
Tributaries	The upper reaches of WC14 directly overlie Longwall 19A and therefore will experience the maximum predicted subsidence effects. It is expected that fracturing of the bedrock (and flow diversions) would occur along the sections of the drainage lines that are located directly above the proposed Longwall 19A and Longwall 19. Fracturing can also occur outside the extents of the longwalls, with minor and isolated fracturing occurring at distances up to approximately 400 m.
Swamps	Den34 and Den148 are partially located above the proposed Longwall 19A and Den12, Den15b and Den148 are partially located above the existing LW7 and LW8. The maximum predicted total compressive strains for these swamps due to the valley-related effects are in the order of 10 mm/m to 20 mm/m. However, the valley-related effects for Den12 and Den15b occur predominately due to previously extracted Longwall 7 and Longwall 8, rather than the proposed Longwall 19A. It is likely, therefore, that fracturing would occur in the bedrock beneath these swamps, predominately in areas located above and adjacent to the mining area.

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 2022, IMC drilled 21 holes above nine 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 (HGEO, 2020, 2021a). The study concluded that mining-induced 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 and the proportion of high-angle fractures, decreases with height above the goaf, with anomalous fracturing within the BACS and within 120 m of 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.

Assessment of the groundwater conditions above extracted longwalls in Area 3A and Area 3B provides evidence that perched water tables continue to develop above extracted longwalls (HGEO, 2021a). The perched horizons observed at Dendrobium are most extensive in strata between the upper CVSS (BGSS to the east of Wongawilli Creek) and lower HBSS and above longwalls extracted three or more years prior. These observations are inconsistent with complete desaturation (draining) to the surface as predicted by Tammetta (2013). Rather, they imply that highly connected and free-draining fracturing extends to approximately 220 to 250 m above the goaf, above which positive and increasing pressure heads are common. For the purpose of numerical modelling of groundwater effects, Watershed (2022) assumed that the height above which positive pressure head is observed is conservatively approximated by the empirical model of Ditton & Merrick (2014) [the “A95” height].

The findings of the drilling investigation can be applied directly to Longwall 19A in Area 3A. It is expected that fracturing associated with Longwall 19A will extend to the surface over at least part of the longwall footprint, resulting in depressurisation of the HBSS and underlying strata; however perched aquifers may remain and/or re-establish above the BACS after several years. The Ditton and Merrick Geol-A95 height above Longwall 19A ranges between 211 and 231 m above the seam (approximately the base of the BACS; Figure 5).

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 (2022). The main conclusions in relation to the MSEC assessment of changes in stream-bed gradient are summarised in Table 8.

In summary, changes in stream gradients along Wongawilli Creek and Sandy Creek are expected to be very small in comparison to the natural gradients in the study area and no localised reversals in gradient are predicted. It is therefore considered unlikely that adverse changes in ponding or scouring will occur as a result of subsidence related tilt from Longwall 19A. Changes in gradient in the minor first order tributaries located above the longwall and development footprints are predicted to be <3 %, which is considerably less than the natural headwater gradients. There is potential for minor and localised increases in ponding and scouring in those drainage lines. However, those impacts are expected to be small in comparison with those which occur during natural flooding conditions (MSEC, 2022).

Table 8. Summary of predicted changes to stream gradient (from MSEC 2022)

Location / feature	Predicted subsidence effects
Wongawilli Creek	The predicted changes in grade due to the mining of Longwall 19A are considerably less than the average natural grade within the study area (0.3%). It is unlikely, therefore, that there would be adverse changes in the potential for ponding, flooding or scouring of the banks along the creek due to the mining-induced tilt.
Sandy Creek	Sandy Creek is not expected to experience measurable tilts, curvatures or strains. Therefore, there is unlikely to be a noticeable increase in ponding, flooding or scouring along the watercourse.
Tributaries	There are no predicted reversals of stream grade along drainage lines SC10, WC13(A) and WC14. There are slight reductions in grades along drainage lines WC13(A) and WC14, 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.
Swamps	Den12, Den15a, Den15b, Den34 and Den148 are located near the bases of drainage lines WC17, SC10, SC10C, WC13 and WC14, respectively. There are no predicted substantial reductions or reversals of stream grade along these drainage lines nor within the extents of the swamps. Similarly, there are no substantial changes for the other swamps within the Study Area. There are small reductions in grades along drainage lines WC13(C) and WC14, upstream of the chain pillars and the edges of the mining area. There is potential for minor and localised increased ponding in these locations, due to the mining-induced tilt, and therefore upstream of Den34 and Den148.

4.4 Watercourse 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.

Surface fracturing, including fracturing of streambeds, has been observed at distances up to 400 m from previously extracted longwalls in the Southern Coalfield. Therefore it is expected that flow diversions are possible within this distance of the proposed Longwall. Changes to down gradient stream-flow characteristics is assessed following completion of each longwall using three different methods, in addition to the exiting TARP methodology. Figure 7 summarises the results of the most recent End of Panel stream-flow assessment (HGEO, 2022).

In summary, significant changes in stream flow are discernible in first and second-order watercourses that flow over the goaf footprint (e.g. upper reaches of Donalds Castle Creek, DC13; tributaries of Wongawilli Creek, WC21 and WC15, and tributaries to Lake Avon: LA2, LA3 and LA4). However, at gauging stations ≥1.5 km downstream of extracted longwalls (DCU and WWL), there are no discernible impacts to flow beyond natural variability and given the uncertainty in the assessment methods.

Site	Watercourse	Catchment Mined under?	Position of sub-catchment relative to mining	A) Low flow Q%ile outside Reference Site Q%ile	B) Change in cease-to-flow frequency (beyond natural)	C) Change in median flow, Q50 (beyond natural)	Comment
DC13S1	DC13	Yes	Above LWs	●●●Level 3	●●●Level 2	●●●Level 3	Similar to LW14-16.
DCS2	Donalds Castle Creek	Yes	Above LWs	●●●Level 3	●●●Level 3	●●●Level 3	Similar to LW14-16.
DCU	Donalds Castle Creek	Yes	Downstream	●●●Not triggered	●●●Level 1	●●●Not triggered	Similar to LW14-16. Findings supported by rainfall-runoff modelling.
WC21S1	WC21	Yes	Above LWs	●●●Level 3	●●●Level 2	●●●Level 3	Similar to LW14-16.
WC15S1	WC15	Yes	Above LWs	●●●Level 3	●●●Level 2	●●●Level 3	Similar to LW15-16. * Changes to low flow accuracy means that Method B assessment assess low flows, not true 'cease-to-flow'.
WC12S1	WC12	Yes	Above LWs	●●●Not triggered	●●●Not triggered	●●●Not triggered	Second panel under catchment. No discernible effect. Findings supported by rainfall-runoff modelling.
WWL	Wongawilli Creek	Yes	Downstream	●●●Not triggered	●●●Not triggered	●●●Not triggered	Similar to LW14-16. Findings supported by rainfall-runoff modelling.
LA4S1	LA4	Yes	Above LWs	●●●Level 1	●●●Level 2	●●●Level 3	Similar to LW14-16. * Changes to low flow accuracy means that Method B assessment assess low flows, not true 'cease-to-flow'.
LA3S1	LA3	Yes	Above LWs	●●●Level 3	●●●Level 3	●●●Level 3	Similar to LW16.
LA2S1	LA2	Yes	Above LWs	●●●Not triggered	●●●Level 1	●●●Level 3	LW16-17 mined under upper part of watercourse. Increase in cease-to-flow frequency.
NDS1	ND1	Yes	Headwater	●●● Not triggered	●●● Not triggered	●●● Not triggered	LW17 is first panel under this sub-catchment. No discernible effects. Findings supported by rainfall-runoff modelling.

●●●●● = result of previous longwalls (LW14-16)

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Figure 7. Summary of stream flow impacts at Area 3B (Watershed HydroGeo 2019)

End of panel assessments for Longwalls 6, 7 and 8 (Ecoengineers, 2013, 2012, 2011) concluded on the basis of data available at the time that there were no significant impacts to stream flow at the downstream gauge on Sandy Creek (SCL). Further review of pool water levels and water chemistry (Appendix 1) indicate effects in upstream watercourses that are likely related to subsidence in Area 3A, including:

- A decline in pool water levels in tributary SC10C which flows across the footprint of Longwall 8 (e.g. Pools 0, 3, 4, 5, 7, 8, 10, 11).
- Evidence for a decline in pool levels in WC17 during extraction of Longwalls 7 and/or 8 (e.g. S12 Pools 9, 10, 11, 12).
- There is no clear evidence for changes in flow or pool levels in Sandy Creek as a result of previous mining in Area 3A.

A decline in water level was noted in Pool 43a on Wongawilli Creek, starting around 2012 (LW6) and continuing to 2019 (HGEO, 2019). An assessment of the pool water levels by Watershed HydroGeo (2018) concluded that the decline in pool level was likely due to a combination of baseflow loss due to mining-related depressurisation of the sandstone substrate and drought conditions (2017 - 2019). The rate of baseflow loss is within the range predicted from groundwater modelling (HydroSimulations, 2016). The most recent End of Panel (Longwall 17) assessment noted that both groundwater piezometric levels and pool water levels have recovered in response to higher-than-average rainfall in 2020-2022.

Based on the subsidence assessment by MSEC (2022), summarised in Table 7, and previous experience at Dendrobium as discussed above, the following effects are expected as a result of Longwall 19A extraction:

- Wongawilli Creek: Fracturing of the stream bed and rockbars is possible within 400 m of Longwall 19A with the likelihood of surface water diversions estimated at 10 %. The cumulative effects of strata depressurisation associated with Longwall 19A and previous longwalls may affect baseflow and water levels in pools adjacent to Area 3A. Those effects would be most noticeable during periods of low flow and may not result in detectable losses at downstream flow gauges (WWL).
- Longwall 19A does not intersect any second or third-order watercourses. Fracturing and flow-diversion is possible in first and second-order tributaries WC14, WC13, being within 400 m of Longwall 19A, noting that the upper reaches of WC14 were directly mined under by Longwall 19.
- Sandy Creek tributaries: Fracturing and diversions of flow are possible on SC10 and first-order tributaries SC10A and SC10B where those tributaries pass within 400 m of the longwall. Noting that SC10B is within 400 m of Longwall 19. Those effects would be most noticeable during periods of low flow and may not result in detectable losses at downstream flow gauges (SC10S1, SCL2), nor at Sandy Creek Waterfall.

4.4.1 Sandy Creek Waterfall

Sandy Creek Waterfall is located 900 m north-east of the commencing end of Longwall 19A, where Sandy Creek flows into Cordeaux Reservoir. The waterfall is approximately 20 m high, 75 m wide with an overhang of up to 21 m. Condition 1, Schedule 3 of the Dendrobium Development Consent requires that mining does not impact the structural integrity or result on more than negligible water diversions at the waterfall. The waterfall became the focus of detailed assessment during the extraction of Longwalls 6 to 8 in Area 3A between 2010 and 2013. Longwall 6 was completed at 365 m from the waterfall in April 2011; subsequent Longwalls 7 and 8 were completed at 410 m and 490 m from the waterfall. As a result of effective planning, monitoring and assessment Longwalls 6 to 8 were successfully extracted with no visible changes to the waterfall (Walsh *et al.*, 2014). End of panel assessments found no significant impact to stream flow at the downstream gauge on Sandy Creek (SCL) following completions of Longwalls 6, 7 or 8 (Ecoengineers, 2013, 2012, 2011).

The mining subsidence assessment by MSEC (2022) concluded that "*at [a distance of 1400m from Longwall 19A], the predicted incremental vertical subsidence, upsidence and closure for Sandy Creek Waterfall are negligible"* and that *"it is unlikely that Sandy Creek Waterfall would experience adverse impacts due to the mining of the future".*

4.5 Surface water loss due to depressurisation

4.5.1 Stream baseflow

Where stream flow is partly sustained by the discharge of groundwater from adjacent aquifers (baseflow), groundwater drawdown or depressurisation due to mining can lead to a reduction in the baseflow component. The potential reduction in groundwater levels and baseflow in watercourses was assessed using a regional numerical groundwater model by Watershed (2022). A summary of the estimated incremental loss of baseflow due to Longwall 19A is shown in Table 9 and the reader is referred to the groundwater assessment report for further details and impact scenarios. For impact forecast purposes, “short-term” is up to 6 years post-Longwall 19A (2023-2028) and “long-term” is >40 years after Longwall 19A (2060-2200). The ”mean” estimate is the mean loss over the assessment period (8 years for the short-term and 140 years for the long-term. Also listed is the maximum loss which is the highest loss in modelled sub-periods within those ranges.

With reference to the mean loss estimates in Table 9, it is apparent that predicted loses in baseflow due to groundwater depressurisation from Longwall 19A alone (incremental effect) is relatively minor, equating to of 0.21% or less of mean daily flow in downstream gauges. In the short-term, depressurisation due to the whole mine, including Longwall 19A (cumulative) is forecast to result in a loss in baseflow relative to the baseline mean of 6.9% or less at downstream gauges.

In the long-term, cumulative drawdown may result in a decrease in flow at the downstream gauges of Sandy Creek and tributary SC10 of 1% or less of mean flow. In Lower Wongawilli Creek, mean flow is predicted to return to pre-mining levels. Groundwater model predictions suggest that long term flow may *increase* due to increases in strata permeability beyond the longwall footprint and associated reductions in evapotranspiration losses. However, as a conservative measure the long-term losses are capped at zero (where flow increases are predicted).

Decreases in baseflow will be most apparent during periods of low rainfall and low-flow in the catchments and may manifest as an increase in no-flow days compared with baseline conditions. An estimate of potential increase in no-flow days is provided in the next section (0).

Table 9. Estimated cumulative and incremental change in surface water flow

Watercourse:	Wongawilli Creek			Sandy Creek			
Statistic:	**WC13**	**WC14**	**WWL**	**SC10A**	**SC10B**	**SC10**	**SCL**
Predicted incremental effects (Longwall 19A only; ML/day change in baseflow)							
Mean flow	NA	NA	**15.5**	NA	NA	**8.1**	**5.7**
Short-term mean	-0.010	-0.003	-0.012	-0.007	-0.002	-0.012	-0.012
Short term (% of mean)			**-0.08%**			**-0.15%**	**-0.21%**
Short term max	-0.014	-0.003	-0.018	-0.010	-0.004	-0.018	-0.018
Long term mean	0.000	-0.001	-0.010	0.000	-0.007	-0.009	-0.008
Long term (% of mean)			**-0.06%**			**-0.11%**	**-0.14%**
Long term max	0.000	-0.002	-0.010	-0.004	-0.009	-0.029	-0.029
Predicted cumulative effects (Whole mine including Longwall 19A; ML/day change in baseflow)							
Short-term mean	-0.013	-0.071	-0.900	-0.011	-0.038	-0.292	-0.393
Short term (% of mean)			**-5.8%**			**-3.6%**	**-6.9%**
Short term max	-0.021	-0.092	-1.337	-0.014	-0.048	-0.363	-0.469

Watercourse:	Wongawilli Creek			Sandy Creek			
Statistic:	**WC13**	**WC14**	**WWL**	**SC10A**	**SC10B**	**SC10**	**SCL**
Predicted incremental effects (Longwall 19A only; ML/day change in baseflow)							
Long term mean	0.000	-0.000*	0.000*	0.000	-0.020	-0.062	-0.058
Long term (% of mean)			**-0.0%**			**-0.8%**	**-1.0%**
Long term max	0.000	-0.023	-0.377	-0.006	-0.026	-0.128	-0.145

Note * At sites where the groundwater model predicts an *increase* in flow compared with the baseline, those predicted "gains" are capped at zero.

4.5.2 Predicted changes in stream baseflow and flow characteristics

A reduction in stream baseflow due to groundwater depressurisation will be most noticeable during low-flow conditions when baseflow (groundwater discharge) dominates the total stream flow. Baseflow reduction would manifest as an increase in low-flow (and no-flow) days during prolonged dry periods. The number of no-flow days per year is an important metric in relation to predicted impacts on aquatic ecosystems and other fauna that rely on permanent or semi-permanent pools.

The predicted effects of baseflow depletion on stream flow characteristics are estimated using flow duration curves, similar to that shown in Figure 6. Model predicted reductions in baseflow are applied to baseline flows for gauged watercourses within, and down-gradient of, the study area. The modified duration curves are shown in Figure 8 to Figure 10; forecasts of potential change in days of no-flow in the watercourse (where no-low is taken to be flow less than 0.01 ML/day) are listed in Table 10.

Effects on flows at WWL have not yet been identified in the EoP Reports (using comparison against AWBM rainfall-runoff modelling) or in more recent analysis using comparison against reference gauge records (HGEO, 2022; 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.

Table 10. Predicted effects on stream flow characteristics

No-flow days per year	Wongawilli Creek WWL	Sandy Creek SCL	Sandy Creek SC10S1
Baseline	**44**	**57**	**39**
Incremental Short term	47 (+3)	60 (+3)	42 (+3
Incremental Long term	46 (+2)	59 (+2)	41 (+2)
Cumulative Short term	97 (+53)	120 (+82)	121 (+63)
Cumulative Long term	44 (+0)	72 (+17)	56 (+15)

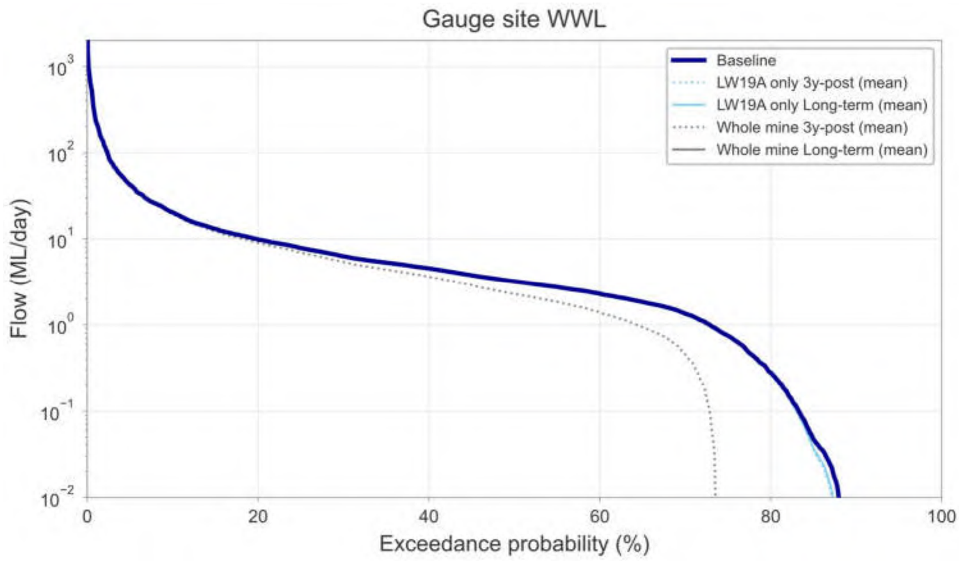

Figure 8. Baseline and forecast flow duration curve for WWL on Wongawilli Creek

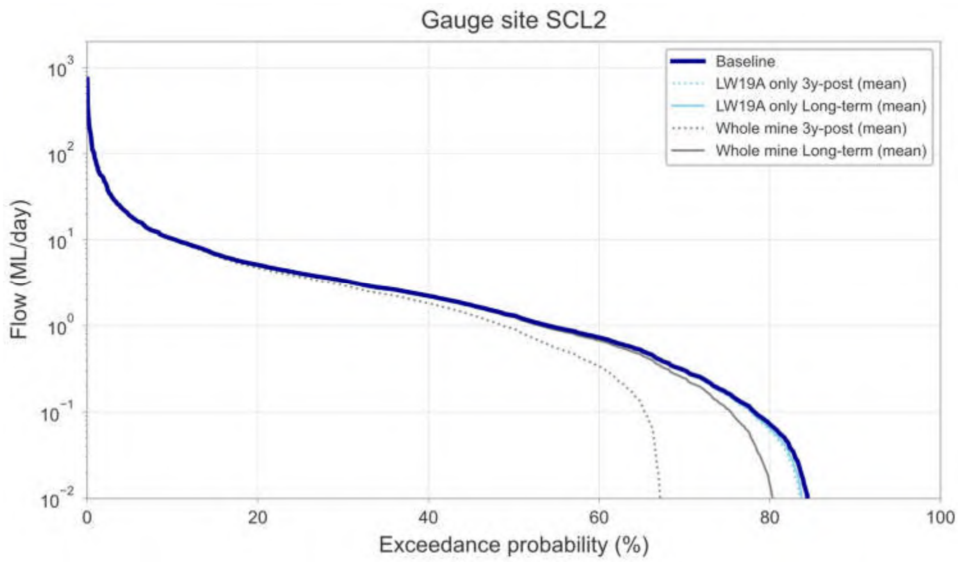

Figure 9. Baseline and forecast flow duration curve for SCL on Sandy Creek

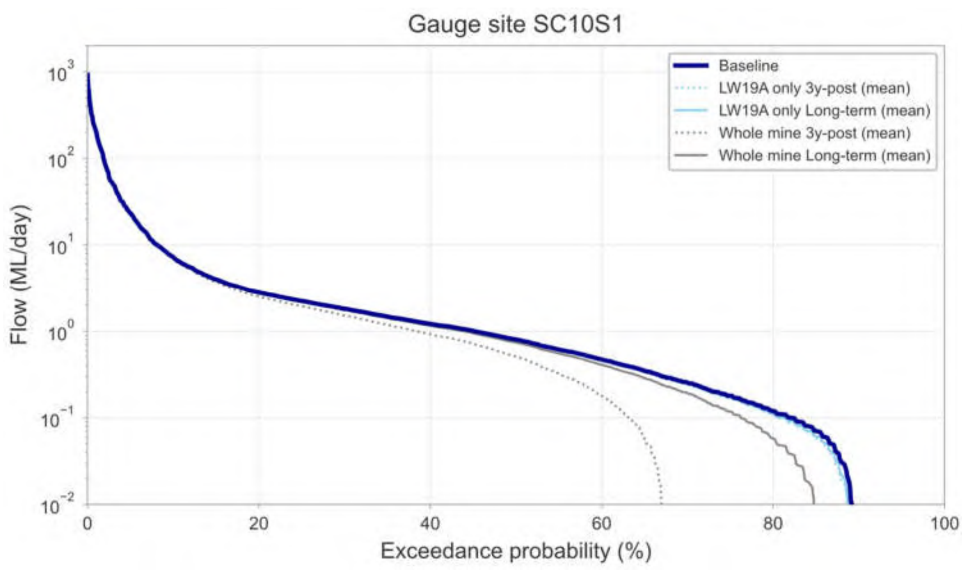

Figure 10. Baseline and forecast flow duration curve for SC10CS1 on tributary SC10

4.5.3 Leakage from reservoirs

Potential losses from storage reservoirs as a result of groundwater depressurisation due to mining was assessed by Watershed (2022) using a numerical groundwater model. The modelling includes scenarios in which the permeability of geological strata adjacent to mining areas is increased 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 19A are shown in Table 11.

The estimated incremental leakage losses from both reservoirs as a result of extraction of Longwall 19A is estimated to be negligible, or effectively nil. This is due to the distance of Longwall 19A from both reservoirs and the effects of previously extracted longwalls on the intervening strata.

Table 11. Estimated leakage from reservoirs (Watershed 2022)

Reservoir	Whole mine cumulative loss (ML/day)	Incremental loss due to Longwall 19A (ML/day)
Lake Avon	0.09 – 0.45	Negligible
Lake Cordeaux	0.12 – 0.30	Negligible

4.6 Stream water quality

Longwall subsidence can result in fracturing of streambeds and this fracturing can lead to changes in stream water quality due to the following processes:

- Diversion of surface flows through shallow fractures resulting from valley closure and the unconfined nature of near-surface strata (to ~10 to 15 m depth);
- Oxidation and dissolution of minerals in the freshly fractured bedrock (notably marcasite [FeS_2], ankerite [$Ca(Mg,Fe^{2+},Mn)(CO_3)_2$] and siderite [$Fe_2$+$CO_3$]);
- Leaching of ions from the bedrock strata present within the surface fracturing zone; and

- Enhanced drainage and discharge of groundwater (with higher EC and dissolved iron and lower DO) to creeks via subsidence induced fractures.

Oxidation of Fe^{2+} in sulphide and carbonate minerals can result in a decrease in pH and release of Fe, Mn and Mg into solution. This can manifest as ferruginous springs, iron staining of stream beds and rock faces, and localised accumulation of ferruginous sediment. The release of hydrogen ions (decrease in pH) may be offset or buffered by pH increases caused by CO_2 outgassing from turbulent stream sections and by ankerite dissolution.

Watercourses within the Longwall 19A study area have been affected by subsidence associated with previous mining in Areas 3A and 3B. Impacts to water quality from previous mining are summarised in Table 12 (reproduced from the most recent End of Panel report).

Table 12. Previous impacts to steam water quality

Catchment	Field parameters (EC, pH and DO)	Dissolved metals
Wongawilli Creek	Downstream (WC_FR6): Baseline median EC = 99 µS/cm, pH = 6.0; DO = 92.8%. No adverse trends during reporting period compared with upstream control (WWU1). **Iron-staining** from Pool50 downstream to Rockbar12 in August 2021 (HGEO, 2021b) **WC_FR6 TARP: None in review period**	Downstream (WC_FR6): Baseline median Fe = 0.28, Mn = 0.04, Al = 0.04, Zn = 0.004 mg/L WC_FR6: No adverse trends WC_Pool38,49: Increasing trend in Fe, Mn in 2021 (Coincident with iron-staining)
Wongawilli Creek tributaries	WC7: No adverse trends WC12: No adverse trends WC15: No adverse trends WC21: Increasing trend in EC and increase in pH at Pool 5 after Longwall 10. Fracturing / Loss of flow.	WC7: No adverse trends WC12: No adverse trends WC15: Increasing Zn trend in Pools 2 and 9 WC21_Pool5: Elevated Fe and Mn in mid-2021; declined in late 2021; increasing sulfate from 2020.
Donalds Castle Creek	Downstream (DCC_FR6): Baseline median EC = 116 µS/cm, pH = 5.5; DO = 89.1%. Decline in EC and pH and decrease in DO in 2020-2021; No significant trends further downstream (at DCL3). Upstream tributary sites show decline in pH to ~4.5 after Longwall 13 (DC Pools 16, 19, 20, 32, 34) **DCC_FR6 TARP: None in review period**	DCC_FR6: Increase in Sulfate, Zn, Al and Mn after Longwall 14; Trends not evident further downstream at DCL3. Upstream sites: DC13_Pool2B and DC_Pool22; Transient increases in Fe, Mn, Al, Zn after Longwall 13; Declined to near baseline levels during 2020-2021.
Lake Avon tributaries	Lake Avon (LA5_S2): No adverse trends. LA4: Fracturing / loss of flow after Longwall 13; Increase in EC; decrease in pH and DO when flow returned in 2020-2021. LA2: Upper reaches mined under by Longwall 17 resulting in loss of flow; no adverse trends, although sampling sparse in 2021 due to low water levels. **LA4_S1 TARP: Level 3 for EC and pH** (HGEO, 2022)	Lake Avon: Slight increase in Fe, Mn, Al and Zn associated with 2017-2019 drought. Declining trends in 2021. LA4: Increase in Fe, Mn, Al, Zn and Si when flow returned in 2020-2021. LA2: No adverse trends, although sampling sparse in 2021 due to low water levels.
Avon River	No adverse trends in EC, pH or DO. EC declined in 2020-2021 following 2017-2019 drought.	No significant adverse trends.
Lake Cordeaux tributaries	Lake Cordeaux (SANDY CREEK ARM): No adverse trends **Lake Avon (SC Arm) TARP: None in review period**	Small spike in concentrations of Fe and Mn associated with 2017-2019 drought. No other adverse trends.
Sandy Creek	SCk_Rockbar5: Baseline median EC = 88 µS/cm, pH = 5.2; DO = 81.4%. Slight increase in EC from 2017; no other adverse trends.	SCk_Rockbar5: Small increase in Fe, Mn from 2020; small increase in Zn from 2016.

	SC10: Increase in EC from 2017; increase in pH to ~6.5 from 2020. SC10C: Increase in EC (to ~260 µS/cm), decrease in pH (to ~3.8) and DO in Pool 1 after Longwall 8 mined under tributary. pH returned to ~6.2 from 2019. EC declining. **SCk_Rockbar5 TARP: None in review period**	SC10_Rockbr3: Small increase in Fe, Mn from 2019; small increase in Zn from 2016. SC10C_Pool1: Increase in Fe, Mn, Al, Zn, Si and sulfate following Longwall 8. Declining trends since 2020.
Cordeaux River	No Adverse trends	CR_S1 and CR_S2: Slight increase in Fe, Mn, and Al from 2020.

In summary, anomalous water quality effects are noted in streams that have been directly mined under by previous longwalls (e.g. WC21, SC10C, LA4, DCC). Those effects include transient or persistent increases in EC, increases (or decreases) in pH and increases in dissolved metal concentrations such as Fe, Mn, Al and Zn. Iron staining in creek beds is commonly associated with watercourses that have been directly mined beneath or are within the mining area of influence. Over the last two years, new or recurrent iron staining has been noted on Wongawilli Creek, WC21, LA5 and SC10C. However, these reactivations may be, at least in part, due to very high rainfall over this period which resulted re-saturation and discharge from near-surface fracture networks. Time series plots of field parameters and selected dissolved metals for stream sampling sites relevant to this assessment are shown in Appendix 1.

Based on previous observations, it is expected that water quality influence due to mining would be minor in stream reaches within subsidence affected areas (SC10 and SC10B; upper reaches of WC14, WC13). Local discolouration of streambeds and rock faces by iron hydroxide precipitation can continue for a number of years but is a temporary impact. Water quality effects on stored waters of the reservoirs are expected to be negligible and undetectable.

4.7 Swamp hydrology

Swamps that have been undermined commonly display hydrological changes shortly following the passage of the longwall beneath the monitoring site. Hydrographs of piezometers at affected locations may show one or more of the following (see Appendix 2):

- A decrease in the average shallow groundwater elevation;
- A decrease in the duration of saturation of the swamp sediments following a significant rainfall event; or
- A change in the shape of saturation peak and recession curves (and recession rate) in response to significant rainfall events.

A recent assessment of shallow groundwater impacts due to mining at Dendrobium was carried out by (Watershed HydroGeo, 2021; 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; SRK, 2020), and no hydrological impacts at swamp piezometers located near mapped lineaments that are greater than 60 m from the goaf (Watershed HydroGeo, 2021;

Watershed Hydrogeo, 2019b). However, it is prudent to consider the possibility of distant impacts where swamps overlie mapped lineaments that intersect the mine footprint.

The hydrological changes are most likely due to the development of surface fracturing and bedding plane openings in the sandstone substrate of the swamp and/or a rockbar at the swamp outlet. The formation of fractures in the substrate may change the swamp from a perched system to a connected system. The impact on the swamp will be dependent on the head difference between the swamp sediments and the sandstone substrate. Where the hydraulic gradient is downwards (into the sandstone, which is common) then the fracturing will lead to greater flows of water from the swamp and a decline in average swamp groundwater levels. It is not yet known whether the hydrological characteristics recover to some degree as fractures are filled with fine sediments and on-going monitoring is required to assess longer-term impacts.

Drying of upland swamps can result in further impacts, including:

- reduction of soil moisture levels and loss of cohesiveness of the swamp sediments.
- decline of groundwater-dependent plant species and consequent changes in vegetation structure.
- decline of groundwater-dependent fauna including macroinvertebrates and stygofauna.
- oxidation of peaty sediments resulting in increased hydrophobicity, lower water holding capacity, potential changes in nutrient cycling, and changes in water quality.
- increased risk of channelization and gully erosion.
- reduced resilience to bushfires.

The locations of mapped swamp vegetation communities relative to the planned longwall is shown in Figure 2. Swamps located within 600 m of the planned longwall is listed in Table 13, with a qualitative assessment of the likelihood that the shallow groundwater regime will be affected by subsidence related ground movements associated with mining (as described above). The likelihood is based on observations at swamps in Area 3B during and after longwall extraction (HGEO, 2021c; Watershed HydroGeo, 2021) and predictions of subsidence related to longwall extraction and other ground movement related to valley closure (MSEC, 2022).

Table 13. Summary of predicted impacts to Upland Swamps

<table>
<tr><th rowspan="2">Swamp</th><th rowspan="2">Veg. community</th><th rowspan="2">Total swamp area (Ha)</th><th rowspan="2">Area (Ha) within 60 m of longwall</th><th colspan="2">Predicted vertical ground movement (mm; MSEC, 2020)</th><th rowspan="2">Likelihood of shallow groundwater effects</th></tr>
<tr><th>Subsidence</th><th>Tilt (mm/m)</th></tr>
<tr><td>Den12</td><td>Banksia Thicket</td><td>5.37</td><td></td><td><20</td><td><0.5</td><td>Previously mined under by Longwalls 7 and 8. Further effects unlikely.</td></tr>
<tr><td rowspan="3">Den15a</td><td>Banksia Thicket</td><td>8.57</td><td>0.65 (7.6%)</td><td rowspan="3">30</td><td rowspan="3"><0.5</td><td rowspan="3">Previously affected by Longwall 19. Effects from Longwall 19A</td></tr>
<tr><td>Cyperoid Heath</td><td>4.40</td><td><0.01 (<1%)</td></tr>
<tr><td>Restioid Heath</td><td>2.49</td><td></td></tr>
</table>

Swamp	Veg. community	Total swamp area (Ha)	Area (Ha) within 60 m of longwall	Predicted vertical ground movement (mm; MSEC, 2020)		Likelihood of shallow groundwater effects
				Subsidence	Tilt (mm/m)	
	Tea-Tree Thicket	2.56				possible where < 400 m from longwall
Den15b	Unvalidated	0.10		30	<0.5	Previously mined under by Longwalls 7 and 8. Further effects unlikely.
	Banksia Thicket	3.25				
	Cyperoid Heath	0.57				
	Tea-Tree Thicket	1.04				
Den 15c	Banksia Thicket	0.65	0.22 (34%)	1300	25	Previously affected by Longwall 19. Effects from 19A Likely
Den34	Mallee Heath	1.90	1.02 (53.6%)	325	11	Likely effects in area of Mallee Heath < 60 m from longwall. Possible elsewhere.
	Banksia Thicket	0.40				
	Tea-Tree Thicket	0.28				
Den96	Banksia Thicket	0.17		<20	<0.5	Unlikely
Den148	Banksia Thicket	0.86	0.49 (56.8%)	1650	16	Previously mined under by Longwall 19. Likely further effects within 60 m of Longwall 19A

There is approximately 21.7 Ha of mapped Upland Swamp vegetation within the Study Area. Of that area, approximately 2.2 Ha (~10%) overlies or is within 60 m of Longwall 19A. Areas of Swamps 12, 15a, 15b, 15c and 148 were previously mined under (or within 60 m of) Longwalls 7, 8 and 19 and are therefore likely to have been affected by subsidence associated with those longwalls. Further shallow groundwater effects are likely within areas of Swamp 15c and 148 that are within 60 m of Longwall 19A, and possible in areas of Swamp 15a that are within 400 m of the longwall. Shallow groundwater effects are likely in Swamp 34 where it is within 60 m of Longwall 19A. 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, 2022).

The IEPMC (2019b) review concluded that monitoring of vegetation change in upland swamps has not, to date, provided a clear and timely measure of possible changes in ecosystem functionality. This is likely due to the decadal timescales of ecosystem response and the difficulty in distinguishing between mining-induced variations and natural variations (for example to drought and climate change). Further discussion of swamp ecology and ecosystem functionality is provided in Niche (2020).

5. PERFORMANCE MEASURES

The performance measures and monitoring of surface water and shallow groundwater in relation to mining at Area 3A are defined in the Longwall 19 WIMMCPP (South32, 2020b). The Trigger Action Response Plan (Appendix A of the SMP) specifies trigger levels and a three-tiered management response for assessing and responding to impacts from mining. The triggers are based on environmental data collected before mining commenced (baseline period).

Stream monitoring sites reviewed as part of this assessment are included in the Area 3A SMP, including sites upstream and downstream of the proposed Longwall 19A. Therefore, the existing TARPs are considered generally applicable to future monitoring and management of mining effects related to Longwall 19A immediately adjacent and down-stream of Area 3A. The existing TARPs for surface water flow, water chemistry and shallow groundwater is reproduced in Appendix 4. Specific recommendations for revision of the monitoring program and trigger levels are given below.

5.1 Surface water monitoring

Watercourses within the study area are (or have been) monitored at multiple sites as part of the previous SMP for Area 3A and the current SMP for Area 3B. The existing monitoring network is considered adequate for the assessment of impacts related to Longwall 19A. Monitoring at existing sites should continue as specified in the Longwall 19 SMP.

5.2 Shallow groundwater

Because swamps are groundwater dependent features, piezometric levels within the swamps, and in the substrate to the swamps, provide a key early indicator of change to the dependent ecosystems (IEPMC, 2019b). Piezometric levels therefore form an important component of TARPs for the management of impacts to upland swamps.

Five of the seven swamps located within the study area have active shallow groundwater monitoring sites. Swamp 96 is currently not monitored; however, at 440 m from Longwall it is considered unlikely that shallow groundwater will be impacted. Swamp 15b is the largest area of Upland swamp vegetation within the study area. There are six active shallow groundwater monitoring sites within the swamp, which are well distributed along its length and amongst mapped vegetation communities. The existing monitoring sites are considered adequate for the assessment of impacts from Longwall 19A.

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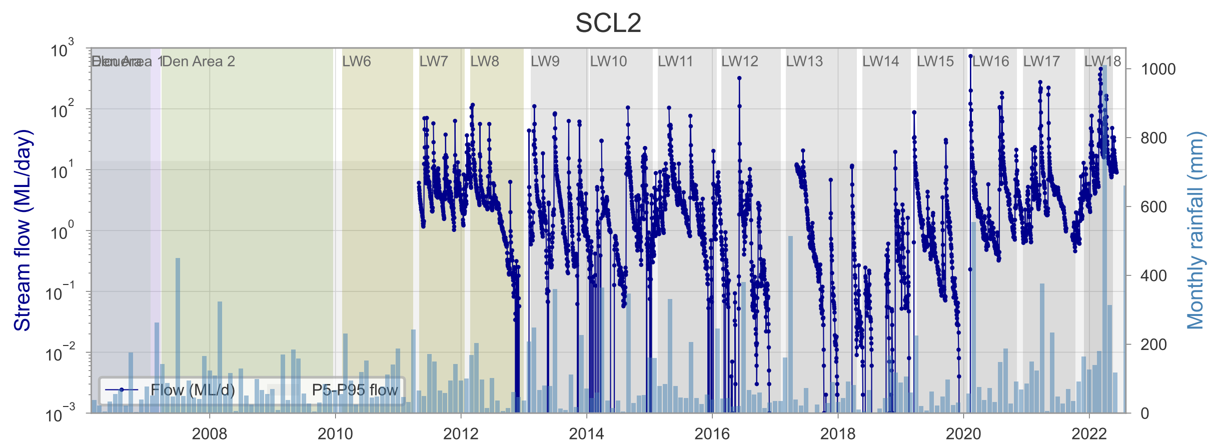
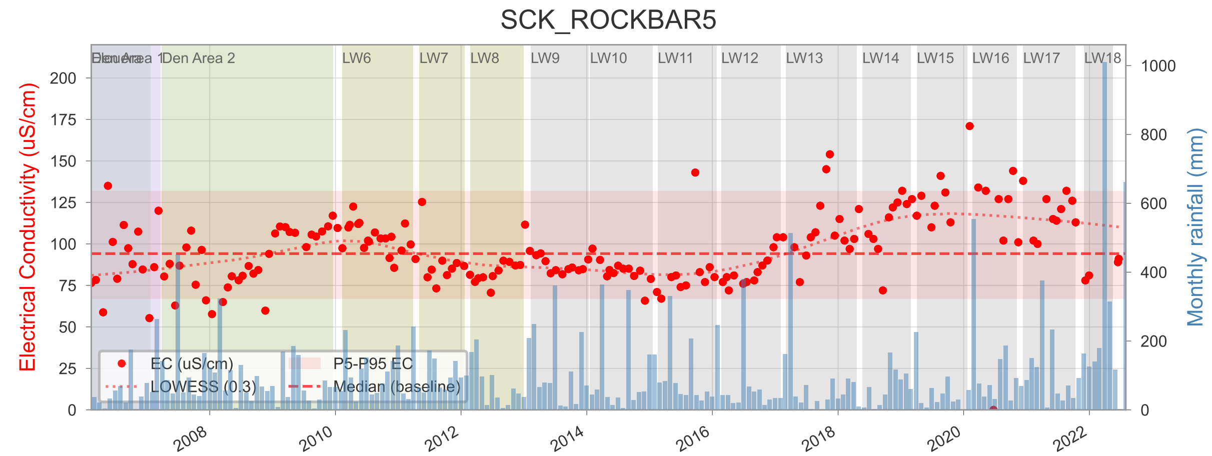
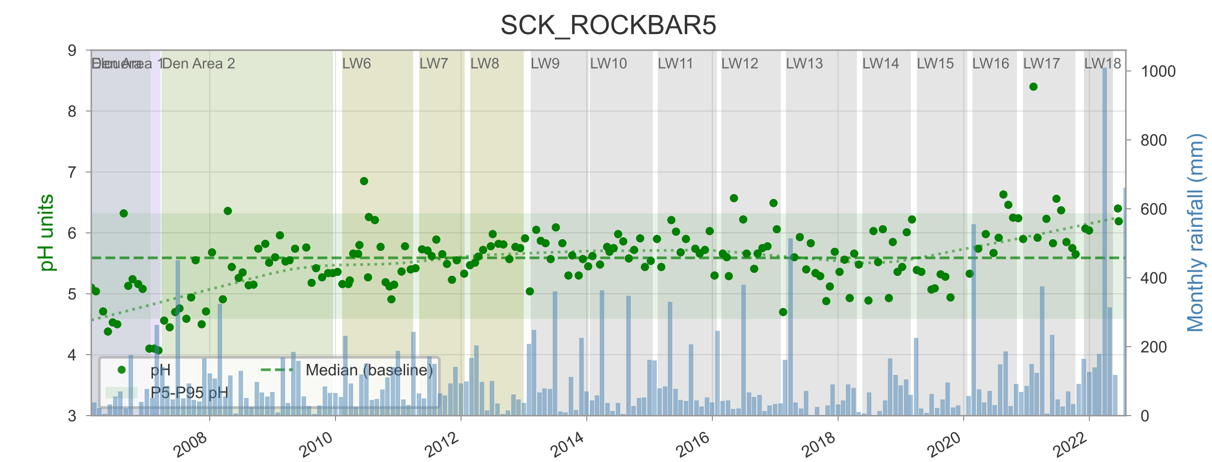
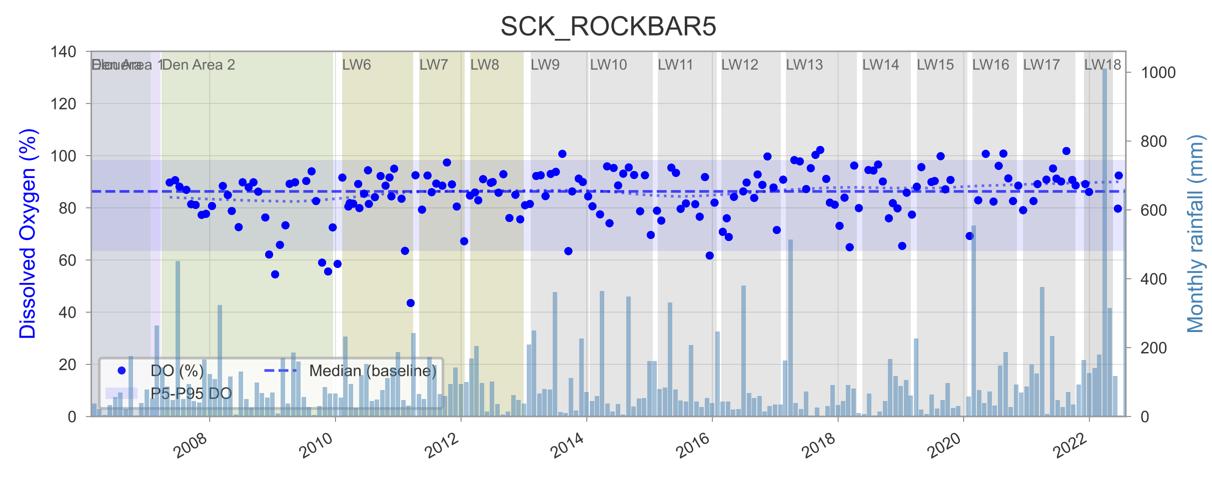
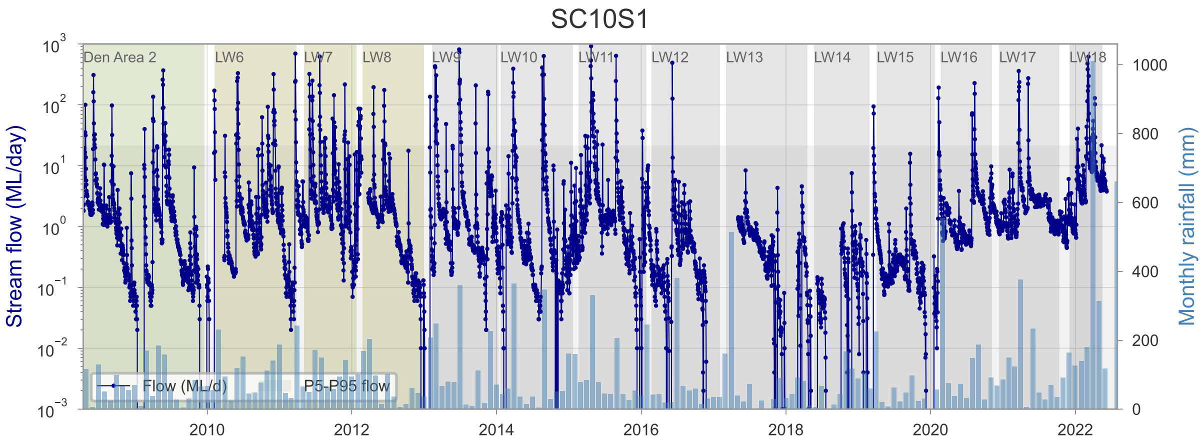
APPENDIX 1 – Surface water chemistry time-series

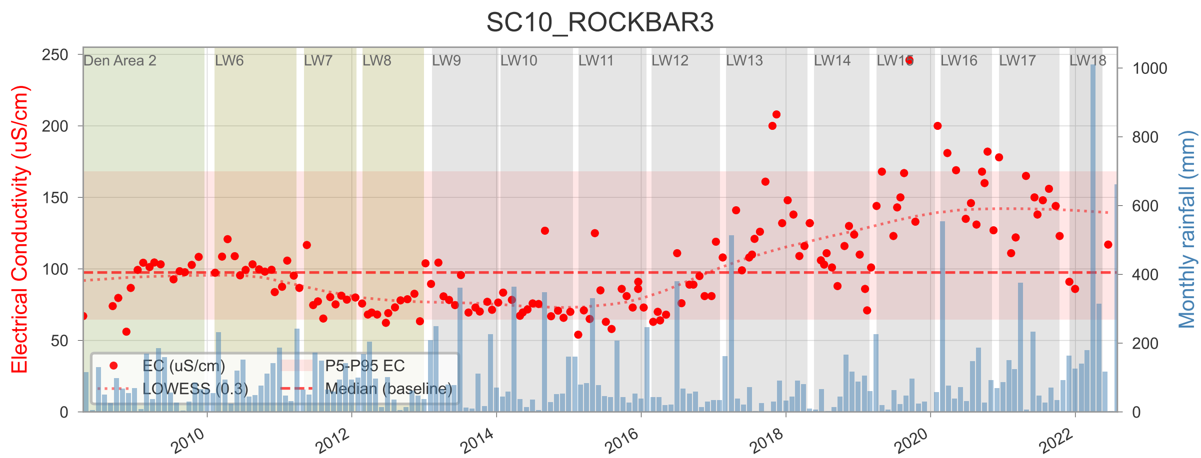

SCL2
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Stream flow (ML/day)
Monthly rainfall (mm)
Flow (ML/d)
P5-P95 flow

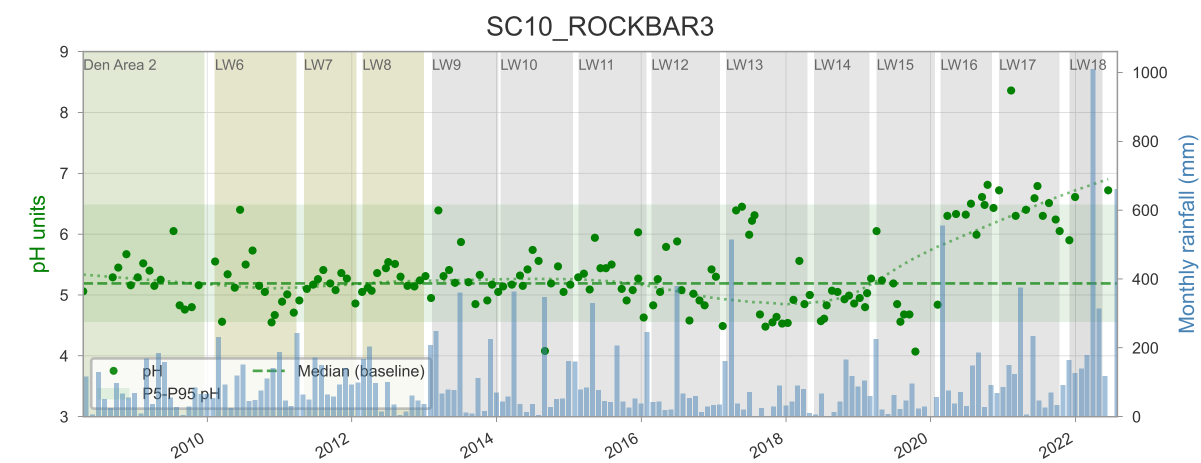

SCK_ROCKBAR5
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
P5-P95 EC
LOWESS (0.3)
Median (baseline)

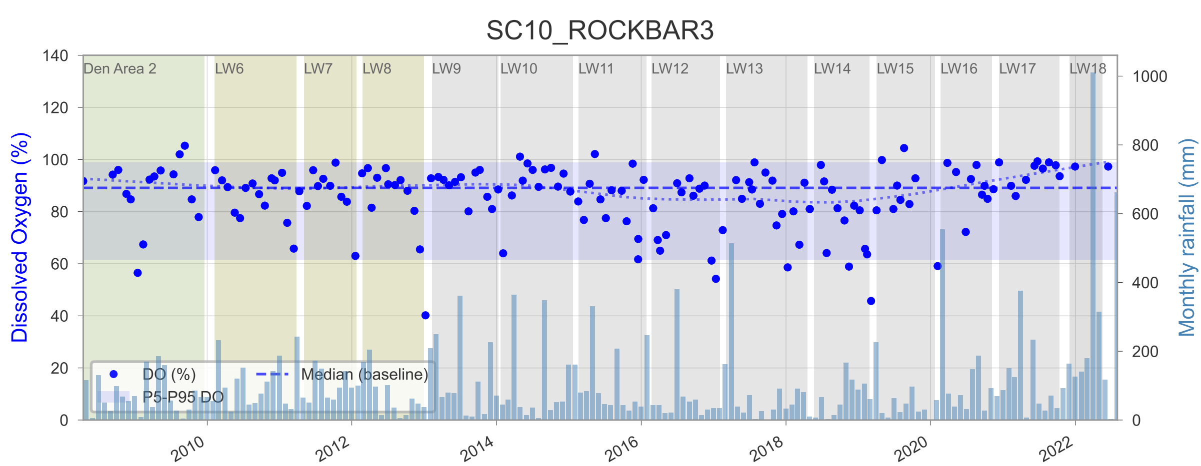

SCK_ROCKBAR5
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
pH units
Monthly rainfall (mm)
pH
Median (baseline)
P5-P95 pH

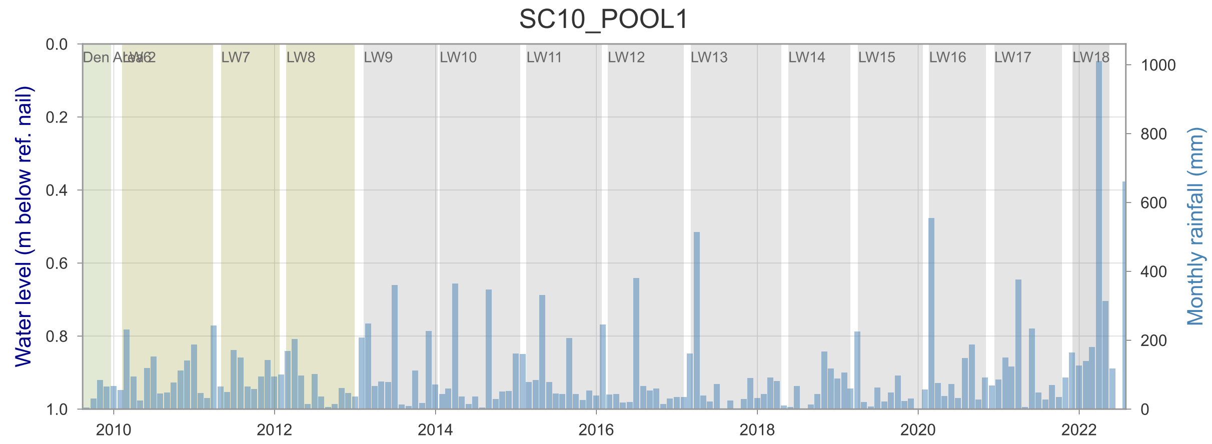

SCK_ROCKBAR5
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
Median (baseline)
P5-P95 DO

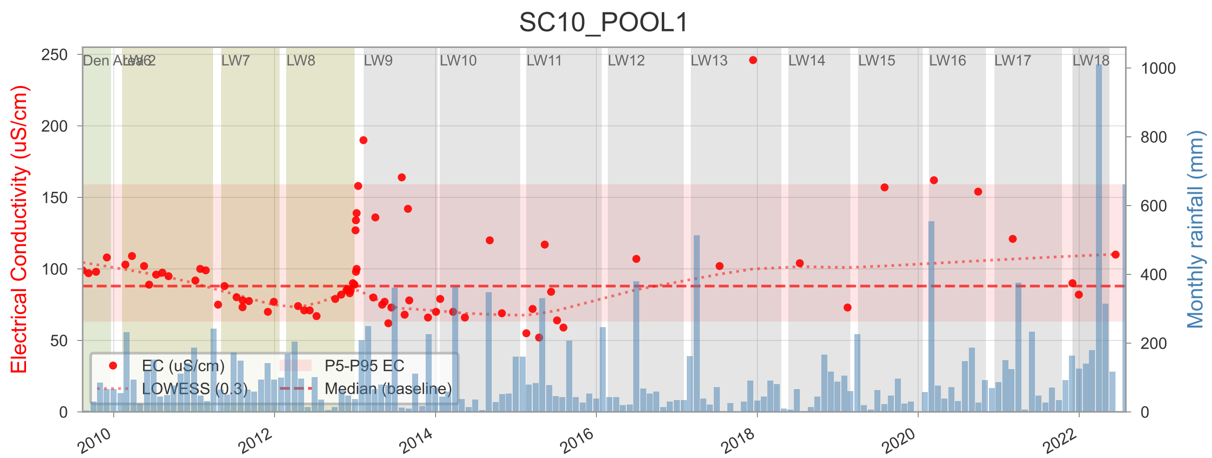

SC10S1
Stream flow (ML/day)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Flow (ML/d)
P5-P95 flow

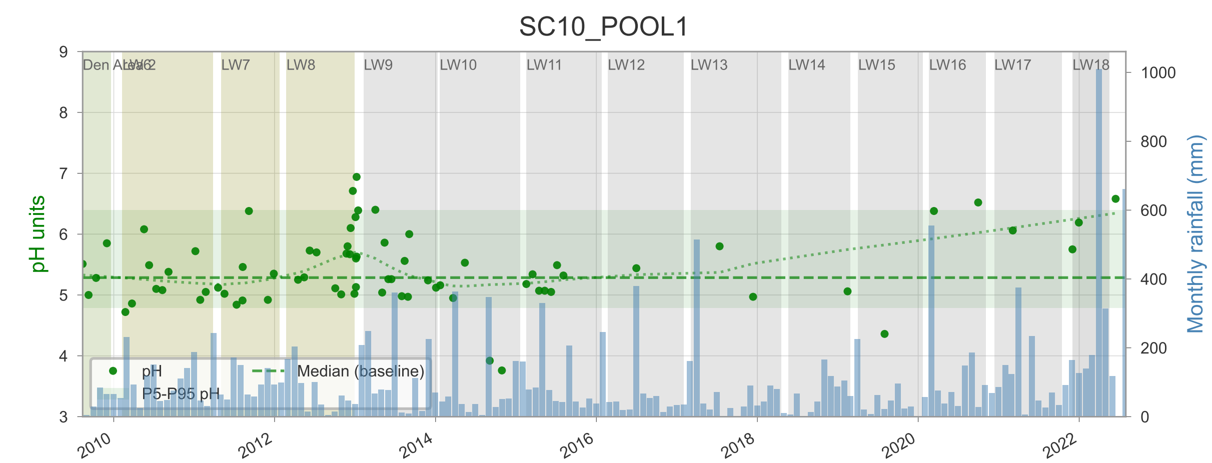

SC10_ROCKBAR3
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
EC (uS/cm)
LOWESS (0.3)
P5-P95 EC
Median (baseline)

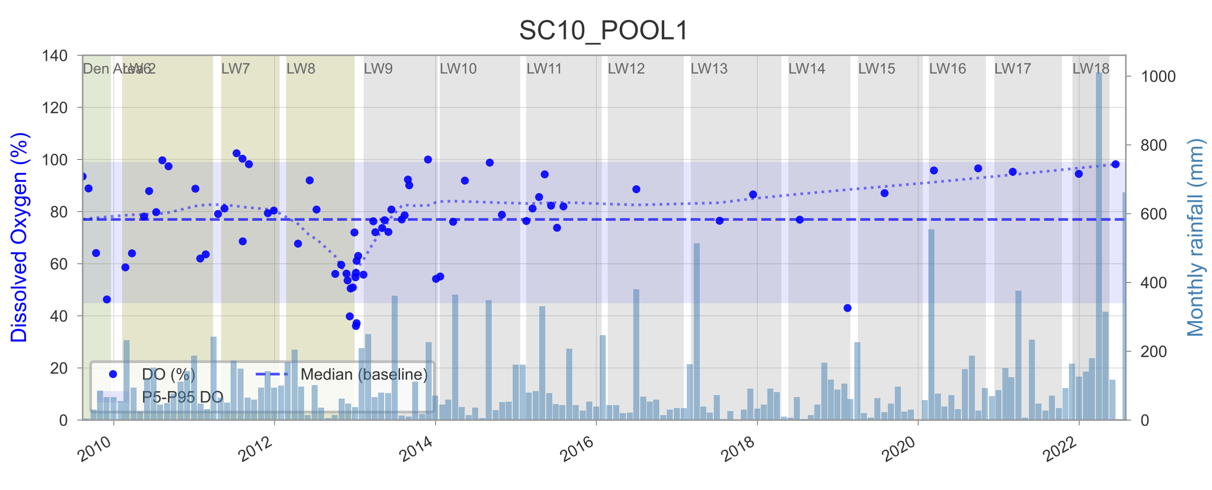

SC10_ROCKBAR3
pH units
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
pH
P5-P95 pH
Median (baseline)

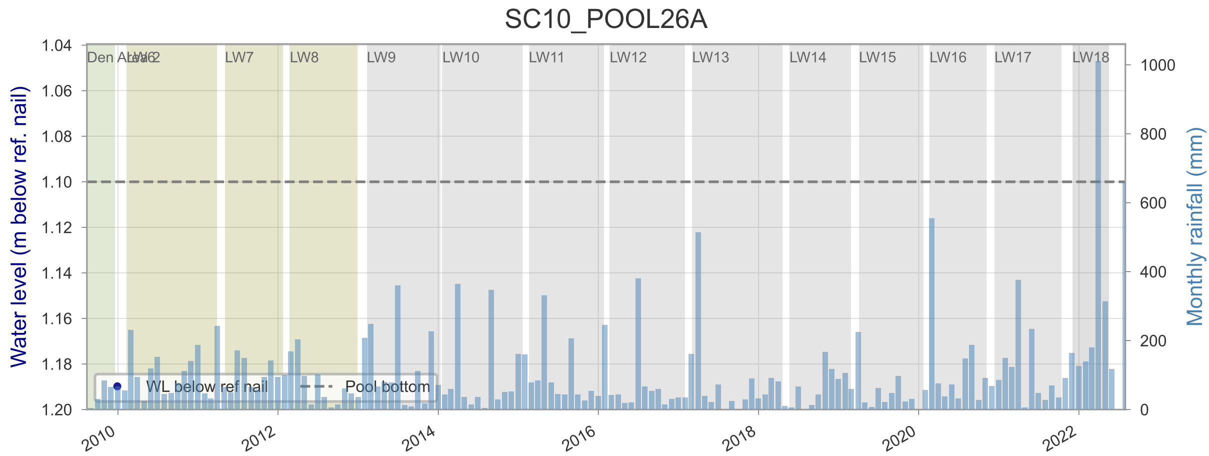

SC10_ROCKBAR3
Dissolved Oxygen (%)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
DO (%)
P5-P95 DO
Median (baseline)

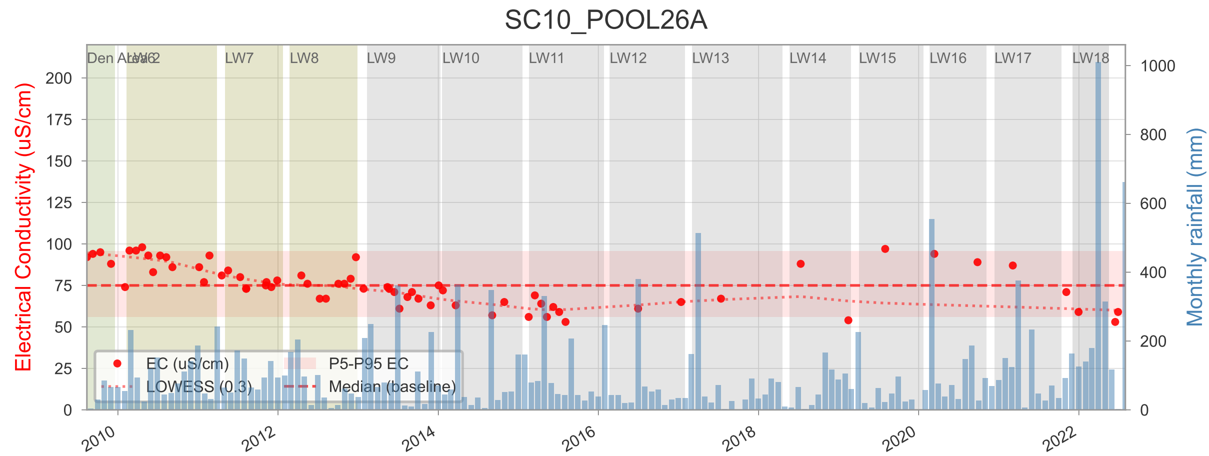

SC10_POOL1
Water level (m below ref. nail)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
1000
2010
2012
2014
2016
2018
2020
2022

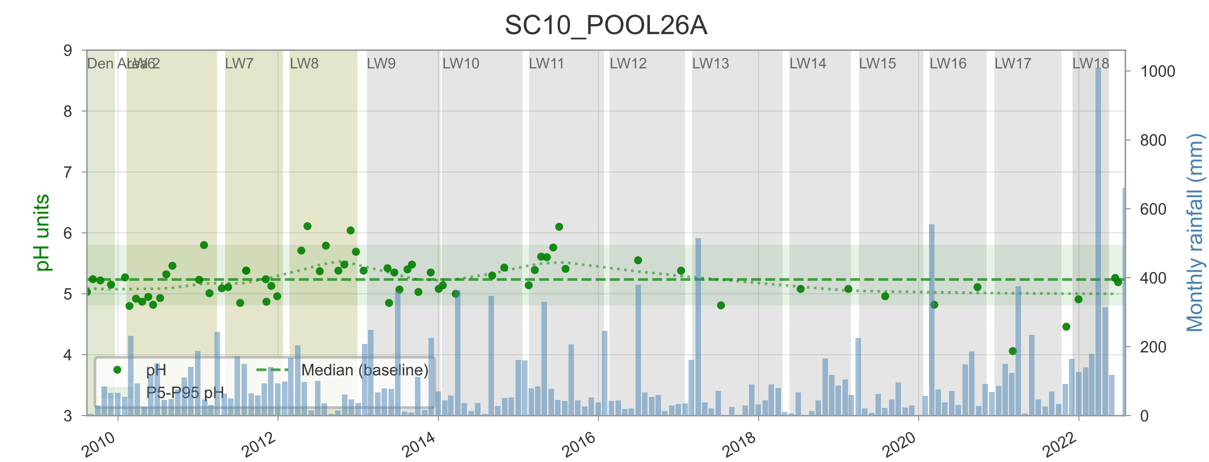

SC10_POOL1
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
EC (uS/cm)
LOWESS (0.3)
P5-P95 EC
Median (baseline)
0
50
100
150
200
250
0
200
400
600
800
1000
2010
2012
2014
2016
2018
2020
2022

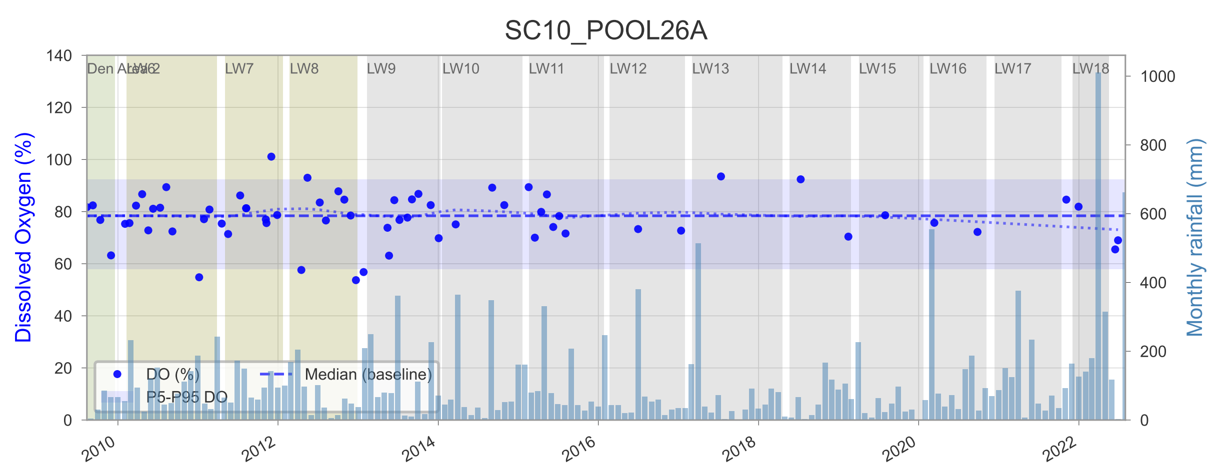

SC10_POOL1
pH units
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
pH
Median (baseline)
P5-P95 pH
3
4
5
6
7
8
9
0
200
400
600
800
1000
2010
2012
2014
2016
2018
2020
2022

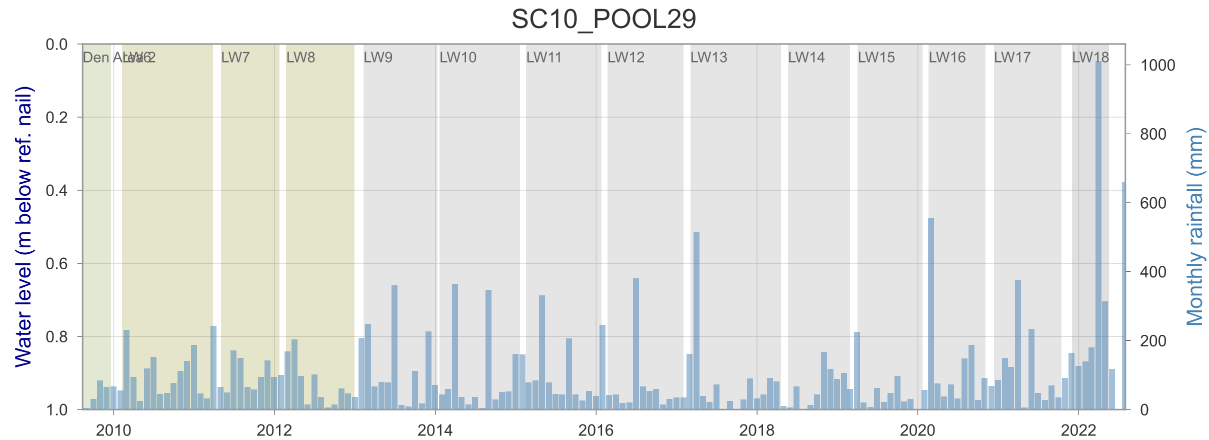

SC10_POOL1
Dissolved Oxygen (%)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
DO (%)
Median (baseline)
P5-P95 DO
0
20
40
60
80
100
120
140
0
200
400
600
800
1000
2010
2012
2014
2016
2018
2020
2022

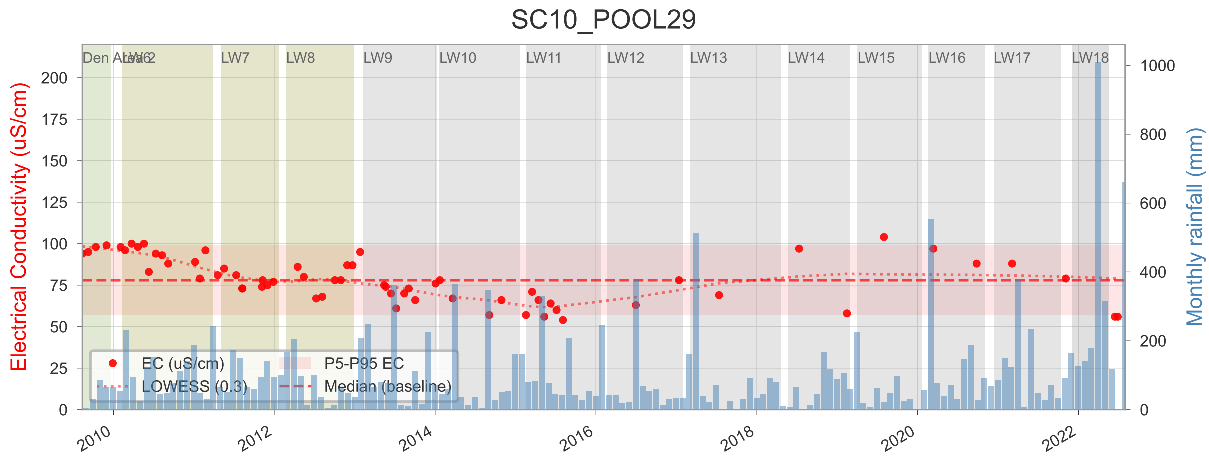

SC10_POOL26A
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
Pool bottom
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

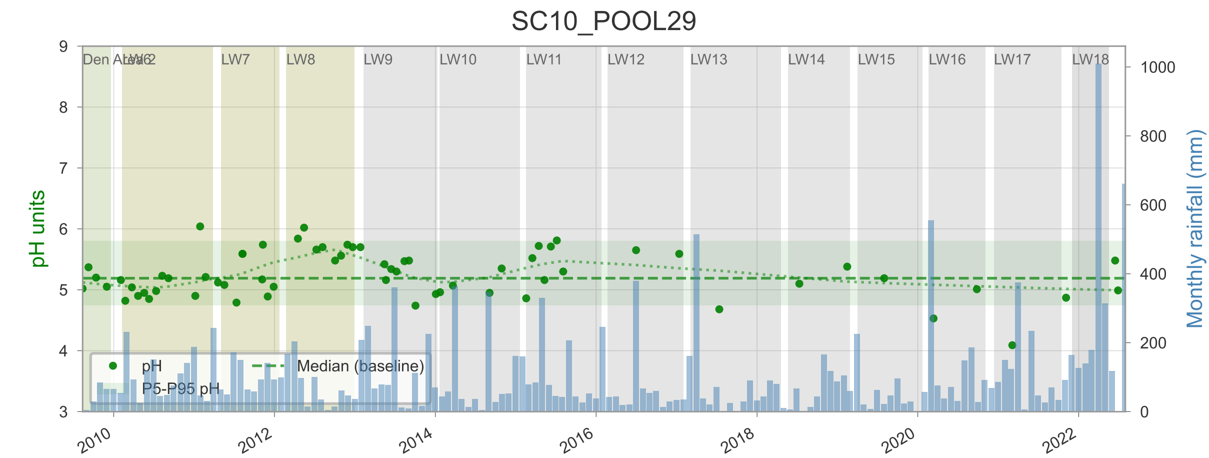

SC10_POOL26A
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
P5-P95 EC
Median (baseline)

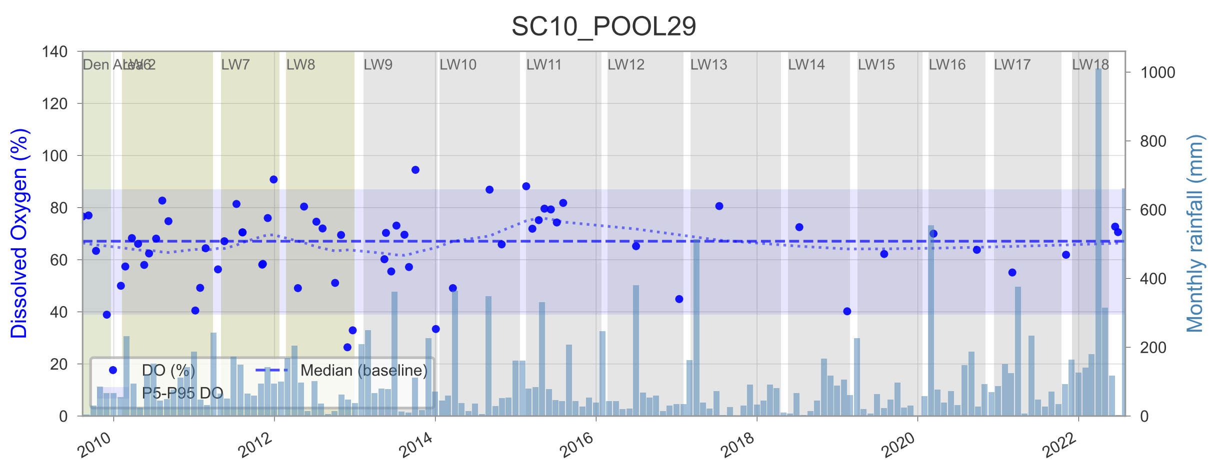

SC10_POOL26A
pH units
Monthly rainfall (mm)
pH
P5-P95 pH
Median (baseline)

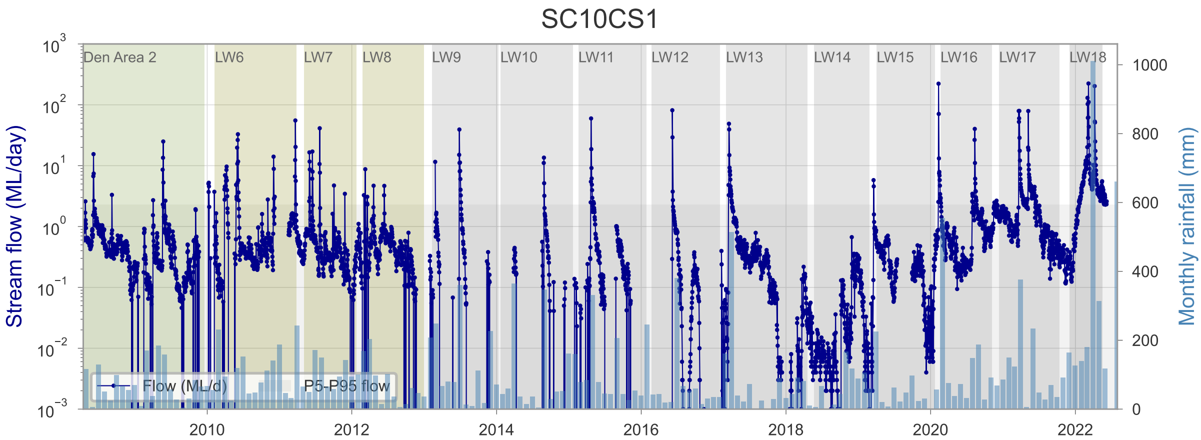

SC10_POOL26A
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
P5-P95 DO
Median (baseline)

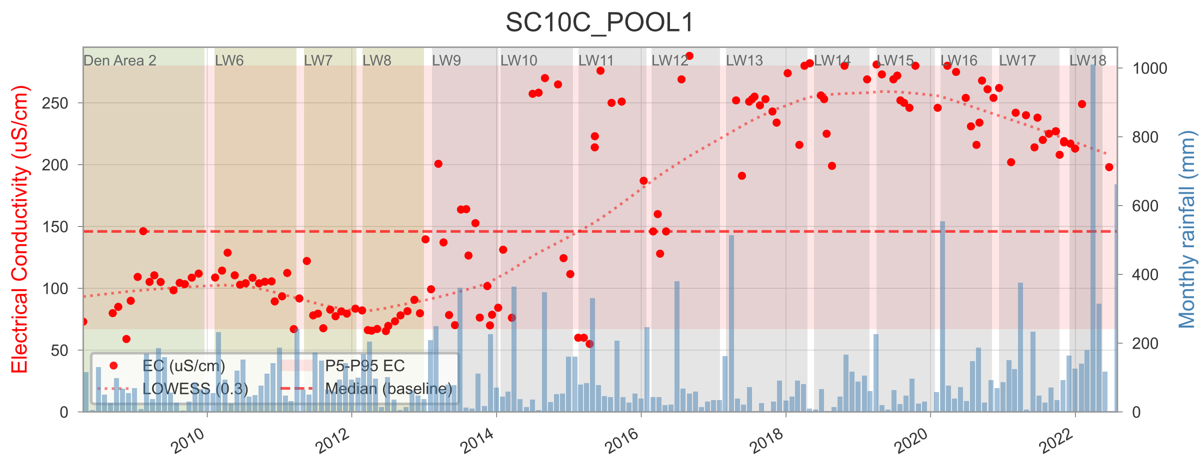

SC10_POOL29
Den Area
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Water level (m below ref. nail)
Monthly rainfall (mm)
2010
2012
2014
2016
2018
2020
2022

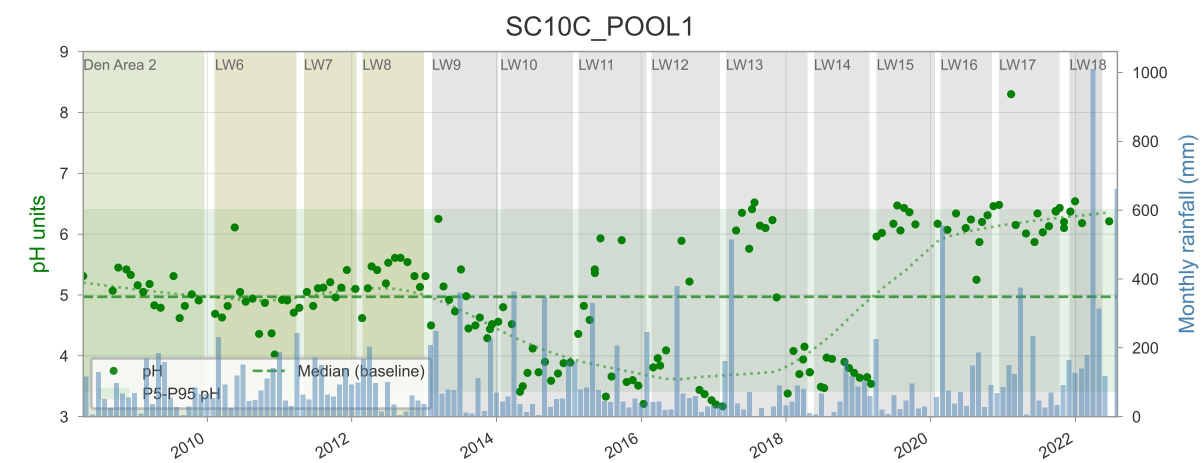

SC10_POOL29
Den Area
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
P5-P95 EC
Median (baseline)
2010
2012
2014
2016
2018
2020
2022

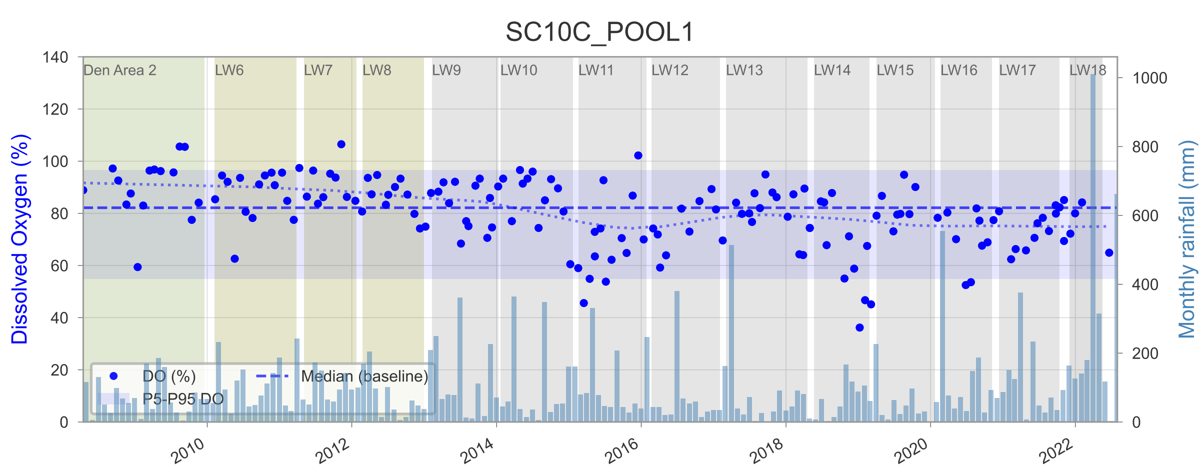

SC10_POOL29
Den Area
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
pH units
Monthly rainfall (mm)
pH
P5-P95 pH
Median (baseline)
2010
2012
2014
2016
2018
2020
2022

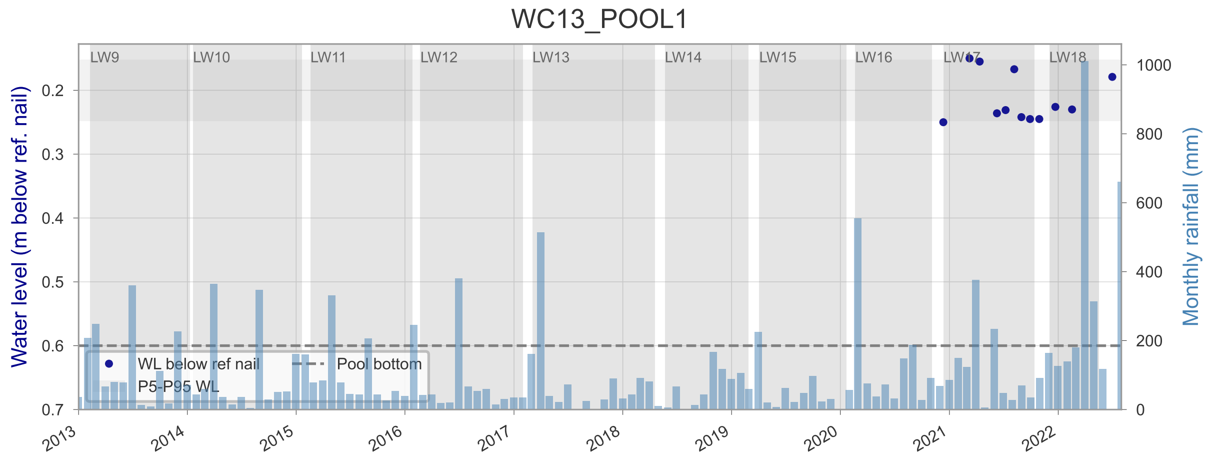

SC10_POOL29
Den Area
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
P5-P95 DO
Median (baseline)
2010
2012
2014
2016
2018
2020
2022

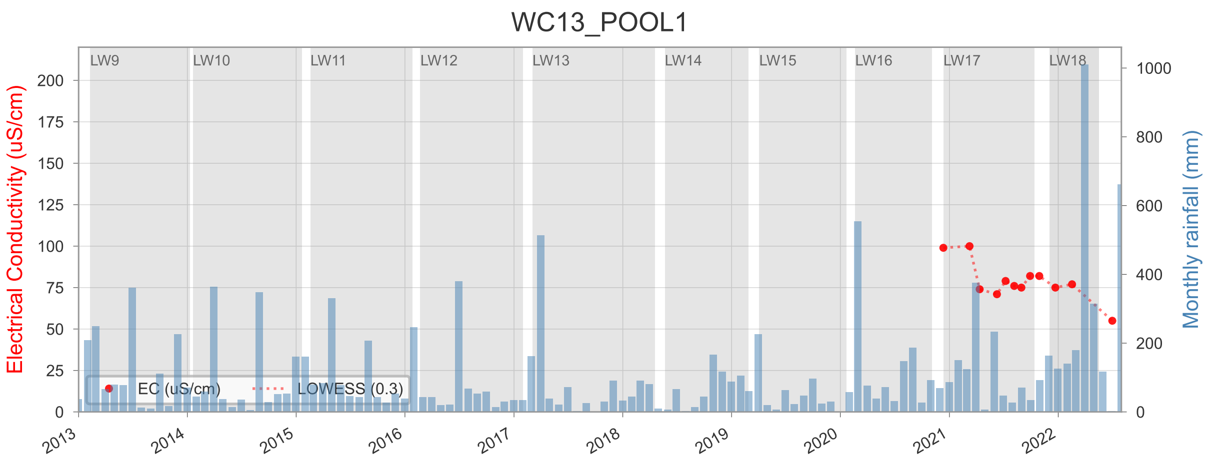

SC10CS1
Stream flow (ML/day)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Flow (ML/d)
P5-P95 flow

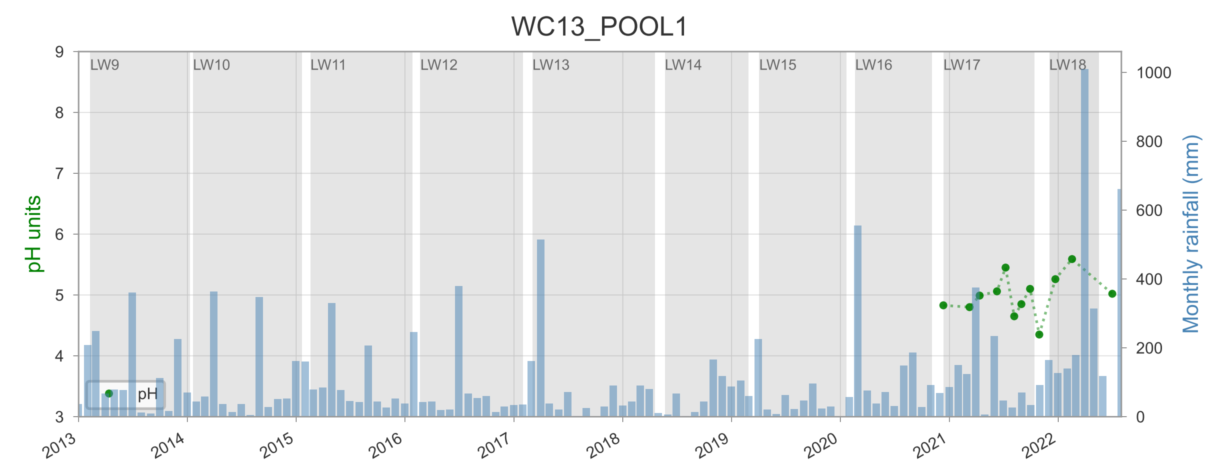

SC10C_POOL1
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
EC (uS/cm)
LOWESS (0.3)
P5-P95 EC
Median (baseline)

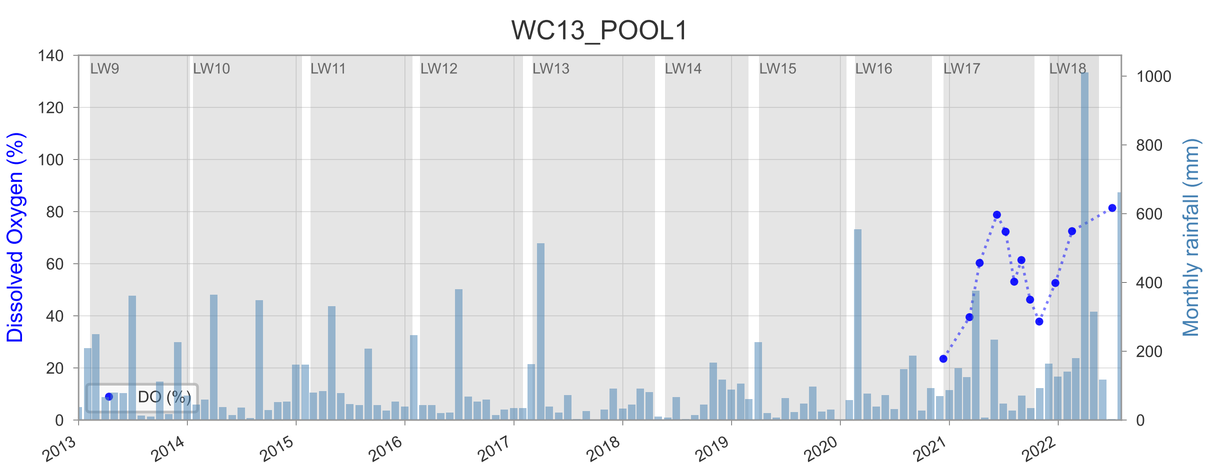

SC10C_POOL1
pH units
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
pH
P5-P95 pH
Median (baseline)

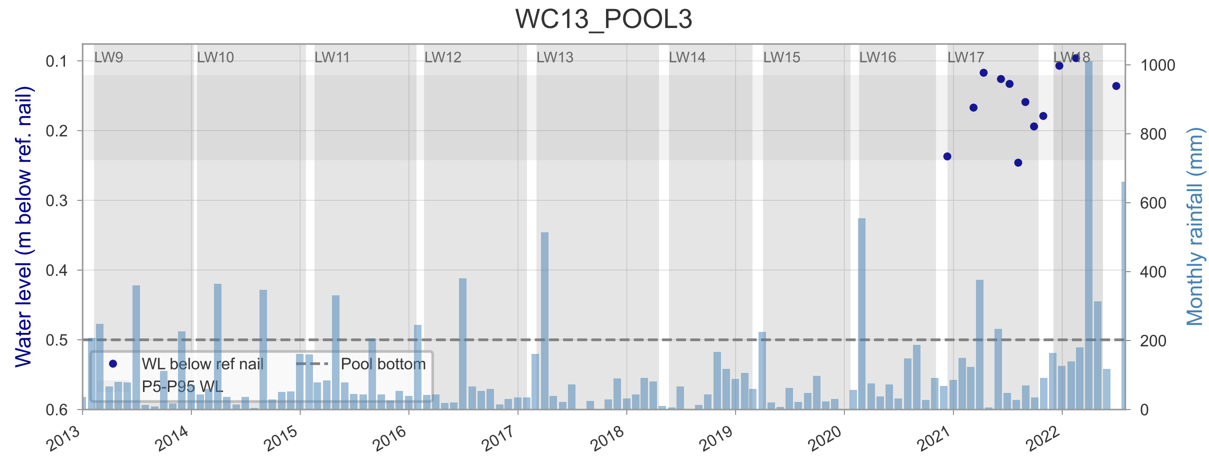

SC10C_POOL1
Dissolved Oxygen (%)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
DO (%)
P5-P95 DO
Median (baseline)

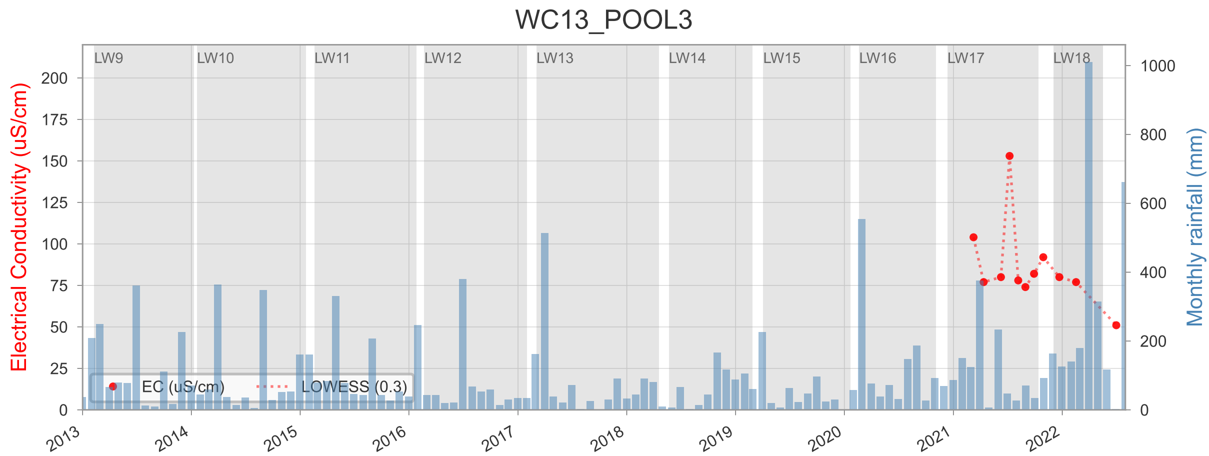

WC13_POOL1
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
Pool bottom
P5-P95 WL

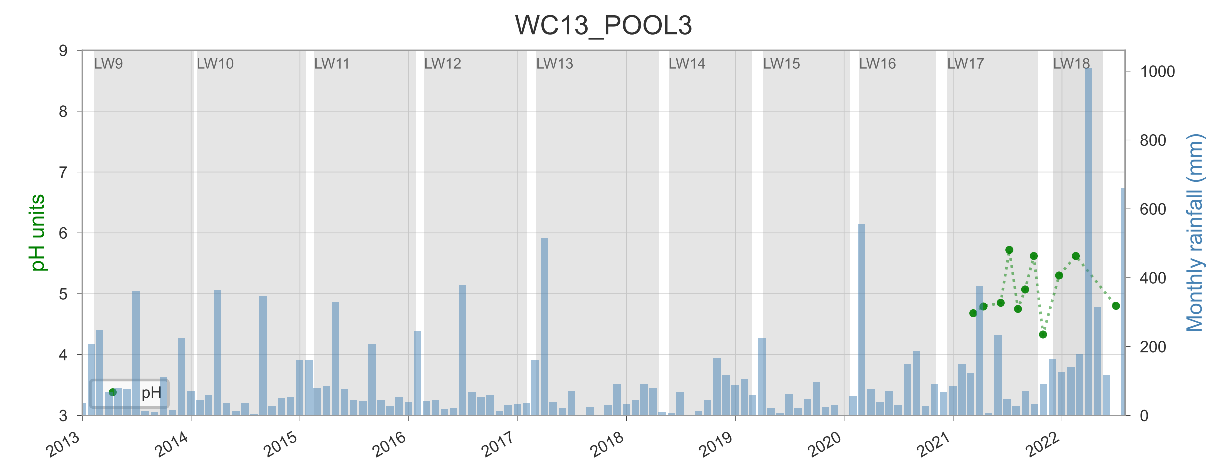

WC13_POOL1
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)

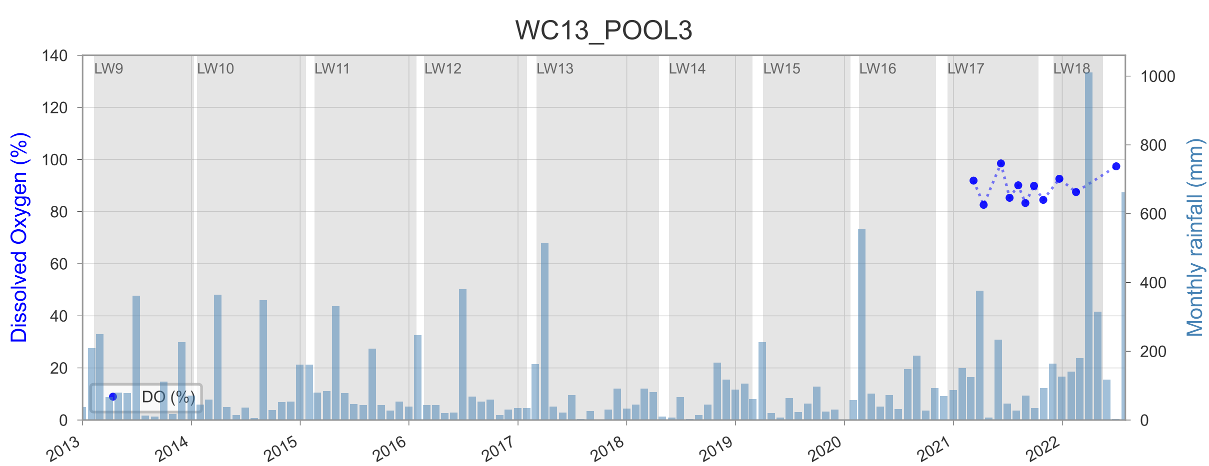

WC13_POOL1
pH units
Monthly rainfall (mm)
pH

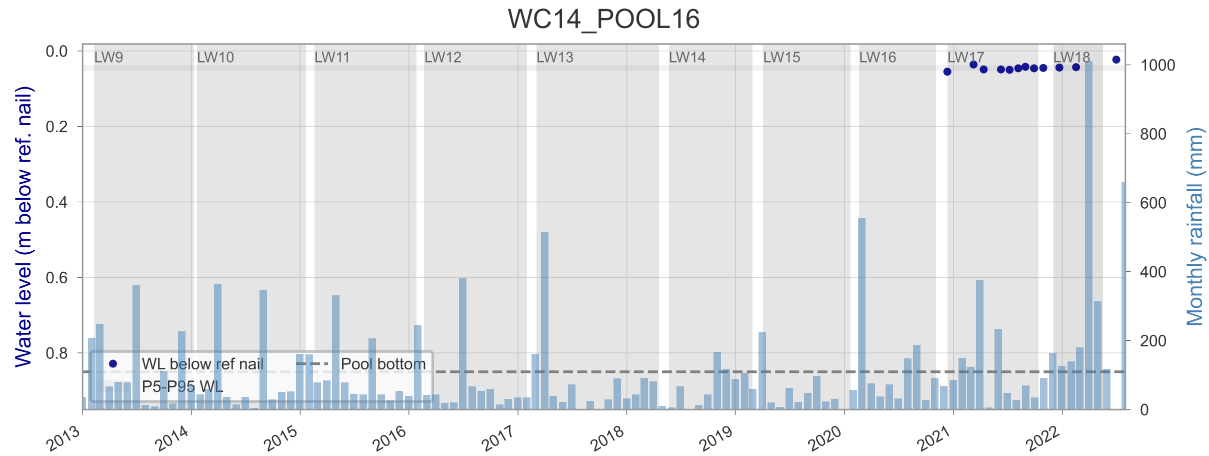

WC13_POOL1
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)

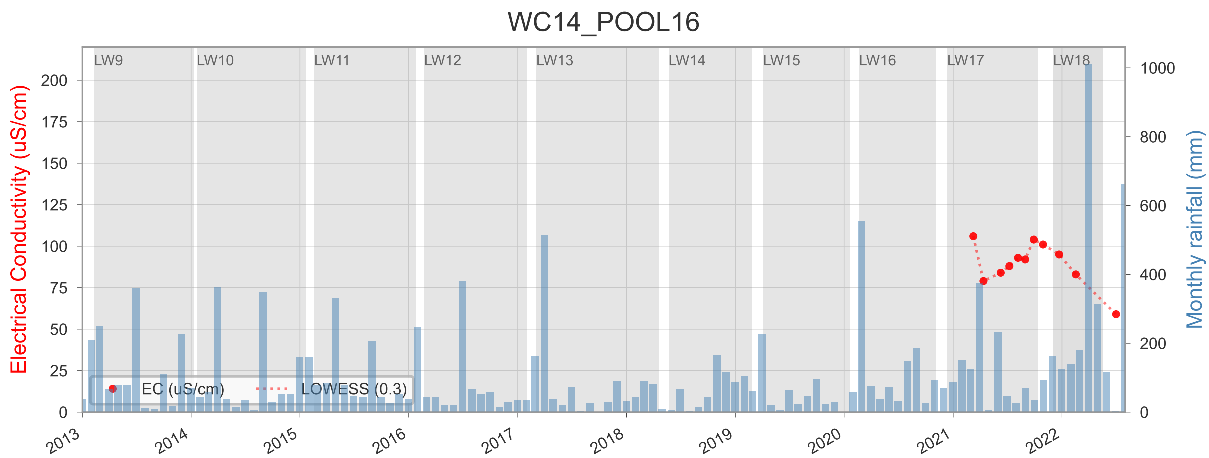

WC13_POOL3
Water level (m below ref. nail)
Monthly rainfall (mm)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
WL below ref nail
Pool bottom
P5-P95 WL

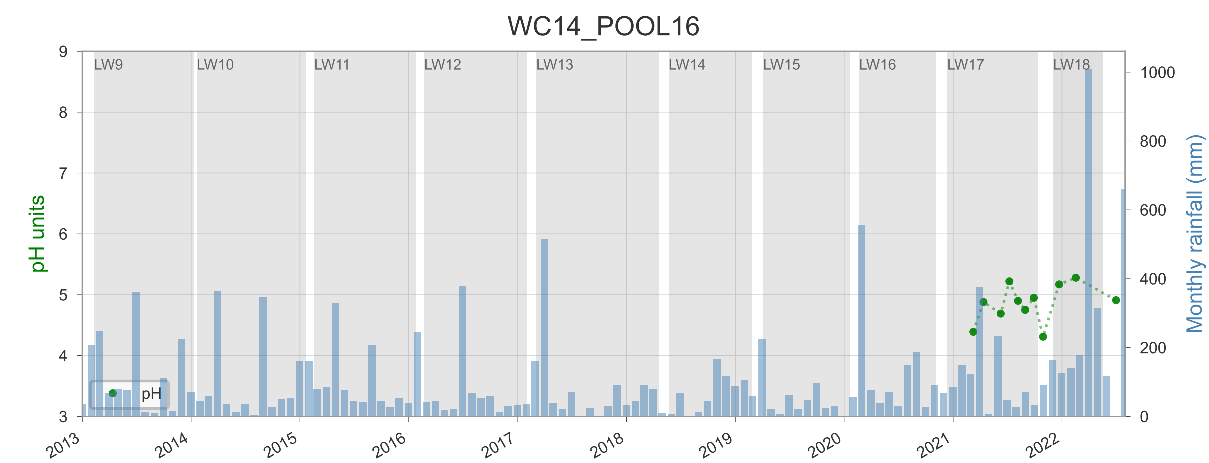

WC13_POOL3
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
EC (uS/cm)
LOWESS (0.3)

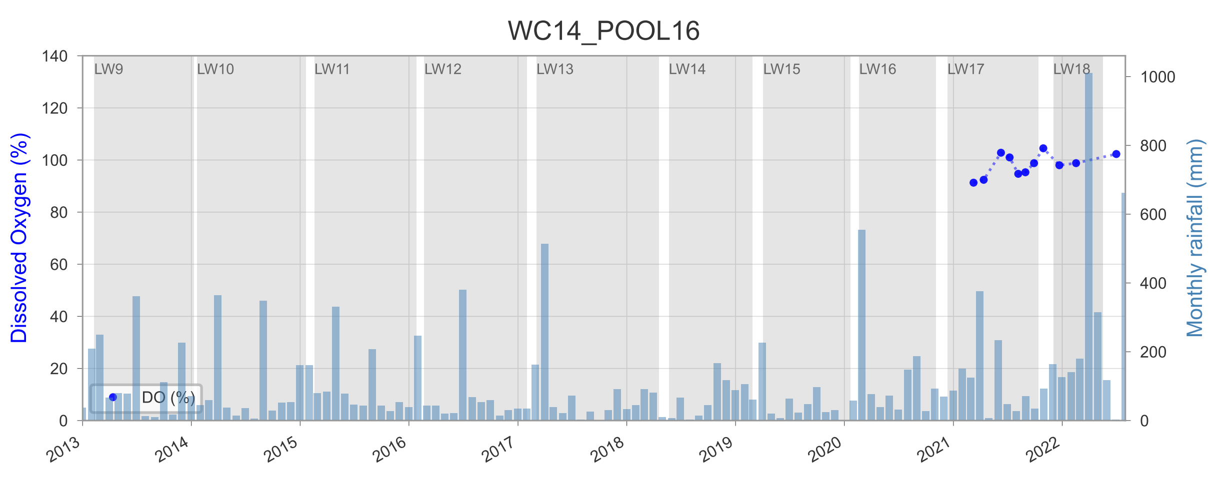

WC13_POOL3
pH units
Monthly rainfall (mm)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
pH

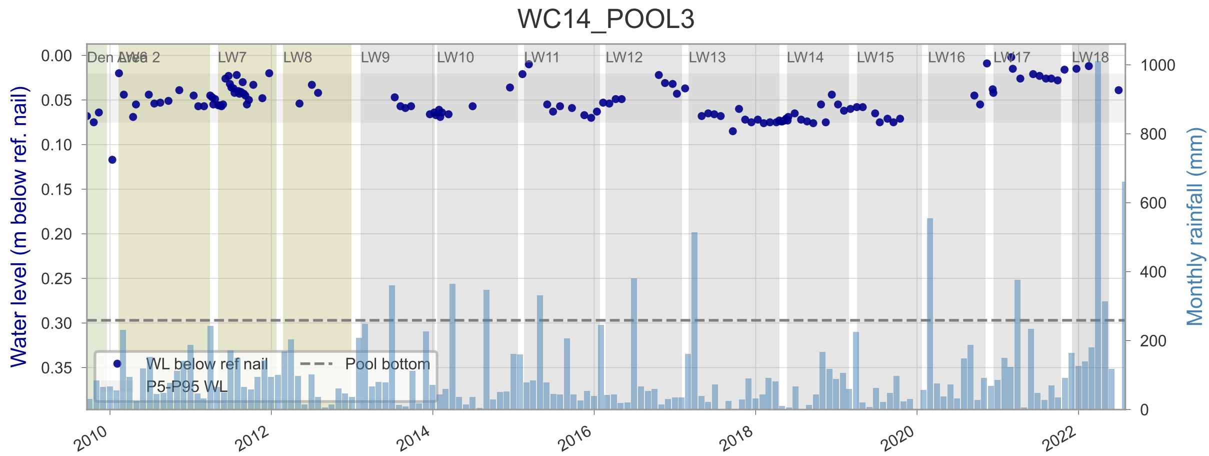

WC13_POOL3
Dissolved Oxygen (%)
Monthly rainfall (mm)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
DO (%)

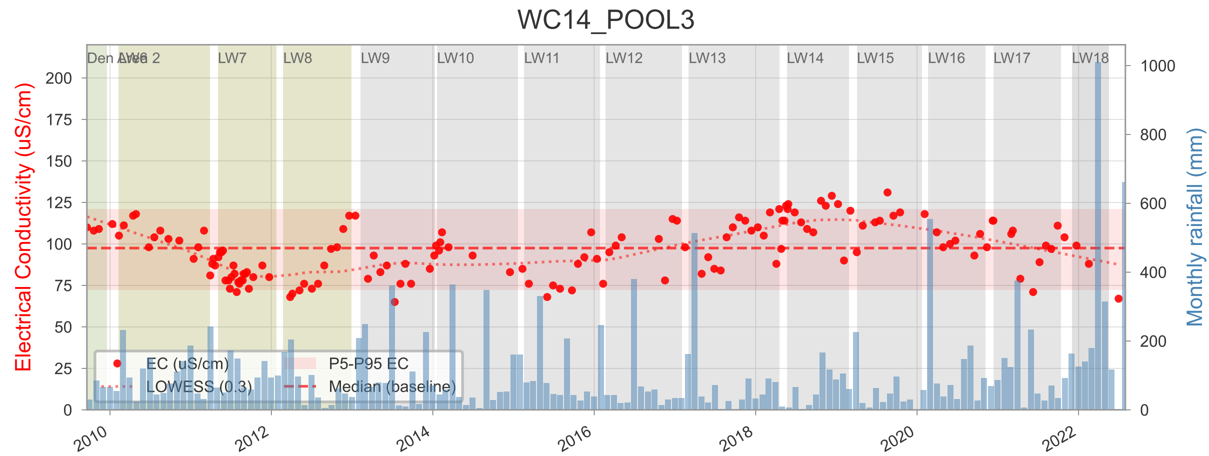

WC14_POOL16
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
P5-P95 WL
Pool bottom
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

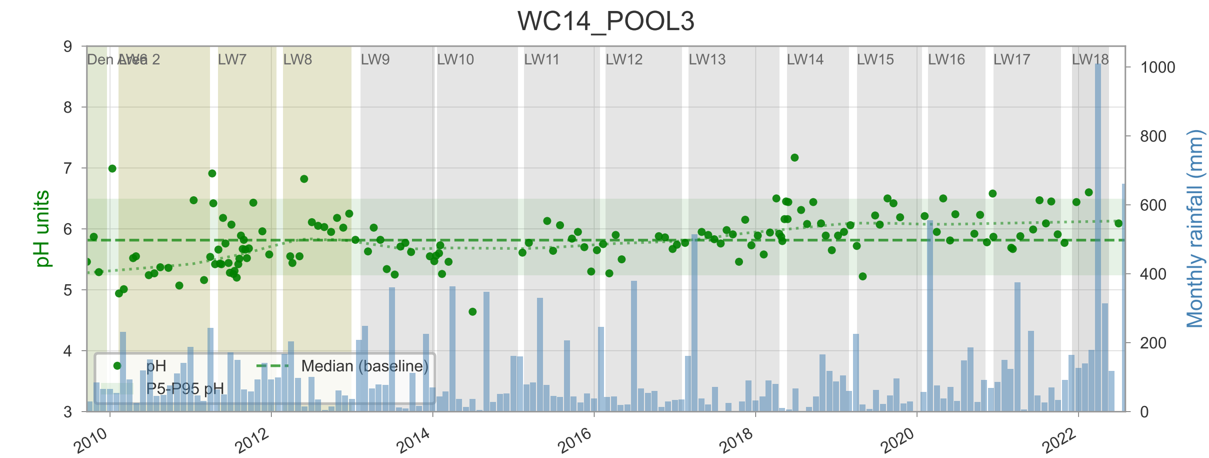

WC14_POOL16
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

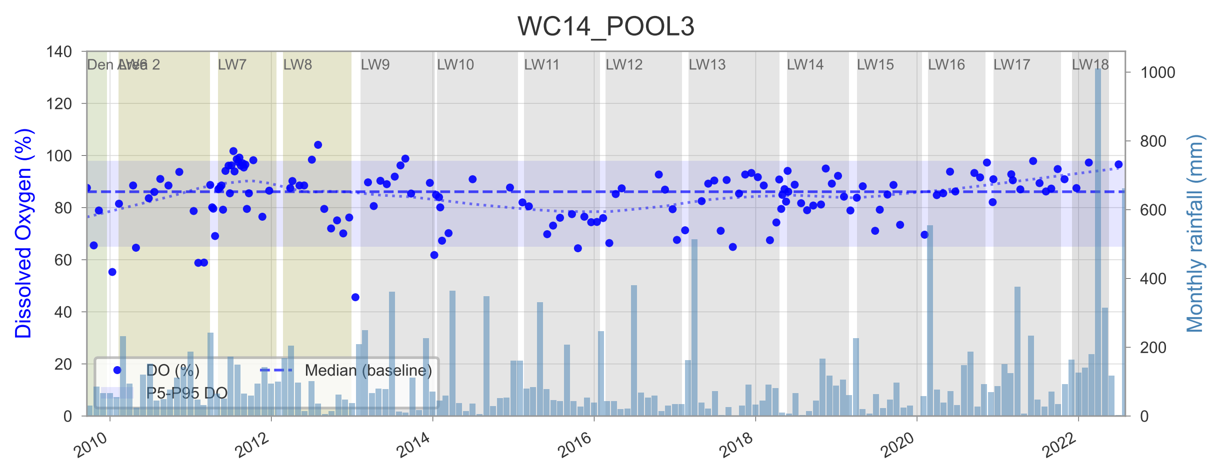

WC14_POOL16
pH units
Monthly rainfall (mm)
pH
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

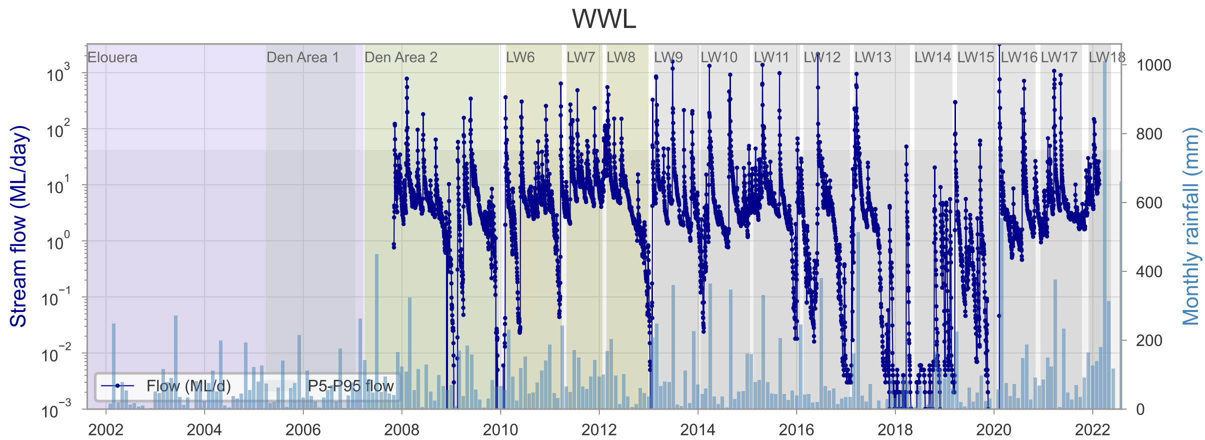

WC14_POOL16
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

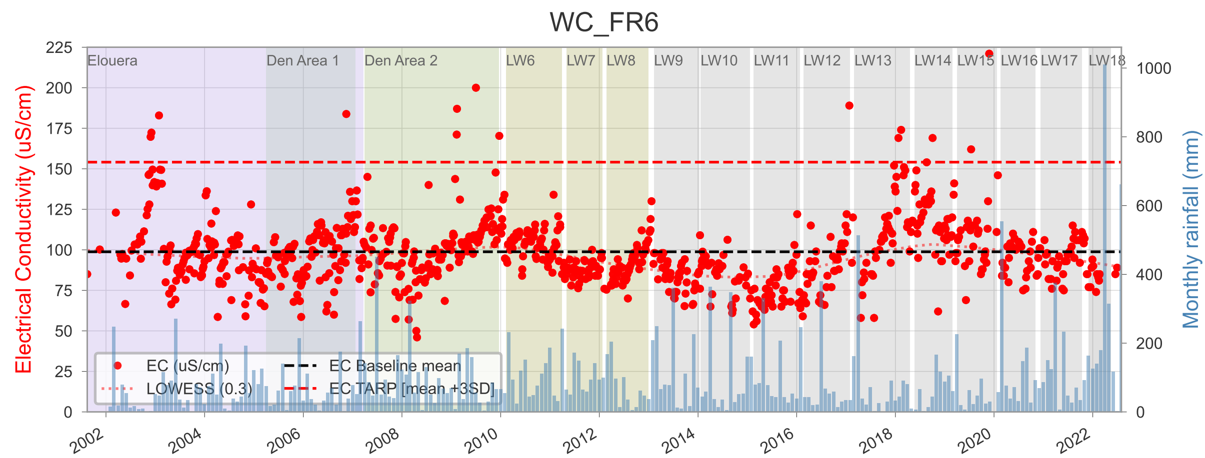

WC14_POOL3
Water level (m below ref. nail)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
WL below ref nail
P5-P95 WL
Pool bottom

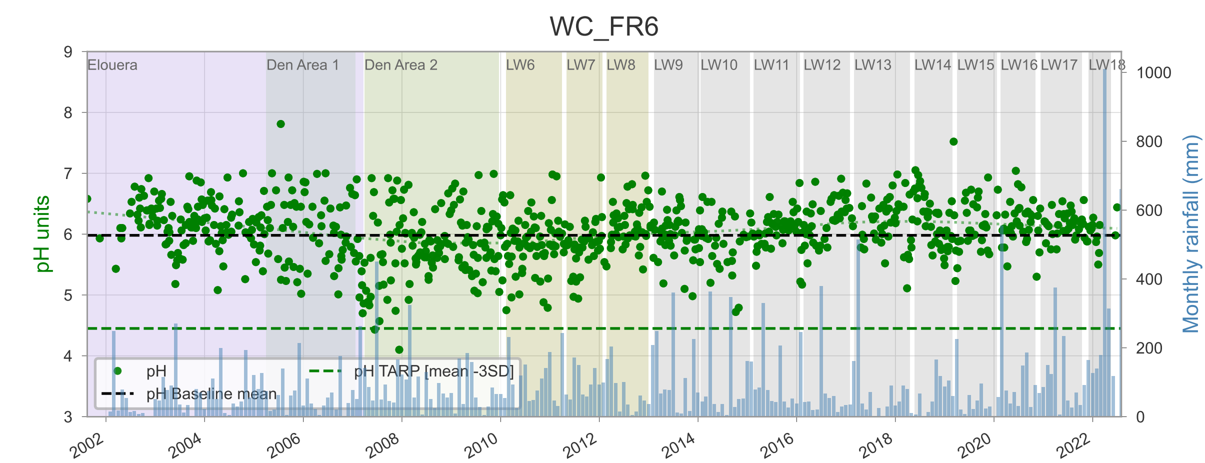

WC14_POOL3
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
P5-P95 EC
Median (baseline)

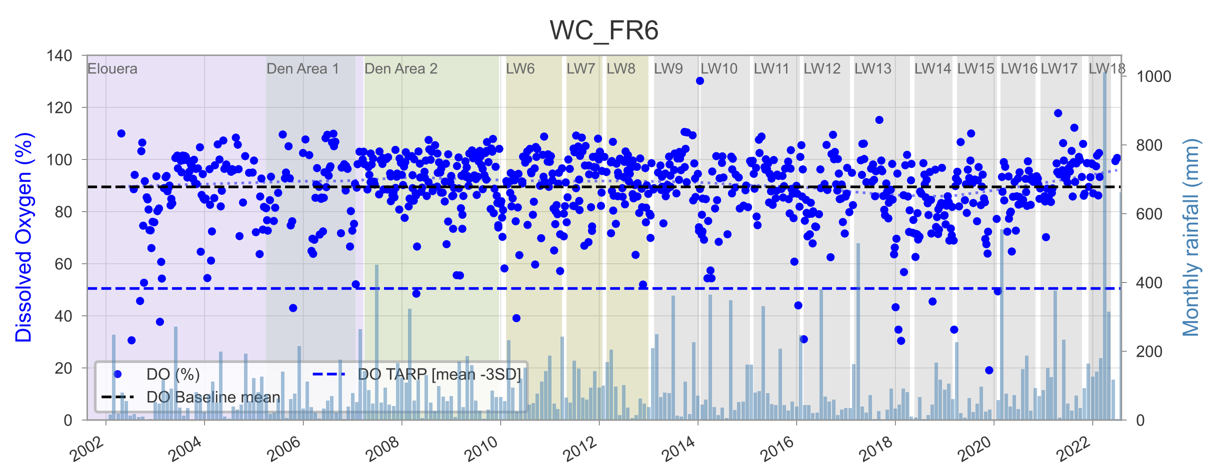

WC14_POOL3
pH units
Monthly rainfall (mm)
pH
P5-P95 pH
Median (baseline)

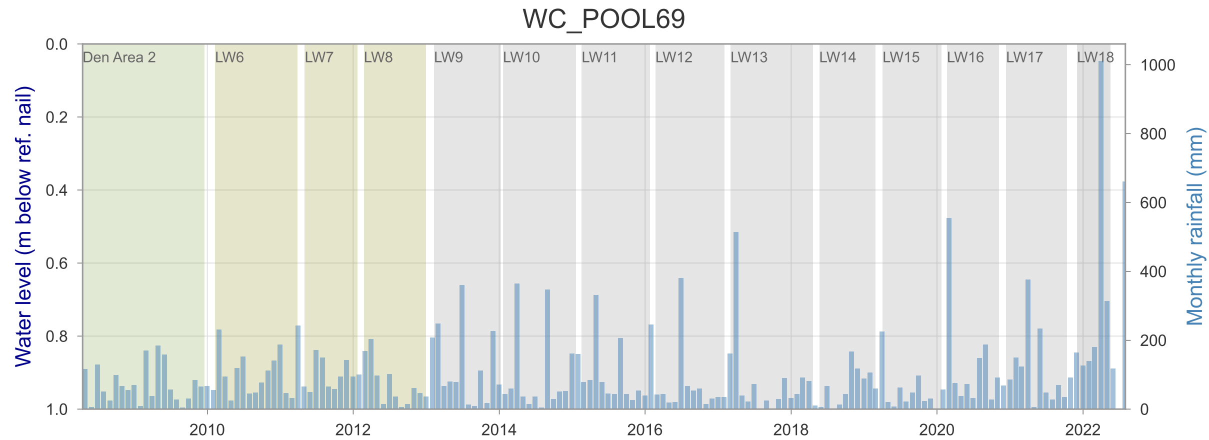

WC14_POOL3
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
P5-P95 DO
Median (baseline)

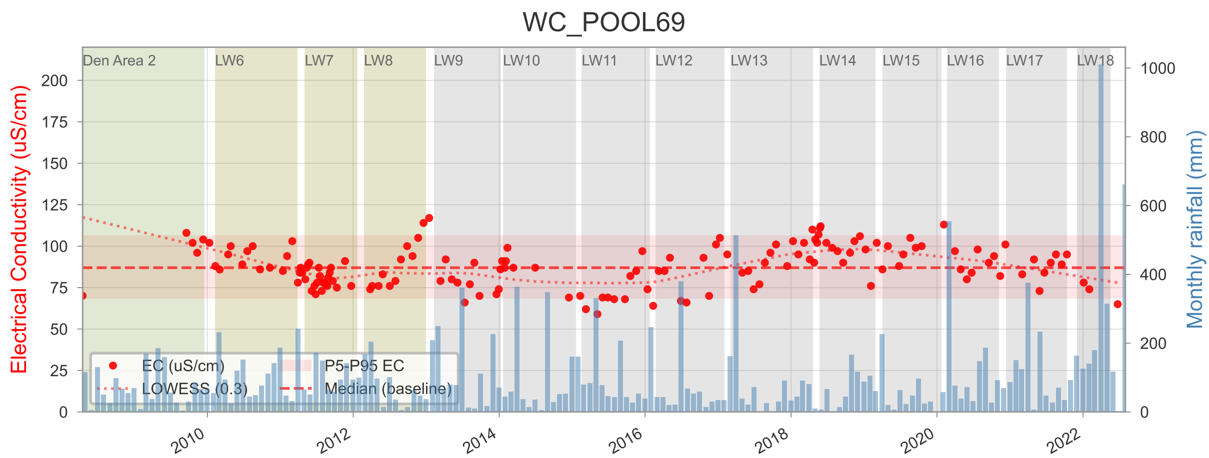

WWL
Stream flow (ML/day)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Flow (ML/d)
P5-P95 flow

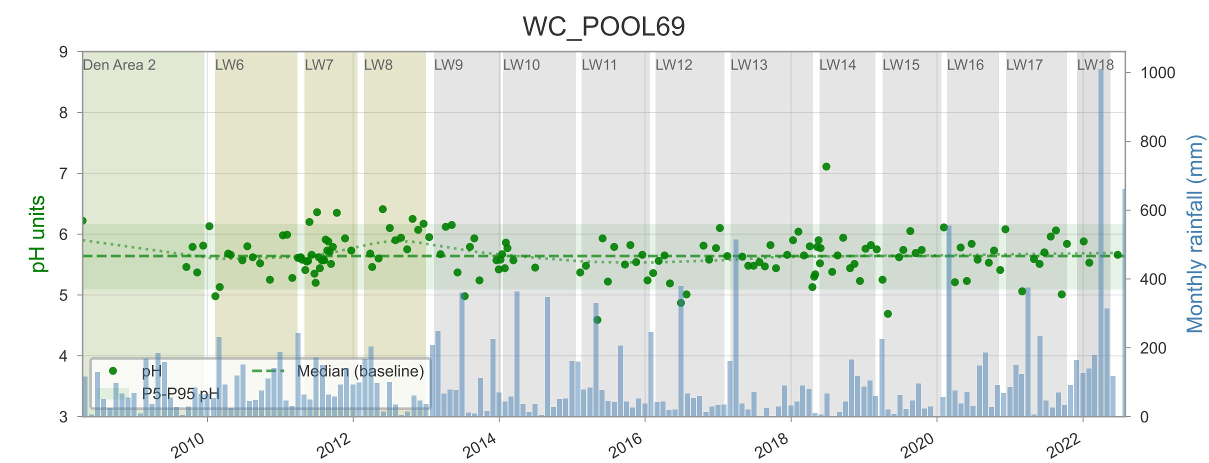

WC_FR6
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
EC Baseline mean
EC TARP [mean +3SD]

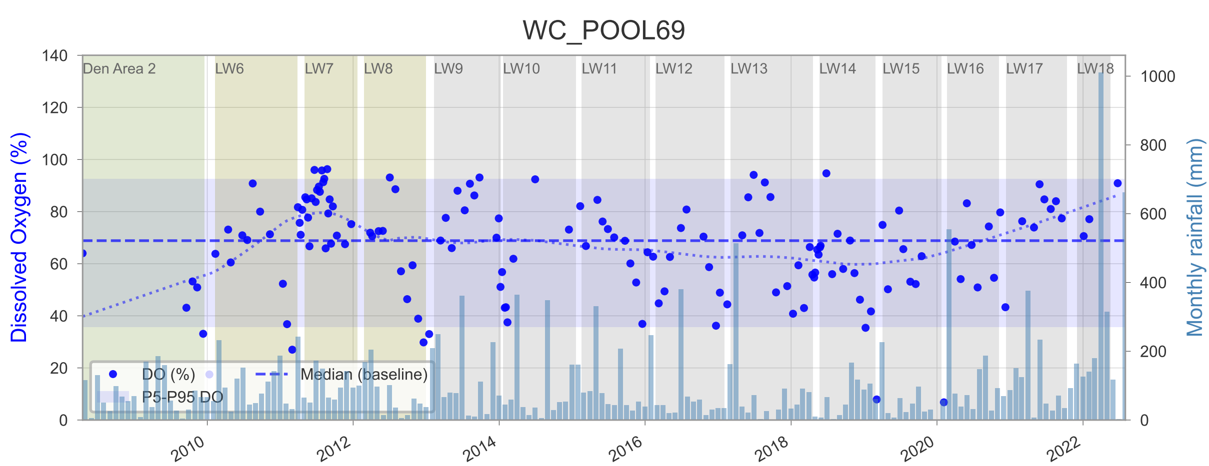

WC_FR6
pH units
Monthly rainfall (mm)
pH
pH Baseline mean
pH TARP [mean -3SD]

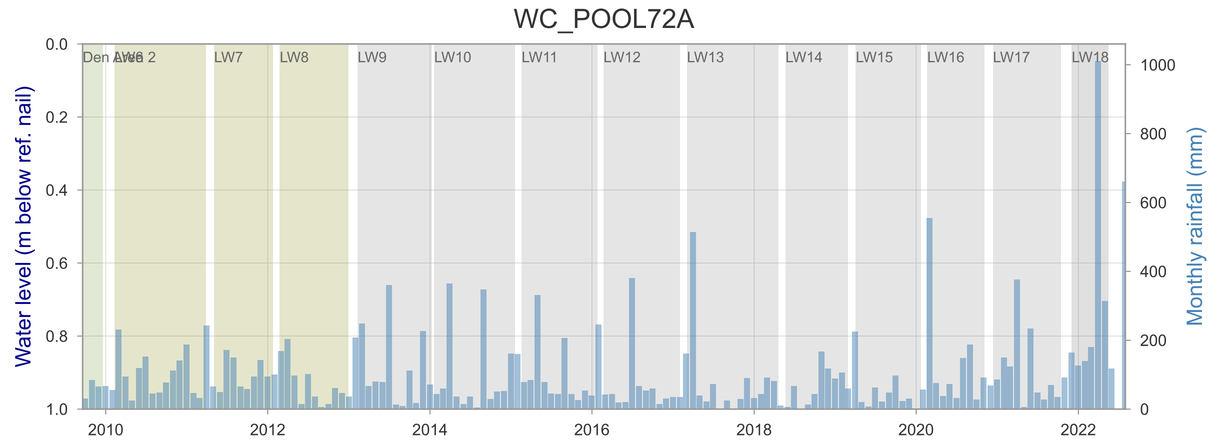

WC_FR6
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
DO Baseline mean
DO TARP [mean -3SD]

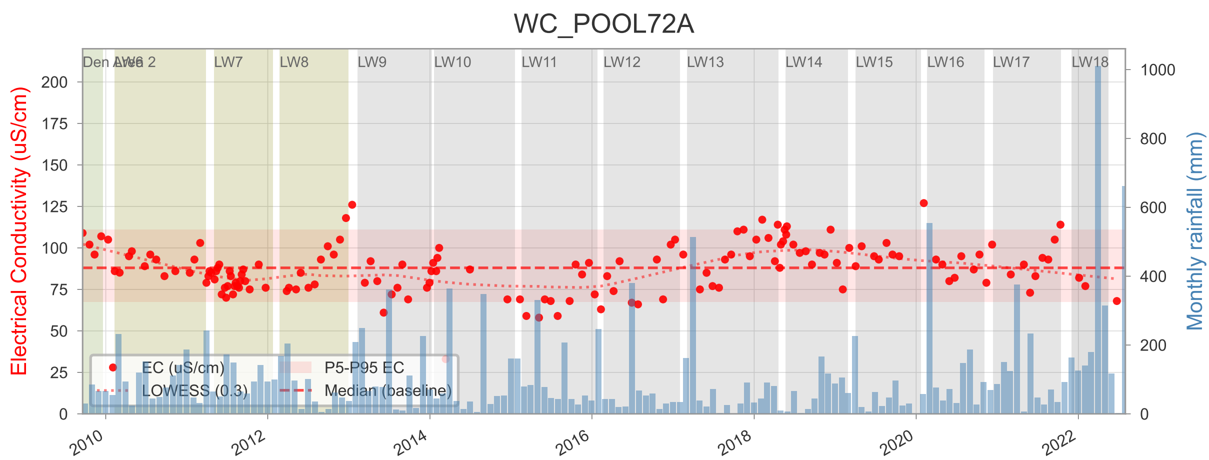

WC_POOL69
Water level (m below ref. nail)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

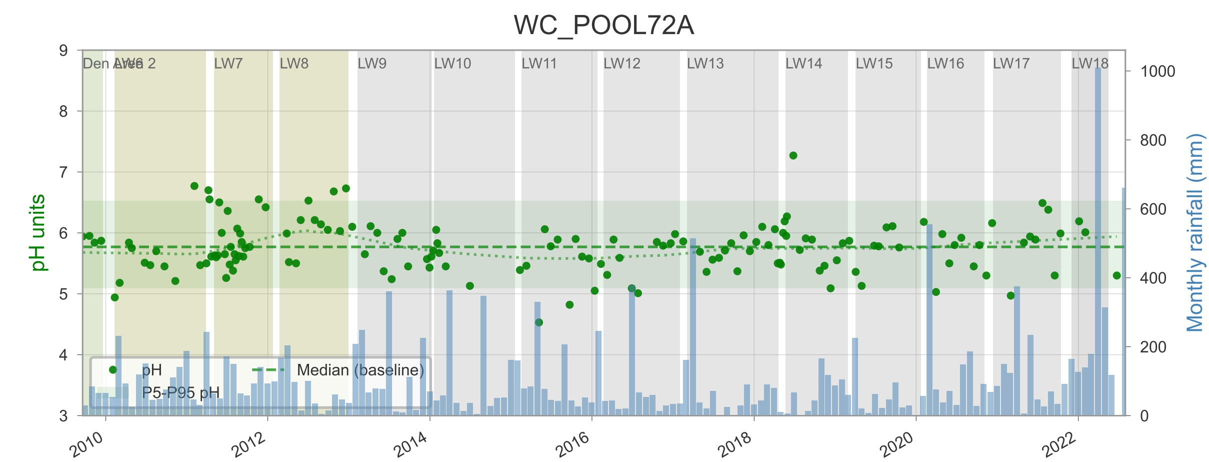

WC_POOL69
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
EC (uS/cm)
LOWESS (0.3)
P5-P95 EC
Median (baseline)

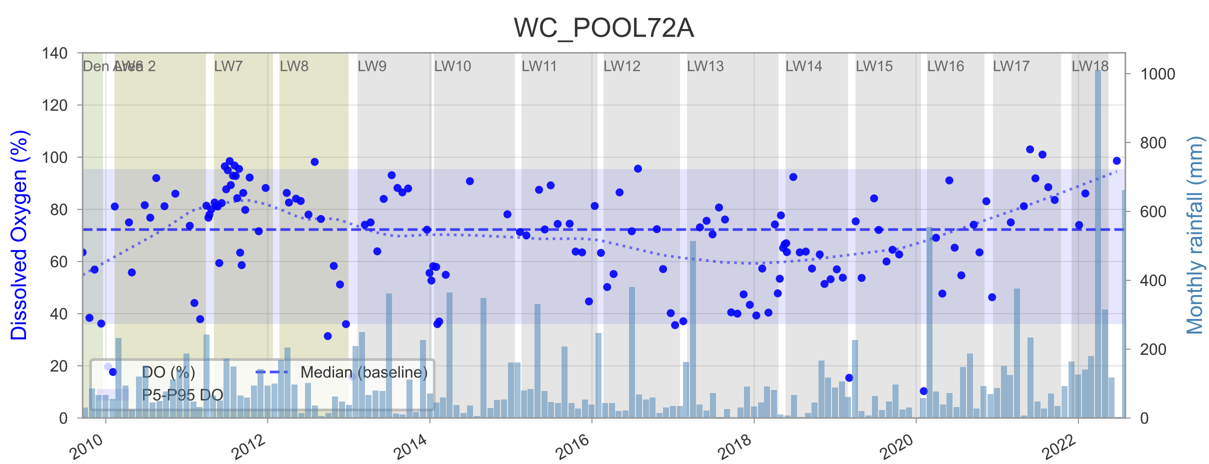

WC_POOL69
pH units
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
pH
P5-P95 pH
Median (baseline)

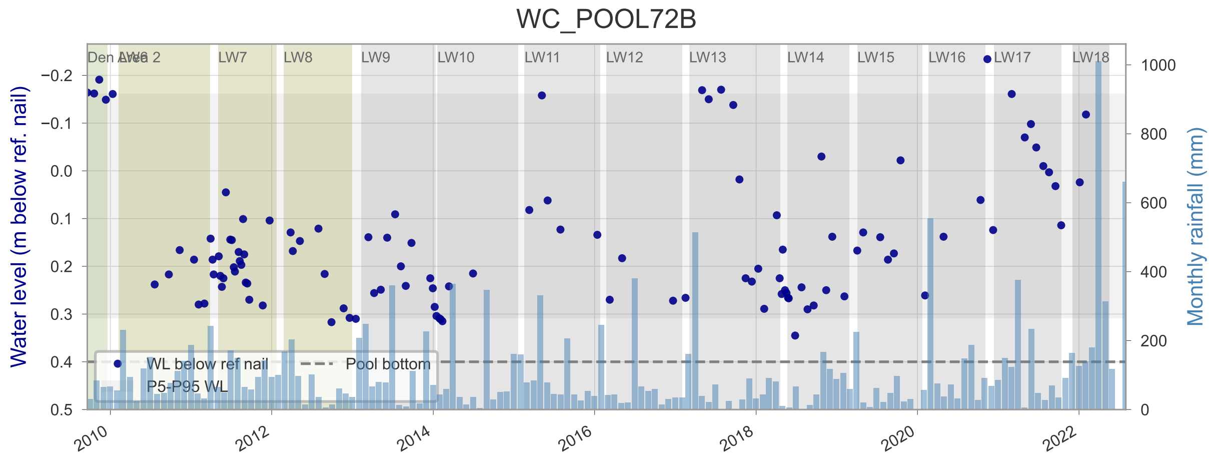

WC_POOL69
Dissolved Oxygen (%)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
DO (%)
P5-P95 DO
Median (baseline)

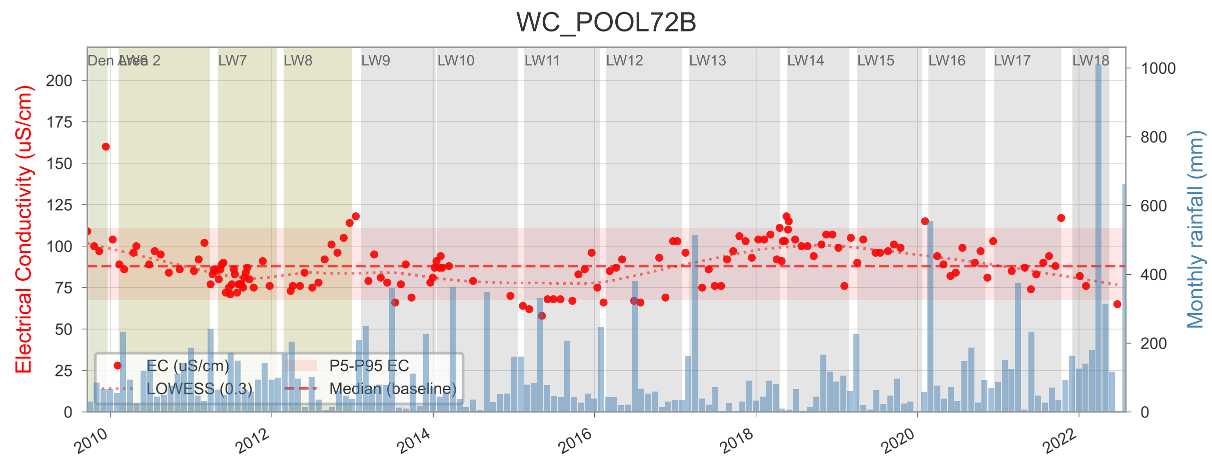

WC_POOL72A
Water level (m below ref. nail)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

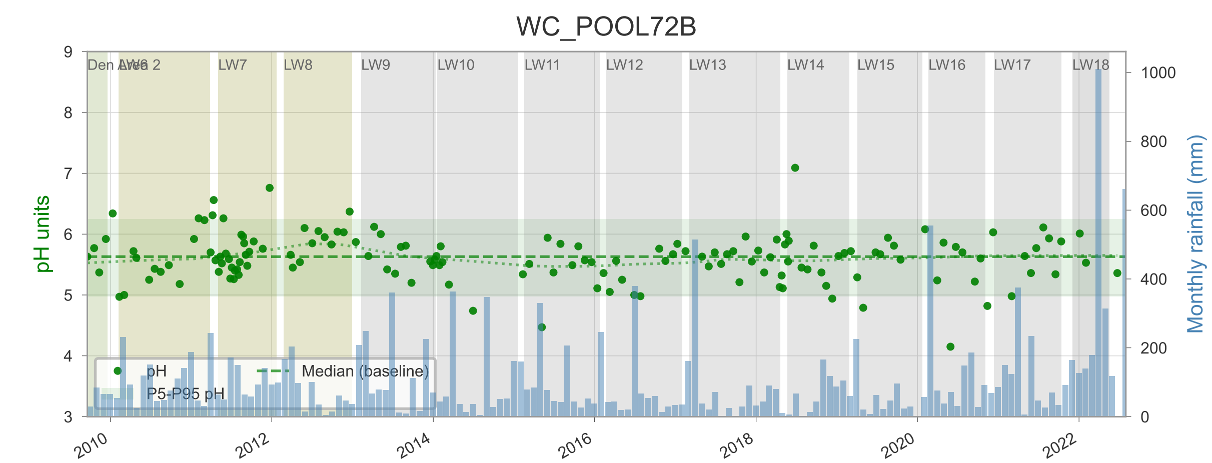

WC_POOL72A
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
P5-P95 EC
Median (baseline)

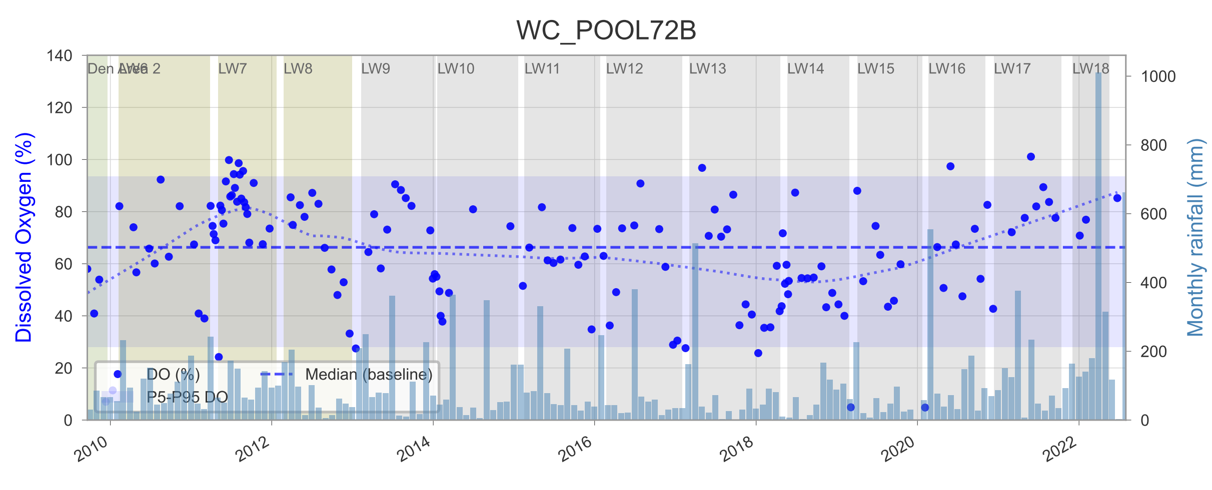

WC_POOL72A
pH units
Monthly rainfall (mm)
pH
P5-P95 pH
Median (baseline)


WC_POOL72A
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
P5-P95 DO
Median (baseline)

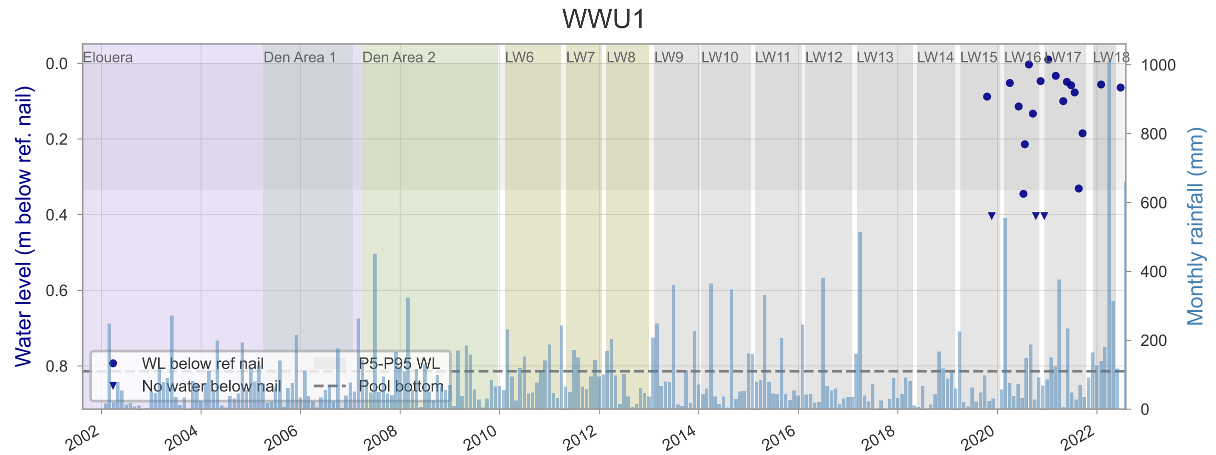

WC_POOL72B
Water level (m below ref. nail)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
WL below ref nail
P5-P95 WL
Pool bottom

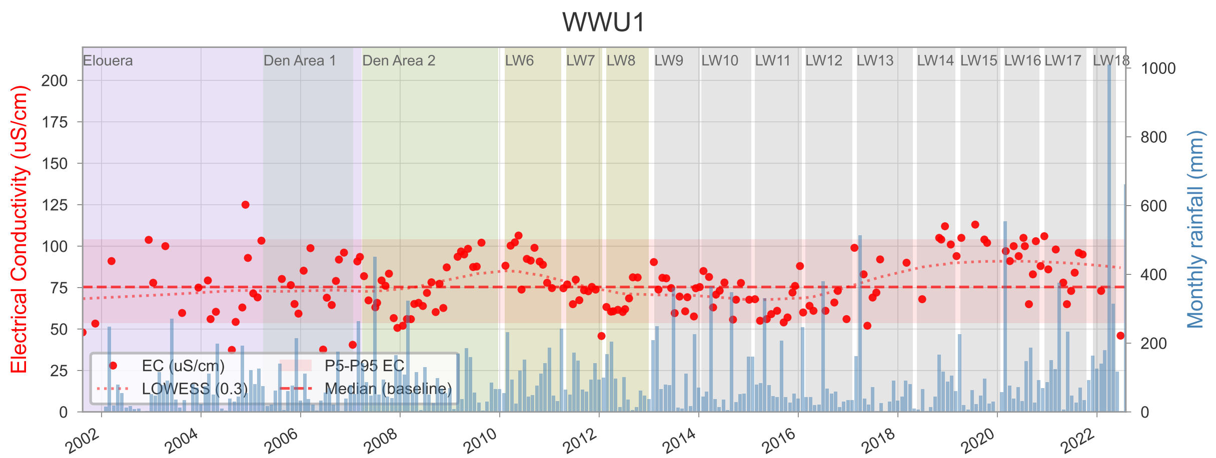

WC_POOL72B
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
EC (uS/cm)
LOWESS (0.3)
P5-P95 EC
Median (baseline)

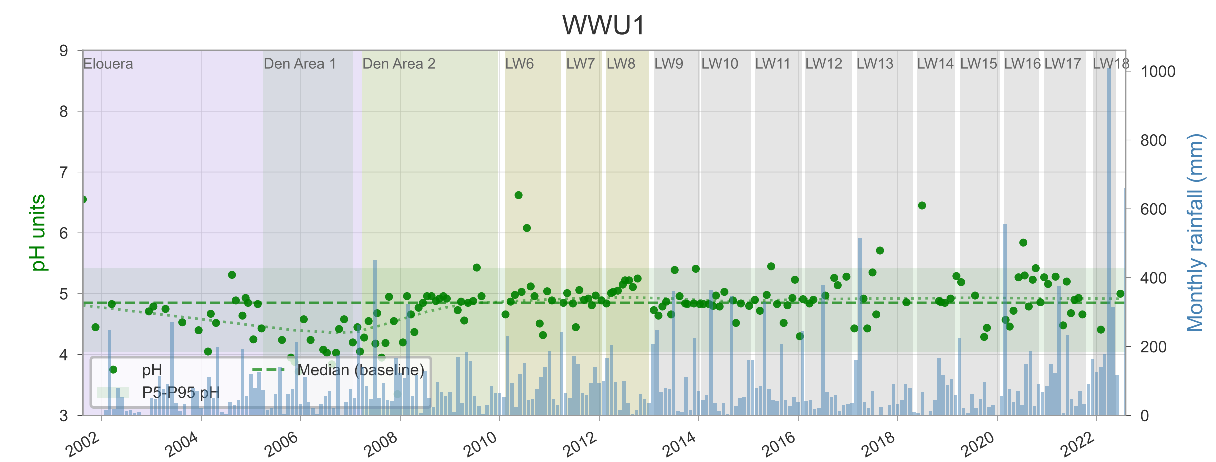

WC_POOL72B
pH units
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
pH
P5-P95 pH
Median (baseline)

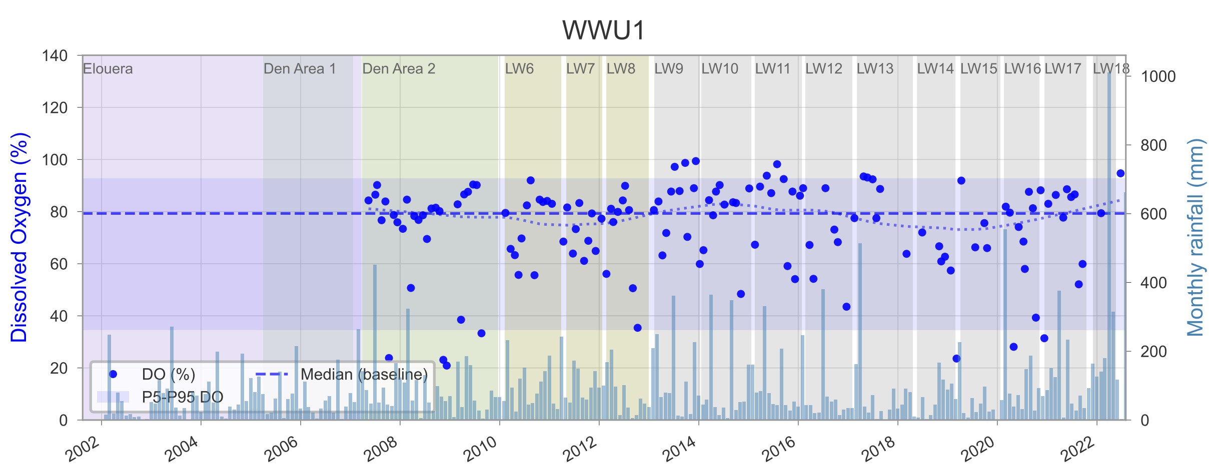

WC_POOL72B
Dissolved Oxygen (%)
Monthly rainfall (mm)
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
DO (%)
P5-P95 DO
Median (baseline)

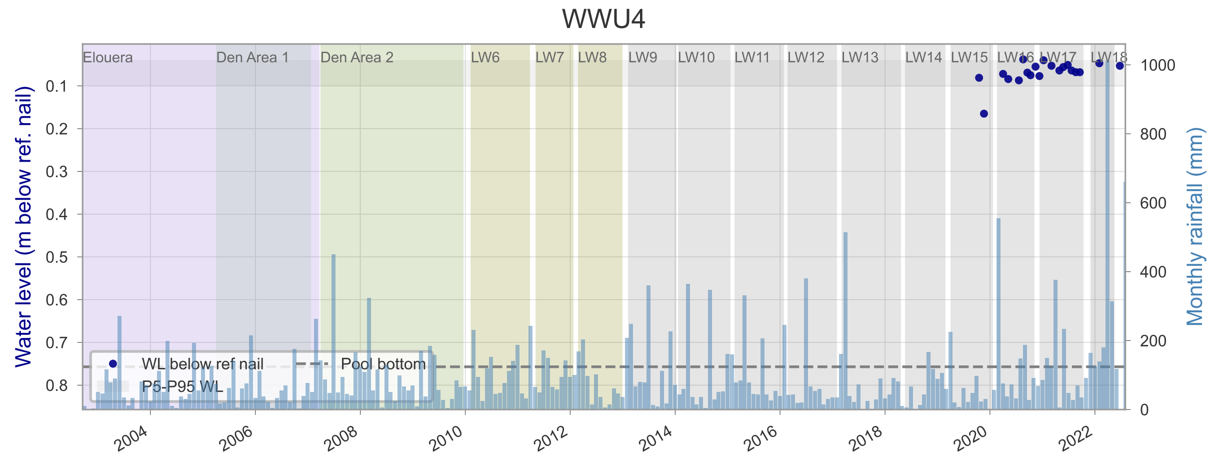
WC_POOL87
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
Pool bottom
P5-P95 WL
WC_POOL87
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
P5-P95 EC
LOWESS (0.3)
Median (baseline)
WC_POOL87
pH units
Monthly rainfall (mm)
pH
Median (baseline)
P5-P95 pH
WC_POOL87
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
Median (baseline)
P5-P95 DO

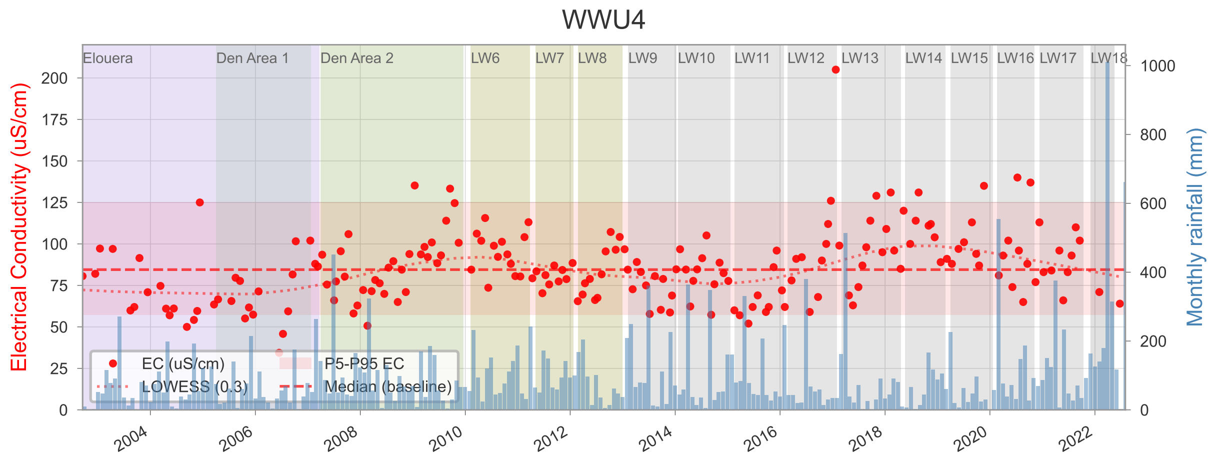

WWU1
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
No water below nail
P5-P95 WL
Pool bottom

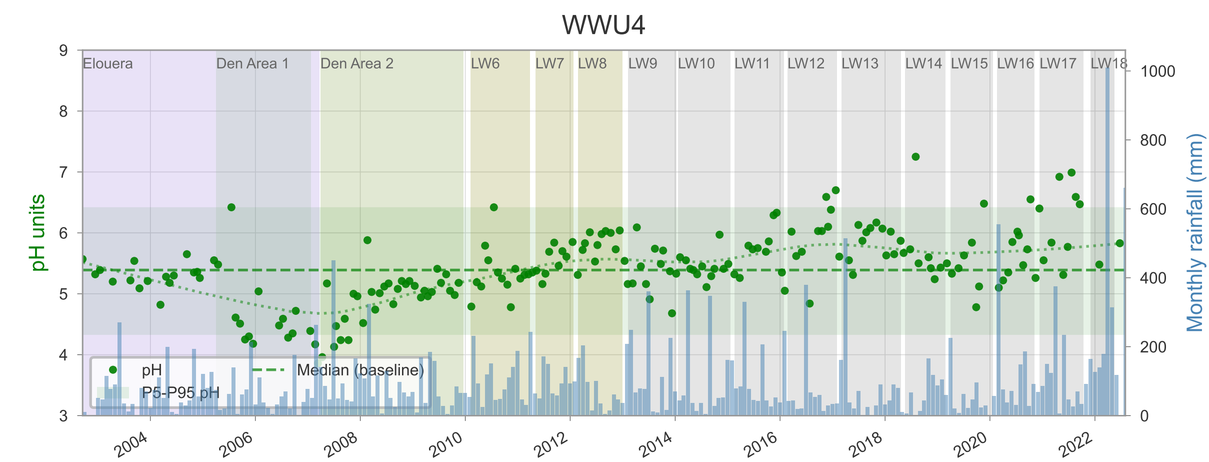

WWU1
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
P5-P95 EC
Median (baseline)

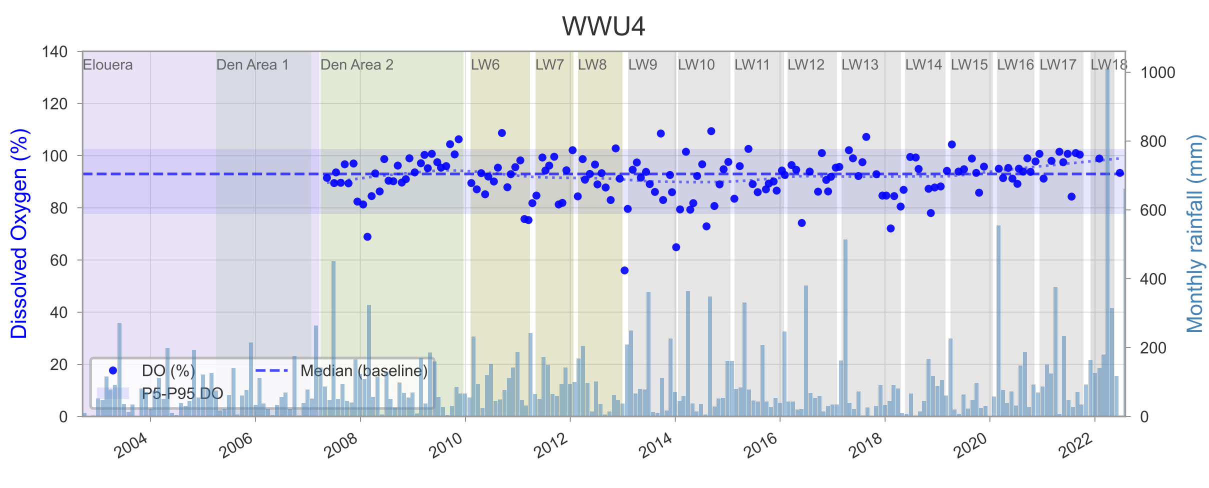

WWU1
pH units
Monthly rainfall (mm)
pH
P5-P95 pH
Median (baseline)

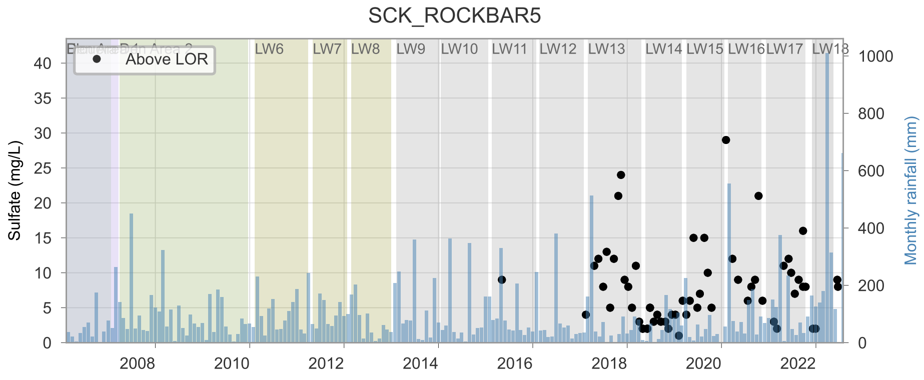

WWU1
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
P5-P95 DO
Median (baseline)

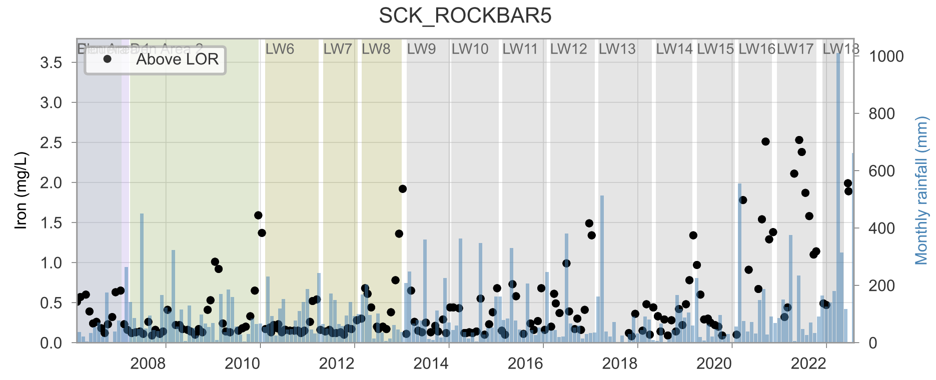

WWU4
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Water level (m below ref. nail)
Monthly rainfall (mm)
WL below ref nail
P5-P95 WL
Pool bottom
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
200
400
600
800
1000
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022

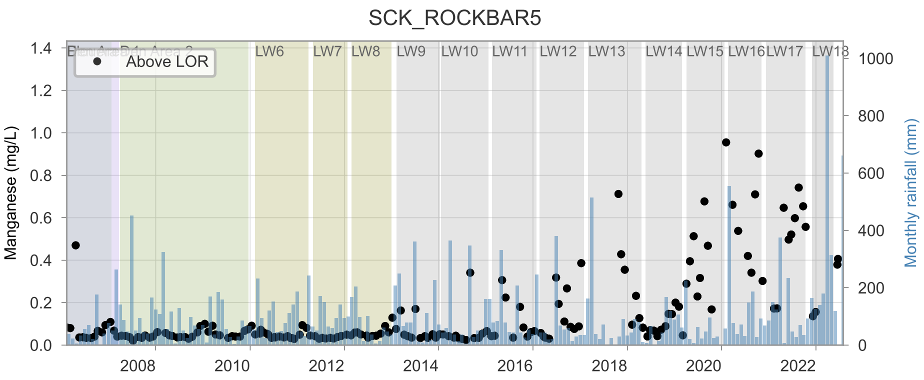

WWU4
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
EC (uS/cm)
LOWESS (0.3)
P5-P95 EC
Median (baseline)
0
25
50
75
100
125
150
175
200
0
200
400
600
800
1000
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022

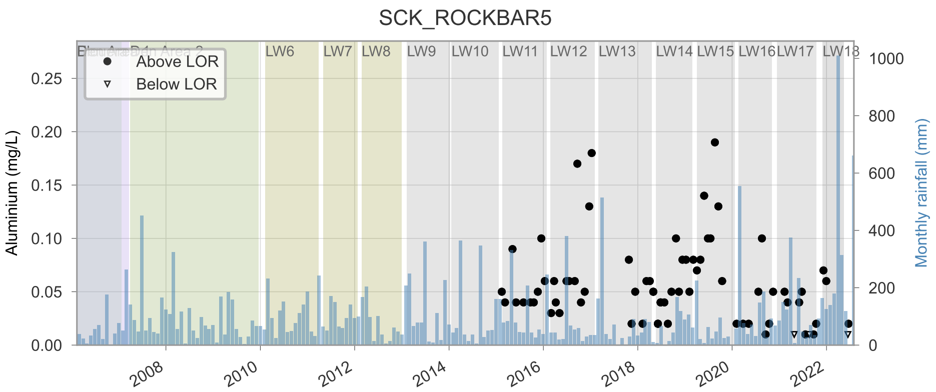

WWU4
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
pH units
Monthly rainfall (mm)
pH
P5-P95 pH
Median (baseline)
3
4
5
6
7
8
9
0
200
400
600
800
1000
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022

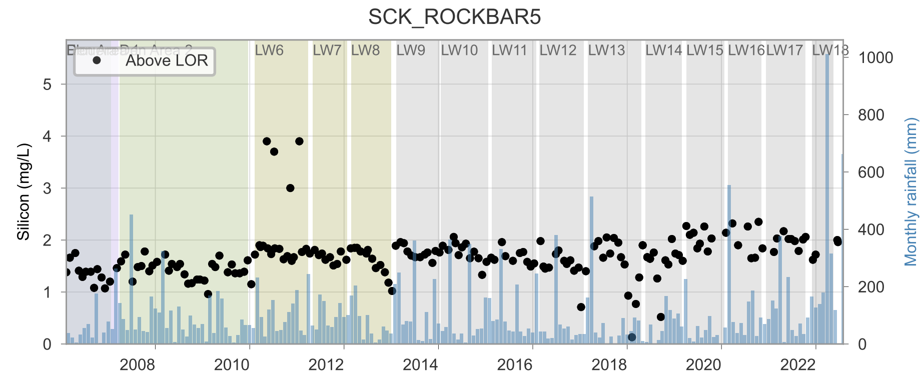

WWU4
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Dissolved Oxygen (%)
Monthly rainfall (mm)
DO (%)
P5-P95 DO
Median (baseline)
0
20
40
60
80
100
120
140
0
200
400
600
800
1000
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022

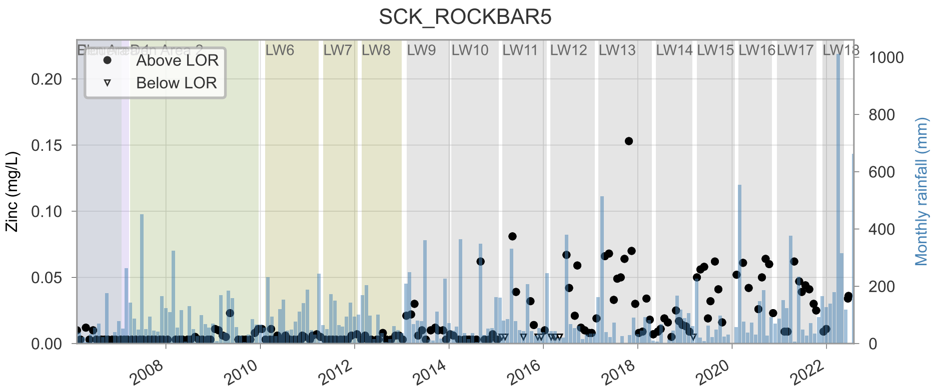

SCK_ROCKBAR5
Sulfate (mg/L)
Monthly rainfall (mm)
Above LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

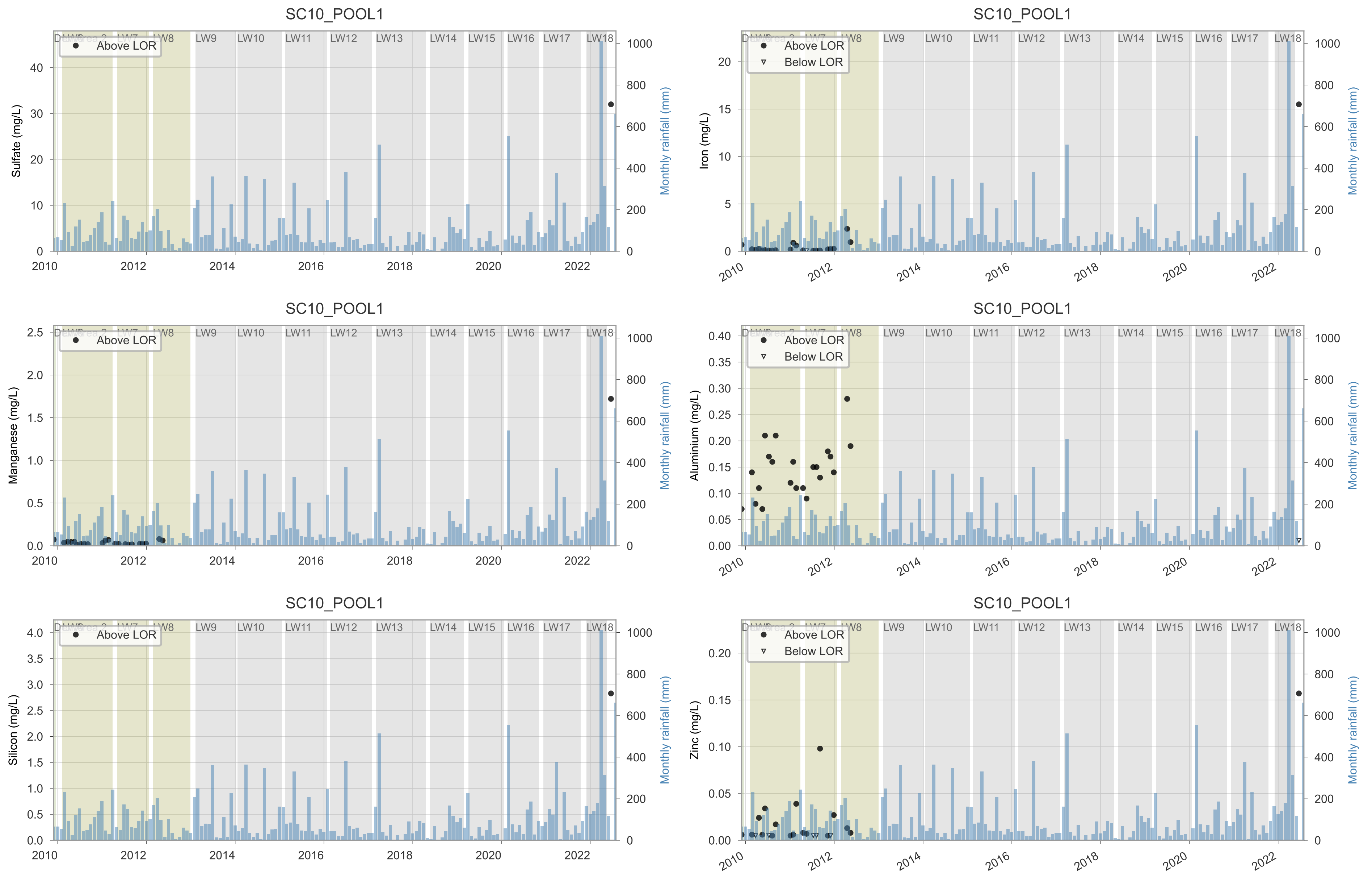

SCK_ROCKBAR5
Iron (mg/L)
Monthly rainfall (mm)
Above LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

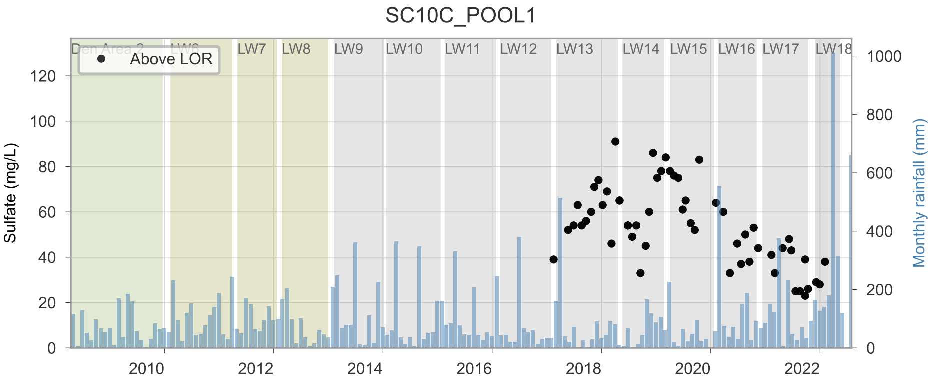

SCK_ROCKBAR5
Manganese (mg/L)
Monthly rainfall (mm)
Above LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

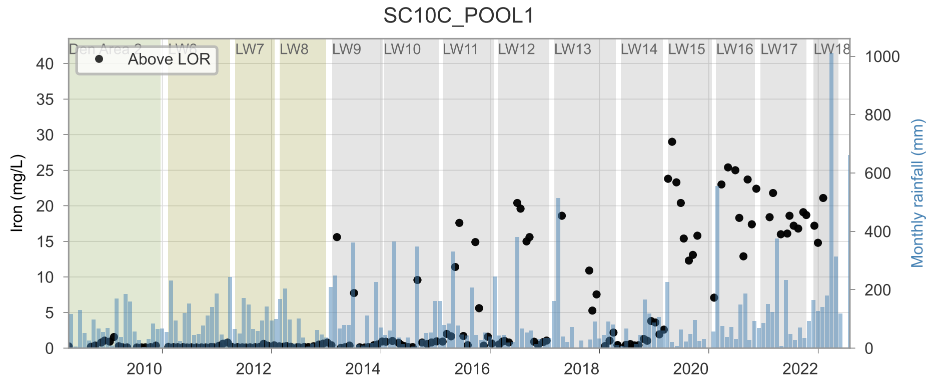

SCK_ROCKBAR5
Aluminium (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

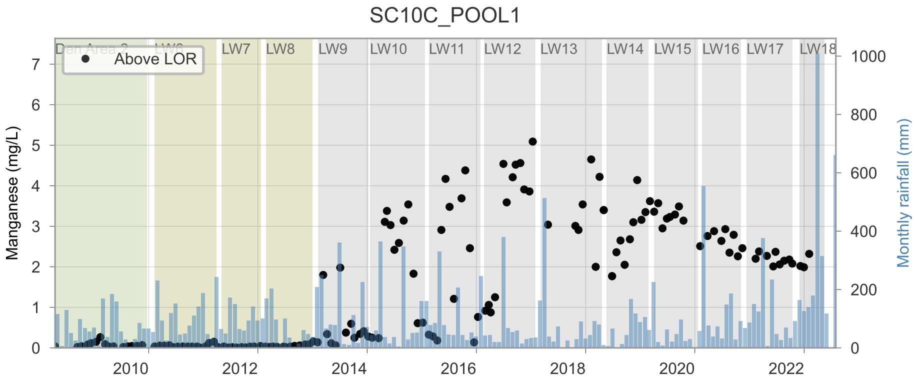

SCK_ROCKBAR5
Silicon (mg/L)
Monthly rainfall (mm)
Above LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

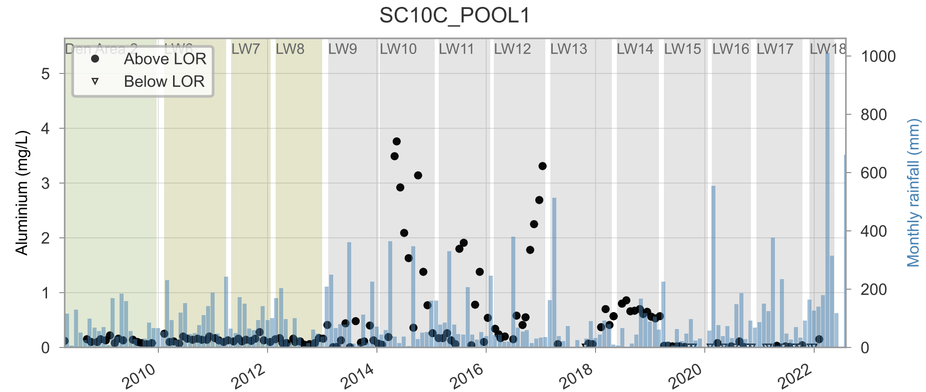

SCK_ROCKBAR5
Zinc (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

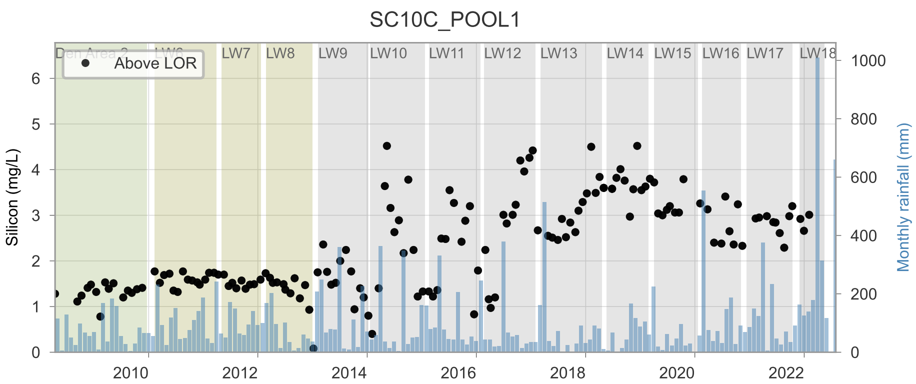

SC10_POOL1
Sulfate (mg/L)
Iron (mg/L)
Manganese (mg/L)
Aluminium (mg/L)
Silicon (mg/L)
Zinc (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
2010
2012
2014
2016
2018
2020
2022

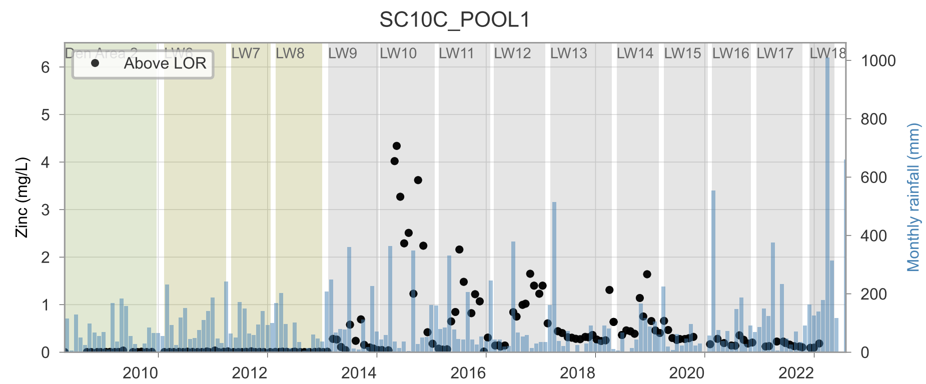

SC10C_POOL1
Above LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Sulfate (mg/L)
Monthly rainfall (mm)

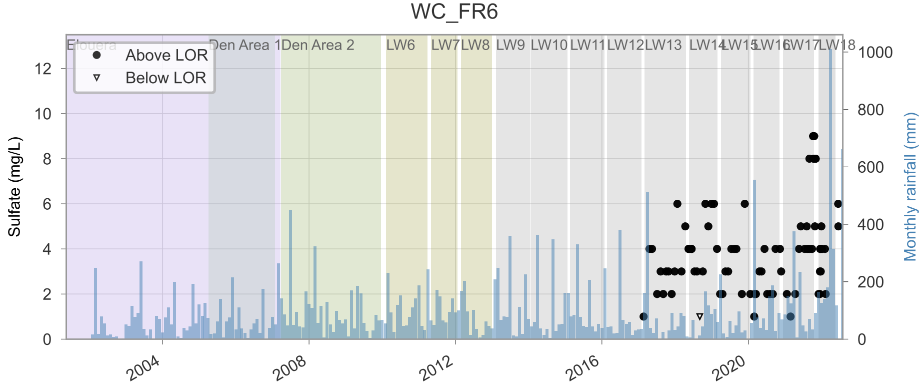

SC10C_POOL1
Above LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Iron (mg/L)
Monthly rainfall (mm)

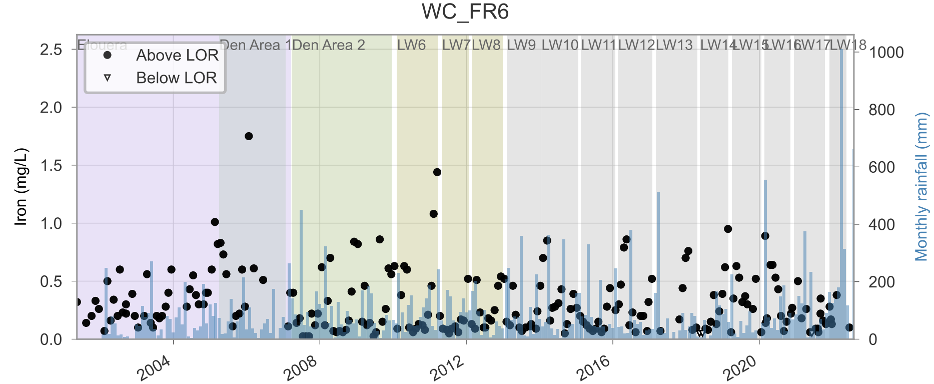

SC10C_POOL1
Above LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Manganese (mg/L)
Monthly rainfall (mm)

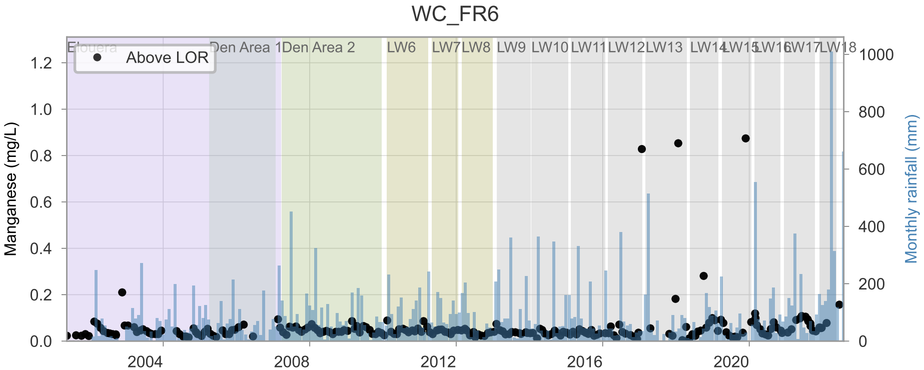

SC10C_POOL1
Above LOR
Below LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Aluminium (mg/L)
Monthly rainfall (mm)

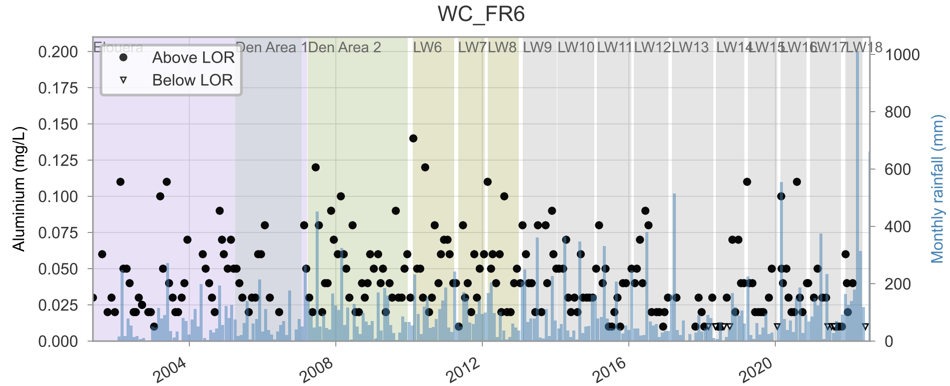

SC10C_POOL1
Above LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Silicon (mg/L)
Monthly rainfall (mm)

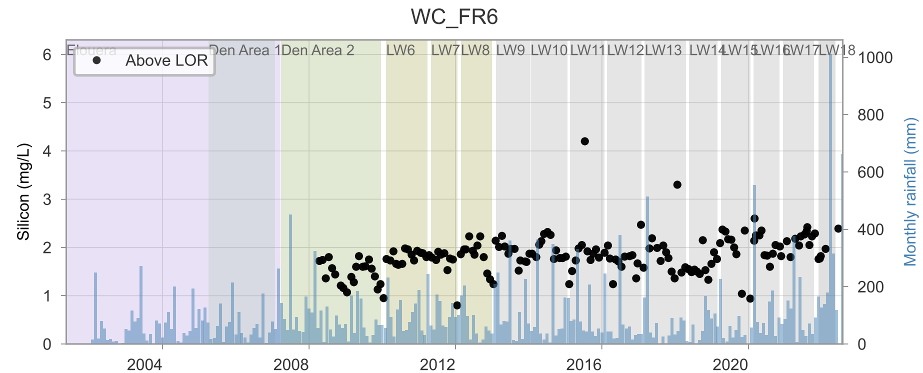

SC10C_POOL1
Above LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Zinc (mg/L)
Monthly rainfall (mm)

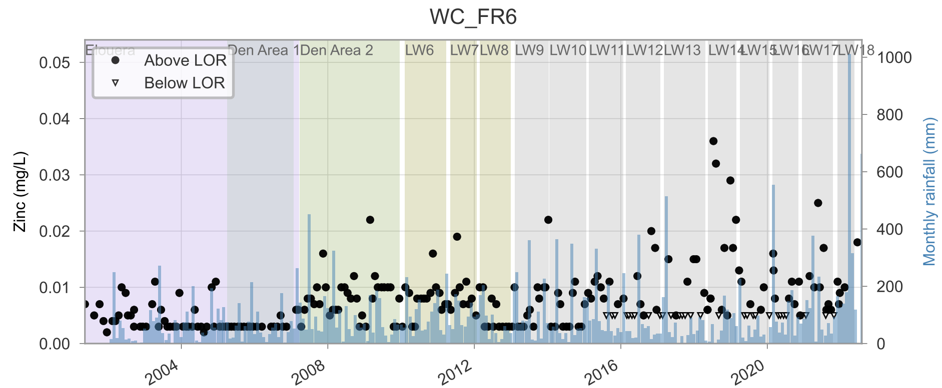

WC_FR6
Elouera
Den Area 1
Den Area 2
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15 LW16 LW17 LW18
Above LOR
Below LOR
Sulfate (mg/L)
Monthly rainfall (mm)

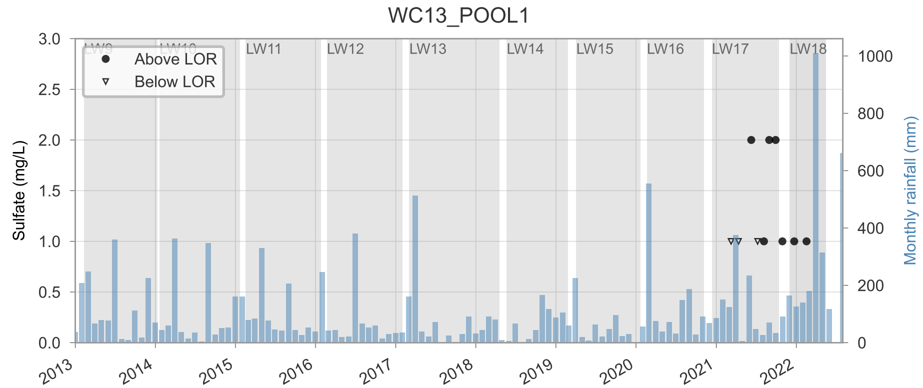

WC_FR6
Elouera
Den Area 1
Den Area 2
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15 LW16 LW17 LW18
Above LOR
Below LOR
Iron (mg/L)
Monthly rainfall (mm)

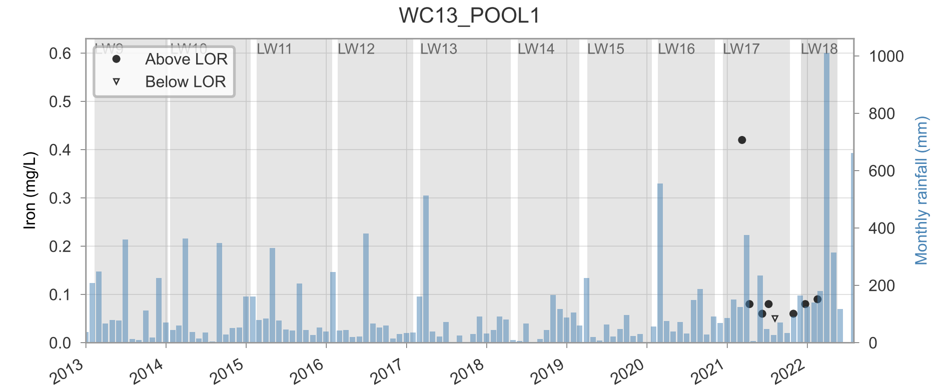

WC_FR6
Elouera
Den Area 1
Den Area 2
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15 LW16 LW17 LW18
Above LOR
Manganese (mg/L)
Monthly rainfall (mm)

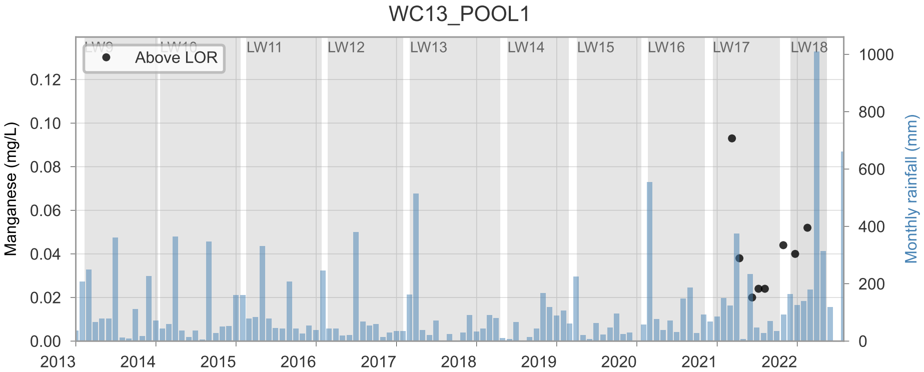

WC_FR6
Elouera
Den Area 1
Den Area 2
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15 LW16 LW17 LW18
Above LOR
Below LOR
Aluminium (mg/L)
Monthly rainfall (mm)

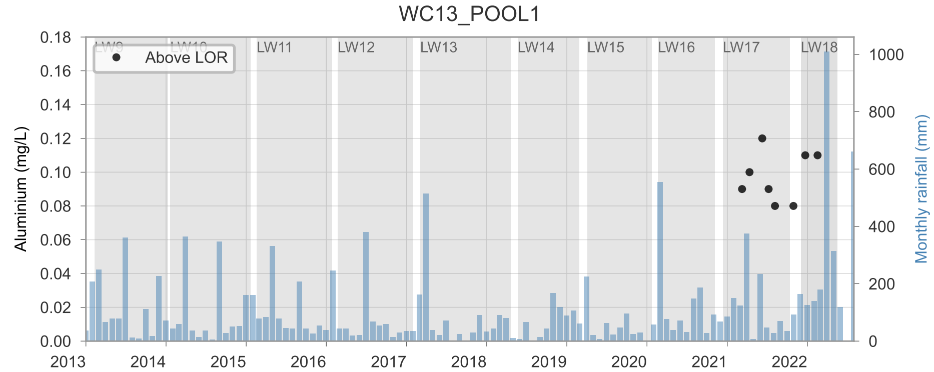

WC_FR6
Elouera
Den Area 1
Den Area 2
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15 LW16 LW17 LW18
Above LOR
Silicon (mg/L)
Monthly rainfall (mm)

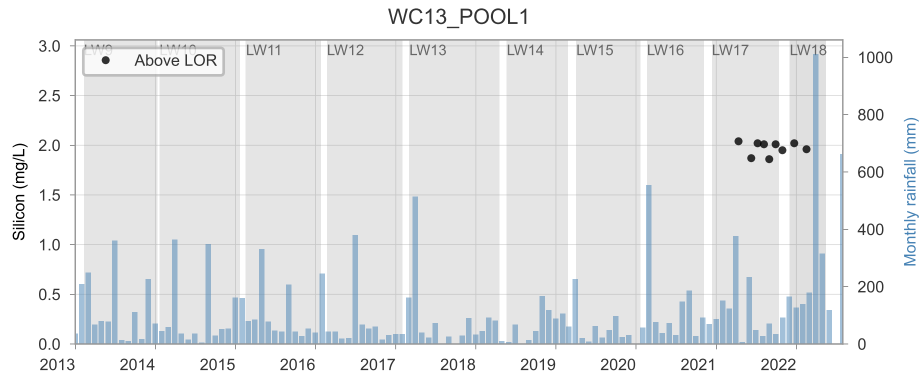

WC_FR6
Elouera
Den Area 1
Den Area 2
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15 LW16 LW17 LW18
Above LOR
Below LOR
Zinc (mg/L)
Monthly rainfall (mm)

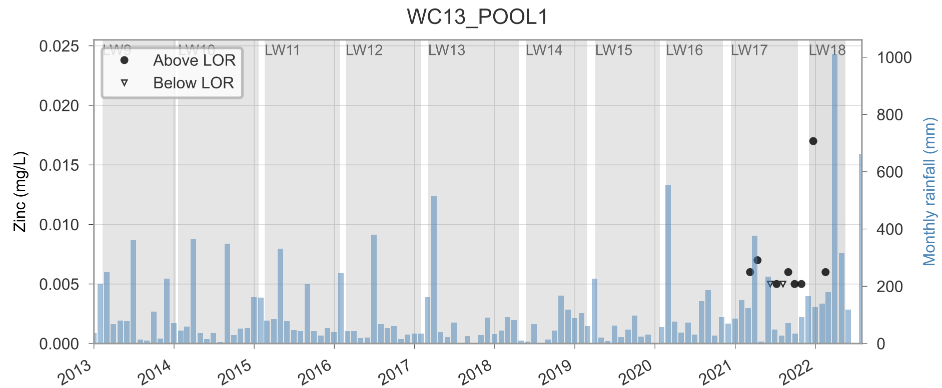

WC13_POOL1
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Sulfate (mg/L)
Monthly rainfall (mm)

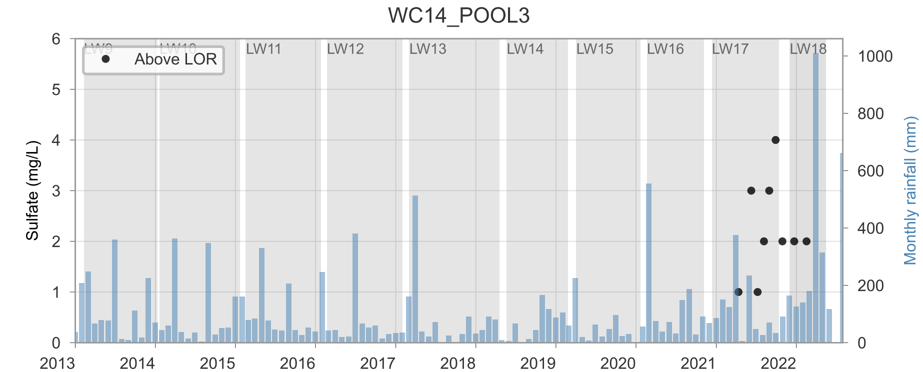

WC13_POOL1
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Iron (mg/L)
Monthly rainfall (mm)

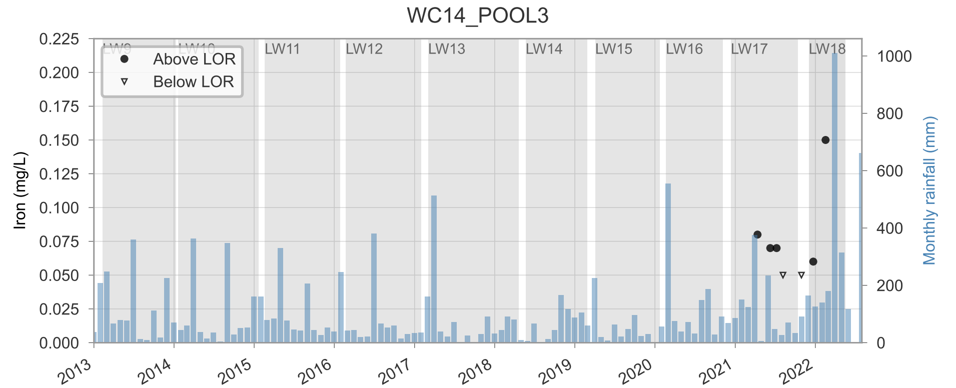

WC13_POOL1
Above LOR
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Manganese (mg/L)
Monthly rainfall (mm)

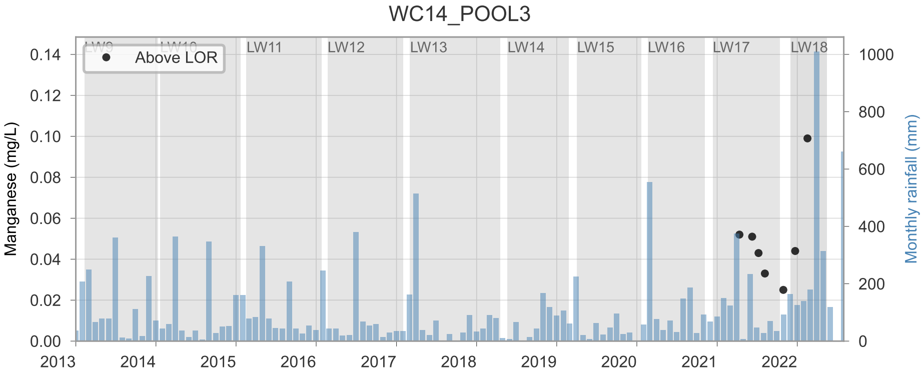

WC13_POOL1
Above LOR
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Aluminium (mg/L)
Monthly rainfall (mm)

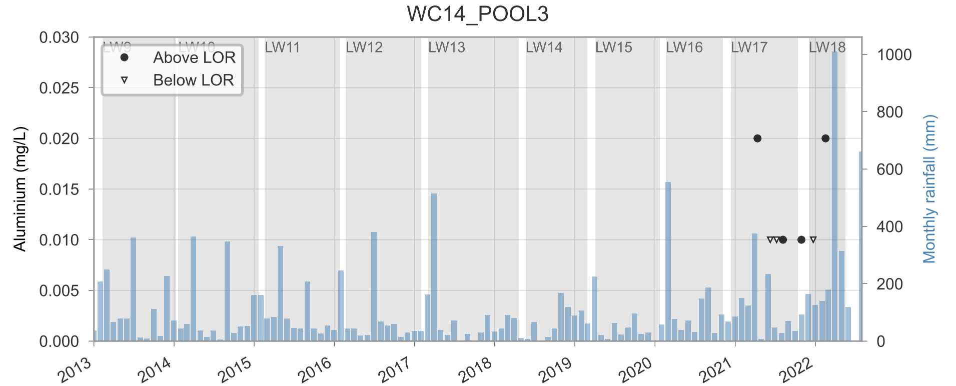

WC13_POOL1
Above LOR
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Silicon (mg/L)
Monthly rainfall (mm)

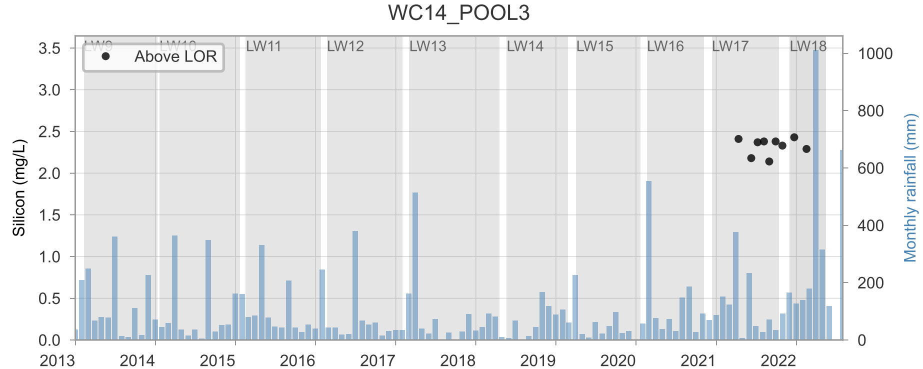

WC13_POOL1
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Zinc (mg/L)
Monthly rainfall (mm)

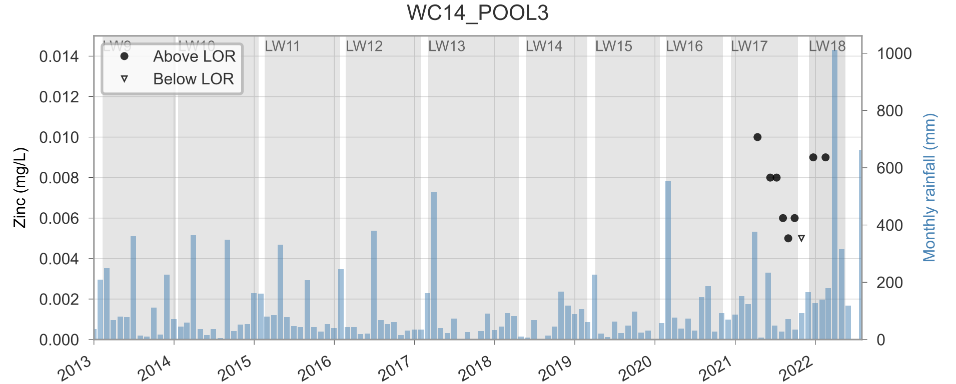

WC14_POOL3
Sulfate (mg/L)
Monthly rainfall (mm)
Above LOR
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022

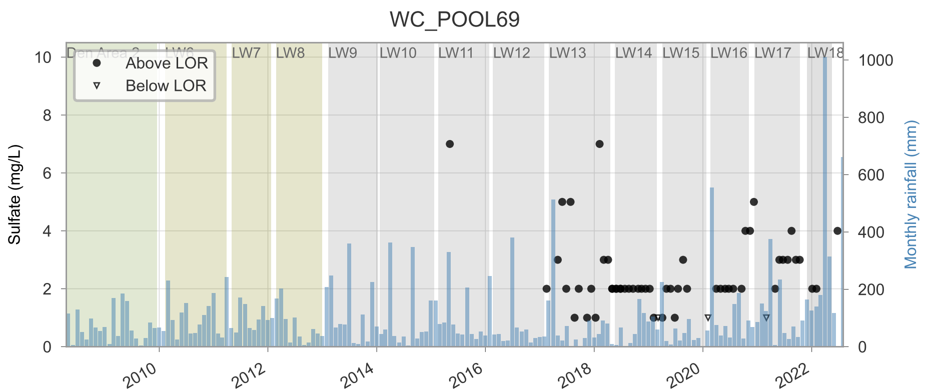

WC14_POOL3
Iron (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022

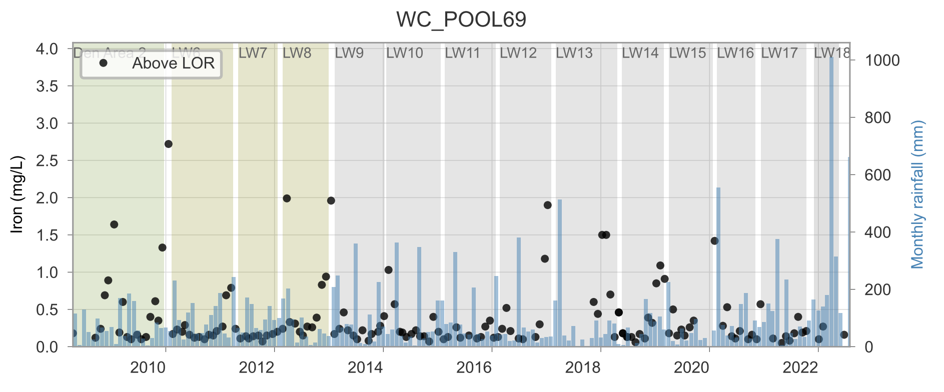

WC14_POOL3
Manganese (mg/L)
Monthly rainfall (mm)
Above LOR
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022

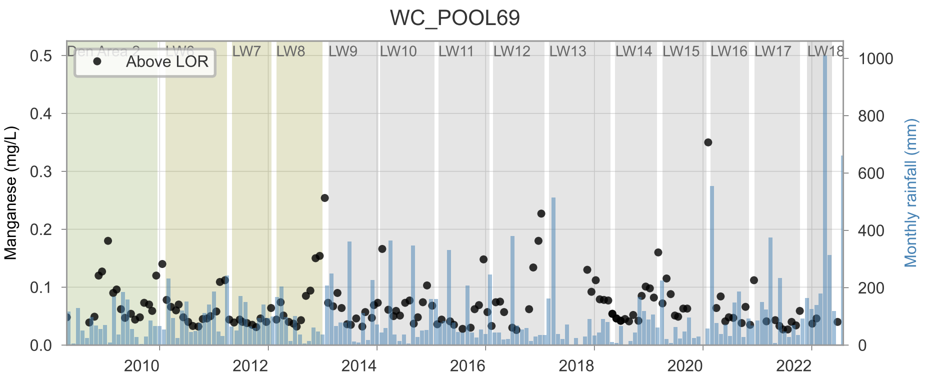

WC14_POOL3
Aluminium (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022

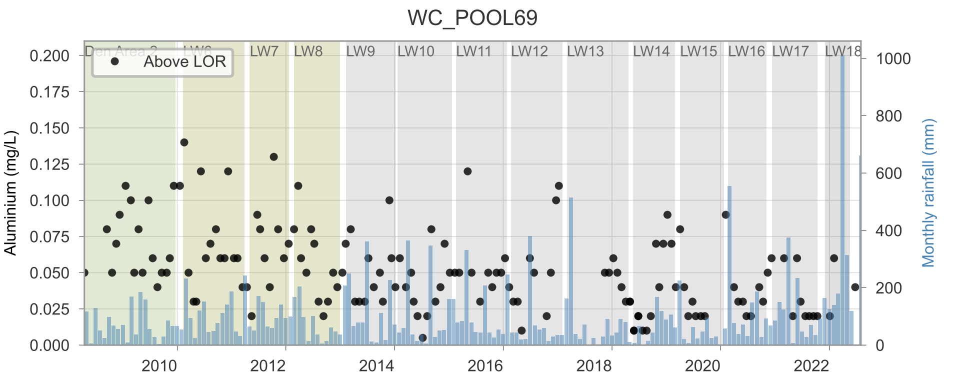

WC14_POOL3
Silicon (mg/L)
Monthly rainfall (mm)
Above LOR
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022

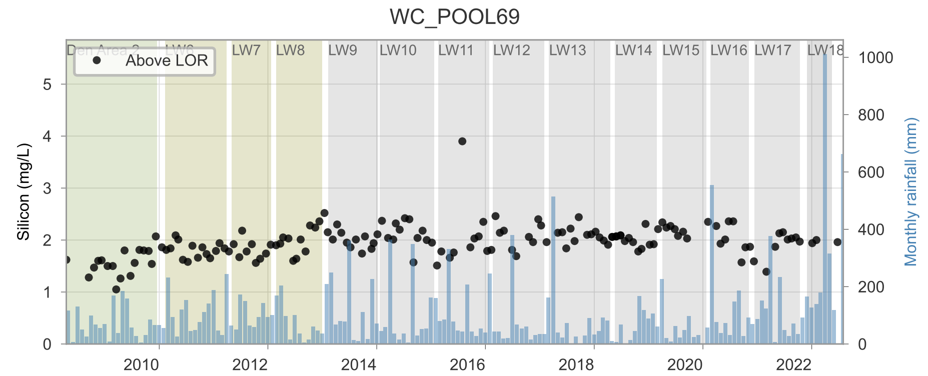

WC14_POOL3
Zinc (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022

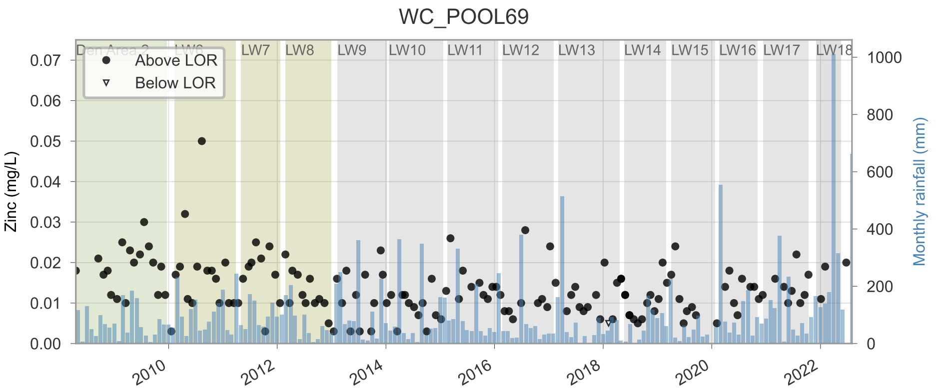

WC_POOL69
Sulfate (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

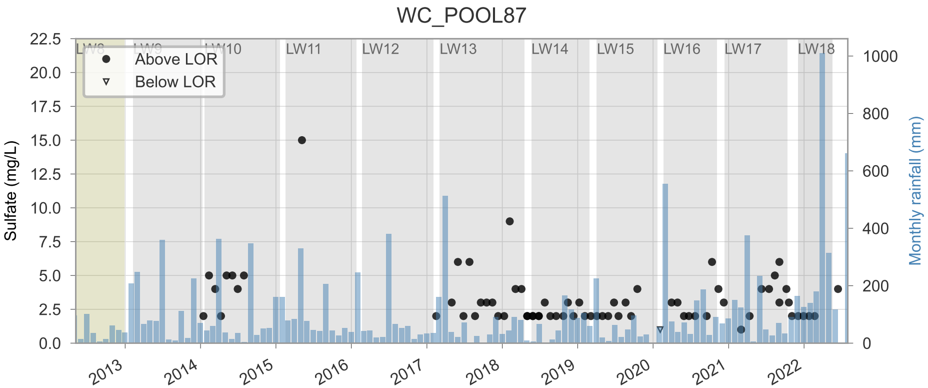

WC_POOL69
Iron (mg/L)
Monthly rainfall (mm)
Above LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

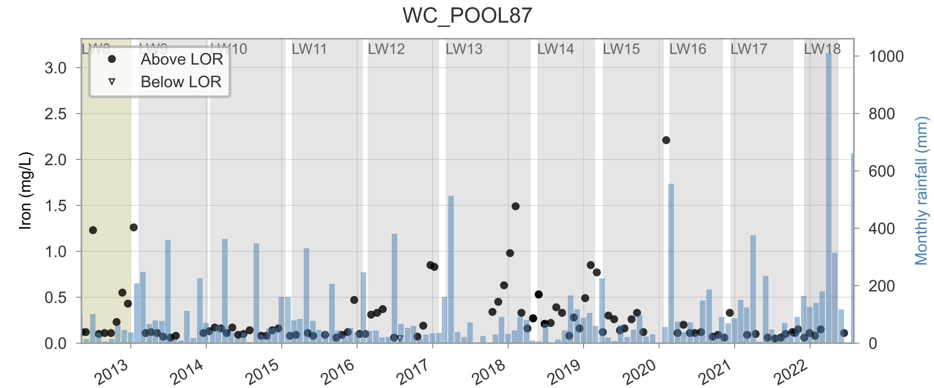

WC_POOL69
Manganese (mg/L)
Monthly rainfall (mm)
Above LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

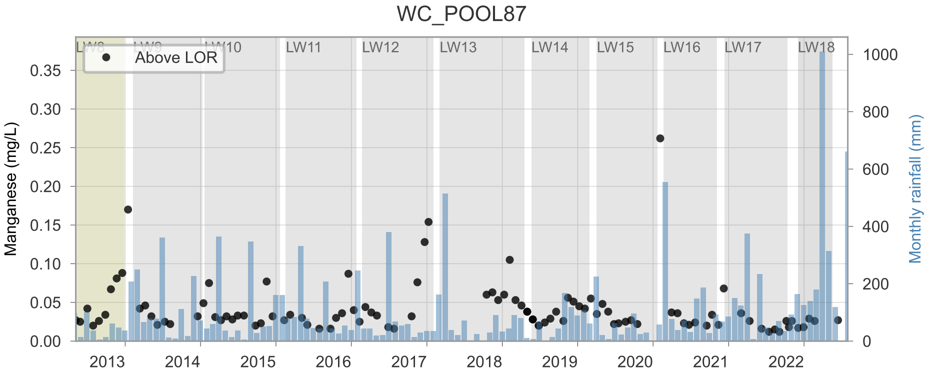

WC_POOL69
Aluminium (mg/L)
Monthly rainfall (mm)
Above LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

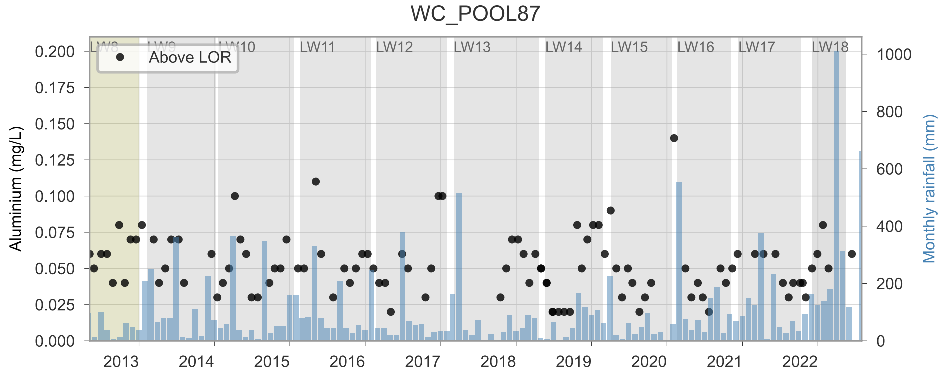

WC_POOL69
Silicon (mg/L)
Monthly rainfall (mm)
Above LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

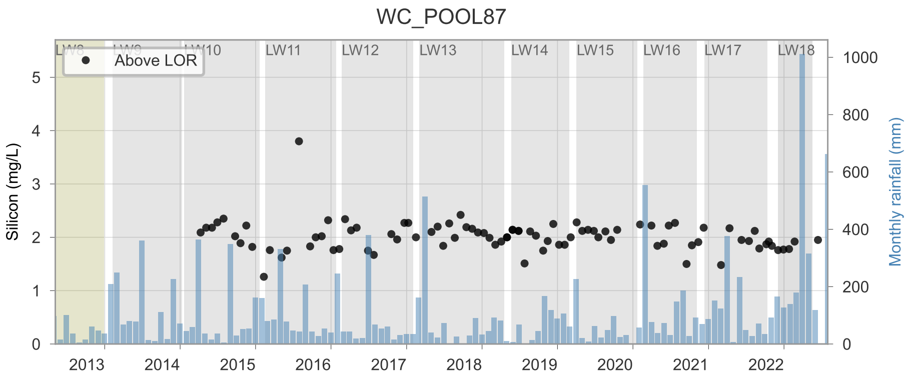

WC_POOL69
Zinc (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

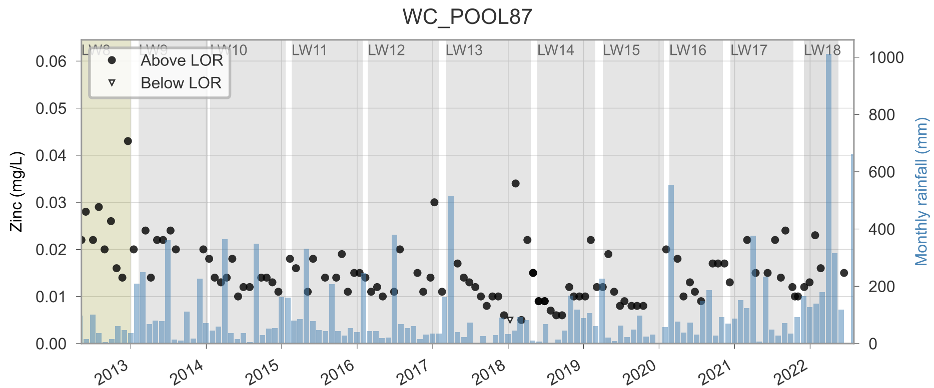

WC_POOL87
Sulfate (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

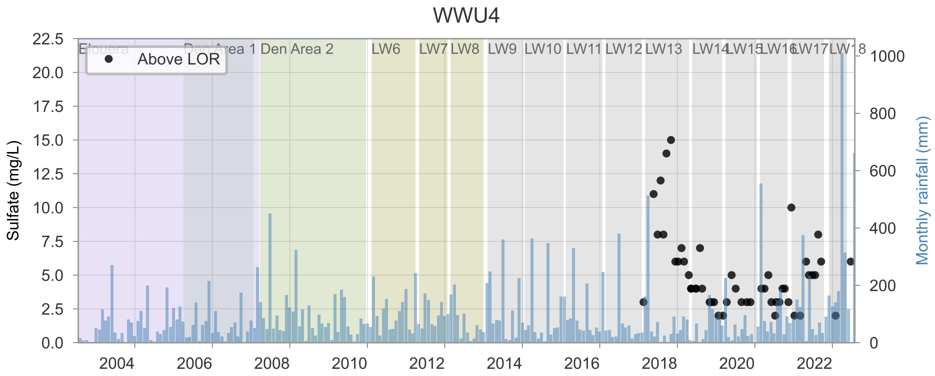

WC_POOL87
Iron (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

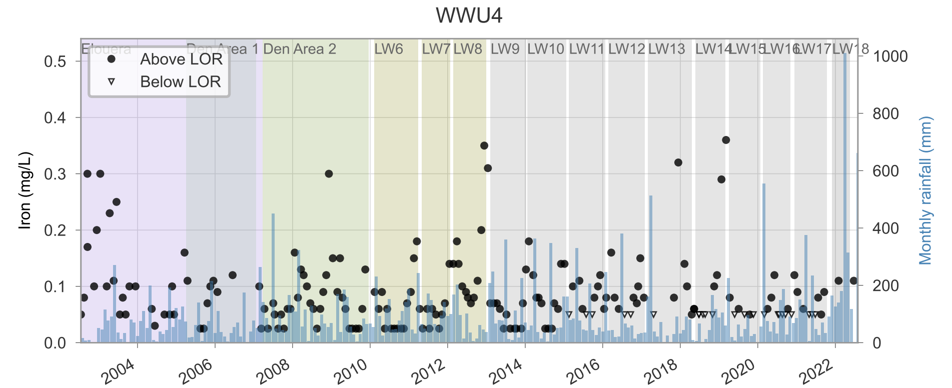

WC_POOL87
Manganese (mg/L)
Monthly rainfall (mm)
Above LOR
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

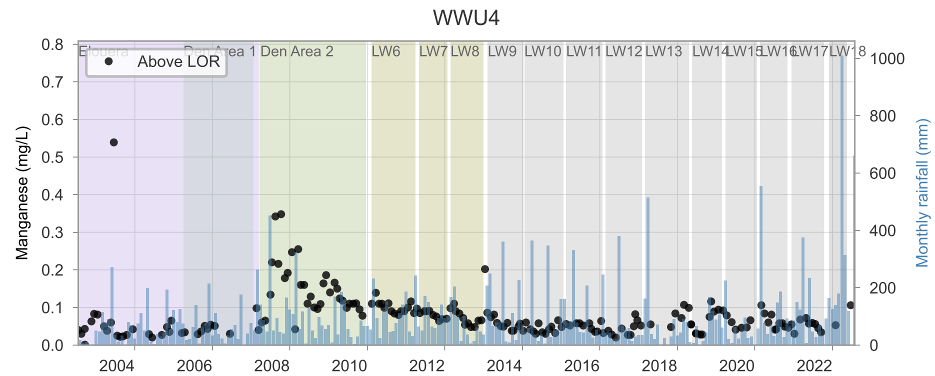

WC_POOL87
Aluminium (mg/L)
Monthly rainfall (mm)
Above LOR
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

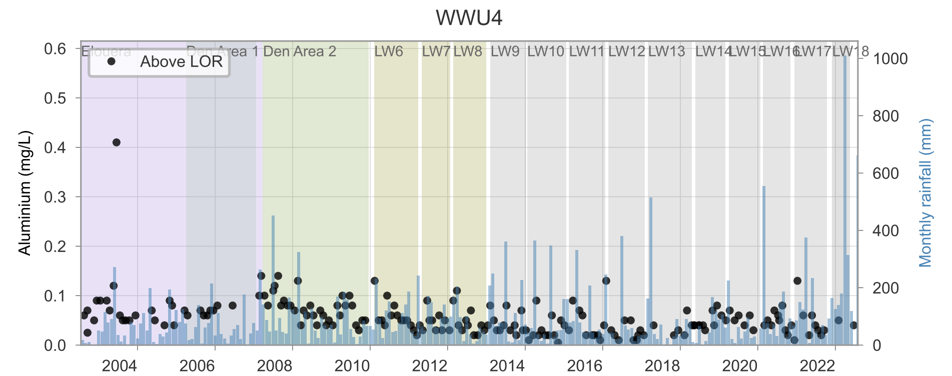

WC_POOL87
Silicon (mg/L)
Monthly rainfall (mm)
Above LOR
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

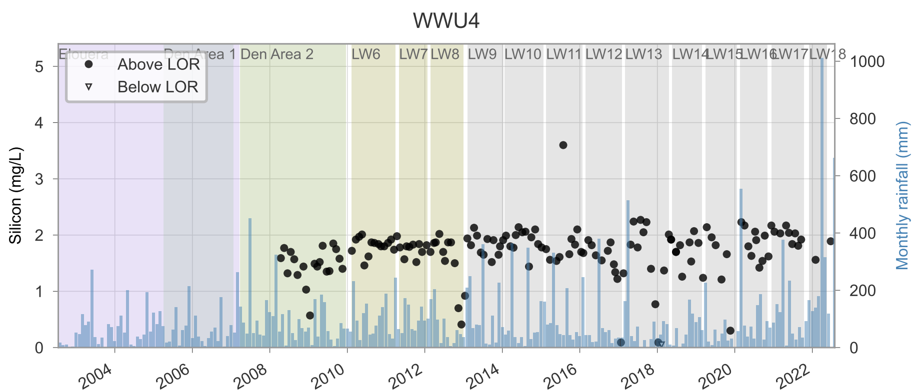

WC_POOL87
Zinc (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18

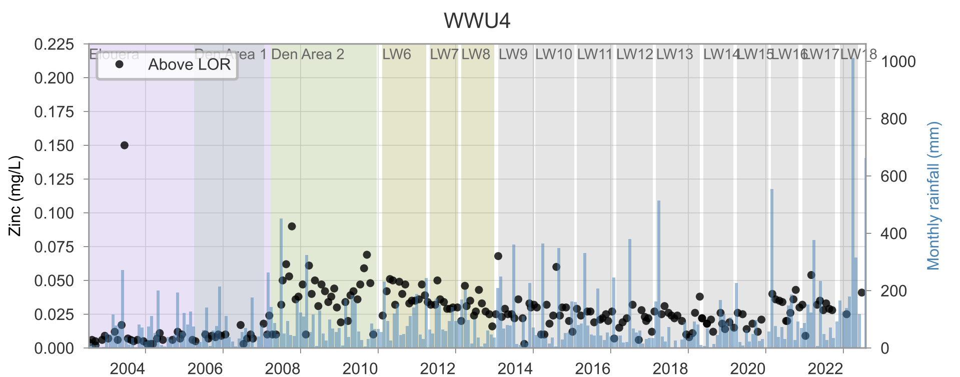

WWU4
Sulfate (mg/L)
Monthly rainfall (mm)
Above LOR


WWU4
Iron (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR

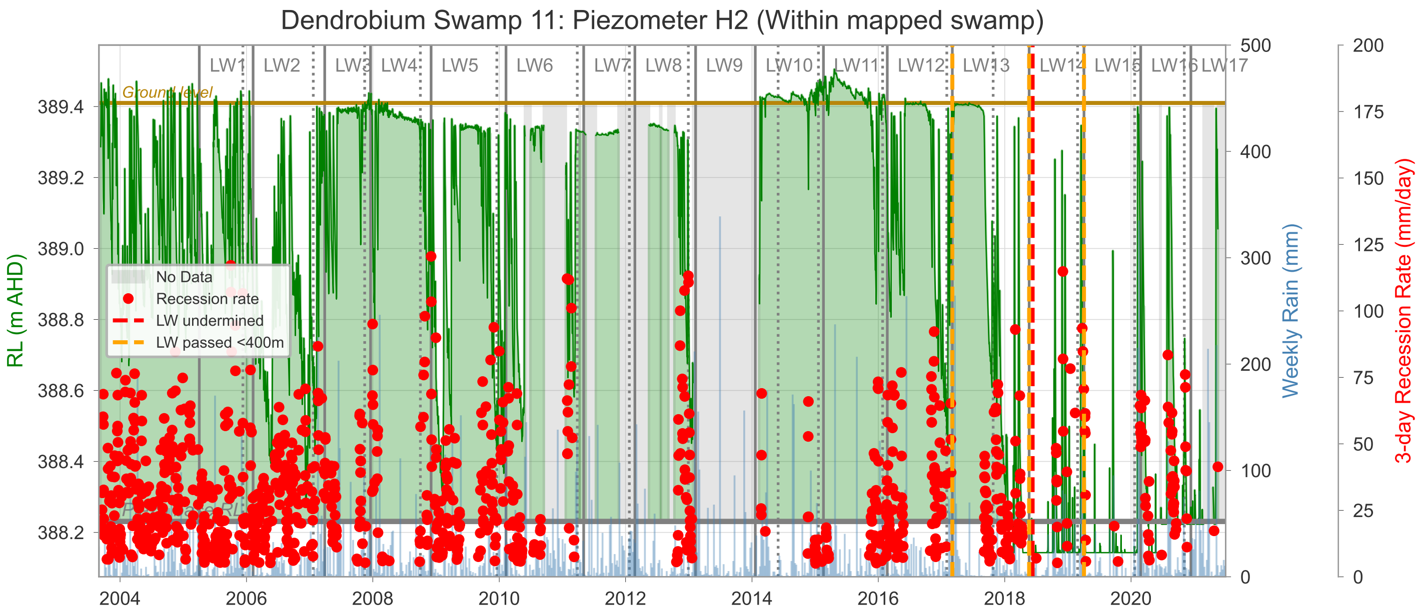

WWU4
Manganese (mg/L)
Monthly rainfall (mm)
Above LOR

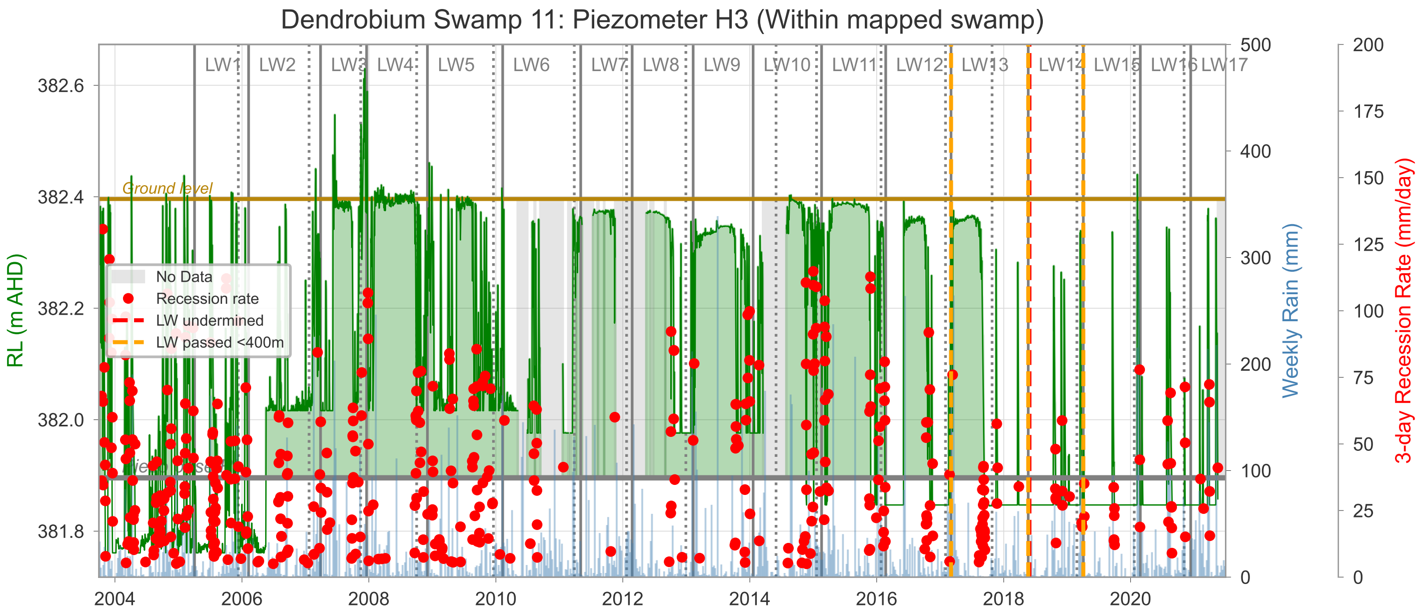

WWU4
Aluminium (mg/L)
Monthly rainfall (mm)
Above LOR

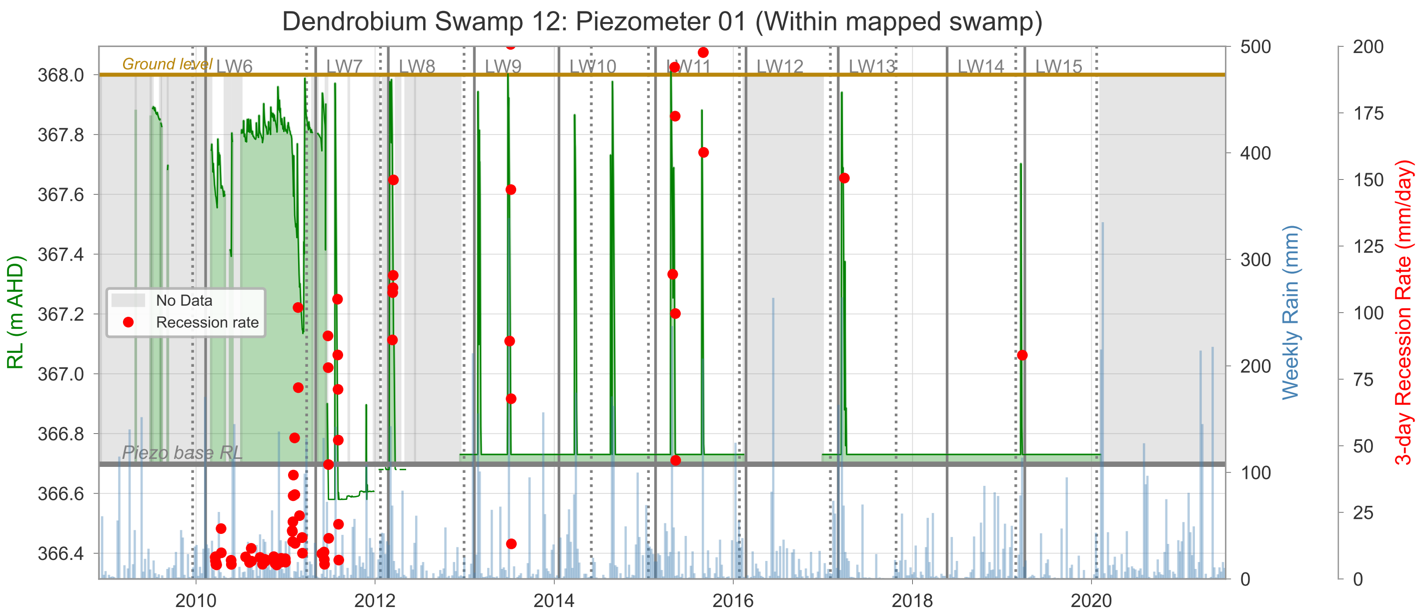

WWU4
Silicon (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR


WWU4
Zinc (mg/L)
Monthly rainfall (mm)
Above LOR

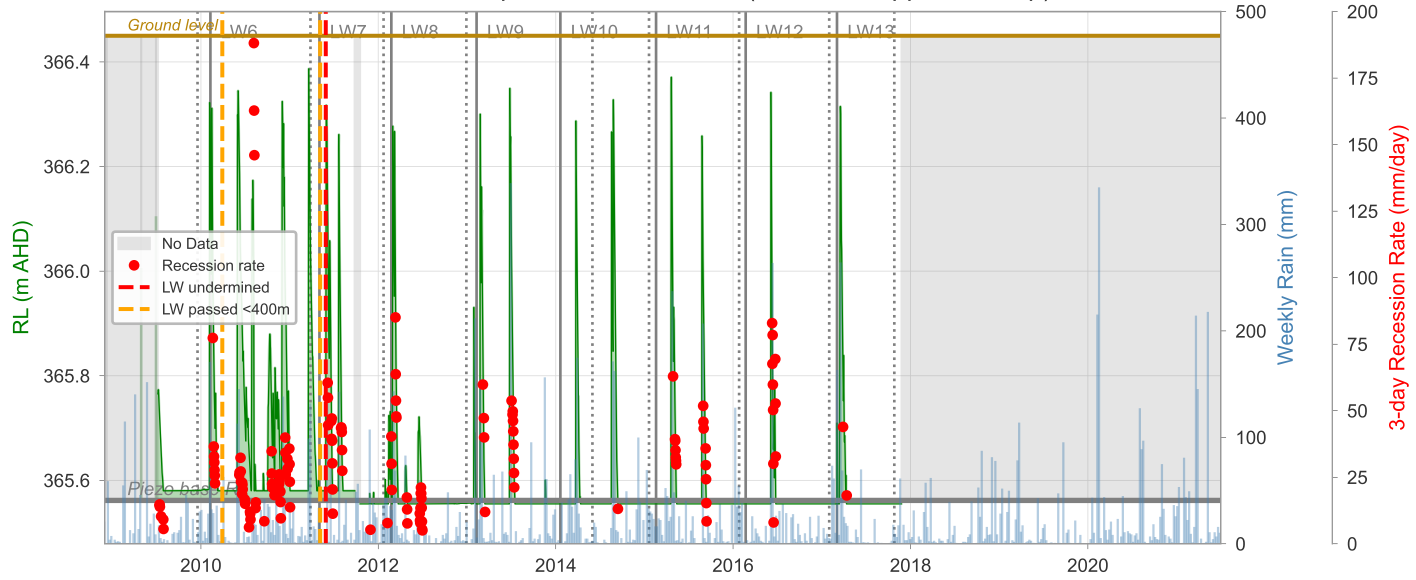
APPENDIX 2 – Swamp shallow groundwater hydrographs


Dendrobium Swamp 11: Piezometer H2 (Within mapped swamp)
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)
Ground level
No Data
Recession rate
LW undermined
LW passed <400m
LW1 LW2 LW3 LW4 LW5 LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15 LW16 LW17
2004 2006 2008 2010 2012 2014 2016 2018 2020

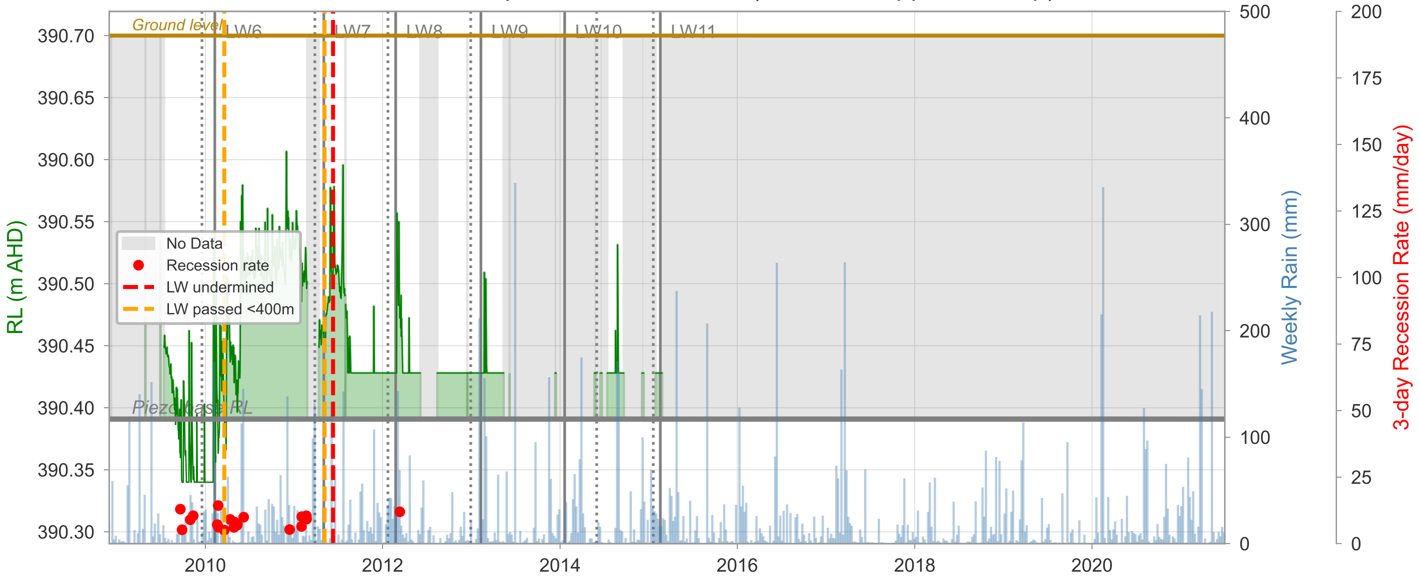

Dendrobium Swamp 11: Piezometer H3 (Within mapped swamp)
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)
Ground level
No Data
Recession rate
LW undermined
LW passed <400m
LW1 LW2 LW3 LW4 LW5 LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15 LW16 LW17
2004 2006 2008 2010 2012 2014 2016 2018 2020


Dendrobium Swamp 12: Piezometer 01 (Within mapped swamp)
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)
Ground level
Piezo base RL
No Data
Recession rate
LW6 LW7 LW8 LW9 LW10 LW11 LW12 LW13 LW14 LW15
2010 2012 2014 2016 2018 2020

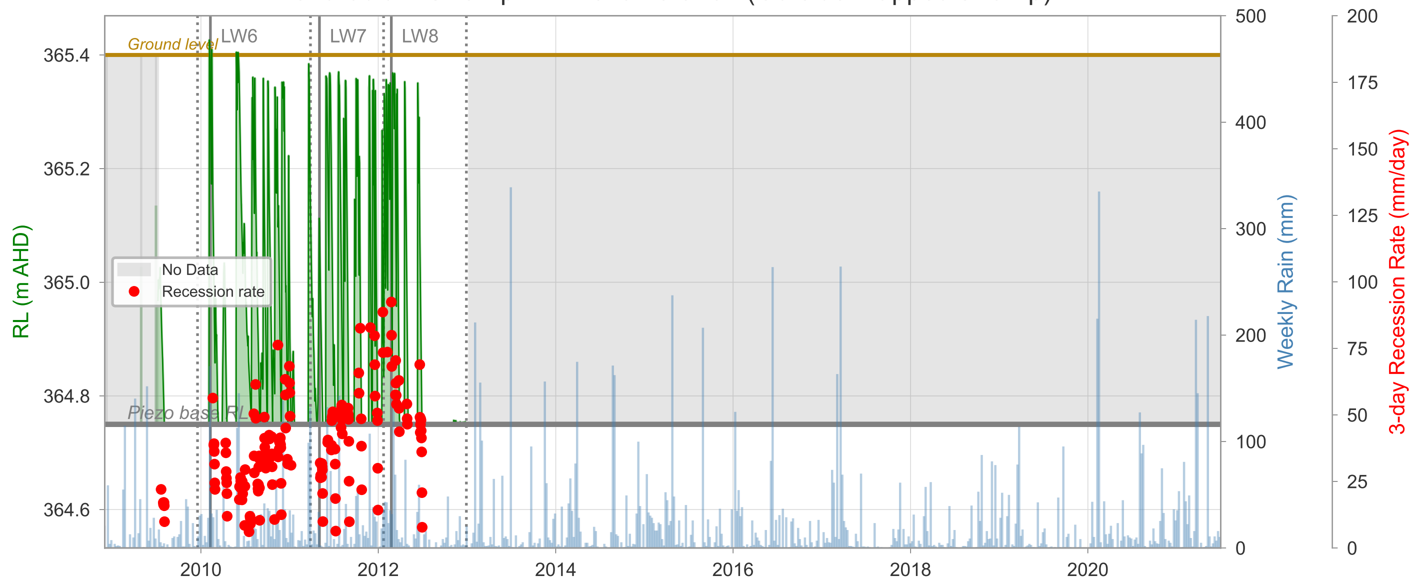
Dendrobium Swamp 12: Piezometer 02 (Outside mapped swamp)

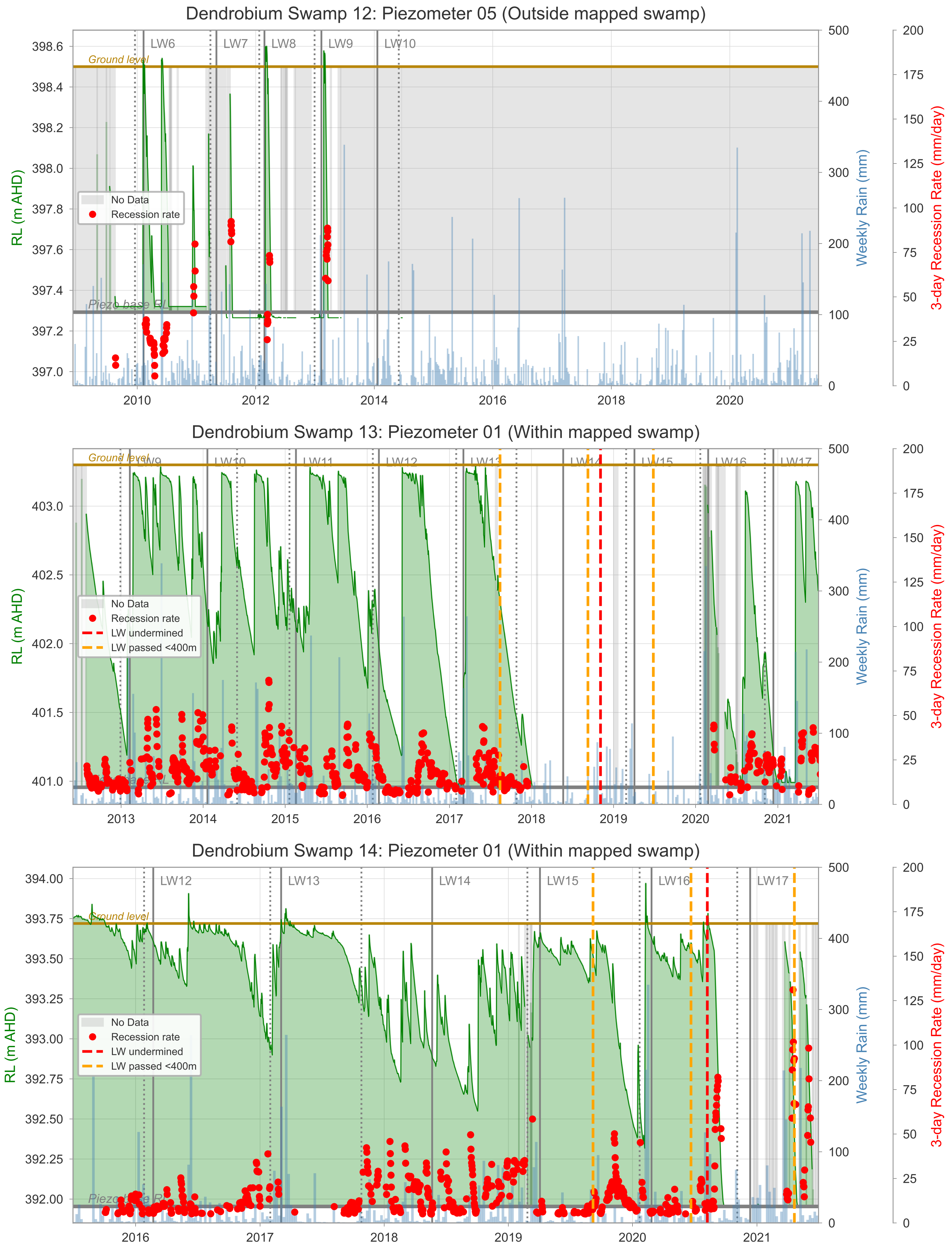


Dendrobium Swamp 12: Piezometer 03 (Outside mapped swamp)

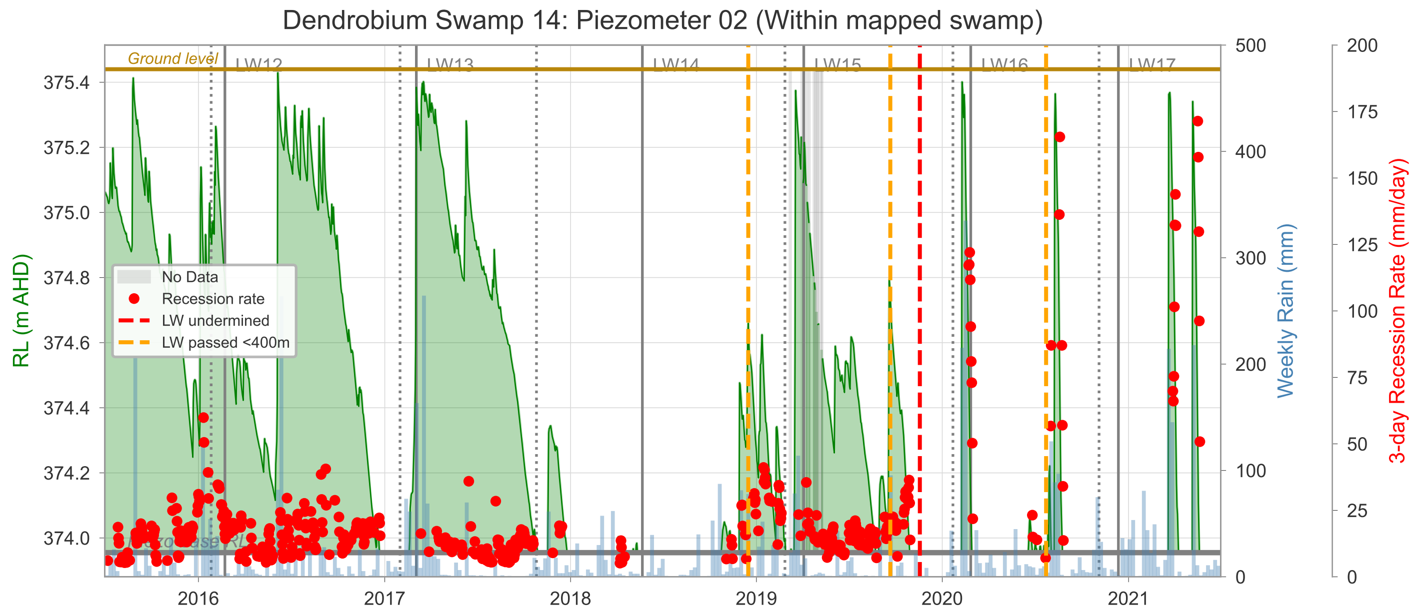


Dendrobium Swamp 12: Piezometer 04 (Outside mapped swamp)

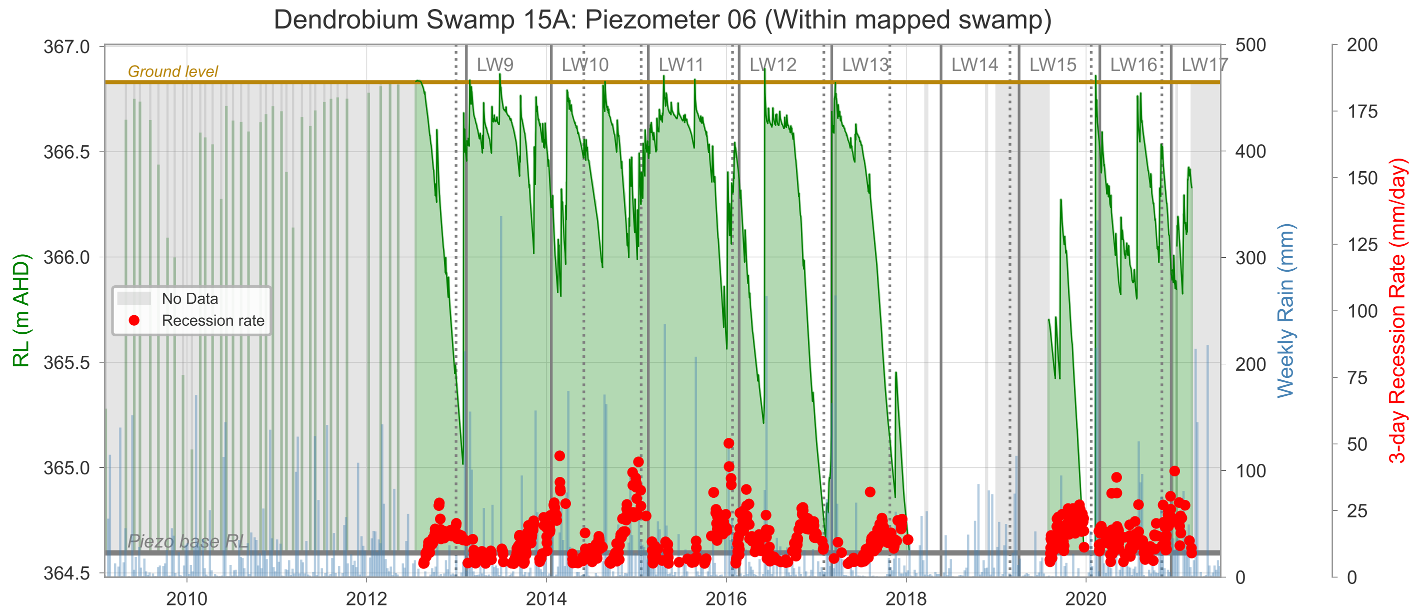




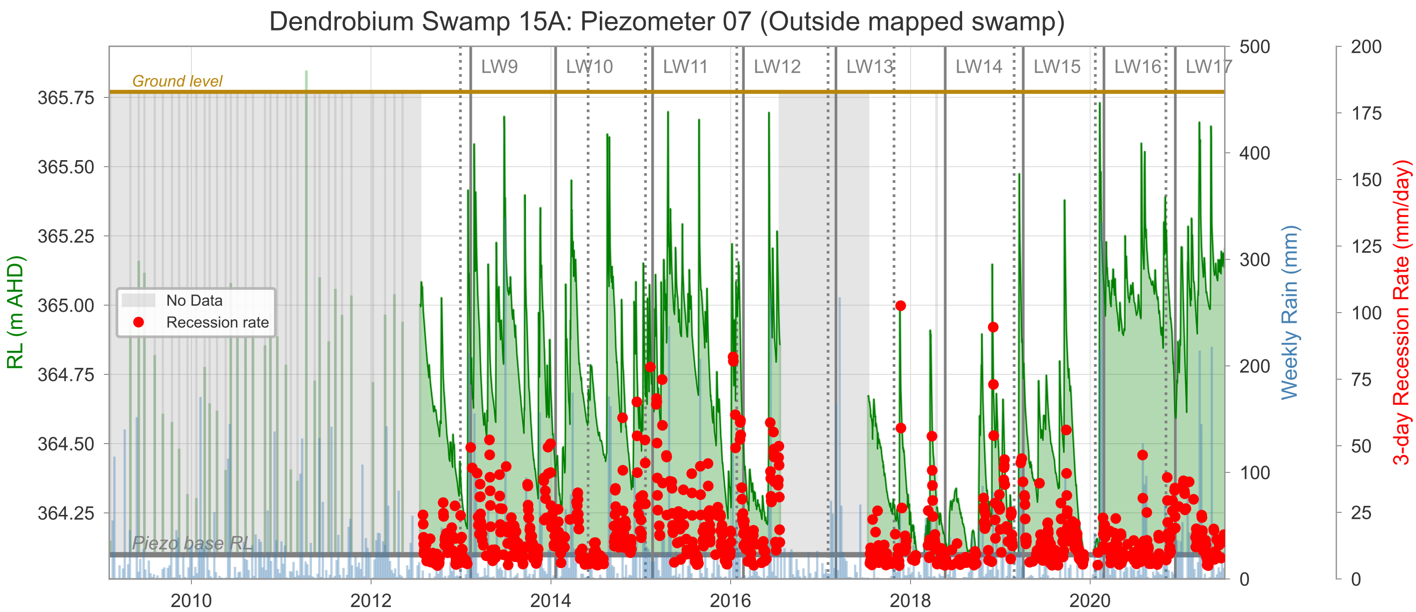
Dendrobium Swamp 12: Piezometer 05 (Outside mapped swamp)
LW6
LW7
LW8
LW9
LW10
Ground level
Piezo base RL
No Data
Recession rate
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)
Dendrobium Swamp 13: Piezometer 01 (Within mapped swamp)
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW undermined
LW passed <400m
Dendrobium Swamp 14: Piezometer 01 (Within mapped swamp)



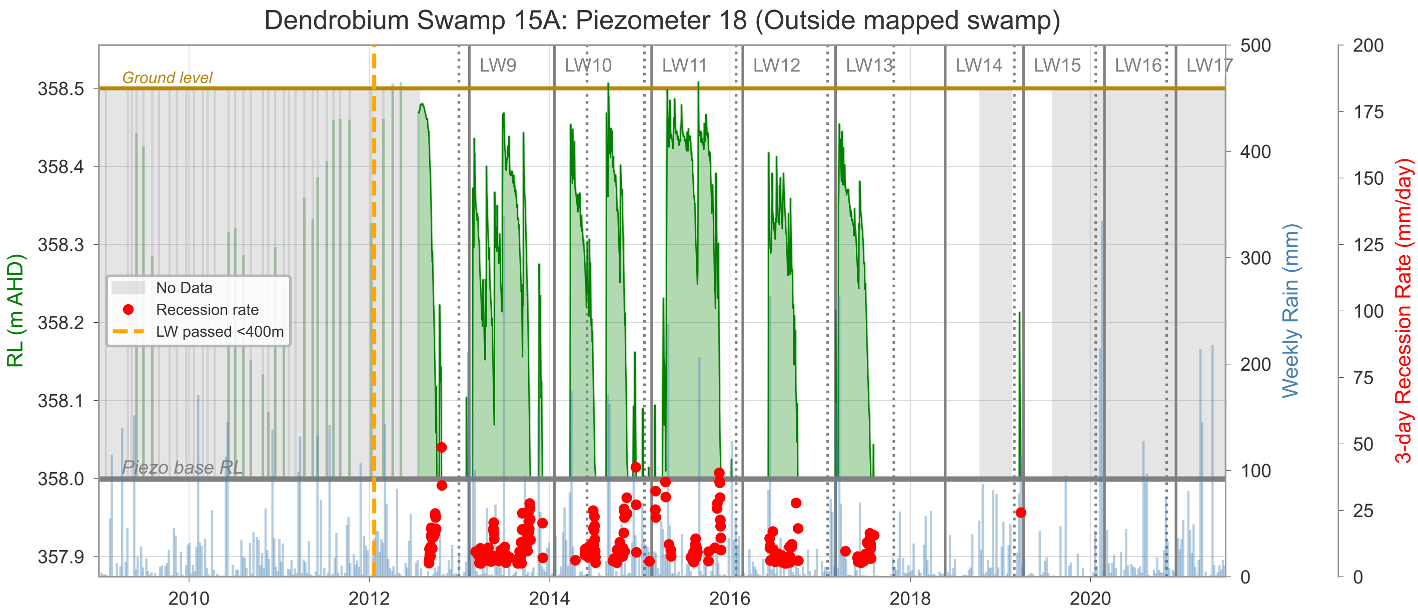
Dendrobium Swamp 14: Piezometer 02 (Within mapped swamp)
Ground level
LW12
LW13
LW14
LW15
LW16
LW17
No Data
Recession rate
LW undermined
LW passed <400m
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)
2016
2017
2018
2019
2020
2021

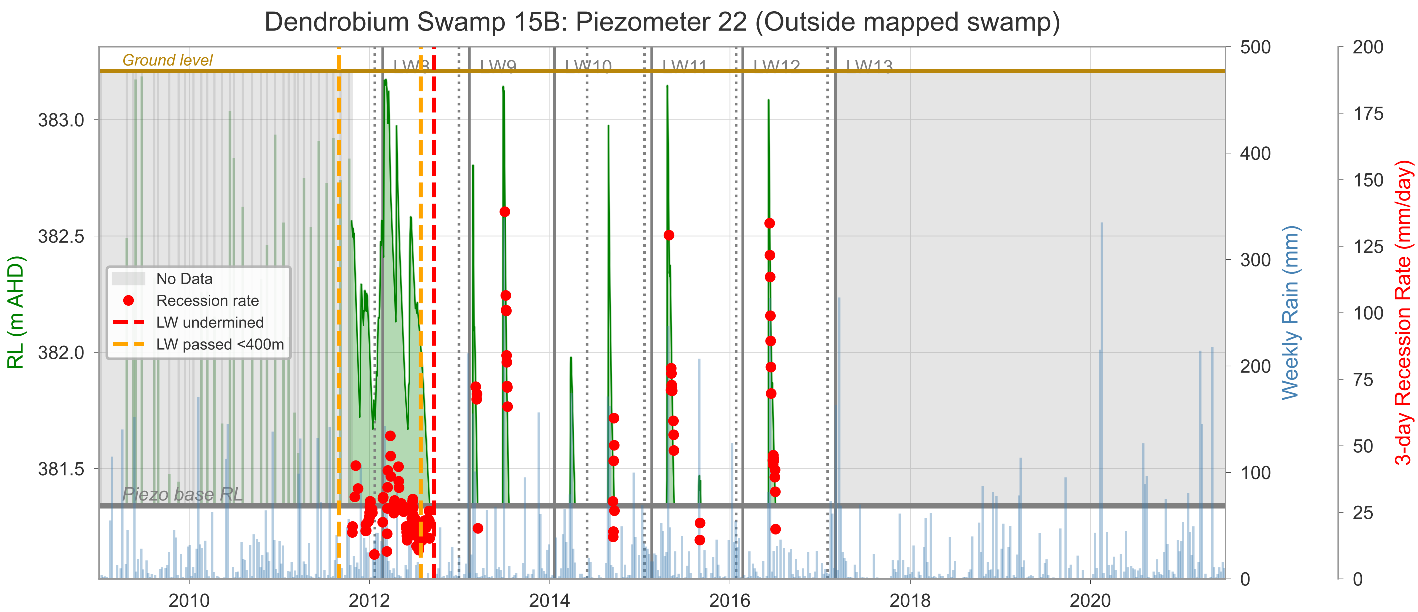


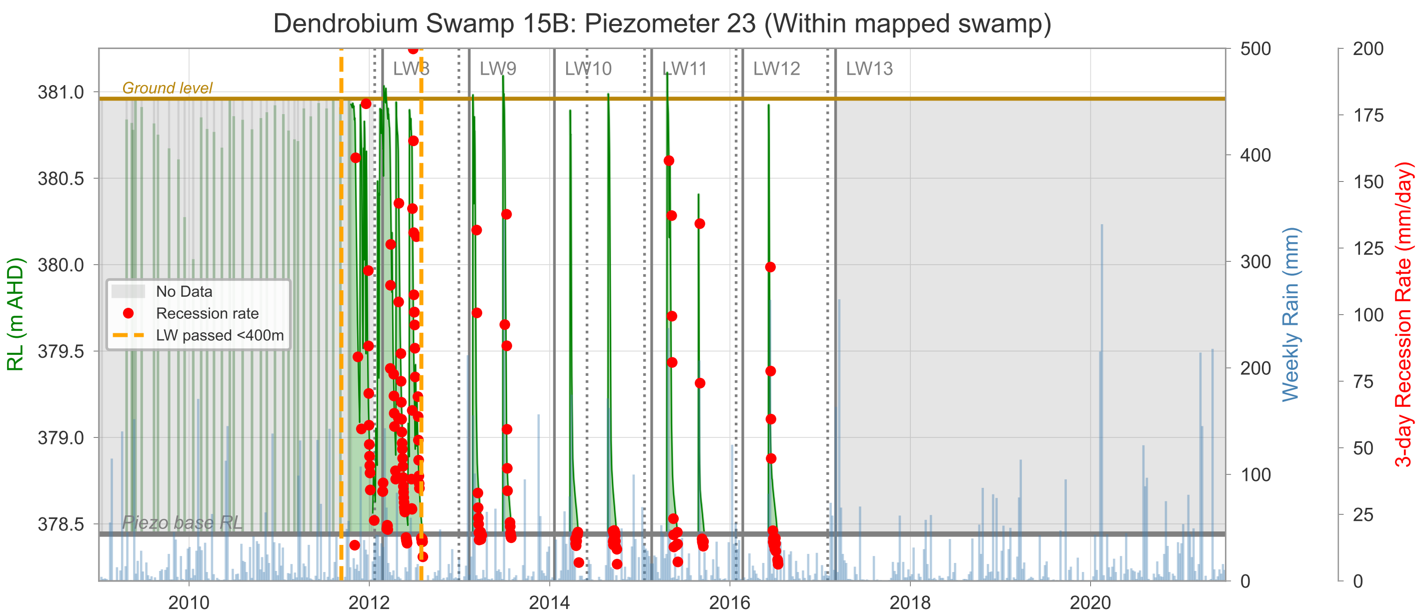
Dendrobium Swamp 15A: Piezometer 06 (Within mapped swamp)
Ground level
Piezo base RL
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
No Data
Recession rate
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)
2010
2012
2014
2016
2018
2020

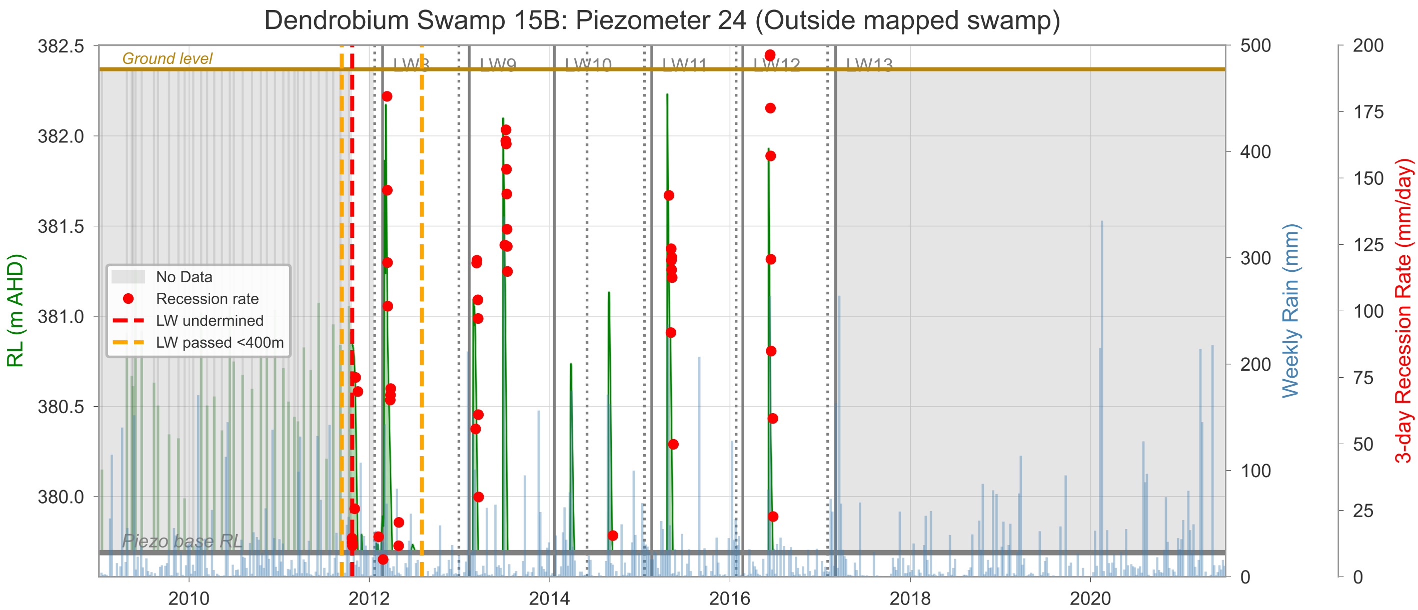


Dendrobium Swamp 15A: Piezometer 07 (Outside mapped swamp)
Ground level
Piezo base RL
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
No Data
Recession rate
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)
2010
2012
2014
2016
2018
2020

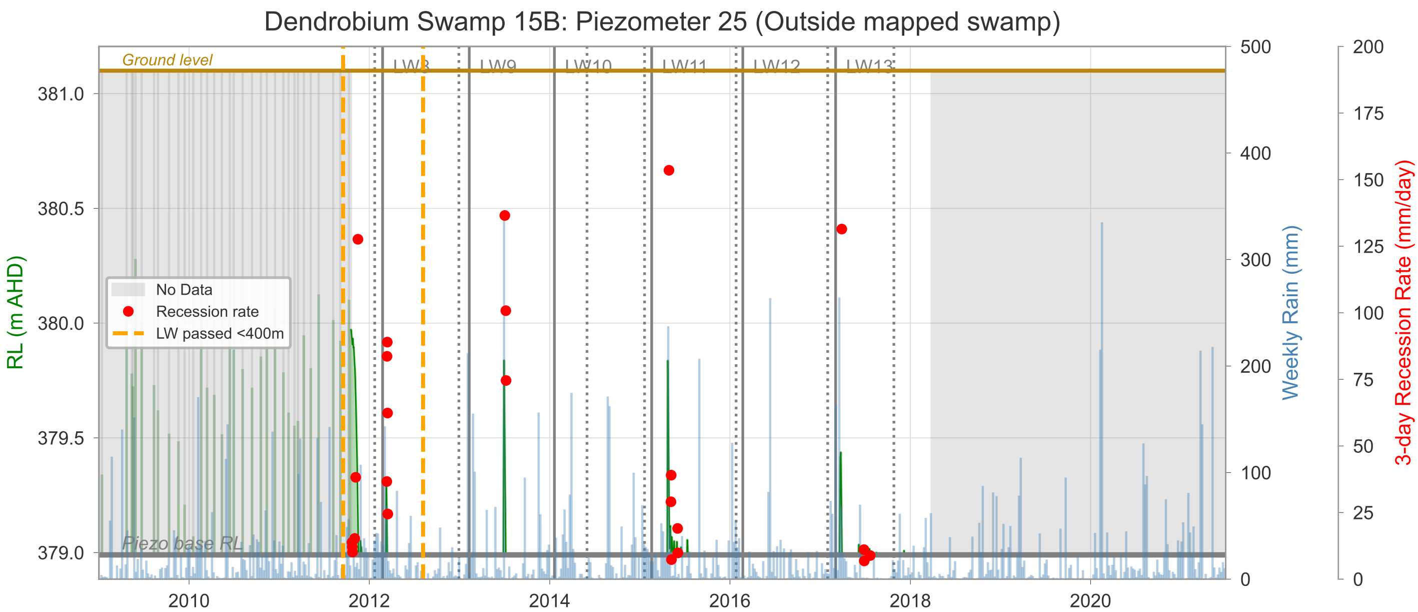

Dendrobium Swamp 15A: Piezometer 18 (Outside mapped swamp)
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)
Ground level
Piezo base RL
No Data
Recession rate
LW passed <400m
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
358.5
358.4
358.3
358.2
358.1
358.0
357.9
2010
2012
2014
2016
2018
2020
500
400
300
200
100
0
200
175
150
125
100
75
50
25
0


Dendrobium Swamp 15B: Piezometer 22 (Outside mapped swamp)
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)
Ground level
Piezo base RL
No Data
Recession rate
LW undermined
LW passed <400m
LW8
LW9
LW10
LW11
LW12
LW13
383.0
382.5
382.0
381.5
2010
2012
2014
2016
2018
2020
500
400
300
200
100
0
200
175
150
125
100
75
50
25
0

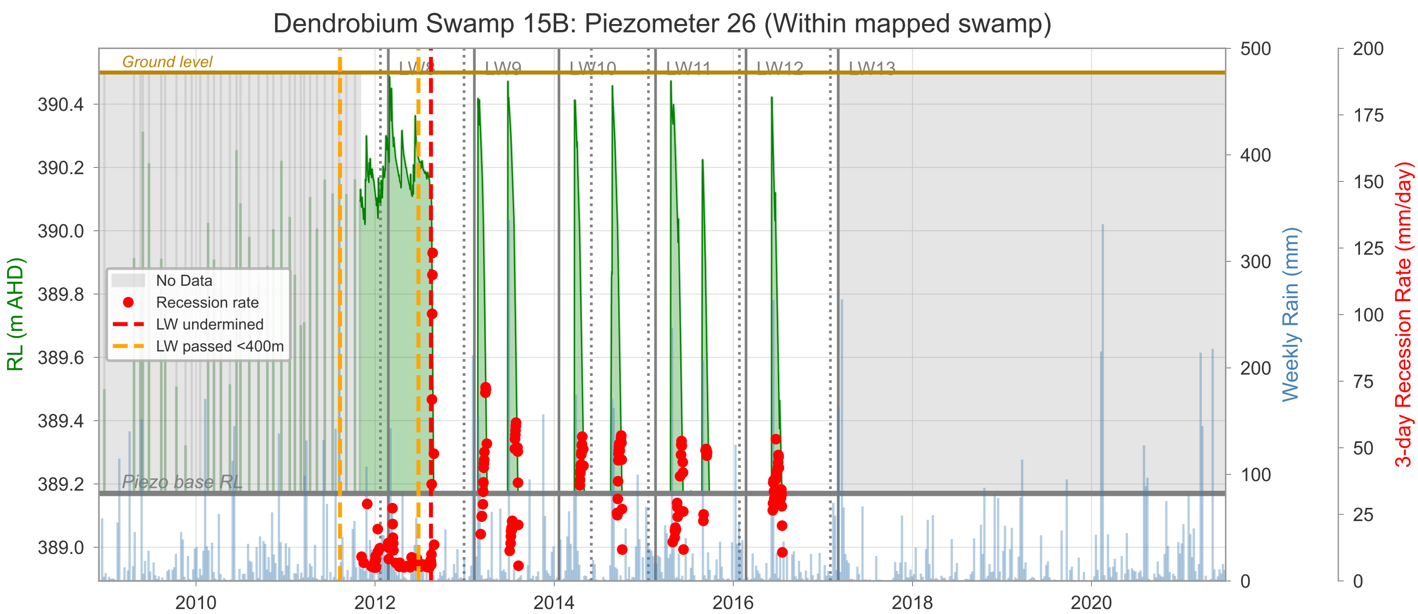

Dendrobium Swamp 15B: Piezometer 23 (Within mapped swamp)
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)
Ground level
Piezo base RL
No Data
Recession rate
LW passed <400m
LW8
LW9
LW10
LW11
LW12
LW13
381.0
380.5
380.0
379.5
379.0
378.5
2010
2012
2014
2016
2018
2020
500
400
300
200
100
0
200
175
150
125
100
75
50
25
0



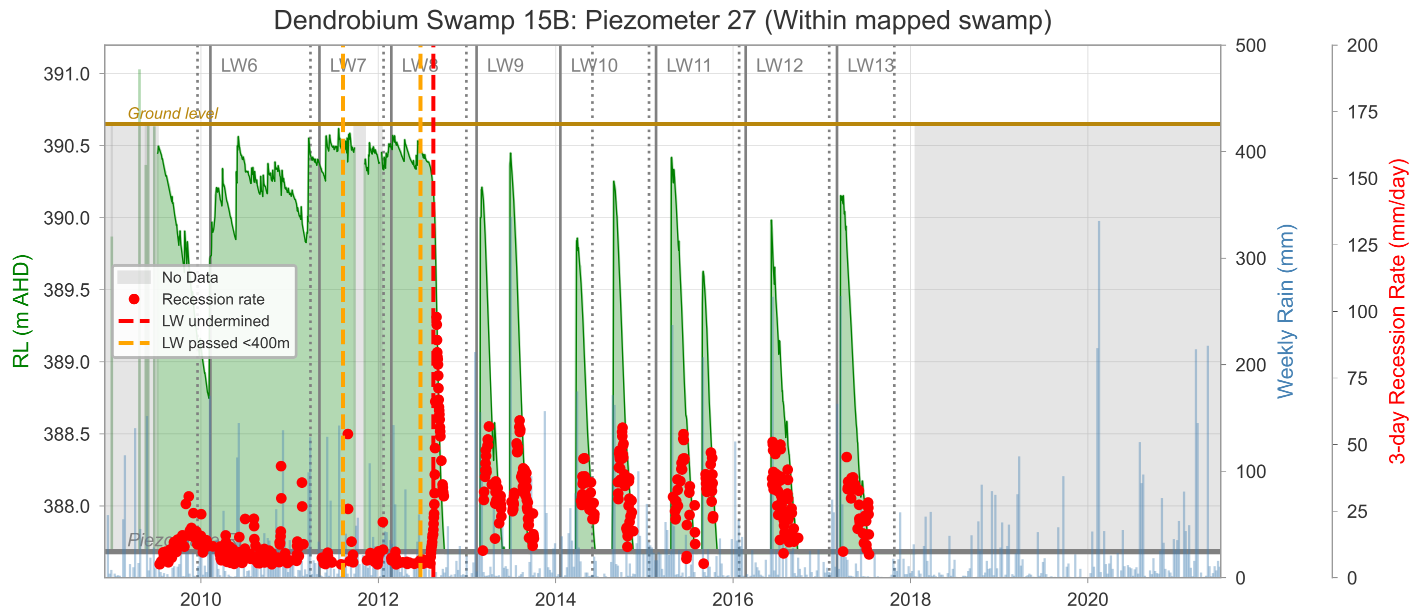
Dendrobium Swamp 15B: Piezometer 24 (Outside mapped swamp)
Ground level
Piezo base RL
LW8
LW9
LW10
LW11
LW12
LW13
No Data
Recession rate
LW undermined
LW passed <400m
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)



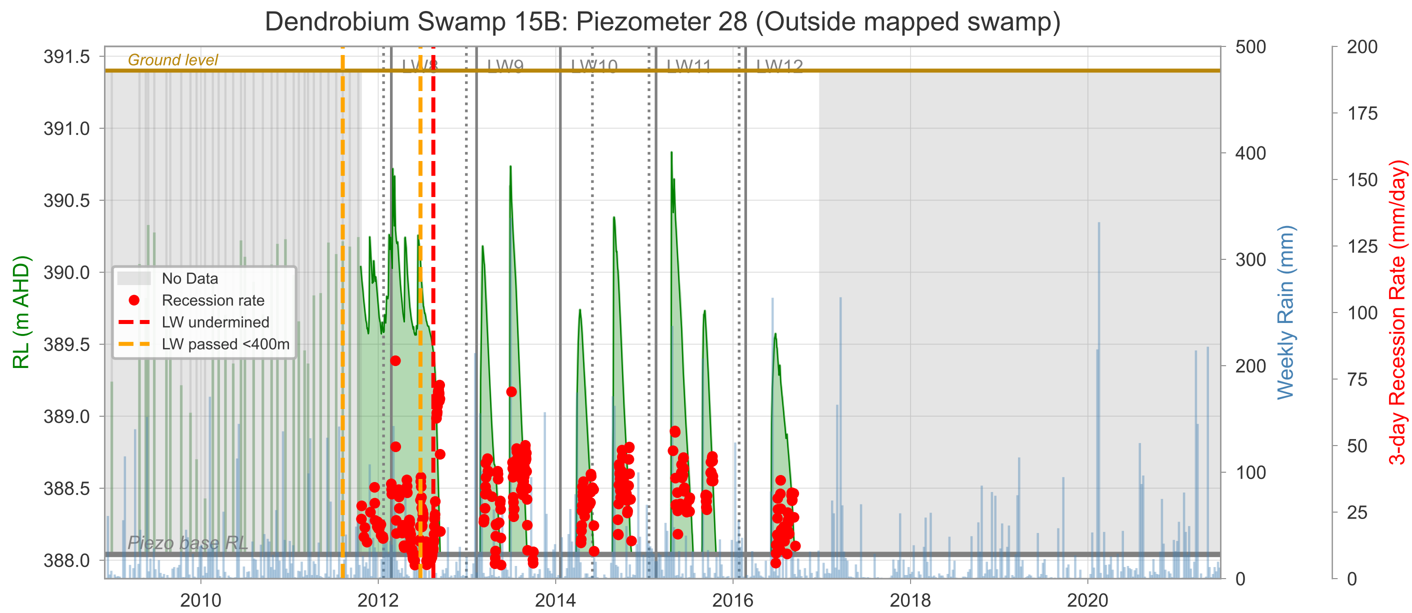
Dendrobium Swamp 15B: Piezometer 25 (Outside mapped swamp)
Ground level
Piezo base RL
LW8
LW9
LW10
LW11
LW12
LW13
No Data
Recession rate
LW passed <400m
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)



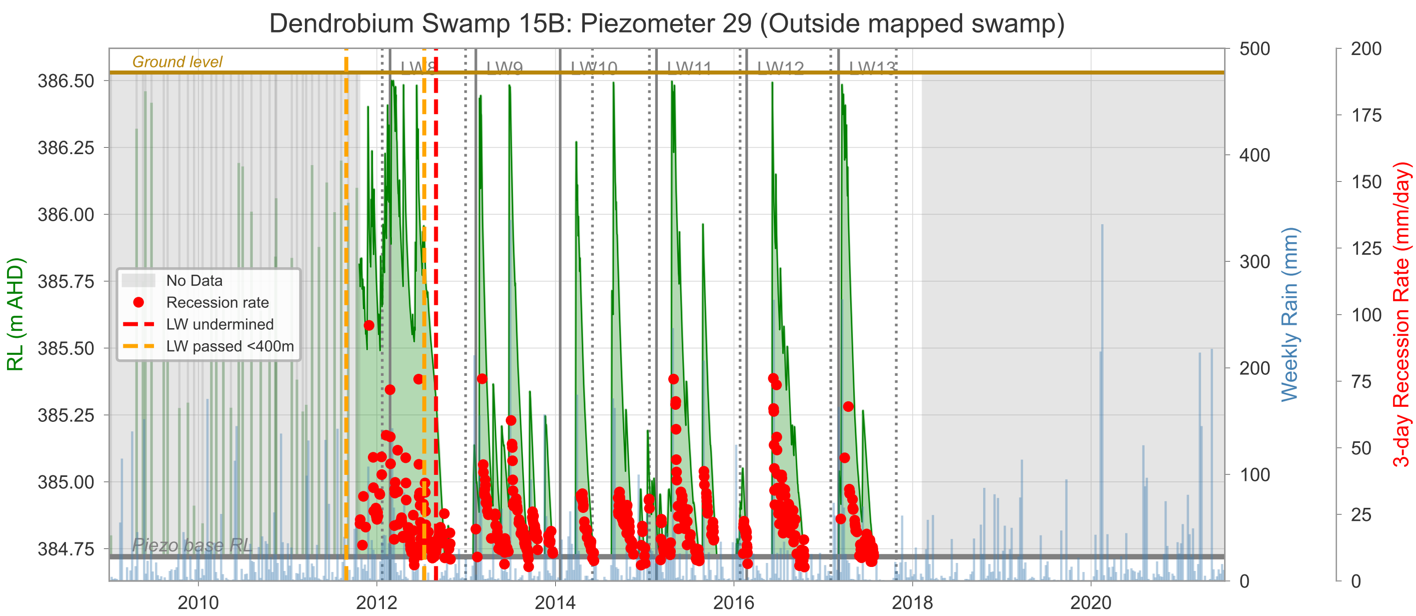
Dendrobium Swamp 15B: Piezometer 26 (Within mapped swamp)
Ground level
Piezo base RL
LW8
LW9
LW10
LW11
LW12
LW13
No Data
Recession rate
LW undermined
LW passed <400m
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)



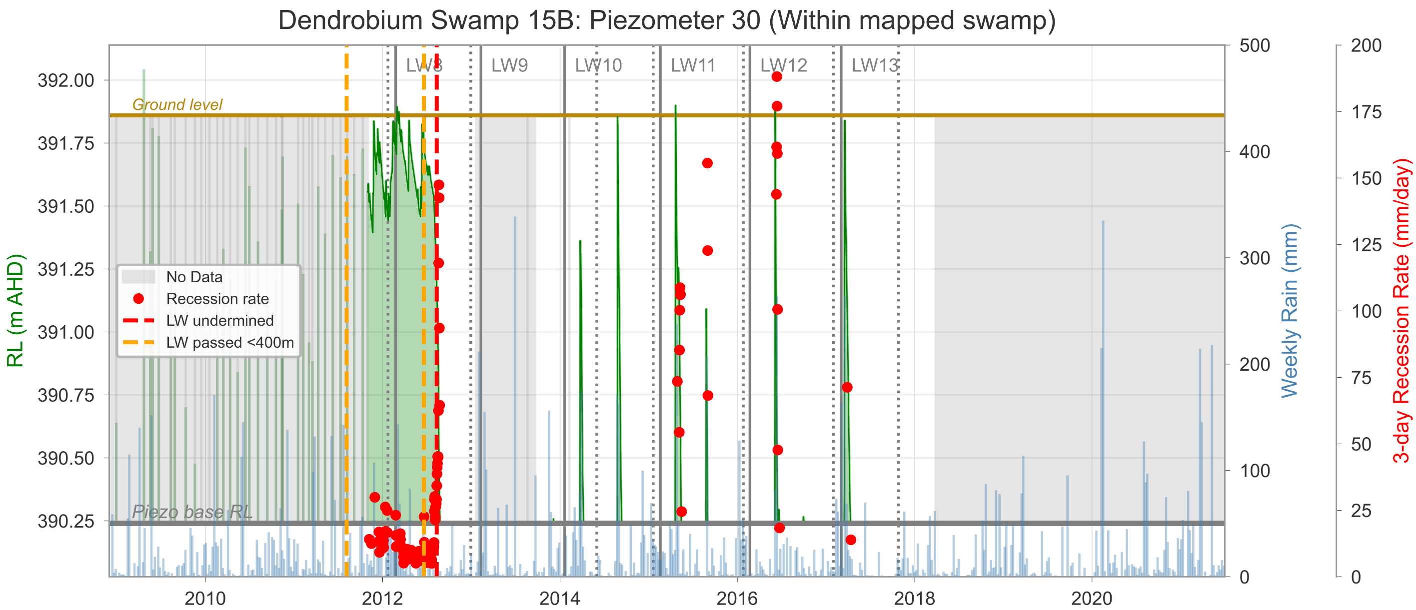
Dendrobium Swamp 15B: Piezometer 27 (Within mapped swamp)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
Ground level
No Data
Recession rate
LW undermined
LW passed <400m
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)

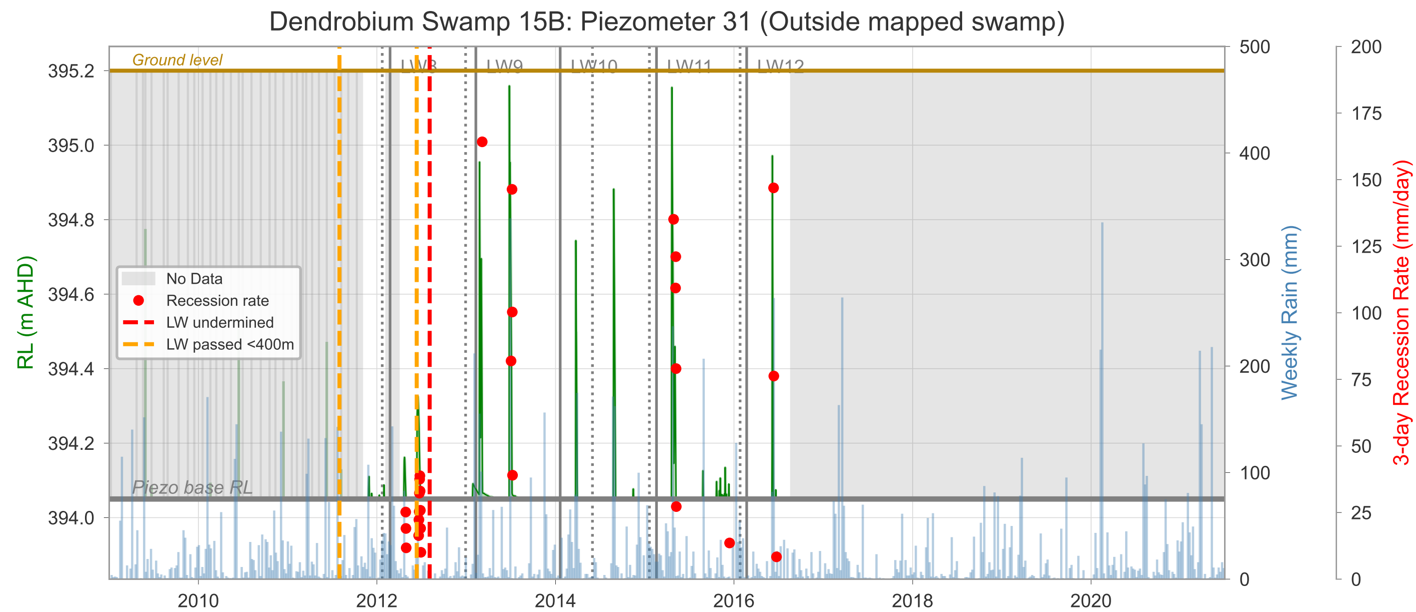


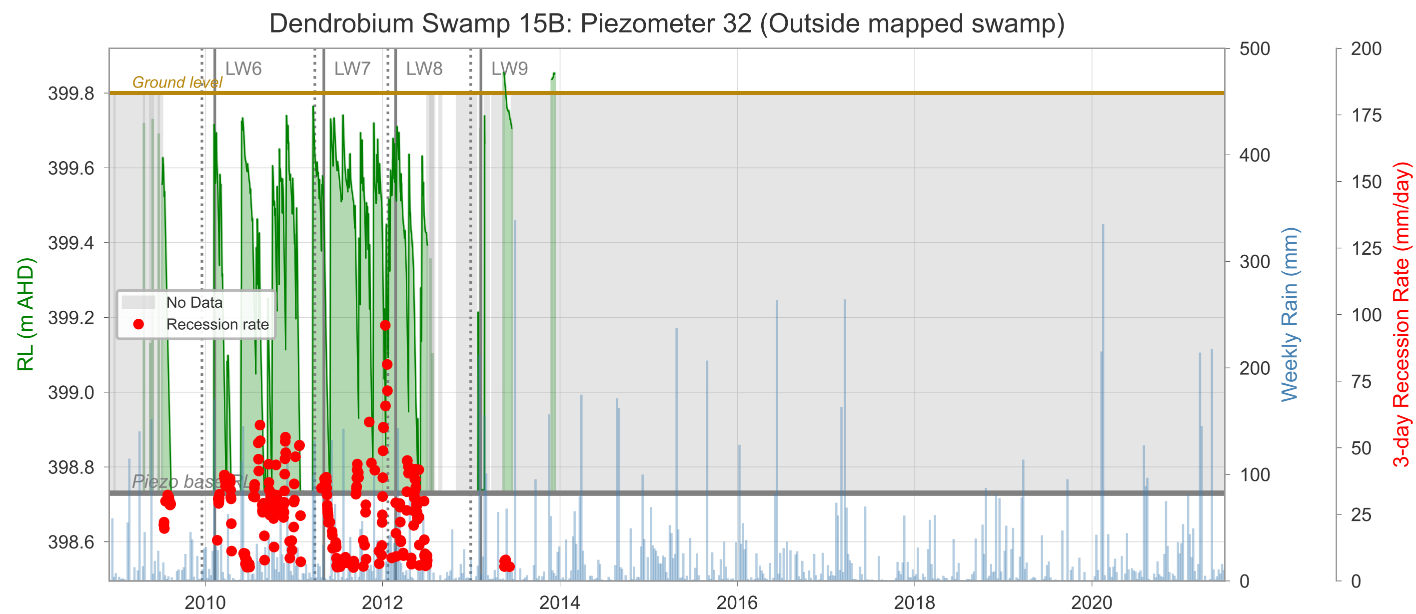
Dendrobium Swamp 15B: Piezometer 28 (Outside mapped swamp)
Ground level
LW8
LW9
LW10
LW11
LW12
Piezo base RL
No Data
Recession rate
LW undermined
LW passed <400m
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)

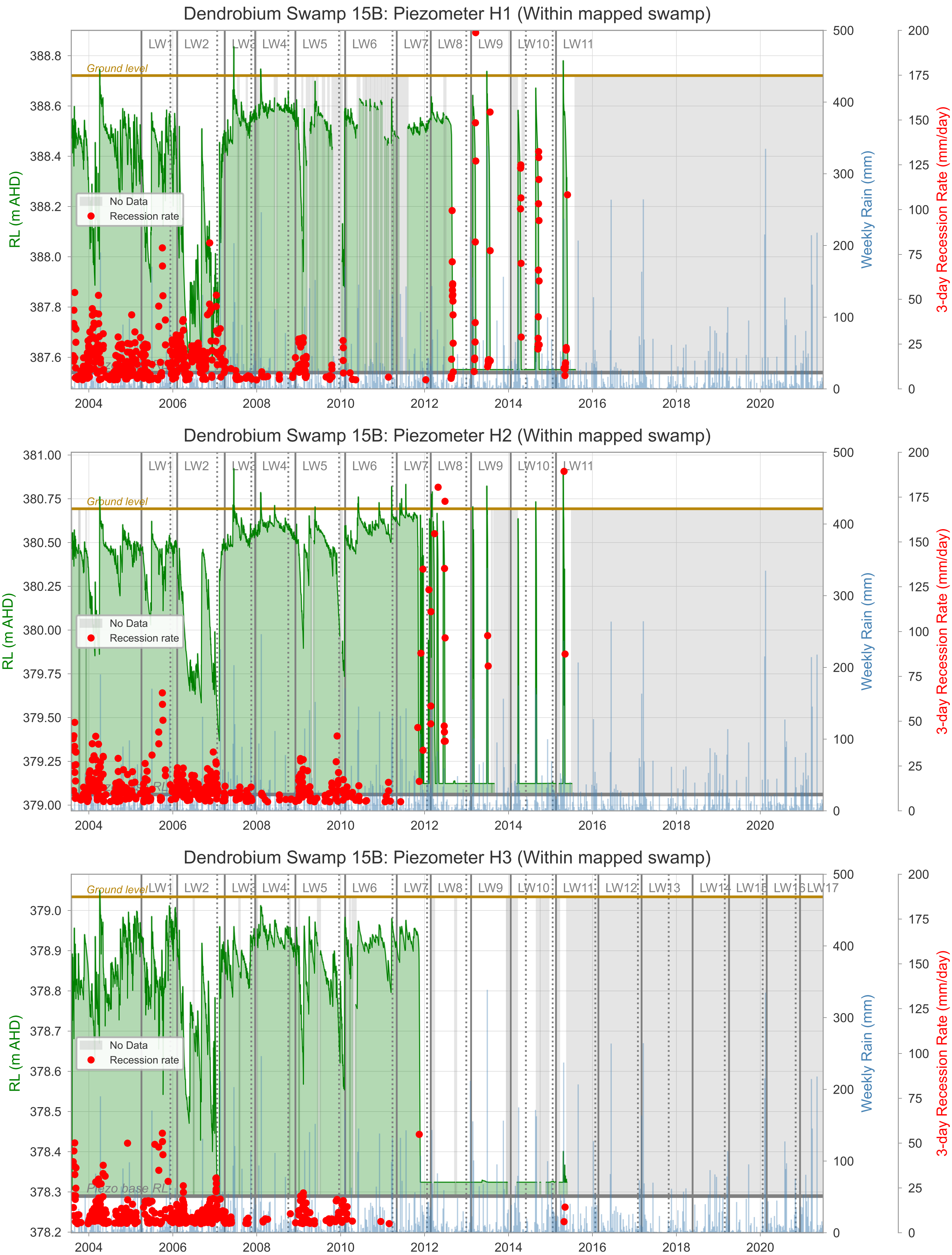


Dendrobium Swamp 15B: Piezometer 29 (Outside mapped swamp)
Ground level
LW8
LW9
LW10
LW11
LW12
LW13
Piezo base RL
No Data
Recession rate
LW undermined
LW passed <400m
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)


Dendrobium Swamp 15B: Piezometer 30 (Within mapped swamp)
LW8
LW9
LW10
LW11
LW12
LW13
Ground level
Piezo base RL
No Data
Recession rate
LW undermined
LW passed <400m
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)


Dendrobium Swamp 15B: Piezometer 31 (Outside mapped swamp)
Ground level
LW8
LW9
LW10
LW11
LW12
Piezo base RL
No Data
Recession rate
LW undermined
LW passed <400m
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)


Dendrobium Swamp 15B: Piezometer 32 (Outside mapped swamp)
LW6
LW7
LW8
LW9
Ground level
No Data
Recession rate
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)


Dendrobium Swamp 15B: Piezometer H1 (Within mapped swamp)
LW1
LW2
LW3
LW4
LW5
LW6
LW7
LW8
LW9
LW10
LW11
Ground level
No Data
Recession rate
RL (m AHD)
Weekly Rain (mm)
3-day Recession Rate (mm/day)
Dendrobium Swamp 15B: Piezometer H2 (Within mapped swamp)
Dendrobium Swamp 15B: Piezometer H3 (Within mapped swamp)
LW12
LW13
LW14
LW15
LW16
LW17
Piezo base RL
2004
2006
2008
2010
2012
2014
2016
2018
2020