South32

Dendrobium Mine

Assessment of surface water flow and quality effects of proposed Dendrobium Longwalls 20 and 21

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ABBREVIATIONS

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

EXECUTIVE SUMMARY

Illawarra Coal Holdings Pty Ltd (Illawarra Coal), a wholly owned subsidiary of South32 Limited (South32), operates the underground Dendrobium Mine in the Southern Coalfield of New South Wales (NSW). Illawarra Coal proposes to extract Longwalls 20 and 21 (LW20 and LW21), located immediately to the north of the currently active mining Area 3B. Longwall extraction will be at a depth of between 290 m and 410 m below the surface with a maximum extraction height of 3.9 m. 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 Nepean, Cordeaux, Avon, and Cataract lakes, before eventually flowing into the Nepean River. Within the study area surface runoff drains into Donalds Castle Creek and Wongawilli Creek, both of which flow in a northerly direction, broadly parallel to LW20.

The main second- and third-order reaches of Donalds Castle Creek pass 490 m west of LW20 and are over 1 km from LW21 at their closest approach. The main third-order channel of Wongawilli Creek passes 124 m east of LW20 and 242 m west of LW21 at its closest approach. A total of 2430 m of Wongawilli Creek passes within 400 m of Longwall 20 and/or 21. Two headwater tributaries to Wongawilli Creek pass over the proposed LW20 panel (WC23, WC25) and one headwater tributary passes over the proposed LW21 panel (WC20). Predictions of mine subsidence related to LW20 and 21 (MSEC, 2019a) 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. Third-order reaches of Wongawilli Creek may experience some fracturing and stream diversion within 400 m of the proposed longwalls.

Where stream flow is partly sustained by the discharge of groundwater from adjacent aquifers (baseflow), mining related groundwater drawdown may result in a reduction of the baseflow component. Estimates based on a regional groundwater model by HydroSimulations (2019) indicate that the baseflow components of Donalds Castle Creek and Wongawilli Creek may decline by up to 0.14 ML/day and 0.20 ML/day following longwall extraction, equating to approximately 8.5% and 1.6% of mean annual streamflow at the downstream gauging sites.

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

Ten areas of Coastal Upland Swamp vegetation are mapped within 600 m of the proposed longwalls. Of those, only the northern end of Swamp 5 overlaps with the proposed first workings, and none overlap the longwall footprints. Based on previous experience at Area 3B and subsidence predictions, it is likely that shallow groundwater levels will be affected at Swamp 144 (being within 60 m of the goaf) and it is possible that affects will be seen in Swamps 09, 140, 141, 142 and 145 (being within 400 m of the goaf). The remaining swamps are unlikely to be impacted since they are located more than 400 m from the proposed goaf and/or are predicted to experience negligible ground movement related to valley closure.

1. INTRODUCTION

1.1 Project background

Illawarra Coal Holdings Pty Ltd (Illawarra Coal), 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 km west of Wollongong (NSW) and within the Metropolitan Special Catchment Area managed by WaterNSW.

Since approval in 2001, underground mining has been carried out using longwall extraction within Areas 1, 2 and 3A, and is currently underway in Area 3B. Illawarra Coal now proposes to extract the first two longwalls in Area 3C within the Wongawilli Coal Seam. These are referred to as Longwalls 20 and 21 (LW20 and LW21).

Previous workings in the Wongawilli Seam are located to the south of the mine at Elouera and Nebo, and to the east at Kemira. The overlying Bulli Seam was mined previously at Mt Kembla to the east of Area 1. Illawarra Coal is preparing a Subsidence Management Plan as part of the approvals process for proposed LW20 and LW21. 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 Subsidence Management Plan (SMP) and should be read in conjunction with that document and other specialist reports referred to in the SMP.

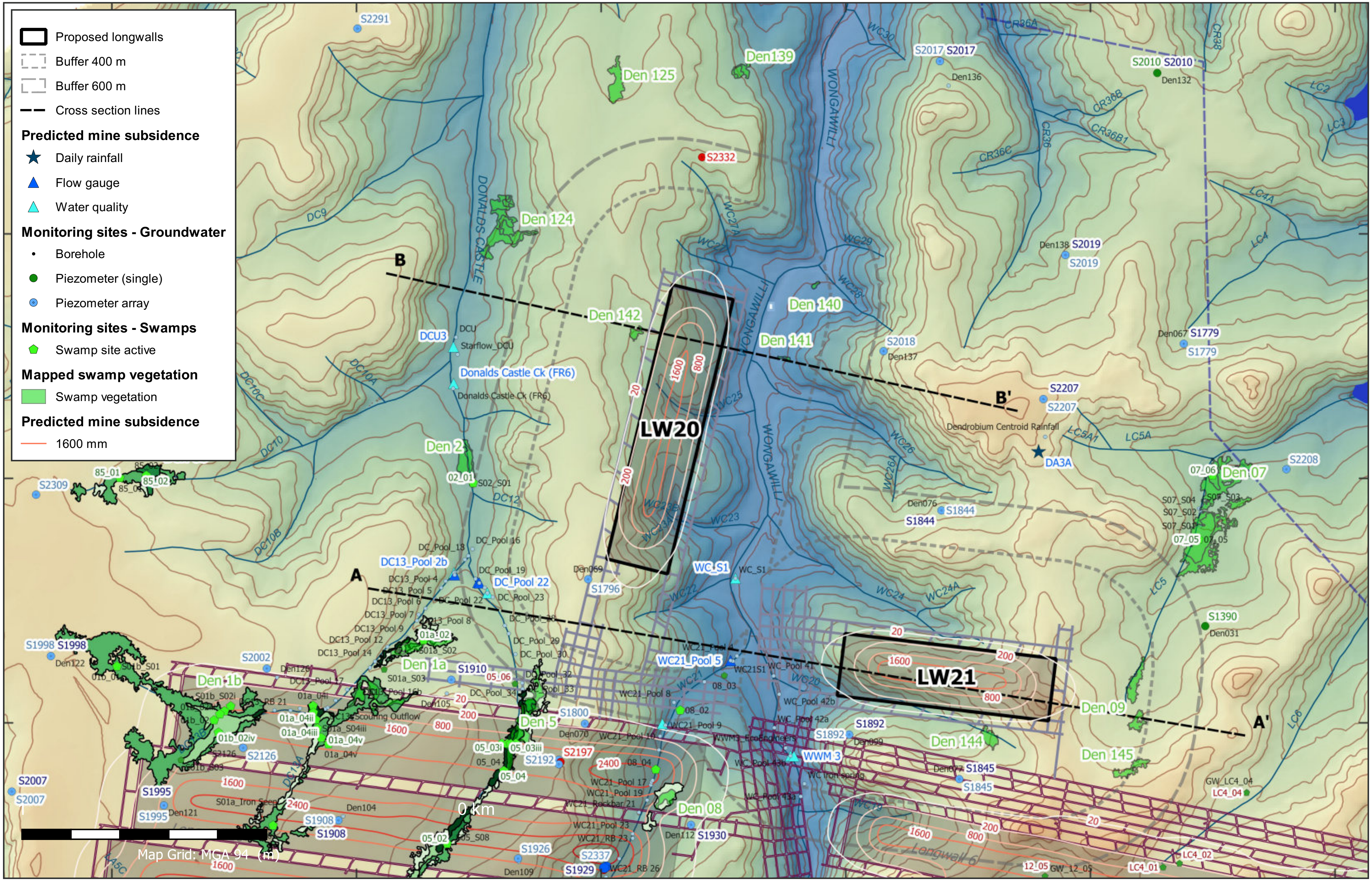
1.2 Scope

The scope of this assessment is guided by the relevant conditions listed in Schedule 3 of the mining approval, as modified in April 2015. In particular it provides:

- Description of surface water hydrology within the Project 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 LW20 and LW21, 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 LW20 and LW21.
- 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).

1.3 Study area

The study area is nominally defined by the area within 600 m of the edge of the longwalls (Approval Condition 8(d)), being the area that is likely to contain most of the subsidence effects (MSEC, 2019a) (Figure 1). The assessment also considers reaches of Wongawilli Creek and Donalds Castle Creek that extend upstream and downstream of the 600 m envelope, as appropriate for the definition of baseline characteristics and long-term impact monitoring.



Dendrobium Mining Area 3B

Monitoring locations for proposed Longwalls 20 and 21

Figure 1

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1.4 Mining geometry

The layouts of the proposed LW20 and LW21 are shown in Figure 1, and longwall dimensions are summarised in Table 1. The longwalls will be extracted from the Wongawilli Seam and extraction will proceed from the north towards the south (LW20) and from east to west (LW21). The proposed longwall extraction height is 3.9 m.

Table 1. Geometry of the proposed longwalls

Longwall	Total void length* (m)	Total void width* (m)	Mining height (m)	Tailgate chain pillar width (m)	Depth of cover (m)
LW20	1154	256	3.9	N/A	320 – 410
LW21	872	256	3.9	N/A	290 – 390

*Including installation headings (~9 m wide; first workings ~10 m wide).

The extent of LW21 within the Wongawilli Coal Seam is shown in an east-west geological cross-section A-A' in Figure 2. Longwall 20 is shown in the cross-section B-B' in Figure 3. The depths of cover to the Wongawilli Seam directly above the proposed longwalls vary between 290 m above the tailgate of LW21 and a maximum of 410 m above the southern end of LW20. The seam floor within the proposed mining area dips from the south-west to the north-east.

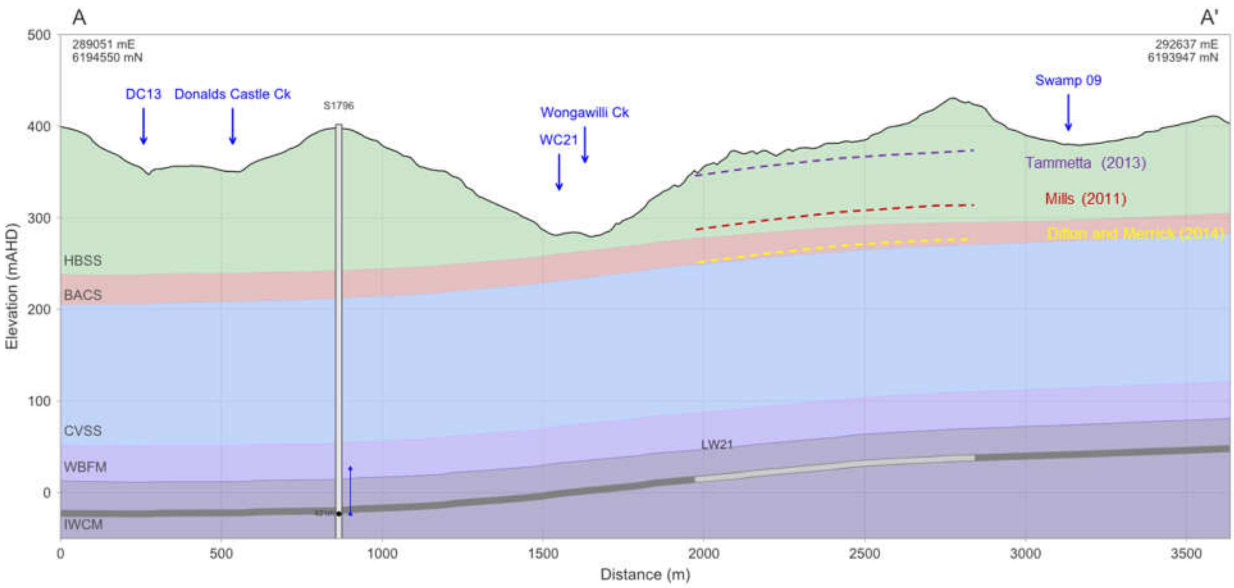

Figure 2. Geological cross section A-A' through Longwall 21 (West-East)

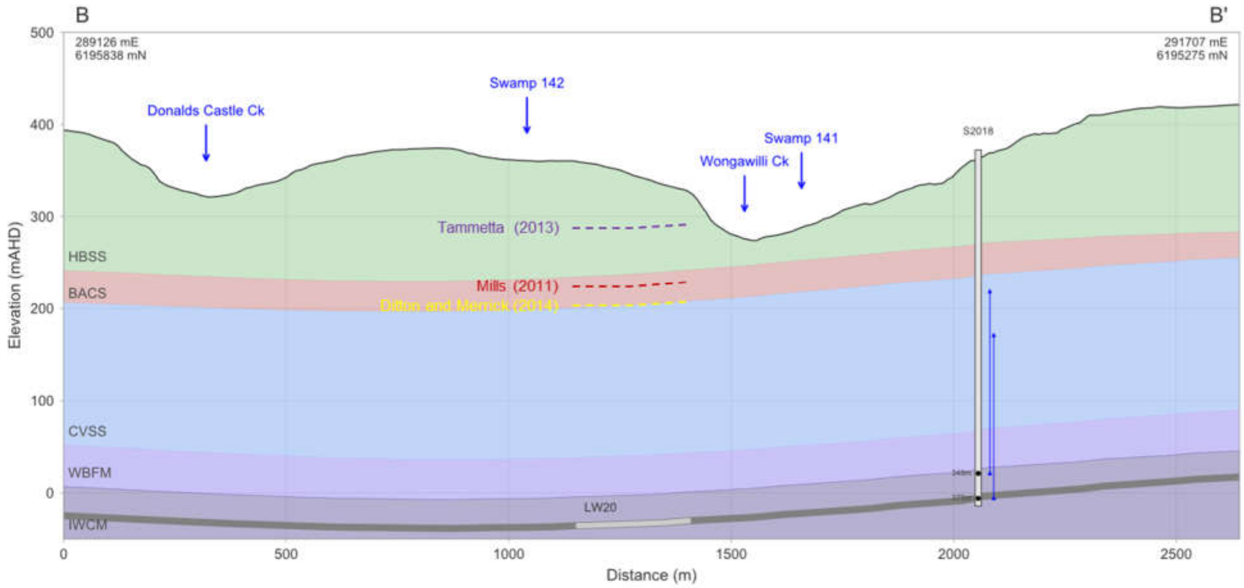

Figure 3. Geological cross section B-B' through Longwall 20 (West-East)

2. BACKGROUND

2.1 Topography

Dendrobium Mine is located on the Woronora Plateau inland of the Illawarra Escarpment. The escarpment rises from the coastal plain to elevations in excess of 400 mAHD around Dendrobium. The plateau generally slopes to the north or northwest, toward the centre of the Sydney Basin. Dendrobium Area 3 is characterised by broad sandstone ridges and plateaus rising to approximately 410 m AHD, incised by relatively steep and rugged gullies. The proposed LW20 is aligned with a NNE-trending ridgeline between the Donalds Castle Creek and Wongawilli Creek valleys and LW21 is approximately perpendicular to LW20 and parallel with a ridge between tributaries WC20 and WC24.

2.2 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.

Within the study area most of the surface runoff drains into Donalds Castle Creek and Wongawilli Creek, both of which flow in a northerly direction, broadly parallel to proposed LW20. The creeks flow into the Cordeaux River approximately 4 km and 1.7 km north of LW20 respectively. Both watercourses are third-order perennial streams that have small baseflow components and increased flows for short periods of time after significant rainfall events. Both watercourses are monitored for flow, water quality and morphological changes at multiple locations (outlined in Section 3).

The main second- and third-order reaches of Donalds Castle Creek pass 570 m west of LW20 and are over 1 km from LW21 at their closest approach. No first or second-order tributaries of Donalds Castle Creek pass over the proposed longwall. However, two tributaries of Donalds Castle Creek are mapped as passing within 400m of LW20. The upper reaches of Donalds Castle Creek drain Swamps 1a and 1b and Swamp 5. Those swamps were mined under previously by LW9 in 2014.

The main third-order channel of Wongawilli Creek passes 215 m west of LW21 and 130 m east of LW20 at its closest approach. A total of 2430 m of Wongawilli Creek passes within 400 m of LW20 and/or 21. Two headwater tributaries pass over the proposed LW20 panel (WC23, WC25) and one headwater tributary passes over the proposed LW21 panel (WC20).

The second-order tributary WC21 is approximately 400 m from both LW20 and LW21, although it crosses the proposed West Mains 2 development. The mid- to upper reaches of tributary WC21 were mined under previously by Longwalls 9 to 13 in Area 3B.

A small part of the study area overlaps with the LC5 sub catchment to Lake Cordeaux catchment. Tributary LC5, flows north-east from just within 100 m east of LW21 into Lake Cordeaux.

2.3 Hydrogeology

Dendrobium Mine is located within the Southern Coalfield which is one of the five major coalfields that lie within the Sydney Geological Basin. The stratigraphy of the Southern Sydney Basin is shown in Figure 4. The Basin is primarily a Permo-Triassic sedimentary rock sequence, underlain by undifferentiated sediments of Carboniferous and Devonian age. The Bulli and Wongawilli Coal Seams are the primary target seams in the top part of the Illawarra Coal Measures. The Coal Measures are overlain by Triassic sandstones, siltstones and claystones of the Narrabeen Group and the Hawkesbury Sandstone. The Hawkesbury Sandstone is the dominant outcropping formation across the mine area, but lower stratigraphic units (Bald Hill Claystone, Narrabeen Group) are exposed in deeply incised parts of Wongawilli Creek and along the south-eastern shores of Lake Cordeaux.

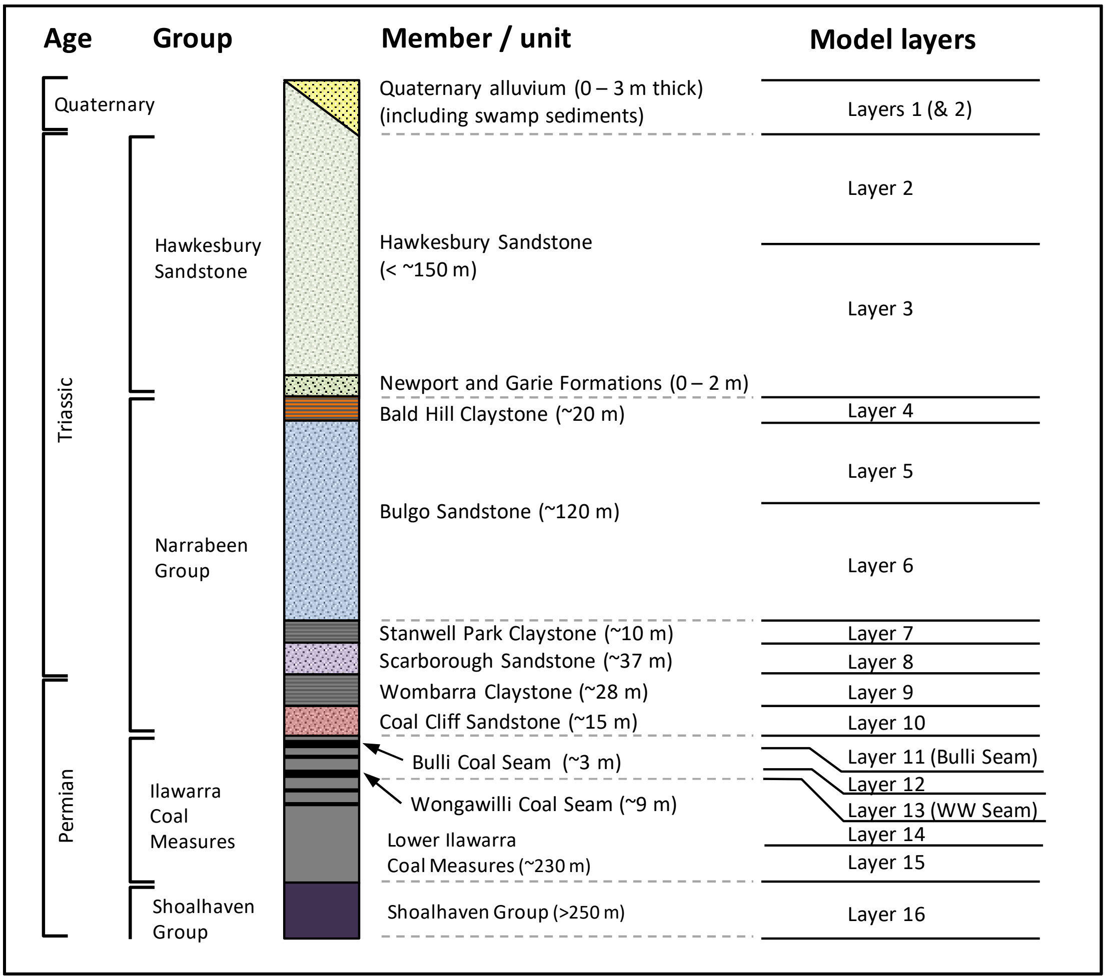

Figure 4. Stratigraphy of the Southern Coalfield and numerical model layers (of Hydrosimulations, 2019)

Three main groundwater systems are recognised:

1. Perched groundwater systems associated with swamps and shallow sandstone. These may be ephemeral and/or disconnected from the deeper groundwater systems;
2. Shallow groundwater systems: layered water-bearing zones within the saturated Hawkesbury Sandstone; 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 Hawkesbury Sandstone in the western half of the Dendrobium Mine area and the Bulgo Sandstone in the eastern half. There will be some recharge from the Reservoirs and streams to host formations at times of high water level and creek flooding. In the western part of Area 3B, the Stanwell Park Claystone pinches out such that the Bulgo and Scarborough Sandstones form a single unit, the Colo Vale Sandstone.

Strong topographic relief and recharge drive vertical groundwater flow near the ground surface, but at depth the alternation of aquifers and aquitards promotes horizontal groundwater flow at the base of permeable units. In general, groundwater flow in shallow systems is strongly influenced by local topographical features such as streams and lakes, whereas deeper groundwater systems are influenced by regional topographic and drainage patterns (Toth, 2009). Regional groundwater flow in the deeper sandstone units (pre-development) is predominantly northwest, towards the Nepean River system and away from the Illawarra escarpment.

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

2.4 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 EPBC Act, and the NSW *Threatened Species Conservation Act, 1995*. Upland Swamps are typically located at the headwaters of low order streams, on low relief plateaus on low permeability Hawkesbury Sandstone. 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 1 and is derived from a combination of mapping by the NSW Office of Environment and Heritage (OEH), ecological consultants and the Illawarra Coal Environmental Field Team (ICEFT). There are ten mapped areas of swamp vegetation within (or at) 600 m of the proposed longwalls. Of those, only the northern end of Swamp 5 and Swamp 144 overlap with the workings of LW20 and LW21, but none directly overlie the longwall footprints. A further five areas of mapped swamp vegetation are located within 400 m of the proposed longwalls (Swamps 09, 140, 141, 142, 145).

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.

2.5 Climate

Weather data has been collected at the Dendrobium Mine since 2003. Mean annual rainfall between 2003 and 2017 was 1033 mm (2.83 mm per day on average). Rainfall decreases westward away from the Illawarra escarpment with Picton, located 20 km to the northwest, recording an average annual rainfall of 803 mm (1886-2018). At Dendrobium, rainfall 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 is generated.

Maximum daily temperature varies seasonally from approximately 20 °C in the winter months (June – August) to 40 °C or higher in the summer (December – February). Evapotranspiration also varies seasonally in line with temperature and solar radiation, peaking during the summer months. Potential Evapotranspiration calculated using the Penman-Monteith formula is typically between 1 and 3 mm/day in the winter months and between 3 and 6 mm in the summer months.

3. BASELINE ASSESSMENT

3.1 Monitoring

This section outlines the network of monitoring infrastructure and sites operated by Illawarra Coal that are relevant to the LW20-21 study area. Further details of monitoring sites and procedures are outlined in the Dendrobium Area 3C Watercourse Impact Monitoring Management and Contingency Plan (South32, 2019a).

3.1.1 Geomorphological mapping

Stream bed morphology has been mapped in detail by the ICEFT 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. rock pool, step, waterfall, sand-bar, etc.), sediment type and vegetation. Key features are mapped and photographed for comparison during and after mining. Major streams and tributaries of Donalds Castle Creek and Wongawilli Creek adjacent to the proposed LW20 and 21 have been mapped as part of the assessments for mining at Dendrobium Mine.

3.1.2 Surface Water Monitoring

Monitoring of surface water is carried out at numerous sites across the Dendrobium Mine lease by the ICEFT on a monthly basis prior to mining and on a weekly basis during mining, as part of the Approved Area 3C SMP (South32, 2019b). There are 37 active monitoring sites on Donalds Castle Creek and Wongawilli Creek (and their tributaries) within 600 m of the proposed longwalls. Stream monitoring sites within the study area are shown in Figure 1. Those sites at which flow and/or water chemistry data is collected are listed in Table 2 and Table 3 (monitoring start dates shown). The list includes selected gauging sites beyond the study area that provide down-gradient impact monitoring and up-gradient control points.

Table 2. Surface Water Monitoring Sites on Donalds Castle Creek

Watercourse	Site	East (mga94)	North (mga94)	Flow gauge	Chemistry	Field parameters
Donalds Castle Creek	Donalds Castle Ck (FR6)	289397	6195388	-	**2001-**	**2001-**
	DCU	289407	6195577	**2007-**	-	-
	DCS2	289502	6194572	**2012-**	-	-
	DC_Pool 22	289535	6194531	-	**2012-**	**2012-**
	DCL3	289587	6199811	-	**2001-**	**2001-**
	DC_Pool_29	289621	6194354	-	-	**2011-**
	DC_Pool_20	289502	6194572	-	-	**2011-**
	DC_Pool_19	289486	6194589	-	-	**2011-**
	DC_Pool 16	289474	6194711	-	-	**2012-**
Tributary DC13	DC13S1	289401	6194605	**2012-**	-	-
	DC13_Pool 1	289443	6194668	-	-	**2012-**
	DC13_Pool 2b	289399	6194614	-	-	**2012-**

Table 3. Surface Water Monitoring Sites on Wongawilli Creek

Watercourse	Site	East (mga94)	North (mga94)	Flow gauge	Chemistry	Field parameters
Wongawilli Creek	WWU	290808	6189716	**2007-**	-	-
	Wongawilli Ck (FR6)	290960	6197376	-	**2001-**	**2001-**
	WWL	290975	6197526	**2007-**	-	-
	WC_S1	290549	6194591	-	**2012-**	**2012-**
	WWU4	290798	6189962	-	**2002-**	**2002-**
	WC_Pool 41	290705	6194192	-	-	**2009-**
	WC_Pool 42b	290728	6194117	-	-	**2008-**
	WC_Pool 42a	290708	6193980	-	-	**2009-**
	WC_Pool_43a	290816	6193699			**2009**
WC21	WC21S1	290529	6194255	**2012-**	-	-
	WC21_Pool 5	290529	6194255	-	-	**2012-**
	WC21_Pool 6	290422	6194168	-	-	**2012-**

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 1 shows areas of swamp vegetation, broadly mapped by OEH and refined through site-scale mapping by ecological consultants and Illawarra Coal. Hydrological baseline characteristics and mining effects at swamps are monitored using shallow (1 to 3 m) piezometers and soil moisture sensors. Figure 1 shows the locations of shallow groundwater monitoring sites in the vicinity of LW20 and 21.

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 (S5_S01, S05_S08, S11_S01, S14_S01, S87_S02). The remaining 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 on Donalds Castle Creek and three sites on Wongawilli Creek that are relevant to monitoring of baseline conditions and potential impact associated with proposed LW20 and 21 (Table 2 and Table 3; Figure 1). Nearby tributaries of Lake Cordeaux (specifically LC5) are not monitored for flow.

Down-stream sites have been monitored since 2007 whereas monitoring at gauging stations on the lower-order tributaries commenced in 2012, prior to the start of mining in Area 3B. Table 4 summarises the baseline flow conditions for the gauging stations relevant to this assessment (pre-2013 / LW9). The last column of Table 4 summarises the effects on stream flow that are attributed to mining at Area 3B in previous reports.

Stream flow duration curves for the baseline period are shown in Figure 5. Limited baseline data are available for gauging stations DSS2, DC13S1 and WC21S1 prior to the start of mining at Area 3B (<1 year) however the summary information and flow duration curves illustrate the following:

- The first and second order stream gauges (up-stream or adjacent to LW20 and LW21) record minor runoff from small headwater catchments that are almost entirely covered by native eucalypt forest and upland swamp vegetation.
- Gauges on third-order reaches for which there is >5 years of baseline data indicate average runoff yields of 10% to 30% of rainfall. The baseflow component is low and calculated to be in the order of 8% (HydroSimulations, 2016a) at downstream gauges.
- Most streams cease to flow during prolonged dry periods, particularly during the summer months when potential evapotranspiration rates are high. During the baseline period, no-flow conditions occurred 2% to 5% of the monitored period, equating to between 6 and 20 days of the year on average (calculated only for gauges with >1-year baseline).

Table 4. Baseline stream flow conditions at stream gauge sites

Water-course	Gauge	Catchment Area (km^2)	Mean flow (ML/day)	Average yield (% rainfall)	Annual no-flow days	Observed mining effects
Donalds Castle Creek	DCS2	1.08	0.18	5%	n/a	Decrease in flow after LW9 mined under watercourse in July 2013
	DC13S1	1.64	0.25	5%	n/a	Decrease in flow after LW9 mined under watercourse in July 2013
	DCU	6.22	1.90	10%	6	Possible decrease in flow post-LW11
Wongawilli Creek	WWU	3.211	3.09	30%	20	Upstream control site; no impact from Dendrobium mining
	WC21S1	2.43	0.64	8%	n/a	Diversion of stream flow after LW10 mined under
	WWL	20.08	14.20	22%	14	No evidence for change of flow at downstream location*

* Qualitative monitoring of flow condition by ICEFT between WWU and WWL has shown that baseflow losses are evident at very low flows in reaches close to longwalls, even if effects are not clear at the WWL downstream gauge

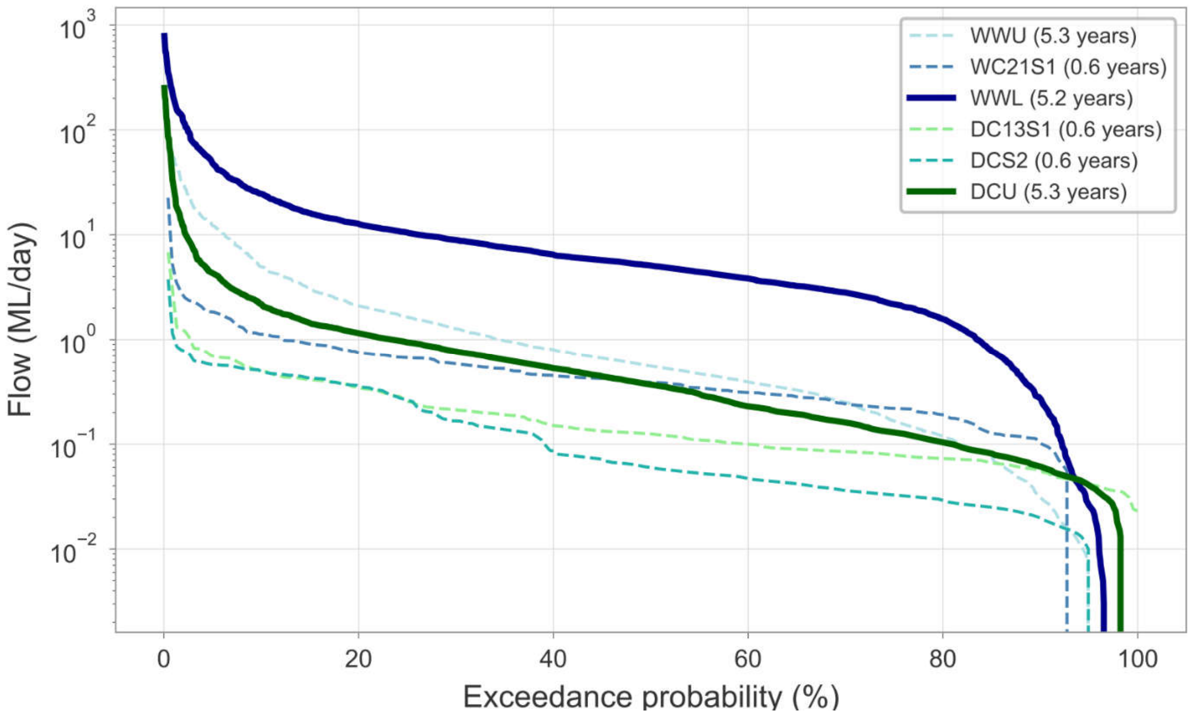

Figure 5. Stream flow duration curves for baseline period (pre-2013)

3.2.2 Stream catchment modelling

The effects of mining subsidence on surface water hydrology is assessed by comparing observed stream flow characteristics for each monitored sub-catchment against predictions of streamflow from a calibrated rainfall-runoff model. The model is calibrated to baseline conditions using observed rainfall and stream flow such that predicted stream flow closely matches observed for a baseline period (e.g. pre-mining). This approach forms the basis for the TARP as defined in Attachment 1 of the WIMCP (South32, 2019a).

Rainfall-runoff modelling was carried out for all stream gauges operated by ICEFT in previous assessments at Dendrobium (e.g. the LW12 and LW13 End of Panel Surface Water Reports; HGEO, 2017 and 2018) using the Australian Water Balance Model (Boughton, 2004). The AWBM algorithm takes average rainfall and potential evaporation across a catchment as inputs on a daily timestep. Model parameters describing soil moisture storages and flow regression are optimised (through model calibration) to achieve an acceptable fit between observed and modelled stream flow. Time-series plots of observed versus modelled stream flow for assessed and relevant stream gauges are presented in Appendix 1. The AWBM version used relies on a modification by Watershed HydroGeo, as discussed in Watershed (2018) and recent End of Panel Reports. This modification has improved the calibration of low flows, especially at WWL on Wongawilli Creek.

3.2.2.1 Data Sources

Rainfall-runoff modelling input data are obtained from the following sources:

- Daily rainfall measurements from Dendrobium's Centroid Rainfall Station;
- Daily and potential evaporation from SILO 'Data Drill' for the location in which Dendrobium lies (DSITI, 2011);
- Catchment areas are calculated in GIS from LiDAR (see Table 4).

3.2.3 Surface water quality

Water chemistry is monitored at three sites on Donalds Castle Creek and three sites on Wongawilli Creek that are relevant to monitoring of baseline conditions and potential impacts associated with proposed LW20 and 21 (Table 2 and Table 3; Figure 1). Regular sampling and analysis has been carried out at the furthest downstream sites (Donalds Castle Creek (FR6), DCL3 and Wongawilli Creek (FR6)) since 2001, resulting in twelve years of baseline data prior to the development of Dendrobium Area 3B (LW9 started in February 2013).

ANZECC (2000) provides a framework for conserving the ambient water quality of streams and lakes through the development of Water Quality Objectives (WQO) based on their agreed environmental values. The approach has been adopted by the NSW Government in the management of the Hawkesbury-Nepean River system (HNCMA, 2008; HRC, 1998). Baseline water quality data (pre-LW9) are summarised and compared against guideline levels for the protection of 95% of freshwater aquatic species (Table 5).

While the ANZECC (2000) guideline provides default trigger values for the protection of aquatic species, its preferred approach is to use local (site) reference data when sufficient baseline data are available. Accordingly, the approved WIMMCP for Dendrobium Mine Area 3B (South32, 2018a) adopts location-specific trigger levels determined from baseline monitoring data. The TARP levels are set for key water quality parameters (pH, Electrical Conductivity and Dissolved Oxygen; see Section 5).

Streams draining the Dendrobium lease are relatively undisturbed. Stream water is fresh (<150 µS/cm), and 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 Donalds Castle Creek and Wongawilli 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. Dissolved oxygen (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 2.

Longwall mining in Area 3B has mined under the upper reaches of Donalds Castle Creek and WC21, a second-order tributary that joins Wongawilli Creek 230 m upstream of monitoring site WC_S1. The end of panel monitoring assessment for LW13 in Area 3B (HGEO, 2017a) identified minor variations in EC and pH and transient increases in dissolved iron at WC21 Pool 53 associated with mining beneath the tributary. However, no significant water quality effects were identified at down-stream locations.

Table 5. Baseline stream water chemistry (pre-Longwall 9 median values)

Median values (mg/L)	Wongawilli Creek			Donalds Castle Creek			ANZECC (2000)# Freshwater 95%
	WWU4	WCS1	Wongawilli Ck (FR6)	DC_Pool 22	Donalds C Ck (FR6)	DCL3	
Samples	*111*	*12*	*132*	*12*	*113*	*125*	
EC (µs/cm)	89	89	101	90	120	143	30-350[a]
pH (pH units)	**5.5**	**6.3**	**6.2**	**5.3**	**5.5**	**5.9**	6.5-7.5 [a]
DO (%)	93	**82.6**	92.5	**82.8**	**89.1**	**77.9**	90-110
Total Alk	<0.5	3	2	<0.5	<0.5	2	-
Cl	19	20	25	21	33	37	-
SO4	4	2	3	1	3	3	-
K	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-
Na	10	11	13	11	16	18	-
Ca	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	-
Mg	2	2	2	0.75	2	3	-
Al	**0.06**	0.05	0.04	**0.16**	**0.12**	0.04	0.055[b]
Fe	0.08	0.20	0.22	<0.10	<0.10	0.24	-
Mn	0.09	0.07	0.04	0.01	0.04	0.04	1.9
Ni	0.006	0.0008	0.0005	0.0005	0.0005	0.0005	0.011
Si	1.73	2.04	1.745	1.69	2.39	2.15	-
Zn	0.03	**0.008**	0.006	0.003	0.004	0.003	0.008
Fe (total)	0.13	0.95	0.5	0.14	0.15	0.43	-
Al (total)	0.08	0.085	0.07	0.19	0.15	0.06	-
Mn (total)	0.08	0.08	0.05	0.01	0.04	0.04	-
Total N	0.005	0.020	0.005	0.007	0.005	0.005	0.25 [a]
Total P	0.005	0.005	0.005	0.0075	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.

3.2.4 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. Hydrographs for shallow piezometers located at swamps within 600 m of LW20 and 21 are presented in Appendix 3. 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 trend ("rainfall CRM"), and the dates that previous longwalls pass under (if relevant) a piezometer.

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

- In some swamps, a sharp peak lasting several days following a significant rainfall event, followed by a rapid recession as described below. The sharp peaks represent input from the rainfall itself and subsequent runoff events. An example is at Swamp 87, piezometer 87_01 in Appendix 3.
- In other swamps, a flat-topped or gently sloping peak with a duration of several weeks, indicating that groundwater levels are sustained near the ground surface following the rainfall event or that there is sufficient water entering the swamp (from rainfall or run-on from up-catchment) and the level of water in the swamp is maintained at a constant elevation by surface drainage. An example is Swamp 85 piezometer 85_02 in Appendix 3).
- A concave downward recession (seen in Swamp 1b at piezometer 01b_01, prior to mining).
- A concave upward recession (seen in Swamp 23, piezometer 23_02).

In many cases swamp hydrographs display characteristic combinations of the above responses, suggesting that each is indicative of a hydrological (or hydrogeological) control that becomes dominant as the water supply declines after the rainfall event.

Swamps that have been undermined commonly display hydrological changes shortly following the passage of the longwall beneath the monitoring site. Those hydrological changes are described in Section 4.7.

4. POTENTIAL MINING EFFECTS

Ground subsidence and depressurisation of groundwater systems associated with underground mining can result in a range of effects on surface water and shallow groundwater systems. In this section, potential impacts are identified, and their likelihood and severity assessed in relation to the proposed mining activities.

In relation to Dendrobium Mine Area 3C 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.
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.
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 the health and distribution of swamp vegetation communities.

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 LW20 and LW21 by mine subsidence consultants MSEC (2019a). The MSEC assessment used the Incremental Profile Method (IPM) calibrated to observations above previously mined longwalls in Area 3B. The main findings from the MSEC report are listed in Table 6, and contours of predicted total subsidence following extraction of both LW20 and LW21 are shown in Figure 1. The reader is referred to the subsidence assessment by MSEC (2019a) for further detail.

Table 6. Summary of predicted subsidence effects (from MSEC 2019a)

Location / feature	Predicted subsidence effects
Within longwall footprint	Contours of predicted vertical subsidence are shown in Figure 1.
	LW20: Up to 1800 mm subsidence, 20 mm/m incremental tilt, 0.3 km^{-1} incremental hogging curvature and 0.6 km^{-1} incremental sagging curvature.
	LW21: Up to 2050 mm subsidence, 30 mm/m incremental tilt, 0.5 km^{-1} incremental hogging curvature and 0.75 km^{-1} incremental sagging curvature.
Wongawilli Creek	Wongawilli Creek is located outside the extents of LW20 and LW21, at a minimum distance of 130 m (from LW20) at its closest point. The maximum predicted vertical subsidence along Wongawilli Creek of less than 20 mm; maximum 60 mm upsidence and 150 mm incremental valley closure.

Location / feature	Predicted subsidence effects
	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).
Donalds castle Creek	Donalds Castle Creek is located outside LW20 and LW21, at a minimum distance of 510 m at its closest point. The maximum predicted vertical subsidence is less than 20 mm and it is unlikely to experience measurable conventional tilts. Subsidence related fracturing and flow diversion were noted at Rockbar DC-RB33 during the extraction of LW9. The rockbar is not expected to experience measurable additional movement or fracturing as a result of extraction of LW20 and LW21. Given that Donalds Castle Creek is located more than 400 m from LW20, it is unlikely that additional fracturing and flow diversion will occur on Donalds Castle Creek as a result of extraction of LW20 and 21.
Tributaries	One headwater tributary of Wongawilli Creek crosses the footprint of LW20 (WC20), and one is very close (WC24). The headwaters of two Wongawilli Creek tributaries cross the LW21 footprint (WC23, WC25). No Donalds Castle Creek tributaries are mapped as crossing the footprint of either of these longwalls. It is expected that fracturing of stream beds will occur, and flow diversions are likely in sections that directly overly the longwalls, with minor and isolated fracturing occurring at distances up to approximately 400 m from the longwalls.
Swamps	Swamps 142 and 144 are predicted to experience vertical subsidence of 30 mm. The remaining swamps within the study area are predicted to experience less than 20 mm vertical subsidence and are not expected to experience measurable conventional tilts, curvatures or strains. Valley related upsidence and closure could result in the movement of the strata beneath Swamps 142, 144 and 09. Based on experience elsewhere (Mills and Huuskes, 2004), surface fracturing due to the unconfined nature of the bed rock could occur to a depth of 10-15 m and result in the diversion of some surface water flows beneath parts of these swamps.

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 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 Independent Expert Panel for Mining in the Catchment (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).

Notwithstanding the inherent uncertainties in the approaches, it is considered useful to compare estimates of the expected height of fracturing for the proposed mining conditions at LW20 (255 m void width) and LW21 (270 m void width) with those at the previously mined longwalls of Area 3B (305 m panel width). Estimates for the range of expected conditions at LW20 and LW21 are compared with estimates for LW9 in Area 3B in Table 7, using three approaches (Ditton and Merrick, 2014; Mills, 2011; Tammetta, 2013).

Table 7. Comparison of estimates of height of fracturing

Longwall	Overburden depth (m)	Longwall width (m)	Height of connected fracturing or		
			Mills (2011)	Tammetta (2013)	Merrick & Ditton (2014) (Geol A95%)
LW20	313 – 407	255	255	306 – 321	209 – 235
LW21	284 – 385	270	270	317 – 335	207 – 236
LW9	390	305	305	374	253

*Note: All estimates assume a mining height of 3.9 m; Ditton's spanning thickness, t, is assumed to be 20 m.

Taken as a guide, these estimates indicate that fracturing above longwalls will not develop to the same extent as above longwalls in Area 3B, largely due to the proposed narrower longwall panels. Estimates based on Mills (2011) and Ditton and Merrick (2014) indicate that connective fracturing will extend to within the Bald Hill Claystone (and below the elevation of the Wongawilli Creek bed). The more conservative estimate based on Tammetta's (2013) approach extends into the Hawkesbury Sandstone at an elevation near, or above, the elevation of the Wongawilli Creek bed adjacent to LW20 (Figure 2 and Figure 3).

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, 2019a). 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 gradient along the third-order streams Donalds Castle Creek and Wongawilli 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 LW20 and 21. Changes in gradient in the minor first order tributaries located above the longwall and development footprints are predicted to be <2 %, 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, 2019a).

Table 8. Summary of predicted changes to stream gradient (from MSEC 2019a)

Location / feature	Predicted subsidence effects
Wongawilli Creek	The average natural gradient of Wongawilli Creek within the study area is 0.37%. Changes in gradient due to mining-induced tilting are predicted to be less than 0.05% (unlikely to be measurable), considerably less than the average natural stream gradient. Therefore, it is unlikely that there would be adverse changes in the potential for ponding, flooding or scouring of the banks along the creek due to the mining-induced tilts. It is possible that there could be some localised changes in the levels of ponding or flooding from mining induced tilt where the maximum changes in grade coincide with existing pools, steps or cascades along the creek. However, such changes are not expected to result in adverse impacts on the creek.
Donalds castle Creek	Within the study area, the predicted changes in stream gradient along Donalds Castle Creek are less than 0.05 % (not expected to be measurable). The predicted changes are considerably less than the average natural stream gradient of Donalds Castle Creek (3.5 %). Therefore, it is unlikely that there would be adverse changes in the potential for ponding, flooding or scouring of the banks along the creek due to the mining-induced tilts.
Tributaries	The maximum predicted tilt for the drainage lines within the study area is 3 %, which is less than the natural stream gradients (typically between 10 % and 20 %. There are no predicted reversals in grade. Therefore, it is unlikely that there would be large-scale adverse changes in the levels of ponding or scouring of the banks due to the mining-induced tilt. It is possible that localised increased ponding could develop due to mining induced tilt in some isolated locations, where the natural grades are small and where the drainage lines exit the mining area.
Swamps	The mining-induced tilt at Swamps Den142 and 144 is small (0.1%) when compared to the natural surface gradients at the swamps (~10%). There are no topographical depressions or reversals in grade predicted to develop within the extent of Swamps due to the extraction of LW21. Therefore, it is unlikely that there would be adverse changes in the levels of ponding or scouring in this swamp as a result of mining induced tilt. The remaining swamps within the study area are located outside the extents of the proposed LW20 and LW21. These swamps are predicted to experience tilts of less than 0.5 % and it is therefore unlikely that these swamps would experience adverse changes in the levels of ponding or scouring due to tilt.

4.4 Flow diversion

Mining directly under or close to surface watercourses can result in diversion of flow from the watercourse and/or loss of surface flow from the catchment. Water diverted from surface channels can be directed through fracture networks to the water table and may re-emerge downstream, as is commonly observed in the Southern Coalfield. If surface fractures intersect deeper (vertically connected) mining induced fracture networks, there is potential for water to be directed into those deeper fracture storages, or to the mine itself. In the latter case, surface flow would be lost from the catchment. Significant losses would be detected as a decrease in flow (and catchment yield) at downstream gauges.

Surface fracturing, including fracturing of stream-beds, has been observed at distances up to 400 m from previously extracted longwalls in the Southern Coalfield. The furthest reported fracture outside of the previously extracted longwalls at Dendrobium Mine was located approximately 290 m south of

LW12 in Area 3B (MSEC, 2019a). End of Panel assessments for completed longwalls in Area 3B have identified fracturing in stream-beads and changes in flow related to mining at the following sites:

- Donalds Castle Creek; Decrease in total flow of ~28% at gauge DCS2 following extraction of LW9 - LW11 directly beneath the catchment headwaters (HGEO, 2017a);
- WC21; Loss of flow during low flow conditions following extraction of LW9 and LW10 directly beneath the watercourse (HydroSimulations, 2016b);
- LA4; Fracturing in the creek bed near gauge LA4_S1 (270 m west of LW13) and diversion of flow and 20-40% reduction in flow at the gauge (HGEO, 2017b);
- Wongawilli Creek; Fracturing related to the extraction of LW9 was noted in Pool 43a (200 m west of LW6 and 410 m east of LW9). An apparent decline in water levels in the pool during 2017 was investigated and found to be related to prolonged dry conditions and groundwater depressurisation rather than an effect of fracturing within the stream/pool (HGEO, 2018a; Watershed Hydrogeo, 2018).

As of the end of LW13, there was no detectable decrease in total stream flow at the down-stream site WWL on Wongawilli Creek. At the downstream site DCU on Donalds Castle Creek there was a possible effect. The absence of a clear down-stream reduction in flow suggests that the losses are below the detection threshold of the AWBM modelling approach.

The observations are consistent with the assessments and modelling carried out by MSEC (2019a), which conclude that:

- The rate of impacts along Wongawilli Creek due to the previous mining [at Area 3B and Area 3A] is considered to be very low. Fracturing [due to the extraction of LW20 and LW21] could occur along the section of Wongawilli Creek that is located within a distance of approximately 400 m from the proposed longwalls (2.5 km length), noting that Wongawilli Creek passes within about 120 m of the northern end of LW21.
- The main third order channel of Donalds Castle Creek does not pass within 400 m of LW20. Therefore, it is unlikely that fracturing and stream diversion will occur along Donalds Castle Creek as a result of subsidence associated with LW20 and LW21.
- First and second-order tributaries to Wongawilli Creek that are located directly above the proposed longwalls could experience the full range of predicted subsidence movements. Surface water flow diversions, similar to that observed on WC21 above Longwalls 9-13, are likely to occur along the sections of drainage lines that are located directly above the proposed longwalls.

4.5 Reduced 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 Donalds Castle Creek and Wongawilli Creek was assessed using a regional numerical groundwater model by HydroSimulations (2019). A summary of the estimated incremental loss of baseflow due to LW20-21 is shown in Table 9 and the reader is referred to Section 5.6 of the HydroSimulations report for further details.

Table 9. Estimated incremental change in baseflow due to groundwater drawdown

Watercourse	Total Average Flow (ML/d)	Average annual baseflow (ML/day)	Change in baseflow after end of LW21	
			After 2 years*	After 10 years
Donalds Castle Creek	1.65	0.017 – 0.099	0.14	0.008
Wongawilli Creek	12.2	1.22 – 1.95	0.2	0.18

* Incremental flow reductions as ML/d converted from ML/yr shown in Table 5-6 of HydroSimulations (2019)

Average annual baseflow is represented as a range based on the baseflow separation and baseflow indices (BFI) presented in Section 2.3.2 of HydroSimulations (2019).

4.5.1 Predicted effects on stream flow characteristics

The predicted effects of baseflow depletion on stream flow characteristics are well-illustrated using flow duration curves. A flow duration curve shows the percentage of time that a stream carries flow exceeding a given rate, and it is useful for defining low-flow and no-flow characteristics. Figure 6 and Figure 7 show flow duration curves for flow gauges DCU on Donalds Castle Creek and WWL on Wongawilli Creek respectively.

For each plot, the modelled flows based on pre-mining data are shown as the heavy green line (i.e. natural conditions). The post-mining assessment period (2013 – 2018 and 2010 – 18 respectively), as modelled using parameters from the baseline, is represented by a dashed purple line. This line illustrates what natural flows would have been without the influence of mining. The observed flows for the same post-mining period are shown as the dotted green line. The difference between the purple and dotted green lines is indicative of the actual effect of mining in these catchments (notwithstanding uncertainties related to flow gauging errors and calibration, as discussed in IEPMC, 2018).

The *maximum* predicted impacts from the groundwater assessment (from Tables 5-5 and 5-6 of HydroSimulations, 2019) for both Donalds Castle Creek and Wongawilli Creek have then been applied for two cases: the predicted impacts as originally approved for Dendrobium Area 3B (blue line) and Dendrobium approved plus proposed LW20-21 effects (red line). The difference between each of the blue or red lines and the heavy green line indicates the maximum predicted impact or flow depletion at each site.

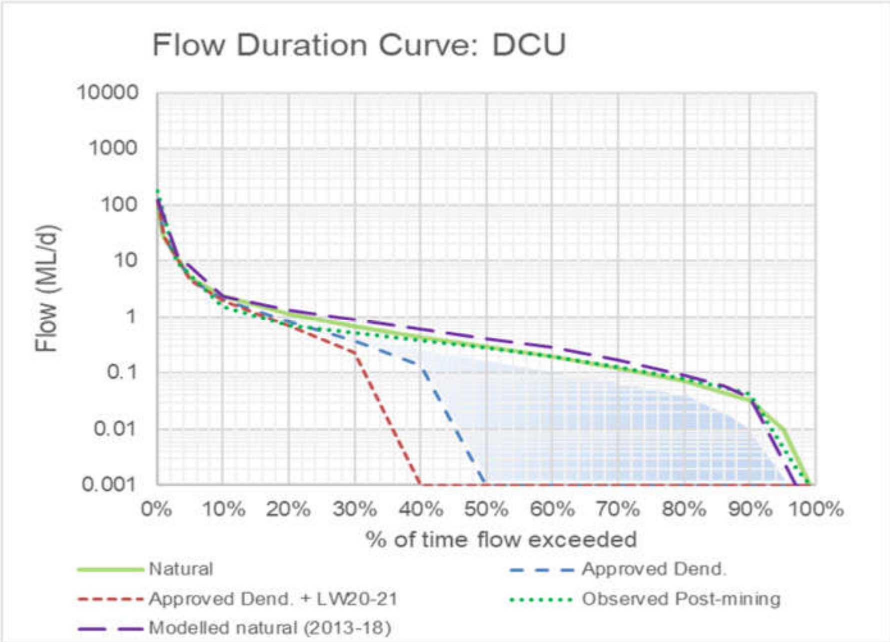

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Figure 6 Flow duration curve for DCU on Donalds Castle Creek

The flow duration curves for DCU (Figure 6) indicates that:

- The actual effects of the Approved Dendrobium mining (dashed green line) have been less than predicted (blue dashed line), based on the 2013-2018 data. Average flow at DCU is approximately 1.9 ML/d, and actual effects at average flows are similar to predicted (i.e. approximately 0.3 ML/d), but at lower flows, the magnitude of actual effects has been 0.2 ML/d or less.
- The groundwater model predicts, that the effect of Areas 3B longwalls will result in a significant decline in low-flows (dashed blue line) and a significant increase in the number of days with no-flows on DCU (from 2-3% of the time to 50%). This is a conservative prediction based on the first bullet point.
- The predicted maximum incremental effect of Longwalls 20-21 is 0.14 ML/d. The cumulative effects of Area 3B and Longwalls 20-21 would be to further reduce flows by about 0.4 ML/d (dashed red line). This could result in cease-to-flow conditions up to 60% of the time at DCU, although an increase to 3-5% is considered more likely based on available pre- and post-mining data shown in Figure 6.

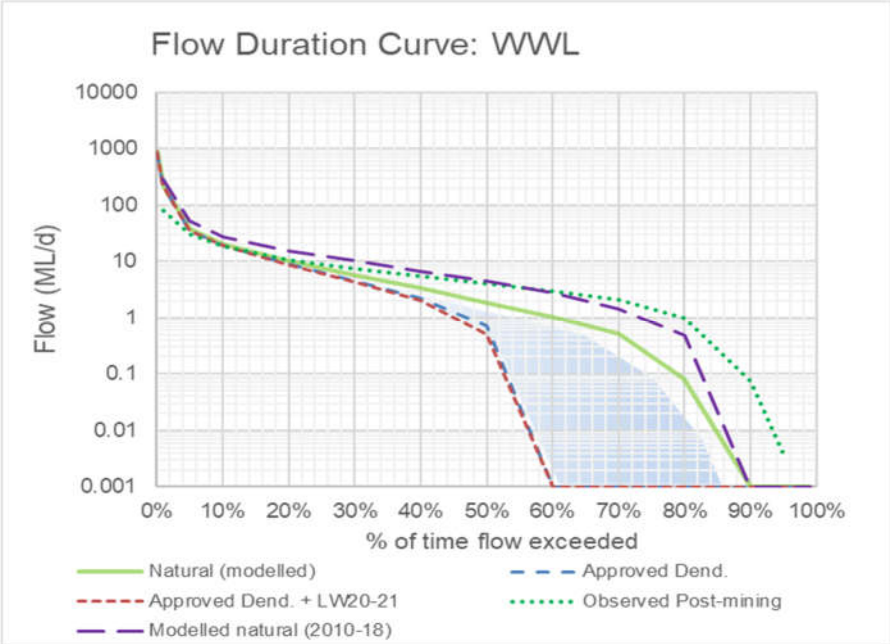

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Figure 7 Flow duration curve for WWL on Wongawilli Creek

The flow duration curves for WWL (Figure 7) indicates that:

- As noted for DCU, the actual effects of Approved Dendrobium at WWL have been less than predicted, based on the 2013-2018 data and modelling (comparison of purple and dotted green lines);
- The groundwater model predicts, again conservatively, that the effect of Areas 3B longwalls would be to result in a significant decline in low-flows (dashed blue line) and a significant increase in the number of days with no-flows on WWL (from about 10% of the time to 40%). As stated above, such a decline has not been observed to date.
- The predicted maximum incremental effect of Longwalls 20-21 is 0.2 ML/d. The cumulative effects of Area 3B and Longwalls 20-21 would be to further reduce flows (dashed red line) by about 1.3 ML/d. This could result in cease-to-flow conditions up to 44% of the time, although an increase to 12-15% is considered more likely based on available pre- and post-mining data shown in Figure 7.

Effects on flows at WWL have not yet been identified in the End of Panel Reports, 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). Therefore, it is possible that effects upstream of or between gauging stations may be more significant than those observed at downstream gauging stations.

4.6 Groundwater 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 increased shallow fractures resulting from valley closure and the unconfined nature of surface sediments (10 to 20m 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;

- enhanced drainage and discharge of groundwater (with high EC and dissolved iron and low DO) to creeks via subsidence induced fractures.

Oxidation of Fe2+ 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 within and near streambeds, and the formation of iron staining of stream beds and rock faces. 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 that have been affected by subsidence (e.g. WC21 during mining of Longwalls 9, 10 and 11) have shown temporary increases in dissolved Fe and Mn, and an increase in pH to near neutral (pH 7) at sampling locations immediately down-gradient of the affected area. The overall salinity of stream waters (as estimated from EC) is controlled largely by rainfall patterns, with EC tending to increase during periods of low rainfall. This reflects evaporative concentration of salts and the relative increase in contribution from groundwater discharge (baseflow). There is no discernible change in EC as a result of mining subsidence. Time series plots of field parameters and selected dissolved metals for stream sampling sites relevant to this assessment are shown in Appendix 2.

It is therefore expected that water quality influence due to mining would be minor in stream reaches within subsidence affected areas. Local discolouration of streambeds and rock faces by iron hydroxide precipitation can continue for a number of years but is a temporary impact. Water quality effects on stored waters of the reservoirs are expected to be negligible and undetectable.

4.7 Swamp hydrology

Swamps that have been undermined commonly display hydrological changes shortly following the passage of the longwall beneath the monitoring site. Hydrographs of piezometers at affected locations may show one or more of the following (See Appendix 3):

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

The most recent assessment of the effects of mining at Dendrobium under swamps is the LW13 End of Panel assessment (HGEO, 2018b). That analysis indicates that almost all piezometers that are directly mined under by longwalls extracted in Dendrobium Area 3A and 3B showed responses to mining. A recent assessment at Dendrobium Mine concluded that hydrological change in Upland Swamps is not evident in shallow groundwater piezometers located more than 60 m from the extracted longwall margin (Watershed Hydrogeo, 2019).

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, 2019b), and no hydrological impacts at swamp piezometers located near mapped lineaments that are greater than 60 m from the goaf (Watershed Hydrogeo, 2019). However, it is prudent to consider the possibility of distant impacts where swamps overlie mapped lineaments that intersect the mine.

The hydrological changes are most likely due to the development of surface fracturing and bedding plane openings in the sandstone substrate of the swamp. The surface fracturing has two main hydrogeological implications:

- it forms fracture networks that allow drainage of the swamp and re-direction of the stored waters to down-gradient locations; and
- increases the fracture storage in the sandstone substrate.

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. On-going monitoring will allow assessment of longer-term impacts.

The locations of mapped swamp vegetation communities relative to the planned longwalls are shown in Figure 1. Swamps located within 600 m of the planned longwalls are listed in Table 10, with a qualitative assessment of the likelihood that the shallow groundwater regime will be affected by subsidence related ground movements associated with LW20 and LW21 (as described above). The likelihood is based on observations at swamps in Area 3B during and after longwall extraction (e.g. HGEO, 2018b; Watershed Hydrogeo, 2019) and predictions of subsidence related to longwall extraction and other ground movement related to valley closure (MSEC, 2019a). Given their proximity to the proposed longwall panels, it is likely that shallow groundwater levels will be affected at Swamp 144 (being within 60 m of the goaf), and it is possible that affects will be seen in Swamps 09, 140, 141, 142and 145 (between 60 m and 400 m from the goaf). The remaining swamps are unlikely to be impacted since they are located more than 400 m from the proposed goaf and/or are predicted to experience negligible ground movement related to valley closure. In the case of Swamp 05, shallow groundwater levels were impacted at the swamp following the extraction of LW9 and it is unlikely that groundwater levels will be further affected.

Table 10. Summary of predicted impacts to Upland Swamps

Swamp	Area (Ha)	Vegetation communities	Distance from LW20/LW21 goaf (m)	Predicted vertical ground movement (mm; MSEC, 2019a)		Likelihood of shallow groundwater effects
				Subsidence	Upsidence	
02	0.96	Banksia thicket, Tea-tree thicket	600	<20	<20	Unlikely
05	1.71	Banksia thicket, Tea-tree thicket, Restioid Heath	550	<20	100	Unlikely (previously impacted by LW9)
07	5.67	Banksia thicket, Tea-tree thicket	595	<20	<20	Unlikely
09	0.80	Banksia thicket, Tea-tree thicket	300	<20	25	Possible
124	2.10	Sedge-Heath Complex, Restioid Heath, Tea-tree thicket	590	<20	<20	Unlikely
140	0.05	Banksia thicket	330	<20	<20	Possible
141	0.04	Banksia thicket	230	<20	<20	Possible
142	0.16	Banksia thicket	70	30	40	Possible
144	0.54	Banksia thicket	50	30	50	Likely
145	0.45	Banksia thicket	336	<20	<20	Possible

5. PERFORMANCE MEASURES

The performance measures and monitoring of surface water and shallow groundwater in relation to mining at Area 3B are defined in the Area 3B Subsidence Management Plan (South32, 2018b). 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 at Area 3B (baseline) and are updated from time to time as the monitoring phase of the SMP progresses. A SMP for LW20 and LW21 has also been developed to support mining in Area 3C (South32, 2019b). This SMP is an extension of the monitoring and management of subsidence impacts from the adjacent Area 3B to Area 3C.

Stream monitoring sites reviewed as part of this assessment are included in the Area 3B SMP, including sites upstream and downstream of the proposed LW20 and LW21. Therefore, the exiting TARPs are considered generally applicable to future monitoring and management of mining effects related to LW20 and LW21 immediately adjacent and down-stream of Area 3B. These TARPs have been reviewed and incorporated into the Area 3C SMP. These TARPs are under review by South32, DPE, WaterNSW and OEH prior to longwall mining in Area 3C. 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

Additional surface water monitoring sites should be established at suitable locations along Wongawilli Creek where it passes within 400 m of the proposed longwalls. These monitoring points should be established, and monthly baseline monitoring started at least two years prior to the commencement of longwall mining at Area C, if possible.

It is understood that a new monitoring site has been approved by WaterNSW at tributary LC5 to Lake Cordeaux. Qualitative monitoring of the flow/trickle/no flow conditions, as per regular ICEFT observations on other watercourses, is recommended in the near future to understand the pre-mining behaviour of this tributary under varying wet and dry conditions.

Monitoring should include field observation (and photography), analysis of field water quality parameters, pool water levels and collection of grab samples for laboratory analysis (at selected sites), consistent with existing monitoring sites and the approved Area 3B SMP. If possible, it is recommended that automated water level loggers are installed at major pools to provide high frequency data (at least one measurement per day).

The exact location and specification for each monitoring point should be determined in consultation with an appropriately qualified and experienced specialist. As a guide, at least three water quality monitoring sites should be established along Wongawilli Creek within 400 m of the proposed longwalls and one to two field observation sites on each of the four lower-order tributaries, down-stream of where they flow across the proposed longwall.

5.2 Shallow groundwater

Additional shallow groundwater monitoring sites are recommended at the following areas of mapped swamp vegetation which are currently not monitored:

- Den 09: At least two piezometers and soil moisture monitoring sites
- Den 142: At least one piezometer and soil moisture monitoring site

- Den 144: At least two piezometers and soil moisture monitoring sites
- Den 145: At least one piezometer and soil moisture monitoring site

Piezometers should be equipped with automated water level dataloggers with at least one reading per day. Installations should be completed at least two years prior to the commencement of mining, if possible. The exact location and construction details of the installation will need to be determined in consultation with an appropriately qualified and experienced specialist.

6. REFERENCES

Advisian, 2016. Literature review of underground mining beneath catchments and water bodies (No. A26324), Report commissioned by WaterNSW.

ANZECC, 2000. Australian water quality guidelines for fresh and marine waters, National Water Quality Management Strategy Paper No 4. Australian and New Zealand Environment and Conservation Council, Canberra.

Booth, C.J., 2002. The Effects of Longwall Coal Mining on Overlying Aquifers, in: Younger, P., Robins, N. (Eds.), Mine Water Hydrogeology and Geochemistry, Geological Society, London Special Publications. pp. 17–45.

Boughton, W., 2004. The Australian water balance model. Environ. Model. Softw. 19, 943–956. https://doi.org/doi:10.1016/j.envsoft.2003.10.007

Cowley, K.L., Fryirs, K.A., Hose, G.C., 2016. Identifying key sedimentary indicators of geomorphic structure and function of upland swamps in the Blue Mountains for use in condition assessment and monitoring. Catena 147, 564–577.

Ditton, S., Merrick, N., 2014. A new sub-surface fracture height prediction model for longwall mines in the NSW coalfields, in: Australian Earth Science Convention 2014, Abstracts No. 110. Presented at the Australian Earth Science Convention, 7-10 July 2014, Geological Society of Australia, Newcastle, NSW, pp. 135–136.

DSITI, 2011. SILO Climate Data Drill [WWW Document]. URL https://www.longpaddock.qld.gov.au/silo/datadrill/ (accessed 5.2.17).

Forster, I., 1995. Impact of underground mining on the hydrogeological regime, Central Coast, NSW, in: Sloan, S. (Ed.), . Presented at the Engineering Geology of Newcastle - Gosford Region, Australian Geomechnics Society.

Fryirs, K.A., Gough, J., Hose, G.C., 2014. The geomorphic character and hydrological function of an upland swamp, Budderoo plateau, southern highlands, NSW, Australia. Phys. Geogr. 35, 313–334.

Galvin, J.R., 2017. Review of PSM report on height of fracturing - Dendrobium Area 3B, Review commissioned by the NSW Department of Planning and Environment.

Galvin, J.R., Timms, W., Mactaggart, B., 2016. Springvale Mine Extension Project - Extraction Plan for Longwall 419, Report for NSW Department of Planning and Environment. Sydney.

Guo, H., Adhikary, D., Gaveva, D., 2007. Hydrogeological response to longwall mining, ACARP Report C14033, CSIRO Exploration and Mining. Australian Coal Industry's Research Program (ACARP).

HGEO, 2018a. Assessment of water level, stream flow and water chemistry trends at Wongawilli Creek (No. D18295), Report by HGEO Pty Ltd for South32 Illawarra Coal.

HGEO, 2018b. Dendrobium Mine End of Panel surface water and shallow groundwater assessment: Longwall 13 (Area 3B) (No. D18304), Report by HGEO Pty Ltd for South32 Illawarra Coal.

HGEO, 2017a. Dendrobium Mine End of Panel surface water and shallow groundwater assessment: Longwall 12 (Area 3B) (No. D17260), Report commissioned by South32 Illawarra Coal.

HGEO, 2017b. Review of Lake Avon sub-catchment LA4 following extraction of Longwalls 12 and 13 (No. D17268), Report commissioned by South32 Illawarra Coal.

HNCMA, 2008. Hawkesbury-Nepean Catchment Action Plan 2007-2016. Hawkesbury-Nepean Catchment Management Authority, Goulburn, NSW.

HRC, 1998. Independent Inquiry into the Hawkesbury Nepean River System: Final Report. Healthy Rivers Commission of NSW, Sydney.

HydroSimulations, 2019. Dendrobium Mine Longwalls 20 and 21 Groundwater Assessment (No. HS2019- 19f), Report by HydroSimulations for South32 Illawarra Coal.

HydroSimulations, 2016a. Dendrobium Area 3B Groundwater Assessment (No. HC2016/02), Report by HydroSimulations for South32 Illawarra Coal.

HydroSimulations, 2016b. Dendrobium Mine End of Panel Surface and Shallow Groundwater Impact Assessment – Dendrobium Area 3B Longwall 11 (No. HC2016/12), Report by HydroSimulations for South32 Illawarra Coal.

IEPMC, 2018. Initial report on specific mining activities at the Metropolitan and Dendrobium coal mines, Report by the Independent Expert Panel for Mining in the Catchment for the NSW Department of Planning and Environment.

McNally, G., Evans, R., 2007. Impacts of longwall mining on surface water and groundwater, Southern Coalfield, NSW, Report prepared for NSW Department of Environment and Climate Change. eWater Cooperative Research Centre, Canberra.

Mills, K.W., 2011. Developments in understanding subsidence with improved monitoring, in: Proceedings of the Eighth Triennial Conference on Management of Subsidence, 2011. Presented at the Mine Subsidence 2011, Mine Subsidence Technological Society, Pokolbin, NSW, pp. 25–41.

Mills, K.W., Huuskes, W., 2004. The Effects of Mining Subsidence on Rockbars in the Waratah Rivulet at Metropolitan Colliery, in: Proceedings of the 6th Triennial Conference, Subsidence Management Issues. Mine Subsidence Technological Society, Maitland, NSW, p. 243.

MSEC, 2019a. Subsidence Predictions and Impact Assessments for the Natural and Built Features due to the Extraction of the Proposed Longwalls 20 and 21 in Area 3C at Dendrobium Mine (No. MSEC978 RevD). Report by Mine Subsidence Engineering Consultants for South32 Illawarra Coal.

MSEC, 2019b. Review of the effects of lineaments and geological structures on the measured surface subsidence in Area 3B at Dendrobium Mine (No. MSEC1034). Report by Mine Subsidence Engineering Consultants for South32 Illawarra Coal.

Peng, S.S., Chiang, H.S., 1984. Longwall mining. Wiley, New York.

PSM, 2017. Height of cracking - Dendrobium Area 3B, Dendrobium Mine (No. PSM3021- 002R), Report commissioned by the NSW Department of Planning and Environment.

Sentek, 2017. Soil Moisture Measuring, Soil Moisture Measurement – Sentek [WWW Document]. URL http://www.sentek.com.au/products/soil-moisture-triscan-sensors.asp (accessed 4.28.17).

South32, 2019a. Dendrobium Area 3C Watercourse impact monitoring management and contingency plan (Management Plan No. B). South32 Illawarra Coal.

South32, 2019b. Dendrobium Area 3C Subsidence Management Plan Volume 2: Subsidence Management Plan (Management Plan). South32 Illawarra Coal.

South32, 2018a. Dendrobium Area 3B Watercourse impact monitoring management and contingency plan (Management Plan No. Rev 1.5). South32 Illawarra Coal.

South32, 2018b. Dendrobium Area 3B Subsidence Management Plan Volume 2: Subsidence Management Plan (Management Plan No. PDM-001-9.6.1D). South32 Illawarra Coal.

Tammetta, P., 2013. Estimation of the height of complete groundwater drainage above mined longwall panels. Groundwater 52, 826–826. https://doi.org/10.1111/gwat.12253

Threatened Species Scientific Committee (TSSC), 2014. Conservation Advice (including listing advice) for Coastal Upland Swamps in the Sydney Basin Bioregion. Department of the Environment, Canberra.

Tomkins, K.M., Humphreys, G.S., 2006. Evaluating the Effects of Fire and Other Catastrophic Events on the Sediment and Nutrient Transfer Within SCA Special Areas. Technical Report 2: Upland swamp development and erosion on the Woronora Plateau during the Holocene, Report commissioned by the Sydney Catchment Authority. Macquarie University. Dept. of Environment and Geography.

Toth, J., 2009. Gravitational systems of groundwater flow: Theory, evaluation, utilization. Cambridge University Press, Cambridge, UK.

Watershed Hydrogeo, 2019. Geographic review of mining effects on Upland Swamps at Dendrobium (No. R008), Report by Watershed Hydrogeo Pty Ltd for South32 Illawarra Coal.

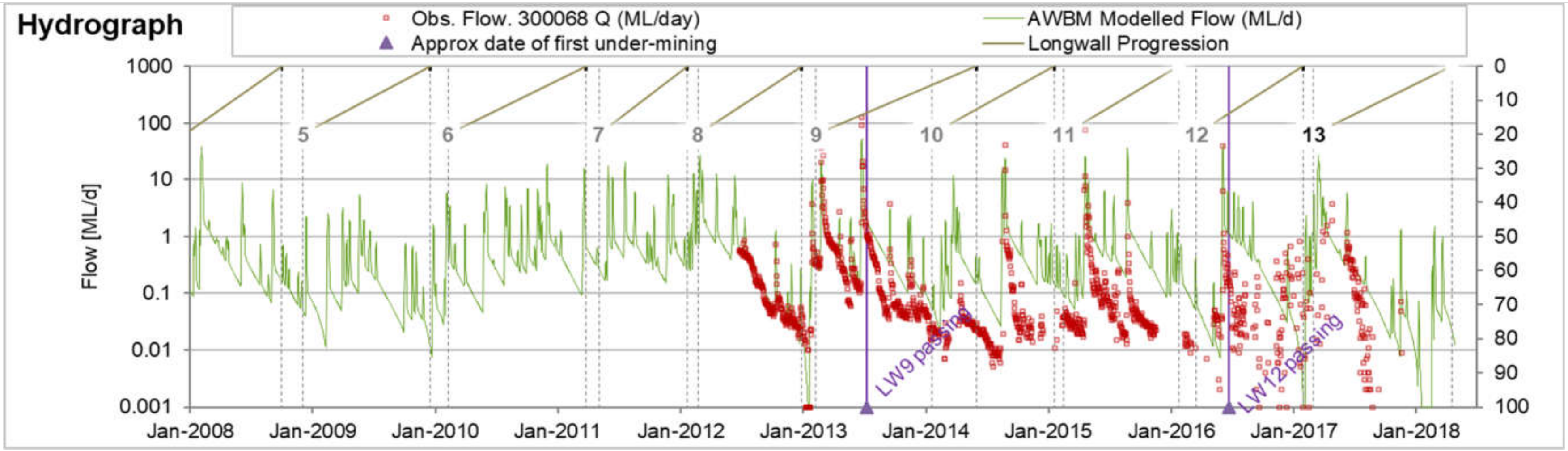
Watershed Hydrogeo, 2018. Dendrobium Area 3B Analysis of low-flow and pool levels on Wongawilli Creek (No. R003i2), Report by Watershed Hydrogeo Pty Ltd for South32 Illawarra Coal.

Whittaker, B., Reddish, D., 1989. Subsidence: occurrence, prediction and control. Elsevier, Amsterdam.

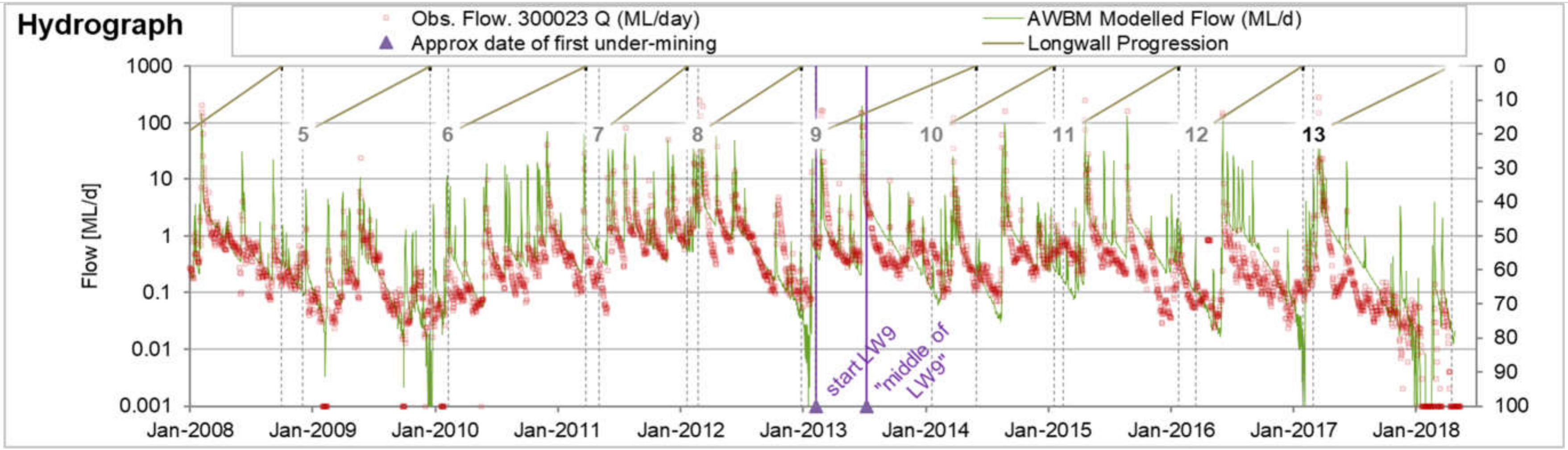
Young, A.R.M., 1982. Upland swamps (dells) on the Woronora Plateau, NSW. University of Wollongong.

APPENDIX 1 – Stream hydrographs

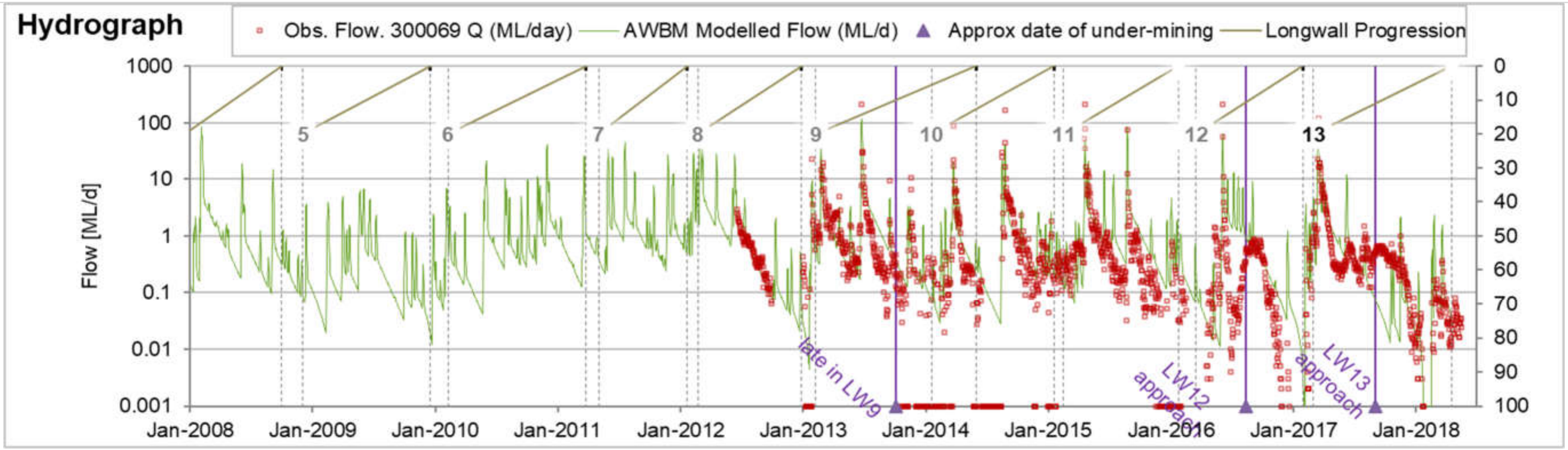
Time series plots of measured stream flow at gauging stations and modelled stream flow from the calibrated baseline AWBM rainfall-runoff model. These plots show the full period used for assessment, i.e. the pre-mining baseline and the post-mining period.



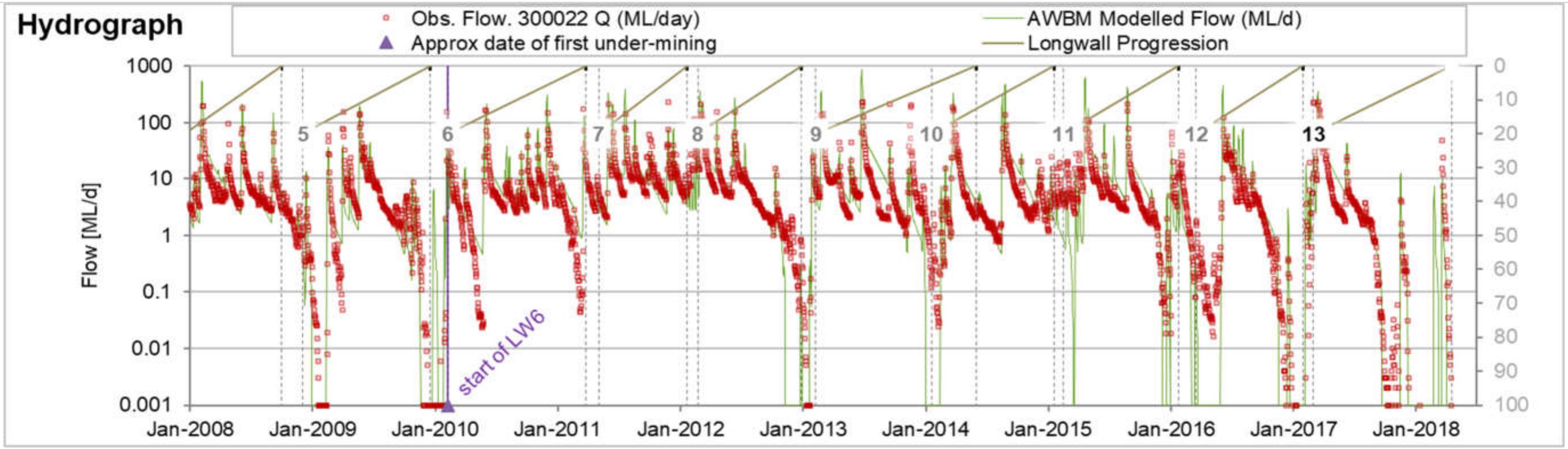
Comparison of AWBM simulated and Observed Flow at DCS2 [300068] on upper Donalds Castle Creek



Comparison of AWBM simulated and Observed Flow at DCU [300023] on Donalds Castle Creek

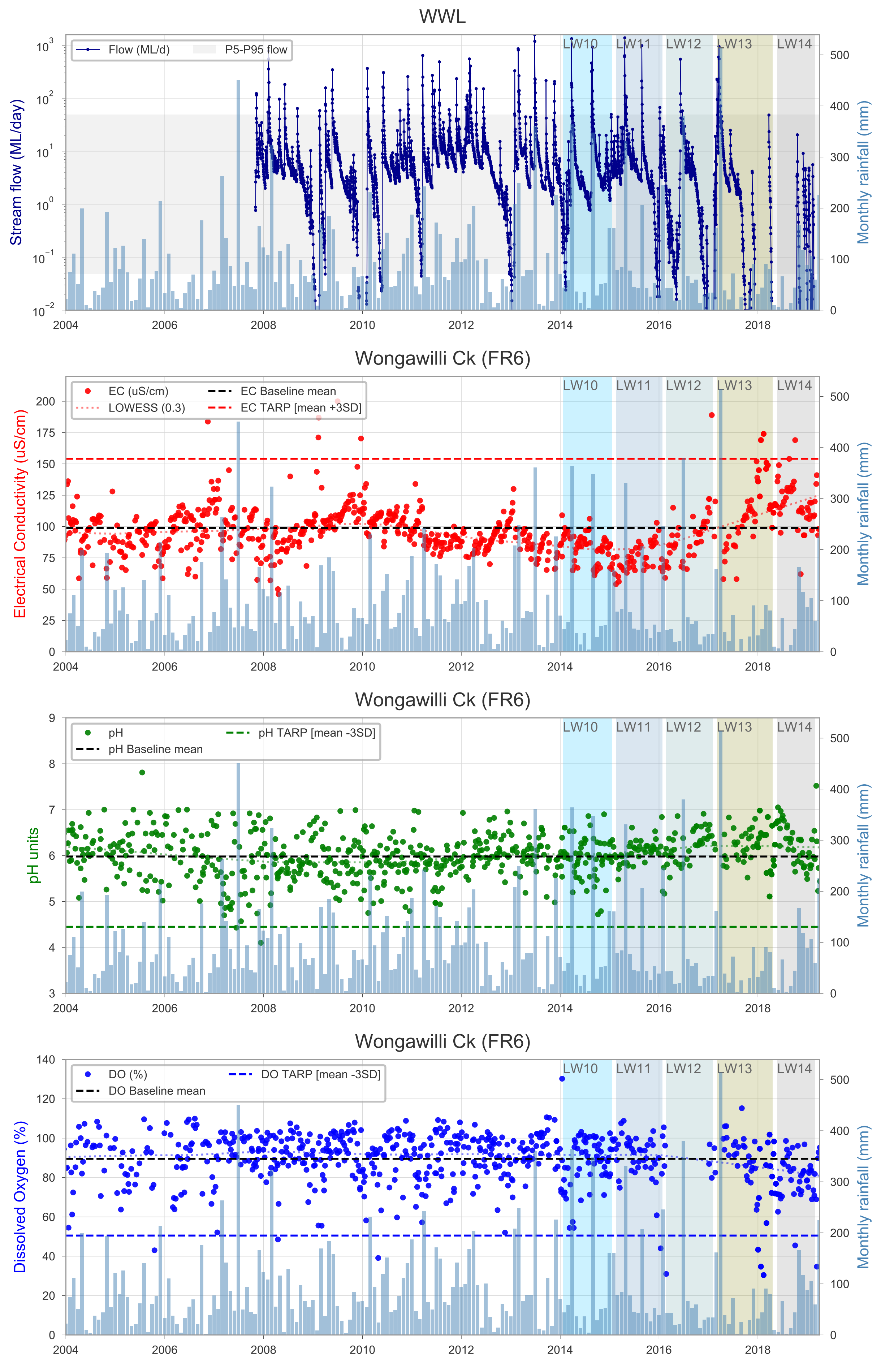


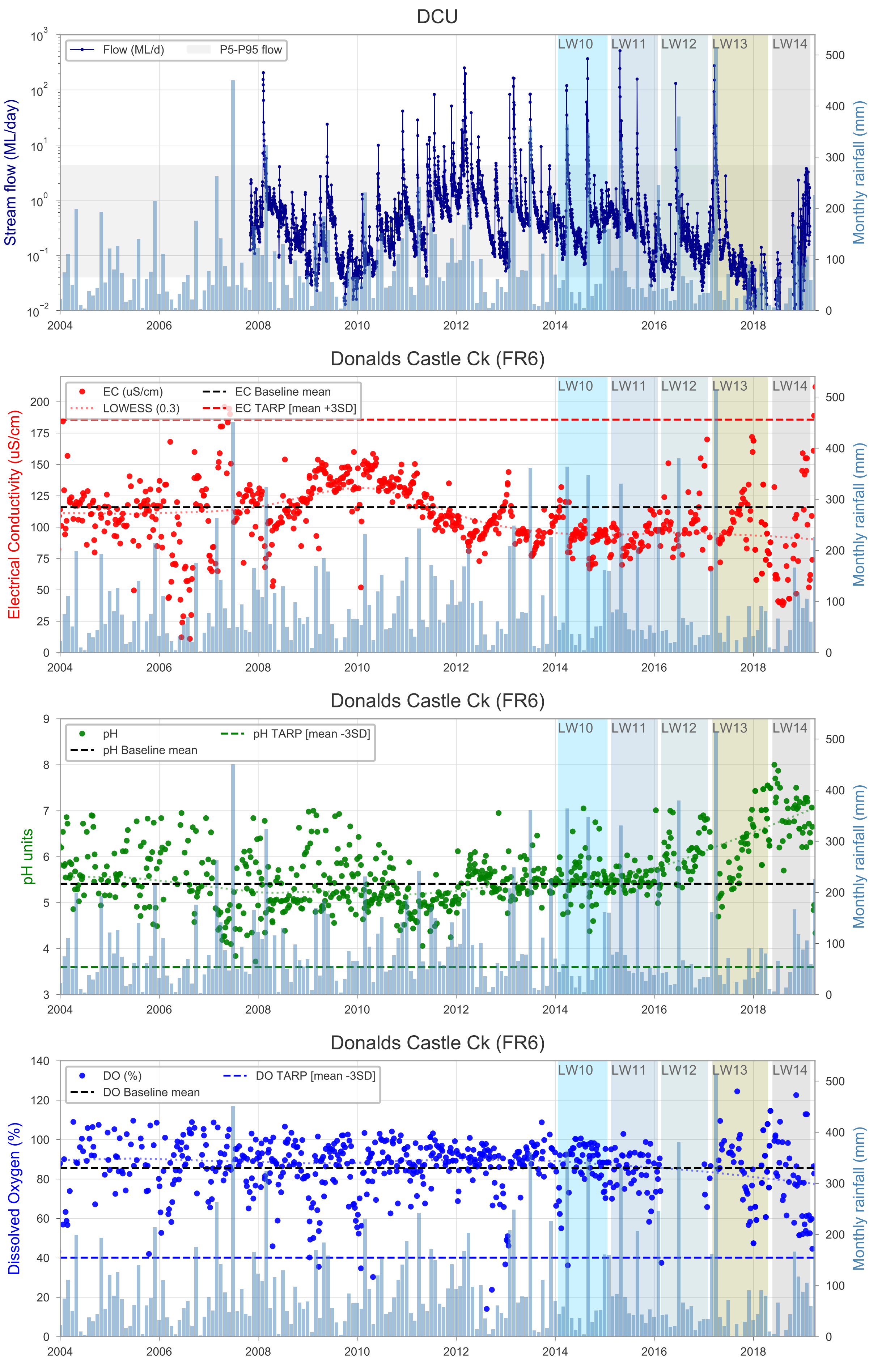
Comparison of AWBM simulated and Observed Flow at WC21S1 [300069] on tributary WC21



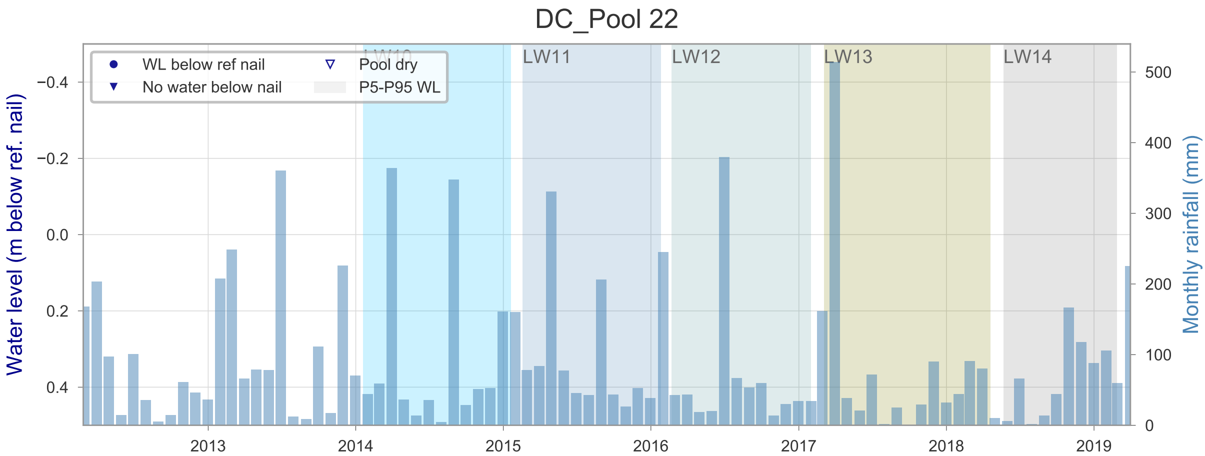
Comparison of AWBM simulated and Observed Flow at WWL [300022] on Wongawilli Creek

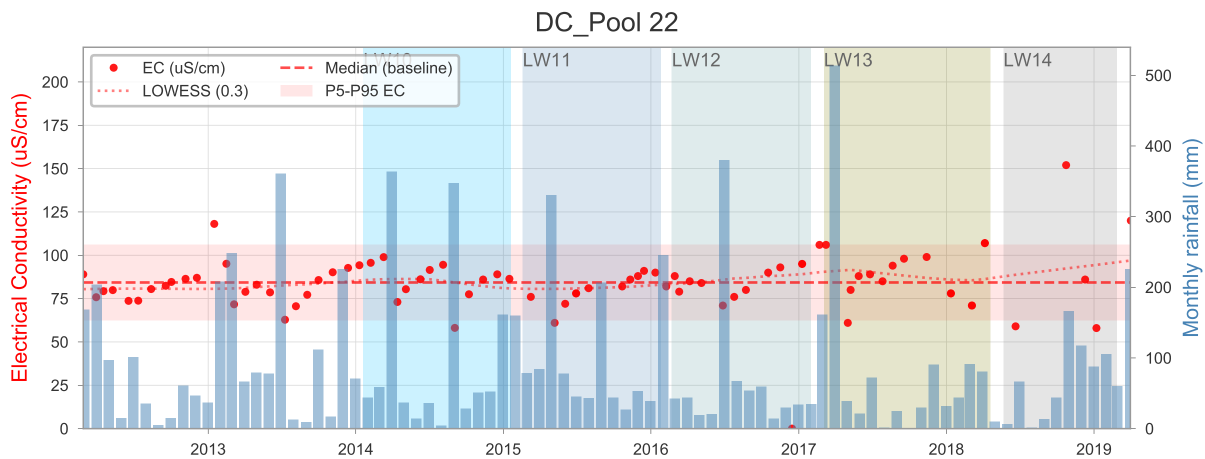
APPENDIX 2 – Surface water chemistry time-series

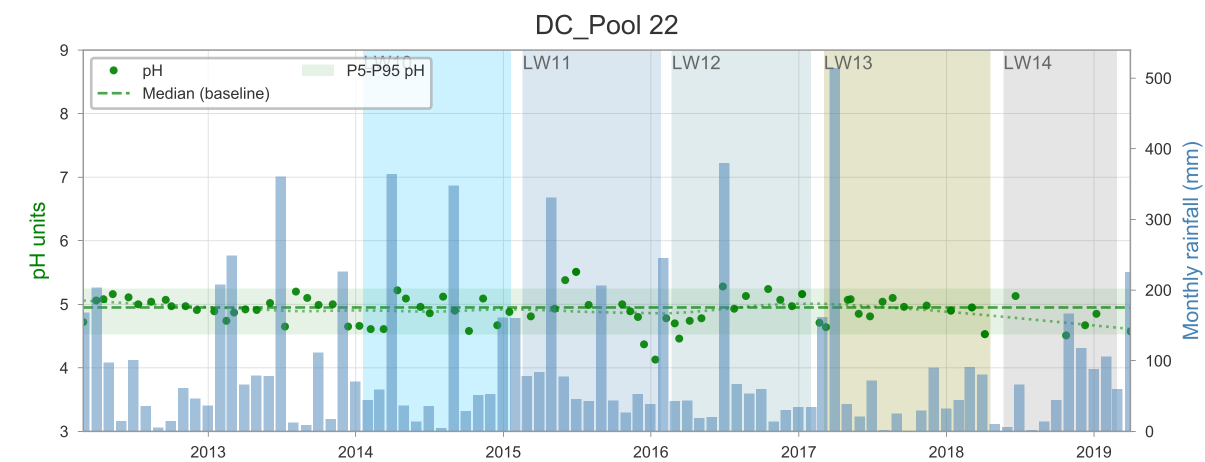

WWL
Flow (ML/d)
P5-P95 flow
Stream flow (ML/day)
Monthly rainfall (mm)
LW10
LW11
LW12
LW13
LW14
Wongawilli Ck (FR6)
EC (uS/cm)
LOWESS (0.3)
EC Baseline mean
EC TARP [mean +3SD]
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
Wongawilli Ck (FR6)
pH
pH Baseline mean
pH TARP [mean -3SD]
pH units
Monthly rainfall (mm)
Wongawilli Ck (FR6)
DO (%)
DO Baseline mean
DO TARP [mean -3SD]
Dissolved Oxygen (%)
Monthly rainfall (mm)
2004
2006
2008
2010
2012
2014
2016
2018

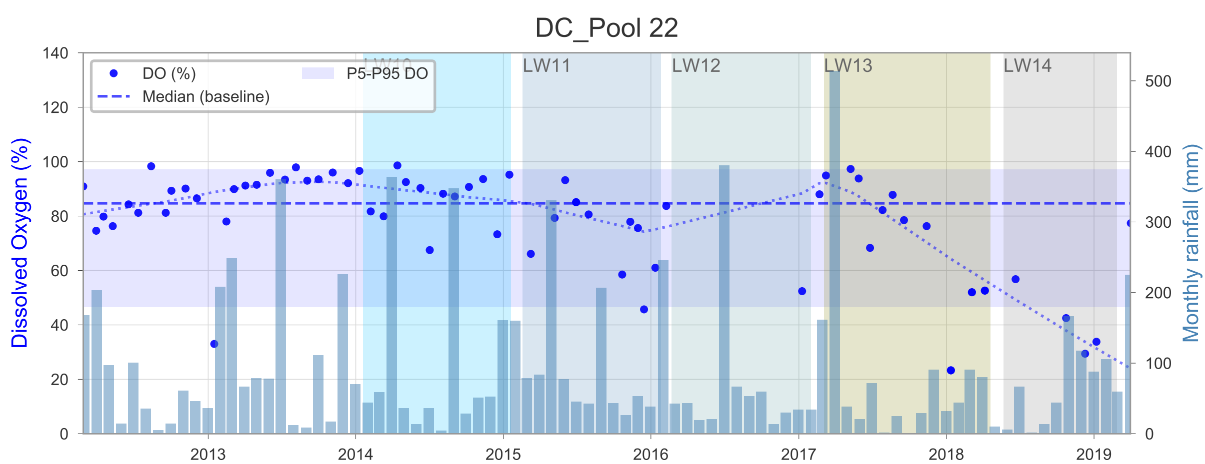


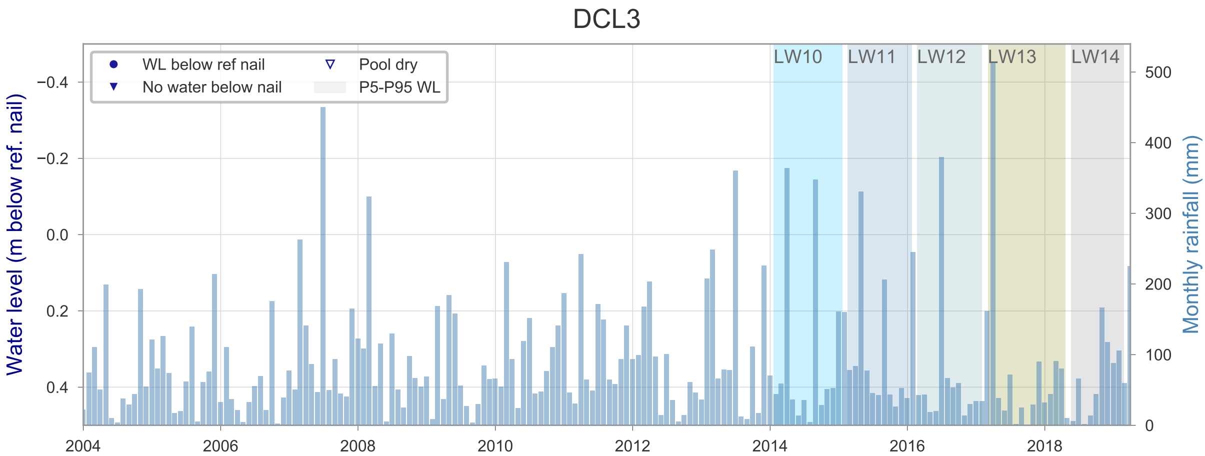
DCU
Flow (ML/d)
P5-P95 flow
LW10
LW11
LW12
LW13
LW14
Stream flow (ML/day)
Monthly rainfall (mm)
Donalds Castle Ck (FR6)
EC (uS/cm)
LOWESS (0.3)
EC Baseline mean
EC TARP [mean +3SD]
Electrical Conductivity (uS/cm)
Donalds Castle Ck (FR6)
pH
pH Baseline mean
pH TARP [mean -3SD]
pH units
Donalds Castle Ck (FR6)
DO (%)
DO Baseline mean
DO TARP [mean -3SD]
Dissolved Oxygen (%)
2004
2006
2008
2010
2012
2014
2016
2018

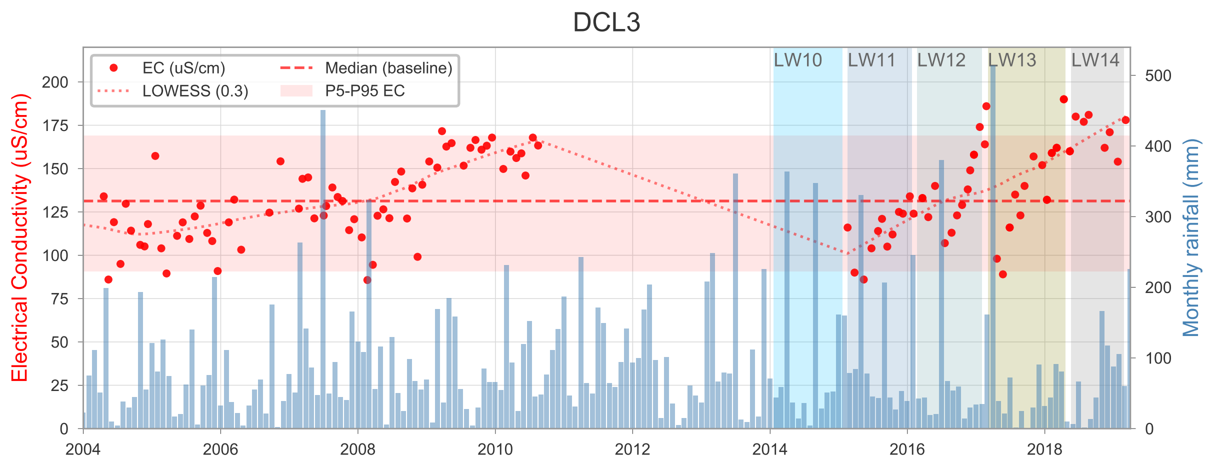

DC_Pool 22
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
LW10
LW11
LW12
LW13
LW14
Water level (m below ref. nail)
Monthly rainfall (mm)

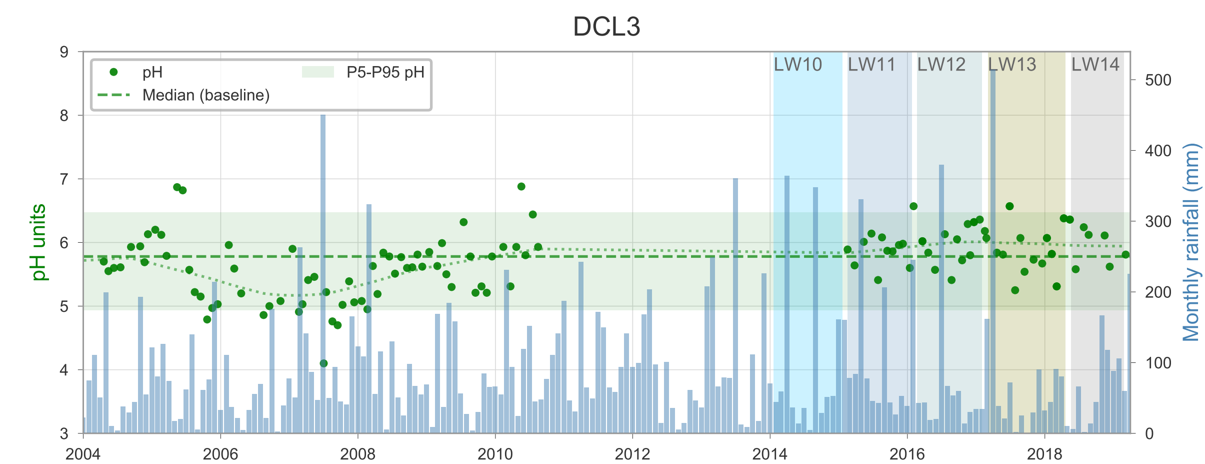

DC_Pool 22
EC (uS/cm)
LOWESS (0.3)
Median (baseline)
P5-P95 EC
LW10
LW11
LW12
LW13
LW14
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)

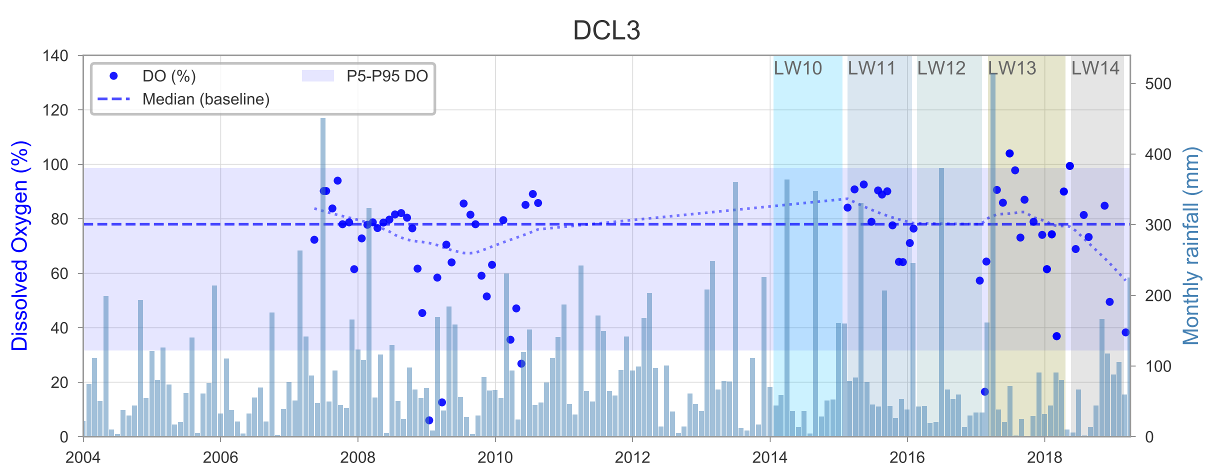

DC_Pool 22
pH
Median (baseline)
P5-P95 pH
LW10
LW11
LW12
LW13
LW14
pH units
Monthly rainfall (mm)

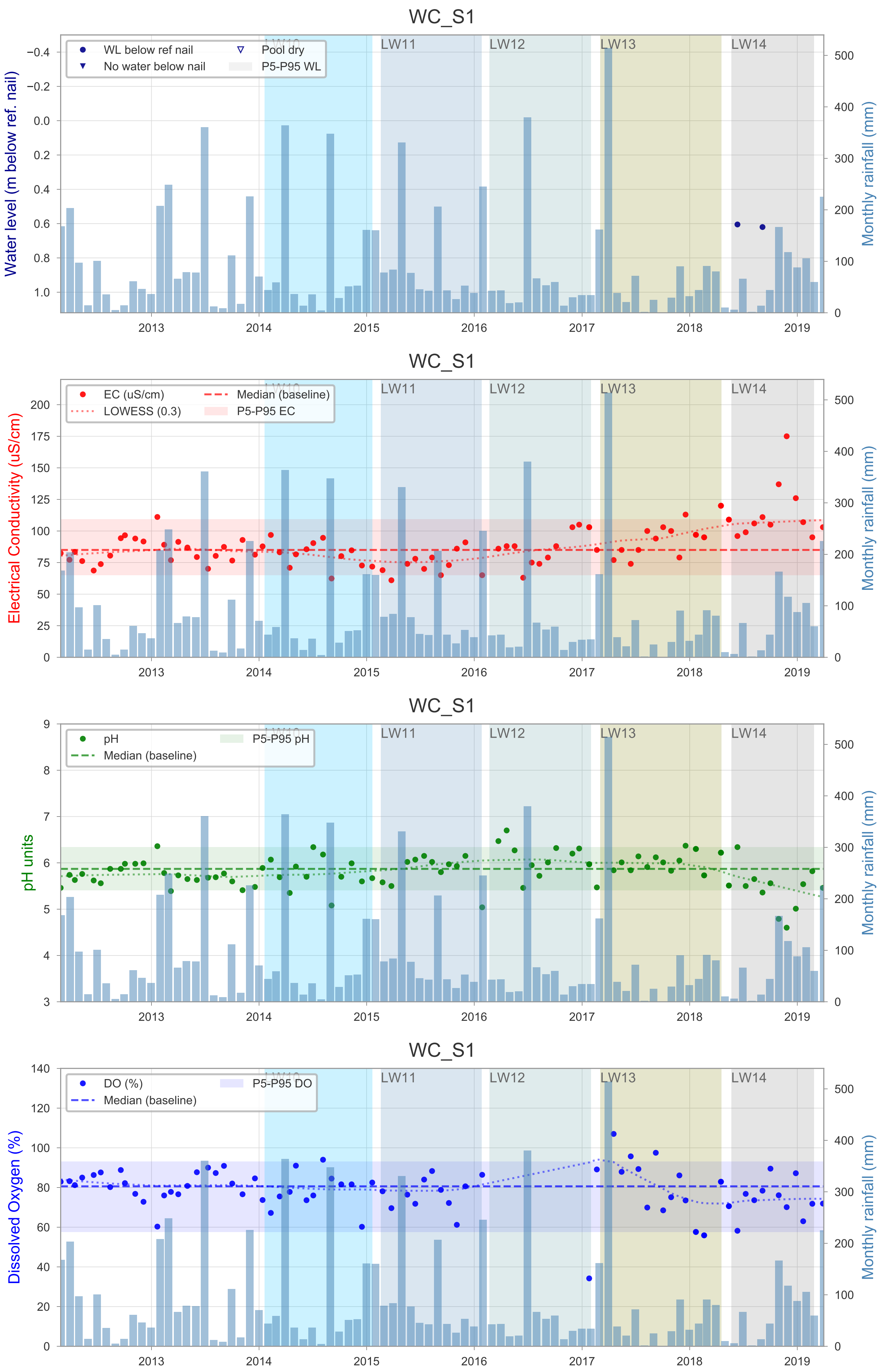

DC_Pool 22
DO (%)
Median (baseline)
P5-P95 DO
LW10
LW11
LW12
LW13
LW14
Dissolved Oxygen (%)
Monthly rainfall (mm)

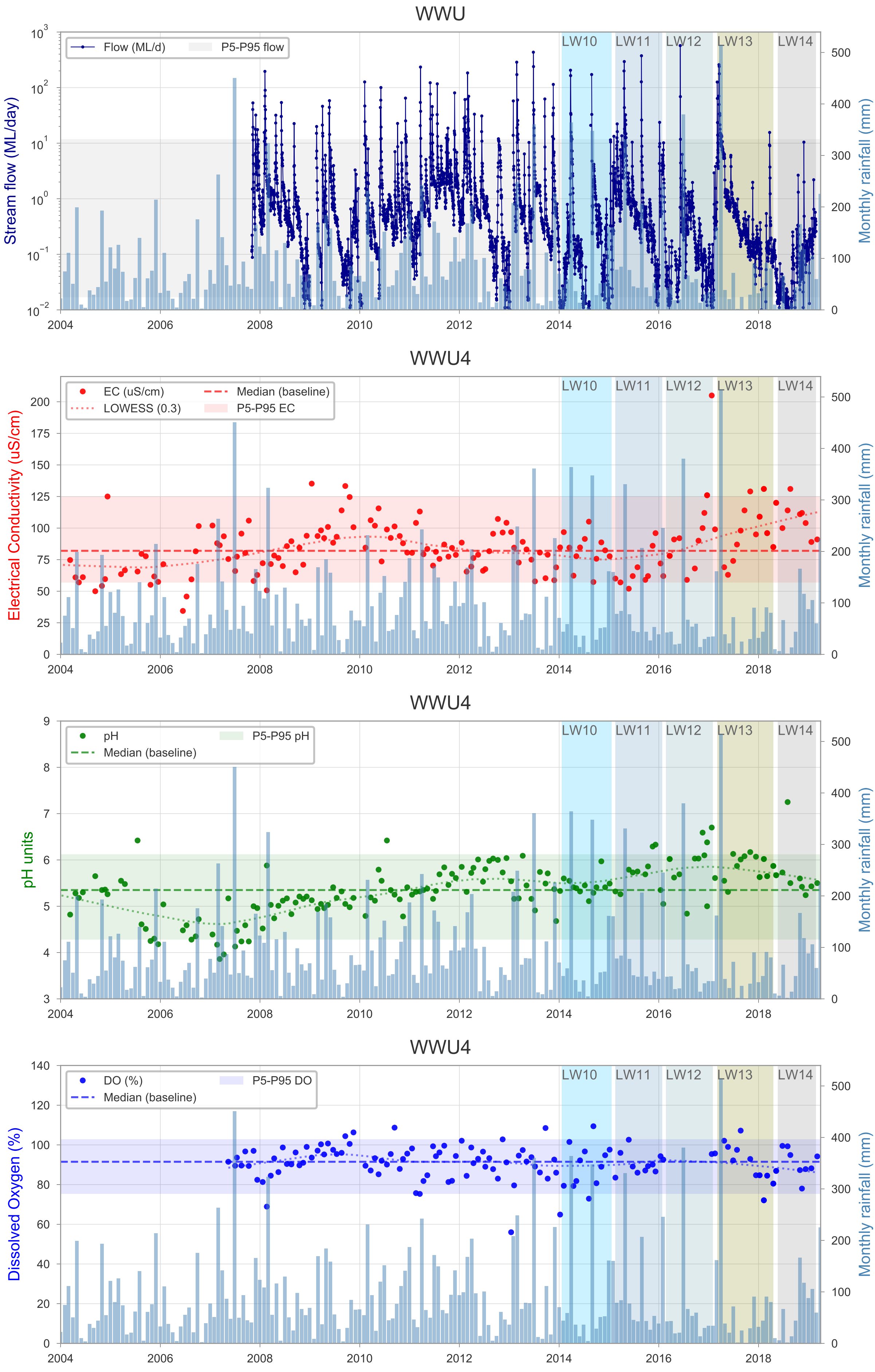

DCL3
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
LW10
LW11
LW12
LW13
LW14
Water level (m below ref. nail)
Monthly rainfall (mm)


DCL3
EC (uS/cm)
LOWESS (0.3)
Median (baseline)
P5-P95 EC
LW10
LW11
LW12
LW13
LW14
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)

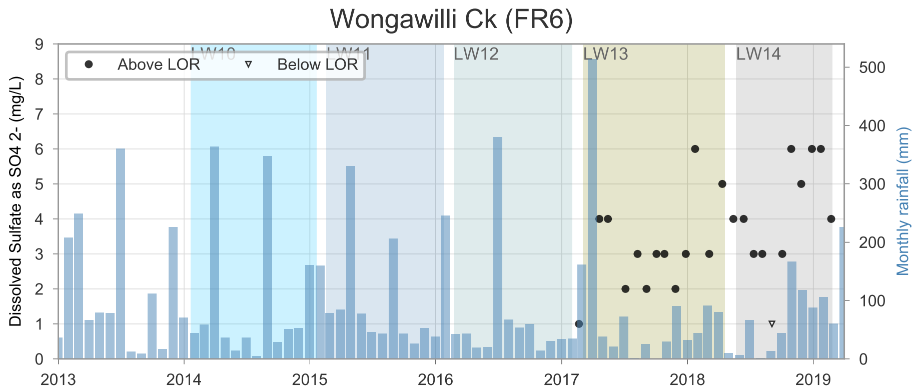

DCL3
pH
Median (baseline)
P5-P95 pH
LW10
LW11
LW12
LW13
LW14
pH units
Monthly rainfall (mm)

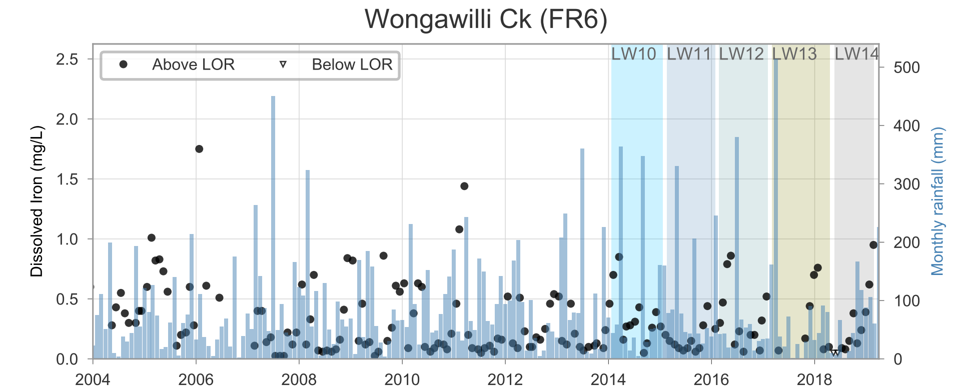

DCL3
DO (%)
Median (baseline)
P5-P95 DO
LW10
LW11
LW12
LW13
LW14
Dissolved Oxygen (%)
Monthly rainfall (mm)

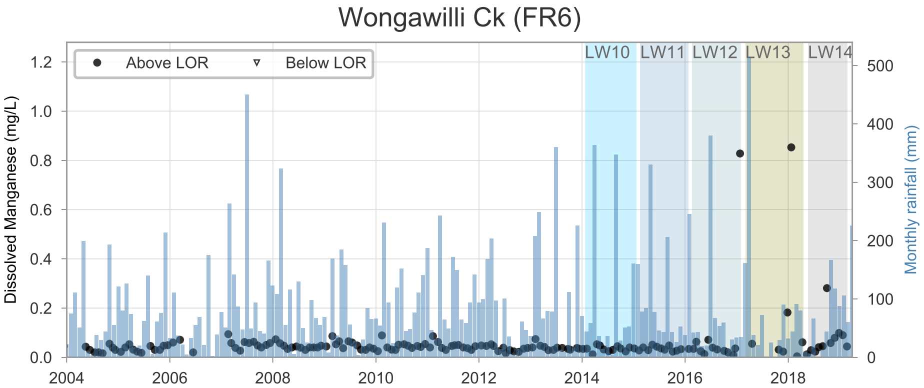

WC_S1
WL below ref nail
No water below nail
Pool dry
P5-P95 WL
LW10
LW11
LW12
LW13
LW14
Water level (m below ref. nail)
Monthly rainfall (mm)
WC_S1
EC (uS/cm)
LOWESS (0.3)
Median (baseline)
P5-P95 EC
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
WC_S1
pH
Median (baseline)
P5-P95 pH
pH units
Monthly rainfall (mm)
WC_S1
DO (%)
Median (baseline)
P5-P95 DO
Dissolved Oxygen (%)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019

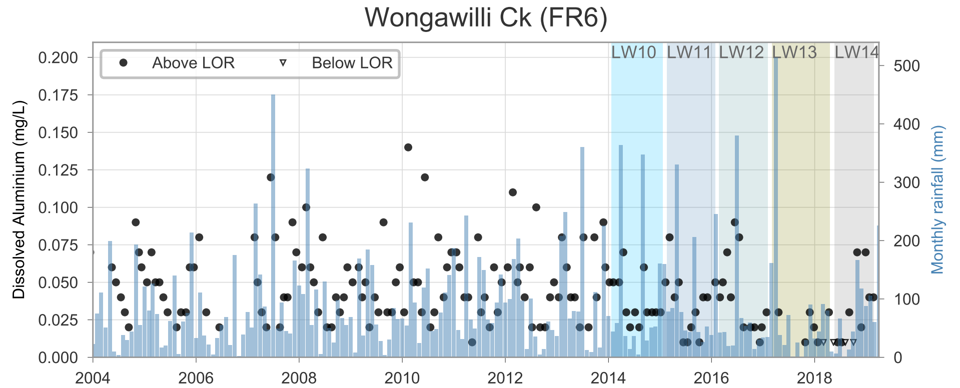


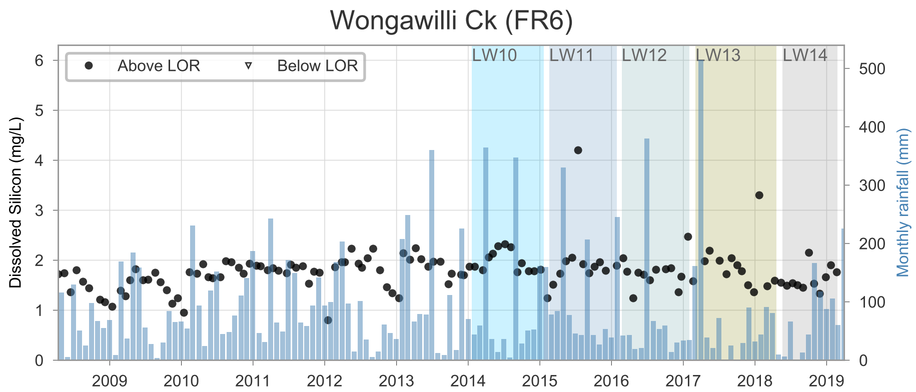
WWU
Flow (ML/d)
P5-P95 flow
LW10
LW11
LW12
LW13
LW14
Stream flow (ML/day)
Monthly rainfall (mm)
WWU4
EC (uS/cm)
Median (baseline)
LOWESS (0.3)
P5-P95 EC
Electrical Conductivity (uS/cm)
Monthly rainfall (mm)
WWU4
pH
Median (baseline)
P5-P95 pH
pH units
Monthly rainfall (mm)
WWU4
DO (%)
Median (baseline)
P5-P95 DO
Dissolved Oxygen (%)
Monthly rainfall (mm)

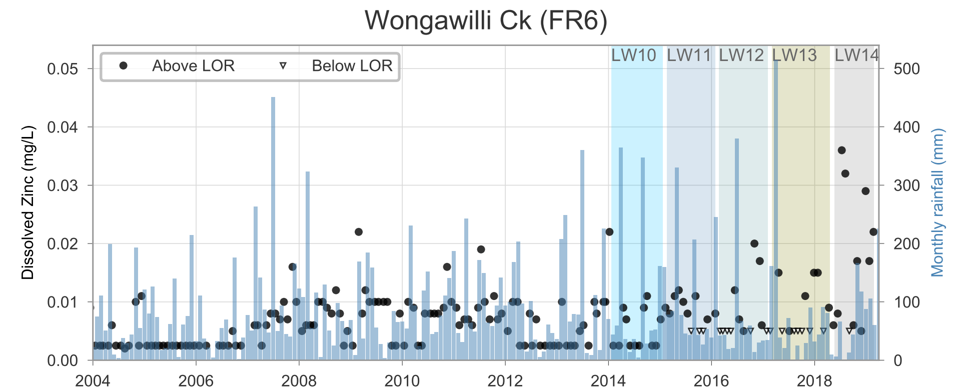

Wongawilli Ck (FR6)
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Sulfate as SO4 2- (mg/L)
Monthly rainfall (mm)

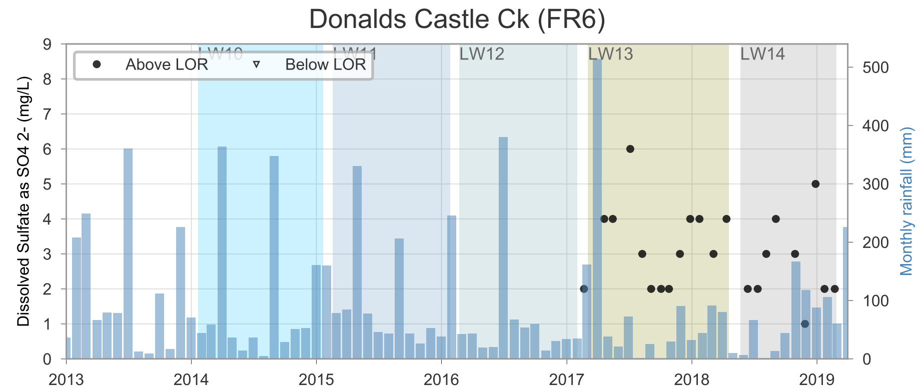

Wongawilli Ck (FR6)
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Iron (mg/L)
Monthly rainfall (mm)

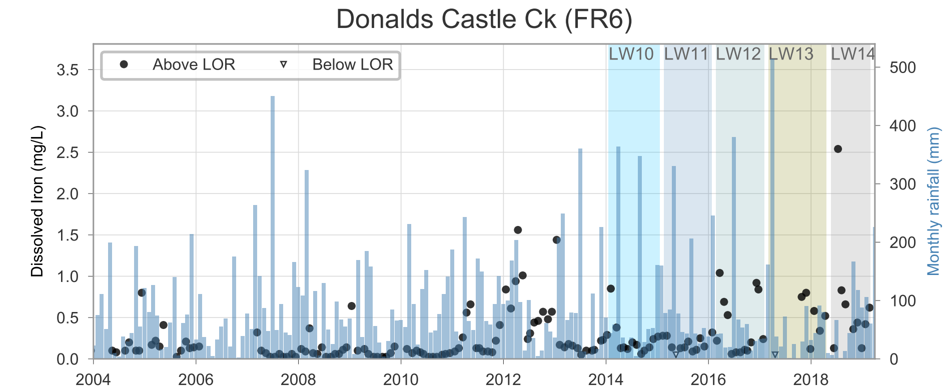

Wongawilli Ck (FR6)
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Manganese (mg/L)
Monthly rainfall (mm)

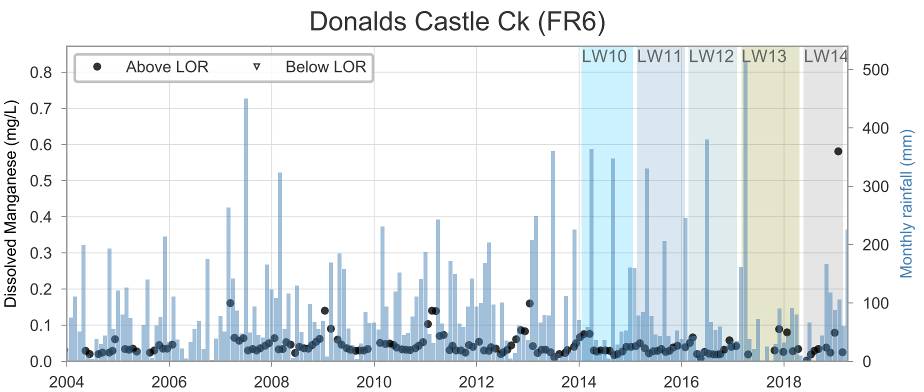

Wongawilli Ck (FR6)
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Aluminium (mg/L)
Monthly rainfall (mm)

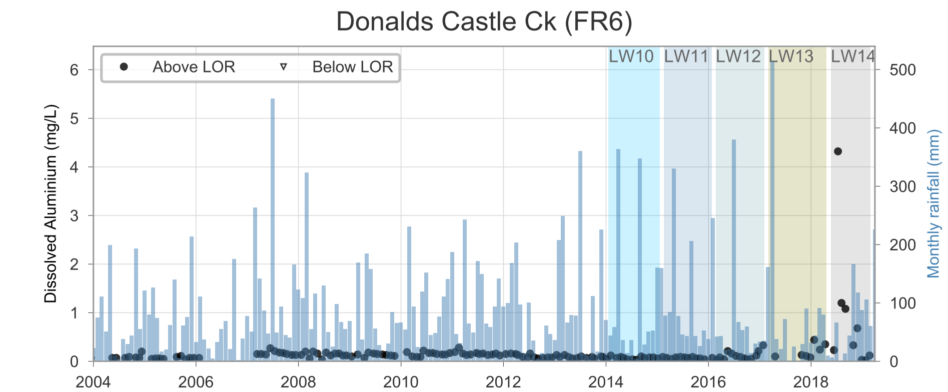

Wongawilli Ck (FR6)
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Silicon (mg/L)
Monthly rainfall (mm)

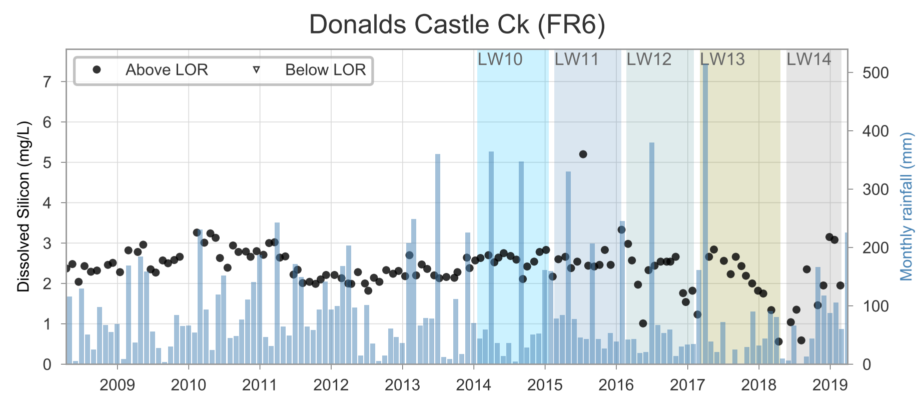

Wongawilli Ck (FR6)
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Zinc (mg/L)
Monthly rainfall (mm)

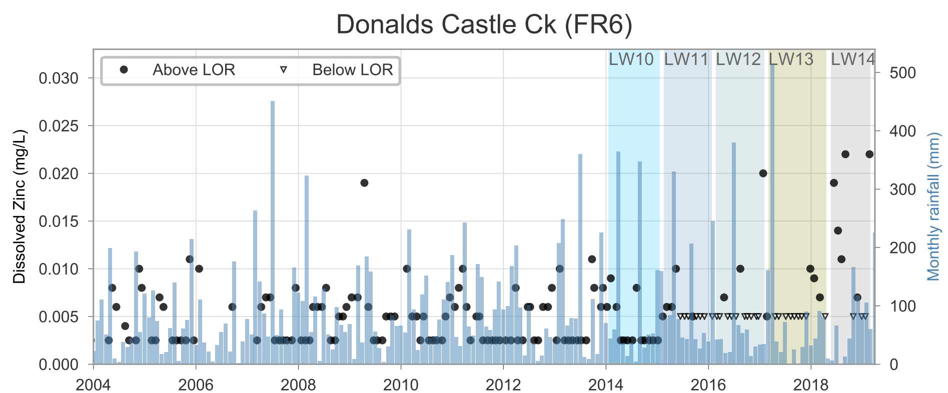

Donalds Castle Ck (FR6)
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Sulfate as SO4 2- (mg/L)
Monthly rainfall (mm)

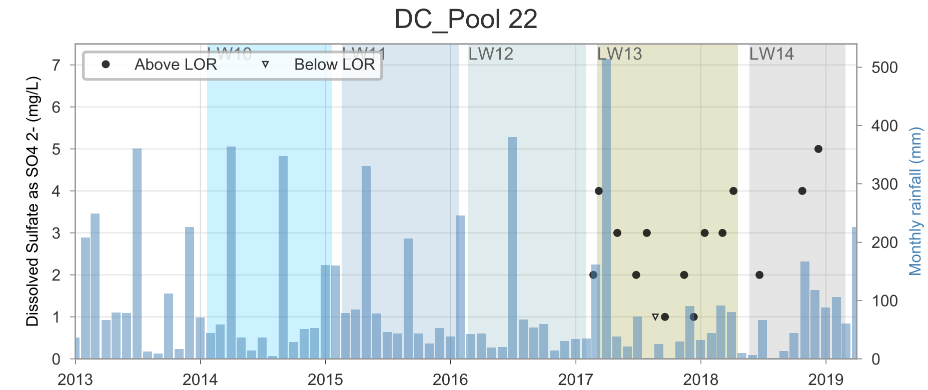

Donalds Castle Ck (FR6)
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Iron (mg/L)
Monthly rainfall (mm)

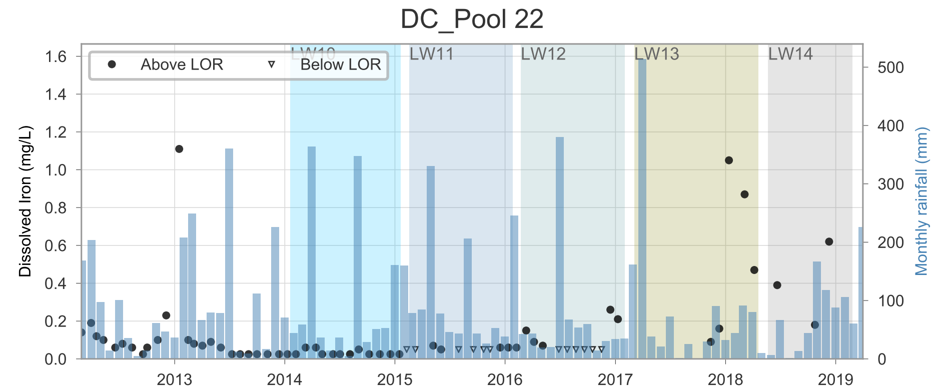

Donalds Castle Ck (FR6)
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Manganese (mg/L)
Monthly rainfall (mm)

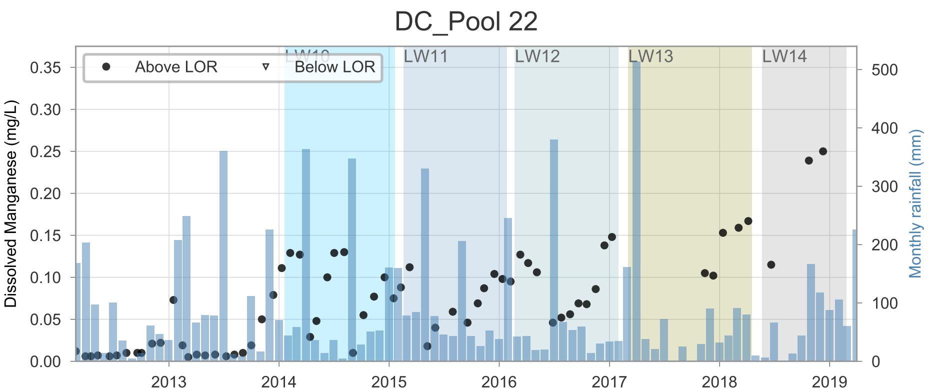

Donalds Castle Ck (FR6)
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Aluminium (mg/L)
Monthly rainfall (mm)

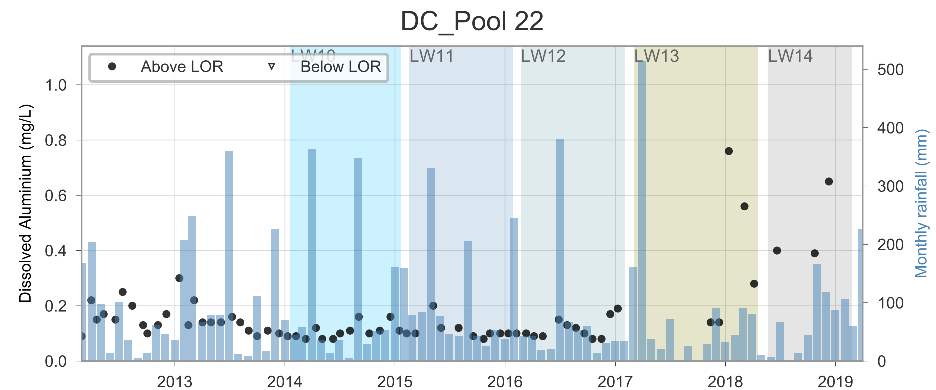

Donalds Castle Ck (FR6)
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Silicon (mg/L)
Monthly rainfall (mm)

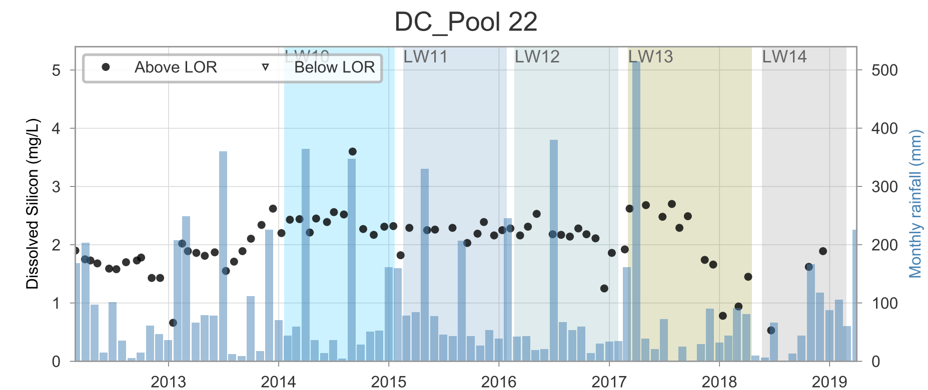

Donalds Castle Ck (FR6)
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Zinc (mg/L)
Monthly rainfall (mm)

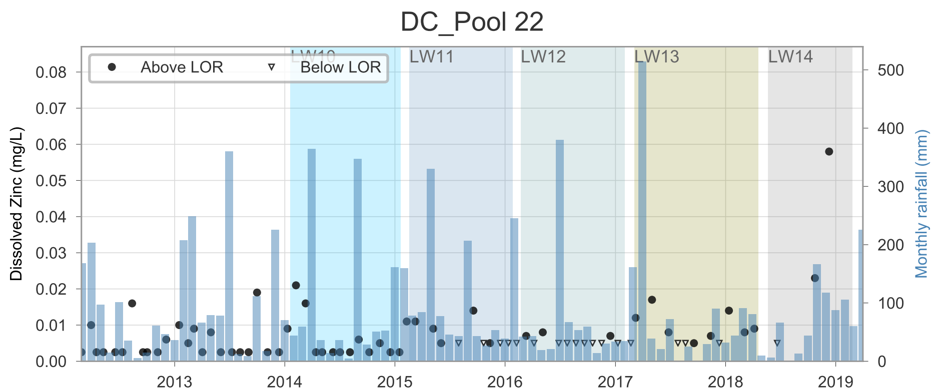

DC_Pool 22
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Sulfate as SO4 2- (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019

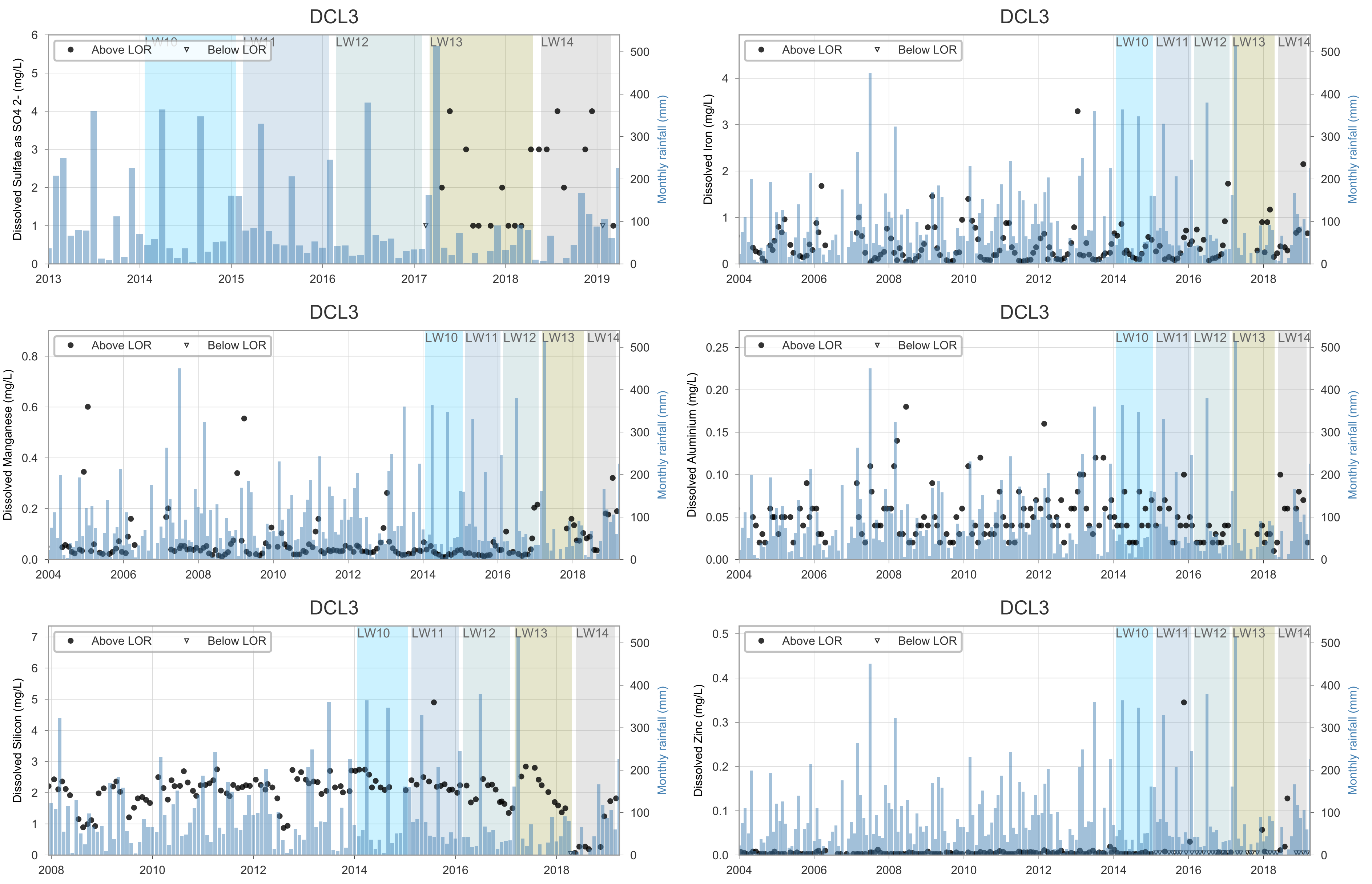

DC_Pool 22
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Iron (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019

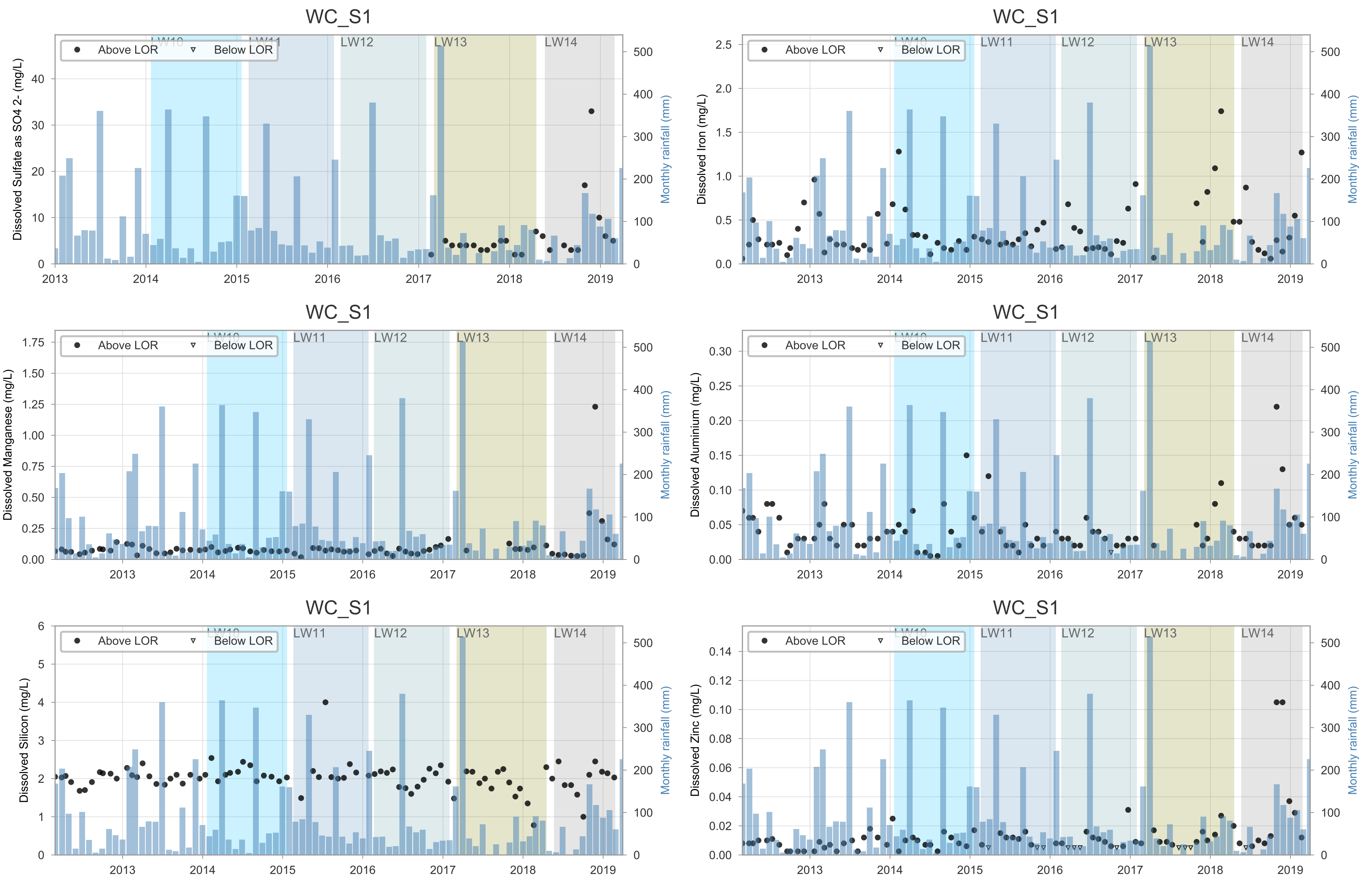

DC_Pool 22
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Manganese (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019

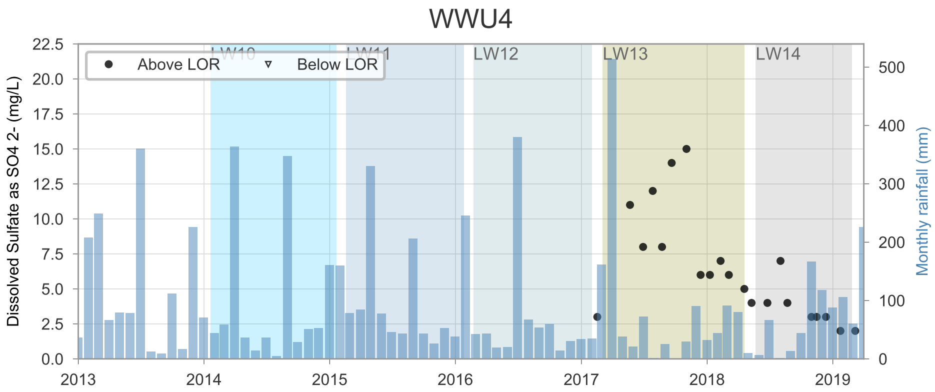

DC_Pool 22
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Aluminium (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019

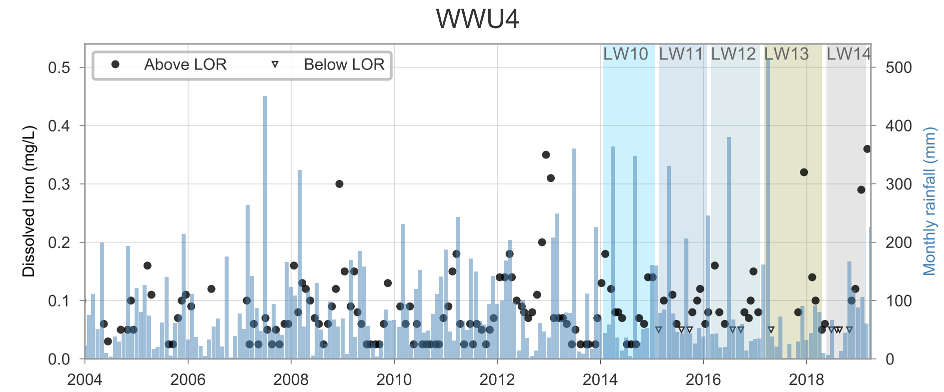

DC_Pool 22
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Silicon (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019

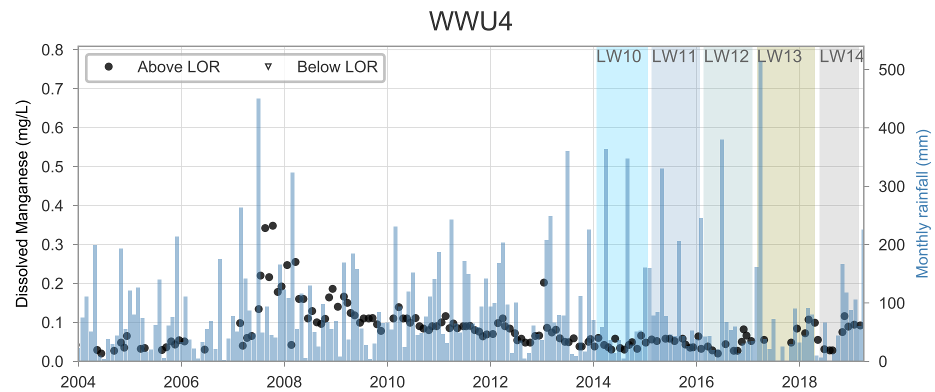

DC_Pool 22
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Zinc (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019

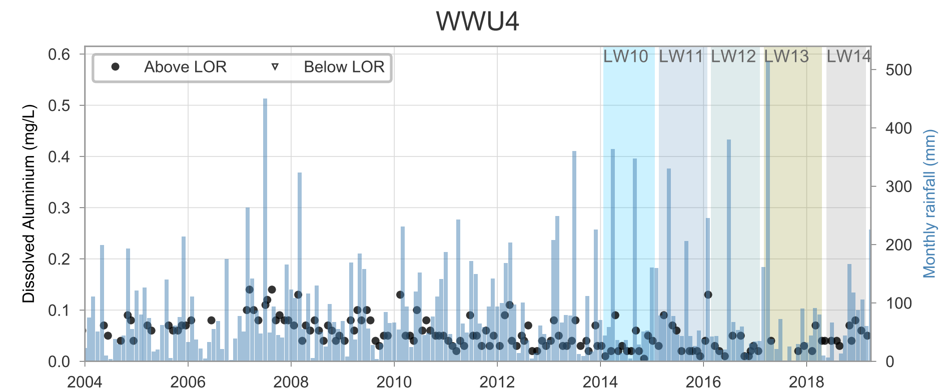

DCL3
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Sulfate as SO4 2- (mg/L)
Monthly rainfall (mm)
DCL3
Dissolved Iron (mg/L)
Monthly rainfall (mm)
DCL3
Dissolved Manganese (mg/L)
Monthly rainfall (mm)
DCL3
Dissolved Aluminium (mg/L)
Monthly rainfall (mm)
DCL3
Dissolved Silicon (mg/L)
Monthly rainfall (mm)
DCL3
Dissolved Zinc (mg/L)
Monthly rainfall (mm)

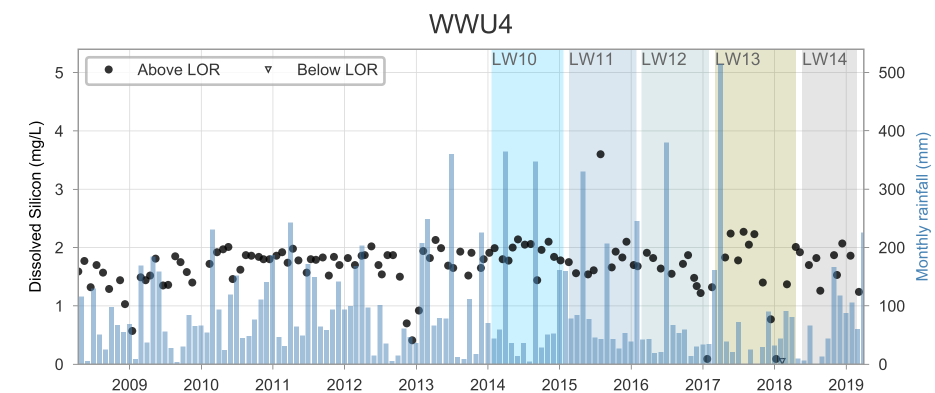

WC_S1
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
Dissolved Sulfate as SO4 2- (mg/L)
Monthly rainfall (mm)
WC_S1
Dissolved Iron (mg/L)
Monthly rainfall (mm)
WC_S1
Dissolved Manganese (mg/L)
Monthly rainfall (mm)
WC_S1
Dissolved Aluminium (mg/L)
Monthly rainfall (mm)
WC_S1
Dissolved Silicon (mg/L)
Monthly rainfall (mm)
WC_S1
Dissolved Zinc (mg/L)
Monthly rainfall (mm)
2013
2014
2015
2016
2017
2018
2019

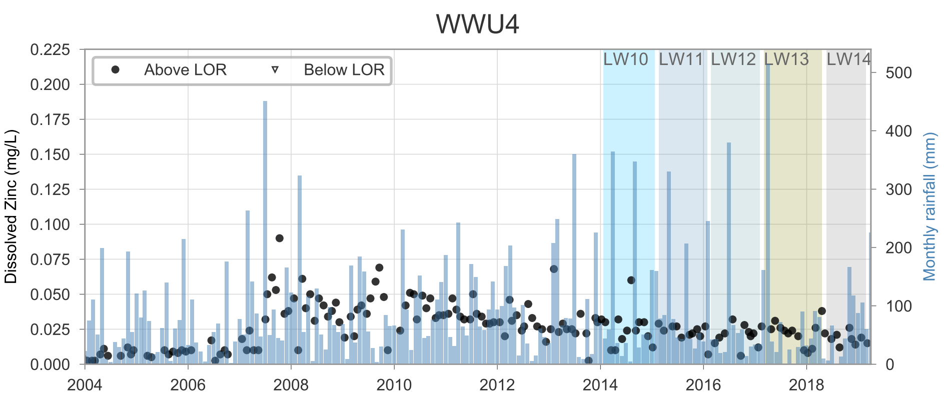

WWU4
Dissolved Sulfate as SO4 2- (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
0
100
200
300
400
500
2013
2014
2015
2016
2017
2018
2019


WWU4
Dissolved Iron (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
0.0
0.1
0.2
0.3
0.4
0.5
0
100
200
300
400
500
2004
2006
2008
2010
2012
2014
2016
2018


WWU4
Dissolved Manganese (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
100
200
300
400
500
2004
2006
2008
2010
2012
2014
2016
2018

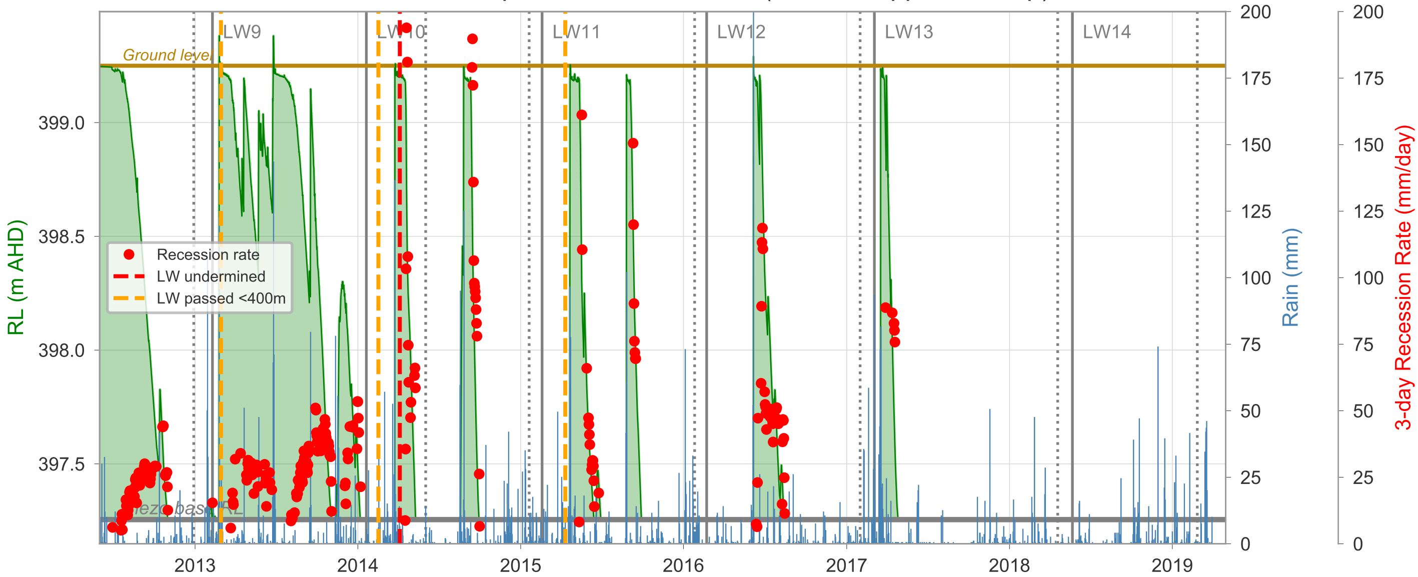

WWU4
Dissolved Aluminium (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
100
200
300
400
500
2004
2006
2008
2010
2012
2014
2016
2018


WWU4
Dissolved Silicon (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
0
1
2
3
4
5
0
100
200
300
400
500
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019

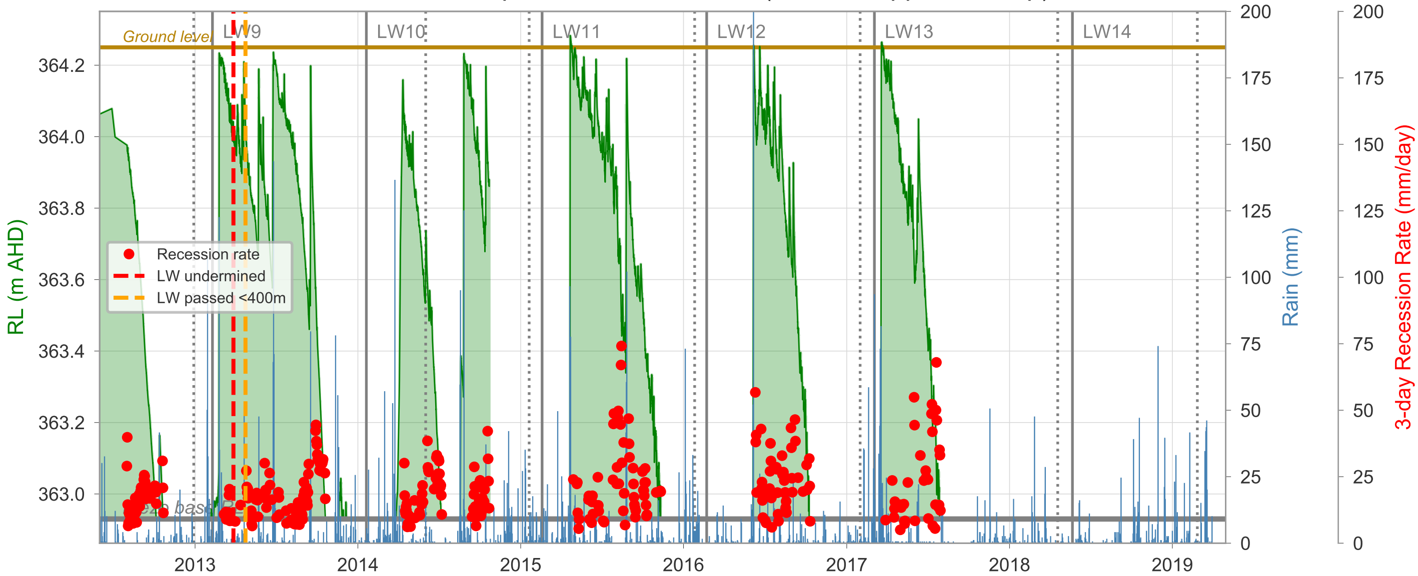

WWU4
Dissolved Zinc (mg/L)
Monthly rainfall (mm)
Above LOR
Below LOR
LW10
LW11
LW12
LW13
LW14
0.000
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
0.225
0
100
200
300
400
500
2004
2006
2008
2010
2012
2014
2016
2018

APPENDIX 3 – Swamp shallow groundwater hydrographs

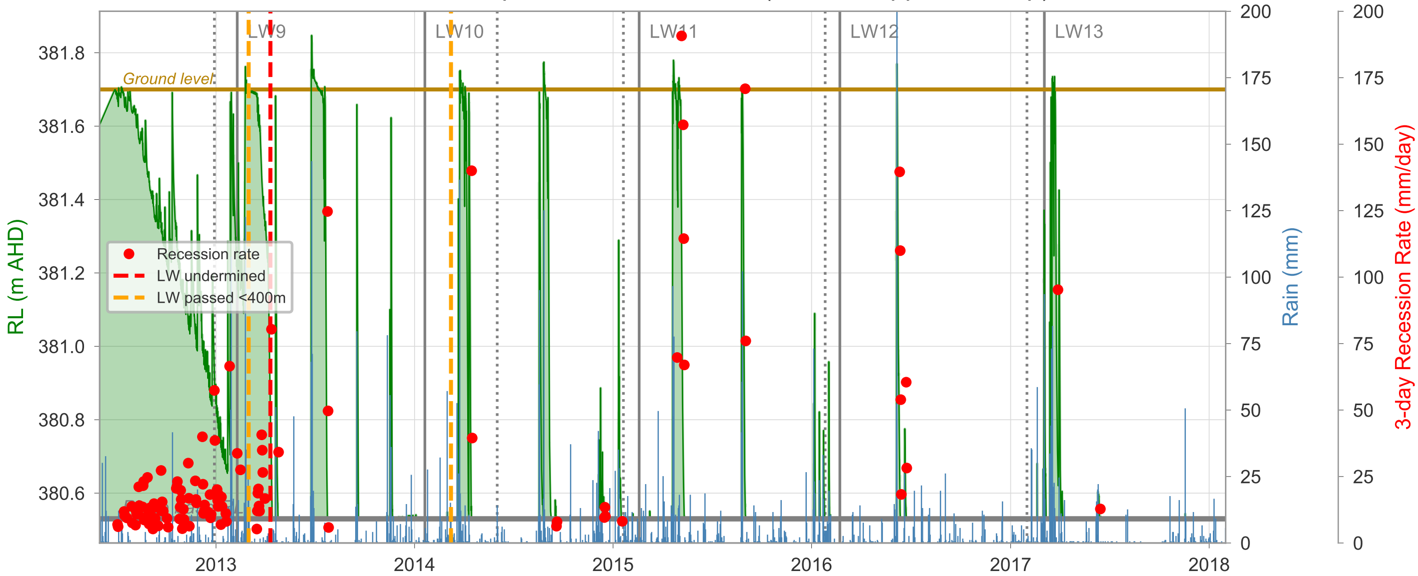
Dendrobium Swamp 01a: Piezometer 01 (Within mapped swamp)

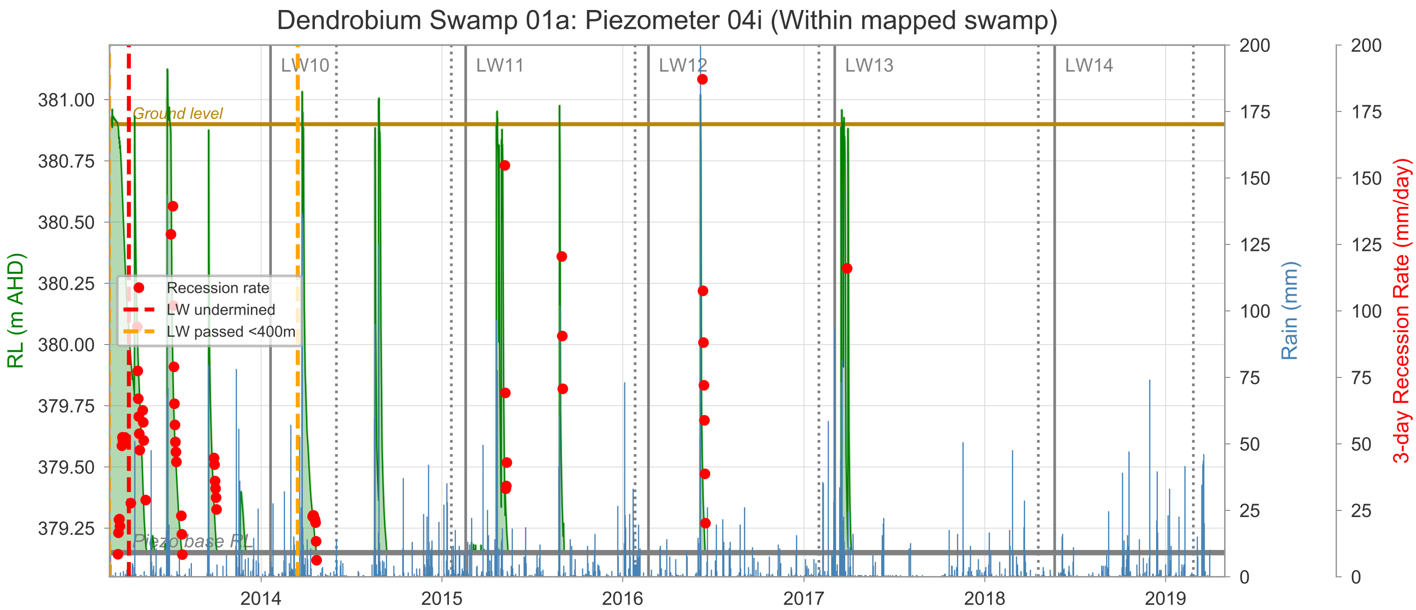


Dendrobium Swamp 01a: Piezometer 02 (Within mapped swamp)

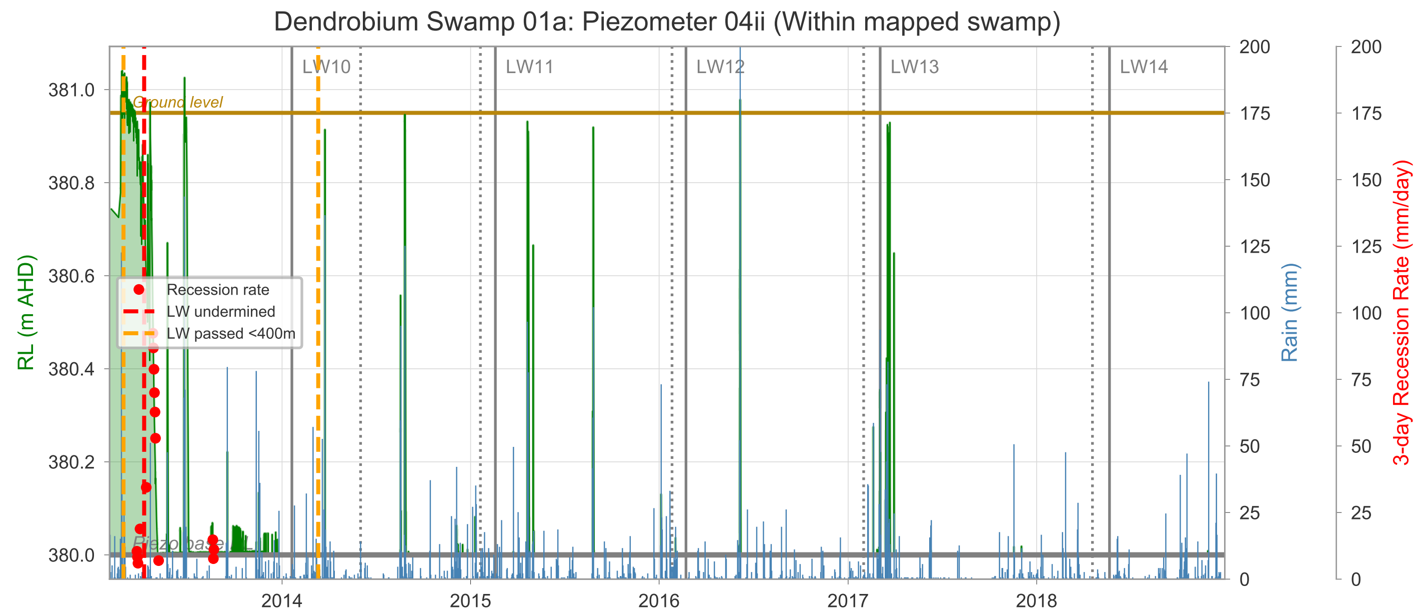


Dendrobium Swamp 01a: Piezometer 04 (Within mapped swamp)

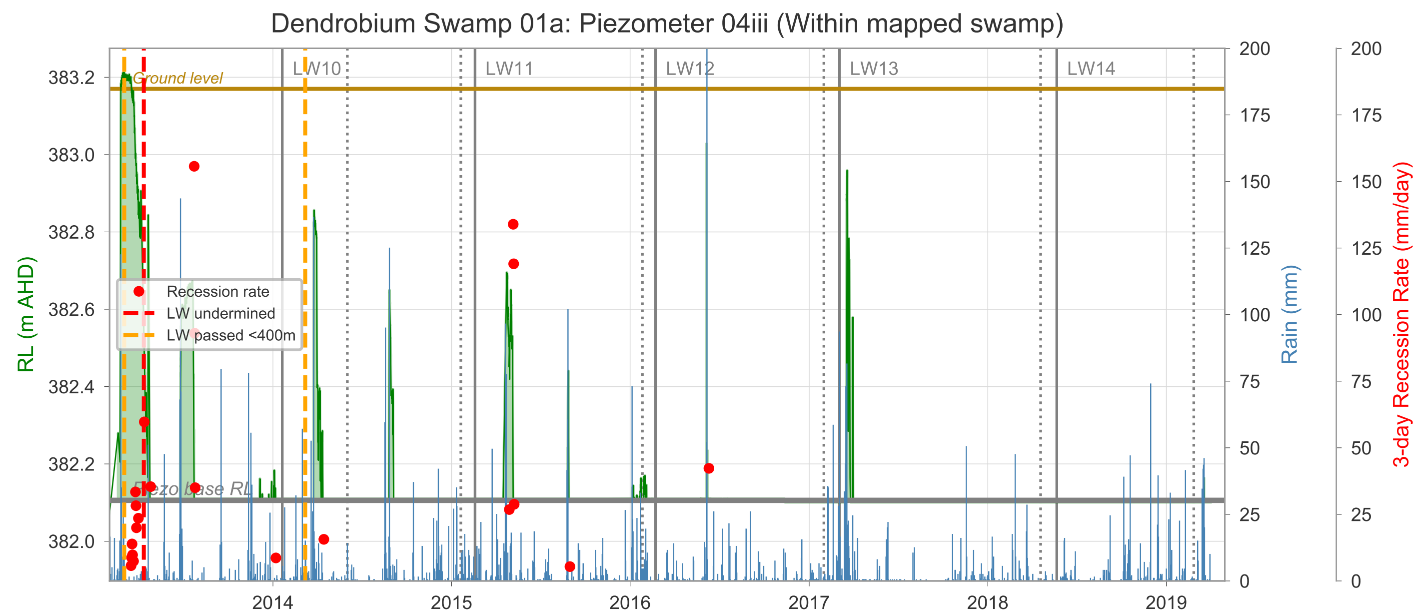




Dendrobium Swamp 01a: Piezometer 04i (Within mapped swamp)
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
Ground level
Piezo base RL
Recession rate
LW undermined
LW passed <400m
LW10
LW11
LW12
LW13
LW14

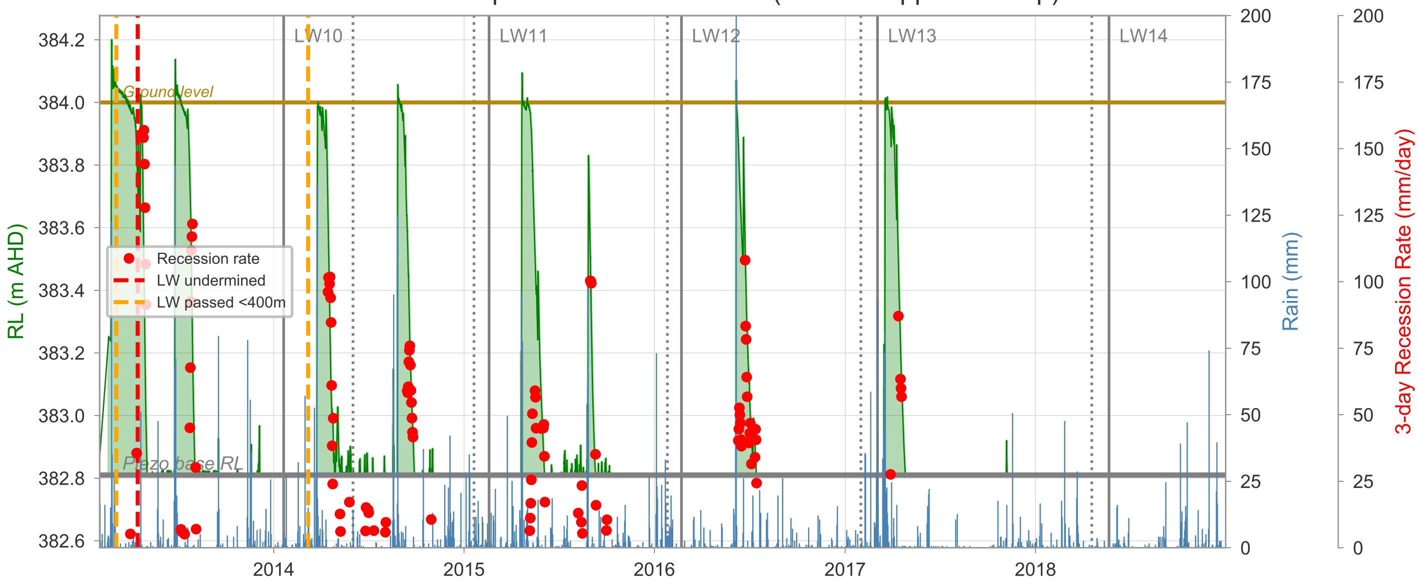


Dendrobium Swamp 01a: Piezometer 04ii (Within mapped swamp)
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
Ground level
Recession rate
LW undermined
LW passed <400m
LW10
LW11
LW12
LW13
LW14

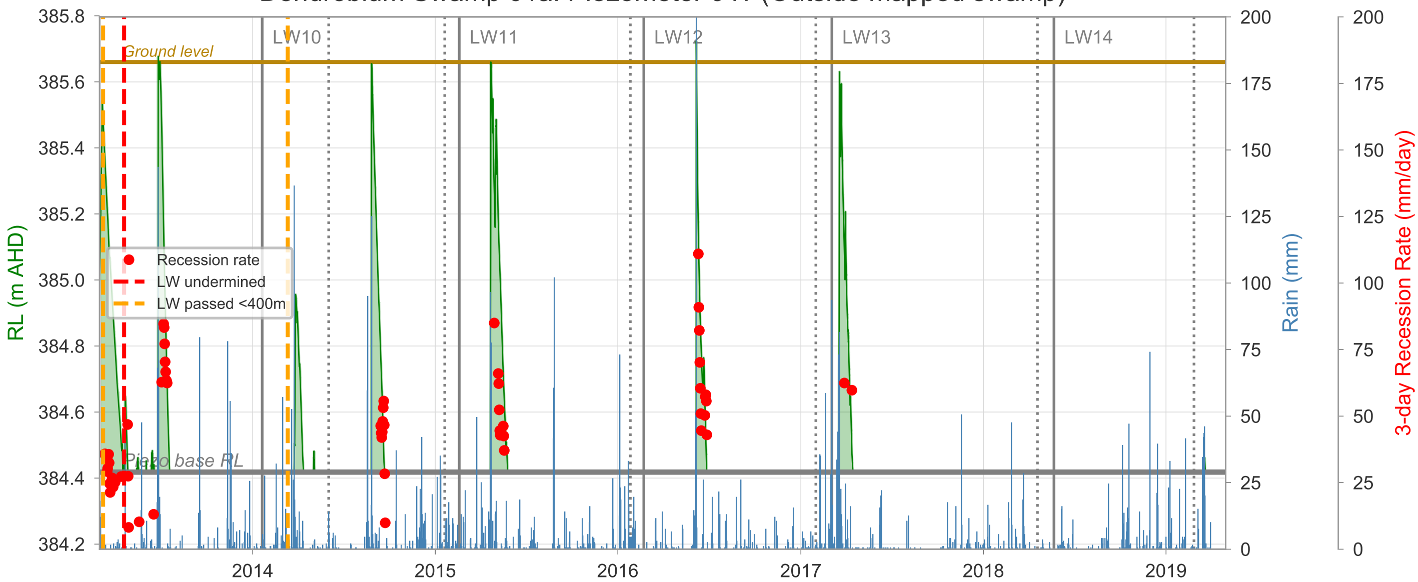


Dendrobium Swamp 01a: Piezometer 04iii (Within mapped swamp)
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
Ground level
Recession rate
LW undermined
LW passed <400m
LW10
LW11
LW12
LW13
LW14

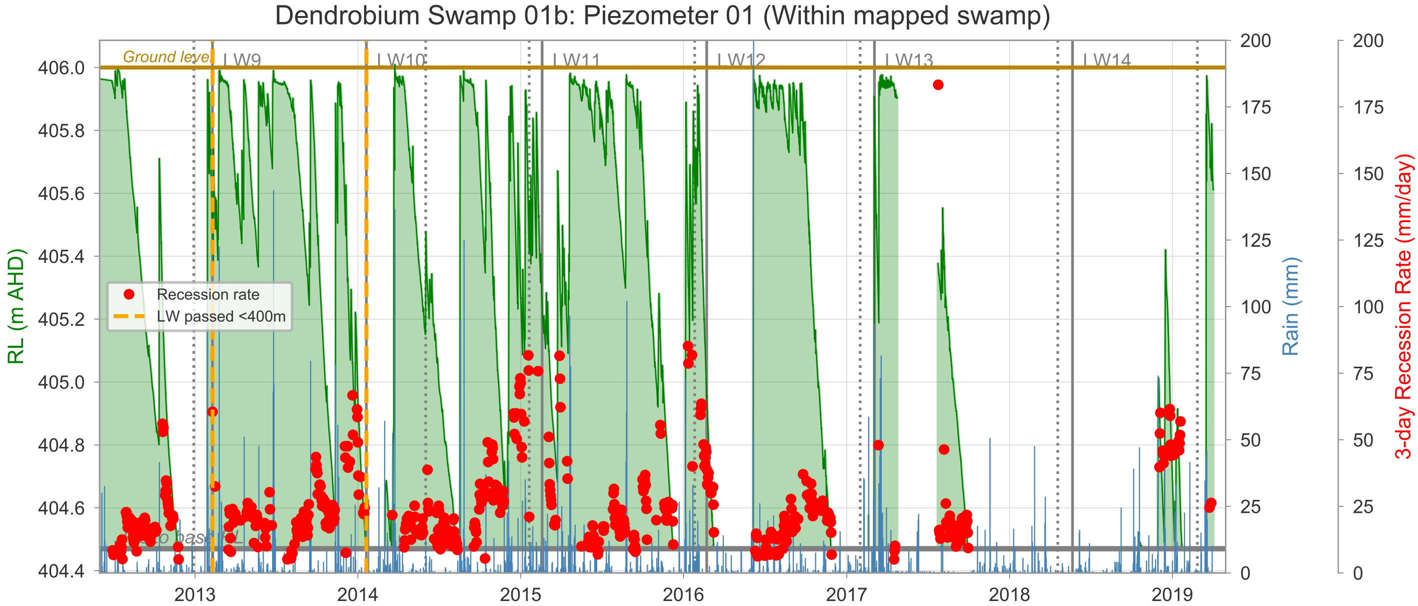
Dendrobium Swamp 01a: Piezometer 04iv (Within mapped swamp)



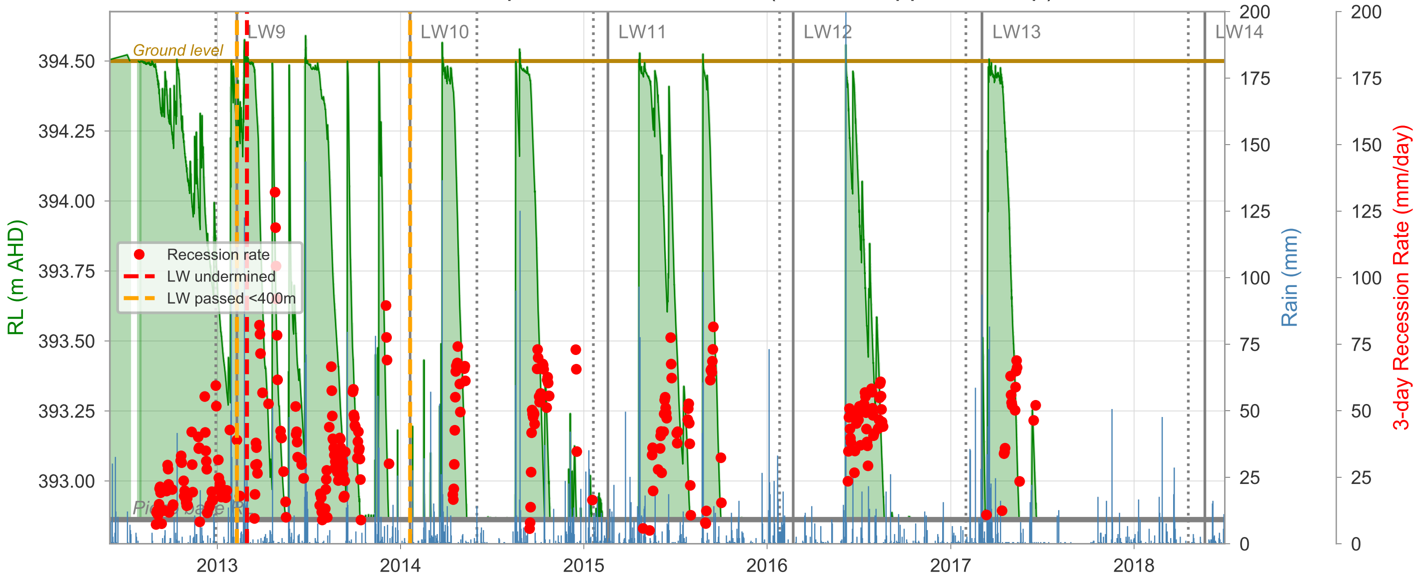
Dendrobium Swamp 01a: Piezometer 04v (Outside mapped swamp)



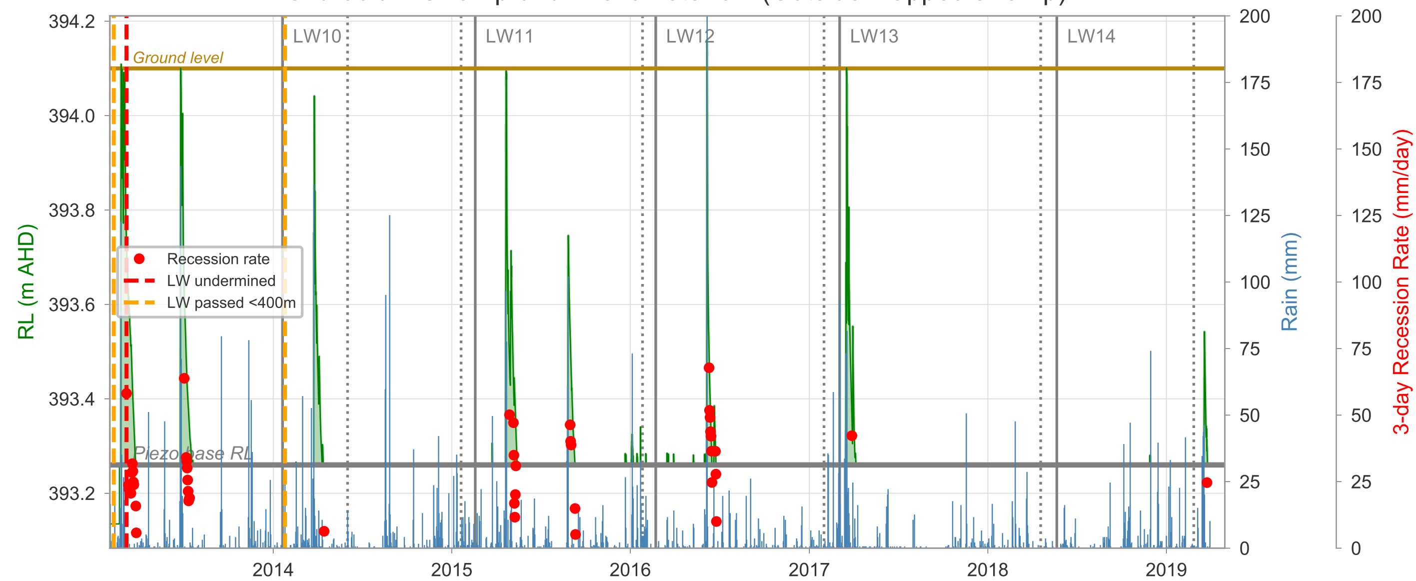
Dendrobium Swamp 01b: Piezometer 01 (Within mapped swamp)



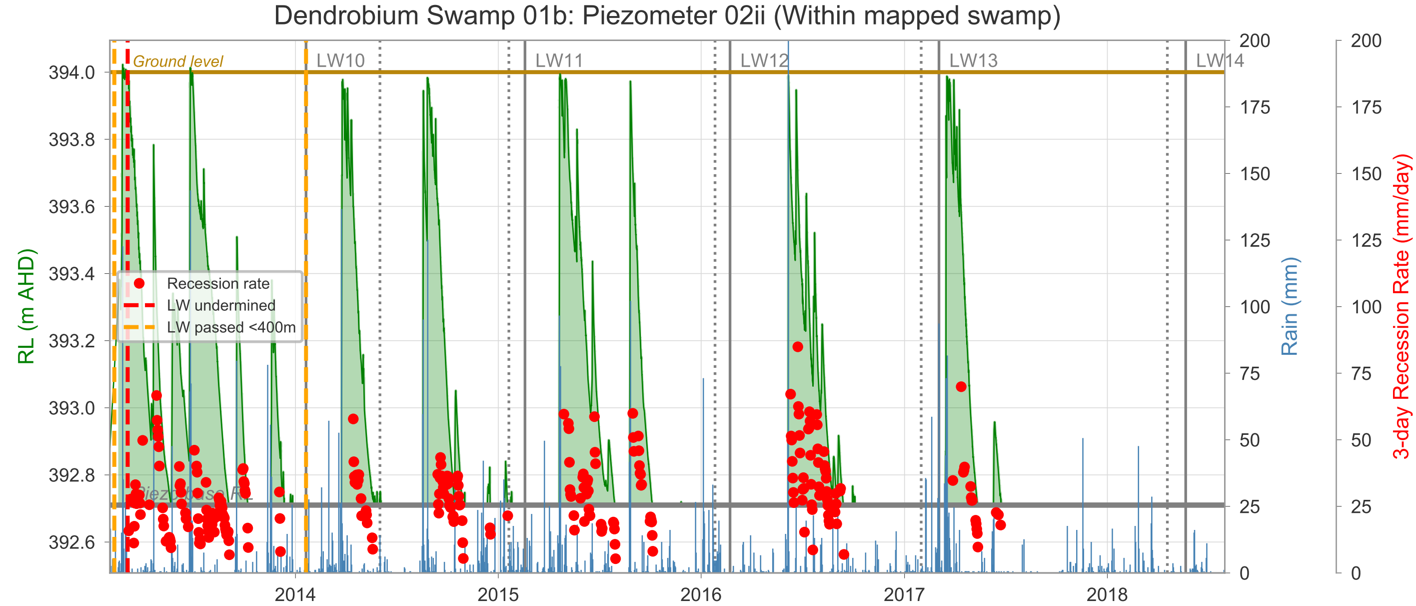
Dendrobium Swamp 01b: Piezometer 02 (Within mapped swamp)

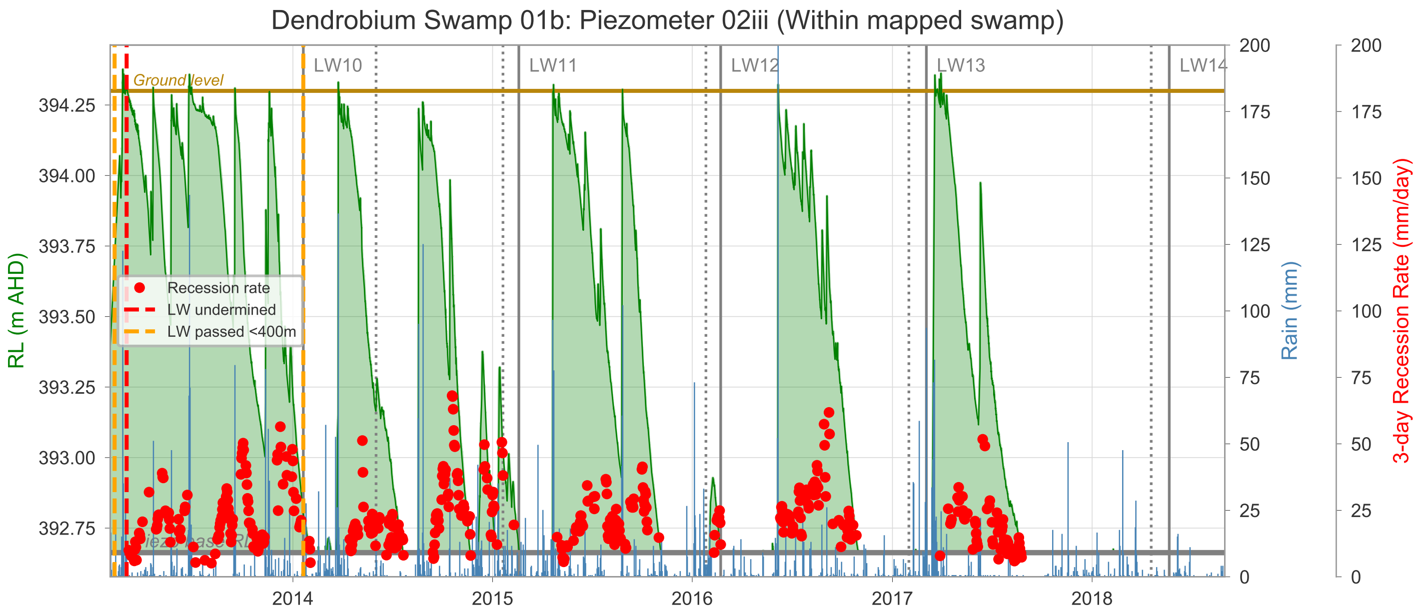


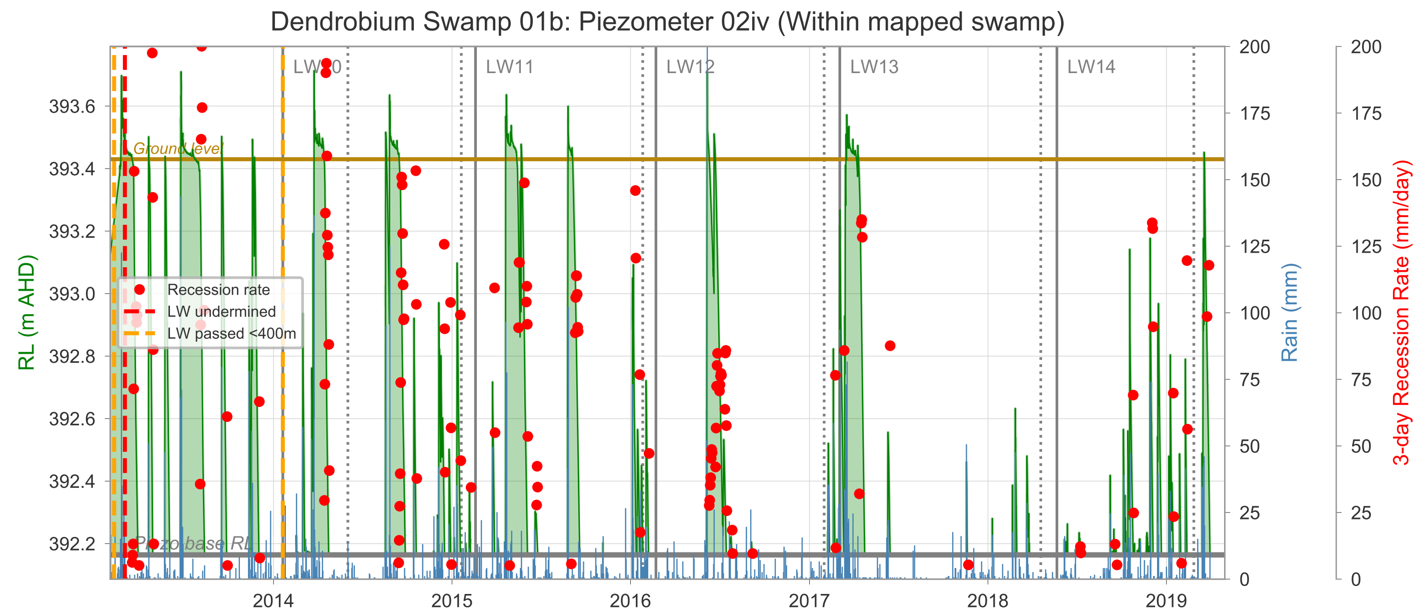
Dendrobium Swamp 01b: Piezometer 02i (Outside mapped swamp)

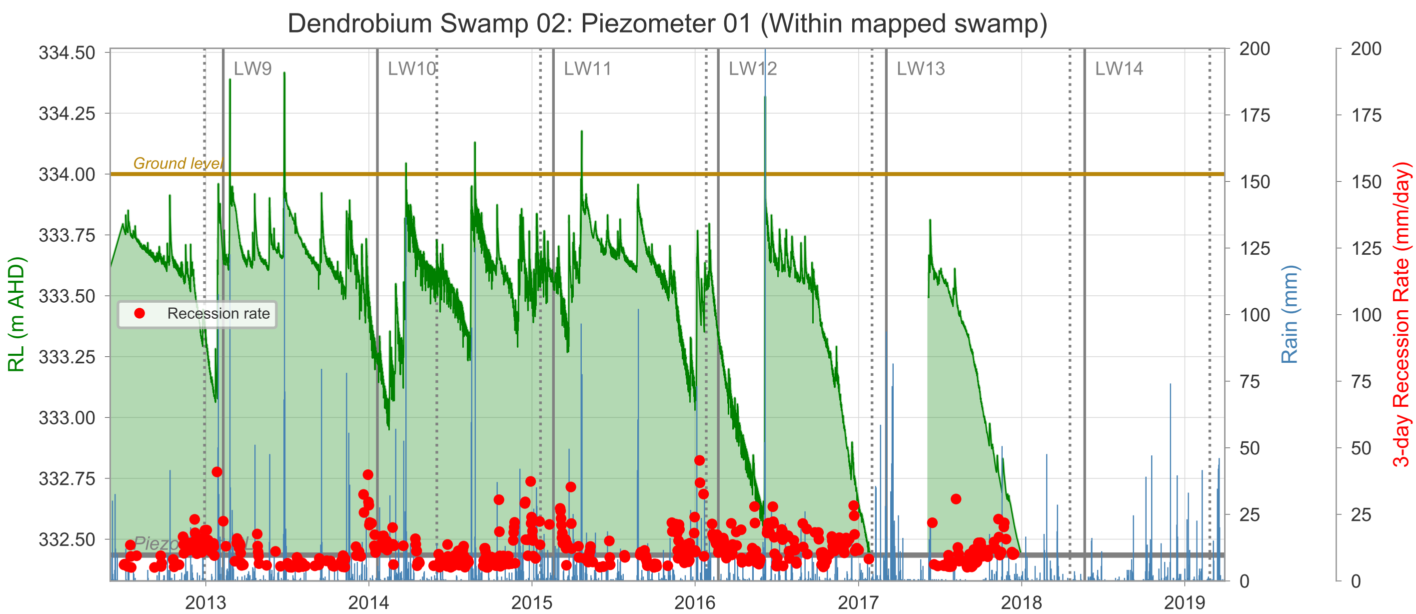


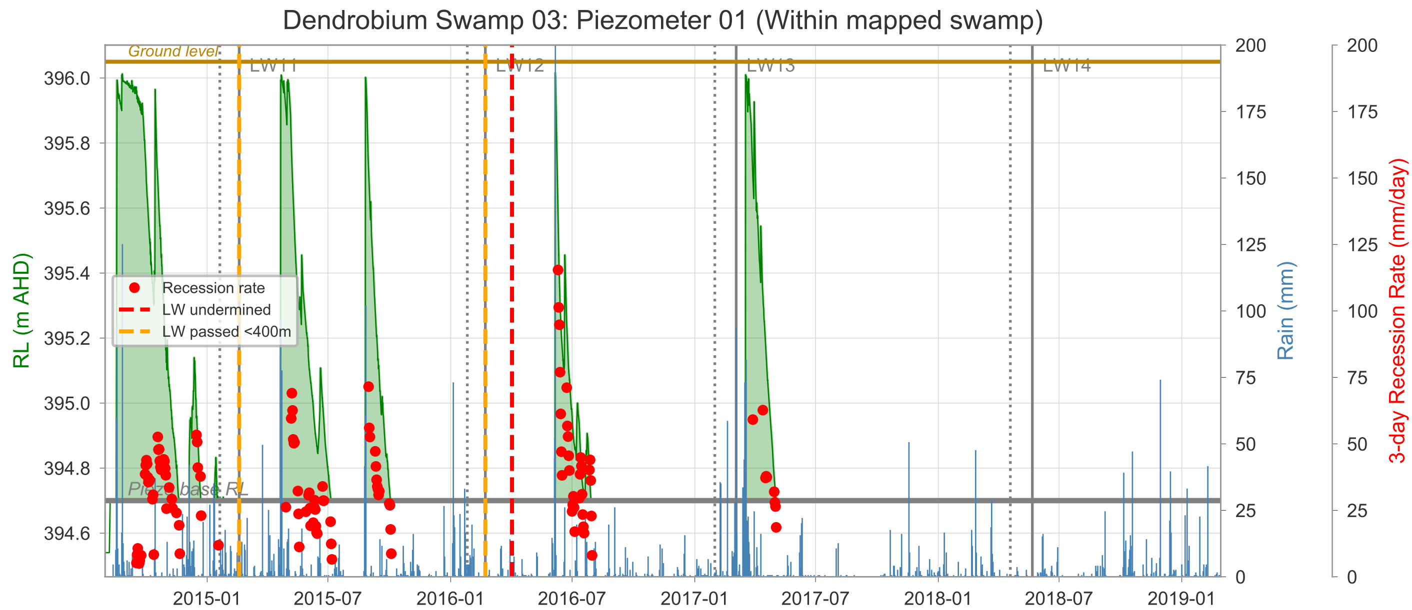
Dendrobium Swamp 01b: Piezometer 02ii (Within mapped swamp)

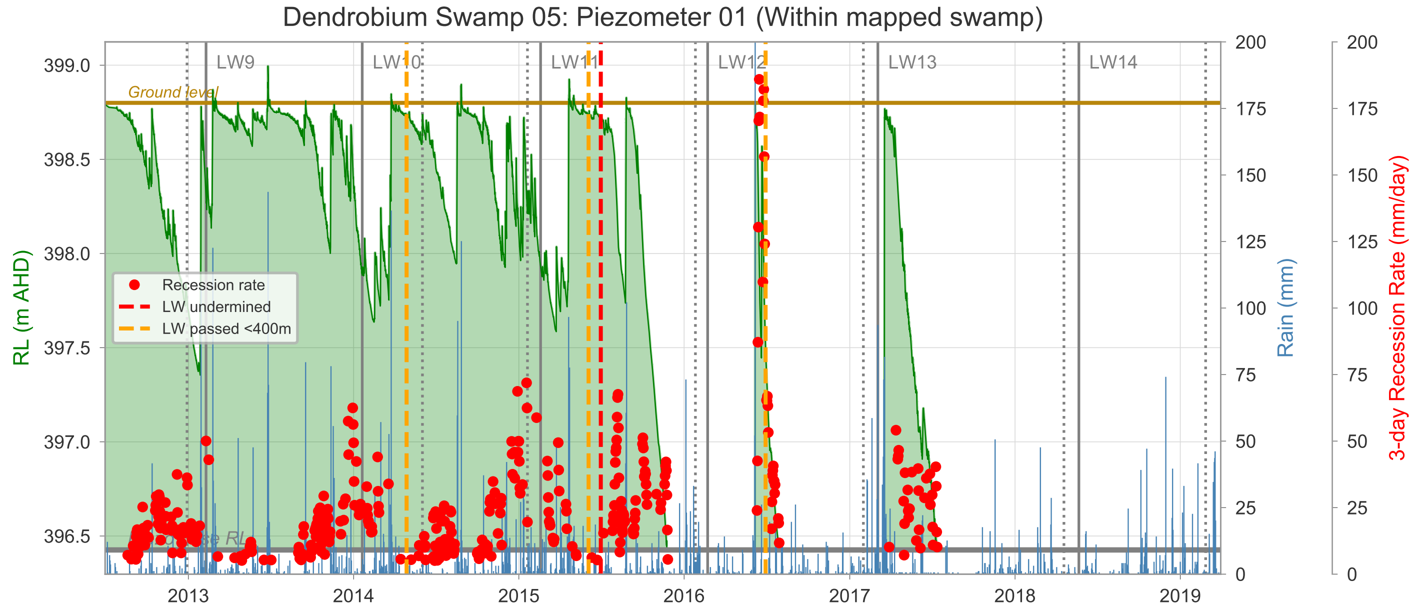


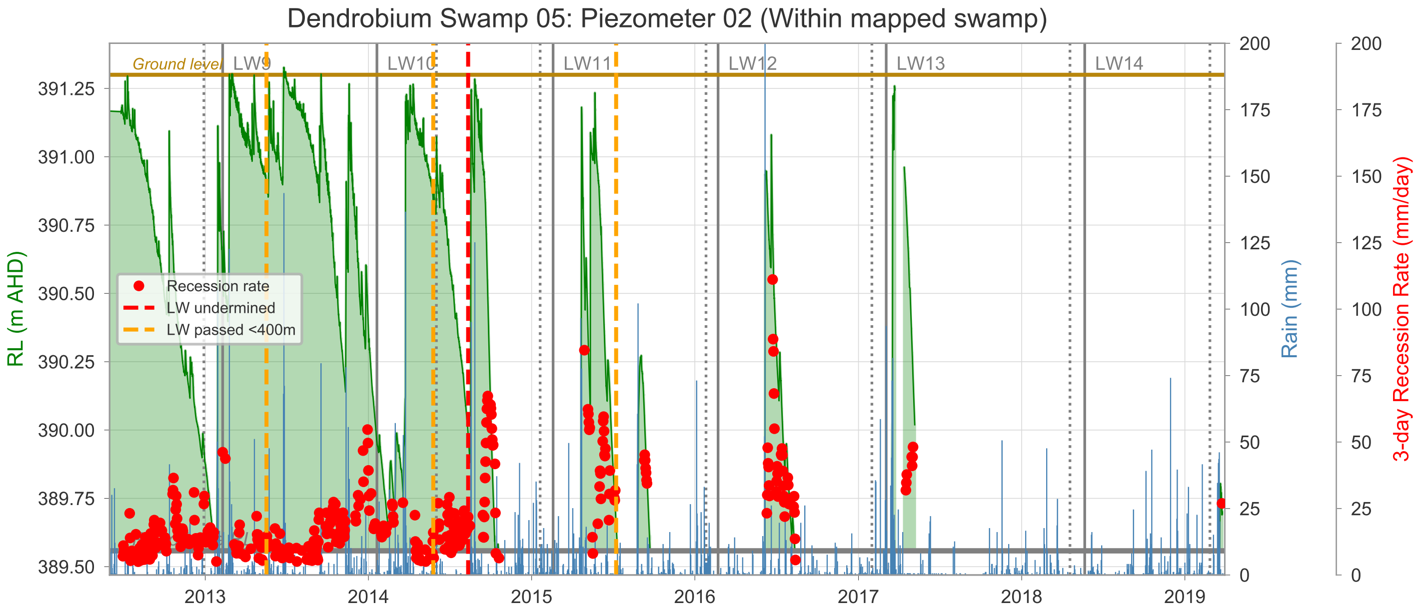

Dendrobium Swamp 01b: Piezometer 02iii (Within mapped swamp)
LW10
LW11
LW12
LW13
LW14
Ground level
Piezo base RL
Recession rate
LW undermined
LW passed <400m
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
2014
2015
2016
2017
2018


Dendrobium Swamp 01b: Piezometer 02iv (Within mapped swamp)
LW10
LW11
LW12
LW13
LW14
Ground level
Piezo base RL
Recession rate
LW undermined
LW passed <400m
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
2014
2015
2016
2017
2018
2019

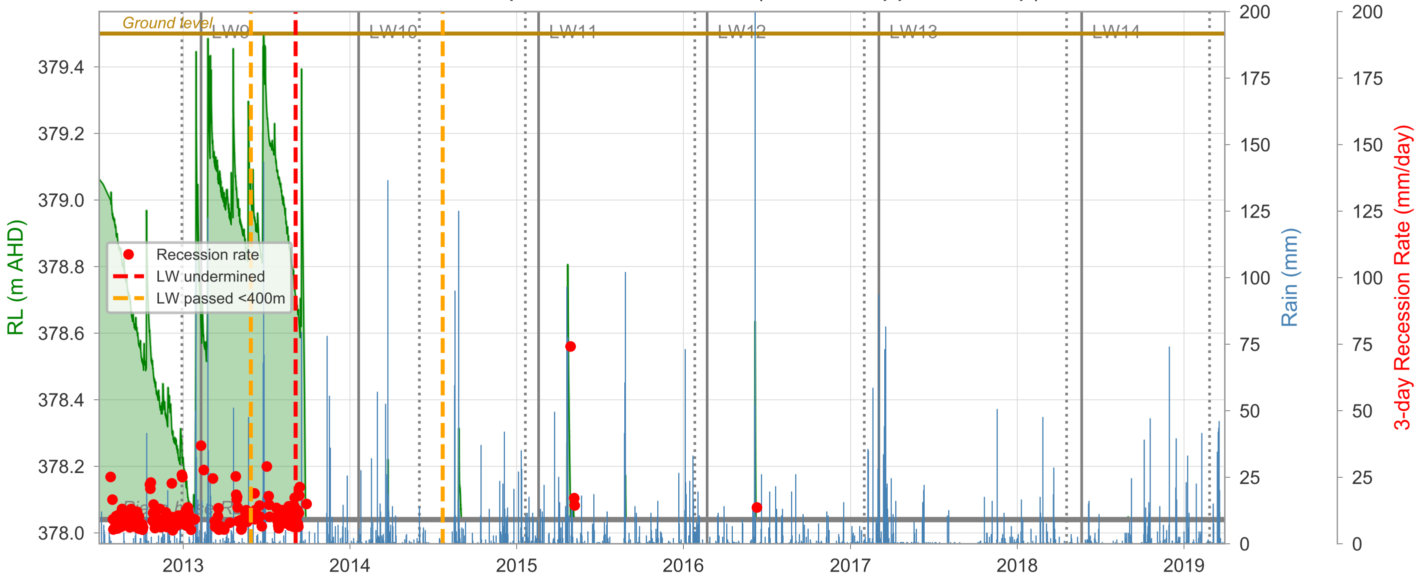

Dendrobium Swamp 02: Piezometer 01 (Within mapped swamp)
LW9
LW10
LW11
LW12
LW13
LW14
Ground level
Recession rate
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
2013
2014
2015
2016
2017
2018
2019


Dendrobium Swamp 03: Piezometer 01 (Within mapped swamp)
Ground level
LW11
LW12
LW13
LW14
Piezo base RL
Recession rate
LW undermined
LW passed <400m
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
396.0
395.8
395.6
395.4
395.2
395.0
394.8
394.6
200
175
150
125
100
75
50
25
0
2015-01
2015-07
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01

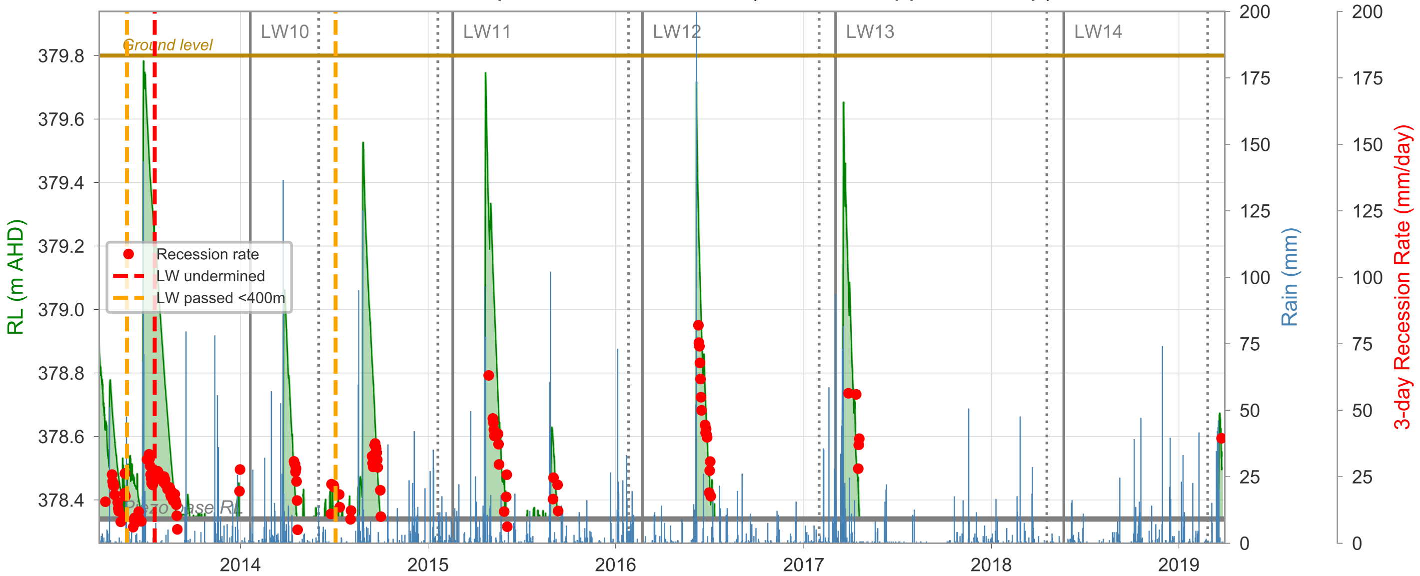

Dendrobium Swamp 05: Piezometer 01 (Within mapped swamp)
Ground level
LW9
LW10
LW11
LW12
LW13
LW14
Piezo base RL
Recession rate
LW undermined
LW passed <400m
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
399.0
398.5
398.0
397.5
397.0
396.5
200
175
150
125
100
75
50
25
0
2013
2014
2015
2016
2017
2018
2019


Dendrobium Swamp 05: Piezometer 02 (Within mapped swamp)
Ground level
LW9
LW10
LW11
LW12
LW13
LW14
Recession rate
LW undermined
LW passed <400m
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
391.25
391.00
390.75
390.50
390.25
390.00
389.75
389.50
200
175
150
125
100
75
50
25
0
2013
2014
2015
2016
2017
2018
2019

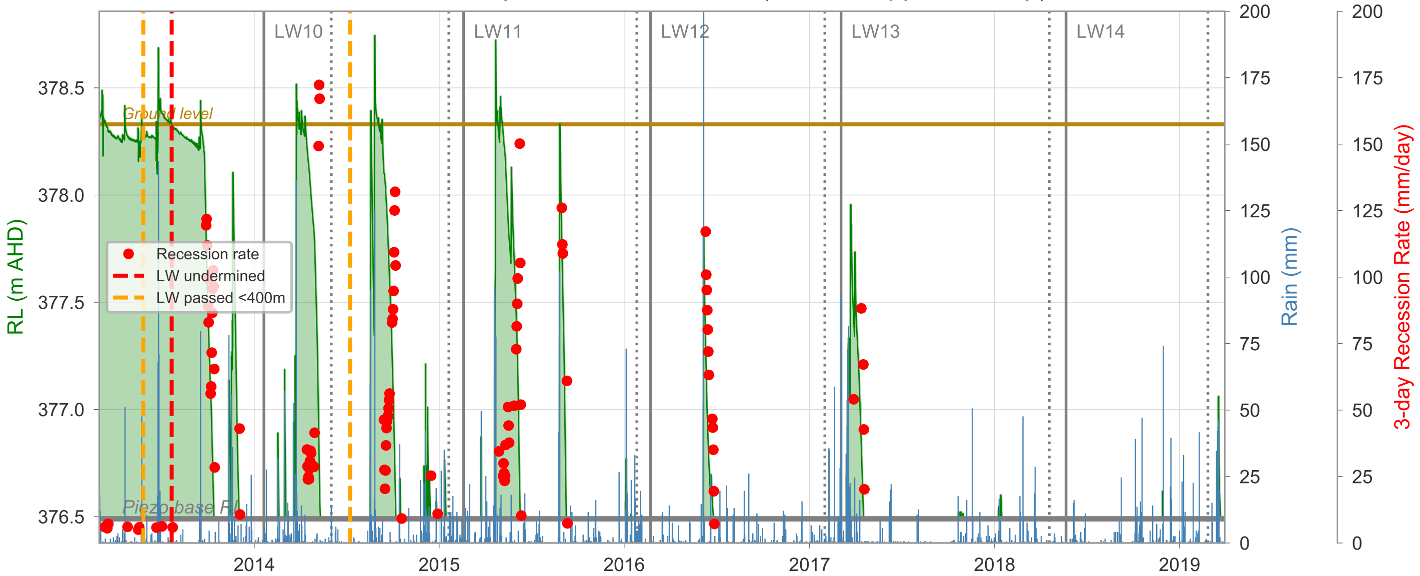
Dendrobium Swamp 05: Piezometer 03 (Within mapped swamp)

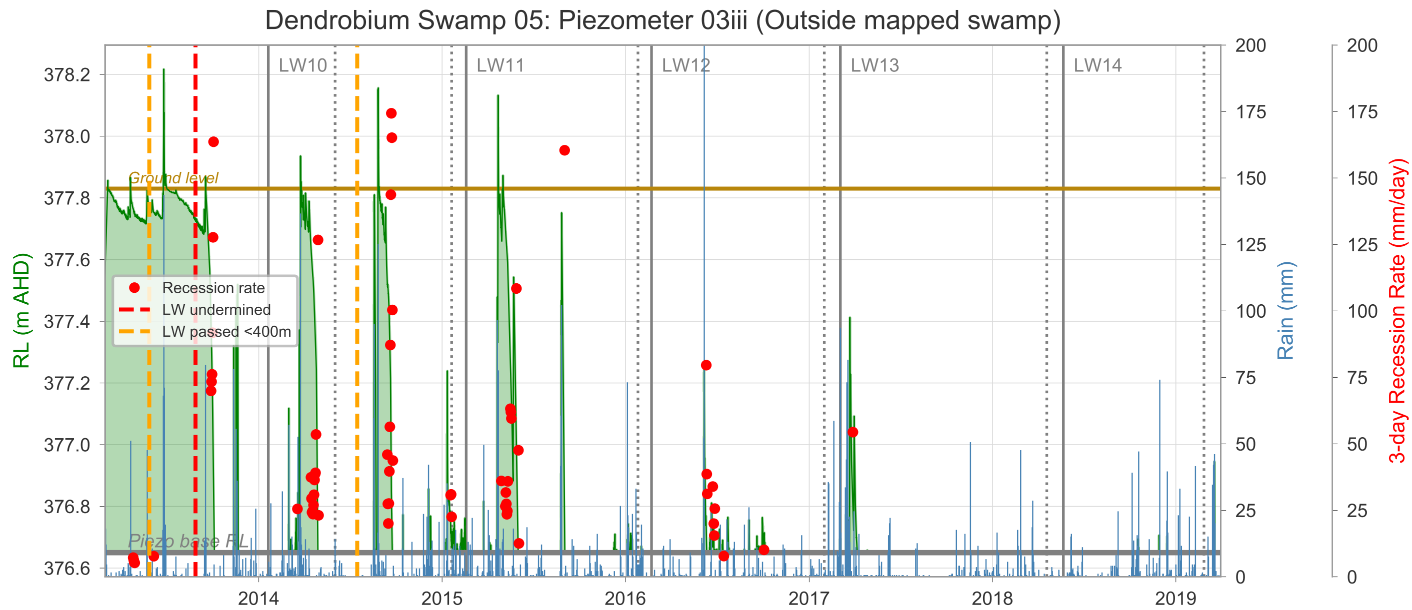


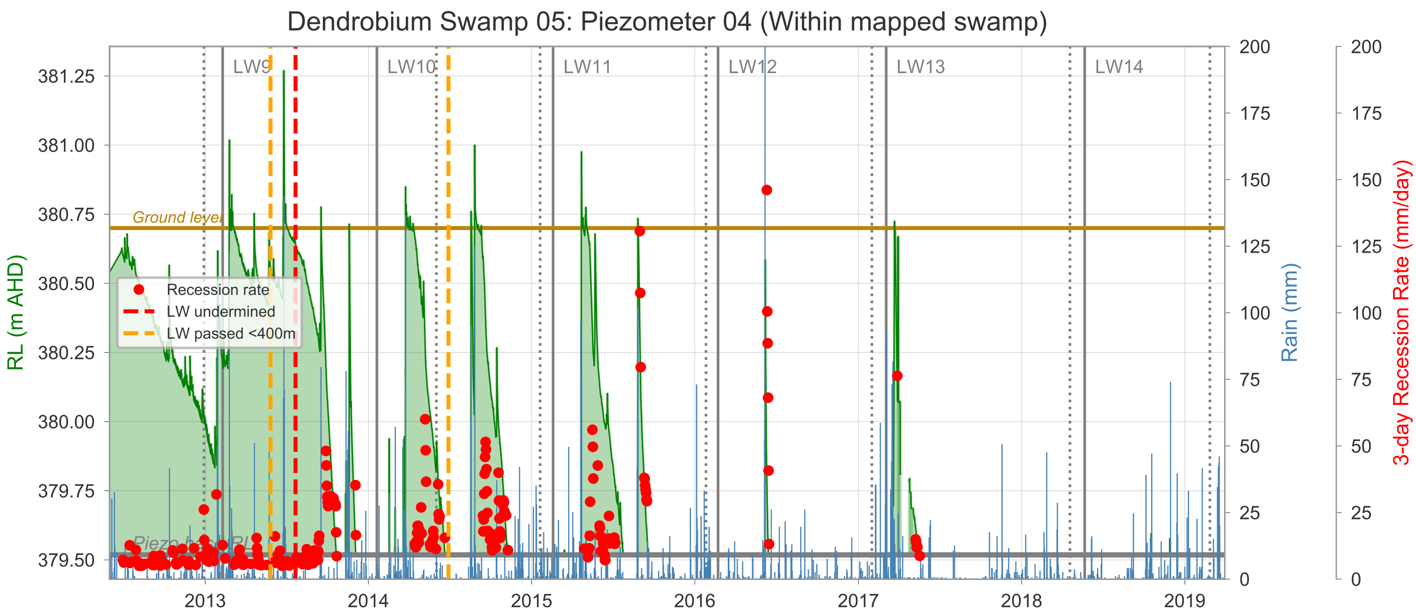
Dendrobium Swamp 05: Piezometer 03i (Outside mapped swamp)

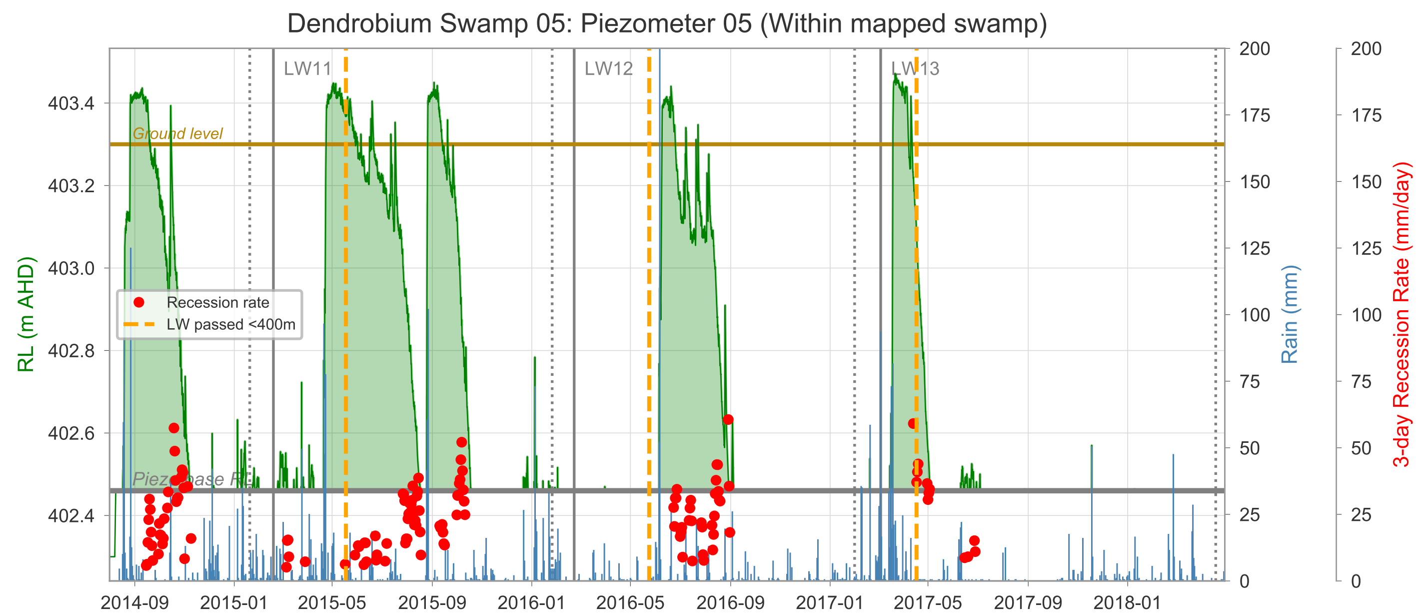


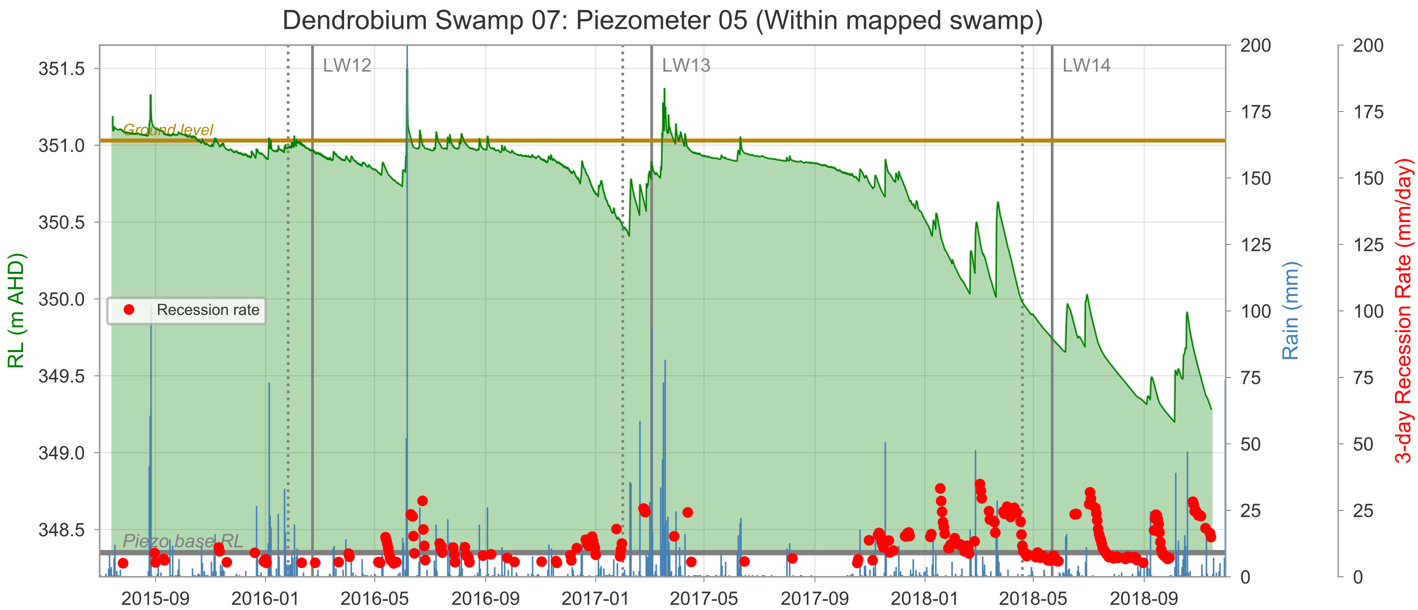
Dendrobium Swamp 05: Piezometer 03ii (Within mapped swamp)



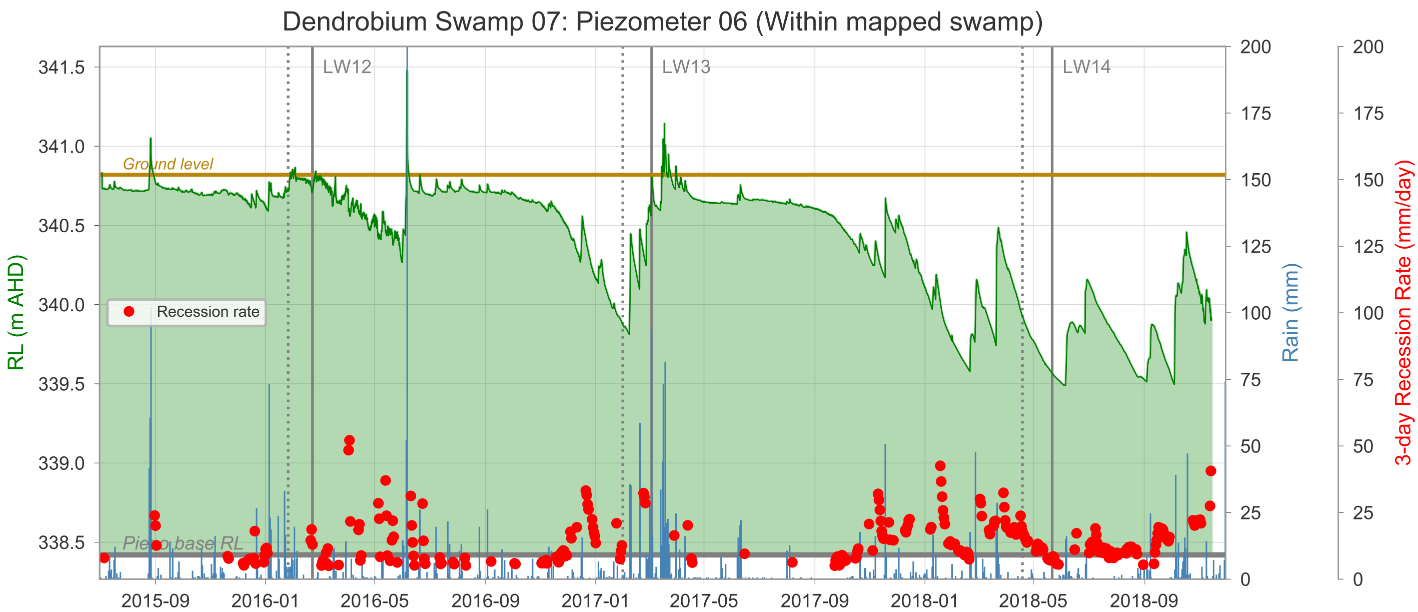

Dendrobium Swamp 05: Piezometer 03iii (Outside mapped swamp)
LW10
LW11
LW12
LW13
LW14
Ground level
Piezo base RL
Recession rate
LW undermined
LW passed <400m
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)


Dendrobium Swamp 05: Piezometer 04 (Within mapped swamp)
LW9
LW10
LW11
LW12
LW13
LW14
Ground level
Piezo base RL
Recession rate
LW undermined
LW passed <400m
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)

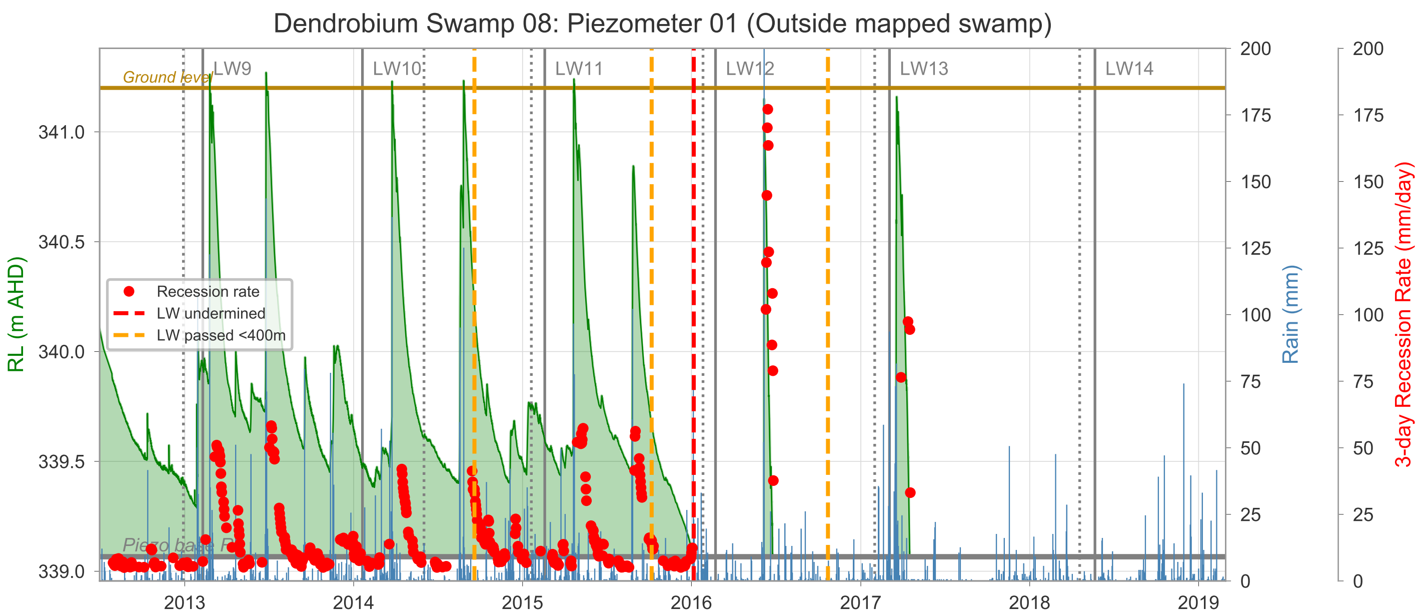

Dendrobium Swamp 05: Piezometer 05 (Within mapped swamp)
LW11
LW12
LW13
Ground level
Piezo base RL
Recession rate
LW passed <400m
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)



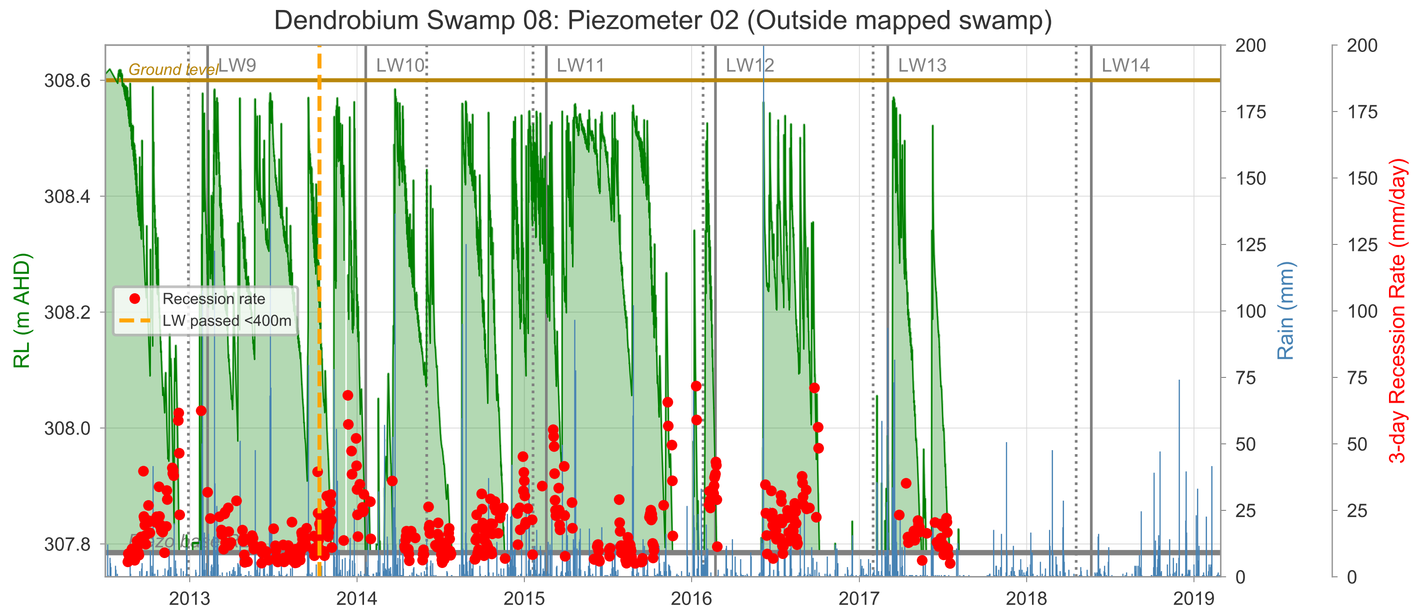
Dendrobium Swamp 07: Piezometer 05 (Within mapped swamp)
LW12
LW13
LW14
Ground level
Piezo base RL
Recession rate
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
2015-09
2016-01
2016-05
2016-09
2017-01
2017-05
2017-09
2018-01
2018-05
2018-09



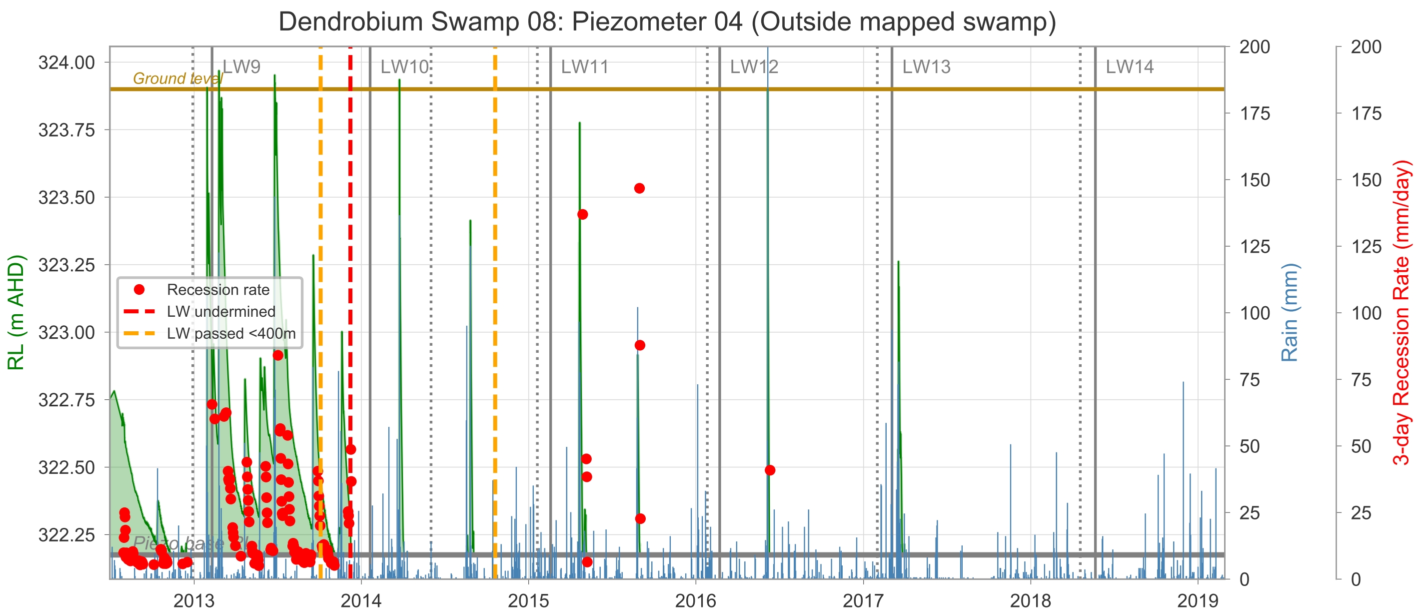
Dendrobium Swamp 07: Piezometer 06 (Within mapped swamp)
LW12
LW13
LW14
Ground level
Piezo base RL
Recession rate
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
2015-09
2016-01
2016-05
2016-09
2017-01
2017-05
2017-09
2018-01
2018-05
2018-09



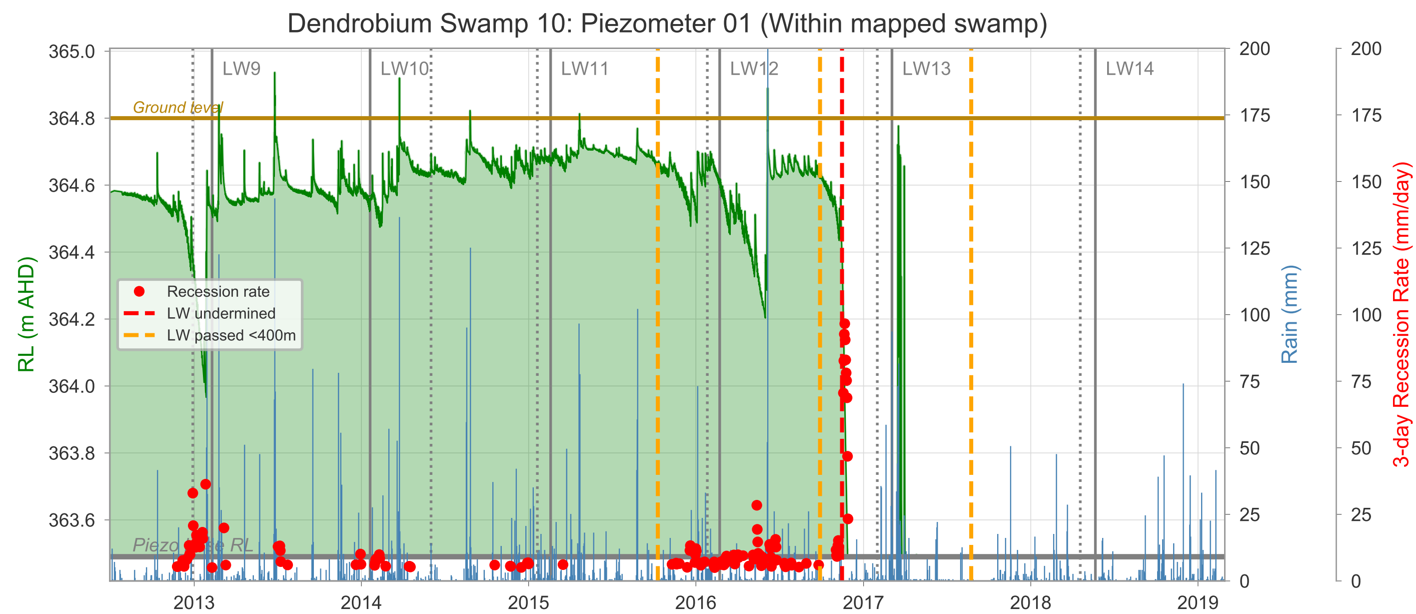
Dendrobium Swamp 08: Piezometer 01 (Outside mapped swamp)
Ground level
LW9
LW10
LW11
LW12
LW13
LW14
Recession rate
LW undermined
LW passed <400m
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
2013
2014
2015
2016
2017
2018
2019



Dendrobium Swamp 08: Piezometer 02 (Outside mapped swamp)
Ground level
Piezo base RL
LW9
LW10
LW11
LW12
LW13
LW14
Recession rate
LW passed <400m
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
308.6
308.4
308.2
308.0
307.8
2013
2014
2015
2016
2017
2018
2019

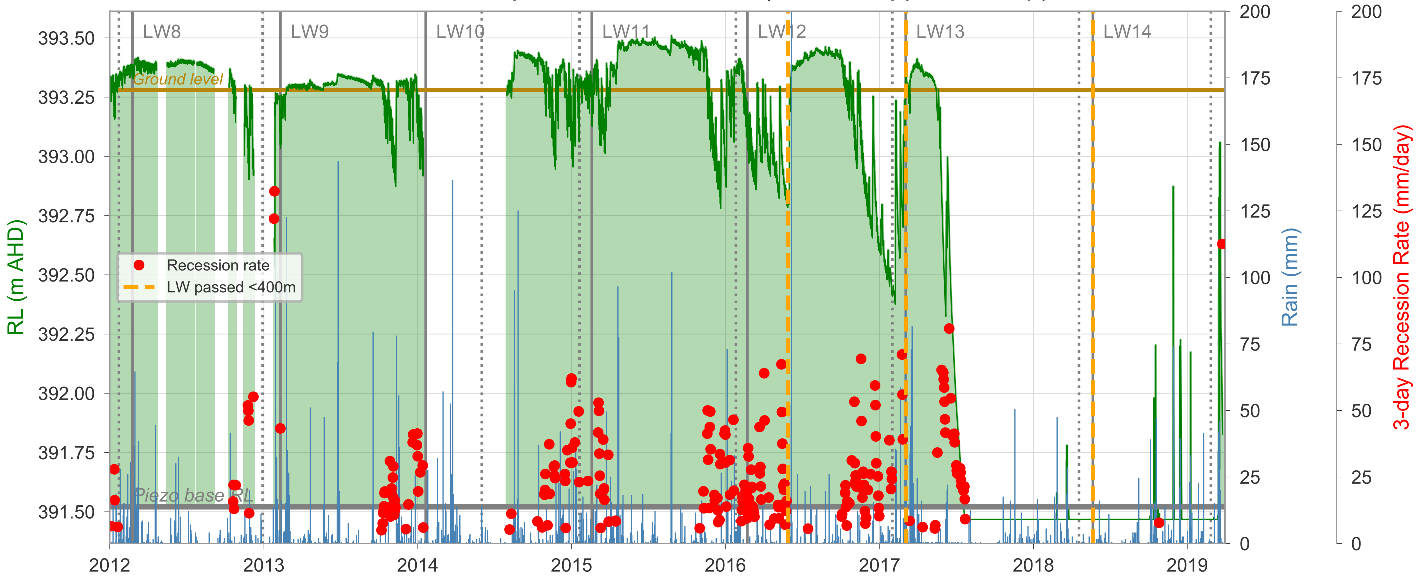


Dendrobium Swamp 08: Piezometer 04 (Outside mapped swamp)
Ground level
Piezo base RL
LW9
LW10
LW11
LW12
LW13
LW14
Recession rate
LW undermined
LW passed <400m
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
324.00
323.75
323.50
323.25
323.00
322.75
322.50
322.25
2013
2014
2015
2016
2017
2018
2019

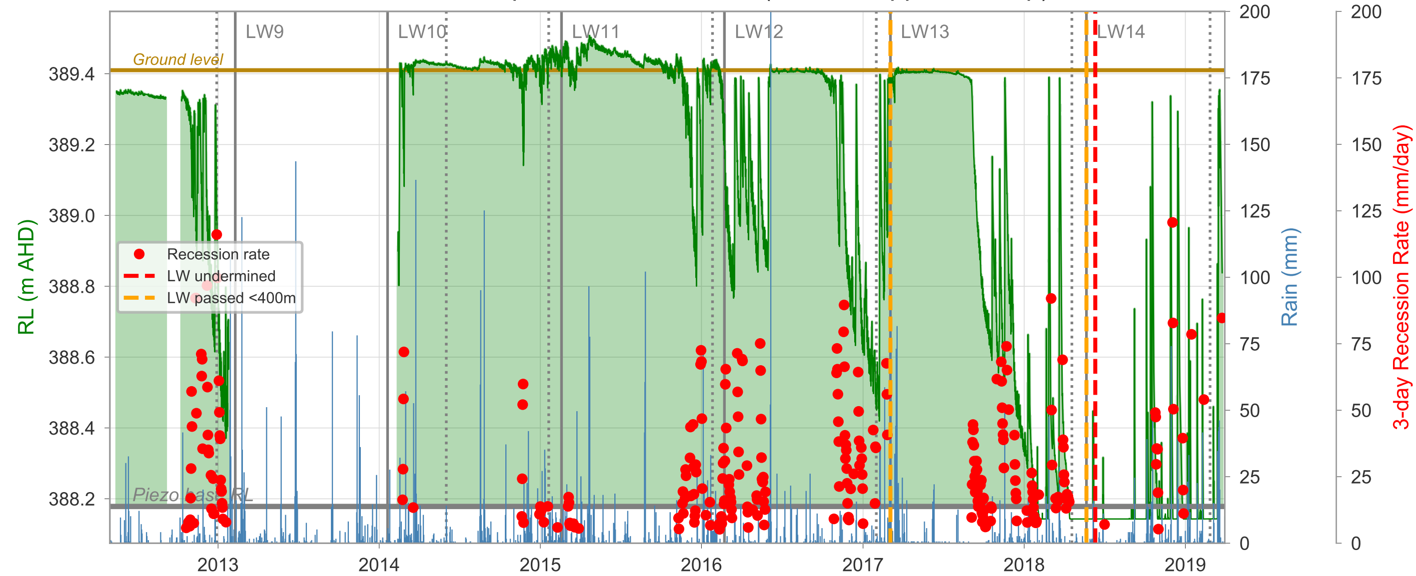


Dendrobium Swamp 10: Piezometer 01 (Within mapped swamp)
Ground level
Piezo base RL
LW9
LW10
LW11
LW12
LW13
LW14
Recession rate
LW undermined
LW passed <400m
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
365.0
364.8
364.6
364.4
364.2
364.0
363.8
363.6
2013
2014
2015
2016
2017
2018
2019

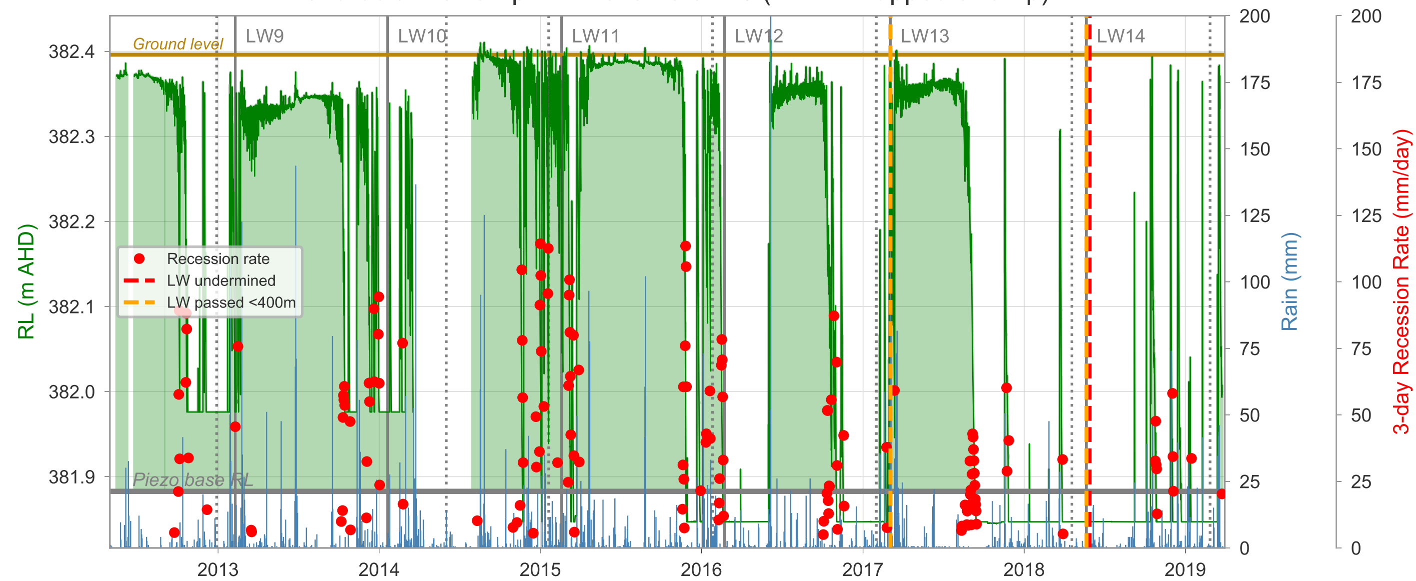
Dendrobium Swamp 11: Piezometer H1 (Within mapped swamp)

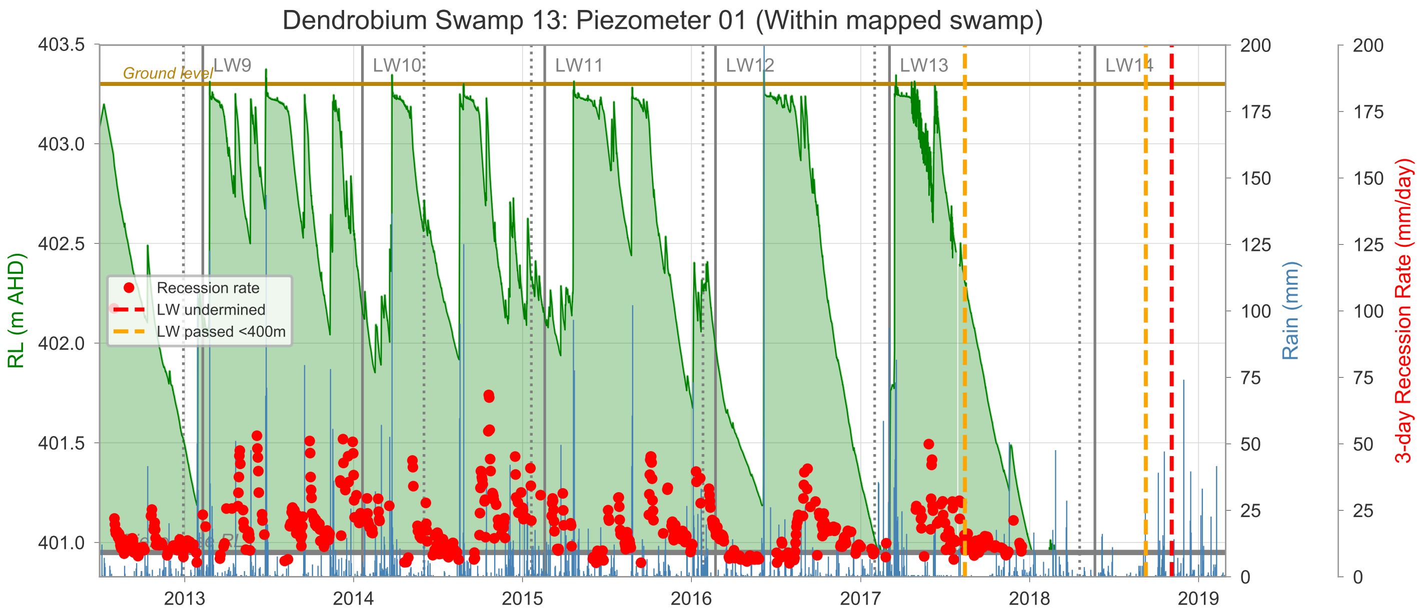


Dendrobium Swamp 11: Piezometer H2 (Within mapped swamp)

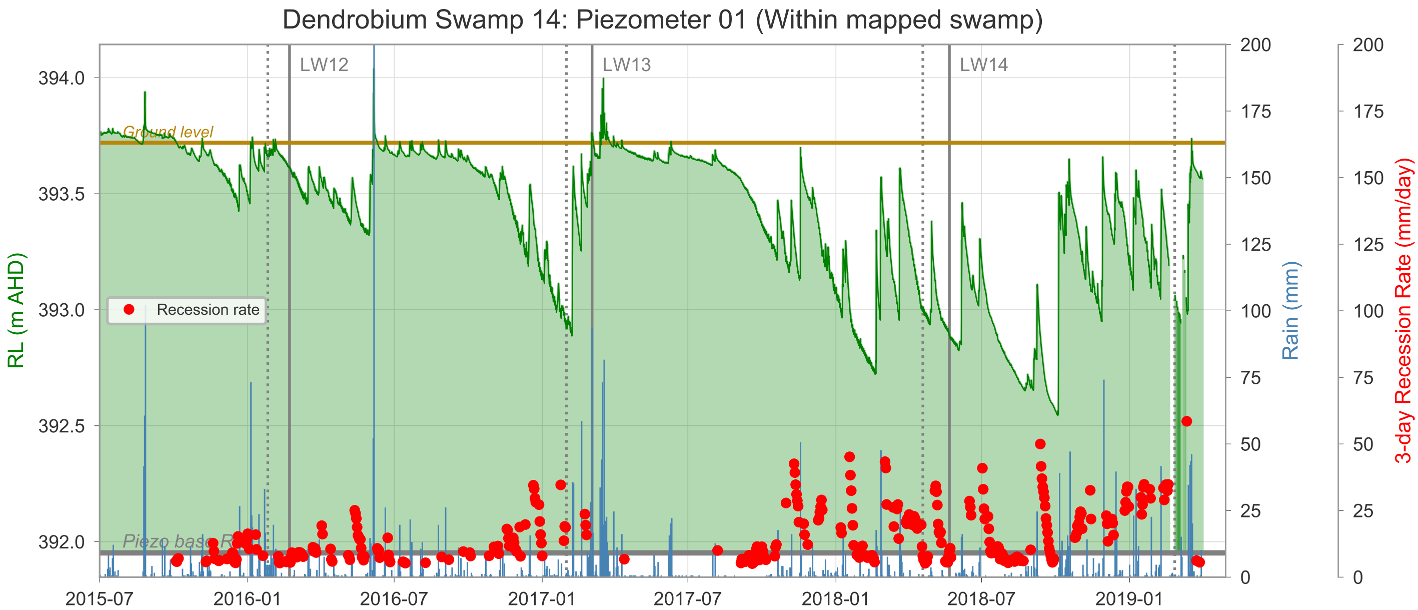


Dendrobium Swamp 11: Piezometer H3 (Within mapped swamp)

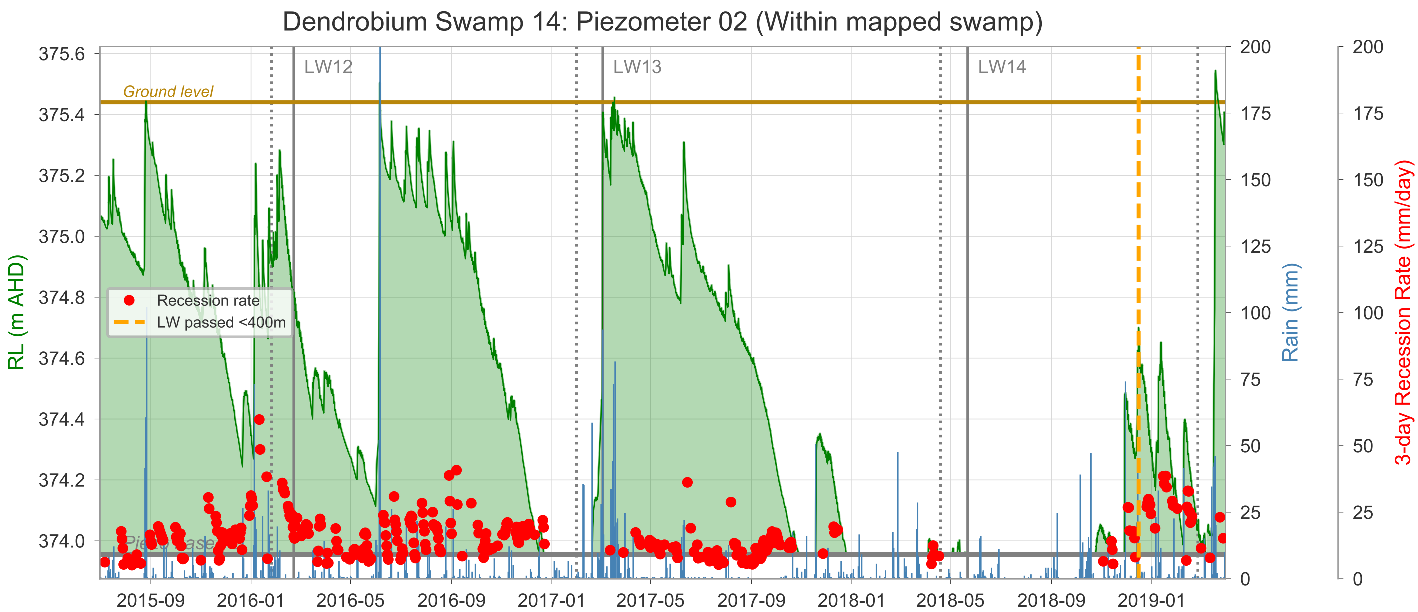




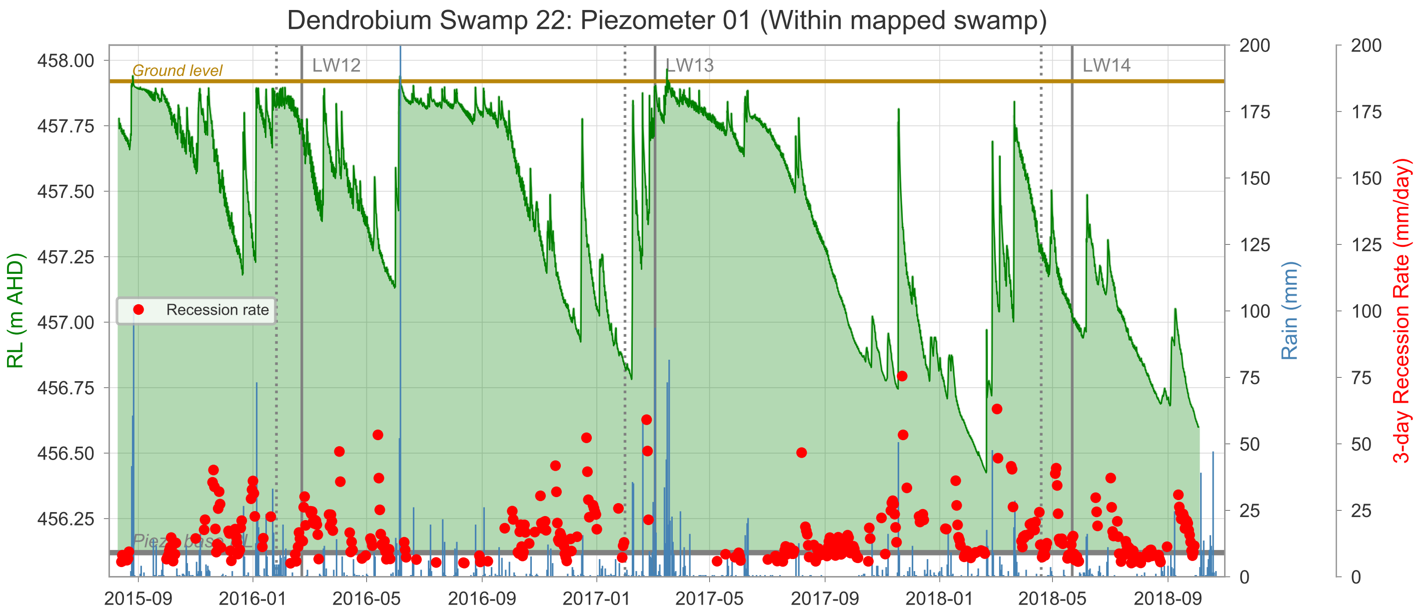
Dendrobium Swamp 13: Piezometer 01 (Within mapped swamp)
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
Ground level
LW9
LW10
LW11
LW12
LW13
LW14
Recession rate
LW undermined
LW passed <400m
2013
2014
2015
2016
2017
2018
2019

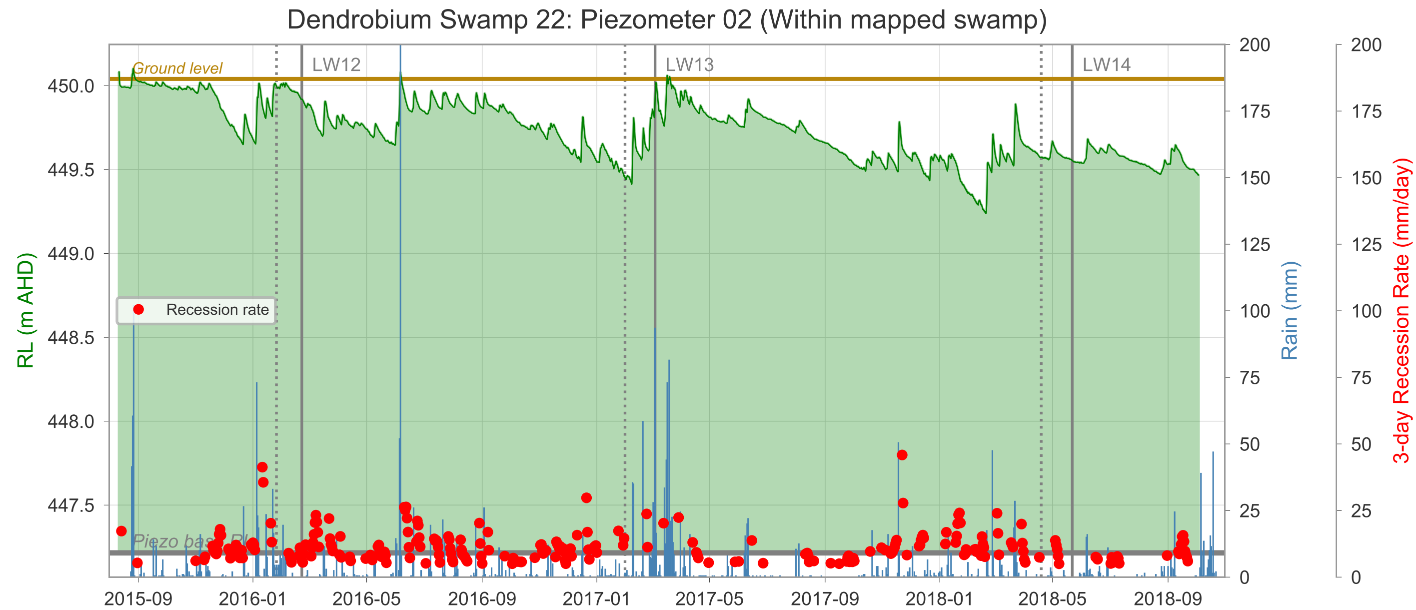


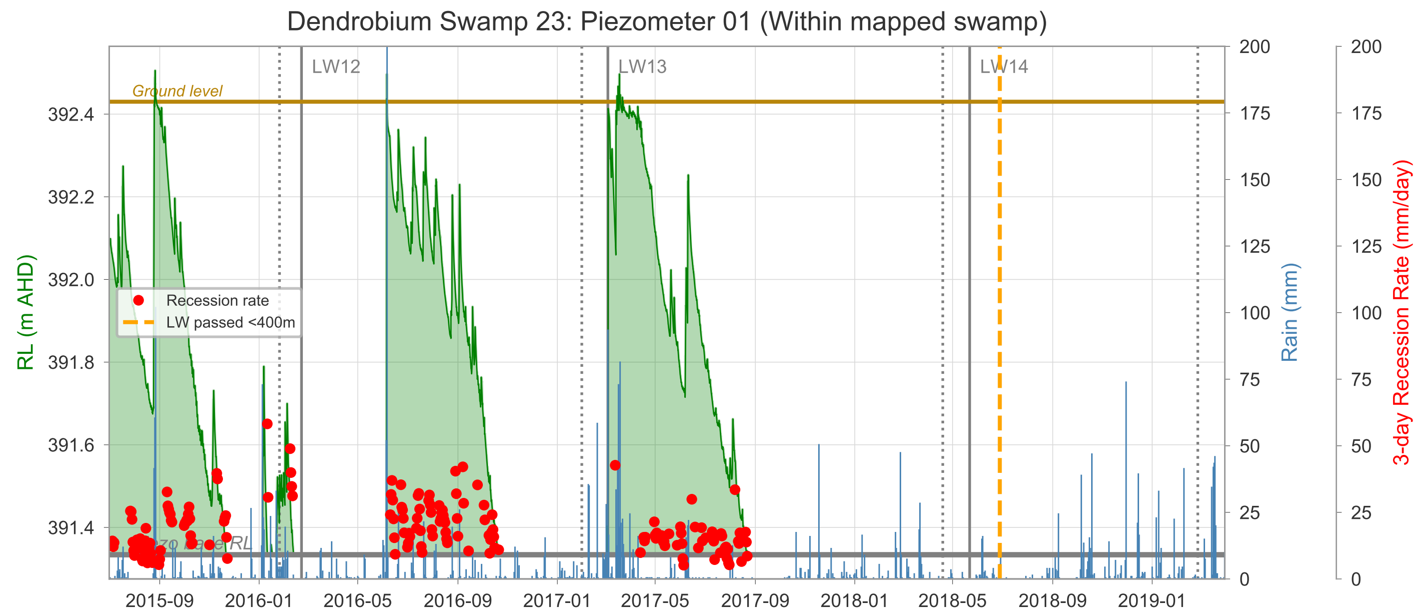
Dendrobium Swamp 14: Piezometer 01 (Within mapped swamp)
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
Ground level
LW12
LW13
LW14
Recession rate
2015-07
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01

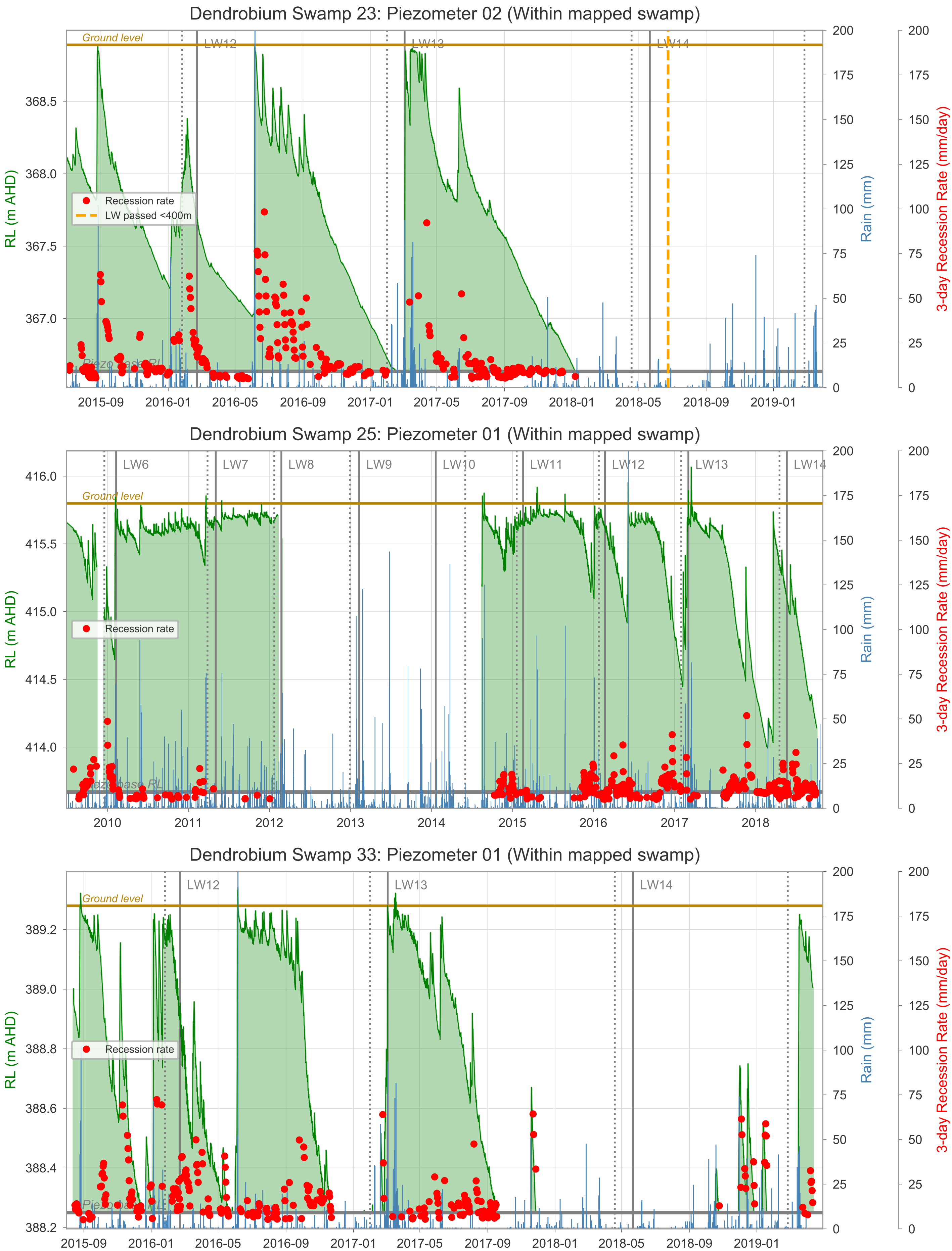


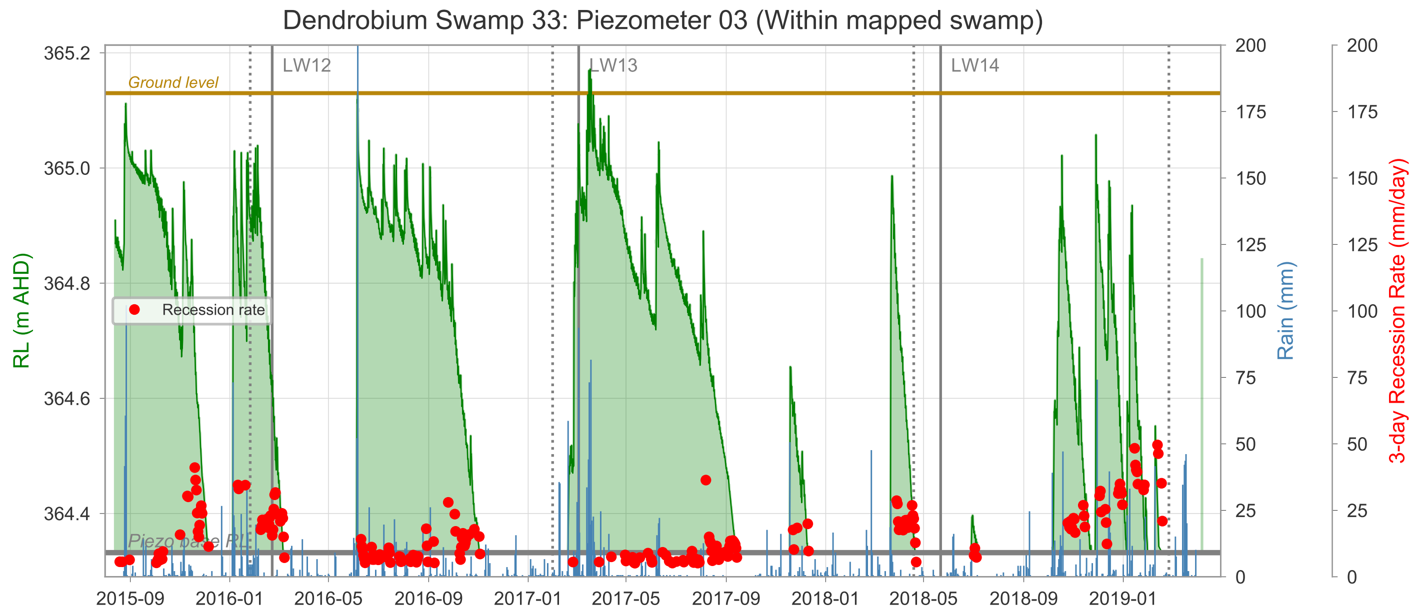
Dendrobium Swamp 14: Piezometer 02 (Within mapped swamp)
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
Ground level
LW12
LW13
LW14
Recession rate
LW passed <400m
2015-09
2016-01
2016-05
2016-09
2017-01
2017-05
2017-09
2018-01
2018-05
2018-09
2019-01

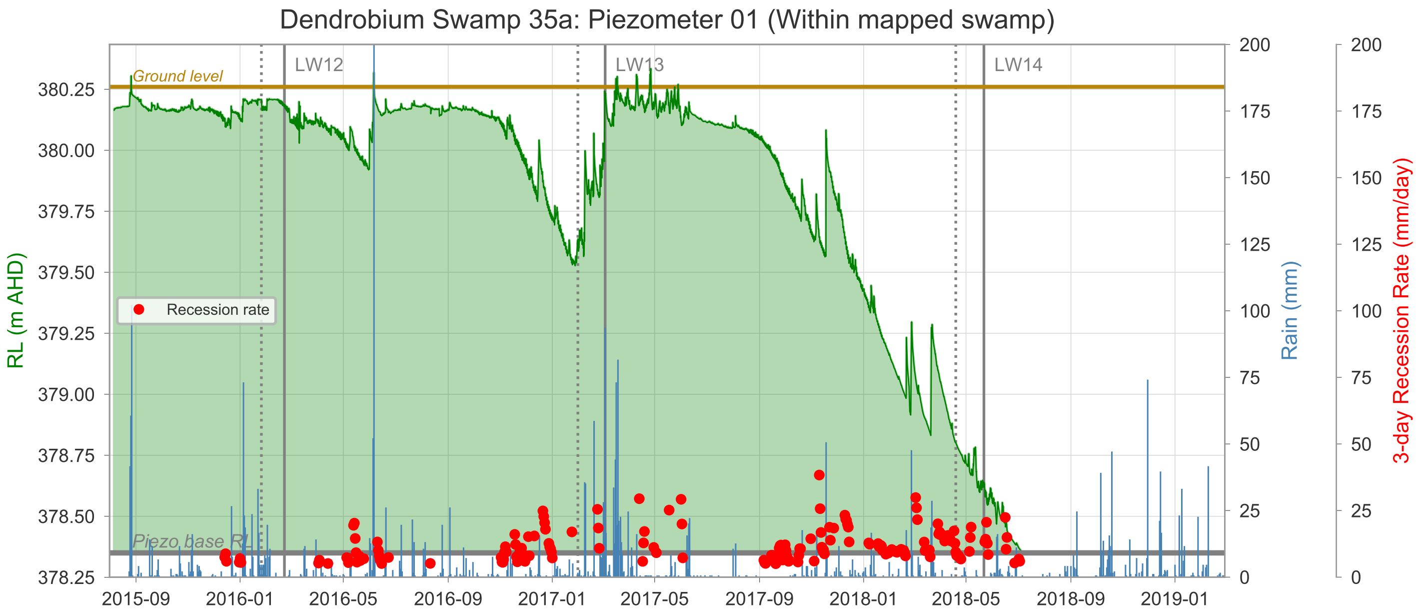

Dendrobium Swamp 22: Piezometer 01 (Within mapped swamp)
Ground level
LW12
LW13
LW14
Recession rate
Piezo base RL
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
458.00
457.75
457.50
457.25
457.00
456.75
456.50
456.25
200
175
150
125
100
75
50
25
0
2015-09
2016-01
2016-05
2016-09
2017-01
2017-05
2017-09
2018-01
2018-05
2018-09

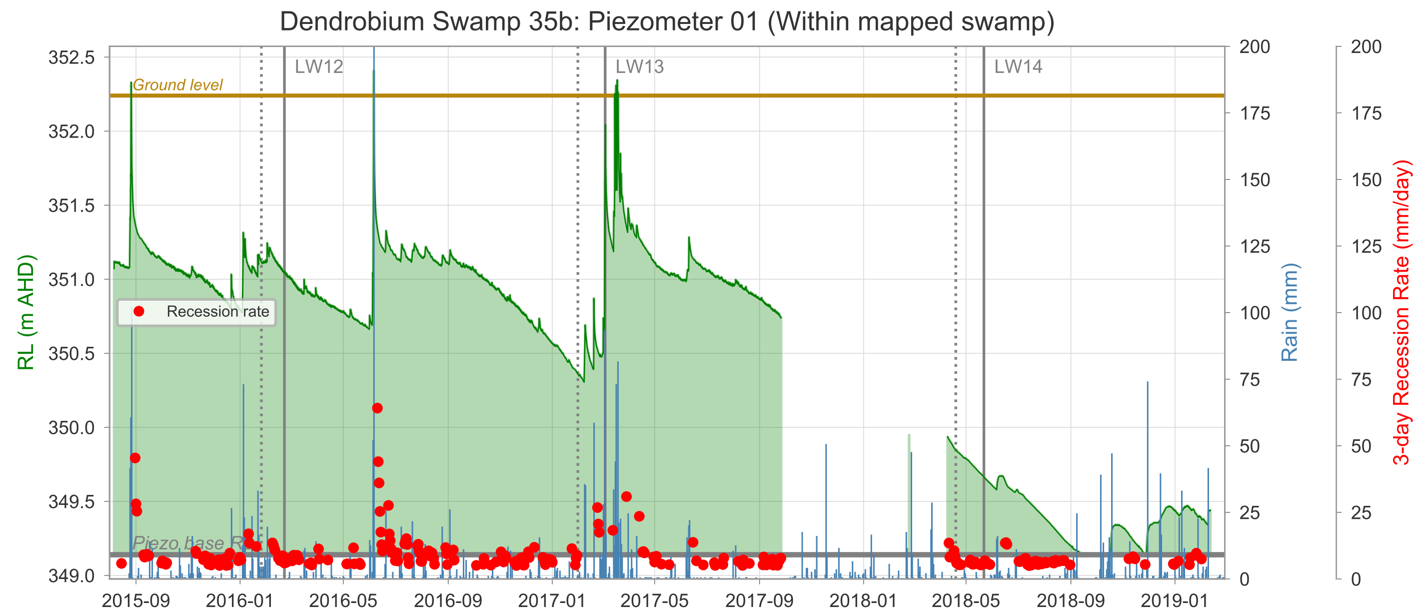

Dendrobium Swamp 22: Piezometer 02 (Within mapped swamp)
Ground level
LW12
LW13
LW14
Recession rate
Piezo base RL
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
450.0
449.5
449.0
448.5
448.0
447.5
200
175
150
125
100
75
50
25
0
2015-09
2016-01
2016-05
2016-09
2017-01
2017-05
2017-09
2018-01
2018-05
2018-09

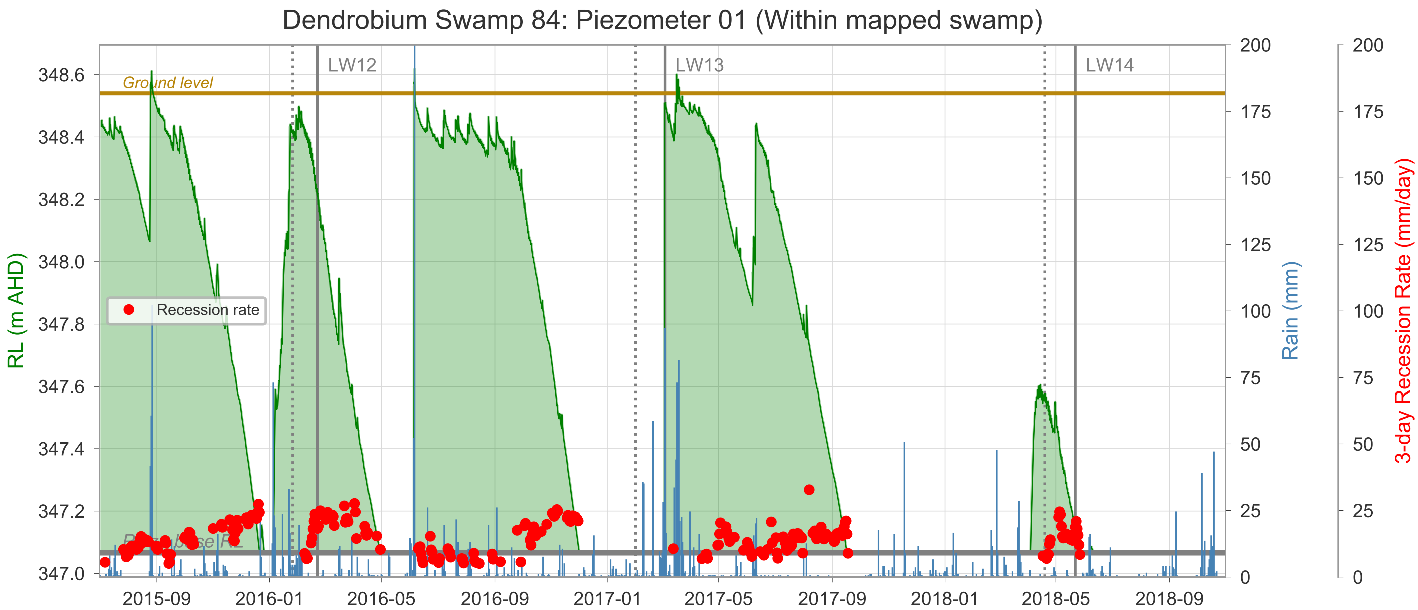

Dendrobium Swamp 23: Piezometer 01 (Within mapped swamp)
Ground level
LW12
LW13
LW14
Recession rate
LW passed <400m
Piezo base RL
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
392.4
392.2
392.0
391.8
391.6
391.4
200
175
150
125
100
75
50
25
0
2015-09
2016-01
2016-05
2016-09
2017-01
2017-05
2017-09
2018-01
2018-05
2018-09
2019-01

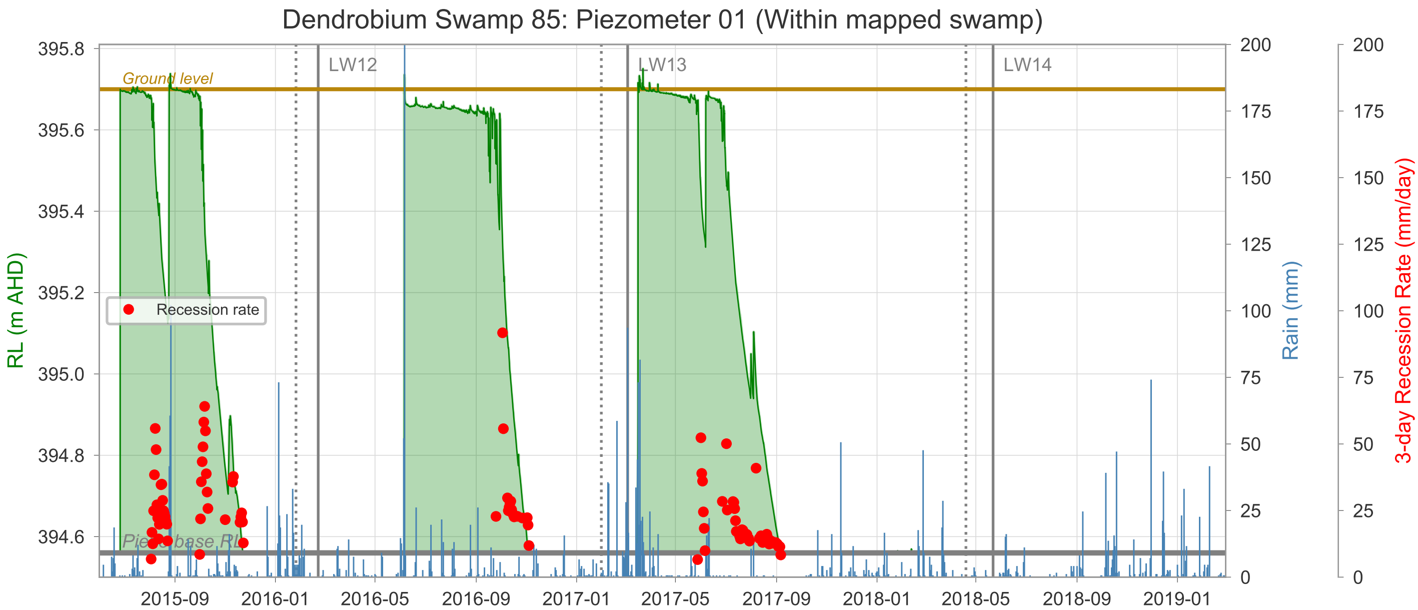

Dendrobium Swamp 23: Piezometer 02 (Within mapped swamp)
Ground level
LW12
LW13
LW14
Recession rate
LW passed <400m
Piezo base RL
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
2015-09
2016-01
2016-05
2016-09
2017-01
2017-05
2017-09
2018-01
2018-05
2018-09
2019-01
Dendrobium Swamp 25: Piezometer 01 (Within mapped swamp)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
Ground level
Recession rate
Piezo base RL
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
2010
2011
2012
2013
2014
2015
2016
2017
2018
Dendrobium Swamp 33: Piezometer 01 (Within mapped swamp)
LW12
LW13
LW14
Ground level
Recession rate
Piezo base RL
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
2015-09
2016-01
2016-05
2016-09
2017-01
2017-05
2017-09
2018-01
2018-05
2018-09
2019-01

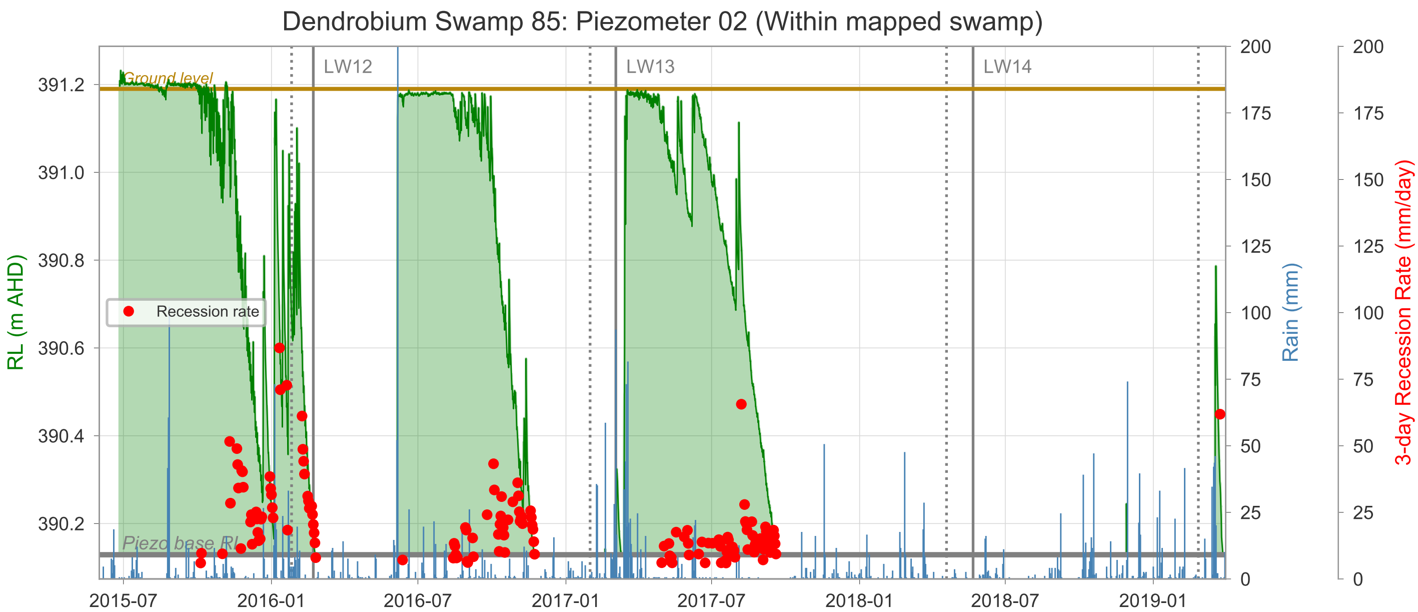

Dendrobium Swamp 33: Piezometer 03 (Within mapped swamp)
LW12
LW13
LW14
Ground level
Recession rate
Piezo base RL
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
365.2
365.0
364.8
364.6
364.4
200
175
150
125
100
75
50
25
0
2015-09
2016-01
2016-05
2016-09
2017-01
2017-05
2017-09
2018-01
2018-05
2018-09
2019-01


Dendrobium Swamp 35a: Piezometer 01 (Within mapped swamp)
LW12
LW13
LW14
Ground level
Recession rate
Piezo base RL
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
380.25
380.00
379.75
379.50
379.25
379.00
378.75
378.50
378.25
200
175
150
125
100
75
50
25
0
2015-09
2016-01
2016-05
2016-09
2017-01
2017-05
2017-09
2018-01
2018-05
2018-09
2019-01

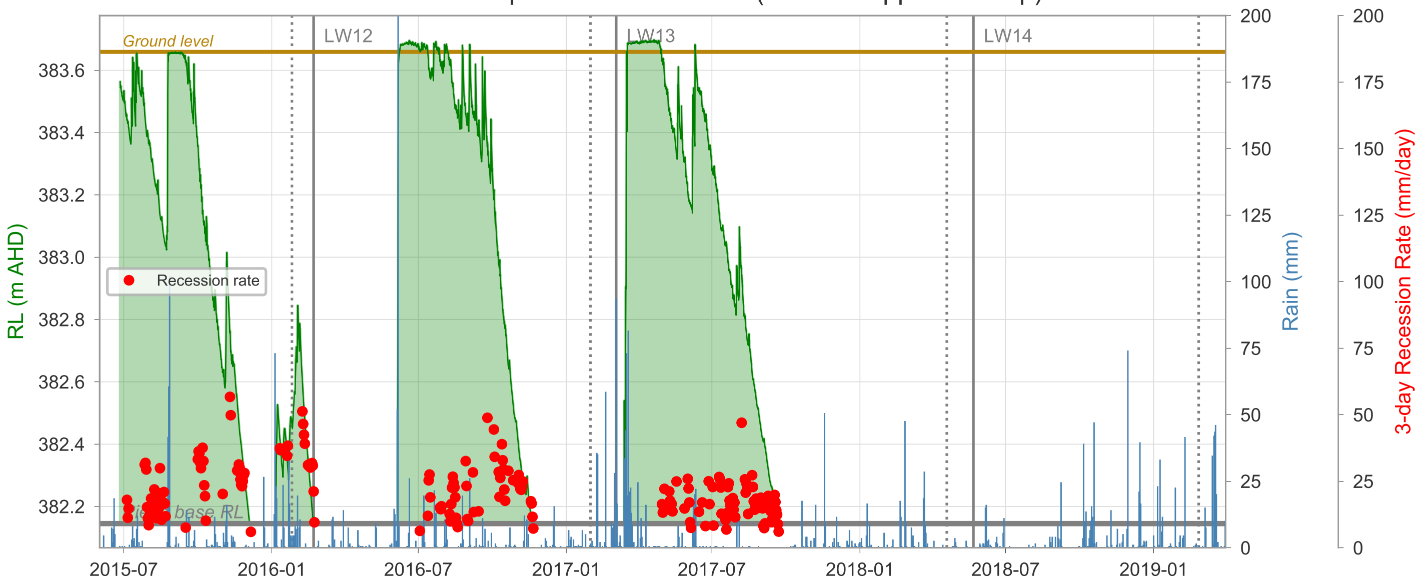

Dendrobium Swamp 35b: Piezometer 01 (Within mapped swamp)
LW12
LW13
LW14
Ground level
Recession rate
Piezo base RL
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
352.5
352.0
351.5
351.0
350.5
350.0
349.5
349.0
200
175
150
125
100
75
50
25
0
2015-09
2016-01
2016-05
2016-09
2017-01
2017-05
2017-09
2018-01
2018-05
2018-09
2019-01


Dendrobium Swamp 84: Piezometer 01 (Within mapped swamp)
Ground level
LW12
LW13
LW14
Recession rate
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
348.6
348.4
348.2
348.0
347.8
347.6
347.4
347.2
347.0
200
175
150
125
100
75
50
25
0
2015-09
2016-01
2016-05
2016-09
2017-01
2017-05
2017-09
2018-01
2018-05
2018-09

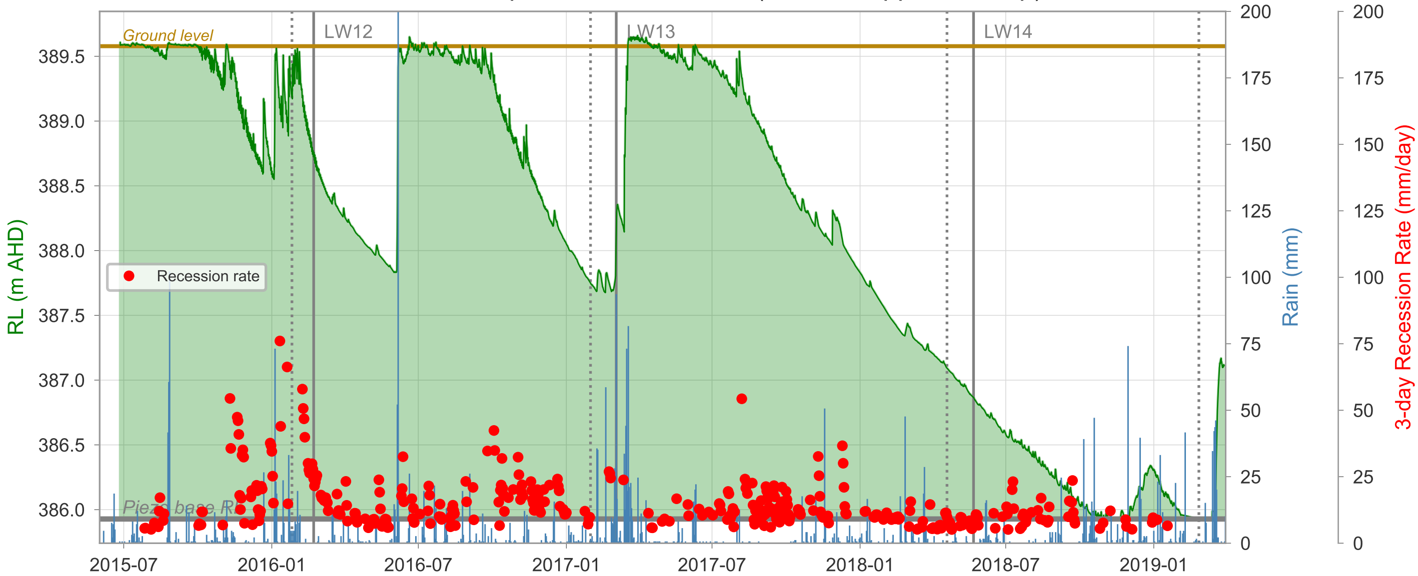

Dendrobium Swamp 85: Piezometer 01 (Within mapped swamp)
Ground level
Piezo base RL
LW12
LW13
LW14
Recession rate
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
395.8
395.6
395.4
395.2
395.0
394.8
394.6
200
175
150
125
100
75
50
25
0
2015-09
2016-01
2016-05
2016-09
2017-01
2017-05
2017-09
2018-01
2018-05
2018-09
2019-01


Dendrobium Swamp 85: Piezometer 02 (Within mapped swamp)
Ground level
Piezo base RL
LW12
LW13
LW14
Recession rate
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
391.2
391.0
390.8
390.6
390.4
390.2
200
175
150
125
100
75
50
25
0
2015-07
2016-01
2016-07
2017-01
2017-07
2018-01
2018-07
2019-01

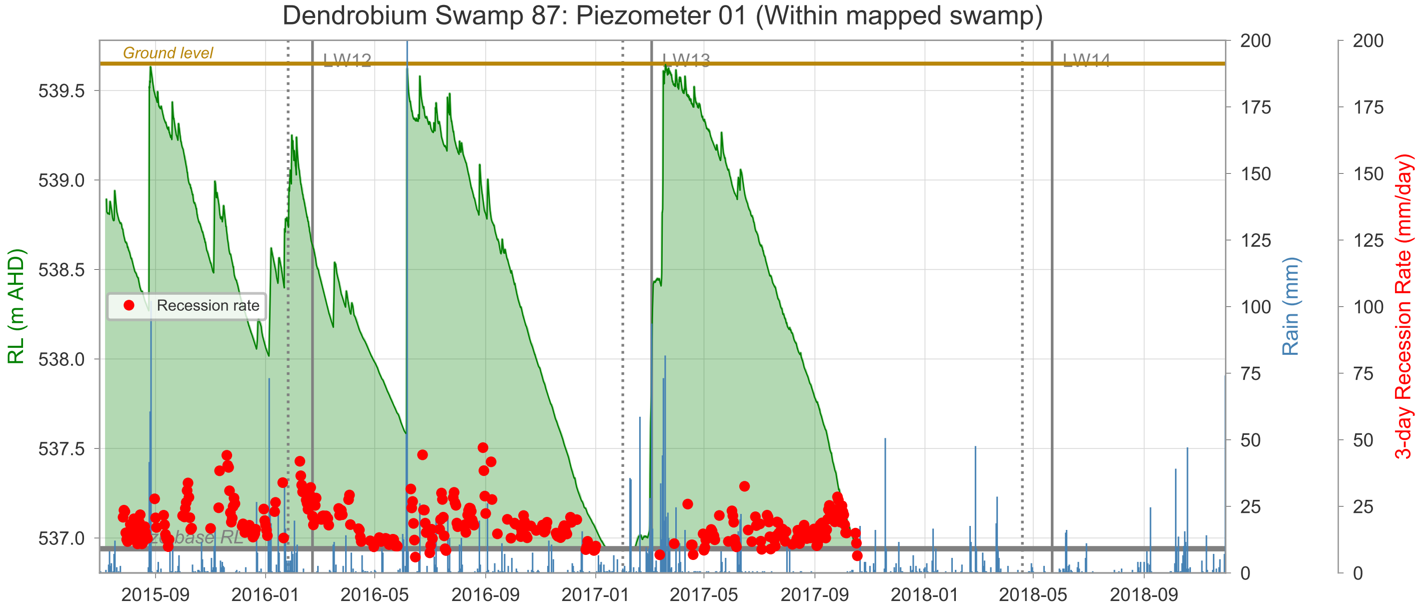
Dendrobium Swamp 86: Piezometer 01 (Within mapped swamp)

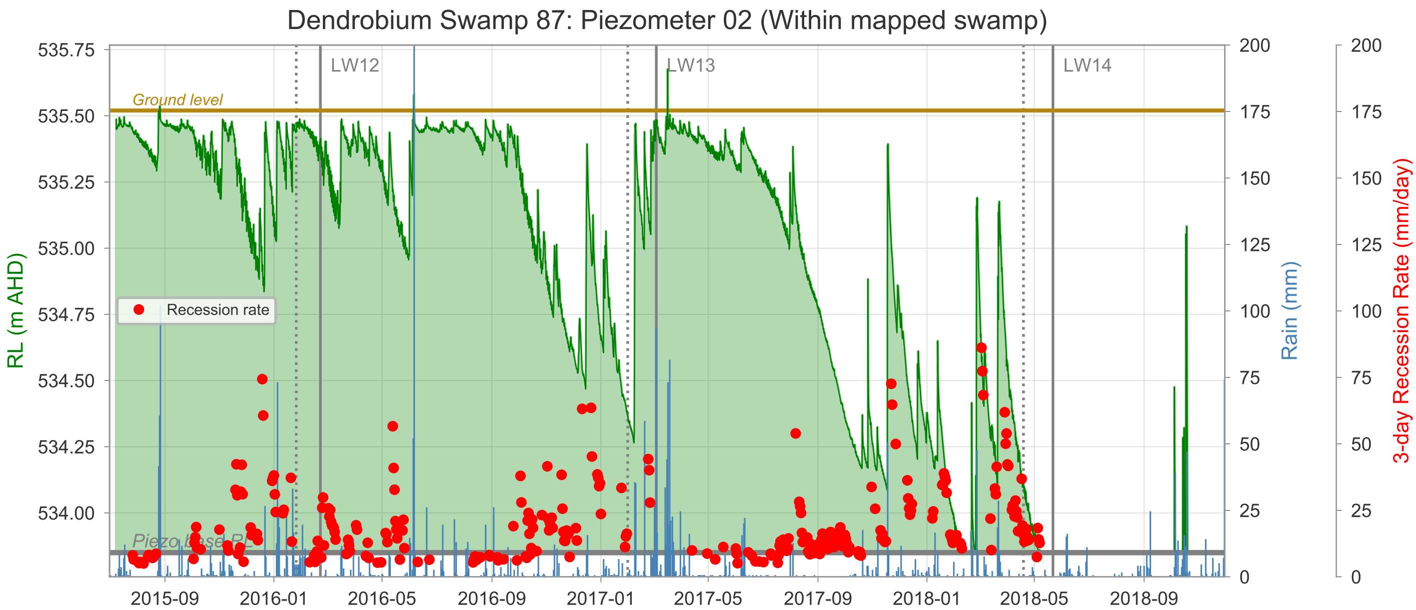


Dendrobium Swamp 86: Piezometer 02 (Within mapped swamp)

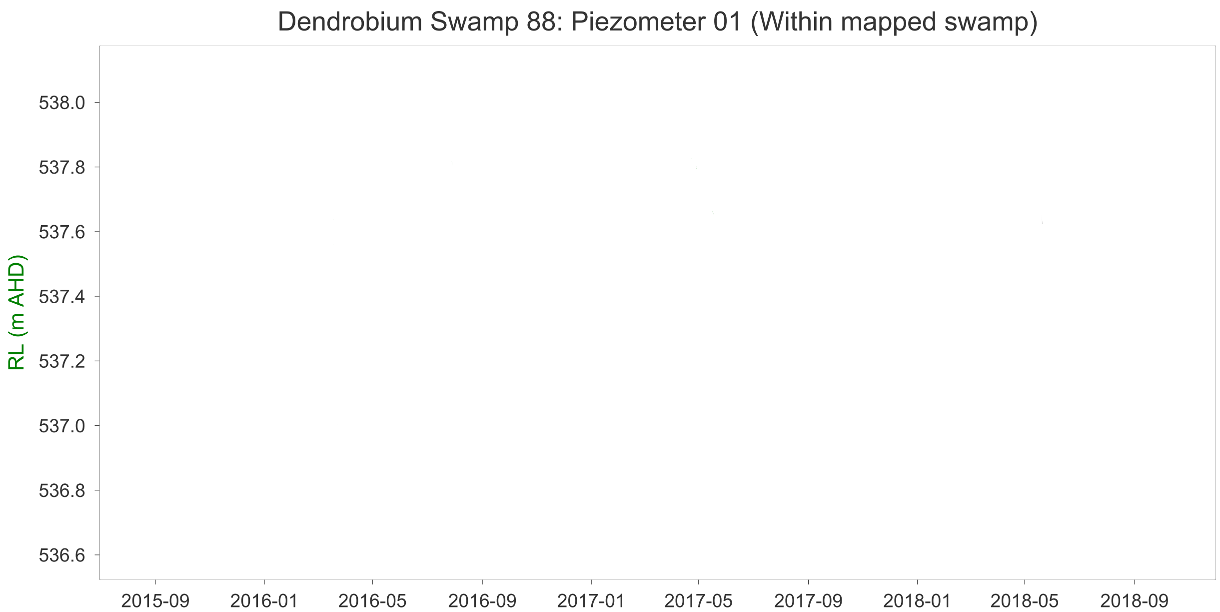


Dendrobium Swamp 87: Piezometer 01 (Within mapped swamp)





Dendrobium Swamp 87: Piezometer 02 (Within mapped swamp)
RL (m AHD)
Rain (mm)
3-day Recession Rate (mm/day)
Ground level
Piezo base RL
Recession rate
LW12
LW13
LW14
535.75
535.50
535.25
535.00
534.75
534.50
534.25
534.00
200
175
150
125
100
75
50
25
0
2015-09
2016-01
2016-05
2016-09
2017-01
2017-05
2017-09
2018-01
2018-05
2018-09



Dendrobium Swamp 88: Piezometer 01 (Within mapped swamp)
RL (m AHD)
538.0
537.8
537.6
537.4
537.2
537.0
536.8
536.6
2015-09
2016-01
2016-05
2016-09
2017-01
2017-05
2017-09
2018-01
2018-05
2018-09

APPENDIX 4 – Trigger Action Response Plan (Area 3B)

Table 1.1 – Dendrobium Area 3 Watercourse Monitoring

Watercourses monitoring within Dendrobium Area 3B will be installed ahead of mining to achieve 2 years baseline data (subject to timing and approval timeframes of any request to install additional monitoring). Monitoring is generally conducted through the mining period and for 2 years following active subsidence. Where impacts are observed the monitoring period will be reviewed and this review will be reported in Impact Assessment Reports and End of Panel Reports. For Level 2 and 3 Triggers and for impacts exceeding prediction this review is conducted in consultation with key stakeholders. The location of monitoring sites is indicated on Figures 2-1 to 2-57.

MONITORING SITE		SITE TYPE	MONITORING FREQUENCY	PARAMETERS
OBSERVATIONAL, PHOTO POINT AND WATER MONITORING				
AREA 3A	Sandy Creek and tributaries (including SC7 and SC10) *Refer to Figure 2-1*	Observation and photo point monitoring: • Sites based on an assessment of risk • Streams and swamps • Pools and rockbars • Previously observed impacts that warrant follow-up inspection	• Monthly 2 years pre and post mining, weekly when longwall is within 400m of monitoring site • Reference sites 6 monthly	Visual signs of impacts to creeks and drainage lines (i.e. cracking, vegetation changes, increased erosion, changes in water colour, soil moisture etc.) determined by comparing baseline photos with photos during the mining period Key water quality parameters in pools analysed to identify any changes resulting from mining Pool water levels to identify any changes resulting from mining
AREA 3B	**Impact Sites:** • Native Dog, Wongawilli and Donalds Castle Creeks, WC21, WC15, LA4, DC13, LA5, ND1, WC6, WC7, WC8, WC9, WC12, WC16 and WC18 • Swamps 5, 10, 11, 13, 14, 23, 35a, 35b, 1a, 1b, 8, 3 and 4 *Refer to Figures 2-2 to 2-11 and 2-25 to 2-32* **Reference Sites:** • Wongawilli Creek, Sandy Creek, LC7B, WC11, SC9A, SC10A, NDC1, DC10 and D10 • Swamps 2, 7, 15a, 22, 24, 25, 33, 84, 85, 86, 87 and 88 *Refer to Figures 2-12 to 2-25, 2-28 to 2-30 and 2-33 to 2-35*			
WATER QUALITY				
AREA 3A	**Wongawilli Creek** WWU1, WWU4, WC_Pool 46, WWM2, WC_Pool 43b and Wongawilli Ck (FR6) **Sandy Creek** SCk_Rockbar 5 (Sandy Creek adjacent to LW7) *Refer to Figure 2-1*	• Grab sample • Field water quality	• Monthly monitoring pre, during and post mining for two years	Manual Field Testing: • Field pH, Temp, EC, DO and ORP • Lab. analytes (incl. lab check of pH, lab. check of EC, DOC, Na, K, Ca, Mg, Filt. SO4, Cl, T. Alk., Total Fe, Mn, Al, Filt. Cu, Ni, Zn, Si)

AREA 3B	**Wongawilli Creek** WWU1 (Wongawilli Creek headwaters) WWU4 (Wongawilli Creek upstream) WC Pool 49 (Wongawilli Creek adjacent to LW15) WC_Pool 46 (Wongawilli Creek adjacent to LW12) WWM2 (Wongawilli Creek adjacent to LW11) WC_Pool 43b (Wongawilli Creek downstream of LW9) Wongawilli Ck (FR6) (Wongawilli Creek downstream) WC21_Pool 5 (Wongawilli Creek tributary downstream of mining) WC21 Pools 30 and 53 (Wongawilli Creek tributaries over mining) WC15_Pool 9 (Wongawilli Creek tributary downstream of mining) **Lake Avon** LA4_S1, LA4_S2, LA5_S1, LA5_S2, LA3 Pool 4, LA2 Pool 5 and LA_1 (Lake Avon tributaries downstream of mining) NDC4 (Native Dog Creek downstream of mining) NDC1 (Native Dog Creek upstream of Area 3B) **Donalds Castle Creek** Donalds Castle Ck (FR6) (Donalds Castle Creek lower) DCL3 (Donalds Castle Creek @ Cordeaux River) DC_Pool 22 (Donalds Castle Creek downstream of mining) DC13_Pool 2b (Donalds Castle Creek tributary downstream of mining) *Refer to Figure 2-35*			

<table>
<tr><td colspan="5">WATER FLOW</td></tr>
<tr><td>AREA 3A</td><td>Wongawilli Creek
WWU (Wongawilli Creek upstream)
WWL (Wongawilli Creek downstream)
Sandy Creek

SCL2(Sandy Creek at downstream)
SC10S1 and SC10CS1 (Sandy Creek tributary)
Refer to Figures 2-35 and 2-36</td><td rowspan="2">• Pressure transducer with data logger</td><td rowspan="2">• Continuous 1 hour logging intervals</td><td rowspan="2">Automatic pool water level measurements which are converted to flows by calculation of rating curves using measured creek cross sections/measured flows at the monitoring point</td></tr>
<tr><td>AREA 3B</td><td>Wongawilli Creek
WWU (Wongawilli Creek upstream)
WWL (Wongawilli Creek downstream)
WC21S1 (Wongawilli Creek tributary downstream of mining)
WC15S1 (Wongawilli Creek tributary downstream of mining)
Donalds Castle Creek
DCU (Donalds Castle Creek @ FR6)
DC13S1 (Donalds Castle Creek tributary downstream of mining)
DCS2 (Donalds Castle Creek downstream of mining)
Lake Avon
LA4S1 (Lake Avon tributary downstream of mining)
Refer to Figures 2-35 and 2-36</td></tr>
<tr><td colspan="5">AQUATIC ECOLOGY</td></tr>
<tr><td>AREA 3A</td><td>Sandy Creek Catchment:
Sites 8, 9, 10, 11, 12 and 13
Refer to Figure 2-57</td><td rowspan="2">• Quantitative and observational monitoring</td><td rowspan="2">• Two baseline monitoring campaigns prior to mining during autumn and spring
• Monitoring during mining in autumn and spring
• Monitoring post mining for two years or as otherwise required
• Monitoring targets sites as mining progresses through the domain</td><td rowspan="2">Macroinvertebrate sampling and assessment using the AUSRIVAS protocol and quantitative sampling using artificial collectors

In consideration of Adams Emerald Dragonfly and Sydney Hawk Dragonfly, individuals of the genus Austrocorduliidae and Gomphomacromiidae are identified to species level if possible

Fish are sampled by visual observations and dip netting in Area 3A, and sampled using a back-pack electrofisher and baited traps in Area 3B</td></tr>
<tr><td>AREA 3B</td><td>Impact Sites:
Sites 2, 3, 4, X4, X5 and X6 (Wongawilli Creek)
Sites X2 and X3 (WC21)
Site X1 (Donalds Castle Creek)

Reference Sites:
Site 1 (Wongawilli Creek – until LW15)
Site 5 (Wongawilli Creek)
Site 14 (Donalds Castle Creek)</td></tr>
</table>

	Site 6 (WC21) Site 7 (Sandy Creek) Sites 15 and 16 (Kentish Creek) *Refer to Figure 2-57*			
TERRESTRIAL FAUNA – THREATENED FROG SPECIES				
AREA 3B	**Impact Sites:** DC13 (Donalds Castle Creek tributary) DC(1) (Donalds Castle Creek) WC15 and 21 (Wongawilli Creek tributaries) LA4A (Lake Avon tributary) ND1 (Native Dog Creek tributary) *Refer to Figures 2-42 to 2-47* **Reference Sites:** WC10 and 11 (Wongawilli Creek tributaries) SC6, SC7-1, SC7-2, SC7A and SC8 (Sandy Creek tributaries) DC8 (Donalds Castle Creek tributary) NDC (Native Dog Creek) *Refer to Figures 2-48 to 2-56*	• Standardised transects in potential breeding habitat for two threatened frog species, Littlejohn's Tree Frog and Giant Burrowing Frog	• Surveys are undertaken in optimal periods over the season (i.e. when frogs are calling and/or active at known sites)	Frog surveys are conducted along creeks with a focus on features susceptible to impacts e.g. breeding pools. Potential breeding habitat for Littlejohn's Tree Frog and Giant Burrowing Frog will be targeted. Standardised transects have been established to record numbers of individuals recorded at each site from one year to the next. Tadpole counts will also be undertaken as part of the breeding habitat monitoring transects. These transects are surveyed by walking down the creekline and counting all amphibians seen or heard on either side of the line

Table 1.2 – Dendrobium Watercourse Impacts, Triggers and Response

Monitoring	Trigger	Action
OBSERVATIONAL, PHOTO POINT AND WATER MONITORING		
Native Dog, Wongawilli and Donalds Castle Creeks, WC21, WC15, LA4, DC13, LA5, ND1, WC6, WC7, WC8, WC9, WC12, WC16 and WC18 General observation of streams in active mining areas when longwall is within 400m Relevant Performance Measure(s): • Wongawilli Creek - minor environmental consequences • Donalds Castle Creek - minor environmental consequences • Waterfall WC-WF54 – negligible environmental consequences	***Level 1 **** • Crack or fracture up to 100mm width at its widest point with no observable loss of surface water or erosion • Crack or fracture up to 10m length with no observable loss of surface water or erosion • Erosion in a localised area (not associated with cracking or fracturing) which would be expected to naturally stabilise without CMA and within the period of monitoring • Observable release of strata gas at the surface • Observable increase in iron staining within the mining area	• Continue monitoring program • Submit an Impact Report to OEH, DoPE, T&I, Water NSW and other relevant resource managers • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2 * • Crack or fracture between 100 and 300mm width at its widest point or any fracture which results in observable loss of surface water or erosion • Crack or fracture between 10 and 50m length • Soil surface crack that causes erosion that is likely to stabilise within the monitoring period without intervention • Observable increase in iron staining within the mining area continues to outside the mining area i.e. 400m from the longwall	• *Actions as stated for Level 1* • Review monitoring frequency • Notify relevant technical specialists and seek advice on any CMA required • Implement agreed CMAs as approved (subject to stakeholder feedback)
	Level 3 * • Crack or fracture over 300mm width at its widest point • Crack or fracture over 50m length • Fracturing observed in the bedrock base of any significant permanent pool which results in observable loss of surface water • Soil surface crack that causes erosion that is unlikely to stabilise within the monitoring period without intervention • Gas release results in vegetation dieback, mortality or loss of aquatic habitat • Observable increase in iron staining within the mining area continues more than 600m from the longwall	• *Actions as stated for Level 2* • Site visit with OEH, DoPE, T&I, Water NSW and other resource manager/s (if requested) • Implement additional monitoring or increase frequency if required • Develop site CMA (subject to stakeholder feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with OEH, DoPE, T&I, Water NSW and other stakeholders • Completion of works following approvals and at a time agreed between BHPBIC, DoPE, T&I and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success • Review relevant TARP and Management Plan in consultation with key stakeholders
	Exceeding Prediction • Structural integrity of the bedrock base of any significant pool or controlling rockbar cannot be restored i.e. pool water level within the pool after CMAs continues to be lower than baseline period • Gas release results in vegetation dieback that does not	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the

Table 1.2 – Dendrobium Watercourse Impacts, Triggers and Response

Monitoring	Trigger	Action
	revegetate • Gas release results in mortality of threatened species or ongoing loss of aquatic habitat • Iron staining and associated increases in dissolved iron resulting from the mining is observed in water at Wongawilli Creek downstream monitoring site WONGAWILLI CK (FR6) • Iron staining and associated increases in dissolved iron resulting from the mining is observed in water at the Donalds Castle Creek downstream monitoring site Donalds Castle Ck (FR6) • Rock fall at WC-WF54 or its overhang • Impacts on the structural integrity of WC-WF54, its overhang or its pool	Development Consent
WATER QUALITY		
Wongawilli Creek Wongawilli Ck (FR6) Baseline means: • pH 5.98 • EC 98.8 uS/cm • DO 89.5% Relevant Performance Measure(s): • Wongawilli Creek - minor environmental consequences	***Level 1*** * • One exceedance of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean during the monitoring period: – pH 4.45 – EC 154.1 uS/cm – DO 50.5%	• Continue monitoring program • Submit an Impact Report to OEH, DoPE, T&I, Water NSW and other relevant resource managers • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2 * • Two exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean during the monitoring period: – pH 4.45 – EC 154.1 uS/cm – DO 50.5%	• *Actions as stated for Level 1* • Review monitoring frequency • Notify relevant technical specialists and seek advice on any CMA required • Implement agreed CMAs as approved (subject to stakeholder feedback)
	Level 3 * • Three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean during the monitoring period: – pH 4.45 – EC 154.1 uS/cm – DO 50.5%	• *Actions as stated for Level 2* • Site visit with OEH, DoPE, T&I, Water NSW and other resource manager/s (if requested) • Implement additional monitoring or increase frequency if required • Review relevant TARP and Management Plan in consultation with key stakeholders • Develop site CMA (subject to stakeholder feedback). This may include: – Limestone emplacement to raise pH where it is appropriate to do so – Grouting of fractures in rockbar and bedrock base of any significant pool where flow diversion results in pool water level lower than

Table 1.2 – Dendrobium Watercourse Impacts, Triggers and Response

Monitoring	Trigger	Action
		baseline period • Completion of works following approvals and at a time agreed between BHPBIC, DoPE, T&I and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success
	Exceeding Prediction • Mining results in two conecutive exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean during the monitoring period: – pH 4.45 – EC 154.1 uS/cm – DO 50.5%	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent
Donalds Castle Creek Donalds Castle Ck (FR6) Baseline means: • pH 5.41 • EC 116.0 uS/cm • DO 85.6%	***Level 1*** * • One exceedance of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean during the monitoring period: – pH 3.60 – EC 185.8 uS/cm – DO 40.1%	• Continue monitoring program • Submit an Impact Report to OEH, DoPE, T&I, Water NSW and other relevant resource managers • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
Relevant Performance Measure(s): • Donalds Castle Creek - minor environmental consequences	***Level 2*** * • Two exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean during the monitoring period: – pH 3.60 – EC 185.8 uS/cm – DO 40.1%	• *Actions as stated for Level 1* • Review monitoring frequency • Notify relevant technical specialists and seek advice on any CMA required • Implement agreed CMAs as approved (subject to stakeholder feedback)
	Level 3 * • Three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean during the monitoring period: – pH 3.60 – EC 185.8 uS/cm – DO 40.1%	• *Actions as stated for Level 2* • Site visit with OEH, DoPE, T&I, Water NSW and other resource manager/s (if requested) • Implement additional monitoring or increase frequency if required • Review relevant TARP and Management Plan in consultation with key stakeholders • Collect laboratory samples and analyse for: – pH, EC, major cations, major anions, Total Fe, Mn & Al – Filterable suite of metals • Develop site CMA (subject to stakeholder feedback). This may include:

Table 1.2 – Dendrobium Watercourse Impacts, Triggers and Response

Monitoring	Trigger	Action
		– Limestone emplacement to raise pH where it is appropriate to do so – Grouting of fractures in rockbar and bedrock base of any significant pool where flow diversion results in pool water level lower than baseline period • Completion of works following approvals and at a time agreed between BHPBIC, DoPE, T&I and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success
	**Exceeding Prediction** • Mining results in two conecutive exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean during the monitoring period: – pH 3.60 – EC 185.8 uS/cm – DO 40.1%	• _Actions as stated for Level 3_ • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent
Lake Avon Lake Avon tributary (LA4_S1) Baseline means: • pH 5.38 • EC 90.8 uS/cm • DO 89.9% (24 months of baseline data available - to be updated with additional baseline data) Relevant Performance Measure(s): • Lake Avon - negligible reduction in the quality of surface water inflows to Lake Avon	_**Level 1**_ * • One exceedance of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean during the monitoring period: – pH 4.90 – EC 129.8 uS/cm – DO 69.5%	• Continue monitoring program • Submit an Impact Report to OEH, DoPE, T&I, Water NSW and other relevant resource managers • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	**Level 2** * • Two exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean during the monitoring period: – pH 4.90 – EC 129.8 uS/cm – DO 69.5%	• _Actions as stated for Level 1_ • Review monitoring frequency • Notify relevant technical specialists and seek advice on any CMA required • Implement agreed CMAs as approved (subject to stakeholder feedback)
	**Level 3** * • Three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean during the monitoring period: – pH 4.90 – EC 129.8 uS/cm – DO 69.5%	• _Actions as stated for Level 2_ • Site visit with OEH, DoPE, T&I, Water NSW and other resource manager/s (if requested) • Implement additional monitoring or increase frequency if required • Review relevant TARP and Management Plan in consultation with key stakeholders • Collect laboratory samples and analyse for: – pH, EC, major cations, major anions, Total Fe, Mn & Al

Table 1.2 – Dendrobium Watercourse Impacts, Triggers and Response

Monitoring	Trigger	Action
		– Filterable suite of metals • Develop site CMA (subject to stakeholder feedback). This may include: – Limestone emplacement to raise pH where it is appropriate to do so – Grouting of fractures in rockbar and bedrock base of any significant pool where flow diversion results in pool water level lower than baseline period • Completion of works following approvals and at a time agreed between BHPBIC, DoPE, T&I and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success
	Exceeding Prediction • Mining results in two conecutive exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean of the Lake Avon inflows during the monitoring period: – pH 4.90 – EC 129.8 uS/cm – DO 69.5%	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent
POOL WATER LEVEL		
Mapped pools in the mining area: • Wongawilli Creek • Donalds Castle Creek	***Level 1*** * • Fracturing not resulting in diversion of flow	• Continue monitoring program • Submit an Impact Report to OEH, DoPE, T&I, Water NSW and other relevant resource managers • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
Relevant Performance Measure(s): • Wongawilli Creek - minor environmental consequences • Donalds Castle Creek - minor environmental consequences	***Level 2*** * • Fracturing resulting in diversion of flow	• *Actions as stated for Level 1* • Review monitoring frequency • Notify relevant technical specialists and seek advice on any CMA required • Implement agreed CMAs as approved (subject to stakeholder feedback)
	Level 3 * • Fracturing resulting in diversion of flow such that <10% of the pools have water levels lower than baseline period	• *Actions as stated for Level 2* • Site visit with OEH, DoPE, T&I, Water NSW and other resource manager/s (if requested) • Implement additional monitoring or increase frequency if required • Review relevant TARP and Management Plan in consultation with key stakeholders • Develop site CMA (subject to stakeholder feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with OEH, DoPE, T&I, Water NSW and other stakeholders

Table 1.2 – Dendrobium Watercourse Impacts, Triggers and Response

Monitoring	Trigger	Action
		• Completion of works following approvals and at a time agreed between BHPBIC, DoPE, T&I and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success
	Exceeding Prediction • Fracturing resulting in diversion of flow such that >10% of the pools have water levels lower than baseline period	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent
Waterfall WC-WF54 Relevant Performance Measure(s): • Waterfall WC-WF54 – negligible environmental consequences	***Exceeding Prediction*** • Fracturing in Wongawilli Creek within 30m of the waterfall which results in observable flow diversion • Fracturing in Wongawilli Creek which results in observable flow diversion from the lip of the waterfall	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent
MODELLED PERIODS OF RECESSIONAL, BASEFLOW AND SMALL STORM UNIT HYDROGRAPH PERIODS		
Subcatchments of Wongawilli and Donalds Castle Creeks and Lake Avon tributaries **	***Level 1 **** • Change 6-12% less than average annual precipitation ***	• Continue monitoring program • Submit an Impact Report to OEH, DoPE, T&I, Water NSW and other relevant resource managers • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2 * • Change 12-18% less than average annual precipitation ***	• *Actions as stated for Level 1* • Review monitoring frequency • Notify relevant technical specialists and seek advice on any CMA required • Implement agreed CMAs as approved (subject to stakeholder feedback)
	Level 3 * • Change >18% less than average annual precipitation ***	• *Actions as stated for Level 2* • Site visit with OEH, DoPE, T&I, Water NSW and other resource manager/s (if requested) • Implement additional monitoring or increase frequency if required • Develop site CMA (subject to stakeholder feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with OEH, DoPE, T&I, Water NSW and other stakeholders • Completion of works following approvals and at a time agreed between BHPBIC, DoPE, T&I and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success

Table 1.2 – Dendrobium Watercourse Impacts, Triggers and Response

<table>
<tr><th>Monitoring</th><th>Trigger</th><th>Action</th></tr>
<tr><td></td><td></td><td>Review relevant TARP and Management Plan in consultation with key stakeholders</td></tr>
<tr><td>Inflows to Lake Avon and Cordeaux River **

Relevant Performance Measure(s):
Lake Avon - negligible reduction in the quantity of surface water inflows to Lake Avon
Cordeaux River - negligible reduction in the quantity of surface water flows from Wongawilli Creek to Cordeaux River</td><td>Exceeding Prediction
Measured surface water flow reduction in Wongawilli Creek at its confluence with Cordeaux River that is greater than predicted by the groundwater model (to the satisfaction of the Director General - Condition 13 of the SMP) that cannot be attributed to natural variation
Surface water flow reduction into Lake Avon is greater than predicted by the groundwater model (to the satisfaction of the Director General - Condition 13 of the SMP) that cannot be attributed to natural variation</td><td>Actions as stated for Level 3
Investigate reasons for the exceedance
Update future predictions based on the outcomes of the investigation
Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent</td></tr>
<tr><td colspan="3">AQUATIC ECOLOGY</td></tr>
<tr><td rowspan="3">Pool water level, interconnectivity between pools and loss of connectivity, noticeable alteration of habitat
Wongawilli Creek catchment – 8 sites
Donalds Castle Creek catchment – 1 site</td><td>Level 1 *
Reduction in aquatic habitat for 1 year</td><td>Continue monitoring program
Submit an Impact Report to OEH, DoPE, T&I, Water NSW and other relevant resource managers
Report in the End of Panel Report
Summarise actions and monitoring in AEMR</td></tr>
<tr><td>Level 2 *
Reduction in aquatic habitat for 2 years following the active subsidence period</td><td>Actions as stated for Level 1
Review monitoring frequency
Notify relevant technical specialists and seek advice on any CMA required
Implement agreed CMAs as approved (subject to stakeholder feedback)</td></tr>
<tr><td>Level 3 *
Reduction in aquatic habitat for >2 years or complete loss of habitat following the active subsidence period</td><td>Actions as stated for Level 2
Site visit with OEH, DoPE, T&I, Water NSW and other resource manager/s (if requested)
Implement additional monitoring or increase frequency if required
Review relevant TARP and Management Plan in consultation with key stakeholders
Develop site CMA (subject to stakeholder feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with OEH, DoPE, T&I, Water NSW and other stakeholders
Completion of works following approvals and at a time agreed between BHPBIC, DoPE, T&I and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success</td></tr>
<tr><td colspan="3">TERRESTRIAL FAUNA – THREATENED FROG SPECIES</td></tr>
<tr><td>Pool water level, interconnectivity between pools and loss of connectivity, noticeable alteration of</td><td>Level 1 *
Reduction in habitat for 1 year</td><td>Continue monitoring program
Submit an Impact Report to OEH, DoPE, T&I, Water NSW and other</td></tr>
</table>

Table 1.2 – Dendrobium Watercourse Impacts, Triggers and Response

Monitoring	Trigger	Action
habitat • Wongawilli Creek catchment – 2 sites • Donalds Castle Creek catchment – 2 sites • Lake Avon tributary – 1 site • Native Dog tributary – 1 site		relevant resource managers • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2 * • Reduction in habitat for 2 years following the active subsidence period	• *Actions as stated for Level 1* • Review monitoring frequency • Notify relevant technical specialists and seek advice on any CMA required • Implement agreed CMAs as approved (subject to stakeholder feedback)
	Level 3 * • Reduction in habitat for > 2 years or complete loss of habitat following the active subsidence period	• *Actions as stated for Level 2* • Site visit with OEH, DoPE, T&I, Water NSW and other resource manager/s (if requested) • Implement additional monitoring or increase frequency if required • Review relevant TARP and Management Plan in consultation with key stakeholders • Develop site CMA (subject to stakeholder feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with OEH, DoPE, T&I, Water NSW and other stakeholders • Completion of works following approvals and at a time agreed between BHPBIC, DoPE, T&I and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success

* These may be revised in consultation with DoPE and T&I and other key stakeholders following analysis of natural variability within the pre-mining baseline data. These TARPs relate to Dendrobium Area 3B and impacts resulting from mining in Areas 1, 2 and 3A were managed under previous TARPs.

** Water budgets during recessional, baseflow and small storm unit hydrograph periods would be determined by hydrologic modelling of pre- and post-mining hydrographic data using the Free University of Amsterdam RUNOFF2005 model and validation of model-determined ETs against those estimated by the independent CSIRO Land and Water Division (Zhang et al.) method. These TARPs would apply only to the whole of catchment water delivered to Lake Cordeaux, Lake Avon and Cordeaux River. Model reliability is maintained only for catchments in excess of 1 km^2 in area. Average annual precipitation is modelled using the most recent 5 years of local record.

*** Hydrologic modelling conducted in the manner described above for the baseline period routinely produces mean estimated water budgets lying within about ±6% of average annual precipitation at the one standard deviation level and within about ±12% at the two standard deviation level.

Office of Environment and Heritage (OEH)

Department of Planning and Environment (DoPE)

Trade and Investment: including Division of Resources and Energy, Office of Water, Fisheries (T&I)

Water NSW (formally SCA)