Barossa Permanent Pools Monitoring

Environmental and Cultural Flows (ECF) Project

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Acknowledgement of Country

The Department for Environment and Water acknowledges Aboriginal people as the First Peoples and Nations of the lands and waters we live and work upon and we pay our respects to their Elders past, present and emerging. We acknowledge and respect the deep spiritual connection and the relationship that Aboriginal and Torres Strait Islander people have to Country.

The Department works in partnership with the First Peoples of South Australia and supports their Nations to take a leading role in caring for their Country.

Disclaimer

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Foreword

The Department for Environment and Water (DEW) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provide the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEW's strong partnerships with educational and research institutions, industries, government agencies, Landscape Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

Ben Bruce
CHIEF EXECUTIVE
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Acknowledgements

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Executive Summary

This technical document presents the results of surface water monitoring at permanent pools within the Barossa Prescribed Water Resources Area (PWRA), undertaken to support the delivery of the Environmental and Cultural Flows (ECF) project commissioned by the Northern and Yorke Landscape Board and funded through the Department for Environment and Water's Landscape Priority Fund. Fifteen monitoring sites across the Barossa PWRA were instrumented in September 2023, providing over two years of continuous data on pool water levels and water quality with results presented for the period September 2023 to December 2025 (the reporting period). These sites were chosen based on historic pool permanence, including through the Millenium Drought.

The reporting period coincided with sustained dry conditions in the region. Since 2017, there has been predominantly below-average rainfall, including consecutive record-low years in 2018–2019 and again in 2024 with only 2022 notably above average. Streamflow at key gauges remained near zero for prolonged periods, producing a rare opportunity to observe pool behaviour under extreme hydrological stress. These conditions effectively provided a short-term stress test for pool resilience. Importantly, the pool water levels recorded in 2024 have been identified as potential trigger points for adaptive management actions as part of the upcoming revised Water Allocation Plan for the Barossa PWRA.

The data show that permanent pools across the catchment exhibit clear seasonal dynamics; however, these dynamics were significantly altered following the exceptionally dry conditions of 2024. In 2024–25, pool drawdown commenced earlier and recovery was delayed, reflecting both later rainfall and carry-over groundwater deficits. At many sites, initial pool recovery occurred prior to significant rainfall events, which may indicate an influence of shallow groundwater processes; however, the mechanisms driving this early response remain uncertain. Given the limited monitoring record, further data collection and investigation are required to determine whether this represents a consistent pattern and to better understand the underlying drivers.

Groundwater connectivity interpretations are based on observed pool behaviour, as no direct groundwater level measurements were undertaken at the monitoring sites; therefore, relationships are inferred from hydrological response patterns and informed by previous studies of groundwater–surface water interactions in similar systems.

A strong gradient in pool resilience was observed across the PWRA. Pools in parts of Tanunda Creek and Jacob Creek demonstrated the strongest resilience with most retaining water throughout the monitoring period and suggesting strong groundwater connectivity. In contrast, several sites—particularly downstream of the North Para weir system—experienced severe drawdown with some drying completely and failing to recover. Other sites showed partial recovery; however, at some locations, peak water levels in 2025 only marginally exceeded the minimum levels recorded during the 2024 drawdown indicating a storage deficit that occurred under consecutive dry years.

It is important to note that the weak or intermittent groundwater connectivity inferred from hydrological response patterns at several sites during the reporting period is considered an emerging trend rather than a reflection of historical conditions. Landholder accounts, along with empirical observations from previous studies and monitoring in the region and the historical persistence of these pools, suggest that more stable groundwater connections were typical prior to the extended dry conditions that have persisted in the region.

Flow connectivity across the catchment was substantially reduced. Upstream flow interception, together with reduced inflows associated with climatic conditions, contributed to a reduction or absence of weir and instream farm dam spill events, thereby limiting downstream recharge and connectivity, particularly in the lower North Para River reach.

Water quality declined as pools contracted with electrical conductivity (EC) exceeding ecological thresholds at multiple sites during drawdown periods. Two key processes were identified: (1) progressive evapo-concentration of salts under low-flow conditions; and (2) short-duration EC spikes associated with first-flush runoff events. These findings indicate that earlier delivery of environmental flows may be more effective in maintaining water quality than later-season interventions.

Although these findings are preliminary — being based on only two years of data — they provide a valuable baseline for understanding pool resilience under extreme dry conditions. The results highlight increasing vulnerability under consecutive dry years, particularly where groundwater connectivity is weak or hydrological connectivity is constrained by infrastructure. This vulnerability is relevant given climate projections indicate continued or intensified dry conditions are expected in the near future in the region. A delayed onset of seasonal replenishment reduces the period during which pools can provide suitable refuge for aquatic and riparian biota.

Key management implications include:

(i) **priority intervention downstream of weirs** - Sites downstream of the weirs (barriers constructed across river to regulate and store water) show the greatest vulnerability, indicating a disproportionate influence of upstream flow interception associated with the large instream weirs. Environmental flows or modified weir operations may assist in maintaining downstream connectivity and supporting pool persistence;

(ii) **protecting surface flows to sustain groundwater recharge** - While recharge processes were not directly assessed in this study, existing knowledge indicates that surface flows (particularly streambed recharge) sustain shallow groundwater systems that support permanent pools. Maintaining, and where possible restoring, flow connectivity is therefore likely to support recharge processes and improve pool persistence;

(iii) **designing environmental flows to address both depth and dilution** - Declining pool levels were associated with increased EC at multiple sites. Provision of environmental flows may assist in maintaining minimum pool depths and provide dilution to reduce EC concentrations below ecological thresholds; and

(iv) **sustained long-term monitoring** – Continued monitoring of permanent pools is essential to validate emerging trends, capture interannual variability, and support development of a robust Environmental Water Plan for the Barossa catchment.

1 Aims and objectives

The Northern and Yorke Landscape Board (N&Y Landscape Board) engaged the Water Science and Monitoring Branch of the Department for Environment and Water (DEW) to undertake surface water (SW) monitoring and hydro-ecological modelling to support the delivering Environmental and Cultural Flows (ECF) project. For the Barossa surface water monitoring component of the project, key activities include:

- installation of loggers to collect water level, water electrical conductivity (EC), and water temperature data at selected permanent pools of high ecological significance;
- undertaking surveys of the pools to collect baseline data that can support future characterisation of pool behaviour under different flow regimes;
- collation and comparison of pool depth data with streamflow data from nearby gauging stations to provide hydrological context for pool behaviour;
- post-processing and analysis of results; and
- reporting of results.

This document presents data collected from the monitoring pools between the commencement of monitoring in September 2023 through to December 2025 and summarises the results and key insights gained from the analysis. These findings aim to provide insight into the hydrological behaviour of the permanent pools and their resilience which can then inform the provision of targeted environmental and cultural flows for the Barossa area. This information will support the assessment of effective environmental flow strategies for the Barossa Prescribed Water Resource Area (PWRA) and inform future flow delivery approaches to help restore and protect both environmental and cultural flows across the catchment.

2 Background

Permanent pools in seasonal (i.e., non-perennial) watercourses are vital ecological features that act as refuge habitat for obligate aquatic flora and fauna during the cease-to-flow period. They are typically sustained by a combination of surface water, subsurface flows and groundwater processes (Bourke et al., 2023). These pools provide essential refuges for aquatic species, support riparian vegetation, and can hold cultural significance for First Nations.

Permanent pools in the Barossa Valley are so termed because they were, until recently, considered to be permanent features in the landscape. Regardless of flow conditions, these pools have endured throughout recent history, including the Millennium Drought. Although no dedicated investigation has been undertaken to determine the precise source of water sustaining these pools, they are understood to reflect a combination of surface water retention and groundwater interactions. The relative contribution of these processes is likely to vary spatially and temporally across the catchment.

Bourke et al. (2023) present a hydrological framework for persistent pools that identifies perched surface water, alluvial water throughflow, and groundwater discharge as the key mechanisms controlling pool persistence. This framework further describes how interactions among these mechanisms, as well as geological and topographic controls, influence the spatial and temporal variability of the pool persistence.

As such, permanent pools not only retain surface water but also may provide a window into the behaviour of subsurface flow and groundwater processes in the catchment. As such, they have the potential to act as important indicators of broader hydrological conditions. Changes in pool persistence or water levels over time can reflect shifts in rainfall patterns, groundwater connectivity, or upstream water extraction or interception (e.g., water course extractions or dam interception). Monitoring these pools can therefore provide valuable insight into their sensitivity to changing climate and catchment conditions and may help detect early signs of stress, such as reduced connectivity with groundwater.

Hancock et al. (2014) studied interactions between groundwater and surface water systems in the Barossa PWRA and found that the groundwater and surface water systems can generally be classed as highly connected with a combination of 'gaining' and 'losing' stream conditions depending on the season and location. Understanding these dynamics is essential for informing environmental flow strategies and supporting the long-term resilience of both ecological systems and cultural assets in the Barossa catchment.

Flows in the Barossa catchment have become increasingly intermittent due to climate-driven changes in rainfall, including reductions in total rainfall and shifts in seasonality (Savadamuthu et al., 2023), combined with water interception by instream dams and weirs. Similarly, overall warmer conditions due to climate change may further exacerbate these impacts through increased evapotranspiration, which can increase interception losses from dams, reduce the frequency of fill-and-spill events, and ultimately limit downstream flows. Further, these processes have almost certainly contributed to reduced groundwater recharge, declining water quality, and deteriorating ecosystem health.

Collectively, these changes have reduced water availability and connectivity within the catchment with significant impacts on all users of water and leading to reduced permanent pools, degradation of fish populations and culturally significant sites. In response to these pressures, the Barossa Water Security Strategy (DEW,2022) identified the need for an environmental water plan as a key recommendation to improve watercourse health and cultural flows.

To improve understanding of changes in pool conditions, loggers were installed at 15 key locations across the Barossa catchment in September 2023. Instrumentation varied by site characteristics with some locations equipped with water level and temperature loggers and others fitted with multi-parameter loggers capable of measuring both water level and EC; the latter providing an indicative proxy to evaluate pool water quality. While monitoring is ongoing, this report presents data collected for a period of more than two years (805 days), from 24th September 2023 to 10th December 2025. In the context of historical flow patterns and water availability within the Barossa catchment, this monitoring program provides essential data to inform the development of a targeted Environmental Water Plan.

3 Methodology

3.1 Permanent pool monitoring sites

Key permanent pools were identified based on a review of aerial imagery and subsequent field investigations (Green et al., 2014). These pools were selected as representative examples of permanent pools in the region that have consistently persisted and maintained relatively stable water levels over time. Sites were also chosen to provide coverage across the main river reaches throughout the catchment.

In total, fourteen permanent pools were selected as monitoring sites based on specific site characteristics, as detailed in Table 3-1 and shown in Figure 3-2. An additional monitoring site (Site 15 Lower Stone Chimney) was established on a major tributary stream in a high precipitation area in the Flaxman Valley. Unlike the other sites, this location represents a stream section rather than a permanent pool and was included to improve spatial coverage in an area where no existing monitoring data were available to support other water management initiatives in the PWRA.

Table 3-1. Selected permanent pools monitoring locations

Main River Section	Site No.	Site Name	Logger Type	Site Characteristics	GW–SW Interactions [a]	Notes [b]
Tanunda Creek						
	1	Lower Upper Tanunda	WL [c]	Pool at the top of the cascade from the headwaters of Tanunda Creek. Located ~400 m upstream of the gauge at Bethany.	Gaining stream reach.	Logger stopped working Oct 2025. Logger placement type B. Survey not conducted.
	2	Mid Tanunda	WL + EC [d]	Permanent pool in the upper part of Tanunda Creek.	Gaining stream reach.	Full survey conducted. Logger placement type A.
Jacob Creek						
	3	Mid Upper Jacob	WL + EC	Located mid Pewsey Vale in a deep valley, downstream of most major tributaries.	Speculative gaining stream reach within a high-rainfall, fractured rock environment.	Full survey conducted. Logger placement type A.
	4	Upper Lower Jacob	WL + EC	Large permanent pool near the end of the Jacob Creek Gorge. Located ~300 m downstream of Jacob Creek at Kaiser Stuhl gauge	Gaining stream reach within a high-rainfall, fractured rock environment.	Survey not conducted. Logger placement type A.
Transition Zone						
	6	Transition Zone	WL	Located near end of Transition Zone. Logger installed to assess how often flows reach the end of the transition zone.	Gaining stream reach.	Second logger installed 30/05/2024 after first logger was lost. Logger placement type B. Survey not conducted

Main River Section	Site No.	Site Name	Logger Type	Site Characteristics	GW–SW Interactions [a]	Notes [b]
North Para River — Downstream of Weirs						
	7	Lower Flaxman	WL + EC	Last permanent water pool before the Transition Zone. Located ~200 m upstream of the gauge at Penrice.	Gaining stream reach. Flows heavily influenced by fill-and-spill processes of 4 large upstream weirs.	Survey not conducted. Logger placement type A.
	8	Lower Flaxman	WL	Located in lower third of the Flaxman Valley. Large, long pool in incised reach.	Gaining stream reach. Flows heavily influenced by fill-and-spill processes of 4 large upstream weirs.	Partial survey conducted. Logger placement type A.
	9	Mid Lower Flaxman	WL	Located approximately halfway down the lower Flaxman Valley. Pool reach located in relatively narrow valley.	Gaining stream reach. Flows heavily influenced by fill-and-spill processes of 4 large upstream weirs.	Full survey conducted. Logger placement type B.
	10	Mid Lower Flaxman	WL + EC	Located downstream of weirs; captures both spill events and potential releases from the weir system.	Gaining stream reach. Flows heavily influenced by fill-and-spill processes of 4 large upstream weirs.	Full survey conducted. Logger placement type A.
	11	Lower Mid Flaxman	WL	Logger installed in the most downstream of the large weirs. Monitored to determine spills from weir system.	Gaining stream reach. Flows heavily influenced by fill-and-spill processes of 4 large upstream weirs.	Partial survey conducted. Logger placement type A. Significant water extraction from weir pool — pool depth does not accurately reflect surrounding GW levels. Data available to only until May 2025, due to accessibility constraints.

Main River Section	Site No.	Site Name	Logger Type	Site Characteristics	GW–SW Interactions [a]	Notes [b]
North Para River — Upstream of Weirs						
	12	Mid Upper Flaxman	WL + EC	One of the most upstream permanent pools in the Flaxman Valley. Most likely to detect changes due to modified dam behaviour in the upper Flaxman Valley	Gaining stream reach. Identified as containing groundwater-dependent ecosystems on low water-holding capacity soils.	Partial survey conducted. Logger placement type A.
	13	Lower Upper Flaxman	WL	Located at the end of the Upper Flaxman Valley, in close proximity to the gorge at Mt McKenzie.	Gaining stream reach. Identified as containing groundwater-dependent ecosystems.	Partial survey conducted. Logger placement type B.
	14	Upper Mid Flaxman	WL	Last permanent pool before the confluence of the North Para River and Stone Chimney Creek.	Gaining stream reach. Identified as containing groundwater-dependent ecosystems.	Partial survey conducted. Logger placement type A.
	16	Mid Flaxman	WL	Last permanent pool before the large weirs. Smaller surface area provides more accurate flow indications than the weir pool itself.	Gaining stream reach	Partial survey conducted. Logger placement type A.

Main River Section	Site No.	Site Name	Logger Type	Site Characteristics	GW–SW Interactions [a]	Notes [b]
Stone Chimney Creek						
	15	Lower Stone Chimney	WL	No permanent pools present. Selected to capture cease-to-flow conditions and provide a record of flows from Stone Chimney Creek.	N/A	Partial survey conducted. Logger placement type B.

[a] From Hancock et al., 2014

[b] Logger placement configurations A and B are shown in Figure 3-1

[c] WL- Water level (depth) logger (Rugged TROLL 100), [d] WL + EC - multi-parameter logger, measures water level (depth) and Conductivity (Aqua TROLL 200)

The monitoring locations were surveyed (where possible) and instrumented with water level (WL) and multi-parameter (WL+EC) loggers. Table 3-1 summarises the logger configuration, site characteristics and relevant methodological notes, including logger placement, survey information and potential data limitations. Full cross-sectional and longitudinal surveys were conducted at Sites 2, 3, 9, and 10 with logger positions indicated in the corresponding figures in Appendix B. Cross section and longitudinal section of the monitoring pools.

Logger placement was aimed for the lowest practical point in each pool; however, accessibility constraints prevented placement at the absolute deepest point in some locations. Consequently, two logger placement scenarios occur across the monitoring sites (Figure 3-1).

1. At sites where the logger could not be placed at the deepest point (Figure 3-1 [A]), measurements represent water level relative to the logger position rather than the actual pool depth. For sites where a full cross-sectional or longitudinal survey was conducted, the vertical offset between the logger and the deepest point of the pool is known. In these cases (Site 2, 3, and 10) pool depth has been derived by applying this offset to the water level data from the loggers.
2. Where the logger was installed at the lowest point of the pool bed (Figure 3-1- [B]), the recorded water level measurements represent the actual pool depth.

Accordingly, data are presented as pool depth to ensure consistency. For unsurveyed or partially surveyed sites, pool depth is referenced to the logger position (pool depth = water level). In these cases, a recorded value of zero indicates that the logger is out of the water, not necessarily that the pool has completely dried. This is noted in Table 4-1 and explained as a footnote in the relevant pool depth variation figures.

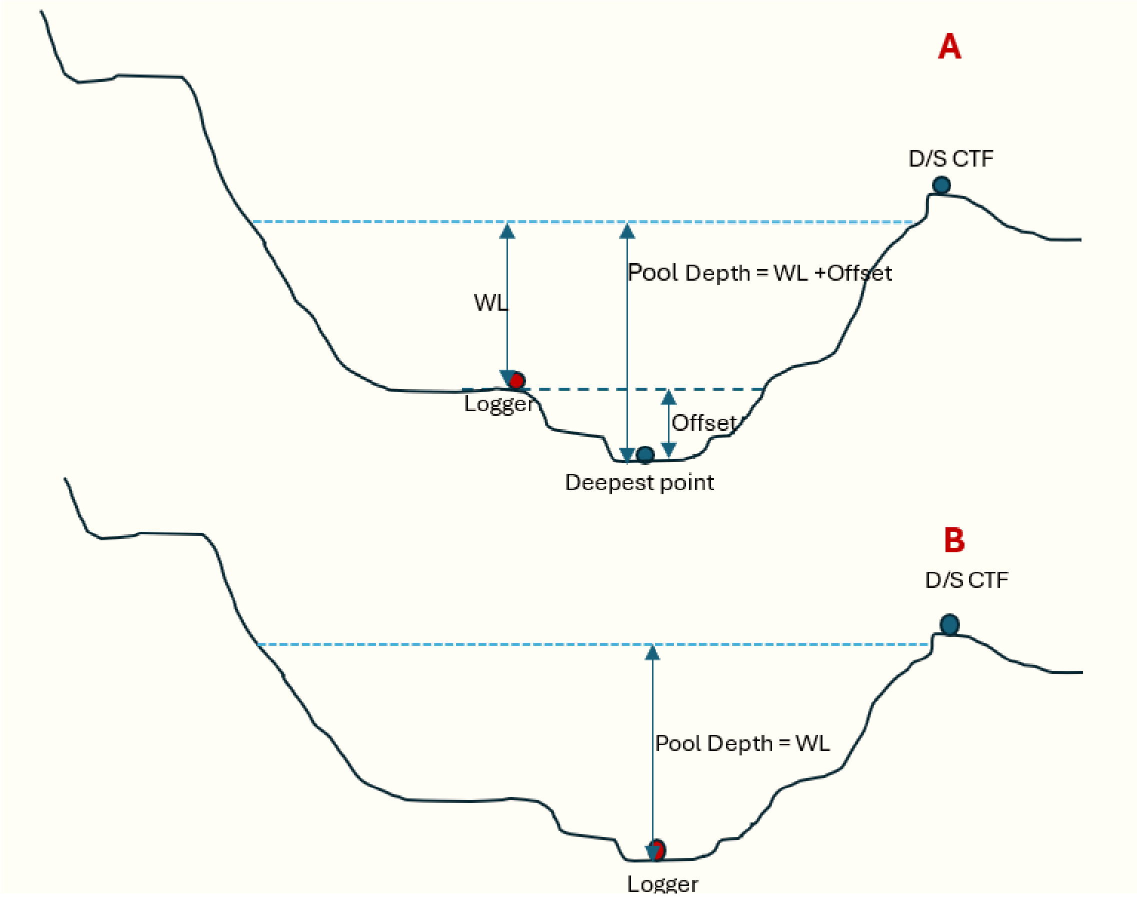

Figure 3-1. Sketch of logger placement
[A] Logger installed above the deepest point of the pool [B] Logger installed at the deepest point of the pool
Dashed light blue line indicates water level reference, The dark blue dashed line (in A) indicates the vertical offset between the logger position and the deepest point of the pool. logger (red), WL=Water level, D/S CTF=Downstream cease to flow.

Based on conceptual understanding derived from observations and the permanent pool framework presented by Bourke et al., (2023), pool depth dynamics across the monitoring network are suspected to be closely linked to groundwater connectivity and surface water inputs. After surface flow ceases, some pools remain fairly stable when supported by active groundwater inflows, while others experience drawdown due to temporary disconnection or fluctuations in groundwater levels driven by seasonal evapotranspiration, recharge variability, or other groundwater processes. Pools fed by springs or strongly connected to groundwater may show minimal reductions, as inflows can offset losses through evaporation.

Electrical conductivity responds to these hydrological dynamics in all pools. As water levels decline, whether from disconnection, partial drawdown, and/or evapotranspiration, EC typically increases due to the concentration of salts, along with other dissolved solids and nutrients. In pools that dry completely or where water levels drop below the logger, EC readings drop to zero when sensors are exposed to air, although soil or sludge adhering to the sensor may cause anomalous values. Conversely, in groundwater-connected pools, EC fluctuations are expected to be generally smaller and reflect any changes in inflows and evapo-concentration processes.

This report covers data from 24th September 2023 to 10th December 2025, hereafter referred to as the 'reporting period'. Monitoring is continuing beyond the timeframe covered in this report, as multi-year records are required to adequately capture natural hydrological variability and support robust interpretation of pool behaviour.

Variations in pool depth and EC, along with rainfall and streamflow data from nearby monitoring sites, are discussed in section 4. Results and observations. Photographs taken during site visits are presented in Appendix C. Photographs.

3.2 Streamflow and rainfall monitoring sites

Streamflow data and rainfall data are presented alongside the pool level and, where available, EC data to provide contextual information for interpreting pool behaviour at the permanent pool sites. Streamflow data from three nearby gauging stations (Table 3-2, Figure 3-2) are used to relate pool dynamics to catchment flow conditions. Stream reach classification based on surface water–groundwater interactions within the PWRA (Figure 3-3; Hancock et al., 2014) is used to support the interpretation of the observed pool dynamics throughout the monitoring period.

Rainfall data from the closest station to each pool site (Table 3-2, Figure 3-2) are used to understand temporal variation in pool conditions. Together, these datasets support the analysis of pool behaviour over time and across different hydrological conditions. The results from rainfall and streamflow assessment are provided alongside the pool level assessment in the Results and observations section.

Table 3-2. Streamflow and rainfall monitoring sites

Pool monitoring site	Relevant streamflow monitoring site	Closest BoM rainfall station
1 Lower Upper Tanunda	A5050535 – Tanunda Creek at Bethany	23318 – Tanunda
2 Mid Tanunda		
3 Mid upper Jacob	NA	23313 – Lyndoch
4 Upper Lower Jacob		
6 Transition Zone		23312 – Nuriootpa
7 Lower Flaxman	A5050517 – North Para River at Penrice	23300 – Angaston

<table>
<tr><td>8 Lower Flaxman</td><td rowspan="4"></td><td rowspan="4"></td></tr>
<tr><td>9 Mid Lower Flaxman</td></tr>
<tr><td>10 Mid Lower Flaxman</td></tr>
<tr><td>11 Lower Mid Flaxman</td></tr>
<tr><td>12 Mid upper Flaxman</td><td rowspan="3">A5050533 – North Para River at Mt McKenzie</td><td rowspan="5">23302 – Collingrove</td></tr>
<tr><td>13 Lower Upper Flaxman</td></tr>
<tr><td>14 Upper Mid Flaxman</td></tr>
<tr><td>15 Lower Stone Chimney</td><td>NA</td></tr>
<tr><td>16 Mid Flaxman</td><td>A5050517 – North Para River at Penrice</td></tr>
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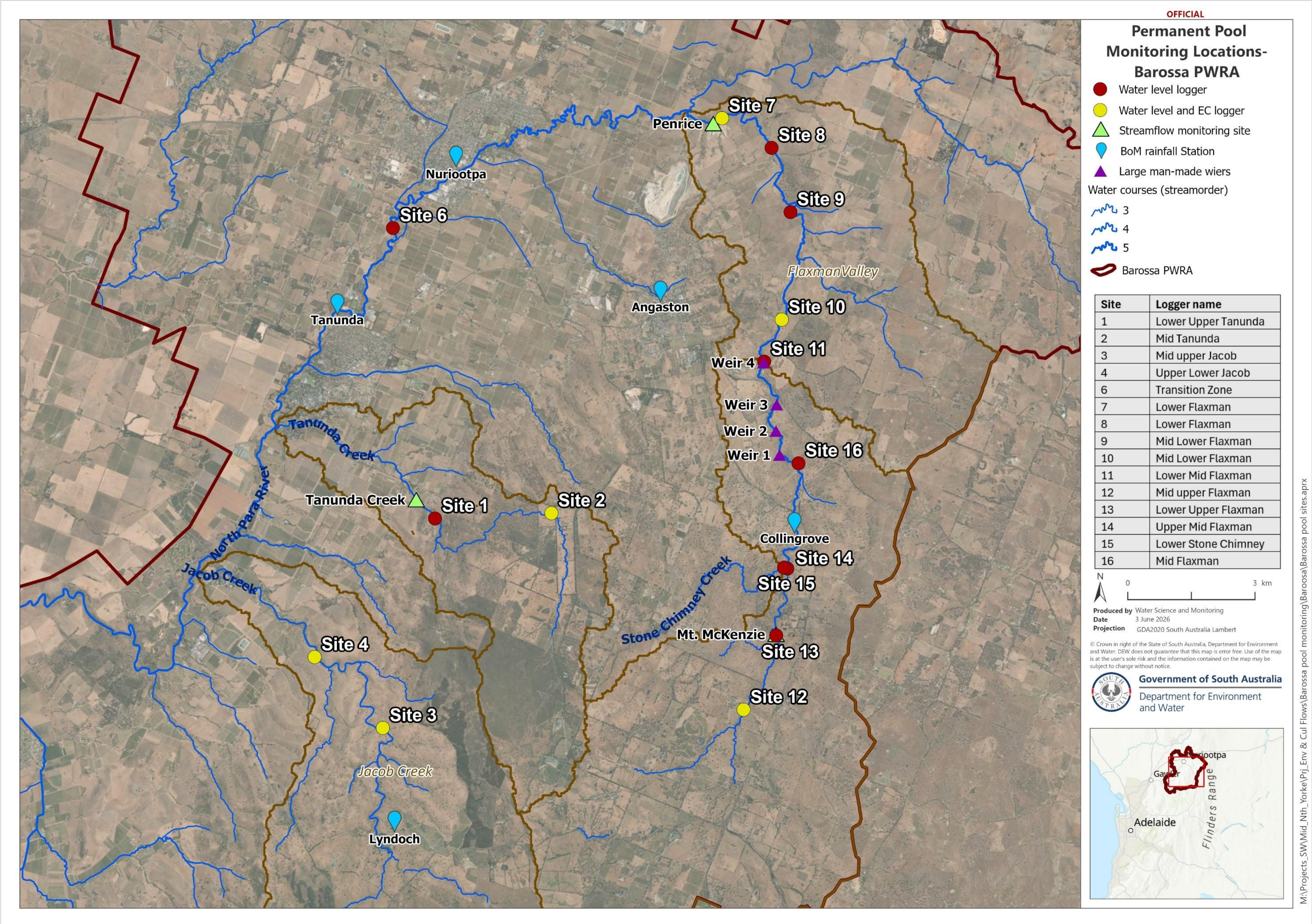


Figure 3-2. Locations of monitoring sites, streamflow gauges, and rainfall stations

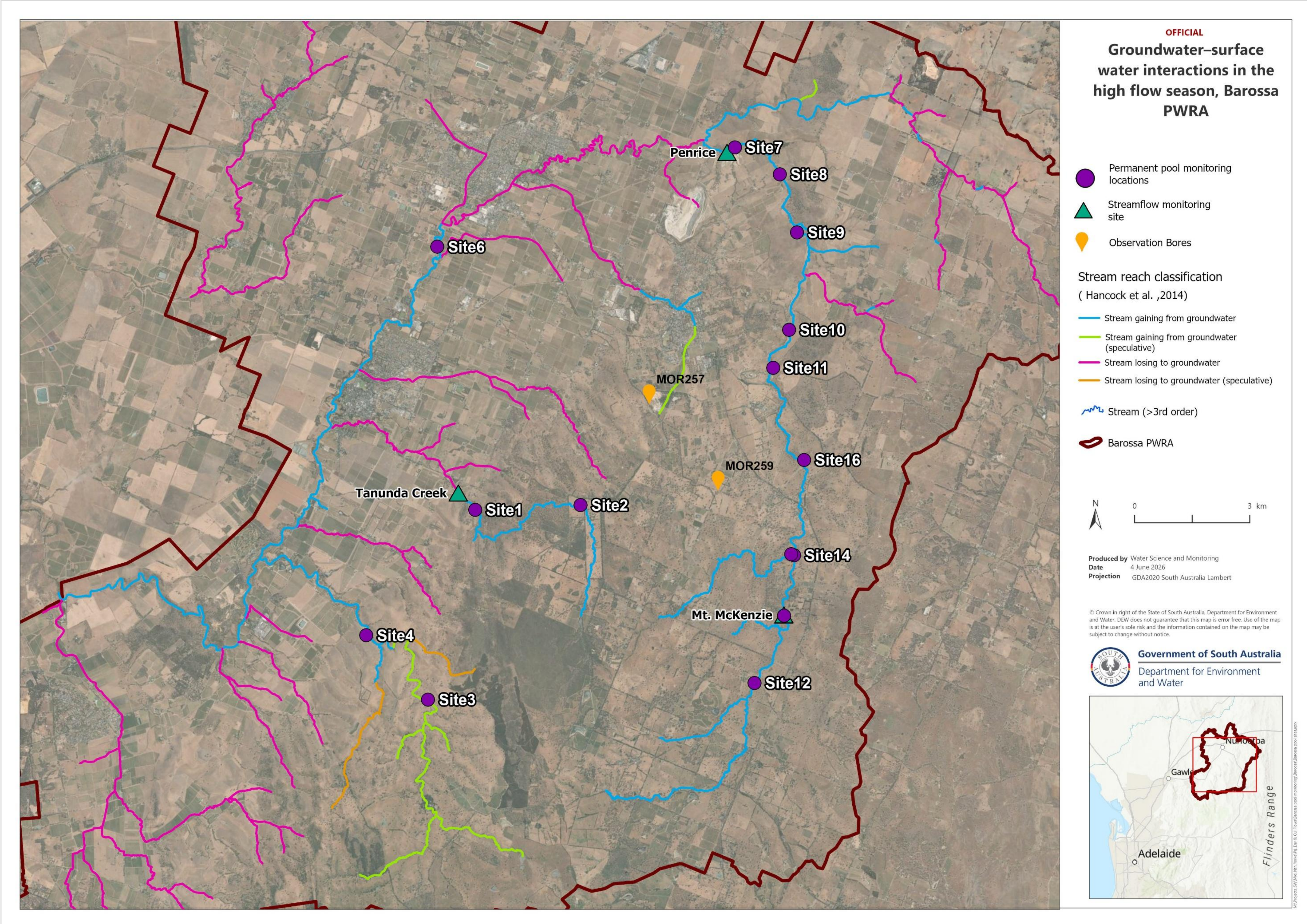


Figure 3-3. Groundwater – surface water interactions in Barossa PWRA (Hancock et al., 2014) and groundwater observation bores in Flaxman Valley

4 Results and observations

This section presents the results for the reporting period, and it is structured as follows: Section 4.1 Regional rainfall and streamflow context; Sections 4.2 to 4.4 present cross-site summaries of pool depth dynamics, flow status, and drawdown and refilling timing; and Section 4.5 presents detailed pool dynamics organised by main river reach. Collectively, these sections present an overview of system-wide behaviour and seasonal patterns observed during the reporting period.

The subsequent subsections present a detailed analysis of individual pools, organised by the main river sections within the study area, as introduced in Table 3-1. For each river section, pool depth dynamics are examined alongside available streamflow and rainfall data to provide hydrological context. This integrated approach supports interpretation of pool responses to seasonal rainfall patterns and broader catchment flow conditions.

Further to the analysis of water level dynamics, this section also summarises key water quality metrics. In particular, periods where electrical conductivity (EC) exceeds the ecologically significant threshold of 5,000 µS/cm are identified to provide insight into potential water quality stress during low-flow and non-flowing conditions. This is based on work in the Mount Lofty Ranges (DEW, unpub. data) where 5,000 µS/cm represents a threshold whereby shifts in the macroinvertebrate community structure are evident and, given the lack of site-specific data, it is used as a proxy for this analysis.

Together, these metrics establish baseline information on pool hydrological behaviour, connectivity, and persistence. The results support improved understanding of surface water groundwater interactions, ecological refuge value, and potential triggers under increasing climate variability.

4.1 Regional rainfall and streamflow context

The reporting period coincided with sustained dry conditions across the Barossa region. Annual rainfall totals from 2023 to 2025 were below the long-term average at all monitoring stations within the study area with 2024 representing the driest year since 1986 across the regional rainfall network (Figure 4-1). This period follows an extended sequence of below-average rainfall conditions from 2017 onwards, during which multiple years rank among the lowest on record (2018-2019) with only 2022 standing out as a notably above average year. This prolonged dry period is critical context, as the resilience of permanent pools prior to monitoring commencing in 2023 may already have been compromised. Savadamuthu et al. (2023) identified an 8% reduction in average rainfall across the Barossa Valley and an associated 32% reduction in river flows.

These rainfall deficits were reflected in markedly reduced streamflow across the catchment. Annual streamflow volumes from 2023 to 2025 were substantially below average at all monitoring stations (Figure 4-2). Conditions in 2024 were particularly severe with the Penrice and Mount McKenzie gauging stations recording near-zero annual flows. At Penrice, streamflow again remained close to zero throughout much of 2025. More broadly, streamflow across the catchment has been consistently below average since 2017 with 2022 again representing the only notably above-average year. This long-term reduction is most pronounced at the Penrice gauge where, effectively, no sustained flows were recorded for extended periods (2018–2021 and 2024–2025), highlighting a prolonged loss of flow connectivity in the lower North Para River.

The sustained rainfall deficits and exceptionally low streamflow during this period provide important hydrological context for interpreting pool drawdown, reduced GW and surface water connectivity, and increased frequency of non-flowing conditions observed across the monitored sites.

In particular, the emerging trends of weakened or intermittent groundwater connectivity at some monitored pools during the reporting period may reflect the cumulative effects of prolonged dried conditions rather than indicative of long-term hydrological behaviour.

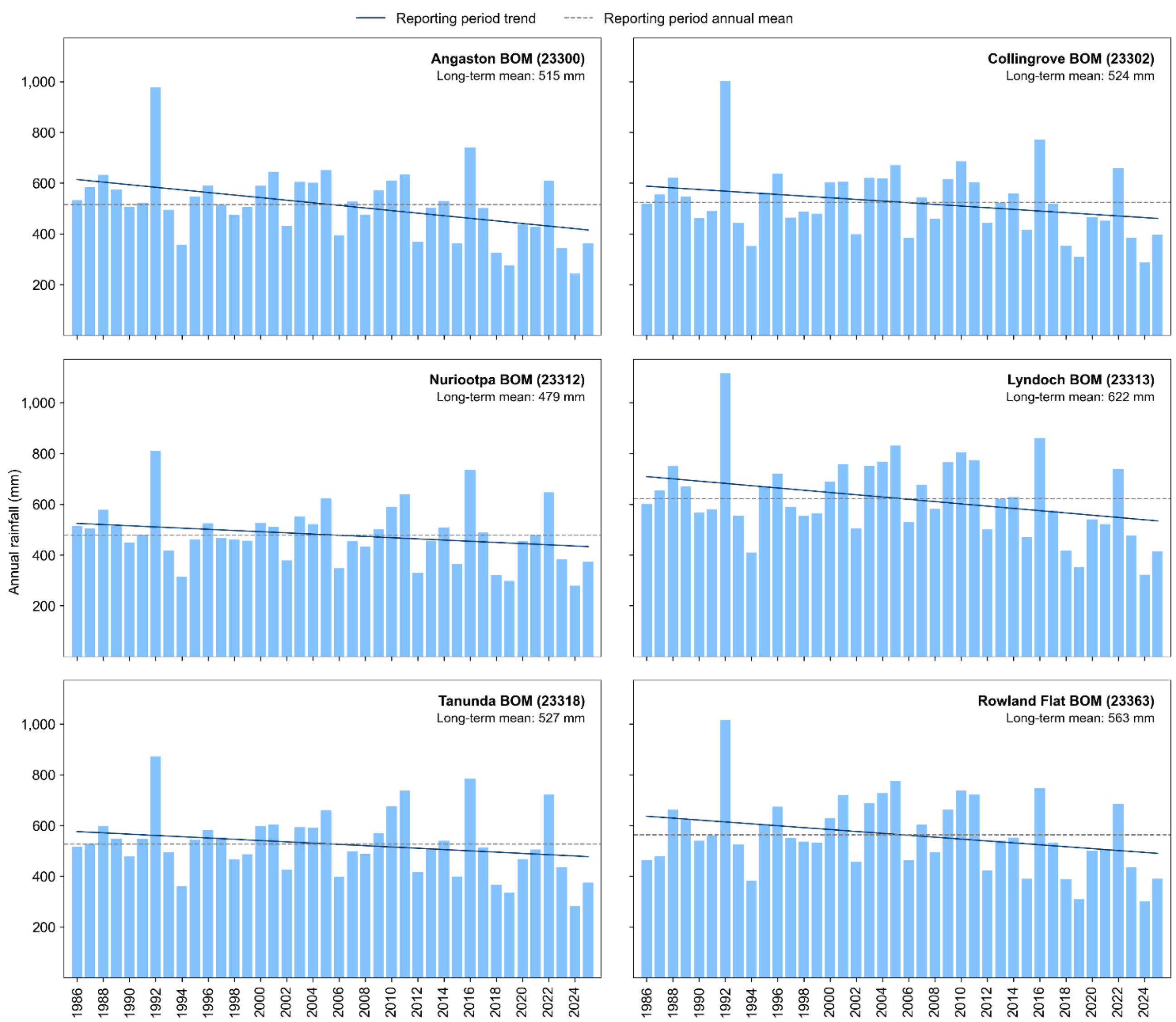


Figure 4-1. Annual rainfall time series (1986–2025) for six monitoring stations across the Barossa

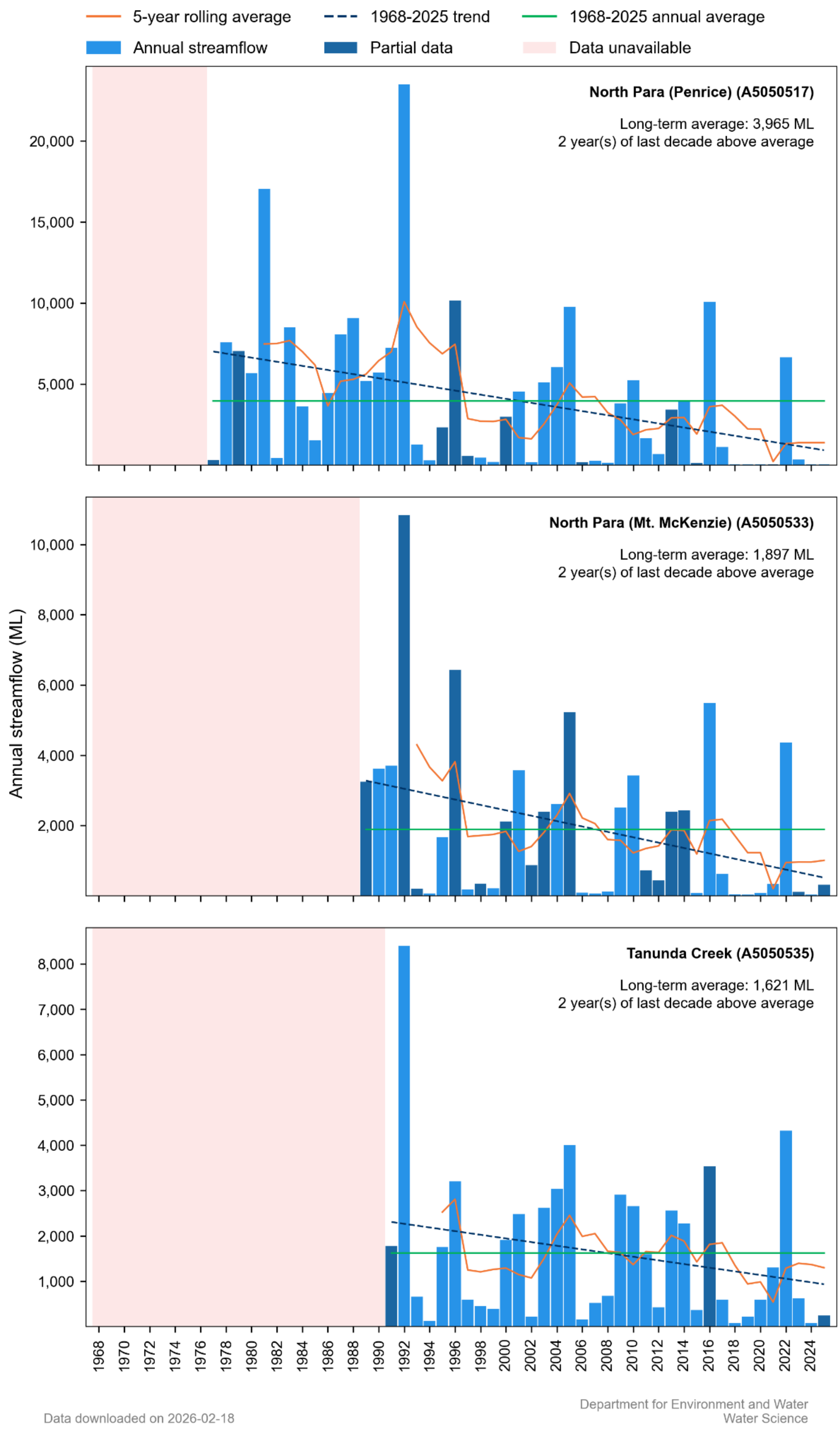


Figure 4-2. Annual streamflow time series for three monitoring stations across the Barossa

4.2 Pool dynamics summary

Table 4-1 summarises pool depth dynamics for the reporting period at the monitored permanent pools. For each site, the table lists the downstream cease-to-flow (CTF) water level, the observed minimum and maximum levels, the estimated flowing days, the flow classification and the recovery status. The CTF level is used to infer flow status. Pool depths above the CTF indicate the pool was likely flowing, while depths below suggest non-flowing conditions. Minimum depths for pools that retained water are reported as the lowest value recorded by the logger if it remained submerged, or as "NA" if water persisted below the logger location, as confirmed by field observations. For pools that dried up, the minimum depth is reported as 0 m based on field observations. Maximum depths reflect the highest water levels recorded in each year and across the reporting period. The comments column provides additional context for each site, including logger malfunctions, periods of drying, subsequent recovery following rainfall, and other relevant ecological or hydrological observations.

Table 4-1. Pool depth observations summary

Site	Site Name	Downstream Cease to Flow level (m)	Min Levels (m)	Max Levels (m)	Flowing Days (of 805) (%)	Flow Classification	Recovery Status	Notes
Tanunda Creek								
1	Lower Upper Tanunda	Survey not conducted	0.40	0.67	766 (100%)	Continuously flowing [a]	Maintained throughout	Logger stopped Oct 2025; 766 days is to that point
2	Mid Tanunda	0.65	0	1.27	638 (79%)	Intermittently flowing	Recovered to or above first-year levels	Dried completely Feb–Jun 2025; first observed drying in recent history
Jacobs Creek								
3	Mid Upper Jacob	0.65	0.50	1.17	759 (94%)	Intermittently flowing	Recovered to first-year levels	Minor drawdown (~0.4 m) in Nov 2024–Feb 2025 only; EC sensitive to first-flush events
4	Upper Lower Jacob	Survey not conducted	1.16	1.57	805 (100%)	Continuously flowing	Maintained throughout	Stable depth and EC throughout; EC below threshold at all times
Transition Zone								
6	Transition Zone	Survey not conducted	0.85	2.57	223 (40%)	Intermittently flowing [b]	Retained water; recovered to prior levels	No confirmed CTF threshold; likely intermittently flowing at ~1.4 m based on hydrograph patterns

Site	Site Name	Downstream Cease to Flow level (m)	Min Levels (m)	Max Levels (m)	Flowing Days (of 805) (%)	Flow Classification	Recovery Status	Notes
North Para River — Downstream of Weirs								
7	Lower Flaxman	Survey not conducted	NA	1.43	71(9%)	Intermittently flowing [c]	Partially recovered; did not return to first-year levels	Max recovery depth ~0.46 m; lower than minimum of first drawdown
8	Lower Flaxman	1.17	0	1.68	120 (15%)	Intermittently flowing	Did not recover; remained dry	Dried Dec 2024; brief water presence Aug–Sep 2025 only
9	Mid Lower Flaxman	1.56	0.38	1.63	0	Not flowing	Retained water; did not return to first-year levels	Critically low levels (~0.5 m) in 2025; very low water levels are a concern for future dry years
10	Mid Lower Flaxman	1.27	0	1.62	68 (8%)	Intermittently flowing	Did not recover; remained dry	Shortest flow duration in study. Dried Nov 2024; only brief ephemeral event Aug 2025
North Para River — Lower Weir Site								
11	Lower Mid Flaxman (Weir)	1.55	NA	1.47	0	Not flowing [d]	Did not recover; levels below initial monitoring level	Weir pool; not a natural permanent pool. No spill event recorded. Data only to May 2025
North Para River — Upstream of Weirs								
12	Mid Upper Flaxman	0.32	NA	1.63	599 (74%)	Intermittently flowing	Recovered to or above first-year levels	Dried temporarily early 2025; 2025 recovery peaks represent episodic

Site	Site Name	Downstream Cease to Flow level (m)	Min Levels (m)	Max Levels (m)	Flowing Days (of 805) (%)	Flow Classification	Recovery Status	Notes
								flows rather than sustained refilling
13	Lower Upper Flaxman	Survey not conducted	0.52	1.40	240 (30%)	Intermittently flowing [c]	Retained water; did not return to first-year levels	Most resilient pool in the upstream NP reach; limited 2025 recovery relative to first year
14	Upper Mid Flaxman	1.28	NA	1.38	15 (2%)	Intermittently flowing [e]	Retained water; did not return to first-year levels	CTF-derived flow duration likely an underestimate; see Section 4.5.4a
16	Mid Flaxman	1.73	NA	1.70	0	Not flowing	Retained water; did not return to first-year levels	Large, deep pool; maintained visual GW characteristics. Limited 2025 recovery suggests growing storage deficit
Stone Chimney Creek								
15	Lower Stone Chimney	0.40	0	0.55	128 (16%)	Intermittently flowing	Recovered; sustained flow in 2025 season, flow season started in early June for 2025	Tributary flow monitoring site; not a permanent pool. 2025 season significantly longer than 2024

Recovery status colour coding: Green = maintained or recovered to first-year levels; Amber = partially recovered or retained water but below first-year levels; Red = did not recover.

a: Logger stopped working Oct 2025; flowing days reflect period to that date only. b: No confirmed CTF threshold; flow status based on hydrograph interpretation. c: No confirmed CTF threshold; flow status based on gauging station nearby d: Weir pool; CTF not applicable; data to May 2025 only. e: CTF-derived flow duration an underestimate; see Section 4.5.4a. NP = North Para River; GW = groundwater; CTF = cease-to-flow.

4.3 Pool flow status relative to CTF during reporting period (CTF Threshold Analysis)

Table 4-2 summarises the flow analysis of the monitored pools based on CTF events during the reporting period. As described in Section 4.2, the CTF level for pools with a full or partial survey is used to infer flow status with pool depths above the CTF indicating likely connection to flowing water and depths below indicating non-flowing conditions.

For sites where a survey was not undertaken, and that are located in close proximity to a streamflow monitoring station (Site 7 and 13), the flow status and flowing days were inferred from the corresponding gauging stations at Penrice and Mount McKenzie, respectively. A similar approach was intended for Site 4 (Jacobs Creek); however, no suitable streamflow data were available for this site during the reporting period. This approach allows consistent comparison of pool flow dynamics across all monitored sites and links observed pool depths directly to hydrological flow conditions.

Sites 1, 4 and 6 do not have formally defined CTF thresholds. For these sites, indicative “likely flow” levels have been inferred based on visual interpretation of the water level time series with supporting discussion provided in the respective site-specific sections.

The data indicate that pools at Sites 1 (logger stopped working from end of October 2025) and 4 likely remained in flowing conditions throughout the reporting period, despite varying climatic conditions. Conversely, three pools (9, 11, 16) did not exceed their respective CTF thresholds at any time during for the reporting period, indicating that they remained in non-flowing conditions over this timeframe. These non-flowing sites are generally deeper pools compared to the others (refer Table 4-1 D/S Cease to Flow level).

Pools at Sites 7, 8, and 10 transitioned to non-flowing conditions several months after monitoring started and did not return to flowing conditions within the reporting period. It should be noted that these pools are located downstream of large weirs and Pools 8 and 10 dried completely by late 2024.

Pools at Sites 2, 3, and 12 transitioned to non-flowing conditions in early 2025; however, the duration of non-flowing conditions at Site 3 was relatively short (~2 months). Flowing conditions at the remaining sites resumed following winter rainfall in 2025.

At Site 6, no clear cease-to-flow threshold could be defined for the second installation; however, further analysis suggests the pool likely experiences episodic surface flows (see Section 4.5.3).

Table 4-2. Pool flow status summary

Site No	Site name	Flow status at start of monitoring (Sep 2023)	Transition to non-flowing conditions	Return to flowing conditions	Flow status at end of monitoring (Dec 2025)	Number of Flowing Days (depth > CTF)
Tanunda Creek						
1	Lower Upper Tanunda	Continuous flowing*				766
2	Mid Tanunda	Flowing	7/01/2025	9/06/2025	Flowing	638
Jacob Creek						
3	Mid Upper Jacob	Flowing	14/01/2025	3/03/2025	Flowing	759
4	Upper Lower Jacob	Continuously flowing*				805
Transition Zone						
6	Transition Zone	Intermittently flowing*				223
North Para River — Downstream of Weirs						
7	Lower Flaxman	Intermittently flowing*				71
8	Lower Flaxman	Flowing	26/01/2024	Not flowing		120
9	Mid Lower Flaxman	Not flowing				
10	Mid Lower Flaxman	Flowing	15/12/2023	Not flowing		68
North Para River — Lower Weir Site						
11	Lower Mid Flaxman	Not flowing				
North Para River — Upstream of Weirs						
12	Mid Upper Flaxman	Flowing	2/01/2025	26/07/2025	Flowing	599
13	Lower Upper Flaxman	Intermittently flowing*				240

Site No	Site name	Flow status at start of monitoring (Sep 2023)	Transition to non-flowing conditions	Return to flowing conditions	Flow status at end of monitoring (Dec 2025)	Number of Flowing Days (depth > CTF)
14	Upper Mid Flaxman	Flowing	10/10/2023	29/08/2025	Not flowing since 2/09/2025	15**
16	Mid Flaxman	Not flowing				
Stone Chimney Creek						
15	Lower Stone Chimney	Flowing	7/10/2023	11/07/2025	Not flowing since 9/11/2025	128

*No CTF threshold, classification is based on discussed assumptions

**This estimate may underrepresent the true occurrence of flow events at this site and should be reviewed as part of future analysis.

4.4 Pool drawdown and refilling dynamics

Table 4-3 summarises the approximate timing of pool drawdown and refilling for each monitored site during the reporting period. As the analysis incorporates two years of data, the timing of pool drawdown and refilling is presented separately for each year where applicable.

Sites 11 and 15 were excluded from this analysis. Site 11 is located at a weir and is impacted by direct pumping, so levels are not reflective of natural processes. Site 15 is specifically monitored to provide a record of flows from Stone Chimney Creek and is therefore not representative of pool depth dynamics.

The timings presented in the table are based on pool depth time series (presented in section 4.5 onwards) and represent approximate periods at which sustained drawdown or refilling trends became evident. These were derived from visual assessment of sustained declining or rising trends in the time series and are therefore indicative rather than exact. Although approximate, they clearly capture the seasonal pattern of pool drawdown and refilling.

Pools at Sites 1 and 4 maintained relatively stable pool depths throughout the monitoring period and both pools are strongly influenced by spring activity with notable springs within 100 m upstream of both pools. This suggests the pools fit the regional groundwater discharge framework presented by Bourke et al. (2023), but further investigation would be required to determine if groundwater discharge to Sites 1 and 4 is driven by geological barriers or topographic controls.

The timing of pool depth drawdown and refilling at other pools; however, indicates clear seasonal behaviour across most monitoring sites. In 2024–25 pool depths generally showed an earlier onset of drawdown compared to 2023–24. In 2024–25, most pool depths began declining in October (spring 2024), whereas in 2023–24 drawdown started in December–January (summer). Although both years were overall very dry years, the earlier drawdown in 2024–25 suggests increased vulnerability of the pools to extended dry conditions possibly through reduced recharge to groundwater and/or possible increased extraction from local groundwater extraction points.

Refilling in 2025 also occurred later compared to 2024 with most pools showing approximately a one-month delay relative to the previous year.

Consistent with observations presented in Section 4.2, pools located downstream of the weirs (Sites 7–10) indicate a concerning trend. Pool depth at Site 8 did not recover following drawdown in mid-October and Site 10 did not indicate a refilling trend after drawdown started in mid-December 2023. In addition, the remaining pools downstream of the weirs began receding earlier than other sites with drawdowns typically starting in October, compared to mid-November at other locations.

The permanent pool at Site 14 also indicates an earlier drying and later filling trend; however, this cannot be confirmed, as the logger is located higher than the deepest part of the pool (from May 2025 observations, Photo 23).

Although groundwater monitoring data are limited in the Flaxman Valley, groundwater level trends in monitoring wells MOR257 and MOR259 (Figure 3-3) (southeast of Angaston completed in the fractured rock aquifer) show a step change from around 2018 (Figure 4-3). There is an overall decline in groundwater levels year-on-year and the peak winter recovered level has lowered over time. This change is significant in MOR259 (located approximately 2 km southwest of Site 16), which has transitioned from seasonally artesian to persistently sub-artesian in recent years suggesting localised reductions of groundwater discharge via seeps or springs.

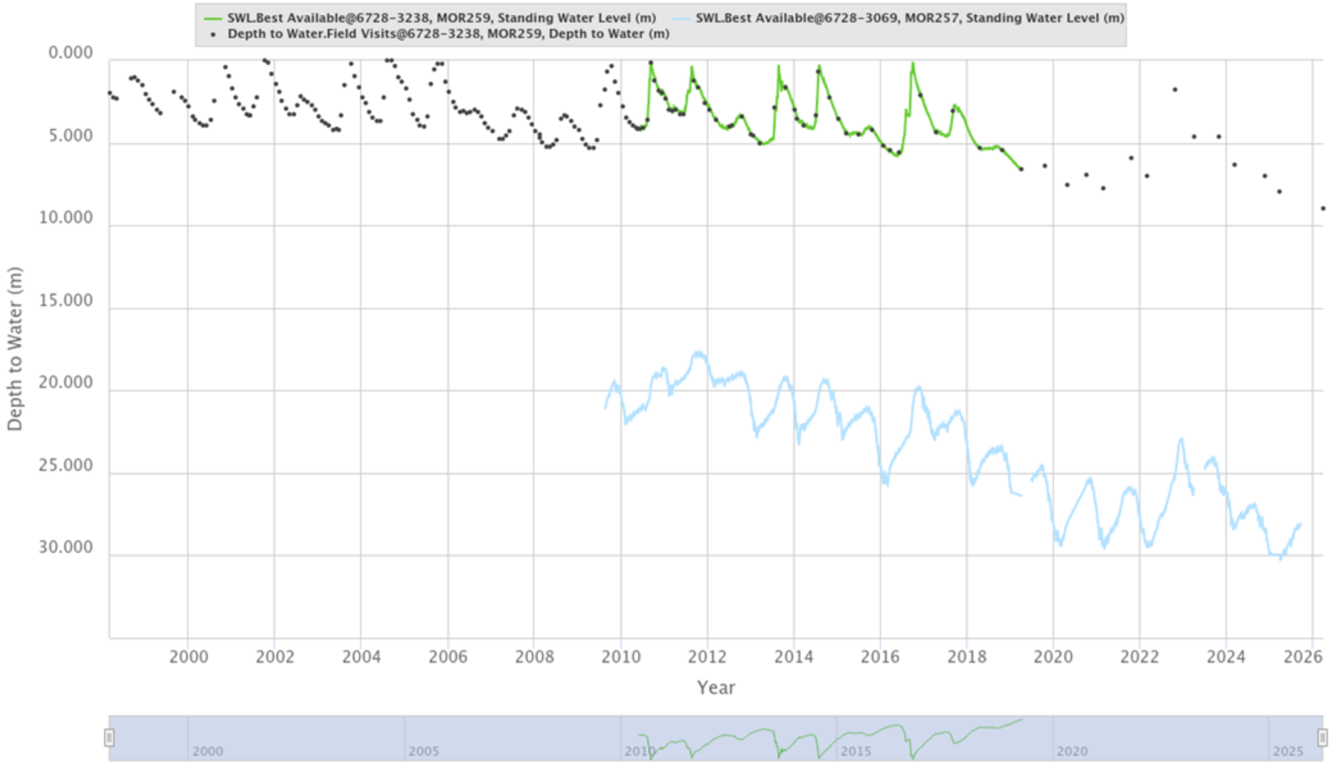


Figure 4-3. Groundwater depth from surface at monitoring bores in the Flaxman Valley.

Changes in the extent and timing of pool filling combined with decreasing groundwater levels suggest some pools upstream of the weirs may be in a transition between hydrological frameworks with potential decreases in groundwater discharge or increases in surface water losses due to lowering water table elevations.

Overall, pools located in the North Para River, particularly those downstream of the weirs, indicate greater susceptibility to seasonal drying. This pattern is likely influenced by reduced downstream flow connectivity associated with the upstream weir system which limits both flows in the river channel and potential recharge to the shallow groundwater.

Further investigation would be required to determine if the changes to groundwater and surface water conditions are persistent and how they may impact the health of each pool in the future.

Table 4-3. Time of pool drawdown and filling dynamics

Site No	Site name	2023-2024		2024-2025		Approx. date of drying (if applicable)	Comments
		Onset of drawdown	Onset of refilling	Onset of drawdown	Onset of refilling		
Tanunda Creek							
1	Lower Upper Tanunda	maintained a relatively stable pool depth					
2	Mid Tanunda	mid-February 2024	early May 2024	mid-November 2024	early June 2025	21/02/2025	Went completely dry and refilled after winter rainfalls
Jacobs Creek							
3	Mid Upper Jacob	maintained a relatively stable pool depth		mid-December 2024	mid-February 2025		
4	Upper Lower Jacob	maintained a relatively stable pool depth					
Transition Zone							
6	Transition Zone	Monitoring started in end of May		late December 2024	mid-April 2025		
North Para River — Downstream of Weirs							
7	Lower Flaxman	early January 2024	mid-June 2024	late October 2024	mid-July 2025		
8	Lower Flaxman	mid-December 2023	mid-June 2024	mid-October 2024	-	24/12/2024	Went completely dry in late December
9	Mid Lower Flaxman	mid-January 2024	early June 2024	late October 2024	early June 2025		

Site No	Site name	2023-2024		2024-2025		Approx. date of drying (if applicable)	Comments
		Onset of drawdown	Onset of refilling	Onset of drawdown	Onset of refilling		
10	Mid Lower Flaxman	mid-December 2023	Did not indicate a clear filling trend			15/11/2024	A 14-day rainfall-driven peak occurred in August 2025; as a short-term event, it was excluded from this analysis.
North Para River — Upstream of Weirs							
12	Mid Upper Flaxman	mid-December 2023	mid-June 2024	mid-October 2024	early July 2025		
13	Lower Upper Flaxman	maintained a relatively stable pool depth		early December 2024	late May 2025		
14	Upper Mid Flaxman	mid-December 2023	mid-June 2024	late August 2024	late July 2025		
16	Mid Flaxman	late January 2024	early May 2024	mid-November 2024	early June 2025		

4.5 Detailed pool dynamics by main river reach

This section presents detailed pool depth dynamics, water quality observations, and hydrological context for each of the four main river reaches monitored during the reporting period: Tanunda Creek; Jacob Creek; the Transition Zone; and the North Para River (Figure 3-2). The North Para River reach is further subdivided into three subsections — downstream of the weir system, the lower weir site, and upstream of the weirs — given the marked influence of the four large impoundments on flow dynamics and pool behaviour across this reach. For each reach, pool depth time series are examined alongside available streamflow data and rainfall data to support interpretation of pool responses to seasonal conditions and broader catchment hydrology. Both Figure 3-3, which illustrates gaining and losing conditions, and the stream reach classification described in Hancock et al. (2014) are used throughout to guide interpretation of groundwater–surface water interactions at individual sites.

Interpretations of groundwater–surface water connectivity are based on observed hydrological response patterns, as no direct groundwater level monitoring was undertaken at the sites; therefore, connectivity relationships are inferred from pool behaviour and available catchment data.

4.5.1 Tanunda Creek (Sites 1 and 2)

As described in Hancock et al. (2014) and indicated in Figure 3-3, the headwaters of Tanunda Creek are generally gaining streams where groundwater contributes to streamflow, while lower section tend to lose water to the groundwater system (losing stream). Sites 1 and 2 are located within the gaining reach of Tanunda Creek. Site 2 is located in the headwaters and Site 1 lies further downstream, near the Bethany gauge (A5050535; Figure 3-2). Notably, Bethany gauge is located in the losing section of the stream in contrast to the gaining conditions at Site 1 and 2.

Figure 4-4 shows the temporal variation in pool depth at Sites 1 and 2, alongside streamflow recorded at Bethany (A5050535) and rainfall recorded at Tanunda (23318). Consistent with the broader regional conditions described earlier, rainfall was very much below average and consequently streamflow at Bethany was extremely limited during parts of the reporting period. From February 2024 to mid-June 2024, and again from December 2024 to March 2025, the streamflow level was below the recordable range, indicating no measurable flow and reflecting extended dry conditions and limited runoff from this area.

Site 1 — Lower Upper Tanunda

Site 1 showed flowing conditions throughout the reporting period with pool levels remaining relatively stable (0.40–0.67 m; Figure 4-4; Table 4-2). Minor fluctuations corresponded with winter 2025 rainfall events, broadly mirroring peaks in the Bethany hydrograph. The limited variations in pool depth and the fairly stable levels during extended periods of low rainfall which does not seem to be affected by evaporation or seepage losses is consistent with the regional groundwater discharge framework of Bourke et al. (2023).

Site 2 — Mid Tanunda

Site 2 showed flowing conditions for roughly 80% (638 days out of 805) of the reporting period (Table 4-2). The site showed a first drawdown period from February to May 2024, followed by a refilling period in response to the 2024 winter rainfall season. However, the pool levels were only sustained from mid-July to mid-October 2024 before a second drawdown commenced approximately four months earlier than the previous year. During this second dry period (November 2024–April 2025), the pool dried up completely; the logger was out of the water in late February, and the pool was confirmed dry during the May 2025 field visit.

The steady decline in depth during dry periods suggests evaporative losses and potential reductions in the surrounding alluvial or unconfined aquifer groundwater levels. The complete drying in early 2025 indicates that groundwater support was insufficient under sustained dry conditions, suggesting temporary disconnection from the regional groundwater table. Recovery following winter rainfall implies that pool persistence during this period was increasingly dependent on rainfall recharge and streamflow contributions rather than continuous groundwater inflow. Further monitoring is required to confirm whether this represents an emerging trend.

The variation in pool depth and EC at Site 2 relative to rainfall is presented in Figure 6-1.

EC values at Site 2 during 2024 generally remained close to, but below, the ecologically significant threshold (5,000 µS/cm), consistent with groundwater influence maintaining relatively stable salinity levels. Concentrations slightly exceeded the threshold when the pool reached its lowest depth prior to refilling before declining again as winter rainfall increased pool volume. The lowest EC values were observed following significant rainfall events in late 2025, indicating dilution from rainfall recharge and/or runoff contributions.

In contrast, during the rapid drawdown period in early 2025, EC increased sharply to substantially higher levels as the pool approached complete drying. This pronounced spike likely reflects evaporative concentration under reduced groundwater inflow and suggests temporary disconnection from the groundwater table. Together, these patterns indicate that while groundwater input may sustain pool persistence during dry conditions, substantial rainfall is required to meaningfully freshen the pool beyond the salinity threshold range.

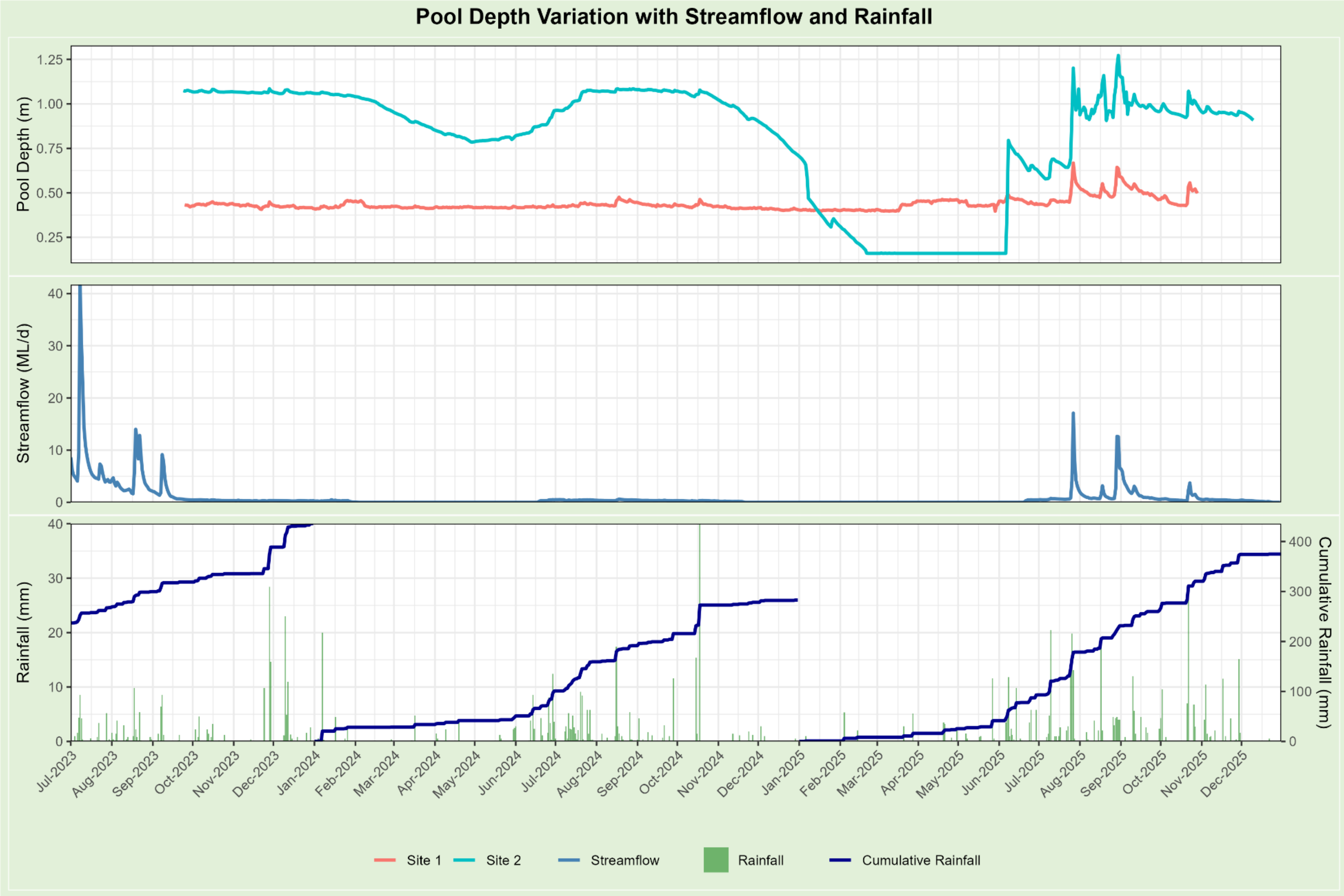


Figure 4-4. Variation in pool depth at Site 1 and 2 compared with streamflow at Bethany (A5050535) and rainfall at Tanunda (23318)

For Pool at Site 2, the minimum recorded pool depth was 0.16 m, which represents a dry pool condition

4.5.2 Jacob Creek (Sites 3 and 4)

As described by Hancock et al. (2014), the headwaters of Jacob Creek are situated within the high-rainfall, fractured rock environment of the Barossa Range. This area has been identified as supporting groundwater-dependent ecosystems, characterised by low water-holding capacity soils, extensive riparian waterlogging, and a series of pools likely sustained by groundwater inflow.

Sites 3 and 4 are located within the headwaters of Jacob Creek with Site 3 located upstream of Site 4. According to Hancock et al. (2014), these sites occur within a reach interpreted as a gaining stream; however, the gaining classification at Site 3 is speculative due to limited data availability resulting from restricted access within this part of the catchment.

Streamflow data for Jacob Creek were not available for the monitoring period. Rainfall records are used here to provide context, consistent with the broader regional conditions described in Section 4.1.

Both monitored pools maintained water levels throughout the dry months observed during the reporting period, consistent with groundwater-supported systems (Figure 4-5 and Figure 3-3). Detailed monitoring results for water level and EC at Sites 3 and 4 are presented in Figure 6-2 and Figure 6-3 respectively.

Site 3 — Mid upper Jacob

Site 3 shows flowing conditions for over 90% (759 days out of 805) of the reporting period (Table 4-2). Pool water levels remained relatively stable during the first dry season in early 2024, showing no noticeable drawdown. However, during the second dry period from November 2024 through late February 2025, the pool depth declined by approximately 0.4 m, before beginning to refill and recover to the 2023–2024 levels by April 2025. This drawdown, occurring after 2024 —the driest year on record since 1986— suggests that while the pool is likely supported by groundwater inflows, it may be susceptible to groundwater level declines during prolonged periods of below-average rainfall.

Interestingly, although water levels did not fluctuate substantially during the 2024 rainfall season, electrical conductivity (EC) spiked above the ecological threshold, reaching a maximum of ~9,000 µS/cm in June 2024 (Figure 6-2). During the following rainfall season, another spike in EC was observed after the first rainfall events in May 2025 with values remaining above the threshold for the remainder of the reporting period. This pattern suggests sediment inputs from initial catchment runoff ("first flush") events are significant contributors of salts in this reach.

Overall, the observed depth dynamics indicate a permanent pool with low seasonal variability that appears to have been supported by regional groundwater discharge historically, although the observed drawdown after 2024 indicates that the pool may be more sensitive to sustained rainfall deficits and subsequent lower groundwater levels. EC dynamics indicate this pool is sensitive to first-season runoff events that influence water quality.

Site 4 — Upper Lower Jacob

Site 4 showed flowing conditions throughout the reporting period (Table 4-2). Pool water level behaviour at Site 4 was broadly similar to that observed at Site 3, suggesting that both pools are influenced by similar groundwater-supported hydrological conditions. Pool depth remained relatively stable with rapid but short-lived responses to rainfall events, particularly during winter 2025.

Outside of rainfall-driven fluctuations, water levels showed limited seasonal variability and do not seem to be affected by evaporation or seepage losses. The limited variations in pool depth and the fairly stable levels during extended periods of low rainfall is consistent with the regional groundwater discharge framework of Bourke et al. (2023).

Electrical conductivity values remained consistently below the ecological threshold (5,000 μS/cm) throughout the monitoring period, indicating relatively stable water quality conditions at this site (Figure 6-3).

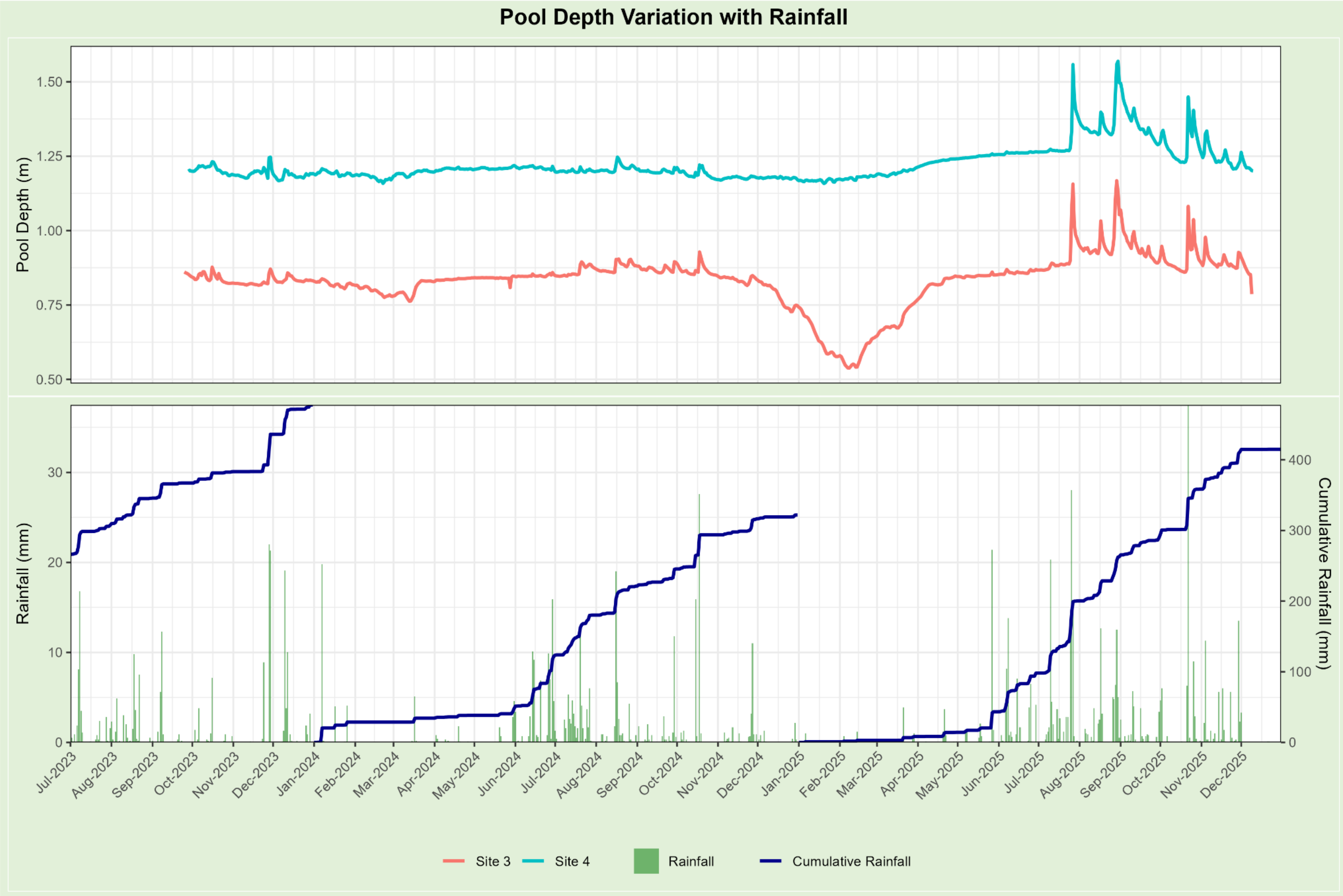


Figure 4-5. Variation in pool depth at Site 3 and 4 compared with rainfall at Lyndoch (23313)

4.5.3 Transition Zone (Site 6)

Site 6 — Transition Zone

The Transition Zone is located in the northern section of the Barossa Valley at the interface between the fractured rock environment of the Flaxman Valley and the sedimentary areas of the valley floor. This area is considered mostly losing zone as the watercourse traverses across the unconfined aquifer to the low point of the valley floor on the western side of the Barossa Valley (Hancock et al., 2014). The permanent pool at monitoring site 6 is one of the first permanent pools to appear at the very end of the Transition Zone where the depth to the groundwater table is shallow enough to allow for connection to the pool.

Figure 4-6 indicate the variation of pool depth with the rainfall from station 23312 (Nuriootpa). Rainfall records from station 23312 (Nuriootpa) are used to provide local context, consistent with the broader regional conditions described in Section 4.1**.** The dataset for this site begins 30 May 2024 due to the replacement of an initial logger that became inaccessible following movement of its mounting structure; see Table 3-1 for further detail.

No confirmed CTF threshold exists for the second logger installation at this site due to dense stands of reeds making identification of the CTF point impossible which limits the ability to formally classify flow status using the approach applied at other monitored pools. However, further analysis of the pool depth time series suggests that the pool likely experiences episodic surface flows. When pool levels approach approximately 1.4 m — the apparent maximum depth at this site — repeated sharp peaks with rapid recessions are observed in the data, closely resembling the hydrograph signature expected of surface flow events rather than groundwater-driven fluctuations. On this basis, the pool is considered likely intermittently flowing when levels approach ~1.4 m. The ~1.4 m level therefore represents a likely, functional threshold above which the pool receives and passes surface flows. Though this interpretation is indicative only, and should be confirmed through further investigation, including establishment of an appropriate CTF threshold for this site if possible (see Table 4-2).

Outside of the sharp peaks, sustained pool levels remained relatively stable following installation with a gradual drawdown starting around November 2024. This drawdown continued longer than that observed at Site 3 with recovery beginning in mid-April 2025 and pool depth returning to previously observed levels.

Overall, the pool depth dynamics at Site 6 indicate a groundwater-supported pool that also likely receives episodic surface flows when levels approach ~1.4 m. During lower water level periods, pool behaviour is consistent with a pool sustained by shallow groundwater. The drawdown during the extended dry period of 2024–25 suggests sensitivity to sustained rainfall deficits. The absence of a confirmed CTF threshold for this installation is a key data gap and determining an appropriate threshold is recommended to support more robust flow classification in future reporting.

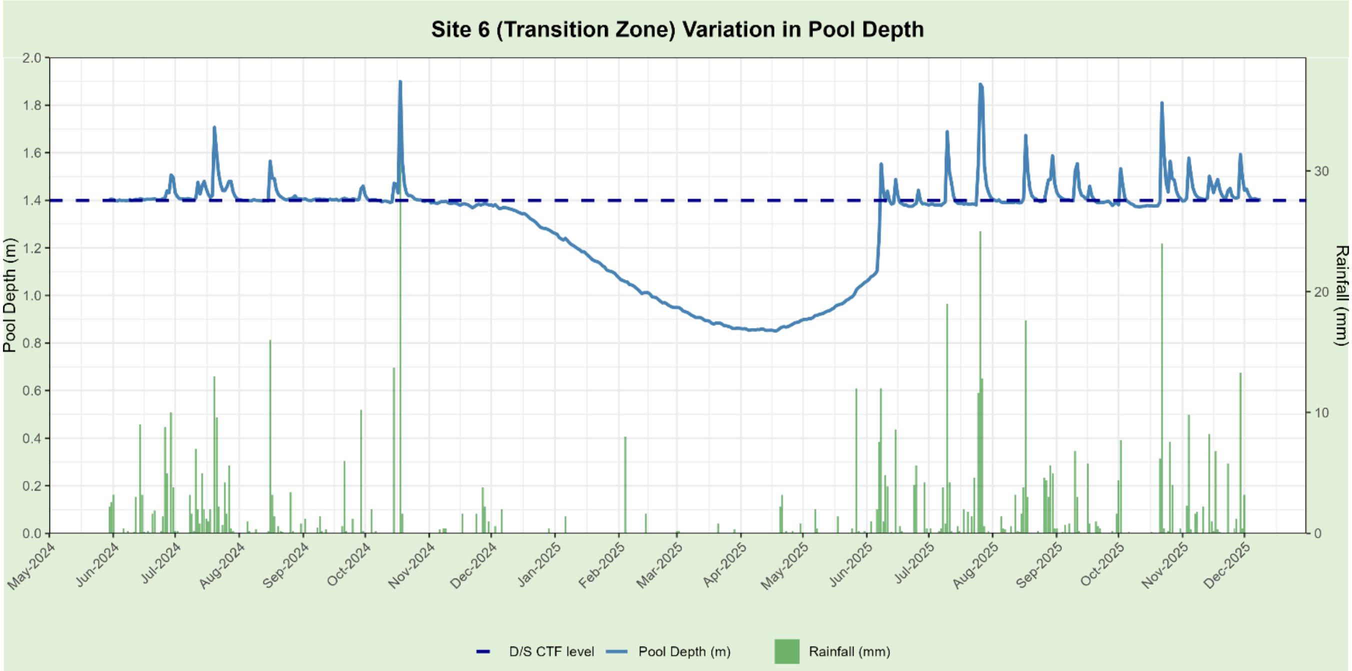


Figure 4-6. Site 6 – Variation in pool depth

D/S CTF level in based on empirical observation not a surveyed CTF level

4.5.4 North Para River (Sites 7-16)

The North Para River is the primary watercourse of the Barossa catchment and contains the majority of the permanent pool monitoring sites (Sites 7–16). Flows along this reach are strongly regulated by four large man-made weirs located in the mid-Flaxman Valley (Figure 3-2). The presence of these structures has a marked influence on pool behaviour, particularly downstream, by capturing runoff and limiting downstream connectivity and possibly local groundwater recharge during low-rainfall years. As described by Hancock et al. (2014), the Flaxman Valley contains predominantly gaining-type stream reaches associated with a fractured rock environment and the local and regional fractures and fold structures characteristic of the region.

Given these distinct hydrological influences, the North Para River reach is presented in three subsections:

- downstream of the weirs (Sites 7–10);
- the lower weir site (Site 11); and
- upstream of the weir system (Sites 12, 13, 14, 16).

This subdivision allows for clearer comparison of pool behaviour between areas influenced by the significant dam development and areas impacted by the compounding effect of dam development and the weirs. This supports a structured assessment of the weir system's cumulative influence on downstream pool dynamics and persistence.

4.5.4a North Para River — Downstream of Weirs (Sites 7–10)

This subsection focuses on Sites 7–10, which are located in the North Para River between the Penrice streamflow gauge (A5050517) and most downstream weir (Site 11; Figure 3-2). These sites represent the reach most directly affected by the cumulative reduction of downstream flows from upstream dam development and the weirs. Pool behaviour within this section therefore provides insight into the extent to which upstream regulation and development influence downstream pool dynamics and persistence, particularly during dry conditions.

The Penrice streamflow gauge (A5050517) is located approximately 400 m downstream of Site 7. To provide context for the monitoring period, streamflow is presented from July 2023 onwards (Figure 4-7). This extended record shows that the 2023 flow season was relatively short with continuous flow occurring only between May and November 2023. From December 2023 onwards, flows were limited to occasional small, short-duration events, lasting from one to several days with flows generally below 0.4 ML/day, while most records remain below the measurable range (i.e., no flow).

During 2024, flows across Barossa stations were very low, reflecting a notably dry year. Tanunda and Mt McKenzie gauges recorded periods of very low flow, while Penrice only registered a few briefs, sporadic events likely representing flow from a small tributary that flows between the gauging station and site 7 (i.e., these flows did not pass though the pool at site 7). In 2025, again, only short ephemeral flows were observed at Penrice (again likely from the small tributary rather than the main channel), despite sustained low seasonal flows being observed at the other two stations, highlighting the strong influence of the upstream weir system in stopping all low flows through the system.

Pool depth data from monitoring sites (Sites 7–10) showed a consistent drawdown trend beginning in late November 2024. Notably, none of the pools within this reach section recovered to the levels observed at the beginning of the monitoring period and Sites 8 and 10 dried completely as confirmed during the May 2024 field visit. Site 8 remained dry for the remainder of the reporting period, while Site 10 held water for a short period between mid-August to mid-September 2025 before drying again.

Consistent with the reduced streamflow at the Penrice gauge discussed above, the limited recovery of pool water levels and periods of complete drying suggest that flow retention by the upstream weirs has a significant impact on the downstream sections, not only by reducing or all completely capturing runoff, but also by potentially reducing recharge to the local groundwater systems that sustain some of the downstream permanent pools during prolonged dry periods.

As summarised in Table 4-2, the shortest flow durations across the study area were all observed at the sites located downstream of the weirs. Sites 7, 8 and 10 were flowing at the start of the monitoring period but did not record further flow events for the remainder of the study, while Site 9 did not exceed the cease-to-flow threshold at any time. Among the intermittently flowing sites, flow durations ranged from only 68 days at Site 10 and 71 days at Site 7.

Overall, these observations highlight the combined influence of prolonged dry conditions and upstream flow regulation on the persistence of downstream permanent pools within this section of the North Para River. The lack of flow at Penrice in 2025 and the full drying of some pools indicate that the weir system effectively impedes downstream connectivity, particularly following consecutive dry years when low weir levels produce a substantial deficit that must be filled before any spill can occur.

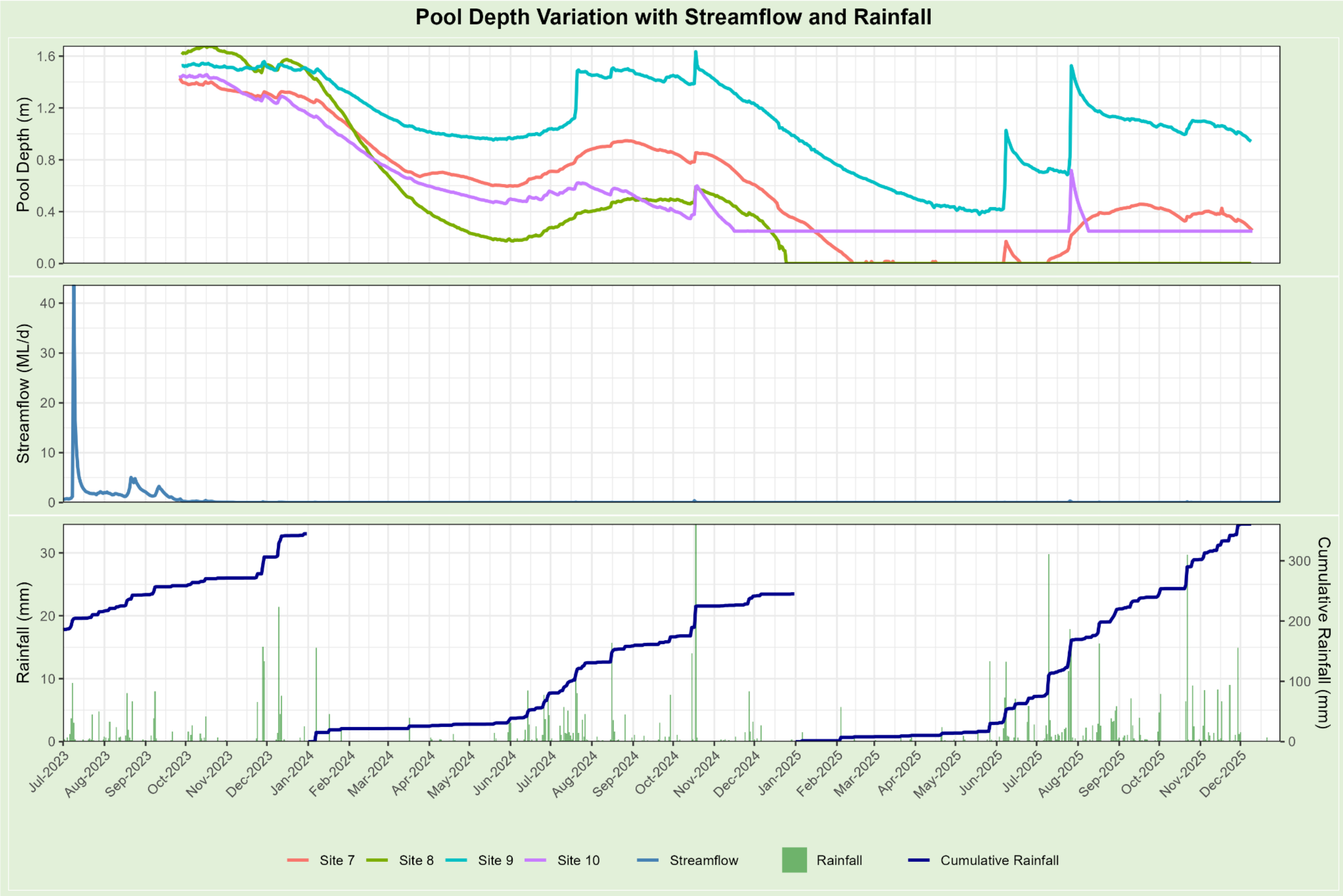


Figure 4-7. Variation in pool depth at Site 7 to 10, compared with streamflow at Penrice (A5050517) and rainfall at Angaston (23300)

Site 7- logger was out of water from mid-February 2025 to early June 2025, Site 8 – pool was dry from end of December, Site 10 – the minimum recorded pool depth is 0.25 m, which represents a dry pool condition and pool was dry from Mid November 2024

Site 7 — Lower Flaxman

Site 7 showed flowing conditions roughly 9% (71 days out of 805) of the reporting period (Table 4-2).

From September 2023 to January 2024, pool depth remained stable at the highest levels observed at this site (Figure 4-7). A gradual drawdown followed with levels reaching approximately 0.6 m by mid-2024 before the pool began replenishing in response to the 2024 rainfall season.

In November 2024, drawdown commenced following the extremely dry conditions with the pool showing a more rapid and sustained decline resulting in pool levels dropping below the logger location around mid-February 2025. The pool began replenishing in mid-June 2025 following winter rainfall, but pool levels barely reached a maximum depth of approximately 0.46 m, which was lower than the minimum observed during the dryest period of the first drawdown.

Electrical conductivity values ranged between approximately 4,000 and 5,000 µS/cm, remaining close to but typically below the ecological threshold during most of the reporting period (Figure 6-4). During periods of pool drawdown, EC levels increased and reached the 5,000 µS/cm ecological threshold, exceeding it as the pool approached drying conditions. This pattern suggests that water quality at this site is sensitive to prolonged dry periods with declining water levels leading to concentration of dissolved solids.

Overall, the observed depth dynamics indicate that this pool exhibits greater seasonal variability and sensitivity to prolonged dry periods compared with other monitored sites. <u>The very limited recovery following winter rainfall suggests that the pool is highly sensitive to below-average rainfall years</u>. These patterns are likely influenced by the reduction in downstream flows and local groundwater recharge associated with the upstream weir system. EC dynamics further indicate that water quality deteriorates as pool levels decline, highlighting the susceptibility of this site to prolonged dry conditions.

Site 8 — Lower Flaxman

Site 8 shows flowing conditions roughly 15% (120 days out of 805) of the reporting period (Table 4-2).

Pool depth declined rapidly from approximately 1.54 m in September 2023 to around 0.2 m by June 2024 and showed the steepest rate of drawdown observed among the sites in this section (Figure 4-7). This site is located beneath a bridge where the stream channel is relatively wide and incised and the pool itself is less well-defined within the channel compared with other sites. These geomorphological characteristics likely increase the surface area of exposed water and potential seepage pathways which may contribute to faster water losses through evaporation and seepage which could explain the more rapid decline in pool depth.

The timing of the first drawdown and first recovery periods match those discussed for site 7 with refilling levels increasing only to approximately 0.6 m in 2024 while remaining substantially below the levels observed at the start of monitoring. The second drawdown began around mid-October 2024, after which the pool continued to decline and dried completely around December 2024, remaining dry for the rest of the reporting period.

Overall, the observed pool depth dynamics indicate limited water retention capacity and a potential for greater water losses through seepage and evaporation <u>with the complete drying of the pool suggesting disconnection from groundwater during extended dry periods</u>. The limited recovery following winter rainfall further <u>indicates that this pool is highly sensitive to prolonged below-average rainfall conditions</u>.

Site 9 — Mid Lower Flaxman

Levels at Site 9 remained below the CTF threshold for the entire reporting period, indicating that no surface flows are assumed to have occurred at this site.

Pool depth declined gradually from January to May 2024, followed by a steady recovery over the 2024 winter months with the pool reaching similar levels to those observed at the beginning of monitoring (Figure 4-7). Unlike other sites in this section, the magnitude of the initial drawdown was relatively small with water levels dropping by only ~0.5 m, compared with declines of over 1 m observed at Sites 7 and 8. After the exceptionally dry conditions observed in 2024, the pool experienced a larger drawdown of approximately 1 m, reaching lows just below 0.5 m. Despite this, the pool remained filled throughout, unlike Sites 7, 8, and 10 which partially or fully dried.

Replenishment began in mid-June 2025 following winter rainfall. Remarkably, this site peaked to levels approaching the maximum observed at the start of monitoring, although sustained water levels during this refill period only reached the lows observed during the first drawdown (~1 m).

The depth dynamics of Site 9 indicate a permanent pool with low to moderate seasonal variability that is <u>strongly connected to shallow groundwater, supporting water retention even under prolonged dry periods</u>. However, <u>while this site appears to be more resilient than other pools in this section, the very low water levels observed following the 2024 dry period (approximately 0.5 m) raise concerns regarding its role as a viable aquatic biota refuge, particularly as it was the only pool downstream of weirs in the North Para River to retain water during the reporting period.</u> Additionally, the sustained rate of pool water level drawdown observed during that period suggests that continued below-average rainfall conditions could lead to further depletion of the remaining pool storage and potentially result in complete drying, indicating increasing vulnerability under prolonged dry conditions.

Site 10 — Mid Lower Flaxman

Site 10 showed flowing conditions for less than 10% (68 days out of 805) of the reporting period (Table 4-2), the shortest flowing period recorded for the entire study area.

Pool depth declined gradually from approximately 1.4 m in September 2023 and became completely dry around mid-November 2024 (Figure 4-7). Winter rainfall in 2024 led to only a minor and short-lived increase in water level (~0.5 to 0.6 m), after which levels declined again, reaching complete dry by mid-November. A brief water level increase was observed in late July–early August 2025 but water levels rapidly receded, reflecting a response more characteristic of an ephemeral flow event rather than sustained pool refilling.

This site shares a similar geomorphology as site 8, located within a relatively wide stream section, although less incised stream banks, the pool is similarly not very well defined within the channel. However, unlike site 8, the initial drawdown at site 10 was less steep, suggesting that subsurface processes or limited groundwater connection may be influencing the rate of decline.

EC data for this site are limited due to the prolonged dry period and indicate greater variability compared with other sites (Figure 6-5). EC rose above the ecological threshold (5,000 µS/cm) during the first drawdown period reaching levels up to ~8,000 µS/cm, reflecting the sensitivity of this pool to prolonged low-water conditions.

Overall, the depth dynamics indicate a pool that is highly sensitive to prolonged dry conditions with minimal groundwater support under below-average rainfall years. Being located directly downstream of the upstream weirs, most flows generated upstream are captured and retained by these structures during low rainfall years, exacerbating the drying conditions observed at this site both by limiting surface water inputs and minimising the recharge to the alluvial channel. The full drying and extremely limited recovery <u>suggest a weak connection to shallow groundwater and a high vulnerability to sustained rainfall deficits</u>.

4.5.4b North Para River – Lower Weir Site (Site 11)

Site 11 — Lower Mid Flaxman

As the most downstream of the four large man-made weirs along the North Para River (Figure 3-2), Site 11 is located in the lower-mid Flaxman Valley. This site is primarily monitored to assess the combined effects of the upstream weir system on flow and water storage in the sites downstream. The pool at this site provides insight into weir spill events and downstream water availability, though it is not a reliable indicator of local groundwater conditions due to its function as a storage and extraction point.

Inflows to this weir are likely influenced by the upstream weir system which functions almost as a continuous impoundment due to the close spacing of the four weirs (distances between unconnected weirs range from ~300 m to ~1,000 m). Consequently, the intermediate pools have limited upstream catchment contributing to flow. The weir upstream of Site 11 sits on a spring, maintaining a near-constant trickle; however, during prolonged dry periods, this flow is insufficient to reach the downstream weir (Site 11).

Pool levels declined gradually from January 2024, dropping below the logger location by March 2024. A partial recovery occurred from July to October 2024, before levels began declining again, reaching below the recordable range by early January 2025. Logger data for 2025 covers only the period to May 2025 due to site accessibility constraints during the December field visit.

Information, provided by the local landholder, indicates that water levels at this site did not recover, remaining below the levels observed during the beginning of the monitoring in 2023.

Overall, the observed depth dynamics indicate that Site 11 did not spill during the reporting period. Extended periods below the recordable range and limited recovery demonstrate that inflows from the upstream spring and weir system were insufficient to sustain water levels during dry periods. This underscores the strong dependence of this site on spill events from the upstream weirs and its vulnerability to extended dry conditions in the Flaxman Valley.

Importantly, the declining levels following dry years exacerbate this effect, as the system must first recover from a larger deficit before the weir can spill. These dynamics highlight the cumulative impediment of flow past the weir system, which strongly impacts downstream pools, particularly during prolonged dry spells.

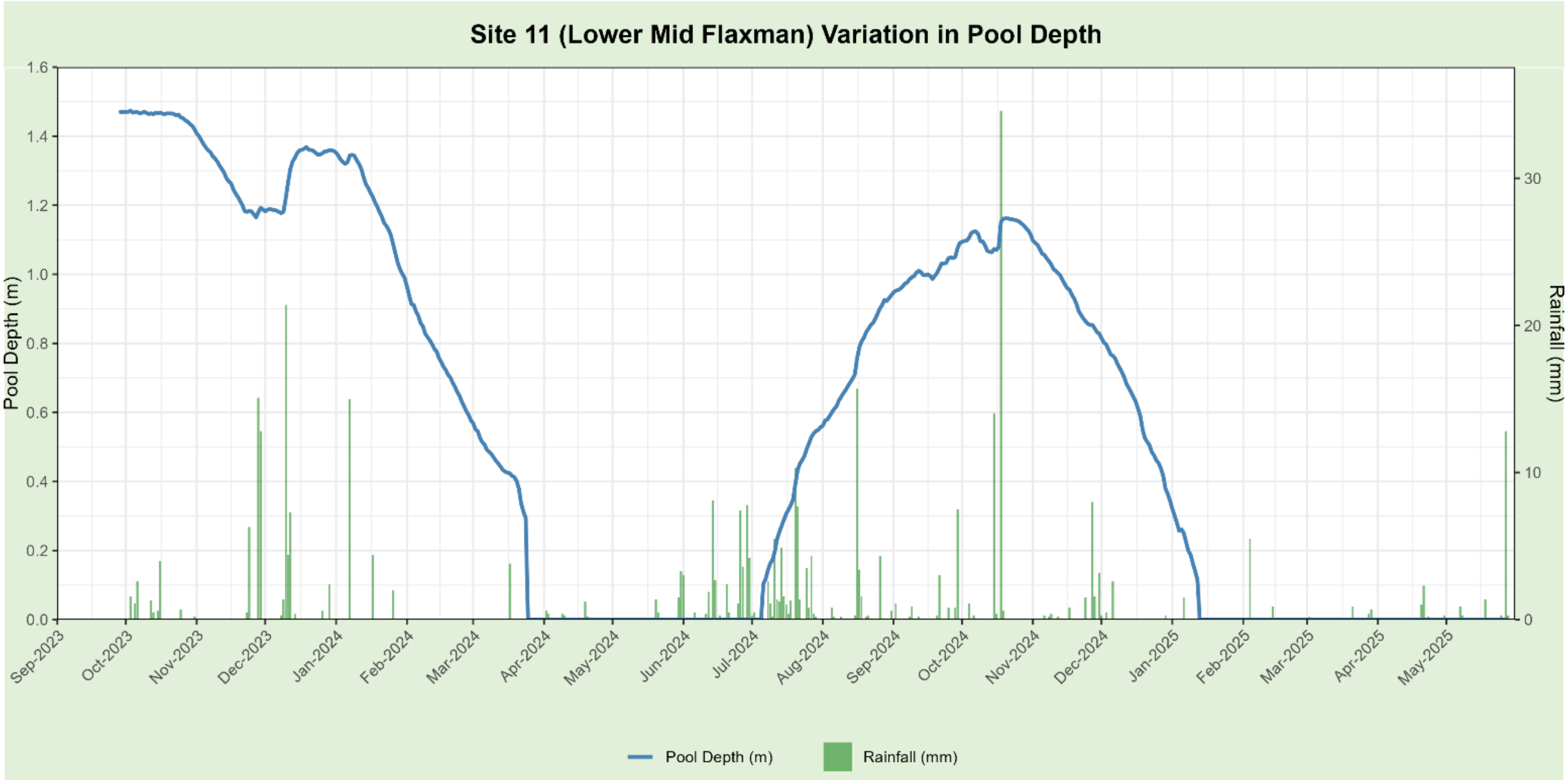


Figure 4-8. Site 11 – Variation in pool depth

Logger was out of water (from end of March to early July and Mid Jan to end of May). Logger data was not downloaded in December 2025

4.5.4c North Para River-Upstream Weirs (Sites 12, 13, 14 ,16)

The headwaters of the Flaxman Valley (mid and upper sub catchments) have been identified as containing groundwater-dependent ecosystems on low water holding capacity soils, associated with a series of ponds likely sustained by groundwater inflow (Hancock et al., 2014). Unlike the downstream reach, these sites are not influenced by weir regulation and; therefore, provide insight into pool behaviour under less impacted hydrological conditions.

The Mount McKenzie streamflow gauge (A5050533) is located within this section of the river and provides context for flow conditions during the monitoring period (Figure 4-9). Sites 12 and 13 are located upstream of the gauge with the gauge situated less than 100 m downstream of Site 13. Site 12 represents the most upstream monitoring location in the North Para River and is considered part of the catchment headwaters. Sites 14 and 16 are located downstream of the Mount McKenzie gauge with Site 14 situated just downstream of the confluence with Stone Chimney Creek, a major tributary of the North Para River. Site 16 is the most downstream monitoring location within this subsection and lies directly upstream of the first weir in the North Para River weir system.

Figure 4-9 shows the variation in pool depth at these four permanent pools compared with streamflow recorded at Mount McKenzie and rainfall recorded at Collingrove (23302). From February 2024 to mid-June 2024, and again from December 2024 to March 2025, the streamflow level was below the recordable range, indicating no measurable flow. Flows during the intervening months were also extremely low with a total annual flow of roughly 5 ML recorded in 2024 compared with a long-term average of approximately 1,900 ML (1987–2025), highlighting the exceptionally dry conditions experienced across the catchment during the reporting period.

Pool depth dynamics across this section generally reflected these prolonged low-flow conditions. Most monitored pools exhibited a progressive drying trend during the extended dry periods with water levels declining in response to the exceptionally under average rainfall. The pool at Site 13 was the only location that retained water throughout the reporting period, suggesting a strong connection to local groundwater. At Sites 12 and 14, water levels declined to the point where the loggers were temporarily out of the water, and field observations during the May 2025 visit confirmed that both pools were close to drying (Photo 21and Photo 23). Following winter rainfall in 2025, all permanent pools in the upper Flaxman Valley showed recovery with water levels exceeding those observed during the first monitoring year at most sites with the exception of Site 16 where levels remained below those observed in the previous years.

Limited groundwater monitoring data in the Flaxman Valley show a step change from around 2018 (Figure 4-3) with an overall decline in groundwater levels year-on-year and lowering of the peak winter recovered level over time. Conditions in monitoring well, MOR259 (Figure 4-3) suggesting groundwater discharge via seeps or springs may be decreasing upstream of the weirs.

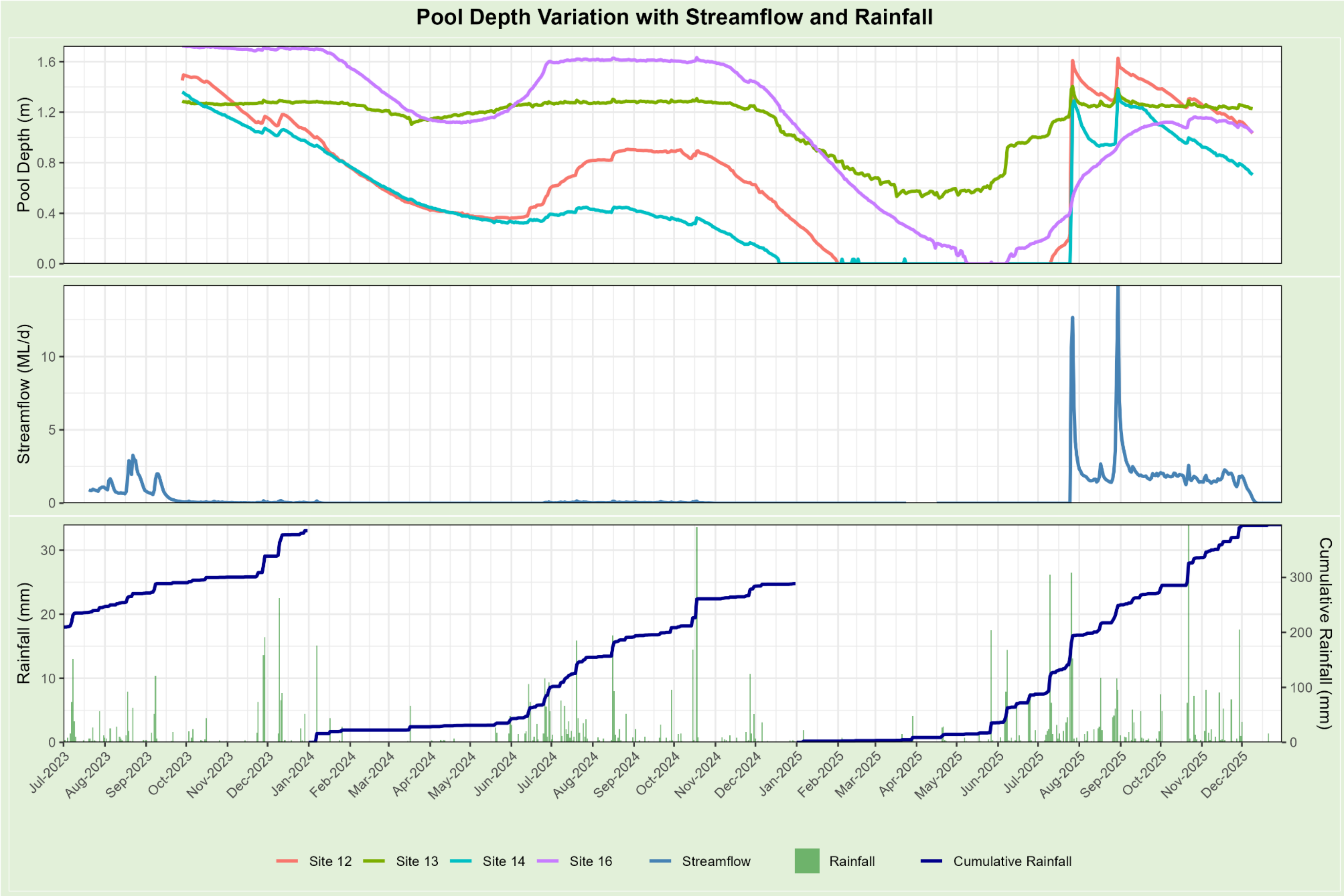


Figure 4-9. Variation in pool depth at Site 12, 13, 14, and 16 compared with streamflow at Mt. Mckenzie (A5050533) and rainfall at Collingrove (23302)

Site 12 - logger was out of water from early February until early July , Site 14- logger was out of water from mid December 2024) to end of July, Site 16 - logger was out of water from mid-May to mid-June.

Site 12 — Mid upper Flaxman

Site 12 showed flowing conditions for approximately 75% (599 days out of 805) of the reporting period (Table 4-2). Pool water levels exhibited substantial variability during the monitoring period, ranging from approximately 1.5 m at the start of monitoring to nearly dry conditions when the logger became exposed in early February 2025. A drawdown began shortly after logger installation in late 2023 with pool depth declining from around 1.5 m to less than 0.5 m before beginning to recover around June 2024 following winter rainfall. Recovery during 2024 was partial with pool levels reaching just under 1 m before a second drawdown began around October 2024, eventually leading to the logger becoming exposed by early February 2025. Pool levels began to recover again following winter rainfall in 2025 with several short-lived peaks exceeding the initial installation depth of approximately 1.5 m. However, these peaks appear to represent brief flow events passing through the channel rather than sustained pool refilling with water levels rising and receding rapidly rather than stabilising as typically observed in permanent pools in this reach.

Electrical conductivity (EC) dynamics broadly followed the pool depth trends (Figure 6-6). EC values exceeded the ecological threshold during the first drawdown period in mid-January 2024, peaking as pool levels approached their lowest levels. Although EC declined once the pool began to refill around July 2024, values generally remained above the ecological threshold, often exceeding 6,000 µS/cm while pool depths remained below approximately 1m. EC values again peaked during the second drawdown period as the pool approached dry conditions prior to the logger becoming exposed in February 2025. Following winter flows in 2025, EC levels declined and remained below the ecological threshold for the remainder of the reporting period.

Overall, the observed depth dynamics indicate that this pool exhibits high seasonal variability and appears to have a weaker and more intermittent connection to shallow groundwater than other pools within the study area. The rapid drawdown during extended dry periods, combined with prolonged periods of elevated EC, suggests that groundwater inflow to the pool may have declined during the exceptionally dry conditions experienced in 2024. Field observations during May 2025, when the pool appeared stagnant and discoloured (Photo 21), further support the interpretation that the pool became disconnected from shallow groundwater during this period. These observations contrast with landholder accounts indicating that this pool typically exhibits much smaller water level fluctuations, suggesting that the variability observed during the monitoring period reflects the unusually dry conditions experienced across the catchment.

Site 13 — Lower Upper Flaxman

Site 13 showed flowing conditions for approximately 30% (240 days out of 805) of the reporting period (Table 4-2). The number of flowing days is an estimation based on the flowing period of the nearby gauge (Mt. Mckenzie (A5050533)).

Pool water levels remained relatively stable from the beginning of monitoring through most of the 2024 rainfall season, generally hovering around approximately 1.3 m with only minor fluctuations. A small decline of roughly 0.3 m was observed around mid-March 2024; however, pool levels quickly stabilised again and remained relatively constant through the remainder of the 2024 rainfall season. Following the exceptionally dry conditions experienced during 2024, pool levels began to gradually decline from around December 2024, reaching minimum levels of approximately 0.5–0.6 m by May 2025. Despite this decline, the pool retained water throughout the entire monitoring period. Pool levels began to recover from early June 2025 following winter rainfall, gradually increasing and returning to levels similar to those observed during the first monitoring year, around 1.3 m.

Overall, the observed depth dynamics indicate that this pool maintains a persistent connection to the regional groundwater system, allowing it to retain water even during prolonged periods of low rainfall and limited surface flow. Although a gradual drawdown occurred during the extended dry period between late 2024 and early 2025, the pool maintained a substantial water depth and recovered steadily following winter rainfall. Compared with other monitored pools in the Flaxman Valley, Site 13 therefore appears to represent one of the more groundwater-connected and resilient pools within the upper catchment.

Site 14 — Upper Mid Flaxman

Site 14 showed flowing conditions for only 15 days of the reporting period based on the cease-to-flow (CTF) threshold analysis (Table 4-2). However, as noted below, this estimate may underrepresent the true occurrence of flow events at this site and should be reviewed as part of future analysis. Pool water levels exhibited a very similar pattern to those observed at Site 12 during the first year of monitoring with both sites showing nearly identical drawdown and recovery timing. From the beginning of monitoring in 2023, pool depth declined steadily from approximately 1.4 m to around 0.3 m by June 2024, before showing a modest recovery following winter rainfall. However, recovery during 2024 was considerably weaker than at Site 12 with water levels increasing only to approximately 0.5 m. Due to this limited recovery, the pool began declining again earlier than at Site 12 with drawdown starting around mid-August 2024 and the logger becoming exposed by mid-December 2024.

Recovery during 2025 began slightly later than at Site 12, around late July following winter rainfall. Similar to Site 12, the resulting water level responses appeared to represent short-lived runoff events rather than sustained pool refilling with rapid increases in depth followed by quick recessions resembling streamflow hydrographs. Given the strong similarity in pool responses between Sites 12 and 14, particularly during the 2025 rainfall season, the very limited number of flowing days estimated from the CTF analysis may warrant further verification.

Field observations during low rainfall conditions indicated that water within the pool was stagnant and discoloured (Photo 23), consistent with conditions observed at Site 12 and suggesting disconnection from shallow groundwater during extended dry periods.

Overall, the observed depth dynamics indicate that this pool exhibits high seasonal variability and limited groundwater connectivity during prolonged dry conditions. The close correspondence between the water level patterns at Sites 12 and 14 suggests that both pools are strongly influenced by broader catchment-scale hydrological conditions rather than sustained local groundwater inputs. The discrepancy between observed water level responses and the CTF-derived flow duration highlights a potential limitation in the current flow classification for this site and should be reviewed as part of future analysis.

Site 16 — Mid Flaxman

Site 16 did not exceed the cease-to-flow (CTF) threshold during the monitoring period, indicating no recorded flowing conditions (Table 4-2). This site is situated directly upstream of the first weir in the Flaxman Valley weir system. The pool at this site is relatively large, deep, and incised within the channel, which may explain why no surface flow was detected despite changes in water level during the monitoring period.

Pool depth at the start of monitoring was approximately 1.7 m and remained relatively stable until mid-January 2024 after which levels began to decline gradually, reaching around 1.2 m before beginning to recover following winter rainfall in mid-2024. However, this recovery remained below the maximum levels observed at the start of monitoring.

A second drawdown began earlier in the following season, around mid-November 2024, and persisted for a longer period than during the previous year. This extended decline resulted in water levels dropping below the logger location around mid-May 2025, although field observations confirmed that a substantial volume of water remained within the pool (Photo 26), reflecting the large size and depth of this pool. Pool levels began to recover again following winter rainfall in mid-June 2025; however, the maximum levels observed during 2025 only reached approximately 1.16 m, barely reaching the minimum levels recorded during the 2024 drawdown period. This limited recovery indicates that the pool entered the 2025 season with a substantial storage deficit following the exceptionally dry conditions of 2024.

Despite the significant decline in recorded water levels, field observations indicated that the pool maintained characteristics consistent with groundwater connectivity with water colour and clarity suggesting continued groundwater influence even during periods of lower water level.

Overall, the observed depth dynamics indicate that Site 16 responds to seasonal rainfall patterns while maintaining groundwater connectivity. However, the substantial and prolonged drawdown observed following the exceptionally dry conditions in 2024, combined with the limited recovery in 2025, suggests that even large groundwater-influenced pools in the upper Flaxman Valley remain sensitive to extended rainfall deficits. The large size of this pool likely contributes to its persistence, allowing it to retain water even when levels fall below the logger location.

4.5.5 Stone Chimney Creek

Site 15 — Lower Stone Chimney

Site 15 showed flowing conditions for approximately 16% (128 days out of 805) of the reporting period (Table 4-2). This site is located at the outlet of the Stone Chimney Creek sub-catchment, a major tributary to the North Para River, and —unlike the other monitoring sites— represents a stream section rather than a permanent pool. This site was selected to capture cease-to-flow conditions and provide a record of flow contributions from this tributary.

Water levels at the beginning of the reporting period were sustained until mid-November 2023 before declining as seasonal conditions became drier (Figure 4-10). During the 2024 rainfall season, water presence at the site was relatively short-lived, occurring only between late August and mid-October. In contrast, the 2025 rainfall season produced a much longer period of sustained water presence with flows beginning in early June and persisting for the remainder of the reporting period with water still present during the final field visit in December 2025.

Overall, the observed water level dynamics indicate that Stone Chimney Creek behaves as a highly responsive seasonal tributary system, where flow conditions are primarily driven by surface runoff from rainfall events rather than sustained groundwater inflows. Given that Site 14 is located just downstream of the confluence between the North Para River and Stone Chimney Creek, flows from this tributary may intermittently contribute to water level responses observed at that site during rainfall events.

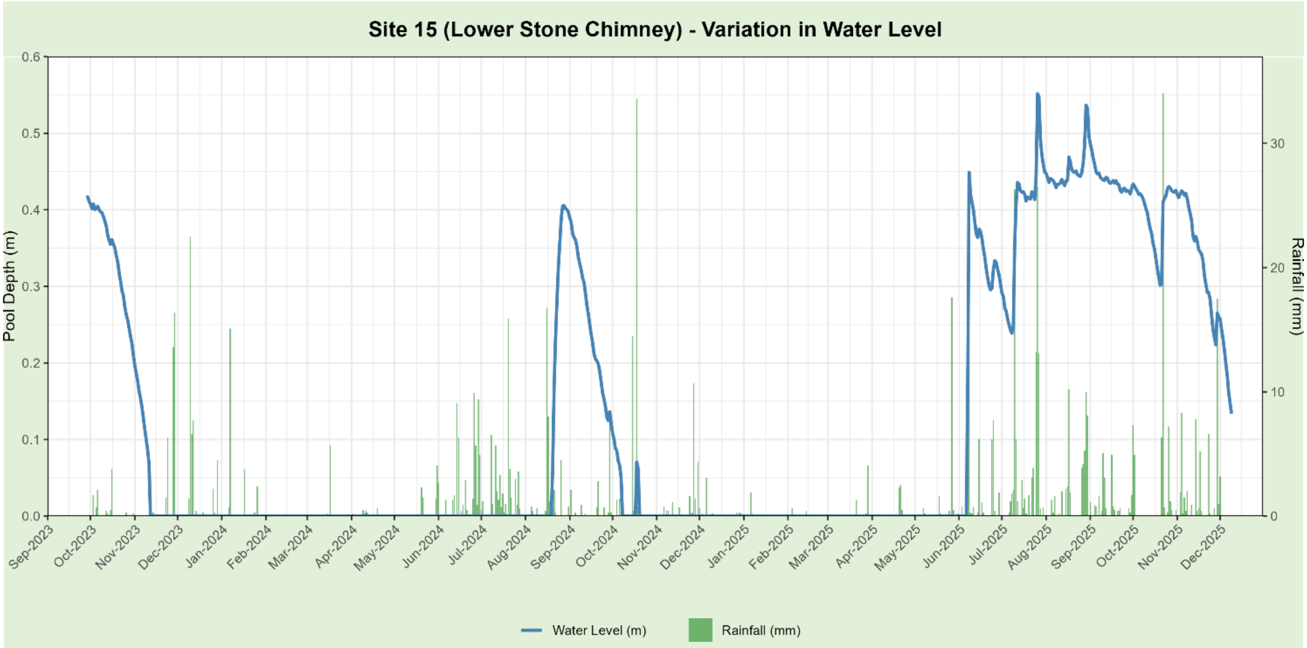


Figure 4-10. Site15 – Variation in water level

No flows occurred between mid-November 2023 and mid-August 2024, and between mid-October 2024 and early June 2025.

5 Summary

5.1 Monitoring Context and Hydrological Setting

Fifteen monitoring sites across the Barossa catchment were instrumented with water level and multi-parameter loggers between during September 2023, providing more than two years of continuous pool depth and water quality data. The reporting period (805 days) coincided with an extended period of dry conditions across the region with annual rainfall totals below the long-term average at all monitoring stations in each year of the study. The year 2024 was particularly severe, representing the driest year since 1986 across the region. These conditions were reflected in markedly reduced streamflow with the Penrice and Mount McKenzie gauging stations recording near-zero annual flows in 2024, and Penrice remaining close to zero for much of 2025.

Therefore, this monitoring period provides an important stress test of pool resilience under consecutive dry years, capturing pool conditions that approach — and in some cases exceed — the lower bounds of historically observed variability. Notably, the pool water levels observed during 2024 have been identified as potential trigger points to inform adaptive management measures as part of the revision of the Water Allocation Plan for the Barossa Prescribed Water Resources Area. The data collected establish a baseline understanding of pool hydrological behaviour, groundwater connectivity, and water quality dynamics that can directly inform the development of a targeted Environmental Water Plan for the Barossa PWRA.

However, it is important to emphasise that the findings presented in this report are preliminary. With only two years of monitoring data, observations can be indicative only and should be interpreted with appropriate caution. A sustained, long-term monitoring effort is required to more robustly characterise permanent pool dynamics, capture the full range of interannual hydrological variability, and improve understanding of the surface water, groundwater, and geomorphological processes governing pool behaviour under varying climatic conditions.

5.2 Overall Pool Behaviour and Resilience

Pools exhibited clear seasonal patterns with drawdown during spring–summer and recovery following winter rainfall. However, in 2024–25, drawdown commenced earlier (October) and recovery was delayed relative to 2023–24, reflecting both later seasonal rainfall and carry-over groundwater deficits from the exceptionally dry 2024 year.

Notably, at most sites, pool recovery began prior to the onset of significant winter rainfall. While this could suggest an influence of shallow groundwater processes, the mechanisms driving this early response remain uncertain. A pressure-related response linked to seasonal atmospheric changes is one possible explanation, as low pressure systems are associated with rising water table elevations. In unconfined aquifers, the timing and extent of water table elevation changes depend on the both the magnitude of the pressure change and the barometric efficiency of the aquifer (F. A. Spane, 2002). This interpretation is currently considered speculative given the limited monitoring record (two years), but measurement of barometric response at several monitoring wells across the PWRA could determine the role this process plays in pool recovery. Additional investigation is needed to better understand the drivers of this early recovery and the relative roles of groundwater–surface water connectivity and antecedent system conditions.

Interpretations of groundwater–surface water connectivity throughout this section are based on observed pool response behaviour, as no direct groundwater level monitoring was undertaken; relationships are therefore inferred from hydrological patterns.

A clear gradient in resilience was observed across pools in the catchment.

I. **Highly resilient (HR) —** Sites 1, 3 and 4 maintained stable water levels throughout the monitoring period with minimal seasonal variation. Strong, stable groundwater connectivity with no evidence of sensitivity to the climatic variability observed during the reporting period.

II. **Moderately resilient (MR)** — Sites 6, 9 and 13 maintained a clear groundwater connectivity throughout but showed measurable drawdown under sustained dry conditions. Water levels mostly recovered following winter rainfall. Some sensitivity to prolonged rainfall deficits but no complete drying observed.

III. **Low resilient (LR) —** Sites 2, 7, 12, 14, 16 experienced significant drawdown and either dried temporarily or levels dropped significantly below the logger location and showed limited recovery relative to first-year levels. Groundwater connectivity appears intermittent or weakening under consecutive dry years. Recovery occurred following winter rainfall but was incomplete or delayed at most sites.

IV. **Highly vulnerable (HV) —** Sites 8, 10 dried completely by late 2024 and did not meaningfully recover during the reporting period. Minimal groundwater connectivity under below-average rainfall conditions. Persistence is highly dependent on surface flow inputs, both through direct inflow to the pools and via recharge of the shallow groundwater system, which are both regulated by the upstream weir system.

These results highlight a clear gradient in pool resilience across the catchment which is closely linked to groundwater connectivity and position relative to the weir system.

As shown in Figure 3-3 and described by Hancock et al. (2014), the monitored pools are located predominantly in gaining stream reaches where groundwater contributes to surface water. The progressive pool level declines observed from November 2024 indicate increasing disconnection from shallow groundwater, consistent with a declining trend in local groundwater levels driven by reduced recharge under below-average rainfall (DEW, 2023). Declining streamflow — caused by reduced rainfall and upstream flow interception by instream weirs — compounds this by reducing streambed recharge, likely a significant source of aquifer replenishment, while also directly reducing water delivery to the pools and contributing to deteriorating water quality and ecosystem health (Savadamuthu et al., 2023).

Importantly, the likely weakened or intermittent groundwater connectivity at several sites should be seen as an emerging trend rather than a reflection of historical conditions. The long-term persistence of these pools — including through previous dry periods such as the Millennium Drought — suggests that the degree of disconnection observed during the reporting period reflects the cumulative effects of extended dry conditions in the catchment, rather than a reflection of baseline conditions.

Shifts in the timing of pool replenishment also have the potential to influence the ecological processes that these pools support. For example, a later onset of seasonal refilling may shorten the period over which pools maintain water levels and conditions suitable for sustaining aquatic and riparian biota with potential consequences for species that rely on these pools as refuges during the dry season. Although the monitoring period is relatively short and the findings are therefore indicative, observed pool behaviour is concerning, particularly given that recent climate conditions and associated catchment runoff are projected to persist or worsen.

5.3 Key Findings by Main Reach

5.3.1 Tanunda Creek

Tanunda Creek pools showed contrasting resilience. Site 1 maintained stable depth throughout, suggesting a strong and consistent groundwater connectivity (HR site). Site 2 was more sensitive, drying completely in early 2025 before recovering fully following winter rainfall (LR site). EC at Site 2 exceeded the ecological threshold as pool levels approached drying, highlighting water quality sensitivity during drawdown.

5.3.2 Jacob Creek

Jacob Creek showed the greatest overall pool resilience of any reach in the study area. Both monitored pools (Sites 3 and 4) maintained water throughout the monitoring period and showed limited seasonal variability under most conditions (HR sites). Site 4 maintained stable depth and EC throughout the monitoring period, suggesting a strong and consistent groundwater connectivity. Site 3 exhibited a minor drawdown of approximately 0.4 m following the exceptional dry conditions of 2024, and showed elevated EC associated with first-flush runoff events.

5.3.3 Transition Zone

Site 6 exhibited a seasonal drawdown pattern with gradual decline from November 2024 suggesting the pool is sensitive to prolonged dry conditions (MR site). Pool depth dynamics suggest the occurrence of episodic surface flows when the pool reaches a water level of ~1.4 m. No confirmed CTF threshold exists for the current logger installation.

5.3.4 North Para River — Downstream of Weirs

The downstream reach in the North Para River (Sites 7–10) showed the greatest vulnerability of any reach, reflecting the combined effects of dry conditions and upstream flow regulation. Sites 8 and 10 (HV site) dried completely by late 2024 and did not recover. Overall, these sites showed the shortest flow durations and the some of the weakest recovery levels across the monitoring sites. The weir system substantially reduces downstream flow connectivity and likely limits local groundwater recharge, compounding to below average rainfall impacts on this reach.

5.3.5 North Para River — Lower Weir Site

The most downstream weir (Site 11) did not record a spill event during the reporting period. Weir levels declined progressively from January 2024 and did not recover meaningfully remaining below initial monitoring levels through to the end of the reporting period based on landholder information. This highlights the strong dependence of downstream connectivity on weir spill events and the cumulative storage deficit that must be overcome before any spill can occur following consecutive dry years.

5.3.6 North Para River — Upstream of Weirs

Upstream pools (Sites 12, 13, 14, 16) showed moderate to high seasonal variability. Site 13 was the most resilient, retaining water throughout and recovering steadily after winter rainfall (MR site). Sites 12 and 14 experienced near-dry conditions but partially recovered following winter rainfall (LR sites). Site 16 showed the least recovery in 2025, barely exceeding the lows of the 2024 drawdown, suggesting a growing storage deficit under consecutive dry years (LR site). The CTF-based flow classification at Site 14 may underestimate actual flow occurrence and warrants review.

5.4 Water Quality Observations

EC monitoring at seven sites (Sites 2, 3, 4, 7, 10, and 12) provided indicative water quality data over the monitoring period. EC exceedances of the ecological threshold (5,000 µS/cm) were recorded at multiple sites, most commonly during periods of pool drawdown when reduced water volume leads to concentration of dissolved solids.

The most pronounced EC exceedances were recorded at Sites 3 and 10, where values reached approximately 9,000 µS/cm and 8,000 µS/cm respectively, and at Site 12 where values regularly exceeded 6,000 µS/cm during the second drawdown. At Sites 2 and 7, EC approached or briefly exceeded the threshold during dry periods but generally remained below the threshold. EC at Site 4 remained consistently below the ecological threshold throughout the monitoring period, consistent with strong groundwater dilution at this site.

Two distinct EC dynamics were observed:

a) **concentration during drawdown** driven by evaporation and changes in inflows during sustained dry periods; and
b) **first-flush spikes** following initial rainfall events, likely reflecting inputs of accumulated catchment sediments and dissolved material.

5.5 Management Implications

The monitoring period captured an exceptional sequence of dry conditions, provides a valuable baseline for understanding worst-case pool behaviour and informing the development of the Environmental Water Plan. Some key observations to inform future planning are summarised below.

- **Hydrologically vulnerable downstream pools:** The sites located downstream of the weirs (Sites 7–10) on the North Para River are the most hydrologically vulnerable in the catchment and would benefit most from targeted interventions. The complete drying of Sites 8 and 10 — and the failure of these pools to recover under 2025 conditions — suggest that reliance solely on rainfall-driven spill is insufficient to sustain these pools under consecutive dry years. Under such conditions, environmental flow releases or modified weir operations may contribute to maintaining downstream connectivity and supporting pool persistence.
- **Resilient pools with groundwater connectivity**: Pools that likely have strong and stable groundwater connectivity, particularly Sites 1, 4, and 13, demonstrated resilience under current conditions and maintained water quality within acceptable thresholds throughout the monitoring period. These observations underscore the importance of sustaining surface flow processes that support shallow groundwater recharge.
- **Increasing vulnerability with consecutive dry years:** The earlier onset and longer duration of drawdown in 2024–25 suggest increasing vulnerability of several pools under multi-year dry conditions. Continued multi-year monitoring is essential to understand water dynamics over time as

informal observations and oral evidence suggests that stress to previously resilient pools only became apparent after successive dry years.

- **Water quality deterioration and EC trends:** EC data highlight that water quality deterioration accompanies declining water levels across multiple sites. Environmental flow delivery that maintains pool viability as aquatic refugia may influence both water depth and dilution processes, thereby reducing the likelihood of EC exceeding ecological thresholds.
- **Monitoring improvements:** Mixed methods for defining flow (surveyed CTFs, gauge data, inferred thresholds) introduce uncertainty in flow classification, such as at Site 14 where flow days are likely underestimated. Logger placement configurations could be improved to better capture flow transitions and pool depth dynamics. Reinstatement of the Jacobs Creek gauge would improve data coverage in a key catchment area, and continuation of the existing monitoring network is essential for robust long-term assessment of pool dynamics. Establishing shallow groundwater monitoring would improve understanding of surface water–groundwater interactions impacting these pools, particularly at sites classified as moderately resilient, low resilient, or highly vulnerable, where groundwater–surface water interactions appear more variable during dry conditions.

These preliminary findings provide important information for the strategic planning of an Environmental Water Plan for the Barossa PWRA. The monitoring program contributes to this by providing baseline information on pool persistence under extreme conditions and improving understanding of the processes driving pool behaviour. Together, these insights strengthen the evidence base for designing targeted environmental flow strategies.

6 Appendices

A. Pool depth and electrical conductivity variation (where appropriate)

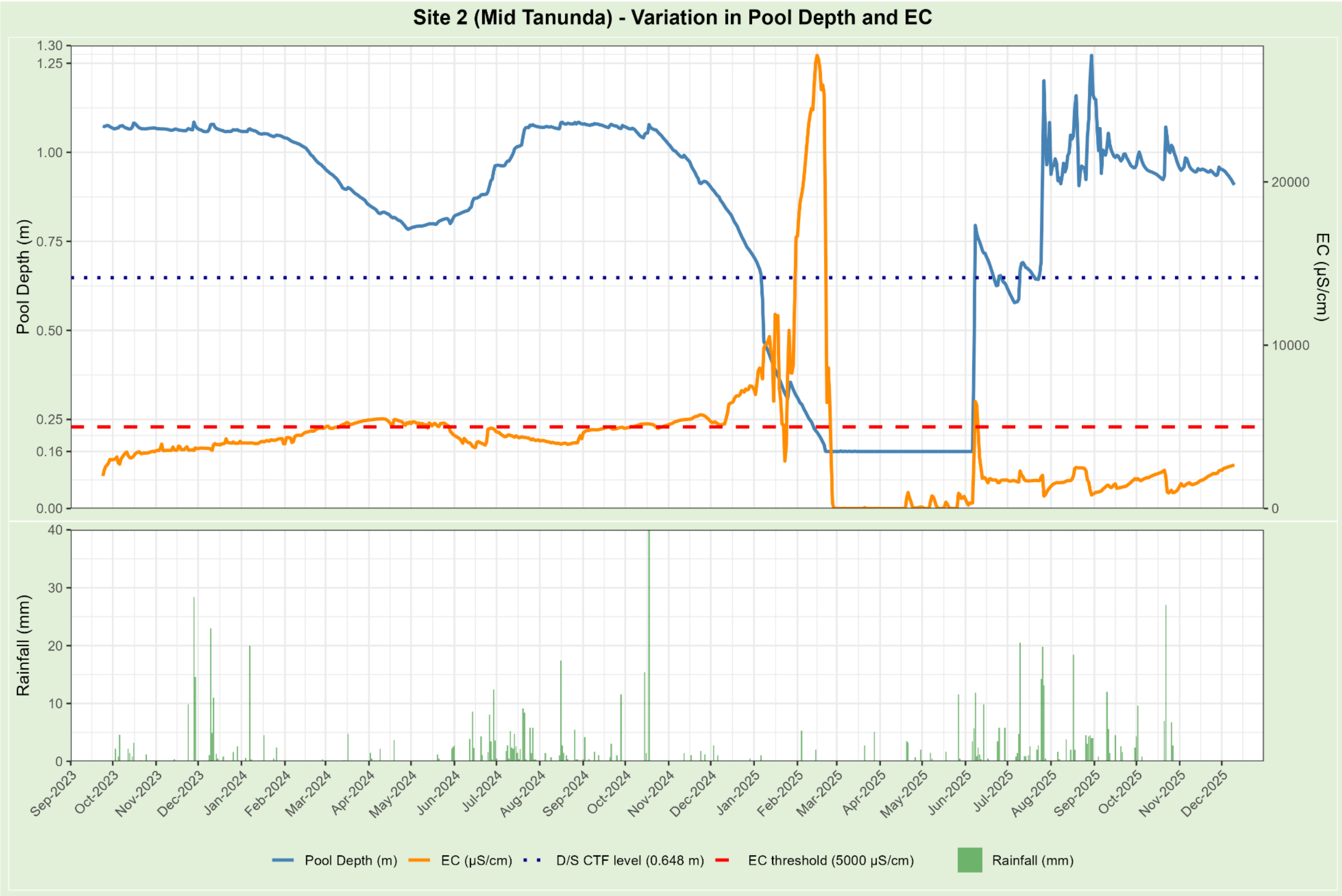


Figure 6-1. Variation in pool depth and electrical conductivity for Site 2

The minimum recorded pool depth was 0.16 m, which represents a dry pool condition. The pool remained dry from late February 2025 (approximately 21/02/2025) until early June 2025 (07/06/2025)

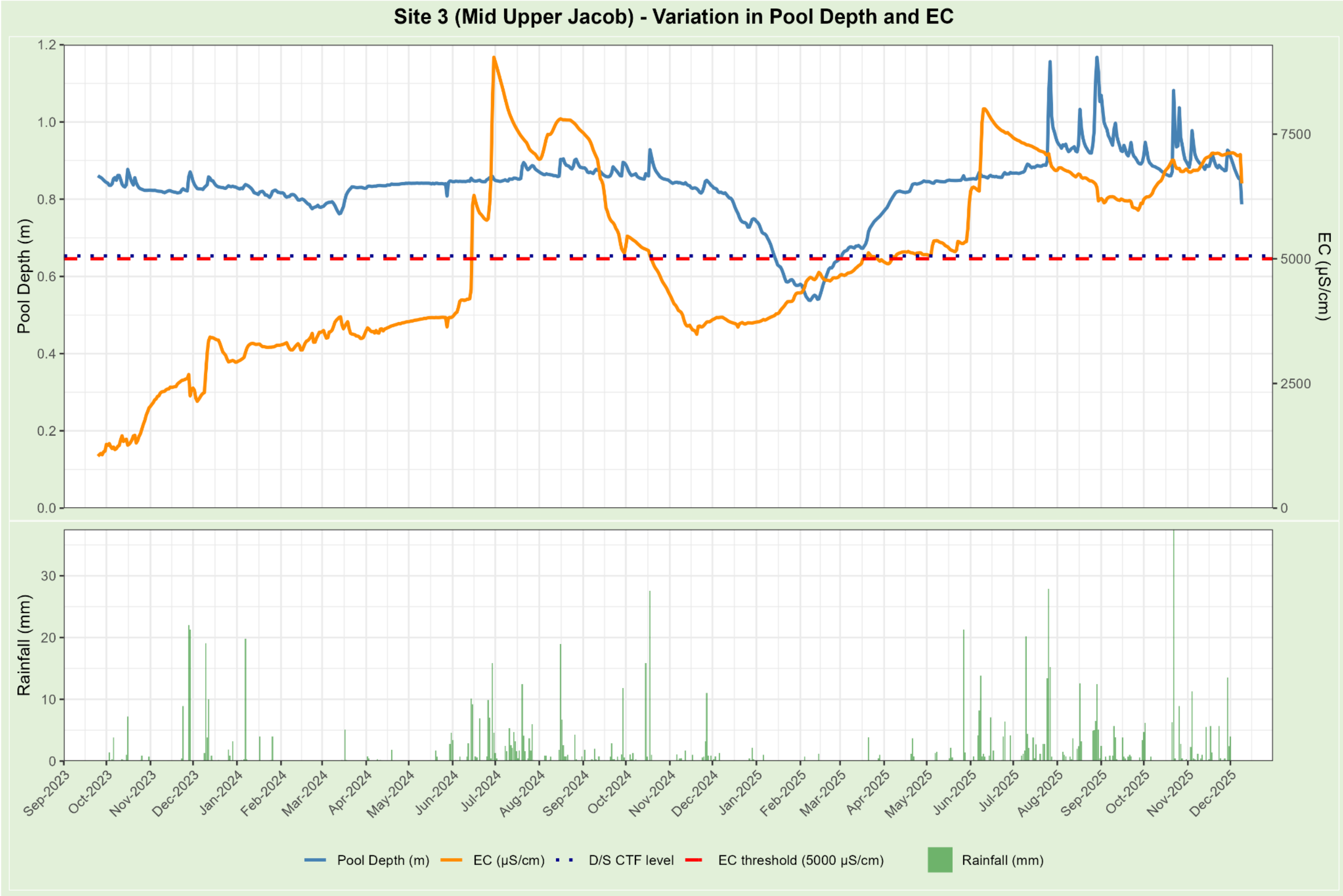


Figure 6-2. Variation in pool depth and electrical conductivity for Site 3

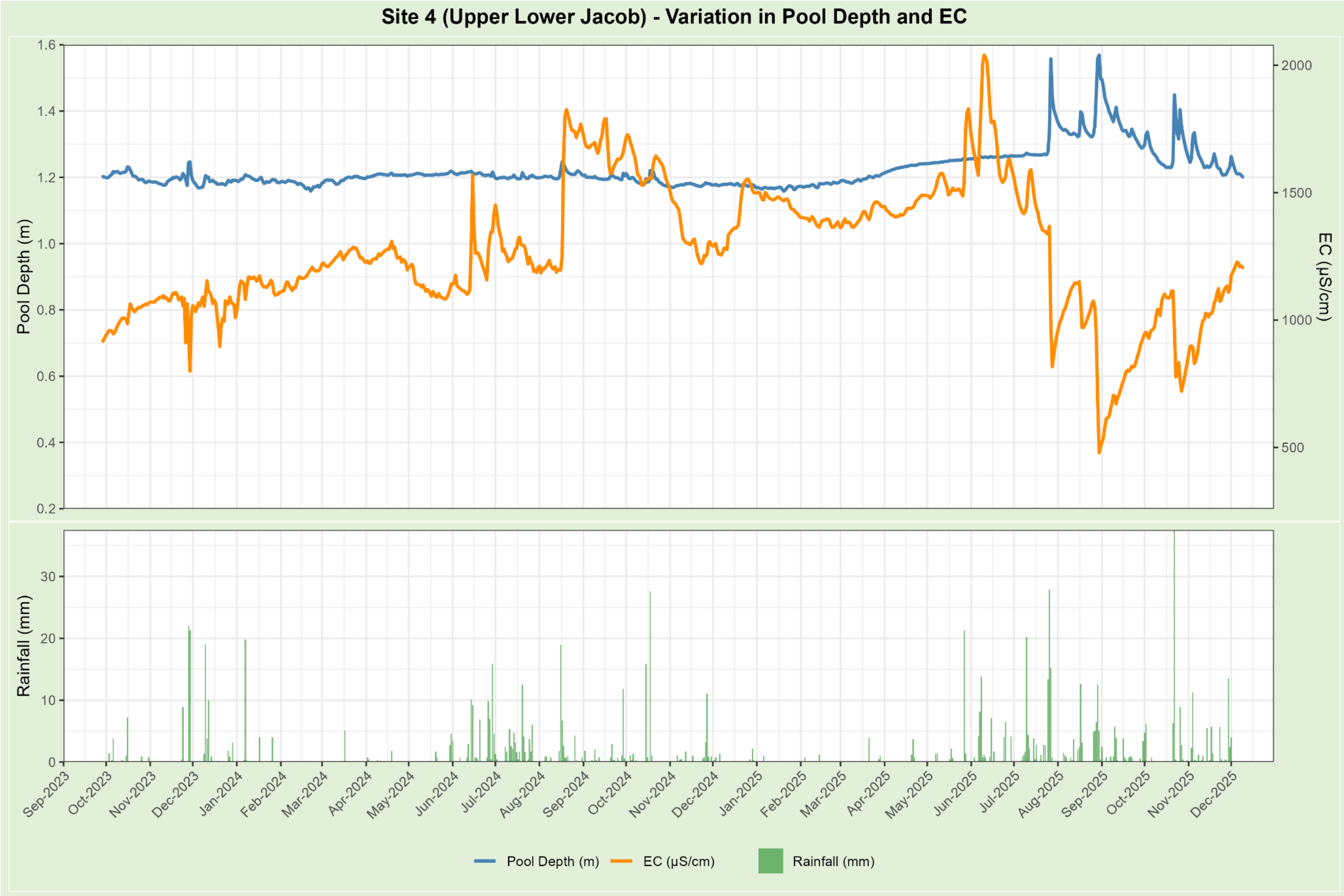


Figure 6-3. Variation in pool depth and electrical conductivity for Site 4

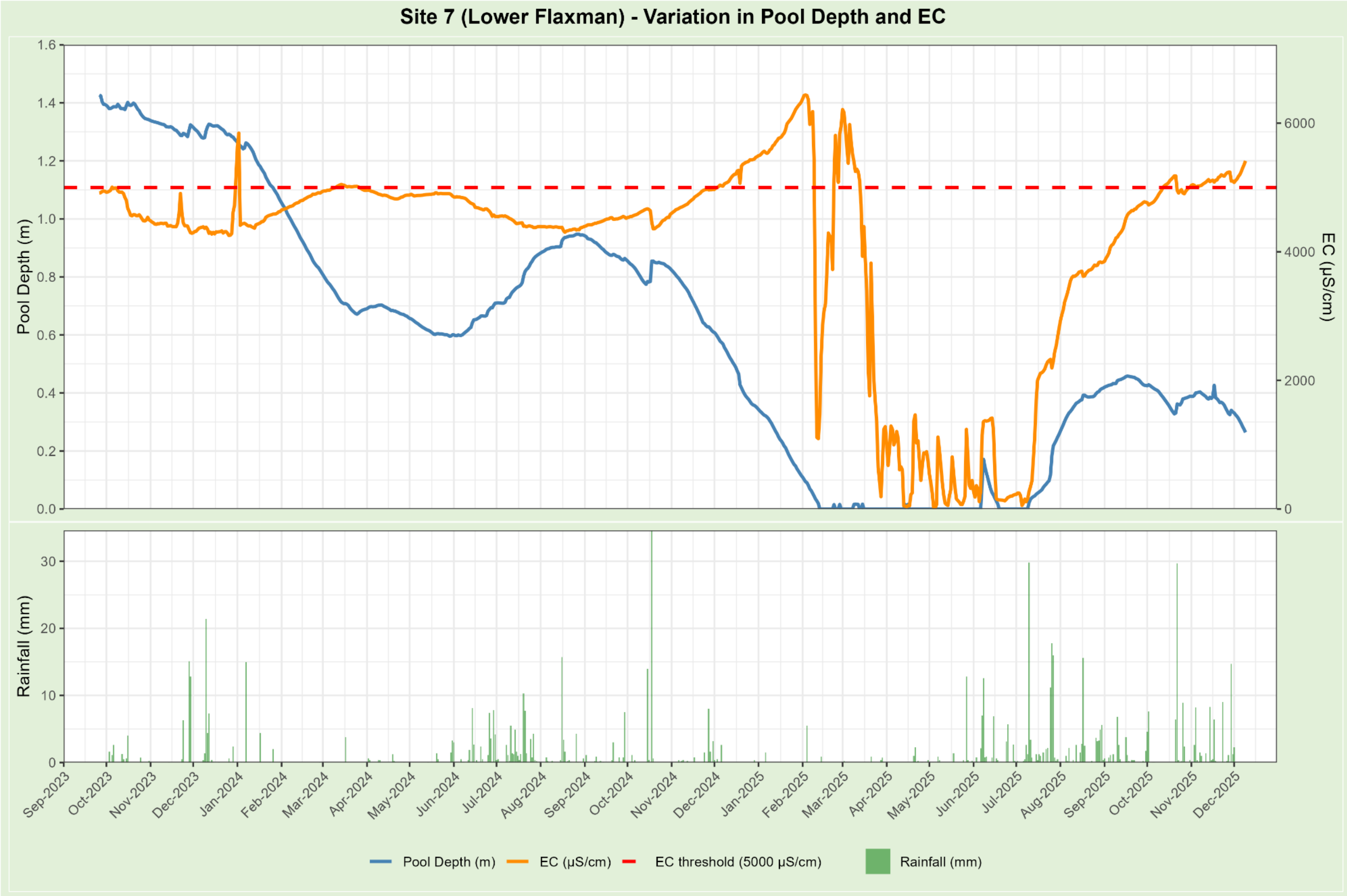


Figure 6-4. Variation in pool depth and electrical conductivity for Site 7

Logger was out of water from mid-February 2025 to early June 2025

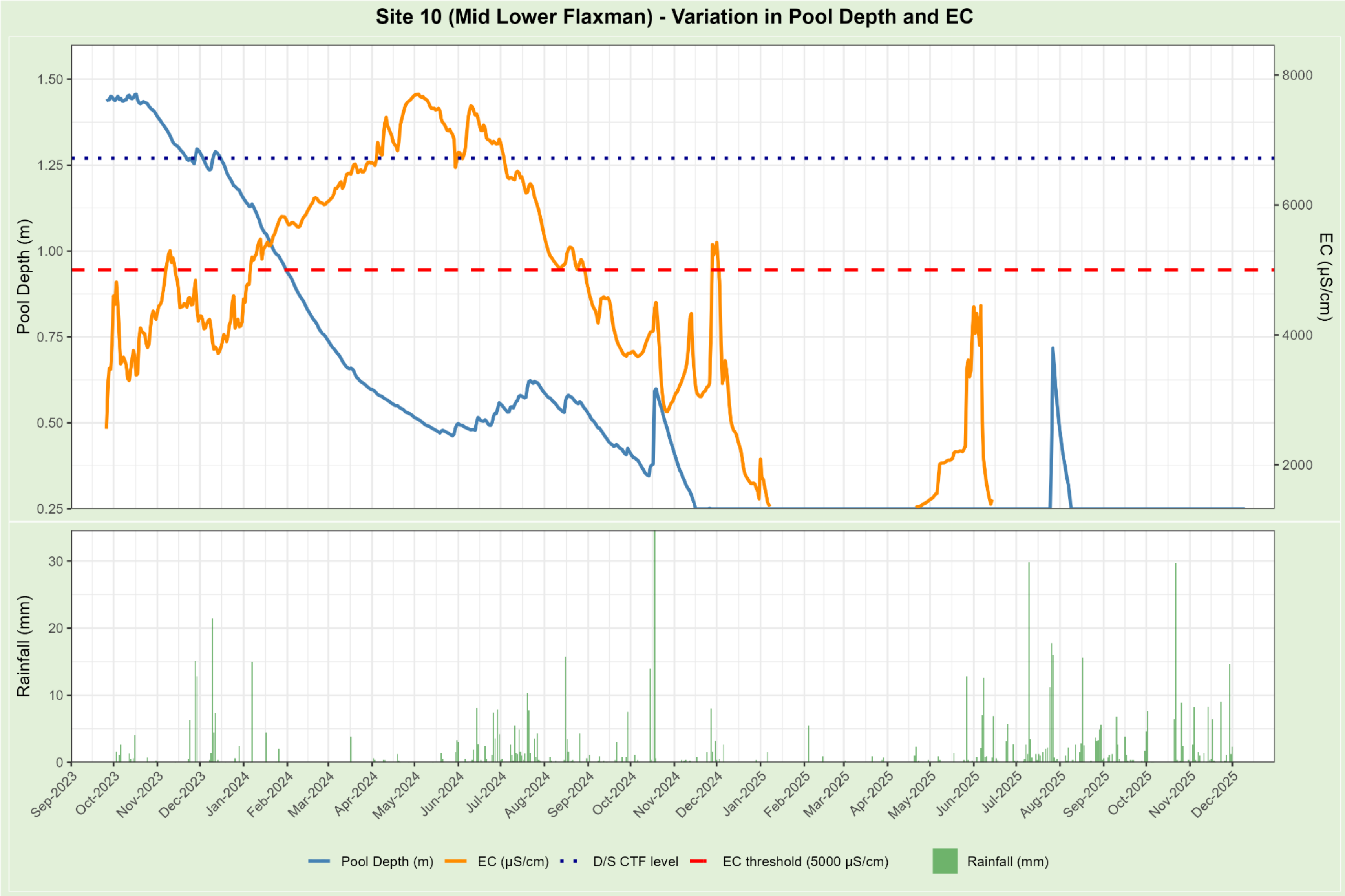


Figure 6-5. Variation in pool depth and electrical conductivity for Site 10

The minimum recorded pool depth is 0.25 m, which represents a dry pool condition. Pool was dry from Mid November 2024 with a small rainfall driven peak in beginning of August 2025

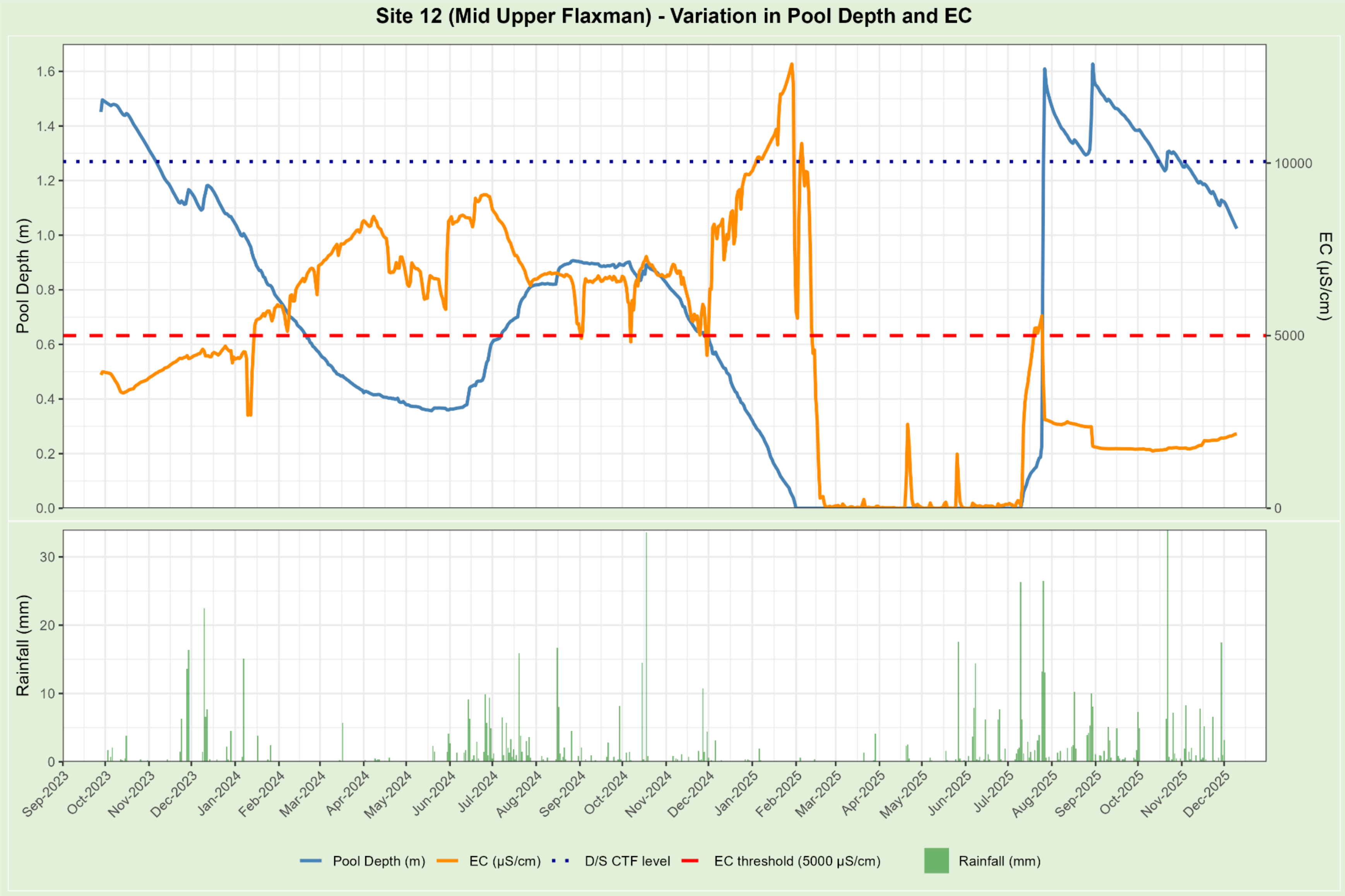


Figure 6-6. Variation in pool depth and electrical conductivity for Site 12

Logger was out of water from early February until early July.

B. Cross section and longitudinal section of the monitoring pools

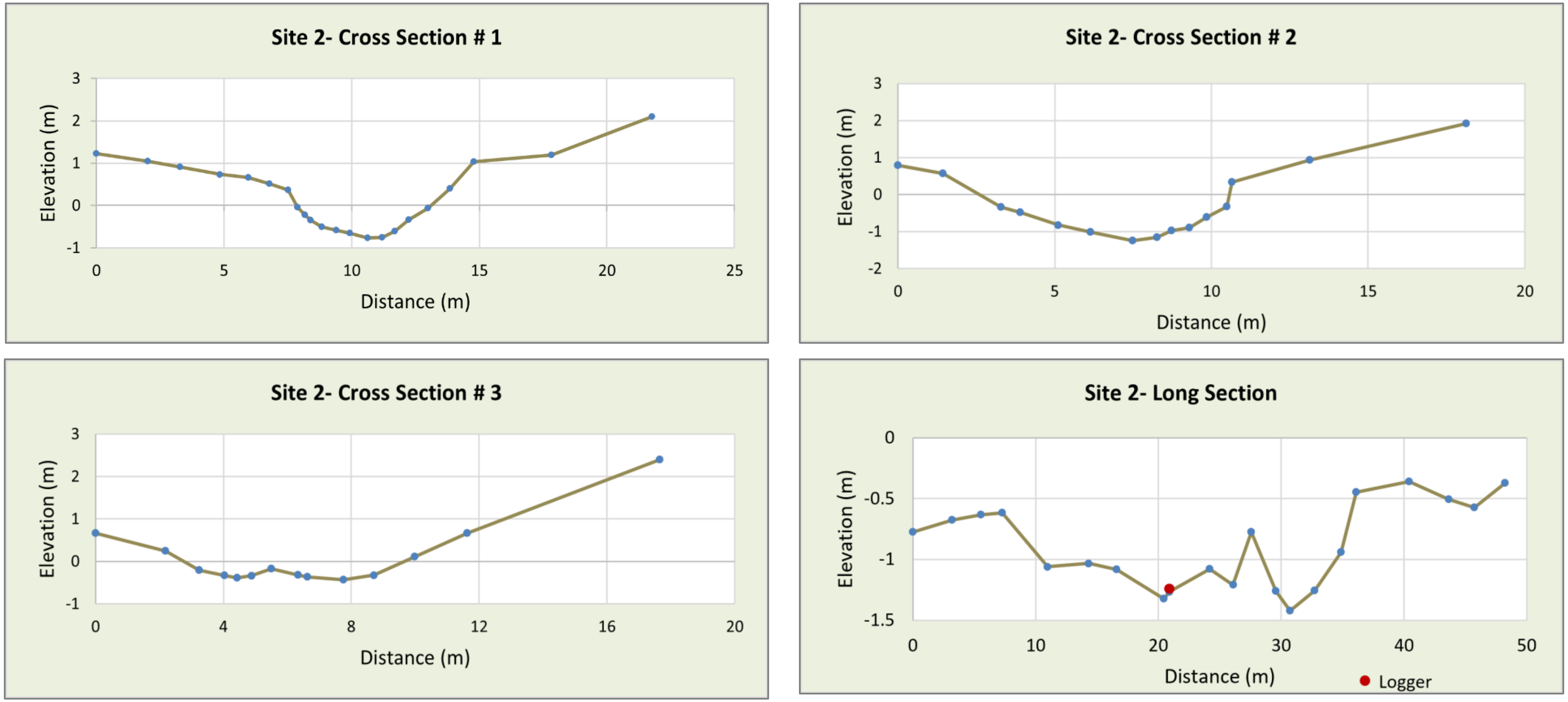
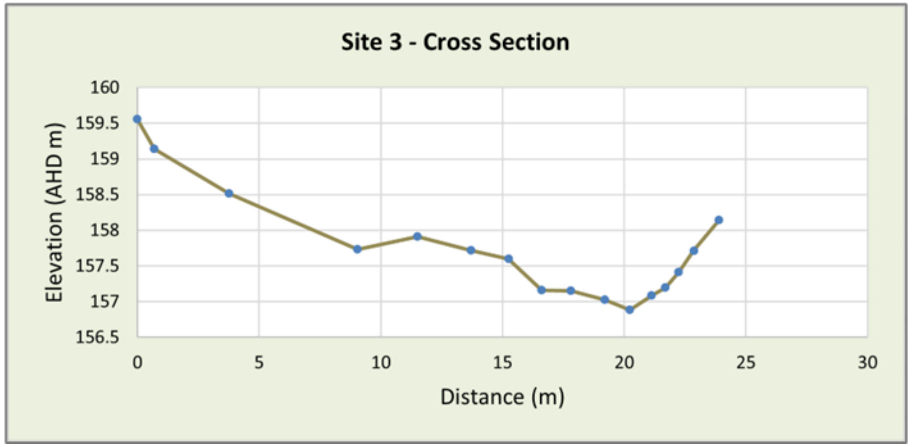


Figure 6-7. Site 2 - Cross section and longitudinal section



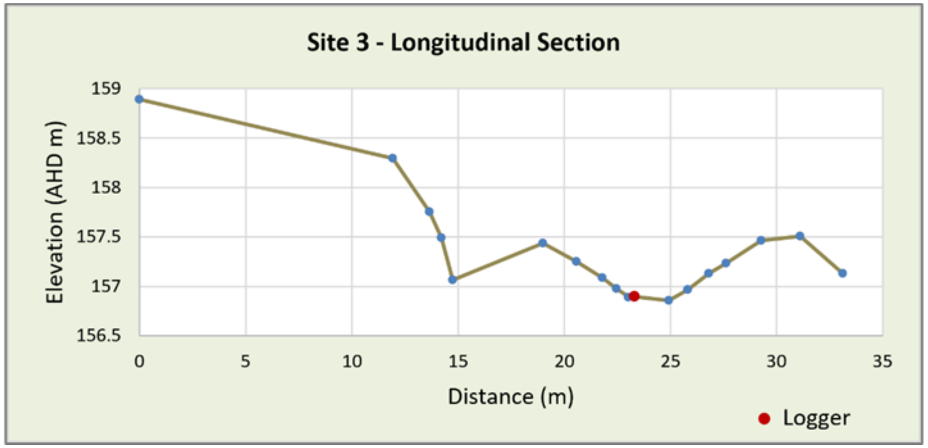


Figure 6-8. Site 3 - Cross section and longitudinal section

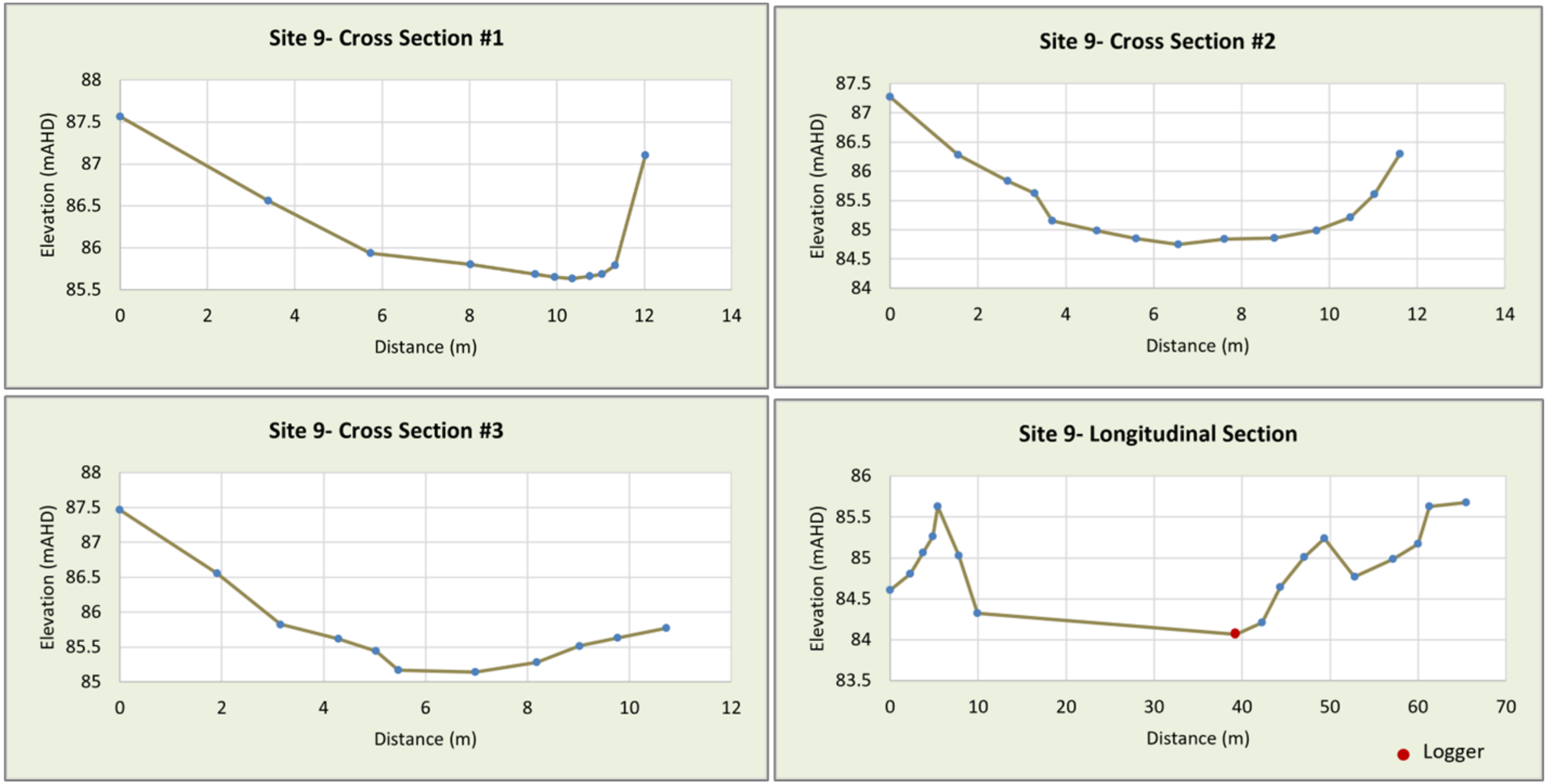


Figure 6-9. Site 9 - Cross section and longitudinal section

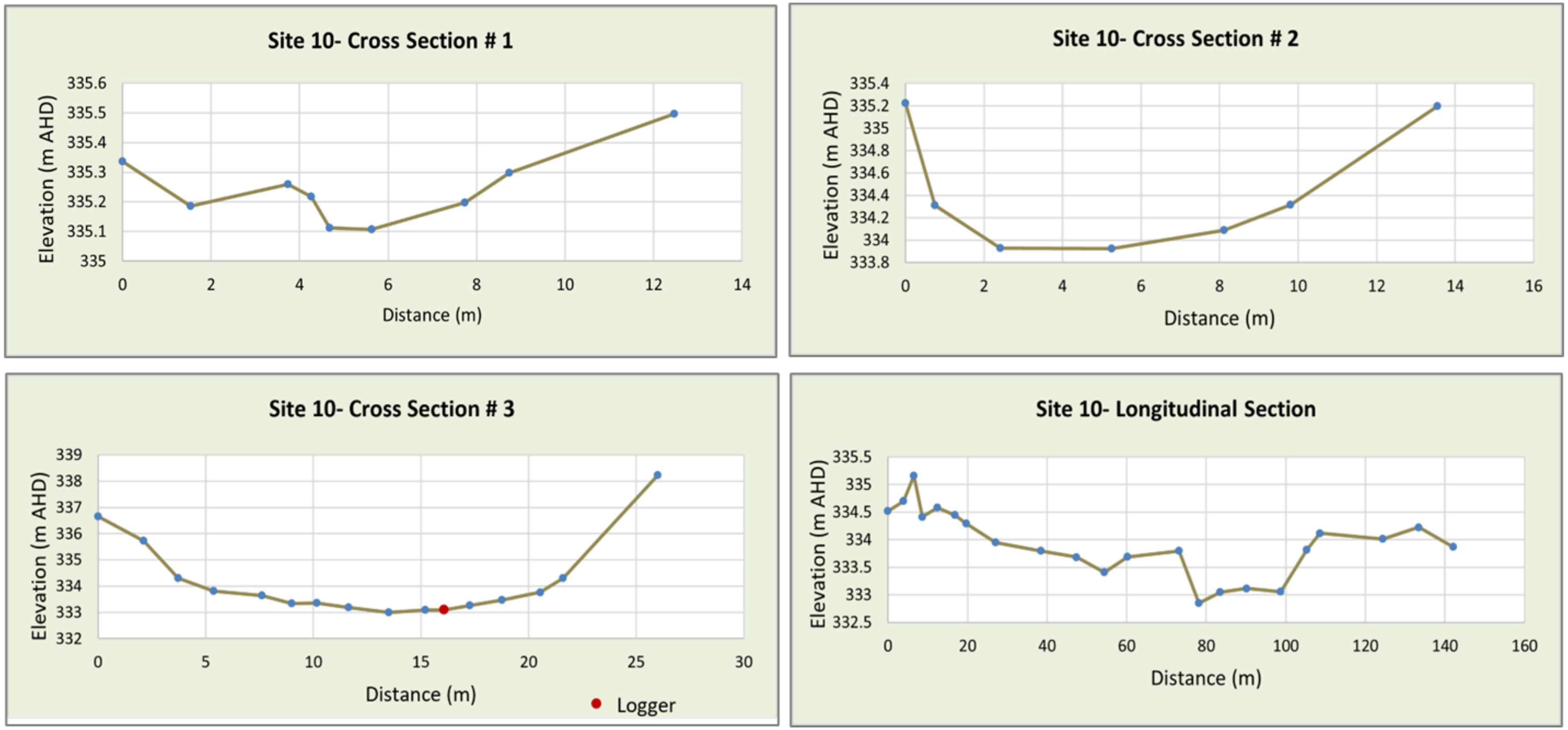


Figure 6-10. Site 10 - Cross section and longitudinal section

C. Photographs

Photo 1.Site 1 – November 2023

Photo 2. Site 2 – May 2025

Photo 3. Site 3 – August 2023

Photo 4. Site 3 – May 2024

Photo 5. Site 3 – May 2025

Photo 6. Site 4 – November 2023

Photo 7. Site 6 – November 2023

Photo 8. Site 6 – May 2024

Photo 9. Site 6 – May 2025

Photo 10. Site 7 – November 2023

Photo 11. Site 8 – May 2025

Photo 12. Site 9 – November 2023

Photo 13. Site 9 – May 2024

Photo 14. Site 9 – May 2025

Photo 15. Site 10 – November 2023

Photo 16. Site 10 – May 2024

Photo 17. Site 10 – May 2025

Photo 18. Site 11 – May 2024

Photo 19.Site 12 – November 2023

Photo 20. Site 12 – May 2024

Photo 21. Site 12 – May 2025

Photo 22. Site 13 – May 2024

Photo 23. Site 14 – May 2025

Photo 24. Site 15 – May 2025

Photo 25. Site 16 – May 2024

Photo 26. Site 16 – May 2025

7 References

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