WaterSmart Dams Surface Water Technical Report

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Contents Page

List of Tables

List of Figures

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Executive Summary

Introduction: A Growing Water Challenge

The South-West Wheatbelt of Western Australia spans 14 million hectares and underpins the state's dryland agriculture economy. Farms rely on dams capturing runoff to provide drinking water for livestock, support spray operations as part of cropping and for other non-potable uses. Shifts in total annual rainfall and the intensity of precipitation since the mid-1970s and again since the 2000s pose a severe challenge for traditional water-harvesting methods. Loss of livestock and pasture rotations from our farming systems, combined with the adoption of no-till cropping, has reduced surface runoff from traditional paddocks. When combined with an altered rainfall regime with a larger proportion of the precipitation received from low-intensity events, this has resulted in many dams within the Wheatbelt having under-performing catchments.

When on-farm sources are exhausted, relying on water carting from scheme water and other supplementary supplies is the single most costly way to source water. It is a poor and costly response to drought adaptation. This project looks at options to address this challenge by: 1) evaluating the performance of enhanced or engineered surface catchments that use PVC tarpaulins and other plastic surfaces (HDPE) to harvest water from low-intensity rainfall events, and 2) the utility of subsurface drainage systems to capture water from waterlogged soils and harvest and store it in dams for on-farm non-potable use.

The WaterSmart Dams Project

WaterSmart Dams (WSD), part of the broader WaterSmart Farms initiative, a partnership of The University of Western Australia (UWA) Centre for Water and Spatial Science (CWSS), with the WA Government's Department of Primary Industries and Regional Development (DPIRD), Grower Group Alliance (GGA) and South-West WA Drought Hub, plus four grower groups (Compass Agriculture Alliance; Fitzgerald Biosphere Group; Merredin and Districts Farm Improvement Group, and; Southern Dirt), and working with growers and site hosts on 12 project demonstration sites across the <600 mm rainfall zones of the Wheatbelt.

Methods and Sites

Study sites spanned the climatic gradient of the Wheatbelt, from Salmon Gums/Esperance area (320–400 mm annual rainfall) to Kojonup and Scotts Brook (600–700 mm). Monitoring used tipping-bucket rain gauges and millimetre-precision water-level loggers combined with V-notch weirs or Parshall flumes to ensure maximum measurement precision.

Surface catchment trials included:

- Giles (Merredin): 15,600 m^2 retro-fitted roaded catchment.
- Goss (Darkan): dual roaded catchments comparing treated vs untreated surfaces.
- Lester (Jacup): 6,545 m^2 repurposed PVC-lined catchment.
- Wandel (Grass Patch): 8,360 m^2 repurposed PVC-lined catchment.
- Borden: 8,877 m^2 HDPE-lined catchment (existing).
- Subsurface drainage sites using either tile drains (Ashtons, Webb) or open V-drains (Souths).

Results and Project Findings

Enhanced Catchments

- For a wheatbelt farm dam to be considered reliable, it requires an enhanced catchment. At the demonstration sites in this project, across our monitoring period, an unmodified paddock surface with a 25 mm runoff threshold would have yielded only 14% of rainfall at Jacup, 0% at Grass Patch, and 15% at Borden. If these sites had used a high-performing roaded catchment with an 8 mm threshold, then 27–59% of rainfall would have been captured.
- Roaded catchment success and getting to an 8 mm rainfall runoff threshold without large amounts of erosion and sediment is highly dependent on contractor expertise, the suitability of the soil type and regular maintenance.
- Plastic-lined catchments constructed from high-density polyethylene (HDPE) sheets and repurposed polyvinyl chloride (PVC) grain tarpaulins, as monitored in this project, initiated runoff from as little as 0.8–1 mm of rainfall, enabling the harvest of 85–90% of annual rainfall during our monitoring period.
- Throughout this project, and in response to grower interest, repurposed polyvinyl chloride (PVC) grain tarpaulins were trialled at scale to cover an existing roaded catchment. While these secondhand tarpaulins are inexpensive to purchase, they require significant investment in site preparation, stitching, and installation. Additionally, their potentially short lifespan (3-7 years) and susceptibility to damage, particularly from wind events, may reduce their cost-effectiveness over time. In contrast, while high-density polyethylene (HDPE) catchments were not trialled at the farm scale but instead monitored at an existing community water supply site in this project, they may provide better return on investment. Although worth noting, both options are cheaper per kilolitre than carting water.

Subsurface drains:

- Subsurface drainage is primarily used to manage waterlogging. However, they can also serve as a supplementary water source, helping to top up dams in wet to average years and improve preparedness for dry periods, but they are not a standalone solution for drought.
- All three monitored subsurface drainage systems (two tile drains and one open drain) produced fresh water suitable for livestock. However, performance varied by site and year, highlighting the need for longer-term monitoring to assess reliability and cost-effectiveness.

Water quality:

- Water quality emerged as a key priority for growers, particularly for spray programs. While not covered in this report, water sampling conducted by UWA for MADFIG and FBG across >130 farm water sources revealed significant variability in both water quality and grower awareness. These findings are detailed in the respective MADFIG and FBG reports available at MADFIG: Water Quality Sampling Project 2023-24 and FBG Spray Water Quality SnapShot.

Project Recommendations and Learnings

1. Prioritise low-threshold catchments in a drying climate with no-till paddocks

With climate change shifting rainfall toward smaller, more frequent events, technologies that reduce runoff thresholds to 1 mm or less are essential. Plastic linings and treated surfaces dramatically increase rainfall capture, improve dam reliability, and reduce dependence on costly water carting.

Further research is needed into the durability, degradation, and lifespan of low-cost PVC linings under field conditions. Based on this project, we suggest secondhand PVC grain tarpaulins have a lower initial cost, but come with high uncertainties around the quality and longevity of the PVC material. Our experience in this project was that the secondhand PVC materials were of lower quality and unsecured against wind at Lesters (that led to destruction of the surface after only 2-3 years, but PVC tarps of higher quality and the use of tyres as weights at Wandell's means this engineered catchment is still in good condition. Evaluation of an existing (approximately a decade old) HDPE catchment suggested that more robust HDPE is a more suitable material for long-term performance, and that higher up-front costs are offset by the assurance of a high-quality product and long-term performance, as well as potential water quality gains.

2. Subsurface Drainage – Helps in average to good years to enter the next drought with more water

Subsurface drainage not only supplies usable water but also mitigates waterlogging, boosting farm productivity. The project found that salinity levels were generally low, and the water was of drinking quality for livestock, with some water meeting human health guidelines for electrical conductivity (salinity). Performance was highly variable, with low runoff in some years. This variability suggests that the performance is unreliable in low-rainfall years.

The assessment of this project indicates that sub-surface drainage is an effective way to address waterlogging, and the drained water should be tested and treated as a valuable water resource. Some questions remain on the water quality of drained water (such as nutrients, which were beyond the scope of this project to investigate), and the performance over time and whether clogging and declining yields reduce performance over time.

3. Linking the science and data with new water evaluation planning tools.

The results of this report have been used to populate the Water Evaluation Platform (WEP) (https://waterevaluationplatform.app/dam/), a decision-support tool developed as part of the WSD project. WEP helps farmers and planners assess water-harvesting options, costs, and reliability, and is based on sound science from real-world performance, as illustrated by the figures in this report. WEP has now been adopted as a practical tool for farm-level non-potable water planning and regional drought resilience programs.

Priority Areas for Future Work

HDPE catchments: Explore the translation of South Australian HDPE farm catchment and lined dam systems to WA, identifying local needs, limitations, and construction challenges. WA-specific testing of materials, welding, and installation methods is necessary to validate the assumed 20-year lifespan used in the economic scenarios presented in this report.

Surface sealing products: Update and expand trials of modern polymer-based spray-on sealants to improve the performance of existing roaded catchments and reduce runoff thresholds.

Subsurface drainage: With the growing interest and investment of growers in tile drainage, further research is needed to understand water quality (e.g., livestock suitability, mobility of farm chemicals) if water is to be used as a non-potable source, alongside agronomic and practical design considerations.

Water quality: Despite growing awareness, a clear need remains for simple, practical tools and advice to monitor and manage water quality for spray programs, where poor water quality can reduce the effectiveness of chemicals and contribute to herbicide resistance.

Leakage repair products: A trial of dam leakage repair products, led by the Compass Agricultural Alliance, provided valuable insights despite inconsistent data due to limited baseline measurements and disturbances of loggers by livestock. Anecdotal evidence suggests potential effectiveness, but performance is highly site-specific. Given the cost-effectiveness of addressing leakage, further investigation of these products and dam lining is warranted.

Conclusion

The WaterSmart Dams project demonstrates that enhancing catchments with plastic linings and implementing subsurface drainage systems can significantly improve water security in the Wheatbelt's increasingly variable climate. Plastic-lined catchments reduce rainfall thresholds from ~8 mm to 0.8 mm, capturing up to 90% of annual rainfall compared to ~30% for traditional roaded catchments and 7% for untreated paddocks. Subsurface drainage systems add a valuable complementary water source while reducing waterlogging and improving productivity.

These innovations are not only technically effective but also economically competitive, offering long-term cost savings compared with carted water. With policy support to overcome upfront cost barriers and accelerate adoption, these methods can significantly improve water resilience for farms and regional communities. They represent a crucial part of the adaptation strategy for Western Australian agriculture in a future defined by drier conditions and more variable rainfall.

1 Introduction

1.1 Background and context

The Wheatbelt region of south-west Western Australia spans approximately 14 million hectares, with regional economic activity heavily reliant on dryland cropping and livestock agricultural enterprises. Clearing for agricultural land was completed by around 1984, with 93% of the region cleared now focused on seasonal grain cropping and pasture production (Prober & Smith, 2009). Agriculture is the region's largest employer and a key contributor to its economic output and the livelihood of regional communities. A large portion of farm businesses rely on farm dams for water for agricultural production, and use catchment and farm dams to store non-potable water for agricultural activities.

The sector faces considerable challenges due to changes in the region's rainfall since the 1970s, necessitating that farm businesses adapt and change their strategies to remain globally competitive while adjusting to a changing climate. Since the 1970s, the south-west has experienced both warming and drying trends, with documented reductions in daily, annual, and total rain days (Baek & Coles, 2021; Baek & Coles, 2013a). These changes have presented challenges for non-potable on-farm water resources, particularly in dryland agricultural areas that receive less than 600 mm of annual rainfall.

Water security, including off-grid or non-reticulated supply of on-farm non-potable water, is a long-running concern. Water deficiency declarations during the 1970s–1990s led to a more coordinated approach to water resource management between the Government and rural communities. During this time, the State Government invested $2.6 million to address drought impacts, with 78% of funding spent on water carting in the south-west (Baek & Coles, 2021; Baek & Coles 2013a). However, water carting is not a drought-proof solution and is highly costly for individual farm enterprises and the government. It was unclear at the time whether the issue stemmed from inadequate recommendations or limited adoption by farmers - a question that remains relevant today, with the allocation of drought support funding now also recognised as a major contributing factor (Davies & Denby, 1988).

Another part of the issue is not only the overall decline in rainfall but also a shift in rainfall patterns. Rainfall events between 10 mm and 25 mm are becoming less frequent (Baek & Coles, 2021). This change poses a significant challenge for farmers who rely on current water harvesting methods. In south-western Australia, most farms depend almost entirely on water captured and stored on-farm (Baek & Coles, 2021). This reliance is even greater for farms in remote or isolated locations without access to scheme water supplies. Various methods are used for on-farm water capture, with the most common being dam systems supplied by catchments (Baek & Coles, 2013b). These catchments may be natural, roaded, or enhanced using materials such as plastic sheeting or spray-on treatments. Other water sources include rainwater tanks that collect runoff from roofed structures, desalination units that process brackish groundwater, deep drilling into fractured rock aquifers, and, in drought emergencies, carted water from government standpipes (Baek & Coles, 2013b; Laing, 1985; Davies & Denby, 1988).

Roaded catchments (RCs) represent a common form of artificial catchment that enhances runoff relative to a cropped or pasture paddock or “natural” catchment. Baek & Coles (2013b) report several thousand being used across Western Australia for agricultural purposes, though the true number may be in the tens of thousands. Regardless of the total number of RCs, it is significantly lower than the estimated number of mapped farm dams in SW WA, which is around 175,000 (DPIRD, 2022). The adoption of RCs followed the severe 1969–70 drought in the southern Wheatbelt, particularly in areas where groundwater resources were limited and farms depended heavily on dams for livestock water. By 1981, over 4,000 RCs were recorded, averaging 1.5 hectares each on WA farms (Laing, 1985). For many isolated farms and dryland communities in WA without access to scheme water, RCs or artificial catchments remain essential (Baek & Coles 2013b).

Typically, RCs consist of areas where sandy topsoil is not present or has been removed, with parallel ridges of compacted, bare clay soil with moderately steep side slopes (feeder slopes), designed to maximise runoff from relatively low-intensity rainfall - especially where natural catchments perform poorly (Laing, 1985, Figure 1). However, these catchments are often poorly maintained; without regular rolling to compact the surface and spraying to control weeds, their effectiveness declines. The condition of the surface directly influences the runoff threshold, or the minimum rainfall required to generate runoff, also known as the rainfall–runoff threshold (Baek & Coles 2013a; Li et al., 2004). Neglected RCs generally have a threshold between 10 and 12 mm (Baek & Coles, 2021; Baek & Coles 2013b), while well-maintained catchments can reduce this to around 8 mm (Davies & Denby, 1988).

Figure 1. An example of a roaded catchment (source Department of Primary Industries and Regional Development (DPIRD).

Another factor contributing to the reduced effectiveness of current water harvesting methods is the widespread shift from conventional tillage to no-till farming practices, which significantly alters the way water moves across the landscape, particularly in terms of surface runoff (DeLaune & Sij, 2012). Conventional tillage involved turning over the soil and incorporating weeds as a form of weed control, but has been replaced by no-till farming systems that use herbicide chemicals to control weed competition (Flower & Braslin, 2006). The proven long-term benefits of no-till systems to soil moisture, soil carbon and health and reduced erosion has led to rapid uptake by Western Australian (WA) growers between 1990 and 2010 (Cornish et al., 2020). Today, no-till is widely adopted, with around 86% of WA farmers applying the practice on at least part of their land, marking a major shift in land management over the past 50 years (Cornish et al., 2020).

By retaining stubble after harvest, no-till systems enhance protection against wind and water erosion, promote soil stability, and increase soil carbon levels, ultimately supporting higher productivity (Flower & Braslin, 2006). These same characteristics - surface cover and improved soil structure- also increase water infiltration into the soil. Research shows that converting from no-till back to conventional tillage results in a 38% increase in surface runoff (Cornish et al., 2020). While these no-till benefits are advantageous for crops and soil quality, they reduce the amount of surface runoff available for collection in dam catchment systems. Bare earth catchments require less rainfall to initiate runoff, whereas stubble-covered ground allows more rainfall to soak into the soil. This further emphasises the need for farms to adopt enhanced catchment systems to improve water capture and security.

As rainfall patterns continue to shift towards more frequent low-rainfall events and fewer moderate ones, maintaining RCs to lower their runoff threshold has never been more important (Baek & Coles, 2021). There has also been growing interest in engineering RCs through various surface treatments or materials that further enhance runoff. There are multiple ways in which RCs can be further improved, some of which are explored in this report. According to Short & Lantzke (2006), directing water from paddocks into dams typically collects about 7% of rainfall as runoff, while RCs significantly improve this, capturing approximately 30% of rainfall. One enhancement method is bituminising the catchment surface, which Short & Lantzke (2006), note can increase runoff capture to around 85%, with Baek & Coles (2013b; 2021) reporting a rainfall-runoff threshold as low as 1–2 mm; however, this method can be costly. Another alternative is to spray the surface with a polymer coating, which reduces the runoff threshold to approximately 4–5 mm (Baek & Coles, 2021; Baek & Coles, 2013b). Lining RCs with materials such as high density polyethylene (HDPE) sheets or repurposed polyvinyl chloride (PVC) grain tarpaulins is also an option. The type of plastic used is very important, especially if it is UV durable/resistant, as Li et al. (2004) found that this significantly affects runoff effectiveness once deterioration begins. For example, Young & Hughes (2022), found that durable, UV-resistant high-density plastics capture up to 95% of rainfall. These enhancements also allow for steeper feeder slopes, as sediment migration and soil stability are not of concern (Kirkland, 1969).

Table 1. Different runoff treatments for non-potable water harvesting mechanisms.

Method	Description	Pros	Cons	Study Summary	Reference
Pasture paddock	• Pasture paddock, land management practice unspecified	• Already existing	• Very low runoff, approx. 7% of rainfall • Runoff threshold of approx. 25mm	• Lots of papers on paddocks as catchments	• Short & Lantzke (2006) • Baek & Coles (2013)
Pasture paddock (No-Till Cropping)	• Cropping paddock under no-till system; crop stubble is retained post-harvest	• Promotes soil stability, less loose sediments migrating towards the dam	• Reduced surface water runoff by 38%, as the soil has increased water infiltration capacity	• Very limited studies specifically on the difference between conventional till and no-till crop management practices in the effect on surface water hydrology	• Flower & Braslin (2006) • Cornish et al (2020) • DeLaune & Sij (2012)
Roaded catchment	• Cleared, compacted area with parallel ridges and steep feeder slopes	• Higher runoff than natural paddocks • Runoff threshold, unmaintained 10-12mm. Maintained 8mm • Widely used and familiar setup	• Requires regular maintenance to maintain low threshold ~8mm • Unable to capture rainfall events below 8mm • Collects approx. 30% of rainfall (unmaintained)	• Widely studied and trialled in WA; consistent evidence on effectiveness if maintained	• Baek & Coles (2021) • Baek & Coles (2013) • Laing (1985) • Davies & Denby (1988) • Short & Lantzke (2006)
Bitumen	• Roaded catchment surface laid with bitumen emulsion	• Very high runoff efficiency – up to 85% • Low threshold (1–2 mm)	• High cost, unrealistic for most farm budgets	• Moderate literature and trailed in WA	• Baek & Coles (2021) • Baek & Coles (2013) • Short & Lantzke (2006)
Spray polymer	• Surface of roaded catchment treated with polymer coating	• More cost effective than bitumen • Lowers runoff threshold to 4–5 mm	• Longevity unknown, performance could decline over time	• Some evidence on effectiveness and threshold reduction, but limited literature and long-term data in WA	• Baek & Coles (2021) • Baek & Coles (2013)
HDPE Catchment	• A roaded catchment lined with High-Density Polyethylene	• Very high runoff efficiency (~95%) • Known UV resistant and durability	• May be expensive depending on scale and installation complexity	• A handful of farmers lead implementation in WA, limited research into use in lining roaded catchments and the runoff threshold. Commonly used in mining operations.	• Government of South Australia & NR EP (n.d.) • Young & Hughes (2022) • Li et al. (2004)
PVC Grain Tarpaulin Catchment	• Roaded catchment lined with repurposed PVC grain tarpaulins	• Low cost in comparison to HDPE • Predicted high runoff efficiency, similar products tested suggested ~80-90%	• Similar, thinner and less durable tarps have been known to deteriorate with UV • Unknown durability currently	• No reported scientific literature on this specific PVC grain tarpaulin • This report covers	• Kirkland (1969) • Young & Hughes (2022) • Shangguan et al. (2002) • Li et al. (2004)
Subsurface Drainage	• Underground system of channels directing excess water discharged from farmlands. These can be tile or open drain systems	• If a closed system, no forgone cropping land • Discharged water can be relatively fresh (depends on the landscape) • Reduces waterlogging and salinity	• Usually high installation cost • Requires periodic maintenance for high performance • Prone to clogging	• Only a few systems have been formally evaluated for different locations in the Wheatbelt landscape. • Gap in literature on the potential use as an alternative non-potable water source	• South Coast NRM (2024) • Ali & Coles (2001) • Abduljaleel et al. (2023) • Priyadharshini et al., (2023) • Stuyt & Dierickx (2006)

More recently, there has also been growing interest in utilising other sources of water in the landscape for non-potable purposes. In some regions, duplex soils experience seasonal waterlogging, where a perched aquifer forms in the sandy topsoil, overlying a less permeable clay layer (South Coast NRM, 2024). In this situation, crops become waterlogged, leading to production losses and challenges in accessing paddocks to undertake maintenance, pest and disease control, and in-season crop nutrition via tractor-based spraying (Kinal & Stoneman, 2012; Wood, 1924). One solution has been to use subsurface drainage to remove excess water from frequently waterlogged soil profiles. It represents a potential source of non-potable farm water where drained water can be directed into farm dams. Table 1, summarises literature on runoff treatments for non-potable water harvesting systems, highlighting what is already known, tested methods, and research gaps. As shown in Table 1, and noted previously, there is a gap in current research and literature, specifically regarding the potential of lining RCs - particularly given the trajectory of the drying climate in this region and the shift to lower-intensity rainfall events.

Project Context and Motivation

WaterSmart Farms is a multi-year initiative launched in 2021, led by the Department of Primary Industries and Regional Development (DPIRD). The project aims to enhance water security and climate resilience in Western Australia's agricultural regions by exploring innovative water management technologies (DPIRD, 2023). Key focus areas include the adoption of on-farm desalination plants to process brackish groundwater into suitable resources for livestock and crop agronomy, optimising desalination technology in the Wheatbelt and Great Southern regions, and developing improved methods for capturing, harvesting, and storing water in farm dams to meet industry needs (Government of Western Australia, 2023).

The WaterSmart Dams project is part of the suite of solutions under the WaterSmart Farms umbrella program. The Centre for Water and Spatial Science at the University of Western Australia (UWA) provided technical leadership for this project, in collaboration with the Grower Group Alliance (GGA), the South-West WA Drought Resilience Adoption and Innovation Hub, DPIRD, grower groups, and on-farm demonstration site hosts. WaterSmart Dams aimed to investigate solutions to improve dam functionality during dry years. Activities include improving existing dam catchments, constructing new ones, and implementing runoff technologies (as described in this report), as well as evaluating evaporation reduction methods (see the accompanying WaterSmart Dams Evaporation Technical Report).

The project collaborates with several grower groups hosting on-farm demonstration sites and extending project outcomes to the farming community, including Compass Agricultural Alliance (Darkan), Southern Dirt (Kojonup), Merredin and Districts Farm Improvement Group (Merredin), and the Fitzgerald Biosphere Group (Jerramungup). Through the overall WaterSmart Dams project, we have established 12 demonstration sites across the dryland agricultural areas in the south-west of Western Australia, classified as receiving less than 600mm of annual rainfall. These sites showcase potential methods to increase on-farm potable water supplies for farmers, such as evaporation suppression technologies, lined and roaded (enhanced) catchments, and alternative water sources, including subsurface drainage systems.

This report focuses on the surface water and subsurface drainage sites. For information on evaporation suppression mechanisms tested, please refer to the WaterSmart Dams Evaporation Technical Report.

1.2 Key questions

The project explores two methods for on-farm non-potable water security, surface and subsurface water harvesting options. Within this, two hypotheses are posed:

- Can tarpaulin and plastics harvest water from low intensity rainfall where other existing methods cannot, and enhance on-farm water security?
- Can subsurface drain in locations with waterlogging and higher in the landscape harvest a high quality and reliable supply of water?

For these two key areas of investigation, we have benchmarked options and produced an evaluation of the costs of water to understand if they are an economically viable and practical solution for farmers.

This technical report provides the scientific basis for the Water Evaluation Platform (WEP): https://waterevaluationplatform.app/dam/, a non-potable water planning tool developed by the UWA Centre for Water and Spatial Science, as part of the WaterSmart Dams project. The analysis and results presented in this report form the basis for default settings and recommended parameters for various catchment types used in WEP.

2 Methods

2.1 Location

2.1.1 Map of WSD Sites

The study sites are located across the broader Wheatbelt region of south-west Western Australia, covering locations from Salmon Gums on the eastern fringe to Kojonup and Scotts Brook in the west, with Jerramungup representing the southernmost extent and Hines Hill the northern (Figure 2). These sites span a diverse range of rainfall zones and landscapes, capturing the variability within the Wheatbelt region. The climate is characterised by hot, dry summers and cool, wet winters (Baek & Coles, 2013a, Prober & Smith, 2009). Rainfall distribution varies significantly across the region, with southern and southwestern sites such as Kojonup, Gardiner, Darkan, and Scotts Brook receiving between 600 and 700 mm annually, moderate rainfall of around 440 to 460 mm at Jerramungup, and drier conditions of approximately 320 to 400 mm in eastern zones like Salmon Gums (BoM, 2024). This variability plays a critical role in determining water availability and the effectiveness of water harvesting strategies across different sites.

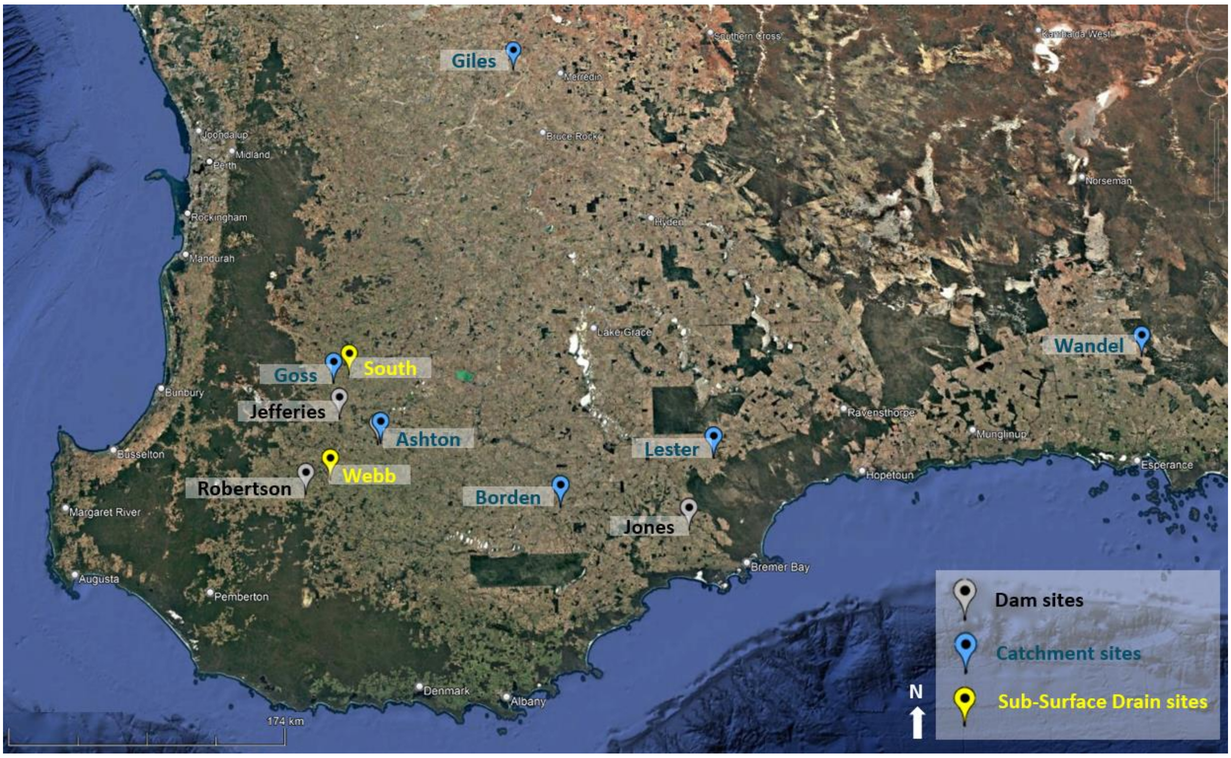


Figure 2. Satellite image of WSD sites across the South-West Wheatbelt region. Background image source – Google.

2.1.2 Benchmarking the 2023 and 2024 Rainfall Seasons

To provide context for interpreting runoff and catchment results discussed in this report, rainfall in 2023 and 2024 was benchmarked to determine whether these seasons were typical or anomalous in terms of recent annual rainfall. For this study, we adopt the period since 2000 to represent long-term (current) average rainfall conditions for the region, based on the work of Alilou et al. (2022), who demonstrated evidence for a regional shift in hydro-climate around 1975 and again in 2000. For completeness, we include benchmarking against rainfall data from 1975 to 2024, using both a longer-term (1975–2024) and a more recent (2000–2024) baseline to represent the “average” climate of the region. Gridded SILO rainfall data were used to perform this analysis individually for each site, as well as across the average of all eight sites to provide a representative snapshot of the Wheatbelt (SILO, 2025). These locations span the northern, eastern, southern inland, and coastal zones of the study area, capturing the region’s rainfall variability. Decile classifications follow the Bureau of Meteorology’s system (BoM, 2024):

- Decile 1–3: Very much below average to below average
- Decile 4–7: Average
- Decile 8–9: Above average
- Decile 10: Very much above average

2.2 Data collection

Each site was instrumented to measure instantaneous rainfall data and water level data. The type and precision of equipment did vary across sites (Table 2).

Table 2. Monitoring equipment, make/type, and precision used at each WSD site.

Site	Type of site	Rain Gauge Configuration	Flume or Weir Type	Water Level Instrument and precision
Lester	Enhanced catchment	0.1, Kisters MiniLog	V-notch	3.5m In-Situ Water Level LT500
Borden	Enhanced catchment	0.2, Kisters MiniLog	V-notch	3.5m In-Situ Water Level LT500
Wandel	Enhanced catchment	0.2, Kisters MiniLog	18 Inch Parshall Flume	3.5m In-Situ Water Level LT500
Giles	Roaded catchment	0.2, Kisters MiniLog	V-notch	3.5m In-Situ Water Level LT500
Goss	Roaded catchment	0.2, Kisters MiniLog	V-notch	3.5m In-Situ Water Level LT500
Ashton	Subsurface drain	0.2, Kisters MiniLog	11-inch Parshall flume	11m In-Situ Water Level LT500
South	Subsurface drain	0.2, Kisters MiniLog	11-inch Parshall flume	11m In-Situ Water Level LT500
Webb	Subsurface drain	0.2, Kisters MiniLog	V-notch	11m In-Situ Water Level LT500

2.2.1 Rimco Tipping Bucket Rain Gauge

All sites were fitted with RIM-7499-BOM tipping bucket rain gauges (0.1/0.2 mm resolution; Campbell Scientific, Queensland, Australia). Gauges were mounted on stable poles at a standard height and positioned away from livestock to avoid false tipping. They were then manually levelled with a digital spirit level to within 0.05°. Rain gauges were installed at surface water monitoring points except at Ashton and Giles, where they were placed on the dam bank near weather station infrastructure (see WaterSmart Dams Evaporation Technical Report). These locations remained close to the monitoring sites and did not affect data accuracy.

Each rain gauge records rainfall via a tipping mechanism, logging a timestamp each time the bucket tips once the predefined volume threshold (0.1 mm or 0.2 mm) is reached. Data were stored using MiniLog ML1A-FL loggers (Kisters, Perth, Australia) and downloaded in the field with WinComLog - MiniLog Configuration Software. Processing methods are detailed in Section 2.4.1. Each site was calibrated and checked after installation and levelling using a Kisters Portable Field Calibration Device (FCD-314 with 50mm/hr simulated rainfall rate), ensuring that the rain gauge was within the manufacturer's specification (all tests <2 tips of error, across three tests).

2.2.2 V-notch weir

Sites with a V-notch weir (Table 2) consisted of a stainless-steel and aluminium V-notch plate cut as a 45° notch and finished with a 45° chamfered edge, attached to an upturned concrete culvert (Figure 3). Structures were installed at the primary flow accumulation point within each catchment to accurately capture surface runoff. Discharge was recorded using a vented In-Situ

Level Troll 500 (3.5 m) water level logger (In-Situ Inc., USA), mounted inside a perforated PVC pipe fixed to the weir's sidewall to allow unrestricted water ingress. The logger uses a pressure sensor to measure water height, with an accuracy of ±0.05% full scale, equivalent to ±1.75 mm for the 3.5 m range.

At installation, the logger's zero datum was set to 0 m, corresponding to the base of the culvert under dry conditions, and reset accordingly in the field. A site-specific rating curve, based on the V-notch dimensions, was applied to convert water level data to discharge (Appendix 1). Discharge (L/s) was calculated only when water levels exceeded the V-notch base, requiring raw logger data to be offset so that the zero-reading aligned with the true no-flow point. The procedure for calculating discharge is outlined in Section 2.4.2.

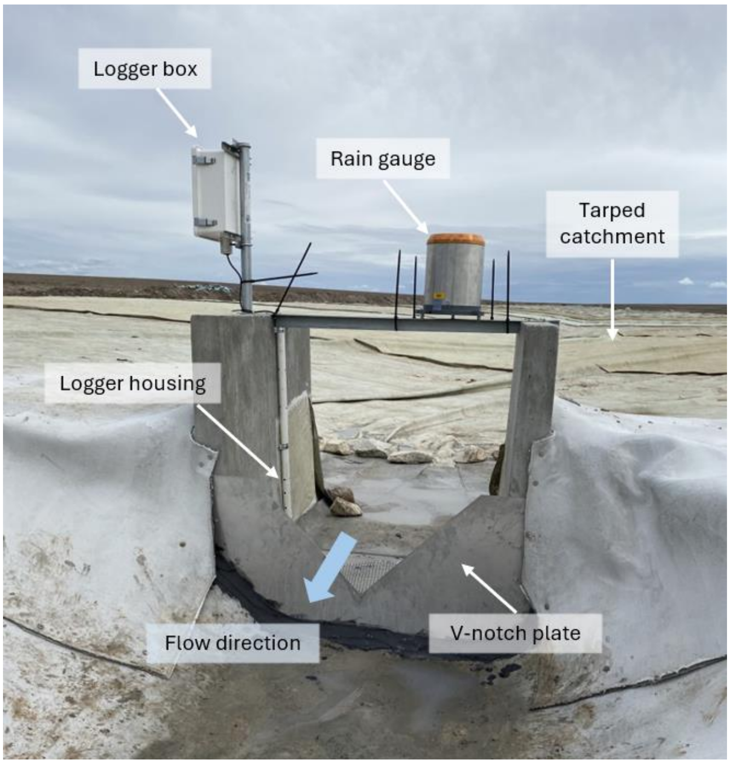


Figure 3. Lester PVC lined catchment site, labelled picture of standard v-notch weir set-up

2.2.3 Parshall flume

Parshall flumes determine discharge by measuring water depth at the throat, where critical flow conditions establish a known relationship between depth and flow rate. These flumes are better suited for low to moderate flows, such as sites with a single sub-surface drain (Ashtons and Southern), where fine precision for measurement is critical (see Table 2, outlining which sites had a Parshall flume). Discharge was recorded using a vented In-Situ AquaTROLL 200 (3.5 m) water level logger (In-Situ Inc., USA), which includes a pressure sensor for water height and also measures electrical conductivity (salinity of discharge water). The logger was housed in a PVC pipe connected to the flume throat via a passage to allow water ingress (Figure 4).

The logger was calibrated to zero at the base of the flume, where 0 m corresponds to no flow. Discharge (L/s) was calculated using a flume-specific rating curve based on Parshall flume hydraulics under critical flow conditions (Appendix 1). Data were typically downloaded without adjustment, as the zero point aligned with the flume throat in the field. The process for converting water level measurements to discharge is outlined in Section 2.4.2.

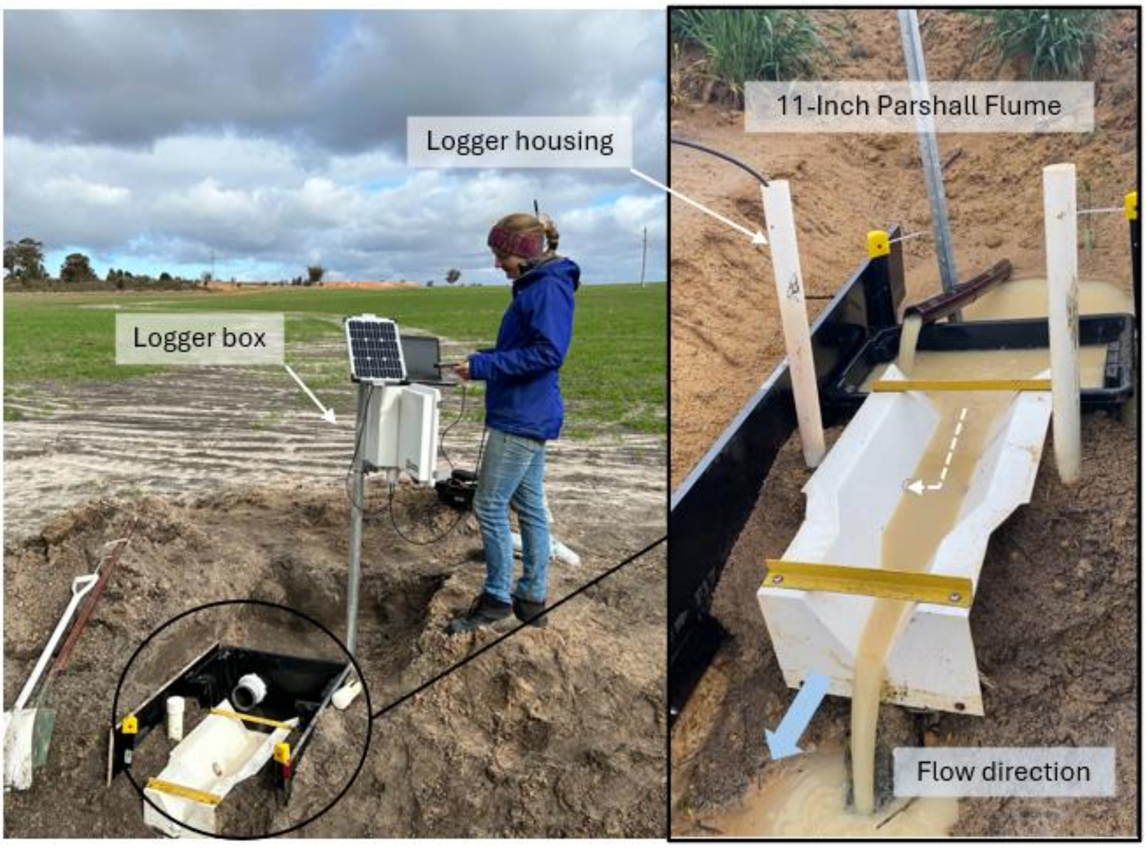


Figure 4. Standard 11-Inch Parshall Flume set-up, Ashtons site with Dr Bonny Stutsel next to logger box conducting the first data download (07/06/2023) (left) and Souths site (right).

2.3 Site description

2.3.1 Giles Roaded Catchment

The Giles site is situated near Merredin, within the Wheatbelt region of Western Australia (refer to Figure 1). An RC was discussed and installed as a collaboration between the owner and an earthmoving contractor on 30 August 2023. A 15,600 m^2 paddock was cleared, compacted, and shaped into five V-shaped troughs distributed across the surface. Flow is directed toward a previously renovated dam.

This site lies within the Booran erosional land system, which is characterised by medium- to fine-textured soils with low permeability. Consequently, the area is prone to runoff and sheet flow, resulting in high volumes of loose sediment that interfere with the operation of water flow monitoring equipment (Bettenay et al., 1964). A V-notch weir was installed at the lower end of the rightmost trough (from a bird's-eye view) (Figure 5), which drains a 3,274 m^2 portion of the catchment. Total catchment discharge is therefore estimated by scaling measurements from this trough by a factor of 4.76.

Figure 5. Satellite image of Giles roaded catchment, culvert and dam system, 2025(left). Drone image looking up the roaded catchment (right-top) and the V-notch weir and logger box (right-bottom).

2.3.2 Goss Roaded Catchment

The Goss site is situated near Darkan, within the Wheatbelt region of Western Australia. On 16 April 2024, monitoring infrastructure was installed on two pre-existing catchments to evaluate the effects of different land management practices on surface runoff. The primary objective was to assess the influence of best-practice management strategies against a ‘do nothing’ approach without any additional interventions.

Two catchments were delineated: Catchment 1 (C1), which remained untreated (‘do nothing’), and Catchment 2 (C2), representing best practice, was graded, rolled, and sprayed for weed control (Figure 6).

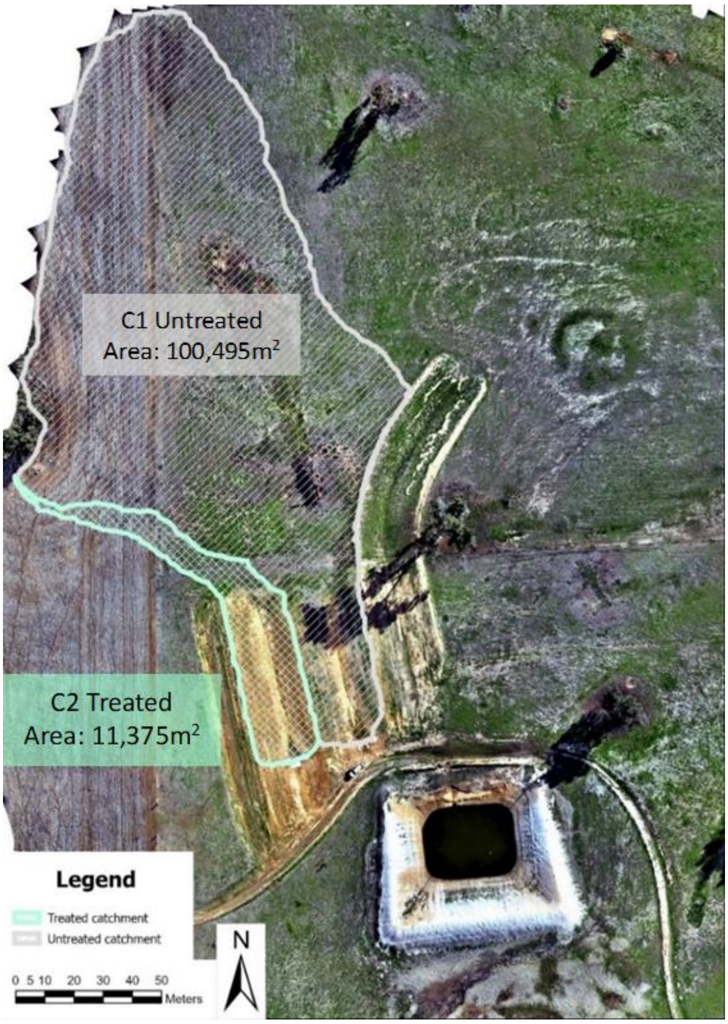


Figure 6.Satellite image of the Goss dual catchment system, with the Digital Elevation Model (DEM) outlining calculated catchment size, C1 untreated (brown) and C2 treated (Green).

Initially, both catchments were presumed to have comparable areas, facilitating direct comparison. However, subsequent analysis using a Digital Elevation Model (DEM) revealed significant discrepancies in catchment sizes (Figure 6). C1 drains from a significantly larger area higher up in the landscape, encompassing a total area of 100,495 m^2, whereas C2 covers 11,375 m^2. This variation in catchment area complicates the direct comparison of discharge volumes between the two sites. Both catchments were equipped with V-notch weirs to measure surface runoff, and a tipping bucket rain gauge was installed at C2 to record instantaneous rainfall data.

2.3.3 Lester PVC tarped catchment

The Lester site is situated near Jacup, within the Wheatbelt region of Western Australia. A previously RC, approximately 15,000 m^2 in area, was reduced to 6,545 m^2, and its surface was enhanced using secondhand PVC grain tarps (
Figure 7). The tarpaulin was installed on 31 March 2023. The site is a community emergency water supply, managed by the Department of Water and Environmental Regulation in partnership with the Lester family, whose property the catchment, dam and tank infrastructure is located on.

Prior to installation, the roaded surface was graded and reshaped into a shallow V-profile before being smoothed. Eighteen tarps were stitched together by Elpha Contracting to cover the catchment, with an additional two tarps used to secure the ends. The tarp edges were anchored in trenches, backfilled, and weighted with rocks to prevent wind uplift. The perimeter was fenced to exclude livestock and prolong the lifespan of the tarps. Plastic and life cycle testing of the tarps was conducted at this site. Additionally, a V-notch weir and a rain gauge were installed at the catchment's accumulation point.

Figure 7. Drone image of WSD Lester site tarped catchment system, May 2023

2.3.4 Wandel PVC tarped catchment

The Wandel site is situated near Grass Patch, within the Wheatbelt region of Western Australia. On 13 March 2024, an 8,360 m² paddock was cleared, and the surface was smoothed; no V-shaped contouring was applied. Twenty-five secondhand PVC grain tarps in good condition were laid and stitched together by Elpha Contracting to cover the catchment area (**Error! Reference source not found.**). The tarp edges were anchored in trenches, which were then backfilled to prevent wind uplift. Cut tyres were placed along the seams to aid in flattening and prevent lifting of the surface by wind. The perimeter was fenced to exclude livestock and extend the lifespan of the tarps. An 18-inch Parshall flume and a rain gauge were installed at the catchment's accumulation point. Runoff from the catchment is directed into a sump, which, once filled, overflows into a pre-existing dam.

Figure 8. Satellite image of Wandel site PVC tarped catchment system, 2025

2.3.5 Borden High Density Polyethylene catchment

A high density polyethylene (HDPE) catchment near the town of Borden was evaluated as by instrumenting a previous research site, with data from 13 September 2024. An 8,877 m^2 section of the bituminised catchment was overlaid with HDPE plastic material (Figure 9). The surface is flat, with no V-shaped contouring, and follows a natural, slight downslope in the landscape. HDPE "sausages" (effectively plastic-welded together HDPE sandbags) are placed on top of the HDPE surface to stop the impact from wind. The catchment edges were anchored in trenches and backfilled to prevent wind uplift. A V-notch weir and a rain gauge were installed at the catchment's accumulation point and re-instrumented for this study.

Figure 9. Drone image of Borden High Density Polyethylene catchment, September 2024.

2.3.6 Ashtons Subsurface Drainage System

The Ashtons site is situated near Kojonup, within the Wheatbelt region of Western Australia. The Ashtons installed the tile-style subsurface drainage system in autumn 2023, and data monitoring commenced on 7 June 2023. The primary objective of the system was to reduce waterlogging in the paddock, enabling increased crop yield and improved access to the field during the winter season for weed control and nutrient delivery.

The soil profile consists of loamy sand overlying a clay subsoil. To establish the system, they used a grader to excavate a single trench up the slope of the paddock. In the trench, they laid a socked agricultural pipe, then backfilled. The pipe terminates in a contour bank located at the base of the slope, which in turn drains into a key dam (see, WaterSmart Dams Evaporation Technical Report). An 11-inch Parshall flume was installed at the drainage system's outlet to measure discharge and electrical conductivity (salt load), and a rain gauge was located at the key dam to record rainfall (**Error! Reference source not found.**).

Figure 10.Photograph of Ashton's site 11-inch Parshall flume outlet with the insert photo showing the style of agricultural pipe used

2.3.7 Webb Subsurface Drainage System

The Webb site is situated near Qualeup, within the Wheatbelt region of Western Australia. The tile drain was installed at the site in May 2023, with data collection commencing on 3 April 2024, following the completion of final surface works and culvert installation. The primary objective was to reduce waterlogging within the paddock.

The tile drains were installed with a "SoilMax" tile plough. The tile plough excavates trenches at a predetermined depth to achieve the desired slope, simultaneously laying agricultural pipe as it progresses. Once laid, the trenches are backfilled to restore the paddock's trafficability (Figure 11). The pipe terminates at a sediment basin, which must fill before it flows through a 15-inch pipe to a V-notch weir (Figure 12). Discharge is measured at the weir before the water enters a dam, which is used for sheep drinking water. This site also had a rain gauge installed.

Figure 11. Photograph of the "Soil Max" tile plough installing pipe behind a DGPS-guided tractor during a demonstration field day (note – photo is not at the Webb property, but from a field day).

Figure 12. V-notch weir setup at Webbs (left), Four tile drains ending at the sump above the dam (centre), Tile drain running on 20/8/2025 (right).

2.3.8 South's Open Subsurface Drainage System

The South site is situated near Darkan, within the Wheatbelt region of Western Australia. The open V subsurface drainage system was installed on 12 July 2023, with data monitoring commencing on 1 August 2023. The system was designed to increase water capture in a key dam, including draining waterlogged areas and interception of throughflow and the perched seasonal aquifer on the duplex soils. The V drains end at a riser that connects to an agriculture pipe that directs flow to an outlet that is equipped with an 11-inch Parshall flume for measuring discharge and a rain gauge for recording rainfall (Figure 13). A contour bank channels flow from the discharge point to the nearby dam.

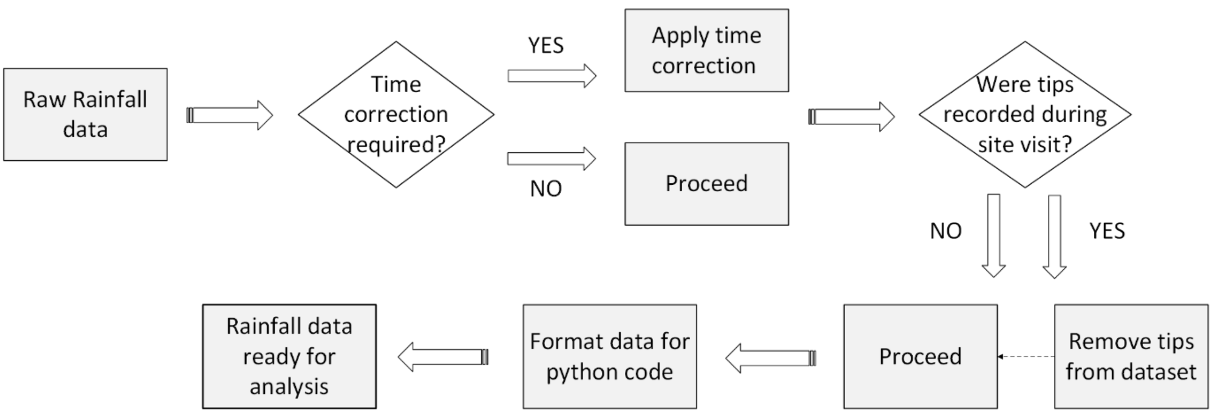
Figure 13. Left: South's site open V subsurface drainage system. Right: Ground-level image of the 11-inch Parshall flume and rain gauge monitoring equipment.

2.4 Data preprocessing

Below outlines the steps required to transform raw data downloaded from field loggers into a usable format for hydrological analysis. Both rainfall and water level datasets undergo a series of corrections and standardisations to ensure accuracy and consistency.

2.4.1 Rainfall Data Processing

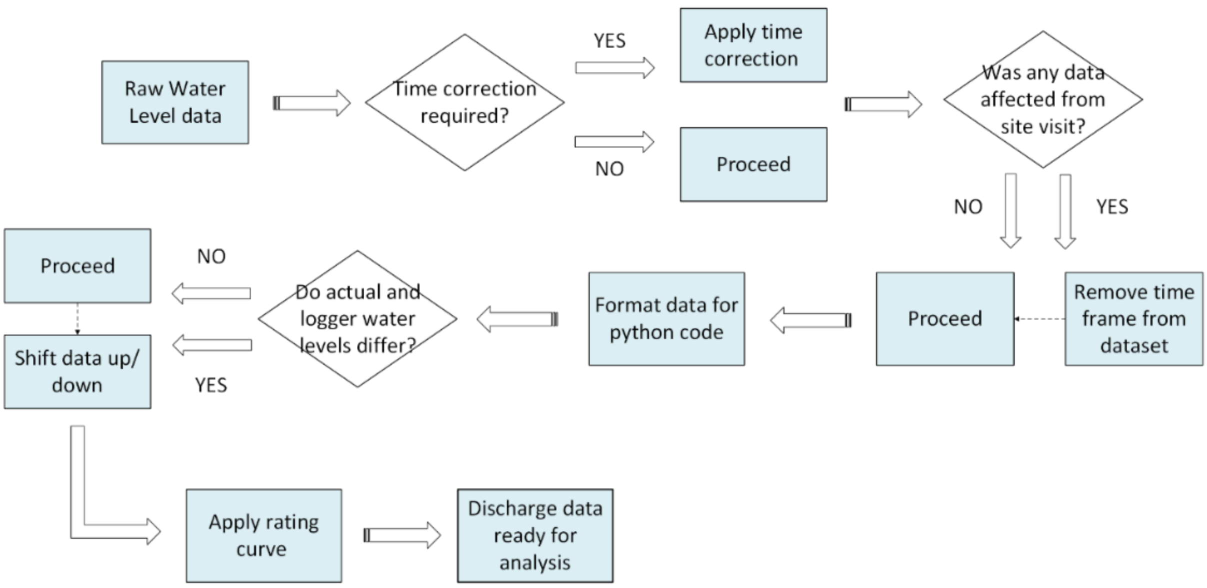
False tips were removed, and time corrections applied when necessary. If the deviation between the logger and actual time exceeded 10 seconds per month, a correction was performed. This adjustment is particularly important at catchment sites where timing is critical to determining the sites rainfall threshold.



2.4.2 Water Level Data Processing

Data collection and correction methods used in this study are applied by the UWA Centre for Water and Spatial Science in all work and based on best practice derived from various sources including the Western Australian Department of Water and Environmental Regulation (DWER) document HYD0101 (Water and Rivers Commission, 1996), US Geological Survey (USGS) manuals on stream gauging, ISO standards, British Standards, and World Meteorological Organisation methods. All data downloaded and quality controlled, including manual removal of false data created by inadvertent actions while flushing, cleaning and calibrating equipment. Time corrections were applied where needed, as accurate timing is critical for analysing catchment surface water dynamics.

Manual water level measurements, where available, were compared to logger data. Discrepancies were corrected by uniformly shifting the dataset. Water levels were then converted to discharge (L/s) using a site-specific rating curve (Appendix 1).

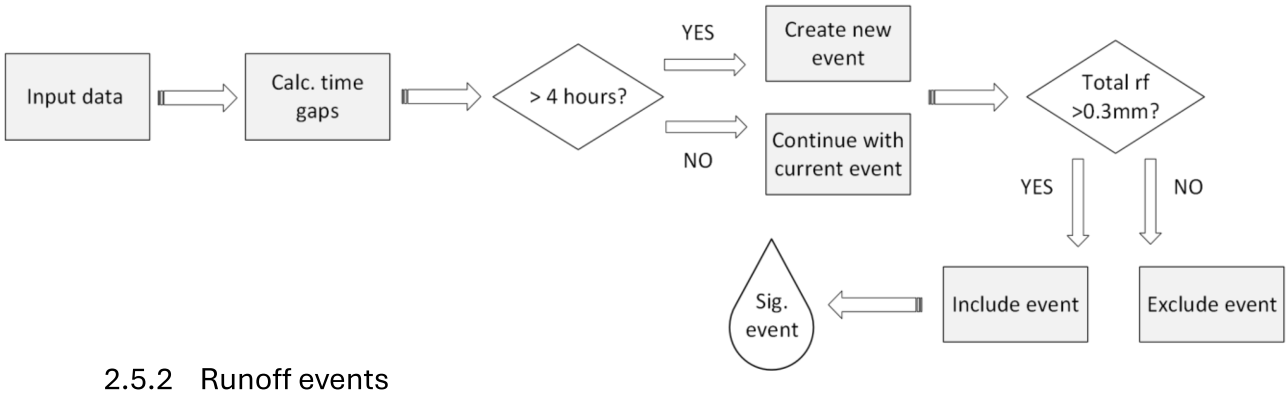


2.5 Data analysis - Catchment Sites

The analysis of data from demonstration sites (Lester, Wandel, Borden, Giles, and Goss) focused on rainfall, including the identification of specific events that caused runoff. Scripts were used to classify individual rainfall and runoff events to calculate both thresholds and event totals. The dataset was then analysed to determine average conditions leading to runoff and to calculate runoff efficiency (runoff coefficient). This study used tip-based rainfall data with a resolution of seconds and event-logged runoff (water level) data recorded at minute intervals. The results were also considered in terms of daily rainfall totals to test how well the event-based findings translate into daily results for water planning tools, such as the Water Evaluation Platform.

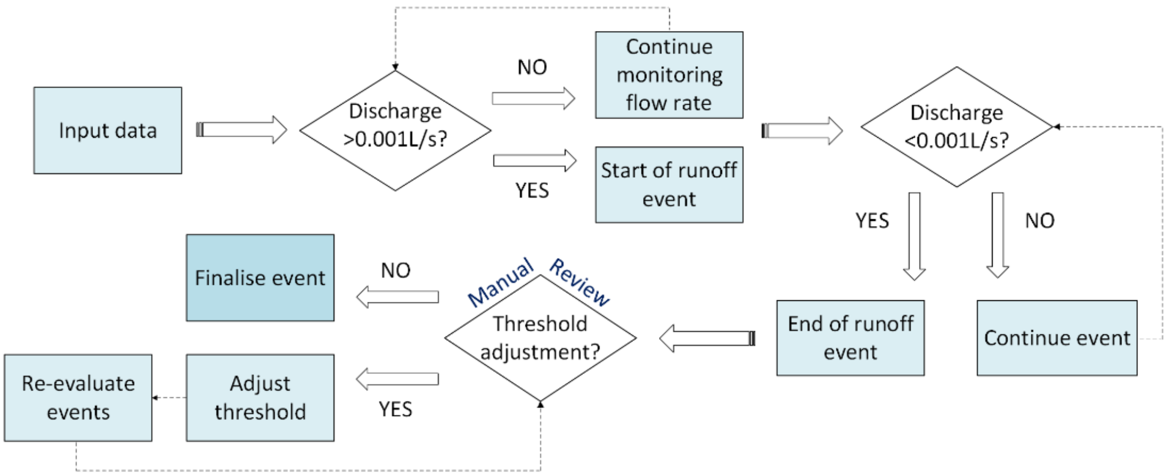
2.5.1 Rainfall events

An individual rainfall event was defined by a time gap between consecutive measurements of at least: 4 hours for enhanced catchment sites (Lester, Borden, and Wandel) and 6 hours for traditional RCs (Giles and Goss). The 4-hour threshold is a figure used by other work within this region and considers the local rainfall patterns in identifying a suitable time interval to define separate events (Hossain et al., 2020; Timbal, 2004). The extended 6-hour threshold accounts for the influence of antecedent wetness on runoff generation in roaded systems (Brocca et al., 2008). Events with less than 0.3 mm of rainfall were excluded based on preliminary data investigation at our sites, as such small totals do not generate measurable runoff (Coles et al., 1997; Li et al., 2004).



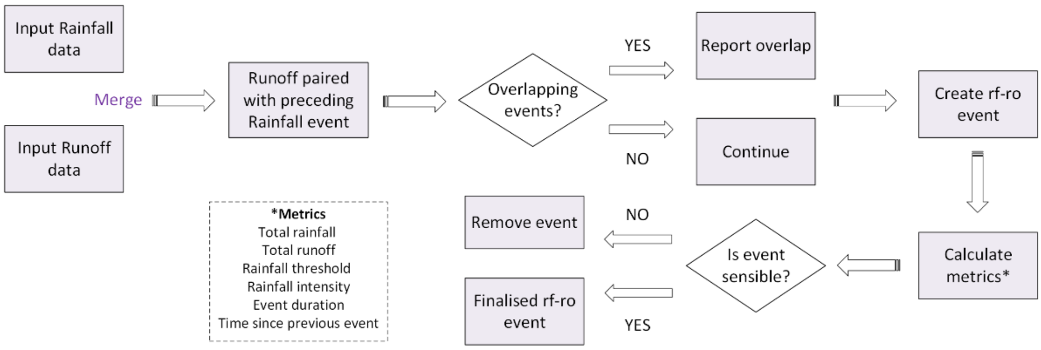
2.5.2 Runoff events

At each time step, the flow rate is compared against a predefined threshold of 0.001 L/s to identify runoff initiation. An event concludes when the flow first falls below the corresponding end value. After processing, each rainfall–runoff event is manually reviewed to ensure the start and end times are accurate. While the 0.001 L/s threshold is generally appropriate, it is occasionally increased to exclude minor flows, such as small trickles over the V-notch caused by wind-induced fluctuations in water level within the full culvert, which do not represent true runoff initiation or total event discharge.



2.5.3 Rainfall-runoff events

Rainfall–runoff events were created by matching each runoff event to the nearest preceding rainfall event, ensuring that rainfall contributing to catchment wetting and runoff initiation was included. When multiple runoff events occurred within a single rainfall event due to level fluctuations around the flow threshold, the earliest start of runoff and the latest end of runoff were used to define the full event duration. Unmatched or overlapping rainfall–runoff pairs were manually reviewed and excluded if they were invalid, resulting in a final dataset of distinct, validated rainfall–runoff events for analysis.



2.5.4 Rainfall threshold

The rainfall threshold refers to the minimum amount of rainfall required before runoff begins from the catchment (Baek & Coles, 2013). For each rainfall–runoff event, total rainfall is measured from the start of the rainfall event to the start of the runoff event, representing the threshold to initiation for each rainfall-runoff event. These values are averaged to determine the overall catchment rainfall threshold. Calculated thresholds are validated against established literature values; if discrepancies arise, the data, along with its processing, are reviewed and revised to ensure accuracy.

2.5.5 Runoff coefficient

A runoff coefficient is a value representing the proportion of rainfall that becomes runoff. It provides insight into how effectively a catchment converts rainfall into discharge. Two methods were used for calculating the runoff coefficient.

2.5.5.1 Simple Method

This method calculates the runoff coefficient as the ratio of total discharge to total rainfall over a given period. This value represents the fraction of rainfall that contributes to runoff.

$$Runoff\ coefficient = \frac{\text{Total Discharge (mm depth)}}{\text{Total Rainfall (mm)}} \tag{1}$$

2.5.5.2 Regression Method

This study applied a method based on Li et al. (2004), adapted initially from Frasier (1975) and Diskin (1970). This approach analyses individual rainfall-runoff events by plotting total rainfall (x-axis) against total discharge (y-axis). A linear regression model is then fitted to the data, where the slope of the regression line represents the runoff coefficient. The regression equation takes the form:

$$Depth\ of\ Runoff = Slope * Rainfall\ (mm) + intercept \tag{2}$$

2.6 Data Analysis - Subsurface Drain Sites

The following analysis was conducted on sites with subsurface drainage systems: Ashton, South, and Webb.

Rainfall (mm), runoff volume (L), and average salt load (kg/L) were calculated over defined time periods. Where data allowed, equivalent time periods were selected across years at each site to enable direct comparison and assess year-to-year reliability or variability. Instantaneous rainfall and runoff values were summed to determine total volumes for each period.

Flow-weighted mean salinity as average salt load was calculated by summing the total salt mass transported during flow periods and dividing by the total discharge volume. Salt mass (g) was computed as the product of discharge (Q) and salinity (g/L), using only data where flow occurred.

$$Average\ Salt\ Load\ \left(\frac{g}{L}\right) = \frac{\sum(Q * Salinity)}{\sum Q} \tag{3}$$

2.7 Data Analysis - Cost per kilolitre of catchment surfaces

A cost-benefit analysis of various surface water catchment types was conducted using a scenario-based approach, drawing on data from the Lester catchment site at Jacup. Each scenario varied the surface type while using consistent catchment area and rainfall data. Rainfall-runoff thresholds for each surface type were derived from demonstration sites within the project.

- For the roaded catchment, an 8 mm threshold was applied based on anecdotal evidence from the Giles site.
- For plastic-lined catchment scenes (PVC grain tarpaulins and HDPE), a 1 mm threshold was used as these surfaces had rainfall thresholds across the project of 0.8–1 mm.

These thresholds reflect site-specific performance from the demonstration site within this project rather than average material performance across many catchments. For example, the 8 mm threshold for the Giles roaded catchment was reported by the site host, and based on experience across the wheatbelt, it represents a higher-performing site. Roaded catchments typically have a rainfall threshold for runoff in the range of 8 to 12 mm. HDPE and PVC generally had similar rainfall thresholds in this project (0.8–1 mm). However, site design factors such as slope, water pooling, and evaporation significantly influence actual performance and threshold values.

In this analysis, we applied consistent rainfall thresholds across both new and existing surface types for tarpaulins and roaded catchments. This simplification is intentional, as the primary aim of these scenarios is not to precisely model water yield, but to explore the relationship between investment and lifespan. By dividing annualised costs by hypothetical water harvested, the analysis focuses on comparing the long-term cost-effectiveness of different technologies.

Each scenario considered upfront infrastructure costs, maintenance, and lifespan to calculate an annualised cost. This was then divided by the hypothetical volume of water captured to estimate a price per kilolitre (kL). This simplified method aligns with the Water Evaluation Platform (WEP) approach, drawing on Kingwell & Bennett (2024), WSD site cost data, and insights from industry professionals and scientific literature.

Scenario site assumptions:

- Jacup Catchment Area: 0.65 ha.
- Closest Standpipe Distance: 38 km (owned by the Shire of Jerramungup).
- Rainfall and Surface Water Data Period: May 2023– May 2024.

To calculate the hypothetical total amount of water captured by each surface, we used rainfall data collected from the Jacup site from May 2023 to May 2024. Following the method described in Coles et al. (2011) for determining runoff, rainfall events exceeding the catchment type threshold were summed to calculate the total amount of rainfall (in mm) that theoretically fell on the site and could be collected by the catchment. This total rainfall was then multiplied by the catchment area and reduced by 20% to account for evaporation and trapped water. The result represents the hypothetical total amount of water captured by the catchment over the given period.

The total water yield was calculated as:

$$Water\ yield = \left(\frac{Total\ Rainfall}{100}\right) \times\ Catchment\ Area\ \times 0.80 \tag{4}$$

Costing

Table 3: Costing assumptions from the WSD site, other resources and reports.

Scenario	Cost Components	Value	Reference
Standpipe Water Supply	Water cost	\$9.687/kL	Water Corporation (Jerramungup step 15 - Regional fixed standpipes charges 2025-26)
	Transport cost	\$0.30/km × 38 km	Kingswell & Bennett (2024)
Roaded Catchment	Construction cost	\$420,000-\$1,713,994/km^2 × 0.006545 km^2	Kingswell & Bennett (2024) and WSD Site
	Lifespan	40 years	Kingswell & Bennett (2024)
	Annual maintenance	\$2,000/year	Kingswell & Bennett (2024)
New Grain tarpaulin lined Catchment	Preparation cost	\$17,847	WSD Site
	Tarps	\$3,500 × 20	WSD Site
	Installation	\$16,150	WSD Site
	Fencing (labour + materials)	\$2,708 + \$1,472	WSD Site
	Lifespan	7-10 years	Tarpaulin contractors
	Maintenance	\$100	Time spent looking over the catchment & patching up
	Replacement cost	(\$3,500 × 20) + \$16,150	WSD Site WSD Site(cost of tarps + installation)

Scenario	Cost Components	Value	Reference
Secondhand Grain tarpaulin lined Catchment	Tarps	$150 × 20	WSD Site
	All other costing as new sceanrio		WSD Site
	Lifespan	5-7 years	Tarpaulin contractors
	Maintenance	$100	Time spent looking over the catchment & patching up
	Replacement cost	($150 × 20) + $16,150	WSD Site (cost of secondhand tarps + installation)
HDPE	Construction cost	$9,000,000/km^2 × 0.006545 km^2	Water Corporation advice
	Lifespan	30	Earth Shields = HDPE provider (10-50 years)
	Maintenance	$200	
South Drain	Construction cost	$20,143	WSD invoice
	Lifespan	25 years	Knights (2024)
	Maintenance	$402/year	Willsher, 2024; Wanchuck & Apedaile, 1988) = 2% of construction cost
Ashtons Drain	Construction cost	$10,991	WSD Site
	Lifespan	25 years	Knights (2024)
	Maintenance	$219/year	Willsher, 2024; Wanchuck & Apedaile, 1988) = 2% of construction cost
Webb Drain	Construction cost	$13,651	WSD Site
	Lifespan	25 years	Knights (2024)
	Maintenance	$273/year	Willsher, 2024; Wanchuck & Apedaile, 1988) = 2% of construction cost

Cost per kilolitre

For each scenario, the cost per kilolitre (kL) was determined using the following method:

Catchment Systems (Roaded, Grain Tarpaulins, Drainage):

$$Annualised\ Cost = \frac{Construction\ Cost}{Lifespan} + Annualised\ Maintenace\ Cost \tag{5}$$

$$Cost\ per\ kL = \frac{Annualised\ Cost}{Annual\ Water\ Yeild} \tag{6}$$

Replacement Costs (if applicable e.g., Grain Tarpaulins):

$$Total\ Annual\ Cost = Annual\ Cost + \frac{Replacement\ Cost}{Lifespan} \tag{7}$$

Carting Water

Cost of water at the standpipe plus the cost to transport the water

$$Total\ \$\ per\ kL = Water\ Cost + (Transport\ Cost\ per\ km\ \times\ Distance) \tag{8}$$

3 Results

3.1 Site Hydroclimate Benchmarking

Rainfall conditions during the study period were consistently dry across the Wheatbelt, with 2023 classified as very much below average at all sites, and 2024 also falling below average in most areas. These dry conditions were broadly consistent across the region, though some patterns emerged. The southern and southeastern sites, including Wandel (near Esperance), Lester (Jacup), and Borden, experienced some of the driest conditions overall, particularly in 2023. Similarly, sites near the Darkan region, including Ashton (Kojonup), Goss, and South, also recorded low rainfall in 2023, mostly in decile 1 or 2. In contrast, Giles, located in the eastern Wheatbelt (Merredin), recorded higher totals in 2024, ranking in decile 6 and 7, likely due to one or two isolated heavy events rather than a broader seasonal shift. Despite this variability, no sites recorded average or above-average rainfall in either year.

The average across all sites, our snapshot of the wheatbelt, found that 2023 was classified in decile 1 across both baselines, indicating very much below average rainfall. 2024 also fell within the very much below average to below average range, ranking in decile 2 (long-term) and decile 3 (recent). These results are summarised in Table 4.

These results confirm that both seasons were considerably drier than average, and this context should be taken into account when evaluating hydrological performance during this period.

Table 4. Rainfall decile benchmarking years 2023 and 2024 across the 8 study sites.

Site	1975-2024 Average (mm)	2000-2024 Average (mm)	2023 Rainfall			2024 Rainfall		
			Rainfall (mm)	Decile (long-term)	Decile (recent)	Rainfall (mm)	Decile (long-term)	Decile (recent)
Lester	453	443	319	2	2	328	2	3
Borden	370	364	301	4	5	260	1	1
Wandel	379	382	263	1	1	285	2	2
Giles	304	291	227	2	3	296	6	7
Goss	467	465	353	2	2	448	5	6
Ashton	459	440	339	1	1	370	2	3
South	453	443	329	2	2	408	5	5
Webb	516	500	402	2	2	419	3	3
Average	422	415	317	1	1	352	1	2

3.2 Roaded Catchment Sites

3.2.1 Giles

Data from monitoring of the Giles site (30 August 2023 and 12 February 2025) found that total discharge from the monitored part of the RC structure was 0.54 ML from 374 mm of total rainfall across a catchment of 3,274m^2. The analysis indicated a rainfall threshold of approximately 5.2 mm and a runoff coefficient of 44%. When scaling these figures to the entire RC, total discharge across the monitoring period into the dam (see, WaterSmart Dams Evaporation Technical Report), was estimated as 2.59 Ml (Table 5).

This site experienced some significant surface erosion issues (refer to **Error! Reference source not found.** for more information on landscape characteristics) which caused challenges with sedimentation in the flume, impacting some measurements of water levels. Four rainfall-runoff events were excluded from the rainfall threshold analysis due to known/suspected sediment accumulation in the culvert, which prevented the logger from detecting the programmed 0.03 L/s increment changes in flow. The high rates of sediment in the culvert resulted in abrupt/false increases in water levels and overestimated discharge volumes, as indicated by the absence of preceding rainfall in our standard analysis methods applied at this site. This appeared to have a more significant impact on smaller events, and there is some uncertainty with the rainfall threshold derived from our analysis (5.2mm). The experience of the site host suggests a value of 8 mm is considered closer to the expected value, and this corresponds more closely to expected values for a well-maintained RC (DPIRD, 2024). Based on both the analysis and the site host's experience, 8mm is suggested as the most realistic value for this site and has been adopted as the value for this system (a well-maintained RC free from weeds) in the WEP.

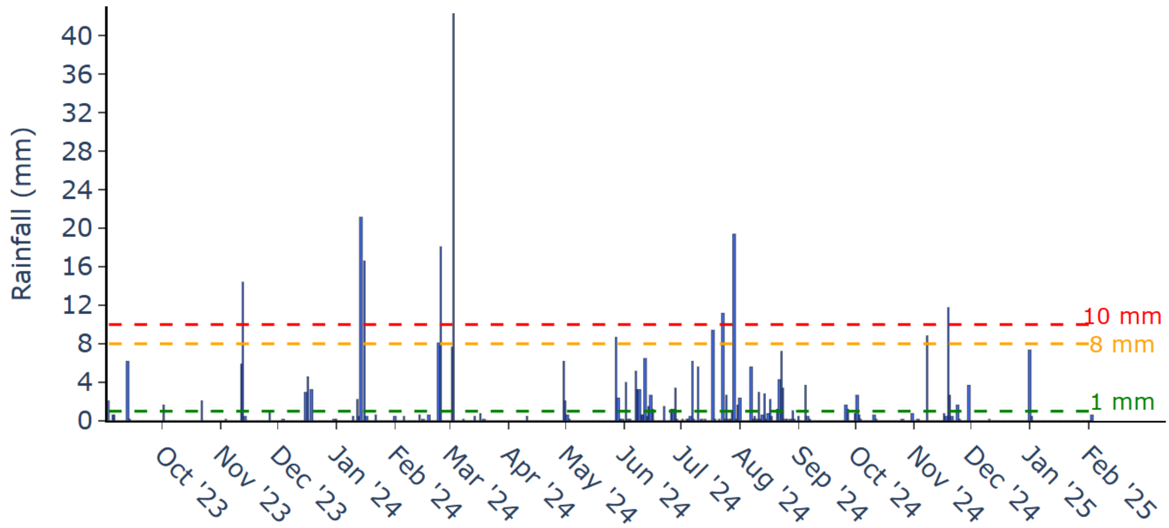
Table 5. Key findings from data analysis on Giles roaded catchment rainfall and runoff data

Monitoring period		30/08/2023 to 12/02/2025
Catchment Area	Monitored Catchment	3,274 m^2
	Whole Roaded Catchment Structure	15,600 m^2
Rainfall	Total	374 mm
	# events	90
Runoff	Monitored Catchment	0.54 Ml
	Whole Roaded Catchment Structure (scaled and calculated)	2.59Ml
Rainfall – Runoff	# events	28
Rainfall threshold (analysis)		5.2 mm
Rainfall threshold (site host)		8 mm*
Runoff Coefficient		0.44

*Figure estimate by the site host based on observations in the field.

To investigate potentially harvestable rainfall at this site relative to thresholds for different catchment types, rainfall was benchmarked against these, and potential runoff and associated dam reliability were simulated at this site using WEP. A total of 91% of annual rainfall originated from events exceeding 1 mm (the threshold associated with a PVC tarp catchment, see sites below). Events exceeding 8 mm (the threshold for both the current site and a well-maintained roaded catchment) accounted for 52% of total rainfall, with rainfall events above 10 mm contributing 45% (representative of a more typical or 'average' RC). If the site had remained as a paddock with a 25 mm threshold, only one event would have generated runoff, representing just 20% of the total annual rainfall (Figure 14). These results demonstrate that lower runoff thresholds are associated with substantially higher volumes and proportions of annual rainfall capture. This analysis highlights that dams with unimproved or natural pasture or crop catchment can only capture a small fraction of the available rainfall and in most regions these will be unreliable for water supply. Use of the PVC surface catchments (1mm threshold) capture a large portion of the total rainfall (91%), with RCs capture 45-52% of annual rainfall.

The Giles site was simulated using the WEP to assess system reliability under both current and modified conditions. The current scenario used the current 1.56ha RC with an 8mm threshold, and demand based on what happened during the study period, where 700 mature sheep were in the area with this as the only water source in February and March. A second scenario investigated lining the catchment with PVC tarpaulins to benchmark changes to costs and reliability. Model parameters for the scenarios are provided in Appendix 2. This was then simulated using gridded rainfall across the period that is believed to best represent the current climate of the region (01/01/2000 to (current) 01/01/2025).



Rainfall threshold	Simulated catchment type	# Events	Total Rainfall > threshold	Proportion
>1mm	PVC Tarp	52	340mm	91%
>4mm	This site (calculated)	25	277mm	74%
>8mm	Well-maintained roaded catchment, this site grower host estimated value	11	196mm	52%
>10mm	Roaded catchment	8	170mm	45%
>25mm	Pasture/crop paddock	1	75mm	20%

Figure 14. Rainfall events at Giles Site from 30/08/2023 to 12/02/2025, outlining the proportion of the sites total rainfall above each chosen rainfall threshold.

Another key aspect of the analysis was understanding the relationship between rainfall and runoff at the site, particularly to visually assess how closely the two variables are related and how responsive runoff is to rainfall. Runoff occurred in fewer, larger steps compared to rainfall (Figure 15). Minimal rainfall and runoff from September to December 2023 align with the dry season. A sharp rise in January 2024 followed a summer storm, with further increases from March to August during the wet season. After August, runoff plateaued despite continued rainfall. Runoff occurred only during larger rainfall events, indicating a non-linear relationship with discharge. This emphasises the predominantly long, dry period over summer, and the impact on water availability in autumn.

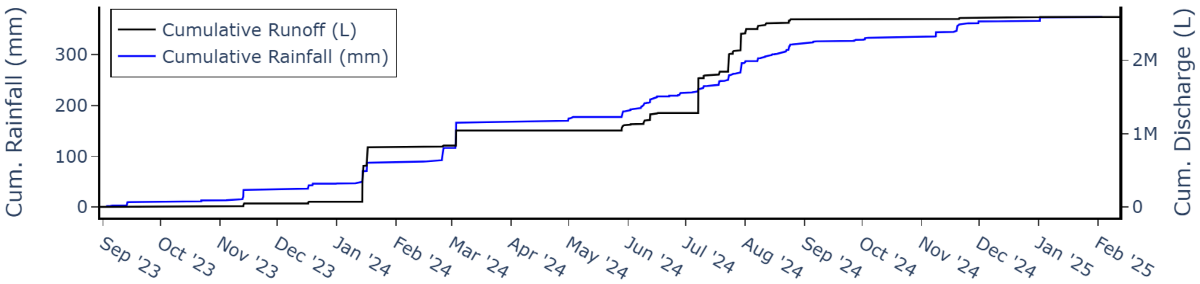


Figure 15. Cumulative rainfall (mm) and runoff (L) of the whole catchment area (projected from measured data in 1 of the 5 bays) from 30/08/2023 to 12/02/2025.

3.2.2 Goss

This site consisted of two catchments monitored from 16 April 2024 to 17 September 2024 and identified that the rainfall threshold was lower by 1mm at the C2 treated bay (sprayed, scraped and rolled), 5.5mm rainfall to initiation, in comparison to the untreated (RC with no weed management) C1 bay (6.5mm). A total of 165 kL of discharge was recorded from both bays during the 2024 winter months (April–September), with 65% coming from the untreated C1 bay (total catchment area 10.04 ha). The treated C2 bay (total catchment area 1.14ha) captured four additional runoff events, due to its 1 mm lower rainfall initiation threshold (refer to Table 6). It should be noted that the C1 and C2 bays include the RC areas, plus an additional catchment area that includes a pasture catchment (Figure 6).

Within this study, we attach high confidence to the runoff threshold values derived from event-based analysis at both sites. In contrast, considerable uncertainty surrounds the runoff coefficients, which represent total runoff relative to rainfall across the whole catchment area. This uncertainty arises from the physical layout of the catchments: the roaded treated (C2) and untreated (C1) bays are positioned side by side, with a natural pasture area upslope that also contributes to runoff. These components exhibit differing runoff behaviours, but cannot be hydraulically isolated, making it impossible to attribute measured runoff volumes to individual treatments (**Error! Reference source not found.** illustrates the likely contributing areas, highlighting the complexity of the catchment boundaries and the limitations this imposes on calculating reliable runoff coefficients.

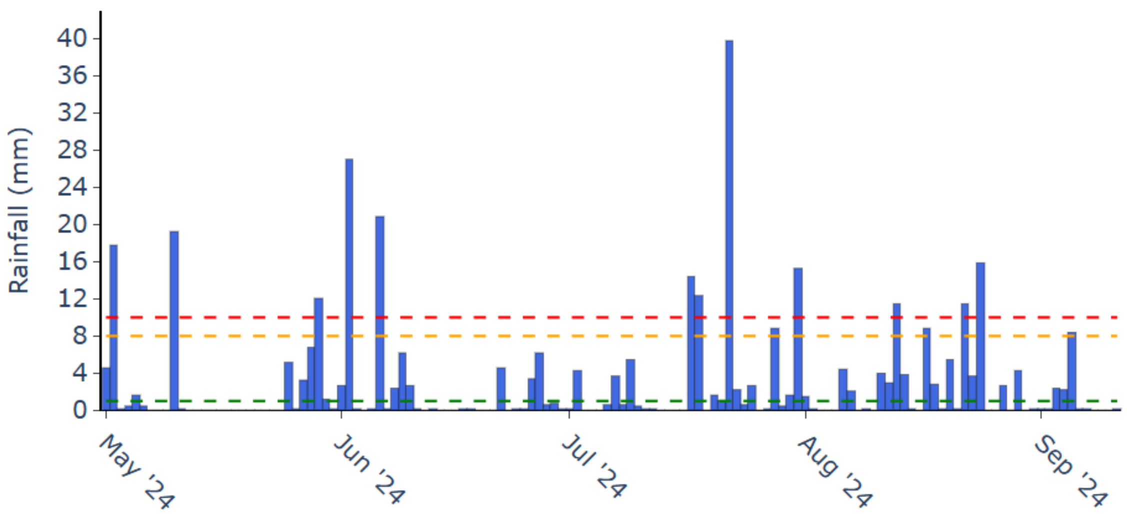
Additionally, the untreated bay had minimal weed growth and sheep compacting the surface. It may not accurately represent the typical conditions of unmaintained catchments across the Wheatbelt (where the threshold to runoff would be expected to be more like 10-12mm).

Table 6. Key findings from data analysis Goss dual roaded catchments rainfall and runoff data

		C1 Untreated	C2 Treated
Date Range		16/04/2024 to 17/09/2024	
Catchment Area		100,495 m^2	11,375 m^2
Rainfall	Total	368mm	
	# events	55	
Runoff	Total	107kL	58kL
Rainfall – Runoff	# events	17	21
Rainfall threshold		6.5mm	5.5mm

N.B. This experiment has significant uncertainties due to the site characteristics, including catchments beyond the roaded area, so the total yield cannot be calculated.

To investigate potentially harvestable rainfall at this site relative to thresholds for different catchment types, the site rainfall was benchmarked against these thresholds and their corresponding potential runoff. Of the total annual rainfall, 76% from events exceeding the 5.5 mm threshold (C2 treated bay) and 74% from events above the 6.5 mm threshold (C1 untreated bay) could be captured by the dual bay system. A significantly higher proportion of 96% could have been captured if the surface were lined with a PVC tarp. In contrast, if the catchment had remained as a paddock with a 25 mm threshold, only 71 mm of the total 368 mm (19%) would have been harvested, a similar result to the Giles site, with only around 20% of the total rainfall above this threshold. These results demonstrate that lower runoff thresholds are associated with substantially higher volumes and proportions of annual rainfall capture.

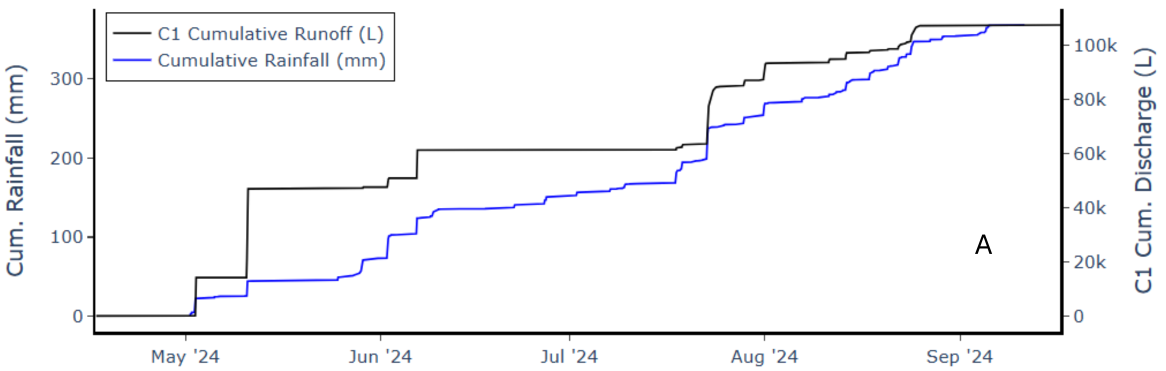


Rainfall threshold	Surface	# Events	Total rainfall > threshold	Proportion
>1mm	2nd Hand PVC tarp	41	353mm	96%
>5.5mm	C2 Treated roaded catchment	18	280mm	76%
>6.5mm	C1 Untreated roaded catchment	17	273mm	74%
>8mm	Well-maintained roaded catchment	17	273mm	74%
>10mm	Average roaded catchment	12	230mm	63%
>25mm	Paddock	2	71mm	19%

Figure 16. Rainfall events at Goss Site from 16/04/2024 to 17/09/2024

Another key aspect of the analysis was understanding the relationship between rainfall and runoff at the site, particularly to visually assess how closely the two variables are related and how responsive runoff is to rainfall. Runoff patterns from the RCs at sites C1 untreated and C2 treated exhibit distinct responses to cumulative rainfall. In both bays, runoff events generally correspond to larger rainfall events, as expected for RCs. However, the cumulative runoff line for C2 treated (dotted) remains closer to the cumulative rainfall line throughout the monitoring period, indicating a more proportionate runoff response (Figure 17b). In contrast, C1 untreated (solid) consistently shows a larger gap between rainfall and runoff, particularly following significant events in late May and July, likely due to its substantially larger contributing area (Figure 17a).

This increased drainage area at C1 untreated results in greater total discharge volumes than anticipated for the designed bay. Despite a higher rainfall threshold of 6.5 mm at C1 untreated compared to 5 mm at C2 treated, C1 untreated exhibits earlier and larger runoff volumes, reflecting its larger effective catchment size. Consequently, this larger catchment area can lead to earlier onset of runoff signals by accelerating runoff volume and flow, producing quicker system responses even at lower rainfall intensities.



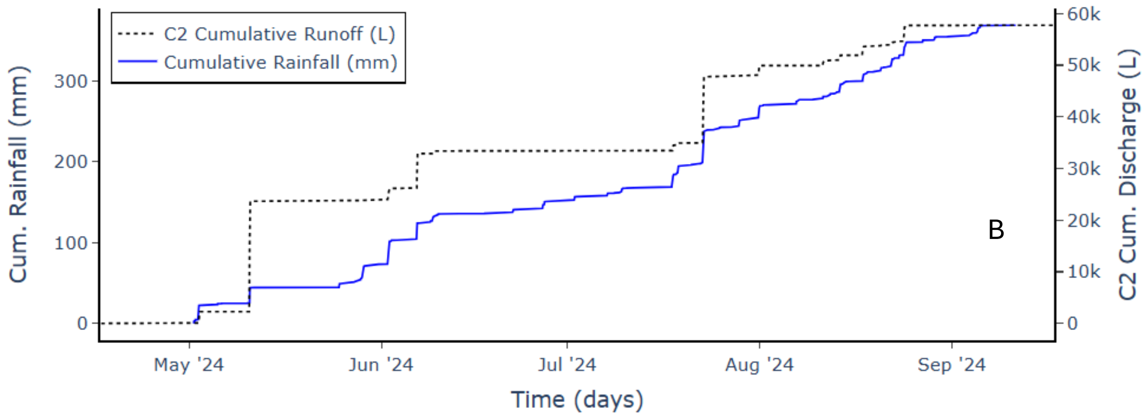


Figure 17. Cumulative rainfall (mm) and runoff (L) for Goss dual roaded catchment system, (a) C1 Untreated and bottom (b) C2 Treated Bay from 16/04/2024 to 17/09/2024.

3.3 PVC Tarp Catchment Sites

3.3.1 Lester

This site features a secondhand PVC tarp-lined (0.65ha) catchment, with rainfall and runoff data collected from May 3, 2023, to February 24, 2025. The key finding was that the system exhibited a low rainfall threshold of 0.8 mm and a high runoff coefficient of 75%. Over the monitoring period, 413 mm of rainfall was recorded, of which 364 mm (88%) generated runoff due to the lower runoff threshold, resulting in a total runoff volume of 1.90 ML (refer to Table 7).

No data were collected between 1 July and 2 September 2024 due to monitoring equipment issues. This period is known for high rainfall, with the nearest Bureau of Meteorology weather station at Jacup recording 109.4 mm during this time (BoM, 2025). Inclusion of this data would likely have increased both the total recorded rainfall and the corresponding runoff volumes.

Table 7. Key findings from data analysis on Lester PVC catchment rainfall and runoff data

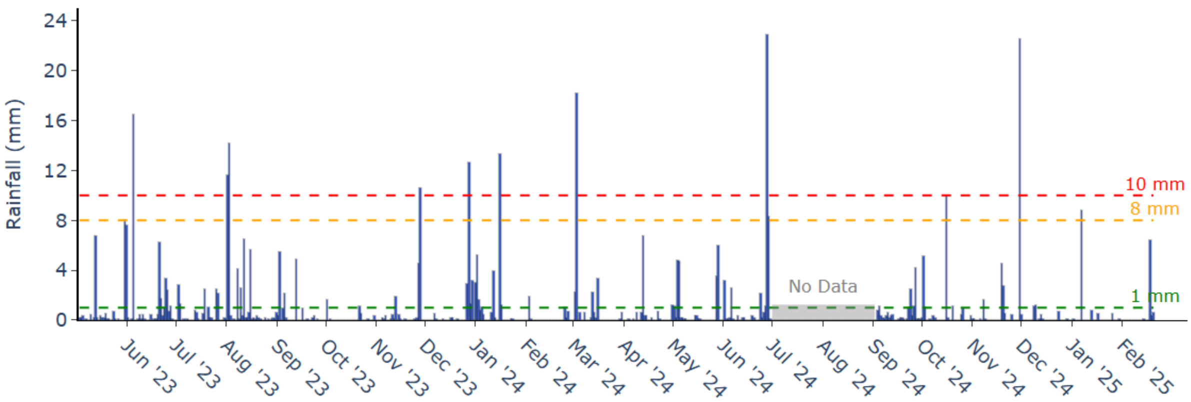
Monitoring period		03/05/2023 to 24/02/2025
Gaps in data		01/07/2024 to 02/09/2024
Catchment Area	Whole catchment	6,545 m^2
Rainfall	Total	413 mm
	# events	145
Runoff	Total	1.90 ML
Rainfall – Runoff	# events	99
Rainfall threshold		0.8 mm
Runoff Coefficient		0.75

To investigate potentially harvestable rainfall at this site relative to thresholds for different catchment types, the site rainfall was benchmarked against these thresholds and their corresponding potential runoff. Of the total recorded rainfall, 88% was captured by the site, which had a runoff threshold of 0.8 mm. In comparison, if the surface had instead been a well-maintained RC with an 8 mm threshold, only 44% of the rainfall would have been captured. A smaller proportion, 39%, would have been captured from events exceeding 10 mm, which is more representative of a typical or 'average' RC. If no catchment system were in place and the area remained as a paddock with an approximate runoff threshold of 25 mm, only two rainfall events - accounting for just 14% of the total rainfall - would have generated runoff. These results highlight the strong relationship between lower runoff thresholds and substantially greater rainfall capture potential.

Lester site was simulated using the Water Evaluation Platform (WEP) to assess system reliability under both current and modified conditions. The current scenario used the current 0.65Ha PVC tarpaulin lined catchment with 0.8 mm threshold, and a demand based on what occurred during the study period, spray program of 5 sprays/annum at the rate of 80 L/Ha (1,600 ha per spray), three sprays between February and March and the remaining two in July and August. A second scenario investigated the previous catchment setup, a 1.5 ha area with a well-maintained RC. The third scenario was also a well-maintained RC, but with the current catchment area of 0.65 ha. Model parameters for the scenarios are provided in Appendix 2. This was then simulated using gridded rainfall across the period that is believed to best represent the current climate of the region (01/01/2000 to 01/01/2025).

Simulation results:

- Lester well maintained RC(8mm threshold current area of 0.65Ha): 72% reliability, at the cost of $2-4/kL (average new RC cost range).
- Lester catchment prior to the intervention for this study, a ~1.5Ha well-maintained RC: 84% reliability
- Current/Lester tarped (0.65Ha PVC-lined catchment with 0.8 mm rainfall threshold): 100% reliability, at the cost of $4-6/kL (2nd hand PVC tarped catchment cost range)



Rainfall threshold	Surface	# Events	Total rainfall > threshold	Proportion
>0.8	This site	80	364mm	88%
>1mm	2nd Hand PVC tarp	69	353mm	85%
>8mm	Well-maintained roaded catchment	10	180mm	44%
>10mm	Roaded catchment	8	161mm	39%
>25mm	Paddock	2	57mm	14%

Figure 18. Rainfall events at Lester Site from 03/05/2023 to 24/02/2025. No data from 01/07/2024 to 02/09/2024.

Another key aspect of the analysis was understanding the relationship between rainfall and runoff at the site, particularly to visually assess how closely the two variables are related and how responsive runoff is to rainfall. Runoff occurred in frequent, small increments throughout the monitoring period (Figure 19). From June 2023 to February 2025, the majority of rainfall events were associated with increases in runoff. Both small and large rainfall events resulted in runoff, with the cumulative rainfall and runoff curves showing close alignment. Runoff was also observed during peak dry months.

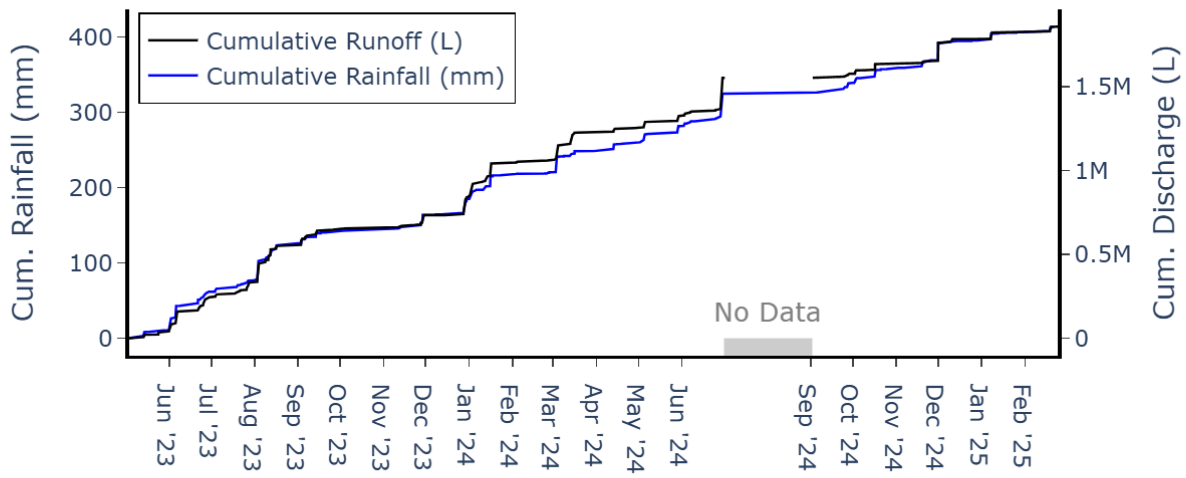


Figure 19. Cumulative rainfall (mm) and runoff (L) at Lester PVC catchment site from 03/05/2023 to 24/02/2025. No data from 01/07/2024 to 02/09/2024.

3.3.2 Wandel

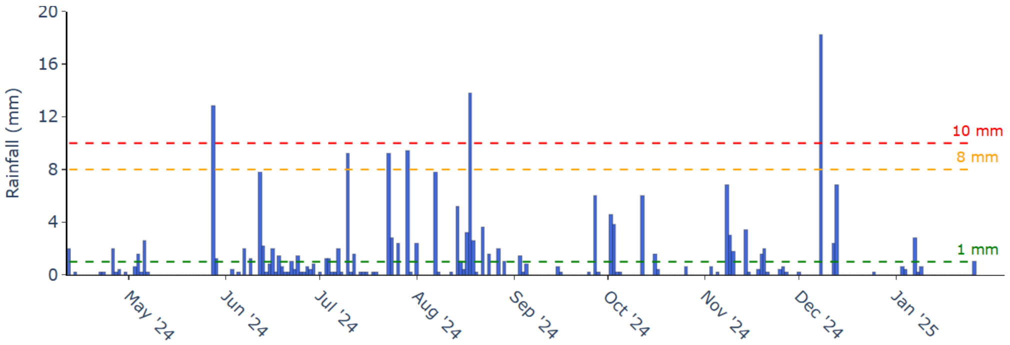
This catchment has a similar secondhand PVC tarp-lined catchment system installed during the project through a collaboration of DWER and the Southeast Premium Wheat Growers Association (SEPWA), with monitoring from 17 March 2024 to 12 February 2025. The key finding was that the system exhibited a low rainfall threshold of 1 mm and a high runoff coefficient of 75%. Over the monitoring period, 217mm of rainfall was recorded, of which 182mm (84%) generated runoff due to the low threshold, resulting in a total runoff volume of 1.19ML (refer to Table 8).

The Wandel site exhibited a slightly higher rainfall threshold than its sister site, Lester (0.8 mm), despite both being lined with secondhand PVC tarpaulin. Although the tarpaulin at Wandel was in better condition, the Lester site's steeper slope and V-shaped tapered catchment design likely contribute to its lower threshold. This configuration likely promotes more efficient channelling of runoff towards the outlet by enhancing the ability of beaded water to overcome surface tension and initiate runoff during smaller rainfall events.

Table 8. Key findings from data analysis on Lester PVC catchment rainfall and runoff data

Monitoring period		17/03/2024 to 12/02/2025
Catchment Area	Whole catchment	8,360 m^2
Rainfall	Total	217 mm
	# events	80
Runoff	Total	1.19 ML
Rainfall – Runoff	# events	51
Rainfall threshold		1 mm
Runoff Coefficient		0.75

To investigate potentially harvestable rainfall at this site relative to thresholds for different catchment types, site rainfall was benchmarked against these and their potential runoff. Of the total recorded rainfall, 84% was captured by the site, which had a runoff threshold of 1 mm, typical of a PVC tarp catchment. In comparison, if the surface had instead been a well-maintained RC with an 8 mm threshold, only 27% of rainfall would have been captured. An even smaller proportion - 19% - would have been captured from events exceeding 10 mm, which is representative of a more typical RC. No rainfall events at the site exceeded the 25 mm threshold associated with an untreated paddock, indicating that under paddock conditions, runoff generation would have been negligible. These results highlight the strong relationship between lower runoff thresholds and substantially greater rainfall capture potential.



Rainfall threshold	Surface	# Events	Total rainfall > threshold	Proportion
>1mm	PVC tarp / this site	45	182mm	84%
>8mm	Well-maintained roaded catchment	5	59mm	27%
>10mm	Roaded catchment	3	41mm	19%
>25mm	Paddock	0	0mm	0%

Figure 20. Rainfall events at Wandel Site from 17/03/2024 to 12/02/2025.

Another key aspect of the analysis was understanding the relationship between rainfall and runoff at the site, particularly to visually assess how closely the two variables are related and how responsive runoff is to rainfall. Runoff occurred in frequent, small steps throughout the monitoring period (Figure 21). From April 2024 to January 2025, the majority of rainfall events were associated with increases in runoff. Both small and large rainfall events resulted in runoff, with the cumulative rainfall and runoff curves showing close alignment. Runoff was also observed during peak dry months.

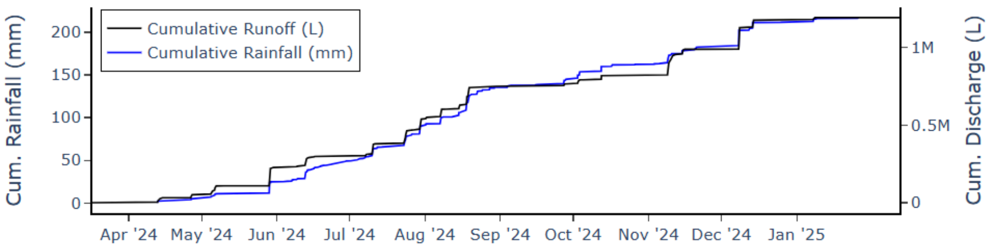


Figure 21. Cumulative rainfall (mm) and runoff (L) at Wandel PVC catchment site from 17/03/2024 to 12/02/2025.

3.4 HDPE Catchment

3.4.1 Borden

The Borden HDPE catchment system was monitored from 14 March 2024 to 12 May 2025, finding runoff required a rainfall threshold of 1mm and a runoff coefficient of 78%. Over the monitoring period, 293mm of rainfall was recorded, of which 268mm (92%) generated runoff due to the low threshold, resulting in a total runoff volume of 1.37ML (refer to

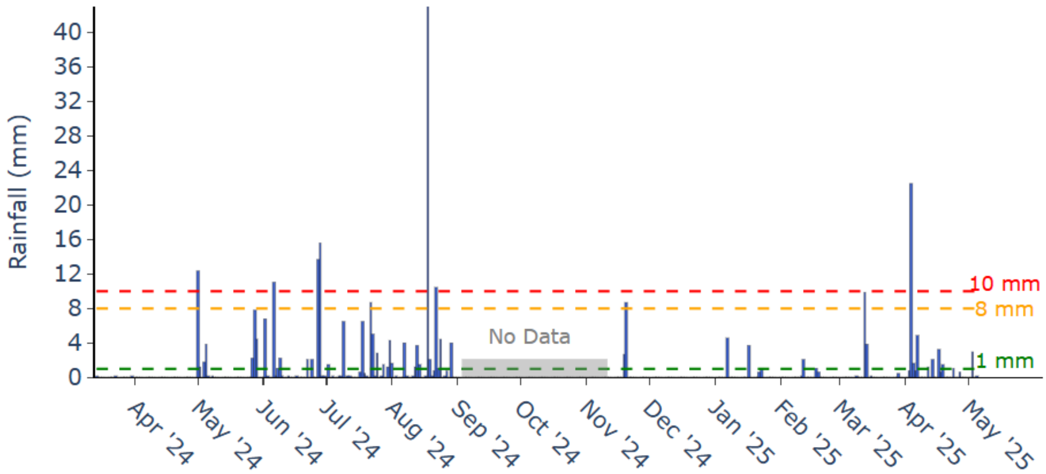
Table 9). There was no runoff data collected between 3 September and 11 November due to issues with the water level logger monitoring equipment.

Although rainfall data was collected during this period, the absence of corresponding runoff data prevented their use in the analysis, which relies on the relationship between rainfall and runoff to draw conclusions. A total of 29 mm of rainfall was recorded over this interval. It is important to note that, had the runoff data been available, the total recorded runoff and rainfall volumes for the monitoring period would likely have been higher.

Table 9. Key findings from data analysis on Borden HDPE catchment rainfall and runoff data.

Monitoring period		14/03/2024 to 12/05/2025
Gaps in data		03/09/2024 to 11/11/2024
Catchment Area	Whole catchment	8,877 m^2
Rainfall	Total	293 mm
	# events	69
Runoff	Total	1.37 ML
Rainfall – Runoff	# events	60
Rainfall threshold		1 mm
Runoff Coefficient		0.78

To investigate potentially harvestable rainfall at this site relative to thresholds for different catchment types, site rainfall was benchmarked against these and their potential runoff. Of the total recorded rainfall, 92% was captured by the site, which had a runoff threshold of 1 mm (HDPE-lined catchment). In comparison, if the surface had instead been a well-maintained RC with an 8 mm threshold, only 59% of rainfall would have been captured. An even smaller proportion - 49% - would have been captured from events exceeding 10 mm, which is representative of a typical RC. If there was no catchment, and the area instead was a paddock, only one rainfall event at the site exceeded the 25 mm threshold. These results highlight the strong relationship between lower runoff thresholds and substantially greater rainfall capture potential.



Rainfall threshold	Surface	# Events	Total rainfall > threshold	Proportion
>1mm	PVC tarp / this site	46	268mm	92%
>8mm	Well-maintained roaded catchment	11	172mm	59%
>10mm	Roaded catchment	8	143mm	49%
>25mm	Paddock	1	43mm	15%

Figure 22. Rainfall events at Borden Site from 14/03/2024 to 12/05/2025. No data from 03/09/2024 to 11/11/2024.

Another key aspect of the analysis was understanding the relationship between rainfall and runoff at the site, particularly to visually assess how closely the two variables are related and how responsive runoff is to rainfall. Runoff occurred in regular, moderate increments throughout the monitoring period (Figure 23). Between March and August 2024, the majority of rainfall events were associated with increases in runoff. Both small and large rainfall events contributed to runoff, with the cumulative rainfall and runoff curves remaining closely aligned. Following reinstatement in November 2024, runoff continued to respond to rainfall in a similar pattern through to May 2025. Runoff was also observed during peak dry months.

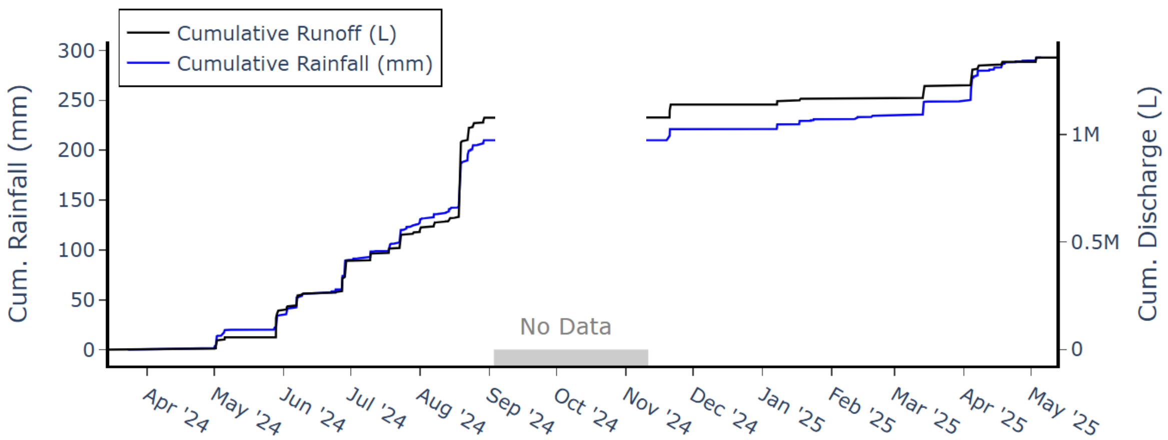


Figure 23. Cumulative rainfall (mm) and runoff (L) at Borden HDPE catchment site from 14/03/2024 to 12/05/2025. No data from 03/09/2024 to 11/11/2024.

3.5 Subsurface drains

3.5.1 Ashtons

Discharge volume and salt load were monitored at Ashtons' subsurface drain system from 7 June 2023 to 26 February 2025. The key finding was that the drain system discharged a total of 1.64 ML of water from 507 mm of rainfall recorded at the site, with the majority - 84% - discharged during the 2023 wet season (1 June to 1 October). Seasonal rainfall totals were similar, with 202 mm recorded in 2023 and 210 mm in 2024. The flow-weighted average salt concentration in the discharged water was 1,223 mg/L, with no significant difference observed between the 2023 and 2024 wet seasons (refer

Table 10).

No runoff data was collected between 2 October 2023 and 3 April 2024 due to issues with the water level logger monitoring equipment. Although rainfall data were recorded during this period, it was excluded from the analysis and overall rainfall totals due to the lack of corresponding runoff data. A total of 53 mm of rainfall was recorded over this interval. It remains unknown whether the drainage system operated during this time; however, it is highly unlikely that the drain ran over the summer months, as it requires the subsurface soil profile to become saturated.

Table 10. Key findings from analysis of rainfall and runoff data from Ashtons' subsurface drainage system

Monitoring period		07/06/2023 to 26/02/2025
Gaps in data		02/10/2023 to 03/04/2024
Rainfall	2023 Winter*	202 mm (Decile 1**)
	2024 Winter	210 mm (Decile 3)
	Total	507 mm
Discharge	2023 Winter	1,378 kL
	2024 Winter	259 kL
	Total	1,636 kL
Salt load	2023 Winter (avg.)	1,230 mg/L
	2024 Winter (avg.)	1,370 mg/L
	Total (avg.)	1,223 mg/L

* Winter = June 1st to October 1st

** Refer to Table 4, rainfall decile years for 2023 and 2024

Figure 24 presents instantaneous rainfall and discharge data, highlighting two equivalent time periods, winter 2023 and winter 2024, for comparison. This enables assessment of year-to-year variability in discharge volume relative to the rainfall received in each season. While the figure provides initial insights, data are currently limited to two winter periods; additional years of monitoring would be required to evaluate long-term variability and reliability more accurately.

Total discharge varied considerably between the two monitored winter periods. The same time frame - 1 June to 1 October - was selected for each year to enable direct and fair comparison. During the 2023 winter period, the drain discharged 1,378 kL in response to 202 mm of rainfall. In contrast, the 2024 winter period, which recorded a similar rainfall total of 210 mm, produced only 295 kL of discharge - an 80% reduction. Despite the comparable rainfall amounts, the substantial difference in discharge volume suggests that other influencing factors were at play.

June – Oct 2023

Rainfall	202 mm
Discharge	1,378 kL

June – Oct 2024

210 mm
259 kL

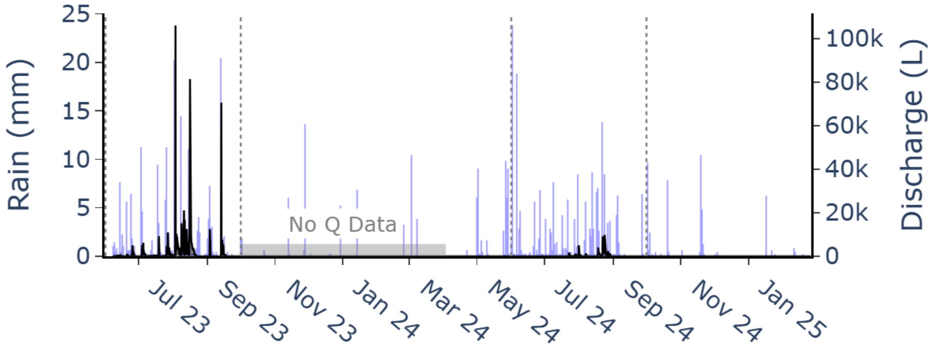


Figure 24. Daily rainfall (mm) and instantaneous discharge (L) 07/06/2023 – 26/02/2025. Dotted lines indicate the chosen winter periods for direct comparison: June 1st to October 1st 2023 and June 1st to October 1st 2024. No discharge (Q) data from 02/10/2023 to 03/04/2024.

Another key aspect of the analysis was understanding the relationship between rainfall and runoff at the site, particularly to visually assess how closely the two variables are related and how responsive runoff is to rainfall. Runoff occurred in large steps during the initial winter months, with a clear gap between cumulative rainfall and discharge (Figure 25). A large runoff event was recorded in August 2023 without a sizeable corresponding rainfall event, suggesting this is a response to the soil profile becoming saturated. Post-summer 2024, runoff accumulation slowed. The relationship between rainfall and runoff became more direct, with runoff steps aligning closely with rainfall events, particularly in September 2024. Runoff plateaued toward the end of the period as conditions became drier.

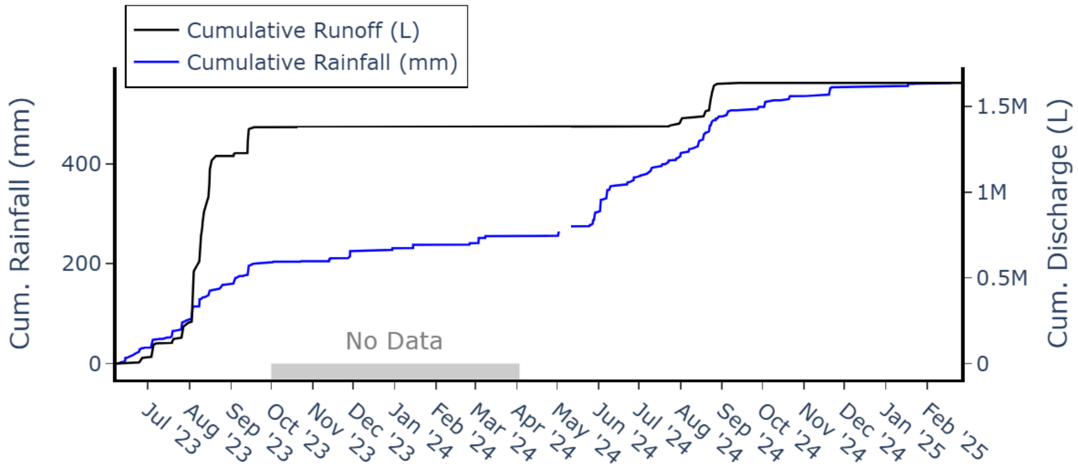


Figure 25. Cumulative rainfall (mm) and runoff (L) at Ashton subsurface drainage system from 07/06/2023 – 26/02/2025. No discharge (Q) data from 02/10/2023 to 03/04/2024.

3.5.2 Webb

Monitoring of Webb's subsurface drainage system assessed volume and salt load from rainfall and runoff data collected between 3 April and 9 October 2024. The drainage system discharged a total of 1.64 ML of water in response to 325 mm of rainfall recorded at the site. All discharge occurred during winter 2024 (1 June to 1 October), which received 260 mm of rainfall, primarily driven by an 18-day continuous flow event from 18 August to 6 September. The average salt concentration in the discharged water was 418 mg/L, indicating relatively fresh water and well below the 2,000 mg/L threshold for safe livestock drinking (refer to Table 11).

No data were collected over the summer of 2024/25. Although monitoring was planned during this period, the equipment was damaged by livestock (sheep), preventing data collection. It remains unknown whether the drainage system operated during this time. Based on observations from the other monitored drainage sites (Ashtons and South), runoff during summer appears unlikely. The site was reinstated on 19 March 2025 to resume monitoring of winter 2025 discharge. Data from comparable sites suggest that even with similar rainfall, reduced discharge is likely due to substantial year-to-year variability in subsurface drainage performance.

Table 11. Key findings from the analysis of rainfall and runoff data from Webb's subsurface drainage system

Monitoring period		03/04/2024 to 09/10/2024
Rainfall	2024 Winter*	260 mm (Decile 3**)
	Total	325 mm
Discharge	2024 Winter	1.64 ML
	Total	1.64 ML
Salt load	2024 Winter (avg.)	418 mg/L
	Total (avg.)	418 mg/L

* Winter = 1st June to 1st October

** Refer to Table 4, sites rainfall decile for year 2024

A key objective was to assess the reliability of water supply from the drainage systems. However, due to data limitations, restricted to winter 2024, it was not possible to evaluate year-to-year variability in discharge volume relative to seasonal rainfall. From the data available, Figure 26 presents instantaneous measurements of rainfall and discharge, as well as the total recorded values for both parameters during the winter of 2024. A distinct peak in discharge is evident in August, corresponding to an 18-day continuous flow event from 18 August to 6 September. This single event accounted for 1.51 ML, representing 91% of the total discharge for the winter 2024 period, and likewise, the entire monitoring period.

	June – Oct 2024
Rainfall	202 mm
Discharge	1,378 kL

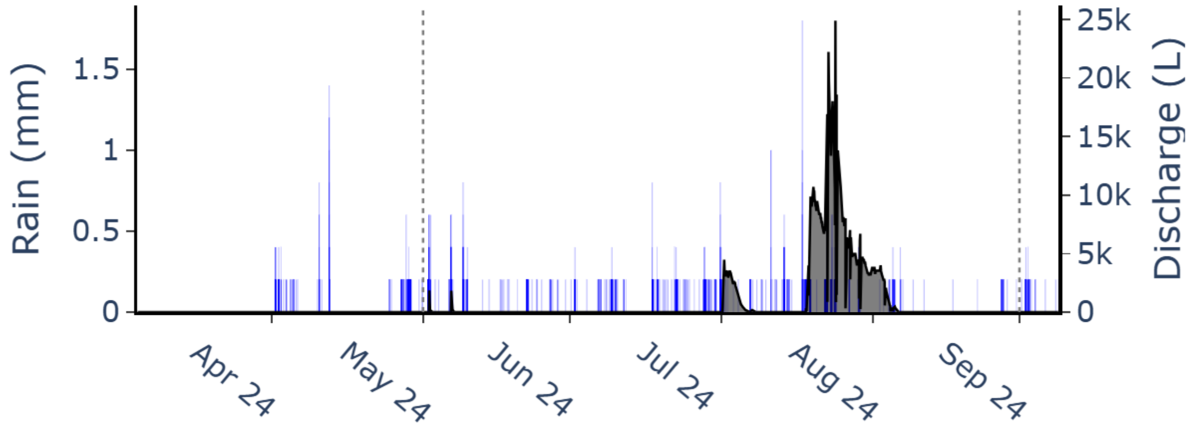


Figure 26. Daily rainfall (mm) and instantaneous discharge (L) 03/04/2024 – 09/10/2024. Dotted lines indicate the chosen 2024 winter period: June 1st to October 1st

Another key aspect of the analysis was understanding the relationship between rainfall and runoff at the site, particularly to visually assess how closely the two variables are related and how responsive runoff is to rainfall. Discharge from the subsurface drainage system showed a clear delay relative to cumulative rainfall, with minimal runoff recorded until late August 2024 despite sustained rainfall (

Figure 27). This delay reflects the system design, where the profile needs to be saturated and discharge from the subsurface drainage system is channelled into a sump that must fill first before it then flows down a 15-inch pipe downhill and through the V-notch weir, collecting the data.

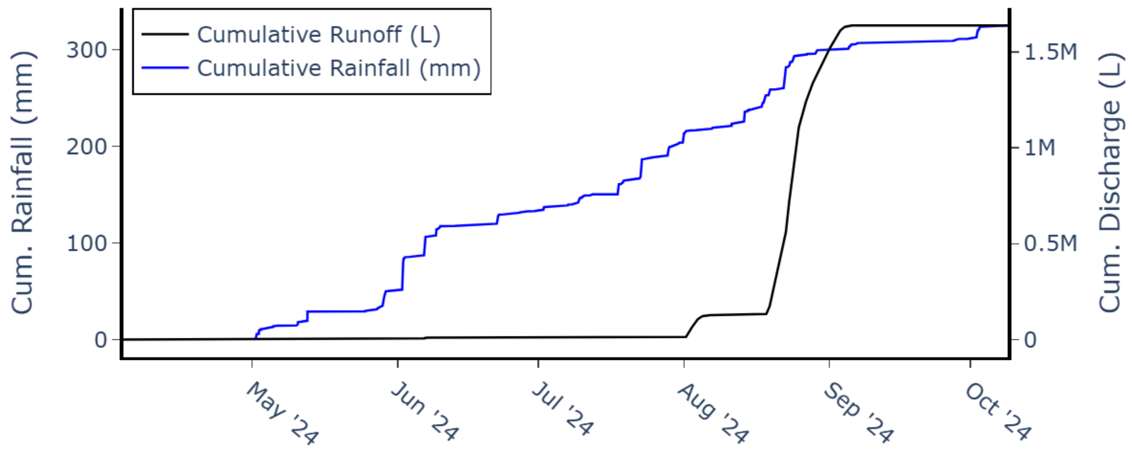


Figure 27. Cumulative rainfall (mm) and runoff (L) at Webb's subsurface drainage system from 03/04/2024 to 09/10/2024.

3.6 Open subsurface drains

3.6.1 South

The South's open subsurface drain system was monitored between 1 August 2023 and 17 September 2024 to assess variation between seasons and years in relation to discharge volume and salt load. The key finding was that the drain system discharged a total of 2.5 ML of water from 533 mm of rainfall recorded at the site, with the majority - 94% - of total discharged during the 2024 winter period (1 June to 17 September), when the drain flowed almost continuously for the winter period. The flow-weighted average salt concentration in the discharged water was 279 mg/L, indicating very fresh water (refer to
Table 12).

Time periods in 2023 and 2024 were selected for direct comparison, representing the longest continuous wet season data available for both years, from 1 August to 17 September. As more data was available in 2024, an additional 'Winter 2024' analysis was conducted, corresponding with the designated winter monitoring period used at the other subsurface drainage sites, 1 June to 17 September (last date of available data).

Table 12. Key findings from the analysis of rainfall and runoff data from South's subsurface drainage system

Monitoring period		01/08/2023 to 17/09/2024
Rainfall	2023 Aug 1st to Sep 17th	129 mm
	2024 Aug 1st to Sep 17th	95 mm
	2024 Winter*	300 mm (Decile 5)**
	Total	533 mm
Discharge	2023 Aug 1st to Sep 17th	95 kL
	2024 Aug 1st to Sep 17th	1,602 kL
	2024 Winter	2,302 kL
	Total	2,466 kL
Salt load	2023 Aug 1st to Sep 17th	160 mg/L
	2024 Aug 1st to Sep 17th	282 mg/L
	2024 Winter (avg.)	282 mg/L
	Total (avg.)	279 mg/L

* 2024 Winter = June 1st to Sep 17th (last data entry)

** Refer to Table 4, sites rainfall decile for year 2024

Figure 28 presents instantaneous rainfall and discharge data, highlighting two equivalent time periods in winter 2023 and 2024 - for comparison. This enables assessment of year-to-year variability in discharge volume relative to the rainfall received in each season. While the figure provides initial insights, data are currently limited to two winter periods; additional years of monitoring would be required to more accurately evaluate long-term variability and reliability.

Total discharge varied significantly between the selected comparison periods (1 August to 17 September). In 2023, the system discharged 95 kL in response to 129 mm of rainfall. In 2024, despite receiving 34 mm less rainfall (95 mm), the system discharged 1,602 kL - over 16 times more water. Rainfall prior to the 2023 period is unknown, while July 2024 alone recorded 110 mm. This substantial difference in discharge suggests the influence of additional factors, potentially including variations in rainfall timing and intensity leading up to the monitored periods, as well as other landscape or surface water hydrology dynamics.

	Aug – Sep 17th 2023	Aug – Sep 17th 2024
Rainfall	129 mm	95 mm
Discharge	95 kL	1,602 kL

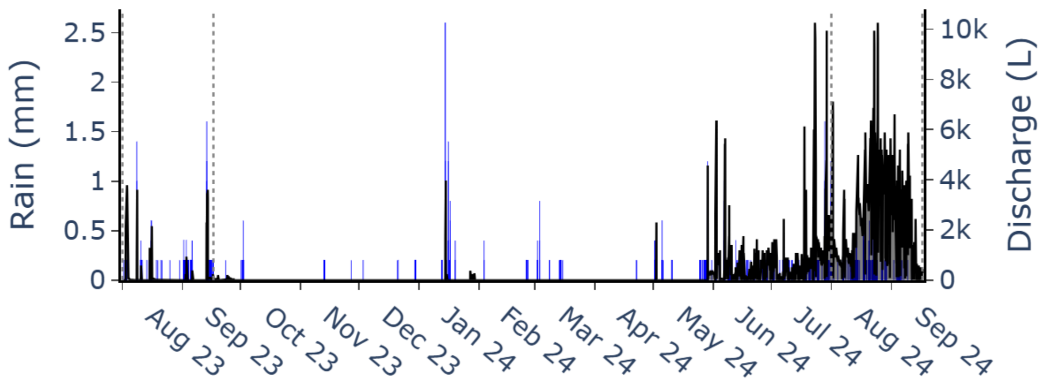


Figure 28. Daily rainfall (mm) and instantaneous discharge (L) from 01 August 2023 to 17 September 2024. Dotted lines indicate the wet season periods with available data for direct comparison: 1 August to 17 September 2023 and 1 August to 17 September 2024.

Another key aspect of the analysis was understanding the relationship between rainfall and runoff at the site, particularly to visually assess how closely the two variables are related and how responsive runoff is to rainfall. Discharge from the drainage system was minimal from installation until approximately June 2024, as shown in Figure 29, by a relatively flat accumulation line. Runoff responded to rainfall events of higher magnitude, indicating a relationship between the variables. A large gap between rainfall and runoff suggests that other factors, including more complex water pathways (such as the development of a partially saturated upper sandy duplex profile that initiates throughflow interception) and saturation of the soil profile, may be important at this site and/or type of sub-surface drain. Post-June 2024, both variables increased steeply, with runoff initially lagging before rising sharply.

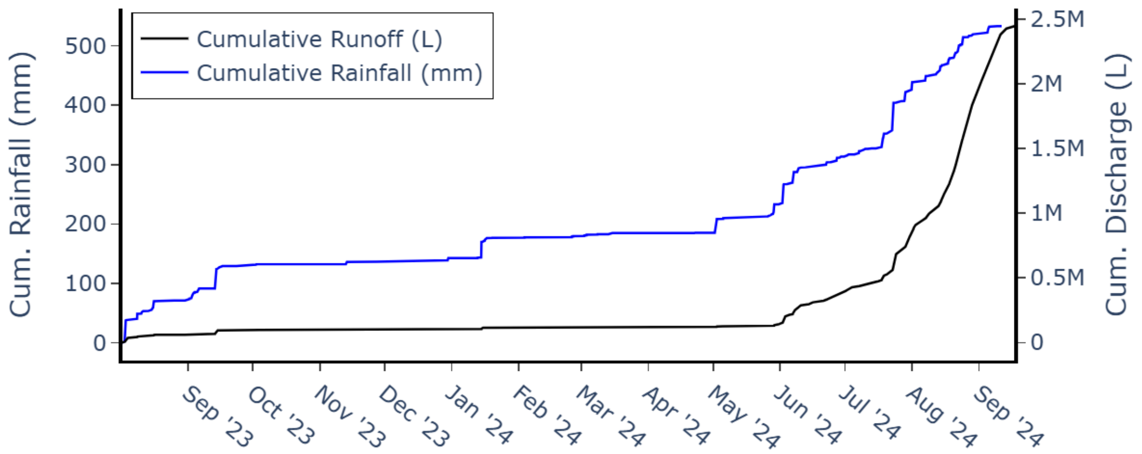


Figure 29. Cumulative rainfall (mm) and runoff (L) at Souths open subsurface drainage system from 01/08/23 to 17/09/24.

3.7 Cost per kilolitre of catchment surfaces for water harvesting

To evaluate the economic viability of different surface water catchment types, a scenario-based cost-benefit analysis was undertaken (section 2.7). In the Jacup scenario, the cost of caring for water is estimated at $21.09/kL, while for a roaded catchment, assuming an annualised cost of $2,280.40 over 40 years, the cost is approximately $2.40/kL. It is important to note that runoff estimates are based on simulations conducted at the Lesters Jacup site, meaning the discharge values reflect the specific climate and hydrological conditions of that location. Therefore, actual runoff and the resulting cost per kilolitre will vary across other sites within the Wheatbelt region.

Using the economics that underpin the WEP, we varied only the lifespan years for each of the plastic catchments, keeping all other inputs constant (Table 13).

Table 13. Plastic lined Jacup catchment scenarios and the cost per kilolitre($/kL).

Scenario	Life Span (yrs)	Annualised cost ($/yr)	Captured water (kL/yr)	$/kL
Grain Tarpaulin (new)	7.5	$26,010	1772	$14.68
	10	$19,533	1772	$11.02
Grain Tarpaulin (Secondhand)	3	$20,209	1772	$11.40
	5	$12,165	1772	$6.87
	7	$8,718	1772	$4.92
HDPE	10	$15,728	1772	$8.86
	15	$11,769	1772	$6.65
	20	$7,846	1772	$4.43

4 Discussion and Conclusion

4.1 Hypothesis 1: Tarpaulin and plastics harvest water from low intensity rainfall where other existing methods cannot, and can enhance on-farm water security?

4.1.1 Key objective and approach

A key question of this study was to evaluate whether tarpaulin and plastic-lined catchments can effectively harvest water from low-intensity rainfall events where conventional methods typically fail, thereby enhancing on-farm water security. To address this, five different catchment systems were analysed, focusing on key performance metrics: rainfall thresholds, runoff coefficients, rainfall-runoff relationships, reliability, and economic cost-effectiveness.

Firstly, rainfall thresholds and runoff coefficients were calculated for each site to assess whether the PVC or HDPE lined systems could generate runoff from low rainfall inputs. We then analysed the rainfall distribution to calculate the amount of harvestable rainfall above each system's threshold and compared these against conventional catchment types (roaded and unmodified paddock). The rainfall-runoff relationship was examined to evaluate the responsiveness of each system, providing insight into whether runoff generation was strongly driven by rainfall. Finally, the systems were assessed for their reliability and cost-effectiveness in enhancing on-farm water security, recognising that financial viability is critical for farmer adoption.

It's important to note that monitoring covered two unusually dry seasons (2023 and 2024), with rainfall benchmarking across seven Wheatbelt stations classifying 2023 as very much below average (decile 1) and 2024 as very much below to below average (deciles 2-3). This provides important context for interpreting system performance.

4.1.2 Key findings: Tarpaulin and Plastic catchment performance

All three lined catchment systems demonstrated exceptionally low rainfall thresholds to initiate runoff: Lester (PVC) at 0.8 mm, Wandel (PVC) and Borden (HDPE) both at 1 mm. These low thresholds allowed the systems to convert a substantial proportion of annual rainfall into harvestable runoff. Specifically, 88% of total rainfall at Lester, 84% at Wandel, and 92% at Borden occurred in events exceeding their respective thresholds, suggesting that 85-90% of rainfall is harvestable for these catchments. At these sites, the runoff coefficients were 75% at Lesters, 75% at Wandel, and 78% at Borden. These findings are relatively consistent with Kirkland (1969), who reported 80-90% runoff efficiency for plastic-lined catchments in Tucson, Arizona, and Shangguan et al. (2002), who found 85% efficiency for plastic sheets in semi-arid China. In slight contrast, Li et al. (2004), in the same region, observed efficiencies of 57-76%, which was attributed to the use of non-UV durable plastic that deteriorated after only five months. These findings highlight that while such systems are generally very efficient at harvesting water, selecting the right, tested materials is crucial for long-term performance.

At these lined sites, rainfall and runoff were highly correlated, with runoff volumes closely tracking rainfall events above the threshold (Figure 19, Figure 21, and Figure *23*) making these systems predictable and reliable under varying rainfall conditions.

These outcomes are particularly notable when compared against benchmarks. Under the same rainfall conditions, a well-maintained RC (threshold 8 mm) would have captured only 27-59% of the rainfall. In comparison, an unmodified paddock surface (threshold 25 mm) would have yielded just 14% at Lester, 0% at Wandel, and 15% at Borden. These findings align closely with those of Li et al. (2004), who reported paddock runoff coefficients of 9-11%, and Short & Lantzke (2006), who found that paddocks produced approximately 7% runoff, while RCs yielded around 30%. Notably, the Short & Lantzke (2006) use data based on a time before and immediately after a major shift in climate and earlier on in the shift to no-till farming that has likely increase soil structure and permeability from the early 2000s in the study region and these are these figures (7%) is viewed as potentially reflecting a past climate and farming system.

Critically, the real advantage of these lined systems lies in their capacity to capture frequent, low-intensity rainfall events that are typically lost under conventional systems. For example, at Lester, 80 separate events exceeded the 0.8 mm threshold, capturing 88% of seasonal rainfall, yet only 8 events exceeded 10 mm (39%) and just 2 exceeded 25 mm (14%). Similar patterns were observed at Wandel and Borden. The significant proportion of low-intensity rainfall events was similarly noted by Coles et al. (2011), a study conducted in the south-west with multiple plots in Merredin and Mt Barker, who stated that “typical compacted surfaces are inefficient at harvesting water from low-rainfall events.” They found that a standard compacted RC missed or produced no runoff from 97% of events below 5 mm. Without lined systems, the majority of smaller rainfall events are entirely lost to infiltration or evaporation. As low-intensity rainfall is projected to increase in Western Australia’s dryland regions, these results of this study further support previous work in highlighting the growing importance of engineered low-threshold surfaces in future water security strategies (Baek & Coles, 2021; Baek & Coles, 2013).

Longevity of PVC plastics and microplastics

A sub-sample of plastic materials from the Lesters site was sent to Excelplas Polymer Technology and Testing to undergo PVC Residual Life Assessment. Tarpaulin samples were stamped 2014 and 2016, indicating they were around 7-8 years old when acquired for the project. Fourier Transform Infrared Spectroscopy (FTIR) analysis showed evidence of degradation consistent with dehydrochlorination. Samples showed low thermal stability at high temperatures and a moderate drop in tear resistance. Overall, the samples were reported to have passed the flex testing, and no cracking was observed. The condition of the samples indicated that they had been in service for 6-8 years. Based on this analysis of PVC, their expected residual life was estimated to be around 5-7 years.

The Lester tarpaulin surface failed after only 2-3 years, a lifespan much shorter than the 5-7 years indicated by lab tests. This was likely due to several factors. The samples tested might have been in better condition than the weakest tarps on-site, some of which had holes requiring patching immediately after installation. Additionally, unlike other sites, the Lesters catchment lacked surface weights. This combination of poor-condition tarps and the absence of weights likely allowed wind to destroy the surface quickly.

Concerns were raised that the PVC catchment surface could deteriorate, releasing microplastics into the dam and contaminating the water. Although the water is only used for non-potable agricultural purposes, we conducted a one-time sampling of water from the catchment and a sediment core from the dam to establish a baseline.

Our analysis revealed no evidence of PVC accumulation in the dam following the installation of the new catchment surface. Counts for microplastics were high in all samples, including blanks. Over 92% of the microplastic sediments were not PVC, with spectral signatures consistent with nylon, polyethylene, and polypropylene. However, our study was limited by the absence of standardised testing methods, clear definitions for microplastics, or defined threshold values. This made it difficult to draw firm conclusions about the source and quantity of microplastics. For future projects where plastic contamination is a concern, a longer-term study with microplastic monitoring experts is recommended.

While Water Corporation uses HDPE for potable water catchments, this report focuses exclusively on non-potable water. Even without evidence of increased PVC microplastics, other issues need consideration. For example, an engineered surface might allow farming chemicals to enter the dam more easily than an earthen catchment, where these chemicals often bind to clay particles. Therefore, water from these catchments should always be treated as non-potable, and its quality should be regularly tested for agricultural purposes, including spraying and livestock.

4.1.3 Key finding: Roaded catchment performance

The RC systems displayed more variable performance. At the dual bay site in Darkan (Goss site), the treated catchment (C2) had a slightly lower rainfall threshold (5.5 mm) than the untreated bay (C1, 6.5 mm), as expected. However, the difference was smaller than anticipated. Literature, such as Baek & Coles (2021) and Coles et al. (2011), suggests typical thresholds of 8-12 mm for RCs in WA, with lower values indicating very well-maintained surfaces. The limited difference in threshold between C1 and C2 may partly be explained by the unexpected nearly ninefold difference in catchment area, which confounded direct comparisons. The larger area of C1 accelerated flow concentration, generating earlier and larger runoff volumes despite its higher threshold. When rainfall proportions are considered, 76% of rainfall occurred above the 5.5 mm threshold (C2) and 74% above the 6.5 mm threshold (C1). In contrast, a PVC-lined system would have captured up to 96% of rainfall, while untreated paddocks would have captured only 19%. It is also important to note that C1 had minimal weed presence despite being untreated, which may not be representative of typical unmaintained RCs in WA.

At Giles, a separate RC, a calculated threshold of 5.2 mm was obtained based on field data; however, due to site characteristics, including fine-textured, low-permeability soils of the Booran erosional land system (Bettenay et al., 1964), an 8 mm threshold - considered standard for a well-maintained RC was applied. With 374 mm total rainfall, 52% of the rainfall occurred above the 8 mm threshold, and only 45% above 10 mm. Only one event exceeded the 25 mm paddock threshold. While sediment transport complicated data collection at Giles, the site highlighted several key considerations. The site suitability was determined by the grower site host with site-specific landscape knowledge and experience. The suitability of soil type is critical for RC success, as high sediment loads can reduce dam storage capacity and increase turbidity, which in turn affects water usability. These findings, consistent with earlier literature, underscore the long-recognised importance of proper site selection and regular maintenance for RCs (Baek & Coles, 2013; Laing, 1985; Davies & Denby, 1988).

4.1.4 Reliability Assessment

Reliability is a key component of water security. Using the WEP model, reliability was assessed for both the Lester (PVC-lined) and Giles (roaded) sites under different surface scenarios. At Lester, the existing PVC-lined system achieved 100% reliability based on real-world extractions and dam demands. If the same catchment had been roaded (8 mm threshold), reliability dropped to 72%. At Giles, the current roaded system achieved 98% reliability, which would have increased to 100% had it been lined with PVC (1 mm threshold). These comparisons demonstrate the clear reliability advantage of lined systems.

4.1.5 Economic Comparison

Economic analysis of catchment surface systems revealed substantial differences in both installation costs and long-term cost-effectiveness. Roaded catchments (RCs) are relatively inexpensive, costing $2–3/kL, but require significantly larger surface areas due to their lower runoff efficiency. If RCs are not appropriately sized and cannot meet water demand, the shortfall must be covered by carting water at a much higher cost of $17–28/kL. In contrast, plastic-lined systems such as PVC and HDPE offer more efficient water collection. PVC tarpaulin systems range from $4.9 to $14.7/kL, and HDPE ~ $4.4 to 9/kL. HDPE systems have higher upfront costs but are more cost-effective over time due to their longer lifespan.

Durability and maintenance are key factors in the long-term viability of catchment surfaces. Secondhand PVC tarpaulins are estimated to last between 3–7 years, while new tarpaulins may last up to 10 years. However, site-specific conditions, particularly anchoring methods, significantly influence performance. For instance, the Lester site experienced complete failure of its secondhand tarpaulin catchment within 2–3 years due to wind damage and the absence of surface weights. In contrast, the Wandell site, which used tyre walls as anchoring weights across the surface, demonstrated greater resilience.

Based on these findings and the successful on-farm adoption of HDPE systems in South Australia and on some corporate farms in WA, HDPE appears to be the preferred material for engineered catchment surfaces. However, further trials and demonstration projects in Western Australia are recommended to validate its performance under local conditions.

4.1.6 Method Considerations

Overall, confidence in the data collected was high for the plastic-lined sites, with minimal issues encountered throughout the monitoring period. In contrast, some challenges were observed at the RCs, particularly sediment accumulation in and around equipment at Giles. This complicated the determination of runoff thresholds. These findings highlight the importance of considering local soil type and landscape characteristics when installing RCs, particularly in areas prone to erosion or sediment movement.

The rainfall and runoff event classification method was effective across all sites. However, it required substantial manual checking to confirm event boundaries and ensure data quality, introducing some potential for human error. This manual review process was applied consistently across all sites, representing a general limitation of the current data processing approach.

To validate our rainfall threshold methodology, we reanalysed data from Baek and Coles (2021), which included four replicates at each location and tested several surface enhancements. We focused on the Soil-Loc spray polymer treatment, also known as Total Ground Control (TGC), as it demonstrated the strongest performance in their study. Baek and Coles reported average rainfall thresholds of 5.02 mm at Merredin and 4.48 mm at Mt Barker. Our application of the threshold method to their dataset produced comparable results, with thresholds of 4.7 mm at Merredin and 3.9 mm at Mt Barker. As the original study did not specify the exact method used to calculate thresholds, some variation was expected. However, both analyses consistently identified Merredin as having a higher threshold than Mt Barker, providing additional confidence in the reliability and general applicability of our method.

Some data loss occurred due to equipment failures outside our control, including water level loggers becoming dislodged from their housings and damage caused by livestock. These incidents highlight the importance of building robust monitoring sites, with secure instrument housing and adequate fencing to minimise disturbance.

Uncertainty in converting water level to discharge using rating curves remains a known limitation. While necessary for estimating runoff volumes, this process inherently introduces a degree of error, particularly where field calibration is limited. Future studies should consider incorporating direct flow measurements where possible to support and validate rating curve estimates.

4.1.7 Conclusion

The results clearly support the hypothesis: tarpaulin and plastic-lined catchments are highly effective at harvesting water from low-intensity rainfall events that would otherwise be lost under conventional methods. These systems consistently demonstrated superior rainfall capture, reliability, and long-term water security benefits, particularly in light of projected climatic trends towards lower-intensity rainfall in Western Australia. While installation costs remain a consideration, the significant yield advantages and predictability of these systems offer an increasingly compelling option for enhancing on-farm water security.

4.2 Hypothesis 2: Can subsurface drain harvest a high-quality and reliable supply of water?

4.2.1 Key Objective and Approach

A key question addressed in this study was whether subsurface drainage systems can provide a reliable and high quality water supply for agricultural use. We compared the performance of the three subsurface drainage systems in this report, including two tile systems (Ashtons and

Webb) and an open system (South). Monitoring of rainfall, runoff (discharge), and salt concentrations enabled evaluation of year-to-year variability in system performance, total water volumes harvested, and water quality.

Unlike surface catchment systems, subsurface drainage involves complex water movement below ground, influenced by soil properties, water table fluctuations, antecedent moisture conditions, and potential system clogging over time (Abduljaleel et al., 2023). While the data collected offer valuable initial insights, longer-term monitoring is necessary to fully determine system reliability under diverse climatic conditions.

It is important to note that the monitoring period encompassed two unusually dry seasons (2023 and 2024). Benchmarking across seven representative Wheatbelt stations classified 2023 as very much below average rainfall (decile 1) and 2024 as very much below to below average (deciles 2–3), providing essential context for interpreting observed hydrological responses.

4.2.2 Key findings: Insert Subsurface Drainage Systems

At the Ashtons site, monitoring between 7 June 2023 and 26 February 2025 recorded a total discharge of 1.6 ML in response to 507 mm of rainfall. Notably, 84% of this discharge occurred during the first winter season in 2023. While seasonal rainfall totals were relatively consistent between 2023 (202 mm) and 2024 (210 mm), discharge volumes differed markedly, with 1,378 kL discharged in 2023 compared to only 259 kL in 2024, representing an 80% reduction. These discharge patterns occurred despite both years falling into very much below average rainfall categories. The average salt concentration across the monitoring period was 1,223 mg/L, remaining well within livestock drinking water guidelines (ANZG 2023). The substantial year-to-year variability, despite broadly similar low rainfall totals, indicates that additional factors beyond rainfall volume, such as antecedent soil moisture conditions, rainfall intensity, and subsurface flow dynamics, strongly influence system performance.

At the Webb site, data collected between 3 April 2024 and 9 October 2024 recorded a total discharge of 1.64 ML from 325 mm of rainfall. The majority (91%) of this discharge occurred during an 18-day continuous flow event in August–September 2024. This season also corresponded to below average rainfall conditions based on decile classifications, further highlighting that substantial flow volumes can occur in relatively dry years when antecedent moisture conditions are favourable. The average salt concentration was low at 418 mg/L, again demonstrating water quality suitable for livestock use (ANZG 2023). A South Coast NRM trial implementing subsurface drainage to reduce waterlogging also reported that farmers observed fresh, clean water emerging from the systems; however, as this study focused on waterlogging, it didn’t collect water quality data (South Coast NRM, 2024).

While only one winter season was captured at Webb, the dominance of a single extended flow event emphasises the highly episodic nature of subsurface drainage. Despite sustained rainfall prior to the discharge event, little flow was initially observed, likely due to the system design, which requires a sump to fill before water is conveyed to the outlet and monitoring system. This results in a delayed onset of flow relative to rainfall.

4.2.3 Key findings: Open Subsurface Drainage Systems

At the South site, monitored between 1 August 2023 and 17 September 2024, a total of 2.5 ML was discharged from 533 mm of rainfall. Similar to the other sites, the bulk of discharge (94%) occurred during the 2024 winter period. Salt concentrations were particularly low at this site, averaging 279 mg/L, indicating exceptionally freshwater quality. When comparing equivalent winter periods, the system demonstrated significant inter-annual variability: 95 kL of discharge occurred from 129 mm of rainfall in August–September 2023, while 1,602 kL was discharged from only 95 mm of rainfall in August–September 2024. Despite receiving less rainfall during the winter period of 2024, higher pre-winter rainfall in July 2024 (110 mm) likely primed the system by elevating the water table. Importantly, both years fell into very much below average to below average rainfall deciles, reinforcing the finding that subsurface drainage performance is driven as much by rainfall timing and antecedent moisture as by total rainfall amounts.

4.2.4 Economic Comparison

Installation costs varied across the three subsurface drainage sites, reflecting differences in design, site conditions, and installation method. The open subsurface system at South incurred the highest construction cost at $20,143, while the tile subsurface systems at Webb and Ashtons were installed at $13,651 and $10,991, respectively. The lower installation cost at Ashtons reflects the farmer undertaking installation directly, reducing labour and contractor costs.

An average system lifespan of 25 years was applied consistently across all sites, based on GRDC farm infrastructure guidelines (Knights, 2024). Ongoing maintenance costs were estimated at 2% of the initial construction cost per year (Willsher, 2024; Wanchuck & Apedaile, 1988), equating to annual maintenance expenses of $402 (South), $273 (Webb), and $219 (Ashtons). These systems to remain performing as effectively as possible require periodic maintenance, as it is known these systems are prone to clogging (Abduljaleel et al., 2023; Stuyt & Dierickx, 2006).

Due to significant variability in seasonal rainfall, highly site-specific factors, and the limited duration of monitoring to date, it is not yet possible to calculate reliable estimates of water yield or unit water cost ($/kL) for these systems. While these preliminary cost figures provide an initial indication of capital and ongoing maintenance requirements, longer-term monitoring is needed to accurately assess economic performance across a broader range of seasonal conditions.

4.2.5 Method considerations

A key limitation of this assessment is the relatively short monitoring period that limits seasonal comparisons. Substantial year-to-year variability was observed, even under similar rainfall totals, highlighting how variables such as antecedent moisture, water table dynamics, and rainfall intensity can strongly influence subsurface drainage responses (Abduljaleel et al., 2023). This makes it difficult to draw firm conclusions on long-term system reliability from the current dataset. It is also known that some drains clog and experience a decrease in performance over time.

Some data gaps occurred due to equipment failures and livestock interference, which affected the continuity of certain monitoring periods. Additionally, both 2023 and 2024 were considerably drier than average, meaning system performance under more typical or wetter conditions remains unknown.

4.2.6 Conclusion

Subsurface drainage systems demonstrated the ability to generate high-quality water suitable for livestock use, even during dry years. However, year-to-year variability in discharge volumes was substantial across all sites and drain types. In some cases, nearly identical rainfall totals produced starkly different runoff volumes, highlighting the complexity of subsurface water movement and the influence of site-specific factors such as antecedent soil moisture, rainfall timing and intensity, infiltration capacity, and system design.

This variability limits the reliability of subsurface drainage as a consistent non-potable water source, particularly during dry or below-average rainfall periods. It is important to note that these findings are based on monitoring conducted over two unusually dry years (2023 and 2024), so system performance under average or wetter seasonal conditions remains unknown. Longer-term empirical monitoring will be critical to better characterise system reliability, refine economic assessments, and develop predictive models that account for this variability.

Consistently, salt loads across all sites remained below livestock drinking water thresholds, though slight variations indicate salinity is site-specific. As a potential non-potable water source, regular water quality monitoring is crucial to ensure its ongoing suitability, especially when used to water livestock.

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6 Appendix

6.1.1 Appendix 1

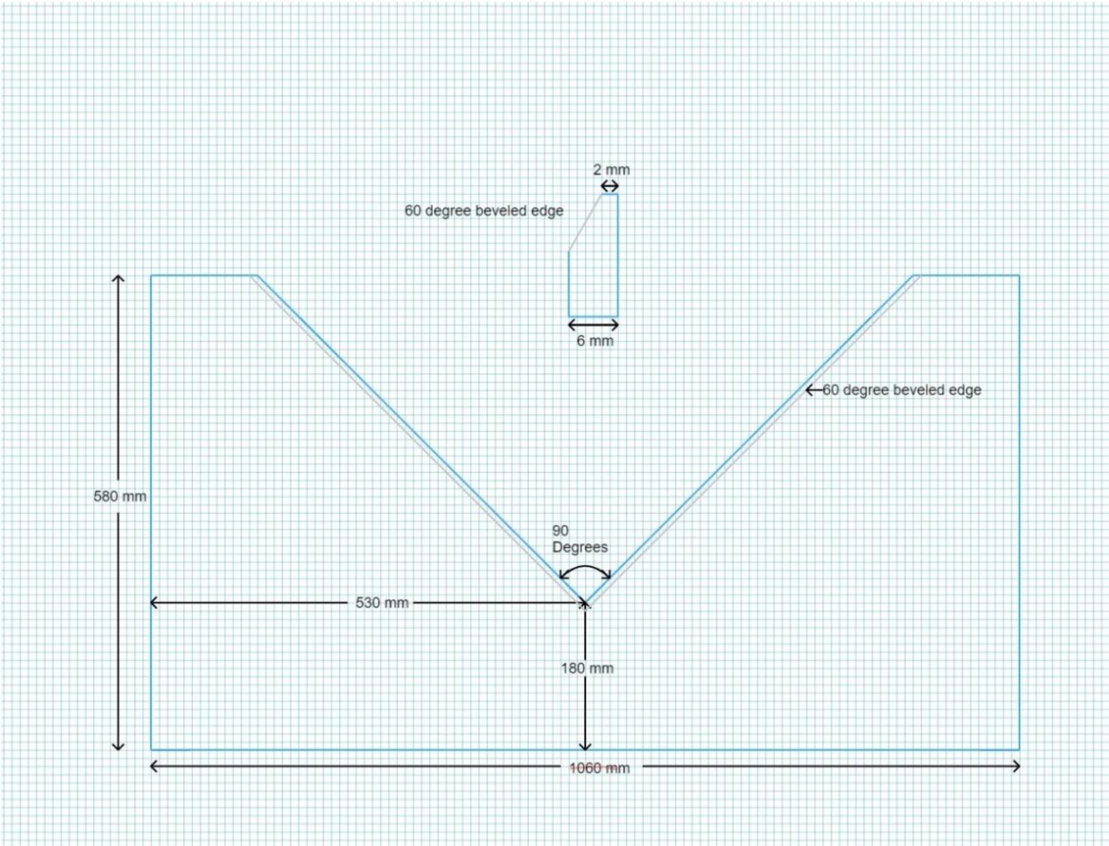

Figure 30: WaterSmart Dams- V-notch weir dimensions

WaterSmart Dams Rating Curves:

V-notch weir rating curve, specific to the dimensions above in (Figure 30). q represents discharge (L/s) and h represents water level/stage height (m)

$$q = 1356 * h^{2.48} \quad for\ h > 0$$

11-inch Parshall Flume, q represents discharge (L/s) and h represents water level/stage height (m)

$$q = 371.9632 * h^{2.0702} \quad for\ h > 0$$

18-inch Parshall Flume, q represents discharge (L/s) and h represents water level/stage height (m)

$$q = 1056 * h^{1.538} \quad for\ h > 0$$

6.1.2 Appendix 2

WEP model input parameters (real data, unless specified otherwise)

Parameters	Giles	Lester	Wandel
Catchment Area	1.56Ha	0.65Ha (tarp) 1.5Ha (roaded)	0.86 Ha
Roaded rainfall threshold	8mm	8mm	8mm
PVC tarp rainfall threshold	1mm	1mm	1mm
Max. Dam depth	5m	6m	
Dam surface length	47m	62m	
Average Slope	30%	24.2%	
Max. Dam Volume	5ML	9.55ML	
Depth % full on start date (01/01/2000)	40%	50%	
Livestock demand	700 mature sheep in Feb & March	5 sprays/annum (total of 640,000L). Each at 1,600 Ha (80L/Ha). x3 between Feb-March & x2 July & August	
Simulation period	01/01/2000 – 01/05/2025	01/01/2000 – 01/05/2025	01/01/2000 – 01/05/2025
Known dam volume to match the simulation to	On 31/08/2023 = 1.3ML	On 1/11/2020 = 4.8ML	