Hydro–ecological investigations to inform Water Allocation Plan reviews of the Eastern and Western Mount Lofty Ranges Prescribed Water Resource Areas

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Foreword

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

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

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

Ben Bruce
CHIEF EXECUTIVE
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1 Summary

The water resources of the Eastern and Western Mount Lofty Ranges (MLR) are managed through water allocation plans (WAPs) adopted in 2013. The Hills and Fleurieu Landscape Board (HFLB) is leading a process to review the WAPs, which includes assessment of the effectiveness of the WAPs in meeting their stated objectives.

This report describes an investigation to support the WAP review process by using hydrological modelling of various climate and WAP implementation scenarios to assess:

1. the effectiveness of policies and principles for surface water that underpin the environmental objectives of the WAPs, that is, what is expected to have happened if the WAPs were implemented as intended
2. the effectiveness of the actual implementation of those policies in meeting the WAPs' environmental objectives, that is, what has happened given how the WAPs have been implemented.

The modelling was carried out in 3 catchments selected to represent a range of climates, landscapes, and extent of water policy implementation across the MLR. These are the Bremer catchment in the Eastern MLR, the Carrickalinga catchment in the Western MLR Fleurieu Peninsula, and 2 sub-catchments of the Onkaparinga catchment in the central hills area of the Western MLR.

The key outcomes from this investigation are briefly summarised below, followed by further information on the key results for different climate and WAP implementation scenarios, as well as recommendations.

- The current extent of implementation of the key WAP rules decreases the overall level of risk to environmental objectives. That is, a likely improvement of environmental outcomes compared to pre-WAP development, when the effects of climate were excluded. However, this improvement is not sufficient to meet the catchment-scale flow objectives that underpin the WAPs' environmental objectives.
- The climate experienced since the WAPs were developed has variable effects on the pattern of flow and hence on the level of risk to environmental objectives, resulting in an increased risk for the majority of surface water management zones, but decreasing the risk for some zones.
- The combined effect of current WAP implementation and climate results is a small increase in the overall level of risk to environmental objectives since WAP development, resulting in expected poorer environmental outcomes. For some zones, the benefits of current implementation are offset by the negative effects on the pattern of flow due to the climate experienced since WAP development.
- Full implementation of the key WAP rules would further reduce the level of risk to environmental objectives, compared to the current extent of implementation.
- The climate experienced since WAP development means that full implementation of the key WAP rules would not be as effective as intended in meeting the flow objective for 2 of the 3 modelled catchments.

These findings support a decision to amend the WAPs, in order to allow them to be more effective in meeting their environmental objectives for surface water, under the current or likely future climate.

Key results

Pre-WAP scenario: This scenario represents the situation before WAP adoption and was modelled based on assumed use from dams and watercourse diversions at the time and with no low flow release (LFR) implementation. Only 19% of the 62 zones investigated met the flow objective under the WAP development period (1974 to 2006) climate, which does not meet the catchment-level flow objective.

If there had been no implementation, and the current level of development remained in place, the overall risk to environmental objectives would have increased as a result of the climate of the post-WAP development period (percentage of zones meeting the flow objective reduced to 12%). However, the results varied between zones and catchments. While 52% of zones failed *more* metrics for the pre-WAP scenario for the post-WAP development period (higher risk), over a third of the zones (37%) failed *fewer* metrics (lower risk). At a catchment scale, the level of risk to environmental objectives increased in the Bremer and Carrickalinga catchments but decreased in the modelled Onkaparinga sub-catchments, as a result of the climate of the post-WAP development period.

Current implementation scenario: The current extent of implementation of the key WAP rules is based on modelling assumed use from current dams and watercourse diversions and the current extent of LFR implementation. The current extent of implementation in the modelled catchments is limited to partial implementation of the 'passing low flows' policy in the Bremer and Carrickalinga catchments. The Bremer catchment includes some high demand zones where water demand and/or dam capacity exceed their limits, but this is generally yet to be addressed.

The overall level of risk to environmental objectives under current conditions has increased slightly since WAP development. Fewer zones passed the flow objective under current conditions (15% for current implementation scenario for post-WAP development period) compared to pre-WAP conditions (19% for pre-WAP scenario for WAP development period). The current extent of implementation of the key WAP rules decreases the level of risk, but the current extent of implementation is limited. For the majority of zones, the climate since WAP development had detrimental impacts on the EWR metrics and increased the level of risk to environmental objectives, and in some cases this detrimental effect offset the beneficial effects of current implementation.

The current implementation scenario showed an overall small decrease in the level of risk to environmental objectives, compared to the pre-WAP scenario, if the effects of climate are excluded (for example current implementation resulted in 2 additional zones meeting the flow objective compared to the pre-WAP scenario, when both are modelled for the post-WAP development period). However, this improvement was not sufficient to meet the flow objective for any of the 3 modelled catchments.

Current allocation scenario: This scenario represents what would happen if licensees used their current allocation instead of current assumed use, modelled using the current allocation taken from current dams and watercourse diversions, with no LFR implementation.

If licensees used their current allocation, rather than their assumed use, there would have been little change in demand for the majority (76%) of zones. As expected, where using current allocation caused demand to increase, the risk to environmental objectives stayed the same or increased when considering the percentage of metrics that failed to meet the objective; and where this decreased demand, the risk to environmental objectives decreased or stayed the same. In all cases, these demand changes were not enough to change the number of zones passing the flow objective compared with the pre-WAP scenario.

Full implementation scenario: The modelled full implementation involves fully implementing the key WAP rules linked to the flow objective of passing low flows at all scope sites; and adjusting both demand and dam capacity to be within their limits at zone and catchment-scales ('full development').

Full implementation of the key WAP rules reduced water demand in 35 zones (34 in Bremer, 1 in Onkaparinga) and increased water demand in 7 zones (6 in Onkaparinga, 1 in Carrickalinga), and did not change water demand in the remaining 20 zones (in Bremer). Full implementation also resulted in low flows being passed at more sites (48 zones with more sites passing low flows compared to current implementation).

Full implementation decreased the level of risk to environmental objectives, compared to the current implementation scenario. For example, 15% of modelled zones passed the flow objective for the current implementation scenario, increasing to 27% of zones for the full implementation scenario (both modelled for the post-WAP development period). In addition, 61% of zones failed fewer metrics under full implementation compared to current implementation, while 35% of zones had no change.

Full implementation of LFR allowed water demand and dam capacity to substantially increase while the level of risk to environmental objectives decreased. For the 7 zones where demand increased under full implementation, the volume of demand was 38 to 243% higher. Six of these zones failed fewer metrics for the full implementation scenario, and one zone failed the same number of metrics as for the current implementation scenario.

However, the catchment-level flow objective was not met for full implementation in the post-WAP development period for the Bremer and Carrickalinga catchments, as a result of the detrimental effect of climate on the EWR metrics in the majority of zones. This objective was met for the modelled Onkaparinga sub-catchments.

The outcomes varied between zones, particularly within the Bremer catchment. For the Bremer, 63% of the modelled zones failed *more* metrics for the full implementation scenario for the post-WAP development period (that is increased risk) compared to the WAP development period, including all of the modelled zones in wetter sub-catchments. However, 28% of the modelled zones failed *fewer* metrics for the post-WAP development period (that is decreased risk), and these were all located in drier parts of the catchment (Upper Bremer, Rodwell Creek or Red Creek sub-catchments).

These outcomes align with analysis of measured rainfall and streamflow data across the MLR carried out as part of a complementary WAP review project (Savadamuthu and McCullough, 2024). That analysis showed a decline in rainfall and runoff, particularly in spring and to a lesser degree in autumn since the Millennium drought for many sites in the MLR. Flow patterns have also been altered in some cases, with reductions observed in the number of flowing days per year, and in autumn and spring median flow. Such changes in rainfall and runoff would be expected to translate into worse outcomes for the EWR metrics and increased risk to environmental objectives, as observed for the majority of zones in this investigation.

Both investigations also found variation in the effects of climate over the MLR. For example, Savadamuthu and McCullough (2024) found rainfall has not declined in some areas such as some sections of the Onkaparinga, the lower elevations of the Bremer catchment and across the Fleurieu region. This corresponds with the findings from this investigation of reduced level of risk to environmental objectives since WAP development for the modelled Onkaparinga sub-catchments and some drier parts of the Bremer catchment.

This investigation has not considered the full suite of regulatory arrangements that accompanied the prescription of the water resources of the Mount Lofty Ranges. It does not explore what would have happened if they were not in place (for example no WAP or other policies about water affecting activities, including no restrictions on dam development and no water licensing system). Under these circumstances, further uncontrolled development could occur, further worsening the risk to environmental objectives relative to the pre-WAP scenario.

While this investigation involved zones in 3 catchments, the study areas were chosen to be representative of the Mount Lofty Ranges prescribed water resources areas generally with a mixture of drier and wetter areas and a range of landscape and water resource development conditions. The investigation shows that the flow objective is not being met in catchments in both Prescribed Water Resource Areas (PWRA)s of the MLR and shows the drivers for this at an appropriate level of detail to identify focus areas for further investigations and policy development during the WAP amendment phase.

Recommendations

The key finding is that 2 of the 3 modelled catchments do not meet their flow objective. This supports amending the WAP to be more effective in meeting its environmental objectives. Amendments could take the form of either or both:

- amending WAP rules to make them more effective at meeting the flow objectives, for the range of historical climate conditions experienced, and/or the expected future climate
- amending the environmental objectives for example, refining the method of calculating the metrics to take better account of shorter-term events like drought; and updating the relationships between the measured

flow regime and environmental condition that underpin the flow objective, to include data collected since WAP development, as discussed in section 6.2.2.

This investigation also identified a range of other issues that could be considered during WAP amendment, including:

(a) taking account of spatial and temporal variability in climate patterns when selecting data to inform policy development (for example, developing policy based only on the recent climate may result in policy settings for the modelled Onkaparinga sub-catchments that result in poorer environmental outcomes if the climate returns to the conditions of the WAP development period).

(b) considering the effects of spatial scale, forestry and variations in water resource development configurations when modelling scenarios and testing impacts on objectives as part of developing and assessing WAP policy.

2 Project overview

2.1 Background

The Hills and Fleurieu Landscape Board (HFLB) are undertaking a comprehensive 10-year review of the Eastern and Western Mount Lofty Ranges Water Allocation Plans (WAPs). The Department for Environment and Water (DEW) was tasked to undertake hydrological modelling and climate analysis to support HFLB's role in:

1. reviewing the effectiveness of the WAPs in meeting their stated objectives
2. informing the decision on the appropriateness of the current WAPs for the future.

The Mount Lofty Ranges (MLR) WAPs include environmental water provisions (EWPs) for surface water. These include objectives defined in terms of desired ecological conditions, and also defined as a flow regime or pattern of flow that is expected to support achievement of the desired ecological conditions at an acceptable level of risk ('flow objective'). The flow objective is the focus of this investigation.

The flow objective is expressed using a series of flow indicators representing environmentally important parts of the flow pattern ('environmental water requirements (EWR) metrics'). An individual EWR metric 'passes' if its value for a surface water management zone meets its target for that zone. The flow objective for a zone is a pass of at least 85% of its EWR metrics. The flow objective has been used to set the rules for 2 key policy areas in the MLR WAPs and associated existing user-licensing processes:

- volumetric limits on water demand and interception, at the scale of surface water management zones and catchments
- 'passing low flows' at defined existing and new dams, and watercourse diversions, or 'low flow release' (LFR).

These 2 key policy areas are referred to as 'key WAP rules' in this report. Section 3.2 provides an overview of how the flow objectives were set, and how they were used to determine the key WAP rules.

To assist reviewing the effectiveness and informing the appropriateness of the current WAPs, hydrological modelling was undertaken to assess the EWR metrics and report on their performance at select zone and catchment scales. The EWR metrics assessed are defined in the current WAPs, as they form the basis for definition of the flow objective and the associated key WAP rules.

Evaluation of the performance of EWR metrics was undertaken by modelling variable use and LFR implementation scenarios across the climate experienced in 2 different time periods: the WAP development period (1974 to 2006) and post-WAP development period (2007 to 2022).

The key WAP rules were developed based on EWR metric performance and their achievement of the flow objective over the WAP development period. Therefore, assessment of EWR metric performance for different scenarios over the WAP development period provides a baseline for comparison, to determine the effects of scenarios modelled under different climate conditions. Future climate may generally be expected to align more with the post-WAP development period, and assessment of resource behaviour for this period will play a critical part in any WAP amendment. This approach is to enable consideration of 2 overarching WAP review questions:

1. The effectiveness of policies and principles for surface water that underpin the environmental objectives of the WAPs that is, *what is expected* to have happened if the WAPs were implemented as intended?
2. The effectiveness of the actual implementation of those policies in meeting the WAPs' environmental objectives that is, *what has happened* given how the WAPs have been implemented?

Hydrological modelling has been carried out in study catchments that have been selected to represent a range of climates, landscapes, and extent of water policy implementation across the MLR. Catchments assessed (Figure 1) were:

- Bremer River, considered high priority as it is one of the largest catchments in the EMLR Prescribed Water Resource Area (PWRA) that drains to the Lower Lakes, having high-demand zones and partial implementation of Low Flow Releases (LFR)
- Carrickalinga Creek, one of few catchments in the Western Mount Lofty Ranges (WMLR) Prescribed Water Resource Area (PWRA) with limited LFR implementation, and located in the Willunga Basin and Fleurieu Peninsula catchments region of the WMLR WAP
- Echunga and Mitchell Creek sub-catchments within the Onkaparinga catchment, representing the largest catchment in the Central Hills catchments area of the WMLR WAP.

2.2 Key outcomes and outputs

This assessment is intended to enable HFLB to report on the effectiveness of the WAPs in meeting the stated flow objective, as reported through EWR metrics, for the climate experienced since WAP development. This project has focused on catchment modelling scenarios and EWR metric evaluation efforts for the Bremer and Carrackalinga catchments and Echunga and Mitchell Creek sub-catchments, only. Outputs for the selected sites include:

- updated surface water models with extended time-series input datasets
- scenario modelling of variable use and LFR implementation for different periods, with flow outputs at zone scale
- technical reporting outlining the success of existing WAP EWR metrics under various scenarios.

Changes in resource capacity and security of supply are not included in this project.

Figure 1. Modelled catchments and sub-catchments used for the investigation.

3 Water allocation planning and the role of hydrological models

This section provides background information to provide context for this investigation. It includes information on:

- general water allocation planning processes for the Mount Lofty Ranges (MLR)
- the processes for setting environmental objectives in the 2013 water allocation plans (WAPs) and for using the flow objectives to set key WAP rules, as well as a description of the EWR metrics that are used to evaluate the flow objectives
- the development of surface water models to support development of the 2013 WAPs, and subsequent updates for later projects.

3.1 Water allocation planning in the Mount Lofty Ranges

Prescribed Water Resource Areas (PWRAs) of the Mount Lofty Ranges span as far south as Cape Jervis to just north of Mount Pleasant and the gateway to the Barossa Valley. The central ridgeline effectively separates the Western Mount Lofty Ranges (WMLR), with rivers and streams predominantly flowing east to west toward St Vincent's Gulf, and the Eastern Mount Lofty Ranges (EMLR), which generally has flows west to east. This region receives the highest rainfall in South Australia and the WMLR contains some of the most important surface water supply catchments for metropolitan water supply, while streamflow from the EMLR supplements the lower River Murray and Lake Alexandrina (Figure 1).

Surface and groundwater resources in these areas are prescribed and Water Allocation Plans (WAPs) limit additional water take for purposes requiring a licence, as well as the expansion of forestry and the construction of new dams. Water allocation plans balance social, economic, and ecological water requirements, as well as Aboriginal water interests, at an acceptable level of risk to the environment. References to 'surface water' in this document also include water in watercourses.

Water resources in the WMLR PWRA are managed through the WMLR WAP (Adelaide and Mount Lofty Ranges Natural Resources Management Board (AMLR NRMB) 2013), which was prepared by the former AMLR NRMB. The EMLR PWRA is managed through the EMLR WAP (South Australian Murray–Darling Basin (SAMDB) NRMB 2019), as prepared by the former SAMDB NRMB. Regional boundaries were rearranged as part of the *Landscape South Australia Act 2019* reforms, and the Hills and Fleurieu Landscape Board (HFLB) now has responsibility for both WAPs.

The EMLR and WMLR WAPs were prepared over the period 2006 to 2013 under the provisions of the *Natural Resources Management Act 2003* (NRM Act), which has since been replaced by the *Landscape South Australia Act 2019*. The separate process to allocate water to existing users in accordance with the NRM Act also started in that period. A common body of investigations and associated key rules and assumptions underpin both the WAPs and existing user-licensing processes.

Both WAPs were adopted in 2013. The EMLR WAP was amended in 2019 to include information on Aboriginal water interests and improve consistency with the federal Murray–Darling Basin Plan.

HFLB started a 10-year review of each WAP in 2022, in accordance with the requirements of the *Landscape South Australia Act 2019*.

3.2 Sustainable water capture and demand at an acceptable level of risk to the environment

As part of the investigations underpinning the development of the 2013 MLR WAPs and existing user-licensing processes, projects were undertaken to define environmental water requirements (EWRs) and environmental water provisions (EWPs), and associated objectives, for the PWRAs. The flow objective was used to set limits on the volumes that could be taken from water resources, together with associated take rules where required, to maintain environmentally sustainable extraction limits.

- Environmental water requirements are those water requirements that must be met in order to sustain the ecological values of ecosystems that depend on the water resources, including their processes and biological diversity, at a low level of risk.
- Environmental water provisions are those parts of environmental water requirements that can be met at any given time. This is what can be provided at that time with consideration of existing users' rights, and the social and economic impacts.

The processes for defining EWRs, EWPs, objectives and extraction limits are described in Vanlaarhoven and van der Wielen (2009), Vanlaarhoven and van der Wielen (2012), and Vanlaarhoven (2012) and summarised in section 2 of the EMLR and WMLR WAPs. The major steps for defining these parameters for surface water are briefly outlined below.

Step 1: Set the overall environmental objective.

An overall environmental objective was set for the MLR PWRAs, to describe the desired state that is to be achieved by providing environmental water. This objective is to maintain and/or restore self-sustaining populations of aquatic and riparian flora and fauna which are resilient in times of drought.

Step 2: Describe qualitative environmental water requirements needed to meet the overall objective

Environmental water requirements were described for different functional groups of fish, water-plants, and aquatic macro-invertebrates. The first step was to identify the flow-dependent ecological processes required to meet the environmental objective for each functional group (for example habitat availability, mixing and spread of populations). The parts of the flow pattern or water regime components required to support each of those processes were then identified, in terms of size, duration, frequency and timing of the flow pattern (for example how long there is no flow in drier seasons and how often large flow events occur). These requirements were summed up across the functional groups found in different parts of the MLR PWRAs, to give descriptive or qualitative environmental water requirements for the major habitats across the area.

Step 3: Identify hydrological EWR metrics with limits to represent the qualitative environmental water requirements

The qualitative environmental water requirements were translated into measurable flow indicators or hydrologic EWR metrics that represent the identified water regime components. For example, an ecologically important water regime component is the total length of time that there is no flow in the drier seasons, which is represented by the hydrological metric of the average total duration (number of days) with a zero-flow rate in the Low flow season.

Limits were set for each EWR metric in terms of how far it could deviate from its value under 'natural' conditions, while still maintaining the ecological process supported by that flow component. An EWR metric that remains within these limits is considered to 'pass', while a metric that exceeds these limits is considered to 'fail' to provide an adequate environmental water requirement. More information on the EWR metrics and their limits is given in section 3.2.1.

Step 4: Set a target for the EWR metrics expected to meet the overall environmental objective at a low level of risk (that is environmental water requirements)

It was considered that meeting the environmental water requirements for surface water equates to passing all of the EWR metrics at a site. This is expected to provide a flow regime that is expected to sustain ecological values at a low level of risk.

Step 5: Set EWP environmental condition objectives to maintain water-dependent ecosystems at an acceptable level of risk (that is environmental water provisions)

WAPs are required to achieve an equitable balance between social, economic, and environmental needs for water. Therefore, it was necessary to set environmental water provision objectives and associated environmental water provisions that are expected have an acceptable level of risk to the environment, while recognising existing users' rights and social and economic impacts.

EWP environmental condition objectives were set that aim to maintain water-dependent ecosystems at an acceptable level of risk for meeting the overall environmental objective above. These EWP environmental condition objectives were expressed as a minimum acceptable ecological condition that is expected to allow populations to be self-sustaining. This was derived from expert interpretation of fish and macroinvertebrate monitoring data from sites across the Mount Lofty Ranges.

Step 6: Determine the flow objective – the environmental water regime expected to support achievement of the EWP environmental condition objective.

An environmental flow regime objective (the 'flow objective') was set to describe the flow regime that was expected to allow the EWP environmental condition objectives to be met. The relationships between ecological condition and percentage of EWR metrics passed for fish and macroinvertebrate monitoring sites across the MLR were used to establish what percentage of EWR metrics represented a pass at a site that was associated with the minimum acceptable ecological condition. The result is the flow objective, which is to pass at least 85% of the metrics (or fail no more than 15% of the metrics) at a site. That is, if the flow objective is met, then it is expected that the pattern of flow is sufficient to support achievement of the EWP environmental condition objective.

This flow objective is applied at the scale of the surface water management zone and catchment.

The pattern of flow is a major factor influencing the nature and condition of water-dependent ecosystems, but it will also be influenced by other factors outside the scope of WAPs, such as land use and management, and pest plants and animals.

Step 7: Use the flow objective to set key WAP rules.

The flow objective was used to set key water management rules by modelling a range of management options with different levels of demand and different options for 'passing low flows', across a range of zones with different climates and different levels, type, and distribution of surface water demand. The results were assessed to identify which of those scenarios met the flow objective of passing at least 85% of the EWR metrics at a site.

This modelling process was done using the surface water models described in section 3.3.

The modelling was carried out using the climate from 1974 to 2006. This period represents a range of wet, average, and dry years, and corresponds to periods for which flow data is available for most modelled catchments.

The result of modelling different options of demand and take rules was that the environmentally sustainable 'take limit' that met the flow objective was 25% of average annual 'adjusted runoff' for the WMLR, and 20% for the EMLR, with low flows passed at low flow release (LFR) scope sites. This take limit caps the annual volume of allocations for stock and domestic use and forestry interception, plus net evaporation from dams in the EMLR. More information on passing low flows is given in section 3.2.2. In addition, interception or diversion limits were set to cap dam capacity plus forestry interception at 50% of average annual adjusted runoff for the WMLR, and 30% for the EMLR. These limits apply at the zone scale. Collectively, these limits and the requirement to pass low flows are referred to as the key WAP rules for the current investigation, and if fully implemented under the same climate as the WAP development period, are expected to meet the flow objective.

As part of the process for setting the key WAP rules, it was found that the flow objective would not be met in all cases. The relationship between water demand at a site and percentage of EWR metrics failed there varies between zones and is likely to be affected by factors such as distribution of dams and watercourse diversions, dam size, and proportion of unlicensed dams present. The acceptable proportion of cases to meet the flow objective differs between the PWRAs:

- For the EMLR, as part of the process of balancing social, economic, and environmental water needs, it was considered that the flow objective should be met at the majority (at least 50%) of test cases.
- For the WMLR, the relationship between estimated water demand and EWR metric performance across sites indicates that the flow objective should be met in at least 75% of sites.

The WAPs contain a range of other rules for management of surface water that are not considered in this investigation. These other rules aim to address different purposes or objectives or implement complementary measures to support the achievement of the overall environmental objective for specific habitats.

3.2.1 EWR metrics

The EWR metrics have been developed to represent the key parts of the flow regime required to support different ecological processes. In turn, there is an assumption that these ecological processes are functioning properly in order to meet the environmental objectives.

The EWR metrics are determined over 4 flow seasons:

- Low flow season (LFS) – generally constant low flows, or no flow, with infrequent shorter periods of high flow following rainfall (typically December to April, and often May)
- Transitional flow season 1 (low to high) (T1) – increasing flow level and duration (typically May, June and up to July)
- High flow season (HFS) – higher baseflow and frequent periods of much higher flows (typically July to October)
- Transitional flow season 2 (high to low) (T2) – decreasing flow level and duration (typically November and sometimes December).

The EWR metrics cover a range of flow components (grouped as metric types): zero flows, low flows, freshes (short pulse flows following rainfall events, that are contained within the stream banks), and bankfull (flows that fill the channel but do not spill onto the floodplain). Overbank events (higher flows that spill onto the floodplain) are considered to be represented by the bankfull metrics.

Metrics for zero flows, freshes and bankfull flows relate to the frequency and duration of those events for each flow season (for example number of years out of the assessment period that freshes occur in the High flow season, or total average duration of zero flows (as number of days) in the Low flow season).

The metrics for low flows are calculated as the seasonal low flow rate as the 80th percentile exceedance non-zero flow rate. This is the flow rate that is equalled or exceeded for 80% of the time in the flow season, calculated using non-zero daily flow values only. That is, for all of the days that there is flow in a flow season, 80% of those days have a flow rate that is higher than the low flow rate, and 20% of those days have a daily flow rate that is lower.

The suite of EWR metrics also includes:

- seasonal average daily flow for each flow season, as a measure of overall seasonal flow
- seasonal timing metrics, that assess whether the Transitional 1 flow season has been delayed (that is delay in the break of season) and whether the Transitional 2 flow season has started early (that is the High flow season stops earlier).
- 'other fresh' metrics that assess frequency of specific types of fresh events in specific seasons, that support particular ecological processes – such as very large flow events that support large-scale fish migration, or larger pulse events that prepare fish spawning areas in breeding season.

The EWR metrics are generally calculated as a single value per metric over the nominated period. For example, the nominated period used for WAP development was 1974 to 2006, and so the metric for average total duration of zero flow in the Low flow season would be calculated as the average annual number of days with zero flow in the Low flow season for 1974 to 2006.

The EWR metrics are assessed by comparing the value of the metric under a modelled scenario with the value under the modelled 'No development' scenario. The No development scenario is used as a surrogate measure for natural conditions. An acceptable target range (percent deviation) is set around the No development value, with a smaller target range set for metrics that are considered to be more critical or sensitive to change. A metric passes for a scenario if the modelled scenario value for the metric falls within the acceptable target range and fails if it does not. The environmental water requirements are met if all the EWR metrics pass at a site; and the flow objective for a zone is met if 85% or more of the EWR metrics pass for the zone (that is no more than 15% fail).

The WAP development process used modelled flow data from a nominated period of 1974-2006 to calculate EWR metrics, set EWP water regime objectives and determine the associated key WAP assumptions and rules.

There is some overlap in terminology between metrics and with water management policy. As outlined above, there is a metric to represent low flow. Low flow occurs in all flow seasons, not just the Low flow season. As defined by the EWR metrics, the rate of low flow (and other flow components like freshes) vary between the different flow seasons and are calculated relative to the overall flow for the season.

In addition, the low flow metric is not the same as passing low flows, or the threshold flow rate used for the LFR policy. As described in section 7.3.1 of both Vanlaarhoven (2012) and Vanlaarhoven and van der Wielen (2012), the threshold flow rate that is passed for the LFR policy has been set based on the size of freshes in the 2 transitional flow seasons. These are the largest environmentally important flow components that have been significantly affected by water resource development. The threshold flow rate is expected to pass low flows in all flow seasons, and freshes in the Low flow season and both transitional flow seasons, for the majority of zones.

3.2.2 Low flow release

Passing low flows, or low flow release (LFR), means that when flow occurs, flows up to a nominated threshold flow rate for a site are not taken, or are returned or released. The threshold flow rate for a location is calculated based on the upstream catchment area multiplied by a unit threshold flow rate that reflects local climate and runoff conditions. The size of the threshold flow rate has been set to pass the environmentally important flow components that have been most effected by water resource development in the MLR. These are low flows in all seasons, and freshes (short pulse flows) for all seasons outside the High flow season. See section 3.2.1 for more information on flow seasons.

Scope sites are all dams used for licensed purposes, dams with a capacity of 5 ML or more that are used for non-licensed (stock and domestic) purposes, and all licensed watercourse diversions.

For the modelling used to set the environmentally sustainable extraction limits and rules during WAP development, LFR was implemented at all scope sites (or all licensed dams and watercourse diversions only, depending on the management scenario being tested). To date, programs to implement LFR at existing sites have taken a 'strategic location' approach that identifies the minimum subset of scope sites needed to pass low flows within an area to meet the environmental flow regime objective. These scope sites in the minimum subset are known as 'Tier 1' sites.

The environmentally sustainable extraction limit and associated requirement for passing low flows apply to both the existing user-licensing process and the WAPs. The environmentally sustainable extraction limits in the WAPs assume that existing users have been, or will be, allocated water consistent with the environmentally sustainable extraction limits, including the requirement to pass low flows. Hence references in this report to implementation of key WAP rules, denotes implementation of key WAP principles as well as the WAPs' assumption about the treatment of existing users.

3.3 Surface-water model development

This section describes the development of surface water models used to support WAP development, and subsequent updates for later investigations.

Hydrological models, also known as surface water models or catchment rainfall-runoff models, are conceptual models that represent interaction of various surface water components of the hydrologic cycle (climate, surface water runoff, interception, infiltration, groundwater recharge, streamflow and baseflow), at a defined scale. Through computer programming languages, mathematical functions built into a model are used to represent the various interaction processes. Models are built to reproduce catchment conditions, and to generate long-term data to enhance further understanding of the hydrological processes within catchments.

3.3.1 Initial model development

Early hydrological models of surface water catchments were constructed using WaterCress (Cresswell 2002), a PC-based water balance modelling platform, and calibrated to observed catchment-streamflow data. This initial rainfall-runoff model development (for example see Teoh 2002, Heneker 2003, Savadamuthu 2006 and Alcorn 2008) occurred in the early 2000s for state water-planning purposes, primarily to assess the impact of farm dams on streamflow. The partially lumped farm-dam models were calibrated to pre-Millenium Drought climate and streamflow data.

During the WAPs prescription process, the above-mentioned surface water models were used to assist the investigations to determine surface water resource capacity. The investigations, summarised in Alcorn et al. (2008) and Savadamuthu and Teoh (2010), were done as part of the process undertaken by the then South Australian Murray-Darling Basin Natural Resources Management (NRM) Board and Adelaide and the Mount Lofty Ranges NRM Board. The main output of these investigations was to define the capacity of the surface water resource or adjusted runoff, which is the average annual runoff adjusted to remove the impact of runoff dams, watercourse diversions, limited areas, and plantation forestry. Models for the EMLR underwent major review and recalibration in 2010 to incorporate updated watercourse demand and observed streamflow data (Alcorn 2010). Runoff dam data from Alcorn et al. (2008) were not changed as part of this amendment process.

3.3.1.1 WaterCress model build (node-link structure)

As discussed, detailed modelling methodology can be found in the reports listed above. Prior to building a WaterCress catchment model, Geographic Information System (GIS) tools are used to delineate a catchment into numerous sub-catchments that drain to various major runoff dams and watercourse extractions. Models are constructed as a series of 'nodes', with each node being generally a rural node that produces runoff for a portion of the total catchment (model sub-catchment defined in GIS); and a dam node containing total dam storage volume for the same model sub-catchment or demand node consisting of watercourse extraction demand. Nodes are linked, based on drainage direction, to form one major catchment and parameterised with hydrological data such as rainfall and evaporation, among others. Discrete nodes representing the relative location of streamflow gauging stations are included, and models are calibrated to observed streamflow records at these nodes. A typical layout of the spatial representation of different components of a catchment as nodes in a model is illustrated in Figure 2.

The structure of the WaterCress models is considered partially distributed, from a perspective of spatial representation of the variability of hydrological parameters within a catchment. For example, dams with small contributing catchment area and/or volume are lumped with similar nearby dams to reduce model complexity and included in the models as a single dam. Models, however, include explicit representation of: (i) spatial variability of rainfall, (ii) location of major blocking dams relative to their contributing catchment areas, (iii) watercourse extractions at a zone scale, (iv) urban catchment parameters and (v) catchment parameters that provide the best fit to observed streamflow in the catchment.

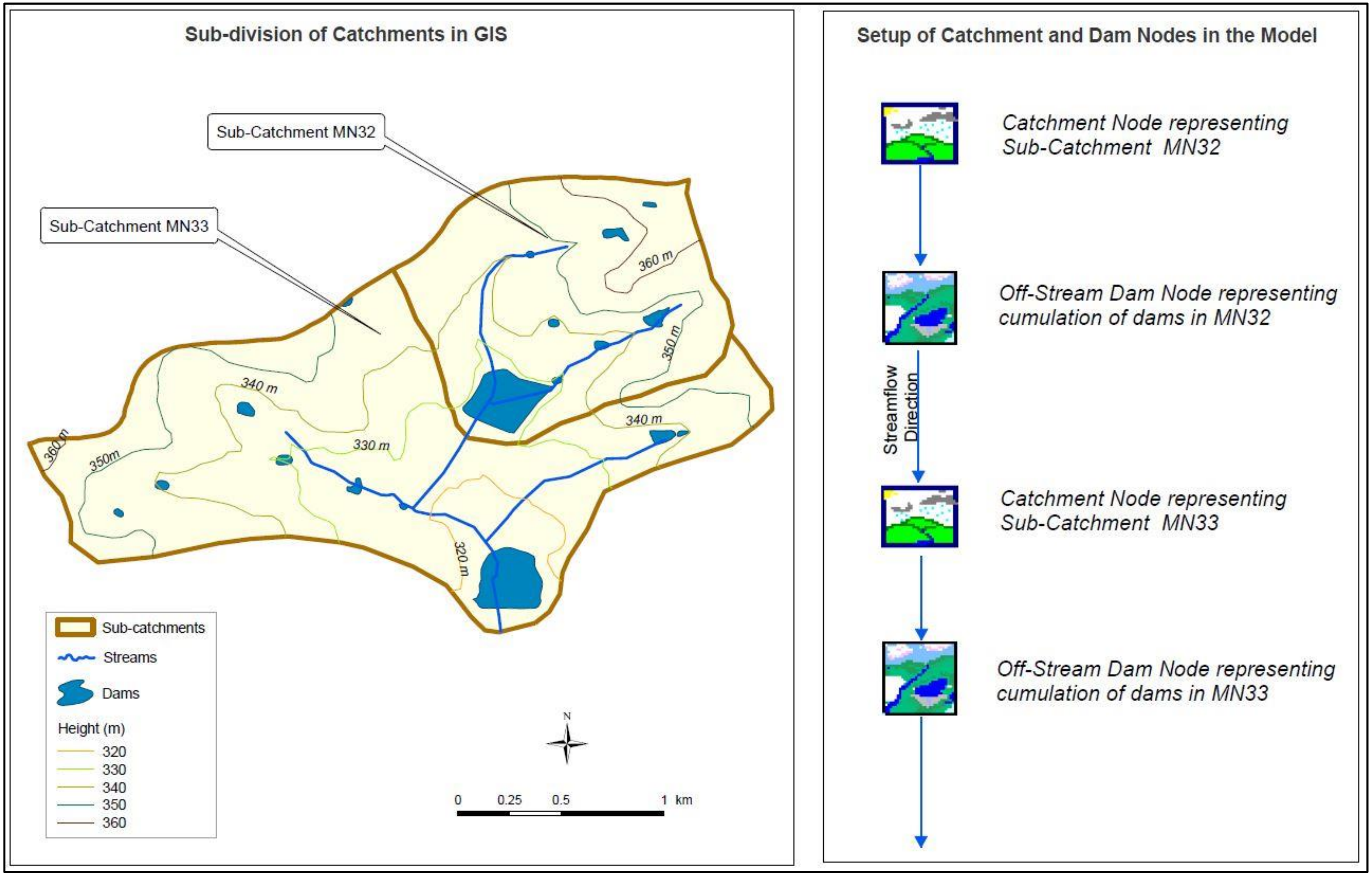

Figure 2. WaterCress model construction – representation of catchment components as model nodes

3.3.2 Migration to eWater Source model platform

The process to transition existing DEW surface water models from WaterCress to eWater Source commenced around 2015. Source is the nationally recognised and best practice hydrological modelling platform in Australia. Maintenance and further development of Source is supported through a Council of Australian Governments agreement under the National Hydrological Modelling Strategy, of which South Australia (through DEW) is a partner. DEW's transition to Source to date can be broadly summarised as:

- 2015 to 2020: construction of new EMLR fully distributed flow routing models (unpublished draft reports), as follows:
  - Catchment-scale models were built that route 'No development flow' (from calibrated WaterCress models) through a configuration of farm dams and watercourse extractions, current at the time of model build.
  - Fully distributed indicates that individual farm dams and watercourse extractions were represented in the model (Figure 3), on a finer scale than that of the WaterCress models.
  - To date, these models have been primarily used to support EMLR WAP implementation activities, that is low flow release scenario modelling at farm dam subwatershed scale.
- 2017 to 2020: construction and calibration of new WMLR rainfall-runoff models (DEW 2021), as follows:
  - These models were built for water supply catchments for SA Water-operated reservoirs.
  - They were fully distributed models.
  - Use to date has included supporting WMLR WAP implementation activities, estimating natural catchment inflow to reservoirs and LFR scenario modelling.
- 2022 onwards: construction and calibration of new EMLR rainfall-runoff models for major catchments, as follows:
  - These are fully distributed models.
  - A Tookayerta model was constructed in 2022 (Penney et al. 2023 draft report).
  - Future modelling of major catchments including Angas, Bremer and Finniss is scheduled to commence soon.

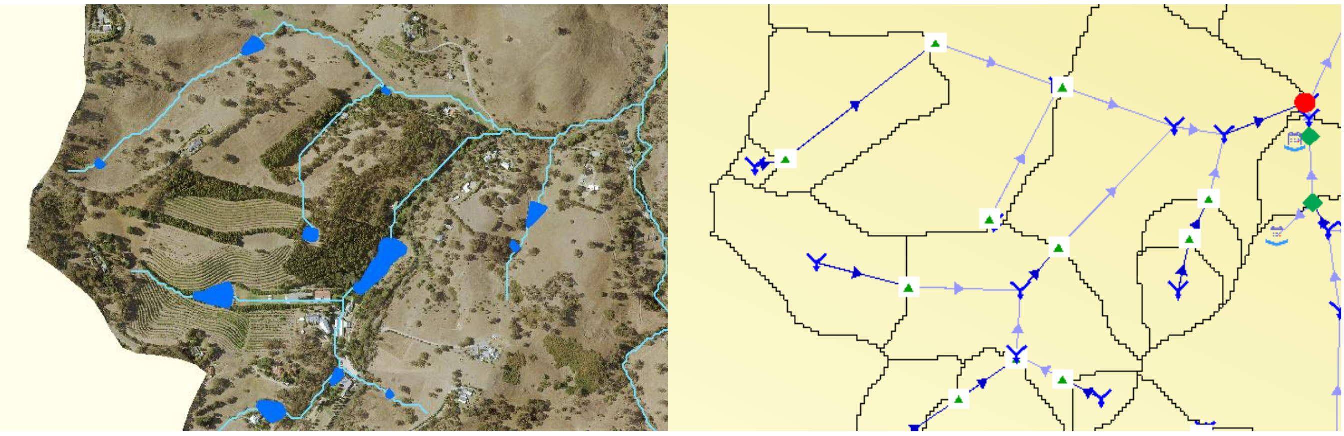

Figure 3. Satellite imagery and corresponding Source model layout highlighting a fully distributed node-link structure

4 Scenario modelling and analysis method

This section describes the methods used for this investigation, including for:

- updates to the surface water models (section 4.1)
- different scenarios using varying combinations of water-resource development, implementation of low flow release (LFR), and climate periods that were modelled for this investigation (section 4.2)
- the water allocation plan (WAP) review questions to be answered by comparing the outcomes of different scenarios (Section 4.3)
- assessing changes to level of risk to environmental objectives (section 4.4).

4.1 Model updates and catchment selection for this investigation

The most recent models for the catchments used for this investigation (as outlined in section 3.3.2) were updated to incorporate recent data on the licensing status of dams, dam capacity for licensed dams, and assumed allocation per licensed dam and watercourse diversion. This data was taken from the October 2022 update of the Mount Lofty Ranges WAP assessment dataset, an internal dataset maintained by DEW and HFLB. Where necessary, climate data, no dams inflow (routing models only, that is Bremer and Carrickalinga) and water use extraction patterns up to the end of 2022 were incorporated.

The most recent Western Mount Lofty Ranges (WMLR) Source models of the reservoir catchments include the Onkaparinga model, which has specific functional units for forestry areas that generate different rainfall-runoff characteristics compared to rural catchments, whereas the original models used for WAP development did not. It was considered that the model assumptions and characteristics used for this investigation should match those used for WAP development where practical, to allow the outcomes to be comparable with those used for setting the key WAP rules. As a result, the sub-catchments or catchments selected for this investigation have minimal areas of forestry. Note that the surface water resource capacity volumes in the 2013 MLR WAPs have been adjusted to remove the effects of plantation forestry, using a procedure applied after the modelling process as described in Alcorn (2010), and Savadamuthu and Teoh (2010).

The catchments or sub-catchments used for this investigation are described below. The combination of areas selected to include representatives of each Prescribed Water Resource Area (PWRA) and the 2 major catchment groups in the WMLR (Central Hills catchments, and Willunga Basin and Fleurieu Peninsula catchments).

Echunga Creek (Figure 4) and Mitchell Creek (Figure 5) are sub-catchments in the Onkaparinga catchment, which are included as representatives of WMLR central hills catchments. These sub-catchments occur upstream of Mt Bold reservoir and are not impacted by imported River Murray water flowing into the reservoir; that is, runoff for these zones is generated from the local sub-catchment area only. There has been no LFR implementation in these sub-catchments. For this investigation, data was used from 4 Echunga Creek zones (O_EC01-04), and for all 3 of the Mitchell Creek zones (O_MT01-03). These Onkaparinga sub-catchments and zones were selected because they included a range of different combinations of dam sizes, position in the catchment and licensing status, and because they have minimal areas of forestry.

The **Bremer catchment** (Figure 6) is located in the Eastern Mount Lofty Ranges (EMLR). This represents: a wide range of climates (moderately wet to very dry), landscape conditions (hills and flatter areas); development conditions (for example different intensities of water resource development); and a range of combinations of dam sizes, positions of dams and watercourse diversions, and licensing status. There has been partial LFR implementation, to varying degrees across the catchment. The volume of dam capacity and/or water demand exceeds the WAP limits for some zones, and for the catchment as a whole. The modelling for this investigation excludes the flood diversions in the lower-Bremer around Langhorne Creek, and also excludes some zones where current model outputs did not replicate previous outputs due to incompatible functionalities between model platform versions, resulting in analysis of data from 54 of the 62 Bremer zones.

The **Carrickalinga catchment** (Figure 7) is a WMLR Fleurieu catchment. The entire catchment is represented by a single zone in the WMLR WAP. There has been partial LFR implementation across the catchment. The total volumes of dam capacity and water demand are within the WAP limits.

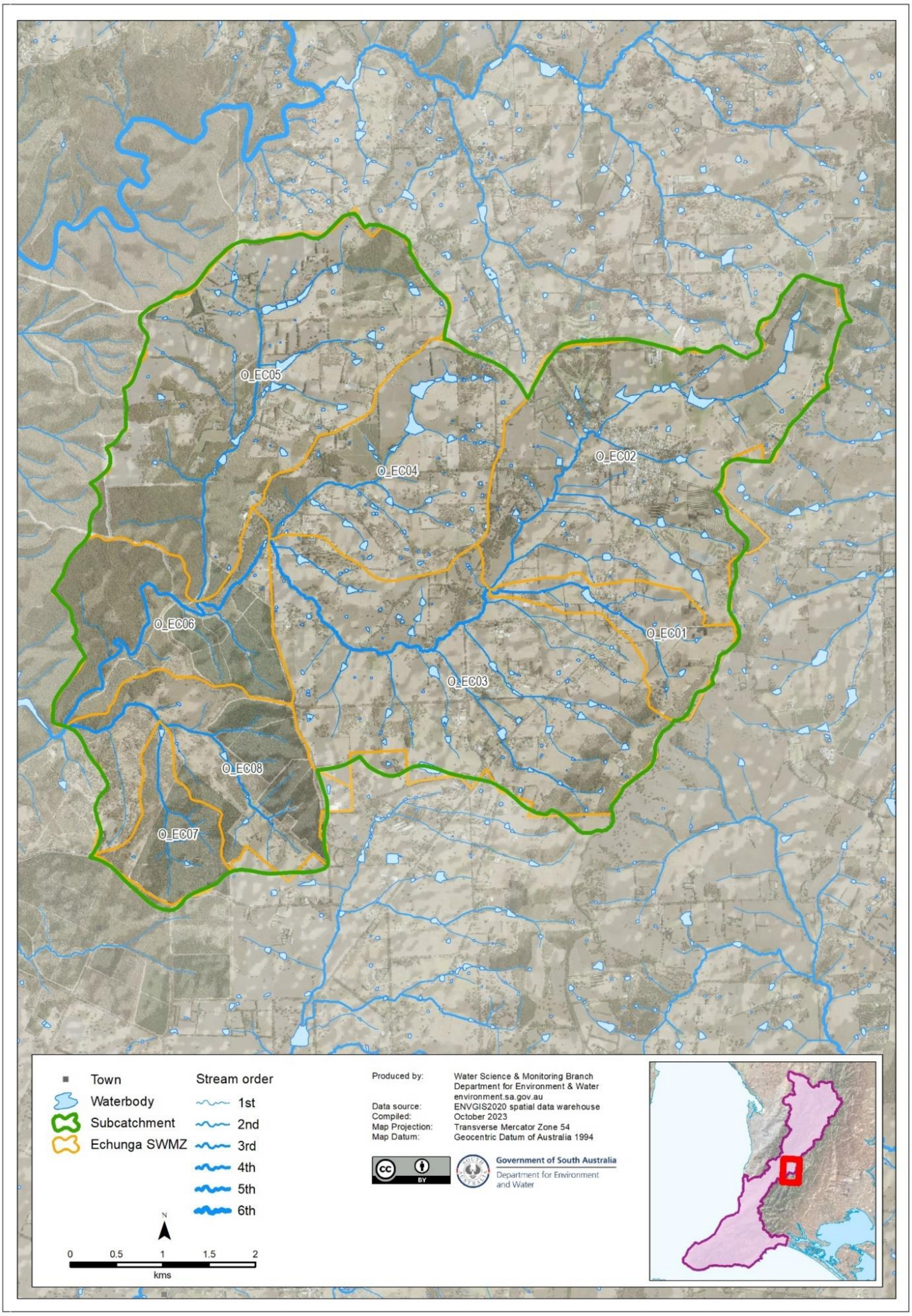

Figure 4. Echunga Creek sub-catchment location map

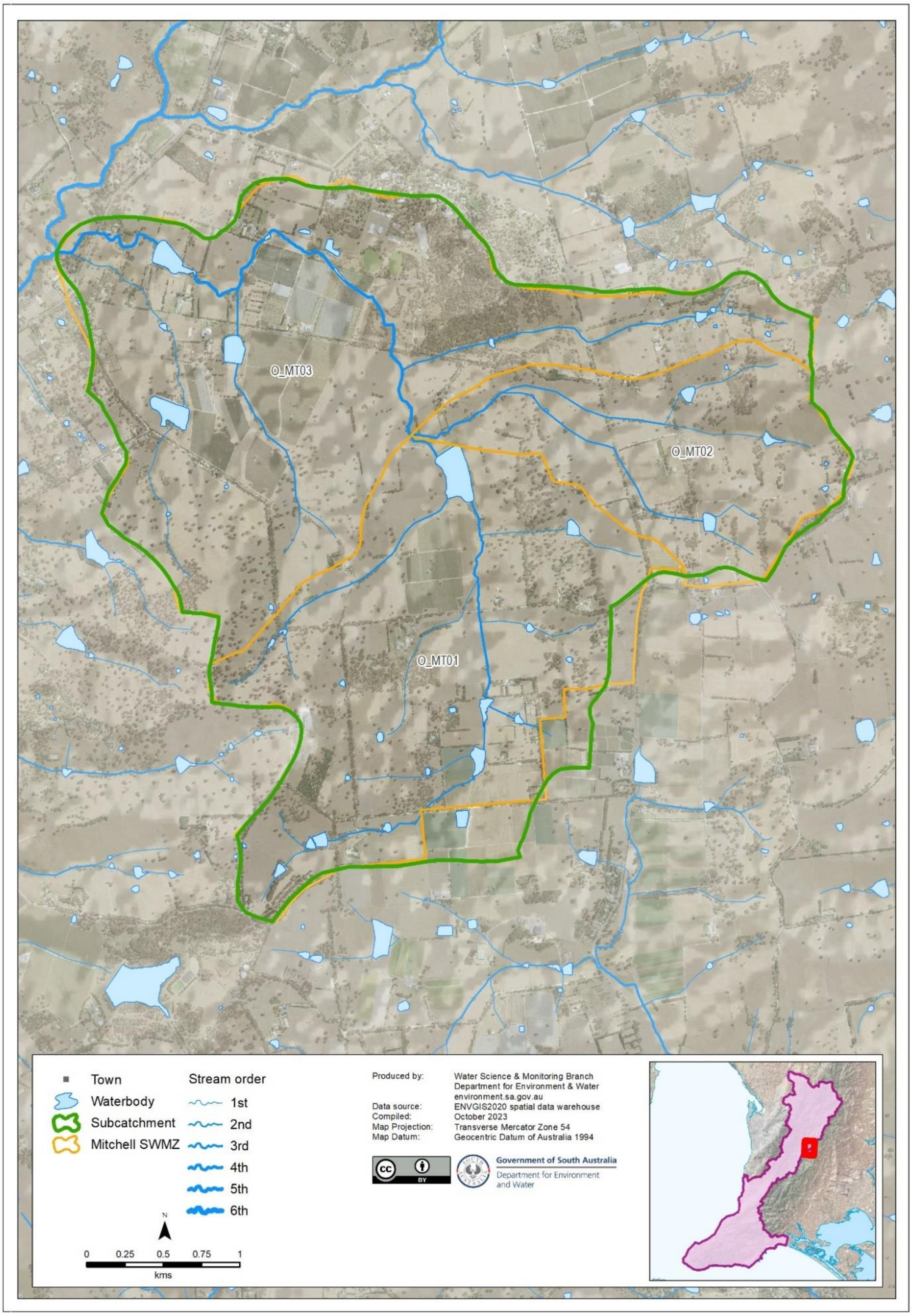

Figure 5. Mitchell Creek sub-catchment location map

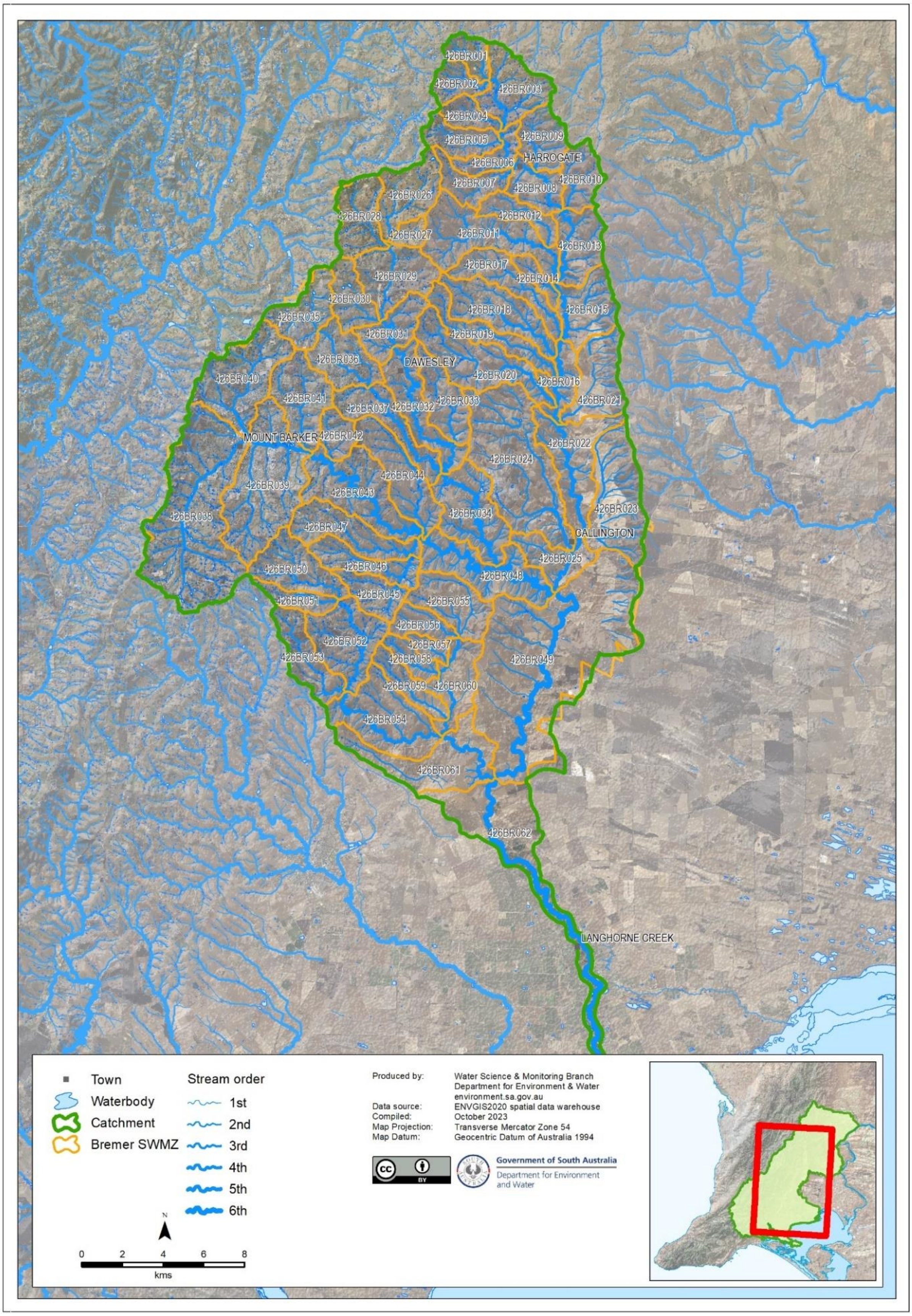

Figure 6. Bremer River catchment location map

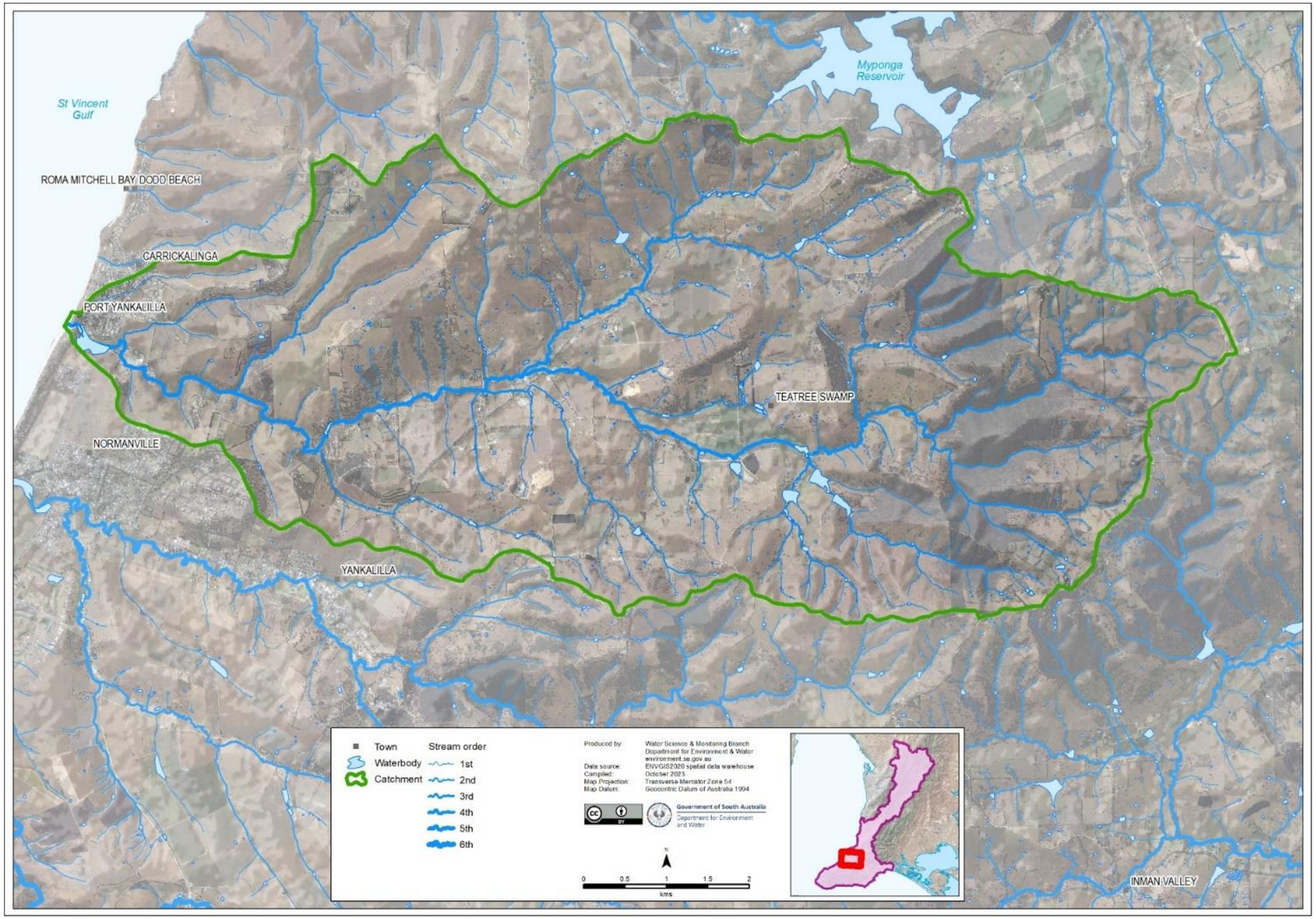

Figure 7. Carrickalinga Creek catchment location map

4.2 Scenario modelling parameters

Scenario modelling involved altering 3 fundamental parameters (individually and in combinations) in the models. These are: 1) water resource development, 2) low flow release, and 3) climate period. The first 2 parameters correspond to the 2 groups of key WAP rules – that is, the water resource development parameter can be used to represent different extents of implementation of the take limits and diversion/interception limits, and the low flow release parameter can be used to represent different extents of implementation of the requirement to pass low flows at scope sites.

The configurations used for each parameter are described below, and the combination of configurations used for each scenario is given in Table 1. Each scenario was modelled for each of the climate periods.

1. **Water resource development**: This parameter describes the water resource development characteristics used in the models. These characteristics were: water sources (location, capacity and licensing status of dams and watercourse diversions); the deemed water volume taken from sources; and the presence of urban areas (altered between configurations for Bremer catchment only). The deemed water volume taken is the maximum annual volume that the model will attempt to use from each source in the model. The actual modelled use volume from a source in any year will vary depending on that year's climate and upstream use.

   The water resource development configurations used in scenarios are:

   a. **No development**:
   Sources: None
   Deemed take: None
   Urban areas: Bremer: None; Onkaparinga: current urban areas as represented in the latest model; Carrickalinga: None (no urban areas present in model).

   This water resource development configuration represents the flow that would occur in the current landscape without dams, watercourse diversions and urban areas (except for Onkaparinga). It is used as a surrogate measure of natural flow for EWR metric calculations and as a baseline for comparison.

   b. **Current assumed use**:
   Sources: current network of dams and licensed watercourse diversions as represented in the latest model
   Deemed take: 50% of licensed dam capacity, 30% of non-licensed dam capacity, and allocation per source for licensed watercourse diversions
   Urban areas: current urban areas, as represented in the latest model.

   The deemed take volumes used for this configuration approximate actual use that applies to both the period before the WAP was adopted, and the period after, where the introduction of regulatory arrangements did have an effect on the volumes of water that water users had legal access to. The models calibrated as part of developing sustainable extraction limits for the WAPs were built on this assumption of deemed take. Licensing data was not available at the times the models were constructed. These deemed take values from dams were based on extensive work done previously on water use from farm dams across the state (McMurray 2004). This water resource development configuration is used partly because it was considered that the model assumptions and characteristics used for this investigation should match those used for WAP development where practical, to allow the outcomes to be comparable with those used for setting the key WAP rules.

   c. **Current allocation**:
   Sources: current network of dams and licensed watercourse diversions as represented in the latest model (as per section 4.1)
   Deemed take: current allocation per dam for licensed dams, 30% of non-licensed dam capacity, and

current allocation per source for licensed watercourse diversions
Urban areas: current urban areas as represented in the latest model.

This water resource development configuration is the same as 'Current assumed use', except that the maximum deemed take from licensed dams is the volume currently allocated, as described in section 4.1. The actual volumes allocated for individual dams vary, with 75% of dam capacity being common.

d. **Full development**:
Sources: current network of dams and licensed watercourse diversions as represented in the latest model (as per section 4.1), with dam capacity adjusted to be at or within WAP limits as far as practical.
Deemed take: 30% of non-licensed dam capacity, and allocation per source for licensed dams and watercourse diversions adjusted to be at or within WAP limits as far as practical
Urban areas: current urban areas as represented in the latest model.

In this water resource development configuration, dam capacity and demand from licensed dams and watercourse diversions are adjusted to be at or within their WAP limits, at the zone and/or catchment scale. This involves increasing dam capacity and demand in zones that are currently not fully developed, or decreasing dam capacity and demand in zones where these values exceed their limits at zone or catchment scale.

There are many ways that dam capacity and demand could be adjusted to create fully developed zones. A broad summary of the overall approach used for this investigation follows, with the specific detail given in Appendix A, section 7.1.

i. The current network of dams and watercourse diversions used for the 'current assumed use' configuration was used as the starting point. No new dams or watercourse diversions were added.

ii. For the analysis reported in Section 5, the capacities of all types of dams were adjusted to be within zone limits by proportionally increasing dam capacities if the zone and its catchment were not fully developed (that is total dam capacity is under its limit), or proportionally decreasing dam capacities if the zone was over-developed. Note that the catchment-scale limits were ignored for the modelled Onkaparinga sub-catchments for these calculations, to reflect the capacity for demand and dam capacity to be increased in these zones if sufficiently decreased in other parts of the Onkaparinga reservoir catchments, as allowed under WMLR WAP rules.

iii. The volume of total demand was calculated for the adjusted sources using the method for 'deemed take' for the 'current assumed use' configuration. If necessary, this total demand volume was then adjusted for licensed dams and watercourse diversions to bring water demand to within zone limits in the same fashion as the dam capacities were adjusted. That is, demand from licensed dams and watercourse diversions was increased proportionally if the zone and its catchment were not fully developed (that is total demand is under its limit) or decreased proportionally if the zone was over-developed. Demand from non-licensed dams was not adjusted, and so remained at 30% of dam capacity.

Note that the catchment-scale limits were ignored for the modelled Onkaparinga sub-catchments for these calculations, to reflect the capacity for demand and dam capacity to be increased in these zones if sufficiently decreased in other parts of the Onkaparinga reservoir catchments, as allowed under WMLR WAP rules.

Incorporating these 4 water resource development configurations in different scenarios provides understanding of their impacts on the resource when evaluating the WAPs.

e. **Low flow release**: This relates to incorporating low flow release (LFR) to scope[1] dams and watercourse extractions in the models. The low flow release configurations used in scenarios were:

   i. **LFR scope sites**: LFRs incorporated to all scope dams and watercourse diversions in the model.

   ii. **LFR currently implemented**: LFRs incorporated to only those scope dams and watercourse diversions where low flow releases have been implemented as of February 2023 (Bremer) and March 2023 (Carrickalinga).

   iii. **No LFR**: Low flows not released.

f. **Climate**: Each of the scenarios outlined in Table 1 were modelled for the climate experienced in 2 periods:

   i. WAP development period: 1974 to 2006: The catchment models used to determine resource capacity, environmental water requirements (EWRs), environmental water provisions (EWPs) and sustainable extraction limits (SELs) in the WAPs were calibrated to streamflow generated for this climate period. The WAPs were developed to represent the resource behaviour for this period and set the baseline for comparison. This period includes part of the Millennium drought, considered to run from 1997 to 2008 for the WAP review investigations (Savadamuthu and McCullough, 2024).

   ii. Post-WAP development period: 2007 to 2022: This period represents the climate since the data period that was used for the modelling that supported WAP development. This period includes part of the Millennium drought, and post-drought climate.

4.3 Modelled scenarios and associated review questions

The different scenarios that were modelled are outlined in Table 1, showing the water resource development and low flow release configurations from section 4.2 that were used for each scenario. Each scenario was modelled for the WAP development period and post-WAP development period.

The modelled scenario outputs are daily time-series flow data at a zone scale. Flow outputs from scenario modelling form input for calculation of the EWR metrics, which are then compared to EWR metrics from other scenarios to evaluate performance under those scenarios.

Both the 'pre-WAP' and 'current implementation' scenarios include current assumed use, as a reasonable representation of likely actual use and for consistency with assumptions with the modelling during WAP development. The same water resource development configuration is used for both the pre-WAP and current implementation scenarios to reflect that there has been little change to allocation volumes and dam capacities since WAP development. This is because unallocated water has been reserved by the Minister since WAP adoption, so no new allocations have been granted and the net increase in dam capacity that has been permitted is extremely limited. Transfer of surface water allocations between locations has been very limited. Reductions in demand or dam capacity (either through natural attrition, or implementation programs such as the EMLR high demand program and the Flows for the Future program (F4F) are small relative to total demand and dam capacity.

The outcomes of modelling scenarios presented in Table 1, when compared to each other, provide answers to some of the key questions that the review is intended to answer. These questions and associated scenario comparisons are listed in Table 2, grouped under the 2 overarching WAP review questions from section 2.1

[1] Scope dams: All dams used for licensed activities and dams greater than 5 ML that use water for non-licensed purposes. Scope watercourse diversions are licensed watercourse diversions.

(presented in reverse order). Note that the overarching review questions have been reframed to refer to the flow objective and key WAP rules considered by this investigation.

The results are presented in section 5, and summarised and discussed in section 6.

Table 1. Model scenarios and descriptions, using the water resource development and low flow release configurations described in section 4.2

Scenario	Description
1. No development	What would the flow regime be if there were no dams and watercourse extractions? Water resource development: No development Low flow release: No LFR Baseline data for comparison with developed scenarios would be available.
2. Pre-WAP	What if it was pre-WAP and nothing changed? Water resource development: Current assumed use Low flow release: No LFR This scenario reflects the situation before WAP development. When applied to the post-WAP development period, it represents what would happen if nothing changed – that is, no change to water resource development, continuation of assumed use rather than current allocation, and no implementation of WAP rules such as WAP limits and passing low flows.
3. Current implementation	What has actually happened? Water resource development: Current assumed use Low flow release: LFR as currently implemented This is the same as the previous pre-WAP scenario, but with LFR applied to dams and watercourse diversions to the extent of current implementation of LFR. This scenario reflects scenarios modelled for LFR implementation programs, such as EMLR Flows for the Future (F4F) and the Securing Low Flows program.
4. Current allocation	What can be expected if all licensed operators used their current allocation, without low flows returned? Water resource development: Current allocation Low flow release: No LFR
5. Full implementation	What can be expected if the key WAP rules were fully implemented? Water resource development: Full development Low flow release: LFR scope sites This scenario involves full implementation of LFR for all scope sites; and adjusting dam capacity and water demand to be within WAP limits – which means increased dam capacity and demand in some zones, and decreased dam capacity and demand in others.

Table 2. Comparison of EWR metric outcomes from different scenarios and periods, and the WAP review questions they help to answer

Question reference	Helps answer this question
Overarching review question 2	Review of the effectiveness of the actual implementation of the key WAP rules in meeting the WAPs' flow objective that is, *what has happened* given how the key WAP rules have been implemented?
A	How has the level of risk to environmental objectives[2] changed since WAP development? (Incorporating effects of both climate and extent of implementation) Scenario comparison: Scn 2 'Pre-WAP' (see Table 1) for 1974 to 2006 representing pre-WAP conditions, that is pre-WAP water resource development (including no LFR) and WAP development climate and Scn 3 'Current implementation' (see Table 1) for 2007 to 2022 representing current extent of water resource development and WAP implementation, under post-WAP development climate Tests effect of both climate and extent of implementation of WAP assumptions, from pre-WAP to current extent of implementation.
B	Has the current extent of implementation changed the level of risk to environmental objectives[3], under the post-WAP development climate? Scenario comparison: Scn 2 'Pre-WAP' for 2007 to 2022 representing pre-WAP water resource development (including no LFR), under post-WAP development climate and Scn 3 'Current implementation' for 2007 to 2022 representing current extent of water resource development and WAP implementation, under post-WAP development climate Tests effect of extent of implementation of WAP assumptions only, from pre-WAP to current extent (only change = passing low flows as implemented). Does not test what could have happened if WAP was not in place (for example further uncontrolled development). Changes due to climate excluded; effects are tested under post-WAP development climate.

[2] 'Section 4.4.2 describes how changes to the level of risk to environmental objectives are measured for this investigation, based on the flow objective and EWR metrics.

[3] Note that one effect of implementing WAP rules is to prevent further development where it would exceed zone or catchment limits for water demand and interception/diversion. This effect is not tested in this question – that is, a scenario has not been modelled of potential further development above the WAP limits.

Question reference	Helps answer this question
C	If nothing happened[4], would the level of risk to environmental objectives have changed because of the post-WAP development climate? Scenario comparison: Scn 2 'Pre-WAP' for 1974 to 2006 representing pre-WAP conditions, that is pre-WAP water resource development (including no LFR), under WAP development climate and Scn 2 'Pre-WAP' for 2007-2022 representing pre-WAP water resource development (including no LFR), under post-WAP development climate Tests effect of climate only, with no implementation.
D	Would the level of risk to environmental objectives change if all licensed users attempted to use their current allocation, without low flows being passed, under post-WAP development climate? Scenario comparison: Scn 2 'Pre-WAP' for 2007 to 2022 representing pre-WAP water resource development (including no LFR), under post-WAP development climate and Scn 4 (see Table 1) 'Current allocation' for 2007 to 2022 representing the same water resource development and LFR status as scenario 2, except with current allocation instead of assumed use, under post-WAP development climate Tests effect of actual use vs potential use without any other implementation. Excludes climate effects; effects are tested under post-WAP development climate.
Overarching review question 1	Review of the effectiveness of the key WAP rules that underpin the WAPs' flow objective that is, *what is expected* to have happened if the WAPs were implemented as intended?
E	Would risk to environmental objectives change from the current level of implementation, if the key WAP rules were fully implemented[5], under the post-WAP development climate? Scenario comparison:

[4] 'Nothing happened' means the WAP rules and assumptions were not implemented, and the current level of water resource development and assumed use stayed the same.

[5] 'Key WAP rules fully implemented' means that if dam capacity and water demand were within zone and catchment limits, adjusted relative to the current scenario (which may include increasing or decreasing these values for zones where relevant for the current scenario); and if low flows were passed at all scope sites.

Question reference	Helps answer this question
	Scn 3 'Current implementation' for 2007 to 2022 representing current extent of development and WAP implementation, under post-WAP development climate and Scn 5 (see Table 1) 'Full implementation' for 2007 to 2022 representing full implementation of key WAP rules, under post-WAP development climate Tests effect of extent of implementation, from current extent to full extent (changes = full implementation of passing low flows; reduction of high demand and high dam capacity where relevant; full development up to demand and dam capacity limits where relevant). Excludes climate effects.
F	How effective would the key WAP rules be (if fully implemented) to address the level of risk to environmental objectives, under the 'expected' climate of the WAP development period (1974 to 2006)? Scenario comparison: Scn 2 'Pre-WAP' for 1974 to 2006 representing pre-WAP water resource development (including no LFR), under WAP development climate and Scn 5 'Full implementation' for 1974 to 2006 representing full implementation of key WAP rules, under WAP development climate Tests effect of implementation, from pre-WAP to full extent. Considered under post-WAP development climate only (that is climate effects excluded – instead considered by comparing results with previous question).
G	How effective would the key WAP rules have been (if fully implemented) to address the level of risk to environmental objectives, under the post-WAP development climate that was experienced? Scenario comparison: Scn 2 'Pre-WAP' for 2007 to 2022 representing pre-WAP water resource development (including no LFR), under post-WAP development climate and Scn 5 'Full implementation' for 2007 to 2022 representing full implementation of the key WAP rules, under post-WAP development climate Tests effect of implementation, from pre-WAP to full extent. Considered under WAP development climate only (that is climate effects excluded – instead considered by comparing results with next question).

4.4 Method for assessing changes to level of risk to environmental objectives

Table 2 outlines a series of comparisons of modelled scenarios, and the WAP review questions that those comparisons are intended to inform. The questions revolve around whether the level of risk to environmental objectives has changed under the different modelled scenarios, and whether the WAPs' flow objective has been met in the post-WAP development period.

Achievement of the flow objective is assessed using the EWR metrics, as outlined in section 3.2. This section describes how the EWR metrics have been calculated for the purposes of this investigation (section 4.4.1) and how changes to the level of risk to environmental objectives has been measured (section 4.4.2).

4.4.1 Calculation of EWR metrics for this investigation

The EWR metrics are described in detail in the references provided in section 3.2, with a summary of key information given in section 3.2.1.

As outlined in section 3.2.1, the EWR metrics are generally calculated as a single value per metric, for a modelled scenario over a nominated period. The EWR metrics are assessed by comparing the value of the metric under a modelled scenario with the value under the modelled 'No development' scenario. An acceptable target range (percentage deviation) is set around the No development value. A metric 'passes' for a scenario if the modelled scenario value for the metric falls within the acceptable target range. The flow objective is met if 85% or more of the EWR metrics pass at a site.

The WAP development process used modelled flow data from a nominated period of 1974 to 2006 to calculate EWR metrics, set EWP water regime objectives and determine the associated key WAP assumptions and rules.

This investigation calculates the EWR metrics for a range of periods – primarily 1974 to 2006 (WAP development) and 2007 to 2022 (post-WAP development). EWR metrics were also calculated over the total period (1974 to 2022), but those results are generally not considered in the analysis in Section 5.

It is important to note that for all periods used in this investigation, the metrics have been calculated using No development scenario data for 1974 to 2006 as the comparison to set the acceptable target range. This has been done because data for this climate period was used for setting the flow objective and associated key WAP rules, and so represents the flow regime that underpins the environmental objectives and acceptable level of risk to environmental objectives used for the WAPs. This is the appropriate period for comparison data to be used for testing the effectiveness of the existing WAPs (as per the WAP review questions) – that is, scenarios are being tested relative to the No development scenario flow data that underpins the flow objective used for WAP development.

Small modifications have been made to the EWR metric calculations to accommodate the different lengths of the assessment periods used for this investigation:

- The metric calculation spreadsheets were updated to calculate metric values using daily flow data from the relevant period.
- There are a range of metrics that calculate the number of years in which a particular event occurs (for example number of years with one or more fresh in the Low flow season). For the metric calculations for 2007 to 2022 (16 years total) and 1974 to 2022 (49 years total), the values for those metrics have been scaled so that they are equivalent to the number of years that event would occur over 33 years (which is the total duration for 1974 to 2006). This means the values from the scenarios (originally calculated for 16, 33 or 49 years) are able to be compared with the No development value calculated for 33 years (1974 to 2006).
  For example, the metric value calculated for the 2007 to 2022 period is multiplied by 33/16, to scale the value calculated as number of years with the event out of 16 years, to be the equivalent value for number of years with the event out of 33 years.

4.4.2 Changes to the level of risk to environmental objectives

This investigation considers changes to the level of risk to environmental objectives for a range of WAP review questions, as outlined in Table 2.

These questions are framed in terms of changes to the level of risk to environmental objectives, but this investigation only explicitly assesses changes to the level of risk to the flow objective, as outlined below. It is assumed that changes to the level of risk to the flow objective would translate into changes to the level of risk to the EWP environmental condition objectives and the overall environmental objective of the WAPs, as outlined in section 3.2.

Changes to the level of risk to environmental objectives is measured for this investigation using the flow objective and EWR metrics as outlined below:

1. Flow objectives: the level of risk to environmental objectives is lower if:
   - a zone meets the flow objective (passing at least 85% of its EWR metrics)
   - the number of zones in an area (such as a catchment) that meet the flow objective increases
   - a group of zones meets their 'catchment-level' flow objective (see section 4.4.2.1).
2. EWR metrics: the level of risk to environmental objectives is lower if the percentage of EWR metrics failing in a zone decreases, regardless of whether the zone meets the flow objective (discussed further in section 4.4.2.2).

4.4.2.1 Catchment-level flow objective

As outlined in section 3.2, it was found during WAP development that the flow objective would not be met for every zone if the key WAP rules were fully implemented. Therefore, it is not appropriate to expect the flow objective to be met for every zone for the full implementation scenario for this investigation.

For the purposes of this investigation, the percentage of zones in a group of zones that meet the flow objective for the full implementation scenario for the WAP development period ('full implementation baseline') represents the expected outcome for full implementation of the key WAP rules. This measure is determined under the climate conditions of the WAP development period that were used to develop the key WAP rules, and under the water resource development configuration for the area of interest.

This measure is used in this investigation to assess whether a group of zones (such as catchment, sub-catchment, or all modelled zones) meets their catchment-level flow objective. A group of zones is considered to meet their catchment-level flow objective for a scenario, if the percentage of zones meeting the flow objective for that scenario is the same or higher than the full implementation baseline for the group of zones.

4.4.2.2 Changes in the percentage of failing EWR metrics

Changes to the number of zones that pass or fail the flow objective is the primary measure of changes to the level of risk to environmental objectives, as the key WAP rules such as 'take', and 'interception' limits have been set based on sufficient sites passing the flow objective. However, this is a coarse measure that hides variation – for example, a zone may fail the objective for 2 scenarios being compared, but it may fail one scenario badly (that is fail a high percentage of the metrics) and it may only just fail the other scenario (for example, fail 16% of the metrics). The second case has a decreased level of risk to environmental objectives, but this is not apparent by only looking at changes to the number of zones passing the flow objective between the 2 scenarios.

A finer resolution picture of changes to the level of risk to environmental objectives between scenarios is given by looking at whether the percentage of metrics failed for a zone has changed between scenarios, regardless of whether the zone passes the flow target. Therefore, the analysis in this investigation looks at both sorts of changes as measures of the level of risk to environmental objectives.

5 Results

5.1 Climate and implementation characteristics of the modelled catchments

This section gives a summary of how the 3 scenario-modelling parameters of climate, water resource development and low flow release vary between the modelled catchments. This information gives context for interpreting the scenario modelling outcomes presented in section 5.2.

5.1.1 Climate and overall streamflow by catchment

5.1.1.1 Measured rainfall and streamflow

Another investigation supporting the Mount Lofty Ranges (MLR) water allocation plans (WAPs) review (Savadamuthu and McCullough, 2024) assesses the behaviour of measured rainfall and streamflow data for 5 MLR catchments, across a range of climate periods centred around the Millenium drought, and also across the same WAP development and post-WAP development planning periods used for this investigation. These 5 catchments include Bremer, Onkaparinga and the Fleurieu region more broadly (which includes Carrickalinga catchment), as well as Finniss (Eastern Mount Lofty Ranges (EMLR)) and Torrens (Western Mount Lofty Ranges (WMLR)) catchments.

A summary of trends across all catchments is given below.

Rainfall was assessed for 24 stations across the MLR Prescribed Water Resource Areas (PWRAs). Overall, the combined results of the analyses provide evidence of a declining trend in long-term annual rainfall in large parts of the MLR, particularly during the last 3 decades. This is primarily due to a possible step change (negative shift) in spring season rainfall (predominantly in October) and to a lesser degree in autumn (in April) rainfall since the onset of the drought. Winter rainfall has generally recovered to pre-drought conditions across most of the stations investigated. The stations that show no evidence of a statistically significant declining trend in annual rainfall are generally located in certain sections of the Onkaparinga and Fleurieu regions, and in the lower elevation/lower rainfall sections of the Bremer River catchment.

Streamflow patterns were assessed for 5 flow stations (for one gauged sub-catchment per catchment). The streamflow behaviour was variable between catchments. While there were similarities between Bremer, Finniss, Onkaparinga and Torrens catchments, Myponga catchment had different characteristics. When comparing the 2 WAP development periods, a common statistic for the 4 non-Myponga gauged sub-catchments was that autumn and spring season median flows were lower in the post-WAP development period. Since onset of the drought (since 1997), daily flow patterns have been altered to varying extents in the 4 gauged sub-catchments. The average number of flowing days per year has reduced in all gauged sub-catchments except in the Finniss. These changes in daily flow behaviour were also observed between the WAP development and post-WAP development periods.

Myponga sub-catchment was found to be hydro-climatically different to the other 4 gauged sub-catchments investigated, as reflected in its rainfall and streamflow data, particularly in seasonality. This is also reflected in the context of drought-related impacts, for example, median seasonal flows in summer progressively increased through the 3 drought-related periods, and except during winter, the highest median seasonal flows were observed in the post-drought period in this gauged sub-catchment.

Annual rainfall-runoff responses were also examined, to identify if the volume of runoff generated from a given amount of rainfall has changed with time. Annual rainfall-runoff relationships developed for the 5 gauged sub-catchments investigated show that the underlying catchment rainfall-runoff response of Meadows Creek sub-catchment (Finniss River) and Mt Pleasant sub-catchment (Torrens River) have potentially shifted (downward) in the period since the onset of the drought (that is less runoff generated for the same amount of rainfall). In the case of the Bremer River (sub-catchment upstream of the gauging station at Hartley), while there are indications of a change in the relationship during the drought period, results for the post-drought period are inconclusive in regard to a downward shift due to incomplete streamflow records. There is little evidence to suggest the rainfall-runoff response has shifted in the Onkaparinga (Scott Creek sub-catchment) or Myponga (sub-catchment upstream of the reservoir) since the onset of the drought.

5.1.1.2 Modelled data

This section summarises modelled annual flow data for the catchments assessed in this investigation, in order to provide context on the potential impact of climate on risk to environmental objectives for the WAP development and post-WAP development periods.

Table 3 shows the modelled median annual flow per sub-catchment from the No development scenario, for the WAP development and post-WAP development periods. Values are given for each sub-catchment, as well as a list of which zones occur in the sub-catchment, and the range of adjusted runoff depth values for those zones from the EMLR and WMLR WAPs. The adjusted runoff depth is the resource capacity volume divided by the zone area, and so gives a measure of how wet the zones are.

It can be seen that most sub-catchments have lower median annual flow for the post-WAP development period compared to the WAP development period, except for the Onkaparinga sub-catchments, and Red Creek in Bremer catchment. An overall reduction in flow is likely to increase the level of risk to environmental objectives. The overall increase in flow seen in the Onkaparinga sub-catchments, and the Red Creek sub-catchment (located in the lower rainfall part of the Bremer catchment), could reduce the level of risk to environmental objectives in the post-WAP development period.

Table 3. Modelled median annual flow per sub-catchment from the No development scenario, for the WAP development and post-WAP development periods.

Catchment/sub-catchment	Zone	Adjusted-runoff range (mm)	Median annual flow (ML)		Change (WAP dev. To post-WAP dev.)	
			WAP dev.	Post-WAP dev.	ML	%
Bremer						
Upper Mt Barker Creek	BR038, 040-042	58 to 87	4,684	3,620	-1,064	-23%
Nairne Creek	BR035-037	32 to 86	1,294	813	-481	-37%
Dawesley Creek	BR026-031	42 to 88	2,169	1,290	-879	-41%
Lower Mt Barker Creek	BR044-047	24 to 61	436	199	-237	-54%
Upper Bremer	BR001-010	17 to 75	2,077	1,843	-234	-11%
Mid Bremer	BR011-025	4 to 28	1,320	1,156	-164	-12%
Rodwell Creek	BR050-054	31 to 90	660	511	-149	-23%
Red Creek	BR055-060	4 to 18	52	73	21	40%
Carrickalinga						
Carrickalinga	Carrickalinga Creek	68	9,147	8,780	-367	-4%

Catchment/sub-catchment	Zone	Adjusted-runoff range (mm)	Median annual flow (ML)		Change (WAP dev. To post-WAP dev.)	
			WAP dev.	Post-WAP dev.	ML	%
Onkaparinga						
Echunga Creek 1-4	O_EC01-04	117 to 123	2,674	2,836	162	6%
Mitchell Creek	O_MT01-03	103 to 109	1,046	1,213	167	16%

5.1.2 Water resource development and low flow release status for different scenarios

5.1.2.1 Comparison of status for current implementation and full implementation scenarios

Table 4 summarises the status of the water resource development and low flow release parameters for the pre-WAP scenario (scenario 2), current implementation scenario (scenario 3), and the full implementation scenario (scenario 5).

The current implementation scenario does not include any changes in water demand or dam capacity compared to the pre-WAP scenario, as these have changed very little on-ground since WAP adoption, as outlined in section 4.3.

Further information on the extent of implementation of these scenarios for individual zones is given in sections 5.1.2.2 (current implementation) and 5.1.2.3 (full implementation).

Table 4. Status of water resource development and low flow release for each catchment, for the pre-WAP, current implementation and full implementation scenarios

Catchment	Pre-WAP scenario	Current implementation scenario	Full implementation scenario
Bremer – 54 modelled zones			
Water resource development	Over-developed at catchment scale; also 22 zones over-developed	Same as pre-WAP	Dam capacity and water demand decreased in 34 zones: unchanged in 20 zones. Note cumulative demand has decreased in some zones because of reduced demand in an upstream over-developed catchment, rather than because of reduction in the zone itself.
Low flow release	No implementation	Partial implementation, occurred in 34 zones	Full implementation at all scope sites, which occurred in 43 zones (11 zones have no scope sites)
Carrickalinga – 1 modelled zone			
Water resource development	Under-developed	Same as pre-WAP	Dam capacity and water demand increased

Catchment	Pre-WAP scenario	Current implementation scenario	Full implementation scenario
Low flow release	No implementation	Partial implementation in the single zone for this catchment	Full implementation at all scope sites in the single zone for this catchment
Onkaparinga – 7 modelled zones (4 in Echunga Creek sub-catchment, 3 in Mitchell Creek sub-catchment)			
Water resource development	Under-developed for 6 zones; over-developed for 1 zone	Same as pre-WAP	Dam capacity and water demand increased in 6 zones; decreased in 1 zone
Low flow release	No implementation	No implementation	Full implementation at all scope sites in all 7 zones

5.1.2.2 Extent of current implementation scenario

The current implementation scenario involves partial LFR implementation in some catchments, and no changes to water demand and dam capacity, compared to the pre-WAP scenario.

The current implementation scenario that has been modelled includes the sites that have been treated to pass low flows as of February 2022 for Bremer catchment and March 2023 for Carrickalinga catchment. There is no current LFR implementation in Onkaparinga catchment.

As noted in section 3.2.2, LFR implementation has taken a strategic location approach to date, which identifies the minimum subset of scope sites required to pass low flows to meet the flow objective for affected zones ('Tier 1 sites'). The LFR implementation projects have focussed on implementation at Tier 1 sites to date.

The data for this section is calculated considering the contributing catchment area for each zone – that is, if a zone doesn't contain any sites passing low flows, but there are sites passing low flows in upstream zones, then that zone is counted as having sites passing low flows.

For the 62 modelled zones, for the current implementation[6] scenario:

- 35 zones (56%) have at least one site passing low flows in the zone or its contributing catchment area, all in the Bremer or Carrickalinga catchments.
- 27 zones (44%) have no sites passing low flows. Of these 27:
  - 11 zones (18%) have no scope sites in the zone or its contributing catchment area, so would not be expected to have any LFR implementation (all in the Bremer catchment).
  - 16 zones (26%) may have Tier 1 sites in the zone or its contributing catchment area but have not yet had any LFR implementation (9 in the Bremer catchment, and all 7 Onkaparinga zones).

The 35 zones with sites passing low flows for the current implementation scenario have 300 scope sites in the zones and their contributing catchment area, of which 242 have been identified as Tier 1 sites. In those zones, 75 of those sites have been treated to pass low flows for the current implementation scenario (31% of Tier 1 sites). Table 6 (in section 5.1.2.3) shows how these are distributed across the modelled catchments.

[6] At the time of writing the report.

The extent of implementation within those zones varies, as indicated by Table 5, which shows the number of zones in categories based on the number of sites passing low flows in the contributing catchment area of the zone, as a percentage of Tier 1 sites in the area. It can be seen that 18 of the 35 zones passing low flows (51%) are passing low flows at less than 25% of their Tier 1 sites, and 4 zones are passing low flows at 100% or more of their Tier 1 sites.

Table 5. Degree of current LFR implementation, for modelled zones with at least one site passing low flows

Categories of the number of sites passing low flows as a percentage of Tier 1 sites in the contributing catchment of a zone	Number of zones in category for current implementation scenario
0-24%	18
25-49%	6
50-74%	4
75-99%	3
≥100%	4
Total	35

5.1.2.3 Extent of full implementation scenario

As outlined in section 4.3, the full implementation scenario involves full implementation of the 2 key WAP rules (passing low flows and keeping demand and dam capacity within limits).

The full implementation scenario involves passing low flows at all scope sites in the modelled zones. Table 6 shows the number of scope sites for the modelled zones per catchment, as well as the number of sites passing low flows for the current implementation scenario, and the number of Tier 1 sites, for comparison[7].

Table 6. Number of sites passing low flows for different cases for all modelled zones, and for the modelled zones in each catchment

Area	Number of sites passing low flows for current implementation	Number of Tier 1 sites in modelled zones for current dams and diversions	Number of scope sites in modelled zones for full implementation
All modelled zones	75	(TBD)	385
Bremer	60	229	255
Carrickalinga	15	20	52
Onkaparinga	0	TBD	78

Full implementation of the key WAP rules has variable effects in different zones as shown in Table 4 – increasing the number of sites passing low flows in some zones but not others; and causing the volume of water demand

[7] As outlined in section 4.1, not all the Bremer zones have been modelled for this investigation, so the number of low flow sites included in this report will be different to the number of sites included in reporting for the Flows for the Future program.

(and dam capacity) to increase, decrease or stay the same in different zones depending on whether the zone is under-developed or over-developed compared to its limits and the status of the catchment it belongs to.

In order to identify how the full implementation scenario differs across zones from the pre-WAP and current implementation scenarios, zones have been categorised based on both:

1. whether the number of sites that pass low flows increases or stays the same, for full implementation compared to the pre-WAP and current implementation scenarios.
2. change in volume of demand with full implementation, compared to the pre-WAP and current implementation scenario (large or small increase or decrease, or no change). Note that the pre-WAP and current implementation scenarios both have the same demand.

When identifying the number of sites passing low flows in a zone, this assessment includes sites in the contributing catchment area of the zone, as outlined in section 5.1.2.2.

'Demand' in this investigation is calculated in accordance with the WAPs, as set out in section 7.1. The volume of demand for a zone presented here is the cumulative demand – that is, the demand for that zone and all zones upstream of it. This cumulative demand is the value that is compared against the cumulative 'main watercourse limits' in both WAPs.

For each zone, the change in demand caused by full implementation compared to current assumed use (as used for both the pre-WAP and current implementation scenarios) has been calculated and expressed as a percentage of the cumulative zone resource capacity as given in the WAP (that is adjusted mean annual runoff for the zone/s in the absence of water resource development, over 1974 to 2006). Zones have been placed into 'change in demand' categories:

1. Full implementation demand is much higher than current assumed use (by >10% of zone resource capacity, for example, current assumed use demand is 9.9% of zone resource capacity, and full implementation demand is 20.0% of zone resource capacity).
2. Full implementation demand is higher than current assumed use (by up to 10% of zone resource capacity).
3. Full implementation demand is the same as current assumed use.
4. Full implementation demand is lower than current assumed use (by up to 10% of zone resource capacity).
5. Full implementation demand is much lower than current assumed use (by >10% of zone resource capacity).

The results are given in matrix tables that show the number of zones in the different change in demand' categories as rows, which are then split across columns showing whether the zone passes low flows at more sites or the same number of sites for full implementation. Table 7 shows the comparison between the current implementation and full implementation scenarios, and Table 8 shows the comparison between the pre-WAP and full implementation scenarios.

Note that:

- the higher demand for full implementation categories (rows 1 and 2) includes the single Carrickalinga zone, and 6 of the 7 Onkaparinga zones. In absolute terms, the volume of demand is 38 to 243% higher for full implementation compared to current assumed use for these zones.
- the 20 zones with no change in demand (row 3) are all in Bremer catchment.
- the lower demand for full implementation categories (rows 4 and 5) includes 34 zones from Bremer catchment, and one from Onkaparinga catchment. In absolute terms, the volume of demand is 5 to 75% lower for full implementation compared to current assumed use for these zones.

The majority of zones pass low flows at more sites for the full implementation scenario compared to the current implementation scenario (77% of zones) and pre-WAP scenario (82% of zones) (column A in Table 7 and Table 8).

There are 11 zones (18%) that have no scope sites in the zone or their contributing catchment area, and so do not pass low flows for any scenarios – all located in Bremer catchment. Ten of these zones also do not have any change in demand for the full implementation scenario, so would have no change in flow regime or level of risk to environmental objectives as a result of full implementation (Table 8, row 3, column B).

Table 7. **Summary of how the full implementation scenario differs from the current implementation scenario across zones, based on change in demand and whether the number of sites passing low flows increases or stays the same with full implementation**

		Number of zones in each combination of *change in demand category* (rows) and *change in number of low flow sites category* (columns), for full implementation compared to current implementation		
Change in demand category for full implementation compared to current assumed use		**A. Pass low flows at more sites with full implementation**	**B. Pass low flows at same no. sites with full implementation**	**Totals**
1	Full imp. demand much higher (by >10% zone RC*)	5	0	5
2	Full imp. demand higher (by up to 10% zone RC)	2	0	2
3	No change to demand between scenarios	9	11	20
4	Full imp. demand lower (by up to 10% zone RC)	23	2	25
5	Full imp. demand much lower (by >10% zone RC)	9	1	10
	Totals	48	14	62

*RC = resource capacity

Table 8. Summary of how the full implementation scenario differs from the pre-WAP scenario across zones, based on change in demand and whether the number of sites passing low flows increases or stays the same with full implementation

		Number of zones in each combination of *change in demand category* (rows) and *change in number of low flow sites category* (columns), for full implementation compared to pre-WAP scenario		
Change in demand category for full implementation compared to current assumed use		**A. Pass low flows at more sites with full implementation**	**B. Pass low flows at same no. sites with full implementation****	**Totals**
1	Full imp. demand much higher (by >10% zone RC*)	5	0	5
2	Full imp. demand higher (by up to 10% zone RC)	2	0	2
3	No change to demand between scenarios	10	10	20
4	Full imp. demand lower (by up to 10% zone RC)	25	0	25
5	Full imp. demand much lower (by >10% zone RC)	9	1	10
	Totals	51	11	62

*RC = resource capacity

** All zones in this column passed low flow at no sites, for both the pre-WAP scenario and the full implementation scenario

5.1.2.4 Effects of the current allocation scenario

This section outlines how the volume of water demand for the current allocation scenario changed in comparison to current assumed use (as part of the pre-WAP scenario).

As outlined in section 4.2 and 4.3, both scenarios are based on the current network of dams and licensed watercourse diversions as represented in the latest model. But the demand volume taken from dams and diversions for the pre-WAP scenario is current assumed use, while the demand volume taken for the current allocation scenario is current allocation. The difference with the current allocation configuration is that modelled demand for licensed dams is the current allocation volume, instead of assumed use of 50% of dam capacity. Current allocation is often higher than assumed use, but is sometimes lower, depending on the licence.

In both cases, the modelled demand is the maximum volume that can be taken from a source. The actual amount that is taken in a year depends on how much water is available at the site, depending on climate and upstream use.

The volume of modelled demand for each zone was calculated for current assumed use and current allocation. Demand is calculated and expressed using the same method as outlined for the full implementation scenario in section 5.1.2.3, including expressing the demand volume as a percentage of zone resource capacity. However, different 'change in demand' categories were used here:

1. Current allocation demand is **higher** than current assumed use demand, by more than 2% of zone resource capacity (for example assumed use demand is 10% of zone resource capacity, and current allocation demand is 12.1% of zone resource capacity).
2. Current allocation demand is **similar** to current assumed use demand (current allocation demand is within plus or minus 2% of assumed use demand, expressed as a percentage of zone resource capacity).
3. Current allocation demand is **lower** than current assumed use demand, by more than 2% of zone resource capacity.

Table 9 summarises the results.

- For 76% of zones, using current allocation instead of current assumed use only causes a small change in demand (± up to 2% of adjusted runoff).
- Using current allocation instead of current assumed use causes a larger increase in demand for 18% of zones (plus 2 to 5.8% of adjusted zone cumulative runoff), or a larger decrease in demand for 6% of zone (minus 2 to 14.6% of adjusted zone cumulative runoff).

Table 9. Number of zones in different 'change in demand' categories, for current allocation demand compared with current assumed use demand.

Change in demand category for current allocation compared to current assumed use		Number (%) zones in category
1	Current allocation demand **higher** than current assumed use, by >2% of zone resource capacity	11 (18%)
2	Current allocation demand **similar** to current assumed use (±2% of zone resource capacity)	47 (76%)
3	Current allocation demand **lower** than current assumed use, by >2% of zone resource capacity	4 (6%)

5.2 WAP review questions: change in level of risk to environmental objectives from scenario comparisons

5.2.1 Question A: How has the level of risk to environmental objectives changed since WAP development (incorporating effects of both climate and extent of implementation)?

Scenarios compared:

Scenario 2 (pre-WAP) for WAP development period (1974 to 2006)
representing pre-WAP conditions, that is pre-WAP water resource development (including no LFR) and WAP development climate

and

Scenario 3 (current conditions) for the post-WAP development period (2007 to 2022)
representing current conditions, that is the current extent of water resource development and WAP implementation, under post-WAP development climate.

This scenario comparison tests the net effects of climate and extent of current implementation of key WAP rules, from pre-WAP to current conditions.

5.2.1.1 Overall outcome

The overall level of risk to environmental objectives under current conditions has slightly increased since WAP development when considered across all the modelled zones together:

- Fewer zones passed the flow objective under 'current conditions' (15%) compared to pre-WAP conditions (19%) (Table 10).
- A majority of zones (52%) failed more metrics under current conditions compared to pre-WAP conditions (Table 11) (that is increased detrimental impact on environmentally important components of the flow regime since WAP development for those zones).

However, the results varied between zones and catchments. While 52% of zones failed more metrics under current conditions (that is higher risk) compared to pre-WAP conditions, almost half of the zones (43%) failed fewer metrics under current conditions (that is lower risk). At a catchment scale, the level of risk to environmental objectives increased in the Bremer and Carrickalinga catchments, but decreased in the modelled Onkaparinga sub-catchments, under current conditions:

- Fewer zones passed the flow objective under current conditions compared to pre-WAP conditions for the Bremer and Carrickalinga catchments, but more zones passed the flow objective under current conditions for the Onkaparinga catchment (Table 10).
- More than half the zones failed more metrics under current conditions in the Bremer and Carrickalinga catchments (54% and 100% respectively). For the Onkaparinga, only 29% of the modelled zones failed more metrics under current conditions (Table 11).

None of the catchments passed their catchment-level flow objective under current conditions (Table 10).

These outcomes are the net result of the effects of current implementation and climate. These factors are considered separately in sections 5.2.2 (implementation) and 5.2.3 (climate). Section 5.2.4 identifies zones where the 2 factors change the level of risk to environmental objectives in different directions.

5.2.1.2 Results data tables

The outcomes reported in section 5.2.1.1 are drawn from the assessments of changes to the level of risk to environmental objectives for current conditions compared to pre-WAP conditions, as per the approaches outlined in section 4.4.

Table 10 shows this assessment based on changes to the number of zones meeting the flow objective between the scenarios, and whether the catchment-level flow objective is met for current conditions (that is whether the number of zones meeting the flow objective for current conditions is the same or more than the number of zones meeting the flow objective for the full implementation baseline).

Table 11 shows this assessment based on changes in the percentage of metrics failed between the scenarios within each zone, regardless of whether the zone meets the flow objective.

Table 10. Assessment of change to level of risk to environmental objectives for current conditions compared to pre-WAP conditions, based on assessment of flow objectives at zone and catchment-level scales

Area (Number of modelled zones)	Number (%) of zones meeting the flow objective for different implementation scenarios and time periods (and change to level of risk)			Do current conditions meet the catchment-level objective?
	Pre-WAP conditions Pre-WAP, WAP dev. period	Current conditions Current implementation, post-WAP dev. period	Full implementation baseline Full implementation, WAP dev. period	
All modelled zones (62)	12 (19%)	9 (15%) (increased risk)	23 (37%)	No
Bremer (54)	11 (20%)	8 (15%) (increased risk)	19 (35%)	No
Carrickalinga (1)	1 (100%)	0 (0%) (increased risk)	1 (100%)	No
Onkaparinga (7)	0 (0%)	1 (14%) (decreased risk)	3 (43%)	No

Table 10 considers net change in the number of zones meeting the flow objective between the periods. When looking at the results for individual zones between the two periods, there are:

- 3 zones that fail pre-WAP conditions, but pass current conditions (that is, risk to environmental objectives has decreased since WAP development) – 2 in Bremer, 1 in Onkaparinga
- 6 zones that pass pre-WAP conditions, but fail current conditions (that is, risk to environmental objectives has increased since WAP development) – 5 in Bremer, 1 in Carrickalinga.

Table 11. Assessment of change to level of risk to environmental objectives for current conditions compared to pre-WAP conditions, based on changes to the number of EWR metrics failing between the scenarios

Area (Number of modelled zones)	Number (%) of zones where level of risk to environmental objectives increases, stays the same or decreases under 'current conditions' (current implementation, post-WAP development period) compared to 'pre-WAP conditions' (pre-WAP, and WAP development period)		
	Increased level of risk for current conditions (failed more metrics)	Same level of risk (no change to % metrics failed)	Decreased level of risk for current conditions (failed fewer metrics)
All modelled zones (62)	32 (52%)	4 (6%)	26 (42%)
Bremer (54)	29 (54%)	2 (4%)	23 (43%)
Carrickalinga (1)	1 (100%)	0 (0%)	0 (0%)
Onkaparinga (7)	2 (29%)	2 (29%)	3 (43%)

5.2.2 Question B: Has the current extent of implementation changed the level of risk to environmental objectives, under the post-WAP development climate?

Scenarios compared:

Scenario 2 (pre-WAP) for the post-WAP development period (2007 to 2022)
representing pre-WAP water resource development (including no LFR), under the post-WAP development climate

and

Scenario 3 (current implementation) for the post-WAP development period (2007 to 2022)
representing the current extent of water resource development and WAP implementation, under the post-WAP development climate.

This scenario comparison tests the effect of the current extent of implementation of key WAP rules, excluding the effects of climate, from pre-WAP water resource development to the current extent of implementation. This comparison is different from that raised by Question A because it uses the same period for both cases – that is, the effect of different climate between the periods on the change in EWR metrics is effectively removed.

5.2.2.1 Overall outcome

The modelled current extent of implementation is limited to partial implementation of LFR that affects 35 of the 62 modelled zones in the current implementation scenario, all located in the Bremer and Carrickalinga catchments (section 5.1.2.2). This scenario does not include any action to address cases where demand and/or dam capacity exceed their limits.

Current implementation resulted in a small decrease in the overall level of risk to environmental objectives for these 35 zones compared to the pre-WAP scenario, when both were modelled for the post-WAP development period to exclude the effects of climate (that is likely beneficial outcome from current implementation):

- The number of zones passing the flow objective increased from 2 to 4 (for pre-WAP to current implementation scenarios, Table 12).

- The majority (51%) of these 35 zones failed fewer metrics for the current implementation scenario compared to the pre-WAP scenario (Table 13).

Current implementation increased the risk for 4 of the relevant zones (11%), which failed more metrics for current implementation compared to the pre-WAP scenario (both modelled for post-WAP development period, Table 13). However, further analysis showed that the level of risk to environmental objectives then decreased for all 4 of these zones for the full implementation scenario compared to the current implementation scenario, including sufficient improvement to allow one of those zones to pass the flow objective (assessed from the data generated for question E in section 5.2.6). That is, partial implementation of the key WAP rules may occasionally increase the risk to environmental objectives, but this may be offset or decreased by full implementation.

5.2.2.2 Results data tables

The outcomes reported in section 5.2.2.1 are drawn from the assessments of changes to the level of risk to environmental objectives for the current implementation scenario compared to the pre-WAP scenario (both modelled for the post-WAP development period), as per the approaches outlined in section 4.4.

Table 12 shows this assessment based on changes to the number of zones meeting the flow objective between the scenarios.

Table 13 shows this assessment based on changes in the percentage of metrics failed between the scenarios within each zone, regardless of whether the zone meets the flow objective.

The analysis for Table 12 and Table 13 only considers the 35 zones that are affected by current implementation of LFR (that is have a site treated to pass low flows within the zone, or in the zone's contributing catchment area). These zones are all located in the Bremer and Carrickalinga catchments.

Table 12. Assessment of change to level of risk to environmental objectives for the current implementation scenario compared to the pre-WAP scenario (both modelled for the post-WAP development period), based on assessment of the flow objective at zone scale

Area (Number of modelled zones)	Number (%) of zones meeting the flow objective for different implementation scenarios and time periods (and change to level of risk)	
	Pre-WAP scenario, post-WAP dev. period	Current implementation scenario, post-WAP dev. period
All relevant zones (35)	2 (6%)	4 (12%) (decreased risk)
Bremer (34)	2 (6%)	4 (12%) (decreased risk)
Carrickalinga (1)	0 (0%)	0 (0%) (no change)

Table 13. Assessment of change to level of risk to environmental objectives for the current implementation scenario compared to the pre-WAP scenario (both modelled for the post-WAP development period), based on changes to the number of EWR metrics failing between the scenarios

Area (Number of modelled zones)	Number (%) of zones where level of risk to environmental objectives increases, stays the same or decreases under current implementation scenario, post-WAP development period compared to pre-WAP scenario, post-WAP development period		
	Increased level of risk for current implementation (failed more metrics)	Same level of risk (no change to % metrics failed)	Decreased level of risk for current implementation (failed fewer metrics)
All relevant zones (35)	4 (11%)	13 (37%)	18 (51%)
Bremer (34)	4 (12%)	13 (38%)	17 (50%)
Carrickalinga (1)	0 (0%)	0 (0%)	1 (100%)

5.2.3 Question C: If nothing happened, would the level of risk to environmental objectives have changed as a result of the post-WAP development climate?

Scenarios compared:

Scenario 2 (pre-WAP) for WAP development period (1974 to 2006)
representing pre-WAP conditions, that is pre-WAP water resource development (including no LFR), under WAP development climate

and

Scenario 2 (pre-WAP) for post-WAP development period (2007 to -2022)
representing pre-WAP water resource development (including no LFR), under post-WAP development climate

This scenario comparison tests the effect of climate differences between the development and post-WAP development period on the level of risk to environmental objectives.

For this question, 'nothing happened' means the key WAP rules were not implemented, including no LFR, and the current level of water resource development and assumed use stayed the same. This is different to 'what would have happened if we did nothing', because if we did nothing, then further uncontrolled development could occur.

5.2.3.1 Overall outcome

The overall level of risk to environmental objectives slightly increased under the climate of the post-WAP development period, compared to the climate of the WAP development period, if there was no change to water resource development or WAP implementation. When considered across all the modelled zones together:

- Fewer zones passed the flow objective under the post-WAP development period climate (11%) compared to the WAP development climate (19%) (Table 14).
- The majority of zones (52%) failed more metrics for the post-WAP development period compared to the WAP development period (Table 15).

However, the results vary between zones and catchments. While 52% of zones failed more metrics for the post-WAP development period, over a third of the zones (37%) failed fewer metrics for the post-WAP development period (that is likely improved environmental flow regime outcomes due to the climate of the post-WAP development period for those zones). At a catchment scale, the level of risk to environmental objectives increased in the Bremer and Carrickalinga catchments, but decreased in the modelled Onkaparinga sub-catchments, for the post-WAP development period, as follows:

- Fewer zones passed the flow objective for the post-WAP development period compared to the WAP development period for the Bremer and Carrickalinga catchments, but more zones passed the flow objective for the post-WAP development period for the Onkaparinga catchment (Table 14).
- More than half the zones failed more metrics for the post-WAP development period in the Bremer and Carrickalinga catchments (54% and 100% respectively). For the Onkaparinga, only 29% of the modelled zones failed more metrics for the post-WAP development period (Table 15).

Carrickalinga catchment met its catchment-level flow objective for the pre-WAP scenario for the WAP development period, but not for the post-WAP development period. The catchment-level flow objective was not met for any periods for the pre-WAP scenario in the Bremer and Onkaparinga catchments (Table 14).

5.2.3.2 Results data tables

The outcomes reported in section 5.2.3.1 are drawn from the assessments of changes to the level of risk to environmental objectives for the pre-WAP scenario for the post-WAP development period compared to the pre-WAP scenario for the WAP development period, as per the approaches outlined in section 4.4.

Table 14 shows this assessment based on changes to the number of zones meeting the flow objective between the scenarios, and whether the catchment-level flow objective is met for the pre-WAP scenario for either period (that is whether the number of zones meeting the flow objective for the pre-WAP scenario for either period is the same or more than the number of zones meeting the flow objective for the 'full implementation baseline').

Table 15 shows this assessment based on changes in the percentage of metrics failed between the scenarios within each zone, regardless of whether the zone meets the flow objective.

Table 14. Assessment of change to level of risk to environmental objectives for the pre-WAP scenario for the post-WAP development period, compared to the pre-WAP scenario for the WAP development period, based on assessment of flow objectives at zone and catchment-level scales

Area (Number of modelled zones)	Number (%) of zones meeting the flow objective for different implementation scenarios and time periods (and change to level of risk)			Does the pre-WAP scenario meet the catchment-level objective for WAP dev. / post-WAP dev. period?
	Pre-WAP scenario, WAP dev. period	Pre-WAP scenario, post-WAP dev. period	'Full implementation baseline' Full implementation, WAP dev. period	
All modelled zones (62)	12 (19%)	7 (11%) (increased risk)	23 (37%)	No / No
Bremer (54)	11 (20%)	6 (11%) (increased risk)	19 (35%)	No / No
Carrickalinga (1)	1 (100%)	0 (0%) (increased risk)	1 (100%)	Yes / No
Onkaparinga (7)	0 (0%)	1 (14%) (decreased risk)	3 (43%)	No / No

Table 14 considers net change in the number of zones passing the flow objective between the periods. When looking at the results for individual zones between the two periods, there are:

- 2 zones that fail the pre-WAP scenario (WAP development period) but pass the pre-WAP scenario (post-WAP development period) – that is, the level of risk decreases under the post-WAP development climate for these zones.
- 7 zones that pass the pre-WAP scenario (WAP development period but fail the pre-WAP scenario (post-WAP development period) - that is, the level of risk increases under the post-WAP development climate for these zones.

That is, there is a net change of 5 zones where the level of risk increases (as per Table 14), across the 62 zones that have been modelled.

Table 15. Assessment of change to level of risk to environmental objectives for the pre-WAP scenario for the post-WAP development period, compared to the pre-WAP scenario for the WAP development period, based on changes to the number of EWR metrics failing between the scenarios

Area (Number of modelled zones)	Number (%) of zones where level of risk to environmental objectives increases, stays the same or decreases under pre-WAP scenario, post-WAP development period compared to pre-WAP scenario, WAP development period		
	Increased level of risk for post-WAP dev. period (failed more metrics)	Same level of risk (no change to % metrics failed)	Decreased level of risk for post-WAP dev. period (failed fewer metrics)
All modelled zones (62)	32 (52%)	7 (11%)	23 (37%)
Bremer (54)	29 (54%)	5 (9%)	20 (37%)
Carrickalinga (1)	1 (100%)	0 (0%)	0 (0%)
Onkaparinga (7)	2 (29%)	2 (29%)	3 (43%)

5.2.4 Outcomes across questions A-C: zones where current implementation and post-WAP development period climate change the level of risk in different directions

The results for Question A-C have been compared for each zone to identify whether there are zones where the current extent of implementation and the climate of the post-WAP development period change the level of risk to environmental objectives in different directions. This analysis looked at changes to level of risk to environmental objectives based on changes to the percentage of EWR metrics failing (as per section 4.4.2.2).

There are 7 zones where current implementation decreased the level of risk to environmental objectives, but the climate of the post-WAP development period increased the level of risk to environmental objectives.

In 6 of these cases, the effect of climate is dominant, so the net result is that the level of risk to environmental objectives has increased since WAP adoption (that is benefit of current implementation is offset by the detrimental effect of the post-WAP development period climate on the flow regime in those zones).

In one case, the effect of implementation is dominant, so the net result is that the level of risk to environmental objectives has decreased since WAP adoption.

There are 2 zones where current implementation increased the level of risk to environmental objectives, but this is offset by a decreased level of risk due to the climate of the post-WAP development period, with the net result that the level of risk to environmental objectives has decreased since WAP development. These are 2 of the 4 zones identified in section 5.2.2.1 where the level of risk to environmental objectives increased for the current implementation scenario but decreased for the full implementation scenario. For these 2 zones, the detrimental effects of partial implementation are offset by the beneficial effect of the post-WAP development period climate on the flow regime in those zones.

5.2.5 Question D: Would the level of risk to environmental objectives change if all licensed users attempted to use their current allocation, without low flows being passed, under the post-WAP development climate?

Scenarios compared:

Scenario 2 (pre-WAP) for post-WAP development period (2007 to 2022)
representing pre-WAP water resource development (including current assumed use, with no LFR), under post-WAP development climate

and

Scenario 4 (current allocation) for post-WAP development period (2007 to 2022)
representing the same water resource development and LFR status as scenario 2, except with current allocation instead of current assumed use, under post-WAP development climate.

This scenario comparison tests the effect of current assumed use versus current allocation, which is the volume that licensed dam users are approved to take. The difference is that modelled demand for licensed dams is the current allocation volume for the current allocation scenario; or 50% of dam capacity for current assumed use.

This comparison does not include any other changes to water resource development or WAP implementation – that is, low flows are not passed, and there are no other changes to demand or dam capacity. Both scenarios are run for the post-WAP development period, so the effects of climate are effectively excluded.

5.2.5.1 Overall outcome

For most zones (76%), the volume of demand for current allocation is similar to current assumed use. That is, the volume of current allocation demand changes by up to 2% of zone resource capacity compared to current assumed use, for 47 out of the 62 modelled zones (Table 9 in section 5.1.2.4). There is a larger increase in demand for current allocation for 18% of zones (plus 2 to 5.8% of adjusted zone cumulative runoff), and a larger decrease in demand for current allocation for 6% of zones (minus 2 to 14.6% of adjusted zone cumulative runoff).

For the 47 zones where current allocation is similar to current assumed use, the level of risk to environmental objectives did not change between scenarios in most cases (Table 17 row 2:43 of these 47 zones failed the same number of metrics for the pre-WAP scenario and the current allocation scenario).

As may be expected, higher demand for the current allocation scenario caused the level of risk to environmental objectives to increase or stay the same (Table 17 row 1); and lower demand for the current allocation scenario caused the level of risk to environmental objectives to decrease or stay the same (Table 17 row 3), when considering changes in the number of metrics failing within a zone. However, these changes were not enough to change the number of zones passing the flow objective as a result of using current allocation demand instead of assumed use demand (Table 16).

5.2.5.2 Results data tables

The outcomes reported in section 5.2.5.1 are drawn from section 5.1.2.4; and from the tables below showing assessments of changes to the level of risk to environmental objectives for the current allocation scenario compared to the pre-WAP scenario, both modelled for the post-WAP development period, as per the approaches outlined in section 4.4.

Table 16 shows this assessment based on changes to the number of zones meeting the flow objective between the scenarios, for all modelled zones together and also split across catchments.

Table 17 shows this assessment based on changes in the percentage of metrics failed between the scenarios within each zone, regardless of whether the zone meets the flow objective. The results for this assessment are shown separately for each 'change in demand' category, where current allocation demand is higher (row 1), similar (row 2) or lower (row 3) than the current assumed use demand. Section 5.1.2.4 describes how the demand volumes have been calculated, and the 'change in demand' categories are the same in Table 9 from that section and in Table 17 below.

Table 16. Assessment of change to level of risk to environmental objectives for the pre-WAP scenario (based on current assumed use) compared to the current allocation scenario, based on assessment of the flow objective at zone scale

Area (Number of modelled zones)	Number (%) of zones meeting the flow objective for different implementation scenarios and time periods (and change to level of risk)	
	Pre-WAP scenario, post-WAP dev. period	Current allocation, post-WAP dev. period
All modelled zones (62)	12 (19%)	12 (19%) (no change)
Bremer (54)	11 (20%)	11 (20%) (no change)
Carrickalinga (1)	1 (100%)	1 (100%) (no change)
Onkaparinga (7)	0 (0%)	0 (0%) (no change)

Table 17. **Assessment of change to level of risk to environmental objectives for the current allocation scenario compared to the pre-WAP scenario (based on current assumed use), for zones in different change in demand categories. Change in level of risk assessed is based on changes to the number of EWR metrics failed between the scenarios.**

Change in demand category for current allocation compared to current assumed use		Number (%) of zones where level of risk to environmental objectives increases, stays the same or decreases under current allocation scenario, post-WAP development period compared to pre-WAP scenario, post-WAP development period			
		Increased level of risk for current allocation (failed more metrics)	Same level of risk (no change to % metrics failed)	Decreased level of risk for current allocation (failed more metrics)	Total
1	Current allocation higher than current assumed use	4	7	0	11
2	Current allocation similar to current assumed use	4	43	0	47
3	Current allocation lower than current assumed use	0	2	2	4
	Total	8	52	2	62

5.2.6 Question E: Would the level of risk to environmental objectives change from the current level of implementation, if the WAP rules and assumptions were fully implemented, under the post-WAP development climate?

Scenarios compared:

Scenario 3 (current implementation) for post-WAP development period (2007 to 2022)
representing current extent of water resource development and implementation of key WAP rules, under post-WAP development climate

and

Scenario 5 (full implementation) for post-WAP development period (2007 to 2022)
representing full implementation of key WAP rules, under post-WAP development climate.

This scenario comparison tests the effect of the extent of implementation of the key WAP rules, from the current extent to the full extent. The changes from current to full implementation are:

- passing low flows at all scope sites for full implementation
- adjusting dam capacity and demand to be within take limits and diversion/interception ('dam capacity') limits at zone and catchment scale, for full implementation.

Note that the 'full implementation' scenario considered in this analysis is based on passing low flows at all scope sites, not just all Tier 1 sites.

Both scenarios are calculated for the post-WAP development period (2007 to 2022), which effectively excludes the effects of climate differences between periods.

5.2.6.1 Overall outcome

Full implementation of the key WAP rules results in a range of different outcomes compared to current implementation (Table 9 in section 5.1.2.3):

- Demand increased in 7 of the 62 modelled zones for the full implementation scenario (1 in Carrickalinga, 6 in Onkaparinga catchment). All 7 of these zones also passed low flows at more sites for the full implementation scenario compared to the current implementation scenario.
- Demand decreased in 35 of the 62 modelled zones for the full implementation scenario (1 in Onkaparinga, 34 in Bremer catchment). Most (91%) of these zones also passed low flows at more sites for the full implementation scenario compared to the current implementation scenario (no change for the other 9%).
- There was no change in demand between the scenarios for 20 modelled zones (all in Bremer). Nine of those zones passed low flows at more sites for the full implementation scenario compared to the current implementation scenario, and the other 11 zones passed low flows at the same number of sites for both scenarios (including 10 zones with no scope sites, that do not pass low flows at any sites for any scenario).

Full implementation of the key WAP rules caused the overall level of risk to environmental objectives to decrease, compared to current implementation, when considered across all modelled zones together, as follows:

- More zones passed the flow objective under full implementation (27%) compared to current implementation (15%) (Table 18).
- The majority (61%) of zones failed fewer metrics under full implementation compared to current implementation, and 20 zones (35%) had no change in the percentage of metrics failed (Table 19). As noted above, full implementation didn’t change conditions in 11 zones, accounting for 52% of the 20 zones that had no change in the percentage of metrics failed.

Full implementation of LFR allowed water demand and dam capacity to substantially increase while the level of risk to environmental objectives decreased. For the 7 zones where demand increased under full implementation, the volume of demand was 38-243% higher for full implementation compared to current assumed use (section 5.1.2.3). Six of these zones failed fewer metrics for the full implementation scenario, and one zone failed the same number of metrics as the current implementation scenario (Table 19, rows 1 and 2).

The changes in level of risk to environmental objectives for full implementation compared to current implementation varied between zones and catchments:

- The decrease in the level of risk to environmental objectives was strongest in the Onkaparinga catchment, where the percentage of zones meeting the flow objective increased from 14% (current implementation) to 86% (full implementation). The single zone representing the Carrickalinga catchment did not meet the flow objective for either scenario (Table 18).
- There are 2 zones that failed more metrics under full implementation compared to current implementation. Both are small, dry zones in the Bremer catchment that each fail 2 extra metrics for the full implementation scenario, despite a reduction in water demand. It appears that these are calculation issues arising from the very low flow rates naturally experienced in the area, and that 3 of the 4 cases do not have an actual increase in risk, and the other is a very small change that may not translate into an actual increase in risk in practice. See section 7.2 in Appendix A for more information.

5.2.6.2 Results data tables

The outcomes reported in section 5.2.6.1 are drawn from section 5.1.2.3; and from the tables below showing assessments of changes to the level of risk to environmental objectives for the full implementation scenario compared to the current implementation scenario, both modelled for the post-WAP development period, as per the approaches outlined in section 4.4.

Table 18 shows this assessment based on changes to the number of zones meeting the flow objective between the scenarios, for all modelled zones together and also split across catchments.

Table 19 shows this assessment based on changes in the percentage of metrics failed between the scenarios within each zone, regardless of whether the zone meets the flow objective. These results are split between zones where the demand was higher (rows 1-2), the same (row 3) or lower (rows 4-5) for full implementation, and also where the number of zones passing low flows increased for full implementation (A. columns) or stayed the same (B. columns) compared to implementation. Section 5.1.2.3 describes how zones have been assigned to these different 'change in demand' and 'change in number of low flow sites' categories. Table 19 below is the same as Table 7 from that section, with the addition of columns showing whether the level of risk to environmental objectives has increased, stayed the same or decreased as a result of the full implementation scenario.

Table 18. Assessment of change to level of risk to environmental objectives for full implementation compared to current implementation, both modelled for the post-WAP development period, based on assessment of the flow objective at zone scale

Area (Number of modelled zones)	Number (%) of zones meeting the flow objective for different implementation scenarios and time periods (and change to level of risk)	
	Current implementation, post-WAP dev. period	Full implementation, post-WAP dev. period
All modelled zones (62)	9 (15%)	17 (27%) (decreased risk)
Bremer (54)	8 (15%)	11 (20%) (decreased risk)
Carrickalinga (1)	0 (0%)	0 (0%) (no change)
Onkaparinga (7)	1 (14%)	6 (86%) (decreased risk)

Table 19. Assessment of change to level of risk to environmental objectives for full implementation compared to current implementation, both modelled for the post-WAP development period, based on changes to the number of EWR metrics failing between the scenarios

	Number of zones in each combination of change in demand category (rows) and change in number of low flow sites category (columns) where the level of risk to environmental objectives increases, stays the same or decreases under full implementation, post-WAP development period compared to current implementation, post-WAP development period						
Change in demand category for full implementation compared to current assumed use	**A. Pass low flows at more sites with full implementation**			**B. Pass low flows at same no. of sites with full implementation**			
	Increased risk (failed more metrics)	**Same risk (no change)**	**Decreased risk (failed fewer metrics)**	**Increased risk (failed more metrics)**	**Same risk (no change)**	**Decreased risk (failed fewer metrics)**	**Totals**
1 Full imp. demand much higher (>10% RC*)	0	1	4	0	0	0	5
2 Full imp. demand higher (up to 10% RC)	0	0	2	0	0	0	2
3 No change to demand	0	5	4	0	11	0	20
4 Full imp. demand lower (up to 10% RC)	1	2	20	0	2	0	25
5 Full imp. demand much lower (>10% RC)	0	1	8	1	0	0	10
Totals	1	9	38	1	13	0	62

*RC = resource capacity

5.2.7 Question F: How effective would the key WAP rules be (if fully implemented) to address the level of risk to environmental objectives, under the 'expected' (WAP development period) climate? Question G: How effective would the key WAP rules be (if fully implemented) to address the level of risk to environmental objectives, under the post-WAP development climate that was experienced?

Scenarios compared:

Question F

Scenario 2 (pre-WAP) for WAP development period (1974 to 2006)
representing pre-WAP water resource development (including no LFR), under WAP development period climate

and

Scenario 5 (full implementation) for WAP development period (1974 to 2006)
representing full implementation of key WAP rules, under WAP development period climate.

Question G

Scenario 2 (pre-WAP) for post-WAP development period (2007 to 2022)
representing pre-WAP water resource development (including no LFR), under post-WAP development period climate

and

Scenario 5 (full implementation) for post-WAP development period (2007 to 2022)
representing full implementation of key WAP rules, under post-WAP development period climate.

Questions F and G test the effect of full implementation of the key WAP rules, compared to the pre-WAP scenario, under the climate of the WAP development period (for Question F) or post-WAP development period (for Question G). The results from the WAP development period (Question F) provide the baseline of what was expected to be achieved through full implementation of the key WAP rules. This baseline can be compared with the results of Question G to show how the climate of the post-WAP development period has influenced the effectiveness of full implementation of WAP rules.

Question G considered here is similar to Question E from section 5.2.7, except that the starting point of development for comparison is different for each question. In both cases, the effect of full implementation under the post-WAP development period is being assessed. However, for Question E, the comparison is with current implementation; while for Question G, the comparison is with the pre-WAP scenario.

5.2.7.1 Overall outcome

The effects of full implementation on water resource development compared to the pre-WAP scenario were quite similar to the effects of full implementation compared to current implementation as outlined in section 5.2.6. Full implementation increased demand in 35 zones compared to the pre-WAP scenario and decreased demand in 7 zones compared to the pre-WAP scenario; it resulted in low flows being passed in 51 of the 62 modelled zones (section 5.1.2.3, Table 7 and Table 8).

Full implementation caused the overall level of risk to environmental objectives to decrease compared to the pre-WAP scenario, for both periods. For example, 43 of the 62 modelled zones (69%) failed fewer metrics for the full implementation scenario compared to the pre-WAP development scenario for both periods (Table 22 and Table 23).

However, the full implementation scenario for the post-WAP development period did not meet the catchment-level flow objective when considered across all zones, or for the Bremer and Carrickalinga catchments (Table 20). The catchment-level flow objective was met for the modelled Onkaparinga sub-catchments. That is, full implementation of the key WAP rules has not met the flow objective for 2 of the 3 modelled catchments as a result of the climate of the post-WAP development period.

The climate of the post-WAP development period exacerbated the detrimental effects imposed by pre-WAP water resource development, when considered across the Bremer and Carrickalinga catchments. For example, for the Bremer, 11 zones (20%) passed the flow objective for the pre-WAP scenario for the WAP development period, and this decreased to 6 zones (11%) for the post-WAP development period (Table 20).

In addition, full implementation is less effective at decreasing the level of risk to environmental objectives under the post-WAP development period climate for these catchments. For example, for the Bremer, the number of zones that were 'fixed' by full implementation (that is do not met the flow objective for the pre-WAP scenario but meet the flow objective for full implementation) was higher for the WAP development period (8 zones fixed by full implementation) compared to the post-WAP development period (only 5 zones fixed) (Table 20).

However, for the modelled Onkaparinga sub-catchments, the post-WAP development climate reduced the impact of pre-WAP development on the level of risk to environmental objectives and improved the ability of these zones to meet the flow objective under the full implementation scenario. That is, these zones did better than expected based on the WAP development period climate. For example:

- the number of zones that met the flow objective was higher for the post-WAP development period compared to the WAP development period for both the pre-WAP scenario (post-WAP=1, WAP=0) and for full implementation (post-WAP=6, WAP=3) (Table 20).
- 71% of the modelled Onkaparinga zones failed fewer metrics for the post-WAP development period compared to the WAP development period for full implementation (Table 21), with the other zones failing the same percentage of metrics for both periods.

The outcomes varied between zones, particularly within the Bremer catchment. For the Bremer, 63% of the modelled zones failed more metrics for the full implementation scenario for the post-WAP development period, compared to the WAP development period (Table 21), including all of the modelled zones in wetter sub-catchments (that is increased level of risk for these zones for the post-WAP development period). However, 28% of the modelled zones failed fewer metrics for the post-WAP development period (Table 21, that is decreased level of risk for these zones), and these were all located in drier parts of the catchment (Upper Bremer, Rodwell Creek or Red Creek sub-catchments). Two of these zones did not meet the flow objective for the WAP development period but met it for the post-WAP development period; while the other 13 did not meet the flow objective for either period but failed fewer metrics for the post-WAP development period.

As observed in the comparison of full implementation with current implementation (section 5.2.6), full implementation of LFR allowed water demand and dam capacity to substantially increase while the level of risk to environmental objectives decreased compared to the pre-WAP scenario, for both periods (Table 22 and Table 23, rows 1 and 2).

5.2.7.2 Key results data tables

The overall outcomes reported in section 5.2.7.1 are drawn from the assessments of changes to the level of risk to environmental objectives for full implementation compared to the pre-WAP scenario, for the WAP development period (question F) and the post-WAP development period (question G), as per the approaches outlined in section 4.4.

Table 20 shows this assessment based on changes to the number of zones meeting the flow objective between the scenarios, and whether the catchment-level flow objective is met for full implementation for the post-WAP development period (that is whether the number of zones meeting the flow objective for full implementation for the post-WAP development period is the same or more than the number of zones meeting the flow objective for full implementation for the WAP development period (the full implementation baseline)). The catchment-level flow objective is met for full implementation for the WAP development period by definition (that is, this scenario sets the baseline for that assessment).

Table 21 shows this assessment based on changes in the percentage of metrics failed between the scenarios within each zone, regardless of whether the zone meets the flow objective. This assessment directly compares the results from the full implementation scenario between the post-WAP development period and the WAP development period.

Table 22 and Table 23 also shows this assessment based on changes in the percentage of metrics failed between the scenarios within each zone, regardless of whether the zone meets the flow objective, for the comparison between the pre-WAP scenario and full implementation for the WAP development period (Table 22) and for the post-WAP development period (Table 23). For these tables, the results are split between zones with different changes in demand (rows) and changes in number of low flow sites between the scenarios, in the same way as for the very similar Table 19 in section 5.2.6 (noting that the starting point for Table 22 and Table 23 is Table 8 from section 5.1.2.3).

Table 20. Assessment of change to level of risk to environmental objectives for full implementation compared to the pre-WAP scenario, for the WAP development period (question F) and also the post-WAP development period (question G), based on assessment of flow objectives at zone and catchment-level scales

Area (Number of modelled zones)	Number (%) of zones meeting the flow objective for different implementation scenarios and time periods (and change to level of risk)				Does G. full imp., post-WAP dev. period meet the catchment-level objective?
	F. Pre-WAP, WAP dev. period	F. Full imp., WAP dev. period	G. Pre-WAP, post-WAP dev. period	G. Full imp, post-WAP dev. period	
All modelled zones (62)	12 (19%)	23 (37%) (decreased risk)	7 (11%)	17 (27%) (decreased risk)	No
Bremer (54)	11 (20%)	19 (35%) (decreased risk)	6 (11%)	11 (20%) (decreased risk)	No
Carrickalinga (1)	1 (100%)	1 (100%) (same risk)	0 (0%)	0 (0%) (same risk)	No
Onkaparinga (7)	0 (0%)	3 (43%) (decreased risk)	1 (14%)	6 (86%) (decreased risk)	Yes

Table 21. **Assessment of change to level of risk to environmental objectives for the full implementation scenario for the post-WAP development period, compared to the WAP development period, based on changes to the number of EWR metrics failing between the scenarios**

Area (Number of modelled zones)	Number (%) of zones where level of risk to environmental objectives increases, stays the same or decreases under full implementation, post-WAP development period) compared to full implementation, WAP development period)		
	Increased level of risk for post-WAP dev. period (failed more metrics)	Same level of risk (no change to % metrics failed)	Decreased level of risk for post-WAP dev. period (failed fewer metrics)
All modelled zones (62)	35 (56%)	7 (11%)	20 (32%)
Bremer (54)	34 (63%)	5 (9%)	15 (28%)
Carrickalinga (1)	1 (100%)	0 (0%)	0 (0%)
Onkaparinga (7)	0 (0%)	2 (29%)	5 (71%)

Table 22. **Assessment of change to level of risk to environmental objectives for full implementation compared to the pre-WAP scenario, both modelled for the WAP development period, based on changes to the number of EWR metrics failing between the scenarios**

	Number of zones in each combination of change in demand category (rows) and change in number of low flow sites category (columns) where the level of risk to environmental objectives increases, stays the same or decreases under full implementation, WAP development period compared to pre-WAP scenario, WAP development period						
Change in demand category for full implementation compared to current assumed use	A. Pass low flows at more sites with full implementation			B. Pass low flows at same no. of sites with full implementation**			
	Increased risk (failed more metrics)	Same risk (no change)	Decreased risk (failed fewer metrics)	Increased risk (failed more metrics)	Same risk (no change)	Decreased risk (failed fewer metrics)	Totals
1 Full imp. demand much higher (>10% RC*)	0	0	5	0	0	0	5
2 Full imp. demand higher (up to 10% RC)	0	0	2	0	0	0	2
3 No change to demand	1	4	5	0	10	0	20

4 Full imp. demand lower (up to 10% RC)	0	3	22	0	0	0	25
5 Full imp. demand much lower (>10% RC)	0	1	8	0	0	1	10
Totals	1	8	42	0	10	1	62

*RC = resource capacity

** All zones in this group of columns passed low flow at no sites, for both the pre-WAP scenario and the full implementation scenario

Table 23. Assessment of change to level of risk to environmental objectives for full implementation compared to the pre-WAP scenario, both modelled for the post-WAP development period, based on changes to the number of EWR metrics failing between the scenarios

	Number of zones in each combination of change in demand category (rows) and change in number of low flow sites category (columns) where the level of risk to environmental objectives increases, stays the same or decreases under full implementation, post-WAP development period compared to pre-WAP scenario, post-WAP development period						
Change in demand category for full implementation compared to current assumed use	**A. Pass low flows at more sites with full implementation**			**B. Pass low flows at same no. of sites with full implementation****			
	Increased risk (failed more metrics)	**Same risk (no change)**	**Decreased risk (failed fewer metrics)**	**Increased risk (failed more metrics)**	**Same risk (no change)**	**Decreased risk (failed fewer metrics)**	**Totals**
1 Full imp. demand much higher (>10% RC*)	0	0	5	0	0	0	5
2 Full imp. demand higher (up to 10% RC)	0	0	2	0	0	0	2
3 No change to demand	0	4	6	0	10	0	20
4 Full imp. demand lower (up to 10% RC)	1	2	22	0	0	0	25
5 Full imp. demand much lower (>10% RC)	0	1	8	1	0	0	10
Totals	1	7	43	1	10	0	62

*RC = resource capacity

** All zones in this group of columns passed low flow at no sites, for both the pre-WAP scenario and the full implementation scenario

5.2.7.3 Further results exploring the full implementation scenario

Effect of different full development options

As outlined in section 7.1 in Appendix A, 3 different options were calculated for the full implementation scenario, with small variations between options in how the demand and dam capacities were adjusted to achieve full development against the take and interception/diversion limits. The EWR metrics were calculated for the 3 different variations of the full implementation scenario. However, the analysis in section 5 only uses a single variation of the full implementation scenario. If the full implementation scenario variation with the lowest percentage of metrics failing was chosen for each zone instead, then 39% of zones would meet the flow objective under the WAP development period climate, compared to 37% of zones meeting the objective using the single variation of the full implementation scenario used for this analysis (as per Table 21).

This outcome illustrates that the way that full development occurs affects the risk to environmental objectives, emphasising the importance of including a wide range of likely water resource development combinations when developing WAP policy (for example different combinations of watercourse diversions, dams of different size and type (licensed or not) and their distributions across space, together with different climate conditions).

Passing the flow objective at the majority of zones

As per Table 21, 37% of zones meet the flow objective for the full implementation scenario for the WAP development period. This relatively low proportion of zones meeting the flow objective largely occurs because 54 of the 62 modelled zones occur in the Bremer catchment, which disproportionately failed the flow objective across test sites when setting the take limits for the 2013 EMLR WAP.

As outlined in section 3.2, the take and interception/diversion limits for the WAPs were set by modelling a range of management options with different levels of demand and different options for passing low flows, and identifying which of those scenarios met the flow objective of passing at least 85% of the EWR metrics. For the EMLR, it was considered that the flow objective should be met at the majority (at least 50%) of test cases, for a modelled management scenario to be considered suitable, as part of the process of balancing social, economic, and environmental water needs (EMLR WAP section 2.4.2.3).

There were 69 test sites used for this modelling in the EMLR across the Angas River (18 sites), Bremer River (22 sites), Currency Creek (8 sites), Finniss River (15 sites) and Tookayerta Creek (6 sites) catchments. These sites generally aligned with the downstream end of zones and were distributed across the major tributaries and climates of each catchment.

The modelled management scenario that is closest to meeting the key WAP rules has been identified for each test site from the historical dataset used for setting the 2013 WAP limits (that is the scenario with demand closest to 20% of adjusted runoff, and with low flows passed at all scope sites). Looking across those selected test sites, 54% of test sites passed the flow objective across the whole EMLR. However, for the Bremer catchment, 41% of test cases passed the flow objective. This is likely to be due to the Bremer catchment having a significant number of zones where there are few licensed sources and scope sites – that is, a limited ability to implement the key WAP rules. For example, 10 of the 54 Bremer zones modelled in this project had no changes implemented through the full implementation scenario, because they had no licensed dams or watercourse diversions to alter demand at, and all the non-licensed dams present were under 5 ML in capacity (that is not scope dams).

5.3 Behaviour of types of metrics between climate periods

This section briefly explores which types of metrics are changing in response to implementation and climate period, and whether the patterns of change are consistent. Further analysis of this nature could be used as part of a WAP amendment process, to identify parts of the flow regime that have changed since WAP development and may benefit from adjustment of WAP policy.

Metric results were considered for 3 groups of zones:

- The modelled Onkaparinga sub-catchments: demand was increased for the full implementation scenario for most zones, and the level of risk to environmental objectives generally decreased for the post-WAP development period.
- 'Bremer decrease zones': the 15 zones in the Bremer catchment where the level of risk to environmental objectives decreased for the full implementation scenario for post-WAP development period (that is failed fewer metrics compared to the WAP development period). Demand was reduced in 12 of these zones for the full implementation scenario.

- ‘Bremer increase zones’: the 34 zones in the Bremer catchment where the level of risk to environmental objectives increased for the full implementation scenario for post-WAP development period (that is failed more metrics compared to the WAP development period). Demand was reduced in 19 of these zones for the full implementation scenario.

The 3 scenarios considered were the pre-WAP scenario for the WAP development period, and the full implementation scenario for the WAP development period and post-WAP development period.

The percentage of metrics that fail within each metric group was calculated for each scenario, for each group of zones. For example, the seasonal flow metric for the Low flow season would be calculated for the full implementation scenario in the WAP development period for each of the seven Onkaparinga zones; and if that metric failed for one of those zones, this would be expressed as 1 out of 7 or 14% of metrics failing for that metric type for the Onkaparinga sub-catchments under that scenario and period. Metric types and flow seasons are described in section 3.2.1.

The results are presented in Table 24. Red text shows cases where the percentage of metrics failed has increased by more than 2% compared to the column to the left, and green text shows cases where this has decreased by more than 2% (absolute value). Bold text indicates cases with a larger difference (>5%).

5.3.1 Effects of full implementation compared to the pre-WAP scenario

Comparison of the pre-WAP scenario with the full implementation scenario shows that full implementation reduces the percentage of metrics failed across most metric types for all groups of zones, particularly for zero flows, low flows, freshes outside the High flow season and seasonal timing. These outcomes reflect the findings from WAP development, and the intent of the key WAP rules.

Full implementation causes more metrics to fail in some cases. For example, the percentage of metrics failing increases for ‘annual-bankfull’ metrics across the Onkaparinga zones, and for ‘other freshes’ in the second Transitional flow season (T2) across the ‘Bremer decrease’ zone group. Both of these metrics represent medium to high flow components, which may be failing more often for full implementation because of the higher level of dam capacity and demand under full implementation (for the Onkaparinga zones), and/or the occasionally observed effect where passing low flows means dams take longer to fill and spill at the break of season, which can sometimes delay medium to large flow events that occur via dam spills.

It is likely that the increases in percentage of metrics failing for low flows in the T1 and High flow season for the full implementation scenario for the WAP development period are calculation artefacts, rather than a real increase in the level of risk. In some cases, the calculated low flow rate is artificially inflated as a result of the high proportion of zero flow in very dry zones that are typical of this group of zones (see Appendix A, section 7.3 ‘Zone BR044, T2 season low flows’ for a description of this effect).

5.3.2 Effects of the post-WAP development period climate

Comparison of the full implementation scenario for the WAP development period and post-WAP development period shows different climate responses for the different groups of zones.

For the ‘Bremer decrease’ group, the metrics get worse (fail more often) for most metric types across all seasons, although the impact is most pronounced in the Low flow season and second (T2, spring) Transitional flow seasons. These results show some correspondence with analysis of trends for rainfall stations across the Bremer catchment (Savadamuthu and McCullough, 2024), which shows a decrease in October rainfall since the Millenium drought for most sites across the Bremer and decreasing trends in autumn (which includes part of the Low flow season) for some wetter stations.

The ‘Bremer increase’ group fail fewer metrics for the full implementation scenario for the post-WAP development period, as reflected in the results for this group of zones in Table 24. The results indicate an overall likely improvement in the flow regime for the first (T1, late autumn) Transitional flow season and for freshes outside the High flow season, but also show likely poorer outcomes for zero flow events in the high flow and second (T2) Transitional flow seasons. This means it will be important to maintain WAP policies that mitigate the risk of worsening zero flow events in these areas, despite the apparent overall reduction in risk to environmental objectives.

For the Onkaparinga zones, there are a range of metrics that improve (fail fewer metrics) for the post-WAP development period, and only 2 that worsen (fail more metrics). This is consistent with the overall outcome that the level of risk to environmental objectives decreases for these zones for the post-WAP development period. The pattern of changes to metrics failing indicates that the climate of the post-WAP development period is generally wetter with a higher level of low flows, although there are detrimental effects for freshes in the Low flow season, and overall seasonal flow in the T2 flow season, in some cases. These outcomes are broadly consistent with the finding of increased rainfall since the Millenium drought in some parts of the Onkaparinga catchment (Savadamuthu and McCullough, 2024).

The results of this analysis reinforce the finding that the effects of the post-WAP development period climate on the flow regime vary across space, both in terms of overall level of risk to environmental objectives, as well as the specific flow components or periods that are affected. This variability should be considered as part of WAP amendment processes, as noted in section 6.2.3.

Table 24. Percentage of metrics failing across zone groups for the pre-WAP scenario (WAP development period (1974 to 2006)) and the full implementation scenario (WAP development period (1974 to 2006) and post-WAP development period (2007 to 2022)).

Season-metric type	% of metrics that fail across the group, for the scenario and period								
	Onkaparinga (7 zones)			Bremer increase zones* (15 zones)			Bremer decrease zones* (34 zones)		
	Pre-WAP 1974 to 2006	Full imp. 1974 to 2006	Full imp. 2007 to 2022	Pre-WAP 1974 to 2006	Full imp. 1974 to 2006	Full imp. 2007 to 2022	Pre-WAP 1974 to 2006	Full imp. 1974 to 2006	Full imp. 2007 to 2022
LFS-Zero flow	24%	19%	19%	56%	**49%**	44%	29%	**18%**	**27%**
LFS-Low flow	100%	100%	100%	40%	**27%**	**33%**	56%	**47%**	**56%**
LFS-Fresh	76%	**19%**	**29%**	91%	**56%**	56%	56%	**34%**	**55%**
LFS-Seasonal flow	86%	**14%**	**0%**	0%	0%	**100%**	0%	0%	**62%**
T1-Zero flow	19%	14%	10%	44%	40%	**31%**	20%	**14%**	18%
T1-Low flow	71%	71%	**29%**	47%	**53%**	**33%**	65%	62%	**74%**
T1-Fresh	38%	**0%**	0%	60%	**31%**	**4%**	39%	**20%**	23%
T1-Seasonal flow	71%	**43%**	**29%**	27%	**0%**	0%	21%	**9%**	**18%**
T1-Seasonal timing	86%	**0%**	0%	91%	**55%**	55%	55%	**42%**	39%
T1-Other fresh	14%	**0%**	0%	55%	**18%**	**0%**	58%	**38%**	**31%**
HFS-Zero flow	0%	0%	0%	44%	**36%**	**42%**	21%	**12%**	**20%**
HFS-Low flow	100%	**14%**	**0%**	47%	**67%**	**47%**	65%	**41%**	44%
HFS-Fresh	5%	0%	0%	9%	**2%**	0%	10%	**0%**	**7%**
HFS-Seasonal flow	0%	0%	0%	0%	0%	0%	3%	0%	0%
HFS-Other fresh	0%	0%	0%	0%	0%	0%	4%	0%	**8%**
T2-Zero flow	0%	0%	0%	42%	**24%**	**38%**	22%	**12%**	**25%**
T2-Low flow	100%	**71%**	**29%**	80%	80%	**27%**	68%	**56%**	53%
T2-Fresh	29%	**0%**	0%	80%	**58%**	**24%**	44%	**21%**	**31%**
T2-Seasonal flow	50%	**0%**	**7%**	31%	27%	**4%**	27%	**7%**	**20%**
T2-Seasonal timing	29%	**0%**	0%	73%	**20%**	20%	48%	**12%**	**27%**
T2-Other fresh	0%	29%	29%	27%	27%	**13%**	5%	8%	**15%**
Annual-Bankfull	0%	**33%**	**14%**	7%	4%	0%	2%	0%	**13%**

Red text shows cases where the percentage of metrics failed has increased by more than 2% compared to the column to the left, and green text shows cases where this has decreased by more than 2% (absolute value). Bold text indicates cases with a larger difference (>5%).

* 'Bremer increase zones' are zones in the Bremer catchment where the number of metrics failing increased for the full implementation scenario in the post-WAP development period, compared to the WAP development period. 'Bremer decrease zones' are zones where the number of metrics failing decreased.

6 Discussion and recommendations

This investigation has evaluated the performance of EWR metrics for modelled surface water scenarios across different select time periods. This enables review of:

- The effectiveness of the actual implementation of the key WAP rules in meeting the flow objective that is, what has happened given how the WAPs were implemented?
- The effectiveness of key WAP rules that underpin the WAPs' flow objective that is, what was expected to have happened if the WAPs were implemented as intended?

The key outcomes from this investigation for these overarching questions are summarised below.

6.1 What happened given how the WAPs were implemented?

In summary, the overall level of risk to environmental objectives under current conditions has increased slightly since WAP development – fewer zones passed the flow objective under current conditions (15%) compared to pre-WAP conditions (19%). The current extent of implementation of the key WAP rules decreases the level of risk, but the current extent of implementation is limited. For the majority of zones, the climate since WAP development had detrimental impacts on the EWR metrics and increased the level of risk to environmental objectives, and in some cases this detrimental effect offset the beneficial effects of current implementation.

The pre-WAP level of water resource development had substantial detrimental impacts on the level of risk to environmental objectives, with only 19% of modelled zones meeting the flow objective for the pre-WAP scenario for the WAP development period (section 5.2.3).

The 2 key WAP rules underpinning the flow objective have not yet been fully implemented, being the LFR policy to pass low flows at sufficient scope sites; and bringing overall demand and dam capacity to within their limits at the zone and catchment scale. The current extent of implementation in the modelled catchments is limited to partial implementation of the LFR policy, affecting 35 zones in the Bremer and Carrickalinga catchments out of the 62 modelled zones.

The current extent of implementation resulted in a small decrease in the overall level of risk to environmental objectives across the zones where implementation has occurred, if the effects of climate are excluded (for example current implementation resulted in 2 additional zones meeting the flow objective compared to the pre-WAP scenario (section 5.2.2)). However, the catchment-level flow objective is not met for any of the 3 modelled catchments for the current implementation scenario for the post-WAP development period (section 5.2.1).

Under the current implementation scenario, 31% of the Tier 1 scope sites in these zones have been treated to pass low flows for the current implementation scenario. There have been no changes to demand volume or dam capacity for the current implementation scenario, which means that the other key WAP rule (to keep demand and dam capacity within their limits) is not met for 23 zones, and for the Bremer catchment as a whole (section 5.1.2.2). Therefore, it may be expected that the level of risk to meeting environmental objectives would be reduced by current implementation, but not to the extent expected by full implementation of the key WAP rules.

Current implementation increased the level of risk to environmental objectives for 4 zones (failed more metrics compared to pre-WAP scenario). However, further analysis showed that the level of risk then decreased for all of these zones for the full implementation scenario. That is, partial implementation of the key WAP rules may occasionally increase the risk to environmental objectives, but this may be offset or decreased by full implementation (section 5.2.2).

Passing low flows is known to cause some negative impacts on the flow regime in some cases. Passing low flows means dams take longer to fill and spill at the break of season, which can sometimes delay medium to large flow events that occur via dam spills. Reducing dam capacity and/or water demand from dams as part of full implementation is likely to allow dams to fill and spill more often. This finding illustrates the importance of full implementation of both of the key WAP rules, which act in complementary ways – the LFR rules help to support low to medium environmental flow components, and the limits on demand and dam capacity primarily help to support medium to high environmental flow components.

If there had been no implementation, and the current level of development remained in place, the risk to environmental objectives would have increased for the majority of modelled zones as a result of the climate of the post-WAP development period. However, the results varied between zones and catchments. While 52% of zones failed more metrics for the pre-WAP scenario for the post-WAP development period (higher risk), over a third of the zones (37%) failed fewer metrics for the post-WAP development period (lower risk). At a catchment scale, the level of risk to environmental objectives increased in the Bremer and Carrickalinga catchments, but decreased in the modelled Onkaparinga sub-catchments, for the post-WAP development period (section 5.2.3).

The combined effects of the current extent of implementation and recent climate resulted in an overall small increase in the level of risk to environmental objectives since WAP development, when considered across all modelled zones. However, the results varied across zones and catchments, reflecting the variation described above for current implementation and climate.

At a catchment scale, the level of risk slightly decreased for the modelled Onkaparinga sub-catchments since WAP development as a result of the beneficial effects of the post-WAP development period climate on the EWR metrics (number of zones meeting the flow objective increased from 0 to 1 for the pre-WAP scenario for the WAP development period to current implementation for the post-WAP development period) (section 5.2.1). The overall level of risk increased for the Bremer and Carrickalinga catchments since WAP development (number of zones meeting the flow objective decreased from 11 to 8 for Bremer, and 1 to 0 for Carrickalinga, for the same scenario comparison as for Onkaparinga) (section 5.2.1). These 2 catchments included 6 zones where the benefit of current implementation for the EWR metrics is offset by the detrimental effect of the post-WAP development period climate on the EWR metrics (section 5.2.4).

If licensees used their current allocation, rather than current assumed use, there would have been little change in demand for the majority (76%) of zones. As expected, where using current allocation caused demand to increase, the risk to environmental objectives increased or stays the same considering the percentage of EWR metrics failed. Where this decreased demand, the risk to environmental objectives decreased or stayed the same. In all cases, these changes were not enough to change the number of zones passing the flow objective as a result of using current allocation instead of current assumed use (section 5.2.5).

This investigation has not considered what would have happened if there was no water management policy in place (for example no WAP or other water affecting activities policies and no water licensing system). Under these circumstances, further uncontrolled development could occur, further increasing the level of risk to environmental objectives from the pre-WAP scenario.

6.2 What was expected to have happened if the WAPs were implemented as intended?

Full implementation of the key WAP rules was expected to meet the catchment-level flow objective for all catchments. The results of this investigation show that full implementation of the key WAP rules would not meet the flow objectives under the post WAP development climate for the Bremer and Carrickalinga catchments. However, the flow objective would be met (and exceeded) across the modelled Onkaparinga sub-catchments. This finding supports amending the WAPs in order to allow them to be more effective in meeting their flow objectives for surface water.

Full implementation of the key WAP rules reduced water demand in 35 zones (34 in Bremer, 1 in Onkaparinga) and increased water demand in 7 zones (6 in Onkaparinga, 1 in Carrickalinga), and did not change water demand in the remaining 20 zones (in Bremer). Full implementation also resulted in low flows being passed at more sites (in 48 zones with more sites passing low flows compared to current implementation, and in 51 zones compared to pre-WAP scenario) (section 5.1.2.3).

Full implementation decreased the level of risk to environmental objectives compared to the current implementation and pre-WAP scenarios. For example, 15% of modelled zones passed the flow objective for the current implementation scenario for the post-WAP development period, increasing to 27% of zones for the full implementation scenario. In addition, 61% of zones failed fewer metrics under full implementation compared to current implementation, while 35% of zones had no change (section 5.2.6).

Full implementation of LFR allowed water demand and dam capacity to substantially increase while the level of risk to environmental objectives decreased. For the 7 zones where demand increased under full implementation, the volume of demand was 38 to 243% higher for full implementation. Six of these zones failed fewer metrics for the full implementation scenario, and one zone failed the same number of metrics as the current implementation scenario (section 5.2.6).

However, the catchment-level flow objective was not met for full implementation in the post-WAP development period for the Bremer and Carrickalinga catchments, as a result of detrimental effect of the climate on the EWR metrics in the majority of zones. This objective was met for the modelled Onkaparinga sub-catchments (section 5.2.6).

The outcomes varied between zones, particularly within the Bremer catchment. For the Bremer, 63% of the modelled zones failed more metrics for the full implementation scenario for the post-WAP development period (that is increased risk) compared to the WAP development period, including all of the modelled zones in wetter sub-catchments. However, 28% of the modelled zones failed fewer metrics for the post-WAP development period (that is decreased risk), and these were all located in drier parts of the catchment (Upper Bremer, Rodwell Creek or Red Creek sub-catchments) (section 5.2.6).

These outcomes align with analysis of measured rainfall and streamflow data across the Mount Lofty Ranges (MLR) carried out as part of a complementary WAP review project (Savadamuthu and McCullough, 2024). That analysis showed a decline in rainfall and runoff, particularly in spring and to a lesser degree in autumn since the Millennium drought for many sites in the MLR. Flow patterns have also been altered in some cases, with reductions observed in the number of flowing days per year, and in autumn and spring median flow. Such changes in rainfall and runoff would be expected to translate into worse outcomes for the EWR metrics and increased risk to environmental objectives, as observed for the majority of zones in this investigation.

Both investigations also found variation in the effects of climate over the MLR. For example, Savadamuthu and McCullough (2024) found rainfall has not declined in some areas such as some sections of the Onkaparinga, the lower elevations of the Bremer catchment and across the Fleurieu region, which corresponds with the findings from this investigation of reduced level of risk to environmental objectives for the modelled Onkaparinga sub-catchments and some drier parts of the Bremer catchment.

While this investigation involved zones in 3 catchments, the study areas were chosen to be representative of the MLR Prescribed Water Resource Areas (PWRAs) generally, with a mixture of drier and wetter areas and a range of landscape and water resource development conditions. The investigation shows that the flow objective is not being met in catchments in both the Eastern Mount Lofty Ranges (EMLR) and Western Mount Lofty Ranges (WMLR) PWRAs and shows the drivers for this at an appropriate level of detail to identify focus areas for further investigations and policy development during a potential WAP amendment phase.

Overall, the finding that 2 of the 3 modelled catchments do not meet their flow objective supports amending the WAPs in order to allow them to be more effective in meeting their environmental objectives for surface water. This amendment could take the form of either or both of the following:

- amending WAP rules to make them more effective at meeting the flow objective, for the range of historical climate conditions experienced, and/or expected future climate
- amending the environmental objectives – for example, refining the method of calculating the metrics to take better account of shorter-term events like drought; and updating the relationships between measured flow regime and environmental condition that underpin the flow objective to include data collected since WAP development, as discussed in section 6.2.2.

A range of related issues arising from this investigation that could be considered during potential WAP amendment are noted below.

6.2.1 Effect of change in rainfall-runoff behaviour

The complementary WAP review investigation examining changes in rainfall and streamflow in the MLR (Savadamuthu and McCullough, 2024) found evidence of a potential shift in rainfall-runoff relationships since the Millenium drought for some sub-catchments, based on examination of measured rainfall and streamflow data. That is, the volume of runoff generated from a given volume of rainfall is less since the drought, in some cases.

The Bremer and Carrickalinga surface water models used for this investigation have generally been calibrated using measured flow data from the WAP development period (as outlined in the references given in section 3.3) and use the same rainfall-runoff relationships for the entire modelled period for this investigation. That is, the modelling does not fully account for the potential downward shift in rainfall-runoff response observed since the onset of the Millenium drought. As a result, modelled flow for the post-WAP development period may be overestimated, and the risk to environmental objectives may be higher for the post-WAP development period than has been calculated for this investigation. Recalibration of models using up-to-date rainfall and streamflow records is expected to provide more realistic flow estimates for the post-WAP development period.

This issue strengthens the case to consider amending the WAPs, as it may be that implementation of the WAPs as intended would be even less likely to meet the flow objectives under the climate of the post-WAP development period.

6.2.2 Refining relationships between flow regime and environmental condition, and metric calculation methods

As outlined in section 3.2, the flow objective is based on the relationships between measured environmental condition and the percentage of metrics passed for those environmental condition monitoring sites, calculated using modelled flow data from 1974 to 2006. The value for each metric is calculated as a single averaged value over the entire period, and the acceptable target range it is compared to is calculated relative to a single averaged value from the modelled 'No development' scenario from 1974 to 2006.

A considerable body of ecological data has been collected since the WAP development period and could be used to update the relationships between environmental condition and flow regime used to underpin environmental objectives and the resulting WAP policies intended to support those objectives. This should be complemented with updated flow data to reflect the observed changes in rainfall-runoff responses (as per Savadamuthu and McCullough, 2024 and noted in section 6.2.1).

The current approach of calculating a single long-term averaged value for each metric is not very sensitive to variation and does not allow assessment of outcomes under different conditions (for example drought years or wet years). Consideration could be given to calculating EWR metrics in a more granular fashion (for example yearly, or averaged over an appropriate window), in order to allow better evaluation of impact of variation in factors such as climate and shorter-term events like drought, and evaluation of how water management policies address such variations. Such an approach may include calculating metrics over different time scales that reflect the requirements of the associated ecological processes.

If the method of calculating EWR metrics is adjusted as part of WAP amendment, it may be useful to review the experiences with the metrics since their development to identify useful features to retain, consider whether other refinements could be included to help address known issues (such as calculation effects noted in section 7.3 in Appendix A), and assess whether there are other issues that should be addressed (for example identify whether the observed correlations between metrics (Maxwell et al. 2015) influence the assessment of risk to environmental objectives).

6.2.3 Climate variability over space and time

The results of this investigation, and the complementary rainfall and streamflow investigation (Savadamuthu and McCullough, 2024), show that the climate and its effects on the flow regime are variable over space within a period, and vary in different ways over time in different areas. For example, in this investigation, the level of risk to environmental objectives increases in some areas and decreases in others under the post-WAP development period, and the patterns of which metric types fail more or less for the post-WAP development period are also different between catchments and groups of zones (section 5.3).

It is recommended that this variability be considered for any WAP amendment process, and the process for selecting data to inform policy development be matched to the intended requirements. Some examples to illustrate this point are given below.

Testing policy options: When selecting a period of time for testing the effects of water management policy options (for example modelling the flow outcomes of different demand limits and water taking rules and assessing their effects on achievement of flow objectives), it may be useful to select a long period of climate data that is likely to include a wide range of likely climates; and couple this with an assessment method that identifies performance of the management policies under different conditions (for example do the policies work in drought, dry, median and wet periods) as suggested in section 6.2.2.

It may be that the more challenging climates occur at different times for different parts of the area. For example, if WAP policy settings were developed for the Onkaparinga sub-catchments modelled for this investigation based on the climate of the post-WAP development period, then if the climate reverted to that experienced during the WAP development period, the level of risk to environmental objectives would increase under those policy settings.

Determining available runoff: A similar argument applies to selecting a period to define water resource capacity where this is used to calculate available runoff or likely water supply for principles that aim to balance water supply and demand (for example EMLR WAP principles 44-45, WMLR WAP principles 42-47). It may be useful to consider setting this value based on the median (or potentially some more conservative measure) determined from a sufficiently long time period that includes drier conditions for all parts of the MLR.

Defining environmental water requirements and provisions: WAPs are required to include an assessment of the capacity of the water resources to meet environmental water requirements, defined as those water requirements that must be met in order to sustain the ecological values of ecosystems that depend on the water resource, including their processes and biodiversity, at a low level of risk (*Landscape South Australia Act 2019*, section 53 (1)(b)(i) and (12)). These differ from environmental water provisions (that is what will actually be provided by implementation of water policy).

The ecosystems present have developed in response to landscape conditions, including climate, over a long period. Defining the requirements to maintain them at a low level of risk should not place undue emphasis on recent climate or likely future climate. However, it will be important to consider likely future climate when testing the effects of water management policy options on achievement of environmental water provisions.

6.2.4 Full implementation scenario variations

The baseline used in this investigation for assessing whether the flow objective has been met is based on one modelled scenario of full implementation, from a universe of many possibilities of full implementation.

It may be that full implementation actually occurs differently (for example if different dams were enlarged, reduced, constructed, or removed, or if there were different distribution of demand across sources etcetera), and so a different number of zones would have passed the flow objective under the WAP development period climate. This investigation included 62 zones with a wide range of water source patterns (distribution of location, dam size, licensing status etcetera), so it is likely that this included a wide range of likely possibilities. As discussed in section 5.2.7.3 'Effect of different full development options', 3 slightly different full development options were modelled for this investigation, with a small difference in level of risk to environmental objectives between the option used for analysis for this investigation, and the combination with the highest risk.

This outcome illustrates that the way that full development occurs affects the risk to environmental objectives, emphasising the importance of including a wide range of likely water resource development combinations when developing WAP policy, such as different combinations of watercourse diversions, dams of different size and type (licensed or not) and their distributions across space, together with different climate conditions.

6.2.5 Scale of assessment

The Carrickalinga catchment is represented as a single zone in the current WAP (and this investigation) but has been divided into smaller zones that represent different aquatic habitats as part of draft WAP development, and implementation of LFR policy. Assessing achievement of the flow objective at the end of the catchment only doesn't allow consideration of whether local-scale environmental provisions are being met, in the same way as occurs for catchment such as Onkaparinga that have zone boundaries based on likely extent of different aquatic habitats or reach types. The smaller zones in Carrickalinga were modelled as part of this investigation, and the results could be assessed to explore the how the scale of assessment affects the risk outcomes.

As part of WAP amendment, consideration could be given to including mechanisms that balance managing water availability and environmental water provisions at a more local scale, with the availability of data required to inform water management policy.

6.2.6 Forestry

As described in section 3.3.2, the latest models for the WMLR reservoir catchments, including Onkaparinga, explicitly incorporate forest areas as specific functional units for forestry areas that generate different rainfall-runoff characteristics compared to rural catchments. The original models used for WAP development did not include such forestry functional units. If the WAPs are amended, some consideration will need to be given to issues including how to account for forestry when determining resource capacity (both commercial and non-commercial forestry), and how to consider the effects of forestry when setting WAP policy.

The surface water resource capacity, or the average amount of water that is available, is calculated for both WAPs as the modelled long-term (1974 to 2006) mean annual runoff, adjusted to remove the impacts of dams, watercourse diversions, limited urban runoff and plantation forestry. The adjustment to remove the impacts of dams, watercourse diversions and urban runoff occurs through adjustments in the models. The effects of forestry are removed using a procedure applied after the modelling process as described in Alcorn (2010), and Savadamuthu and Teoh (2010).

The modelled adjusted flow described above is the same as the 'No development' scenario used as the comparison for calculating the EWR metrics. For this investigation, it was not considered practical to remove the effects of forestry from the Onkaparinga model, but including large forestry areas in the modelled data would distort the outcome. That is, the 'No development' flow data would be less than would be expected (and less than the WAP values) because some of the runoff would be intercepted by forestry. This issue was dealt with for the investigation by choosing zones with minimal forestry areas. However, this approach cannot be taken for WAP amendment purposes, as this work will need to consider the entire area.

Therefore, it is recommended that consideration be given to how to account for the effects of forestry on flow, if 'No development' flow or similar is needed as part of WAP amendment investigations or policy development. This may need to include consideration of whether separate treatment is required for commercial forestry, as defined in the *Landscapes South Australia Act 2019*.

In the current MLR WAPs, water interception by commercial forestry is included as part of the total water demand that is counted against the take limits. Water interception by other forestry is not considered. The forest functional units in the latest WMLR surface water models may include both commercial and non-commercial forestry areas (for example native forest in conservation areas), so some thought may need to be given on how both cases are dealt with.

Including forest functional units in the models also provides an opportunity to better test the effects of forestry on environmental water provisions. The work to set the take and interception/diversion limits for the 2013 WAPs was based on assessing the effects of dams and watercourse diversions on the flow regime. This work did not directly assess the effects of forestry on the flow regime. Instead, the WAPs assumed that a given volume of water demand or interception would have the same effect on the flow regime regardless of whether it was a dam, watercourse diversion or patch of commercial forestry. However, it is likely that the effects are different given the different physical processes involved in water interception for the 3 types of water demand. Including forest areas in the model that realistically reflect their effect on the flow regime can allow testing of their effects on environmental water provisions, and hence potentially development of more tailored WAP policy settings.

6.2.7 Dataset to support further investigations

This investigation has created a large dataset of flow data and metric results from a range of scenarios that can be explored further as part of WAP review and amendment. This could include further investigation into variation of metric response in different locations, in conjunction with analysis of changes in climate and overall flow pattern for those locations, as a mechanism for identifying parts of the flow regime that may benefit from adjustment of WAP policy.

7 Appendix A – methodology and results

This appendix includes more detailed information on some aspects of the investigation's methodology and results.

7.1 Calculation of the 'full development' configuration of the modelled 'water resource development' parameter

This section documents the process used to calculate the 'full development' configuration of the modelled 'water resource development' parameter, briefly described in section 4.2.

The 'full development' configuration for the water resource development parameter includes adjusting dam capacity and demand from dams and watercourse diversions to be at or within their WAP limits for dam capacity and demand, at the zone and catchment scale. A rules-based approach was used to calculate the full development configuration for the modelled zones, to ensure a consistent and transparent approach.

The full development configuration was calculated based on meeting the take limits and interception/diversion limits that make up part of the key WAP rules underpinning the flow objective, as outlined in section 3.2. The key WAP rules relating to passing low flows is implemented through the 'LFR scope sites' configuration of the 'low flow release' modelling parameter.

'Demand' for surface water and watercourses is calculated in accordance with the relevant WAPs (EMLR WAP principle 34, and WMLR WAP principle 30 plus agreed interpretation). This demand volume is calculated as allocation volume (calculated for this exercise as watercourse allocation, or licensed dam capacity x demand factor) plus non-licensed dam capacity x 0.3. For the EMLR, this also includes assumed evaporation from dams, calculated as dam capacity x evaporation factor for the zone, in accordance with the EMLR WAP (principle 34 b).

Both WAPs include the volume of surface water intercepted by commercial forests as part of demand, but this has not been accounted for in this investigation as the commercial forestry area is minimal in all the modelled zones and is not included in the Bremer and Carrickalinga models. The Onkaparinga models include the effects of forested areas, but the effects have been minimised for this project as the modelled zones have minimal forested areas, and the effects of forestry are included in all modelled scenarios, including the 'No development' scenarios.

A simple approach was taken for calculating the full development options:

- No new dams or watercourse diversions were added to the model, to simplify model updates, and to keep the same number of LFR scope sites in the model to support comparison to results from other modelling projects (such as work to support LFR implementation projects).
- Only the 'take' limits[8] (at zone and catchment scale) and 'dam capacity' limits[9] (at zone scale) were considered, as these are the key WAP rules that underpin the flow objective (together with passing low flows). The WAPs include other rules to manage how much water may be taken for an individual source (for example minimising

[8] The 'take' limit is the annual limit on the volume of surface water and watercourse water that can be taken from a defined area such as a zone. In the EMLR WAP, this is the 'evaporation and consumptive use limit' (as per EMLR WAP principle 36-42), and in the WMLR WAP this is the 'extraction limit' (as per WMLR WAP principles 32-35).

[9] Both WAPs include a limit on the total volume of dam capacity plus interception by commercial forestry that is allowed per zone. In the EMLR WAP, this is the 'interception limit', and in the WMLR WAP, this is the 'diversion limit'. The effects of commercial forestry have been ignored for this project, as outlined elsewhere in this section.

impacts on downstream users and environmental assets etcetera) but calculating the requirements to fully assess all WAP principles for changes to over 2,900 dams and diversions in the model would not be practical.

- The WAPs include headwater zones, which don't receive inflow from other zones; and receiving zones, which do receive inflow from other zones. Both types of zones have a local scale take limit that applies to sources that take runoff generated *within* the zone and excludes sources that take water from a main watercourse that receives water from another zone. Receiving zones also have a cumulative take limit that applies to all sources that take runoff generated across the entire catchment area of the zone (that is all sources in the zone in question and all upstream zones) – referred to as the main watercourse limit in both WAPs. Both the local-scale and cumulative take limits were considered when calculating the full development options.
- 'Demand', or the volume taken from dams and watercourses, was only adjusted for watercourse diversions and licensed irrigation dams. The volume taken from dams for stock and domestic use (including from licensed stock and domestic dams of 5 ML or more in the WMLR) is not measured or regulated, and the assumed use of 30% of dam capacity for stock and domestic dams is a long-standing assumption for MLR modelling, based on investigations of dam use (McMurray 2004).

Three different options of fully developed rule sets were used, with variations on which dams had their capacity adjusted, as outlined below – options A, B and C.

All options followed the same basic approach outlined in the steps below, with specific variations for options A, B and C noted within individual steps.

1. Adjust dam capacity to be within the zone's limit for dam capacity (interception limit for EMLR, diversion limit for WMLR), as follows:
    a. If total dam capacity in the zone is over its dam capacity limit, then reduce the capacity of relevant dams proportionally so that total dam capacity meets the dam capacity limit.
    b. If total dam capacity in the zone is under its dam capacity limit, but the catchment is already fully/over developed (that is catchment-scale demand exceeds catchment limit), then do not adjust dam capacity.
    c. If total dam capacity in the zone is under its dam capacity limit, but the catchment is not fully developed, then increase the capacity of relevant dams proportionally so that total dam capacity meets the dam capacity limit, or until assumed demand from the adjusted dam capacity equals the zone or catchment limit, whichever occurs first.

    Steps 1a. to 1c. were implemented differently between options A, B and C as follows:

    - For option A, only the capacity of scope dams was adjusted (all licensed dams, and non-licensed dams with a capacity of 5 ML or more). For options B and C, the capacity of all dams was adjusted. As option A reduces the capacity of scope dams only, a minimum allowable adjustment was included (down to 25% of original capacity). This minimum was primarily included to account for zones where the non-scope dam capacity exceeds the dam capacity limit – in these zones, if all the scope dams were reduced to zero, then total dam capacity would still exceed the limit, so a minimum value for scope dams was required to reduce excessive selective reduction of scope dams relative to non-scope dams.
    - In addition, for options A and C, dam capacity adjustment was restricted in order to ensure that the number of scope dams did not change. That is, non-licensed scope dams were reduced to a minimum of 5 ML, and non-scope dams were increased to a maximum of 4.9 ML. The capacities of other dams in the zone were further adjusted where necessary, to bring total dam capacity to the

dam capacity limit. This extra rule was not applied to option B, so new scope dams could be created (if stock and domestic dams were increased from below to above 5 ML) or removed (if stock and domestic dams were reduced to below 5 ML).

2. Once dam capacity has been adjusted, then adjust watercourse allocations and the demand factor from licensed dams so that total demand in the zone is within the take limit for that zone, and for any downstream zones (including whole-catchment scale), as follows:

   a. When adjusting the demand factor of licensed dams, the demand factor was reduced to a minimum of 0.3 (assumed stock and domestic use) and increased to a maximum of 0.65. The upper limit on the demand factor was included to avoid assigning excessively large allocations to dams that would rarely be able to be accessed, once evaporation is considered.

   b. In some cases, stock, and domestic scope dams (over 5 ML capacity) were 'converted' to licensed irrigation dams as part of the full development process, and therefore could have their demand factor increased above 0.3. This was done to allow total zone demand to be increased enough to reach the zone's take limit.

   c. The local scale take limit was considered first:

      – If total demand relating to the local-scale limit exceeds that zone's local-scale take limit, then reduce relevant watercourse allocations and the demand factor from relevant licensed dams proportionally so that the total demand volume meets the zone's take limit. 'Relevant' licensed watercourse diversions and dams are those that do not take water from a main watercourse.

      – If total demand relating to the local-scale limit is less than that zone's local-scale take limit, and there are no zones downstream where total cumulative demand exceeds the zone's cumulative take limit, then increase relevant watercourse allocations and the demand factor from relevant licensed dams proportionally so that the total demand volume meets the zone's take limit.

7.2 Calculation of the cumulative take limit

The cumulative take limit was considered once zones had been adjusted for the local-scale take limit as above. This process started from the most upstream receiving zones in the catchment and worked downstream to the end of the catchment.

If total cumulative demand for a receiving zone (that is demand in the zone in question, and in all upstream zones) exceeds the cumulative main watercourse limit for the zone, then reduce watercourse allocations and demand factor for licensed dams proportionally for those sources within the receiving zone, so that the total demand volume meets the zone's cumulative take limit.

In some cases, it was not possible to reduce demand within the zone in question sufficiently to be able to reduce cumulative demand to be within the cumulative limit (for example no or insufficient licensed demand in the zone in question, or because of application of the minimum dam demand factor of 0.3 in the zone in question). In this case, demand would be reduced in upstream zones as well, using the same approach (that is reduce watercourse allocations and demand factor for licensed dams proportionally, for those sources within the zone in question and those upstream of it).

If total cumulative demand for a receiving zone (as above) is less than the cumulative main watercourse limit for the zone, then increase watercourse allocations and demand factor for licensed dams proportionally for those sources within the receiving zone so that the total demand volume meets the zone's cumulative take limit. The upstream zones will already have had their demand adjusted up to their own zone's limits in previous steps, so do not need to be adjusted further.

Some of the key outcomes from application of the full development approach are given below:

- Dam capacity and licensed demand for the Carrickalinga Creek zone were increased for the full development process.
- The Echunga Creek and Mitchell Creek sub-catchments in the Onkaparinga catchment were treated as if each sub-catchment was the entire catchment. That is, the demand and limits for downstream zones that were not included in the modelling were not considered. The outcome is that dam capacity and demand in these zones was increased for 6 of the 7 zones, but not for O_EC04 (where dam capacity and local-scale demand exceeded the zone's limits).
- Total demand in the modelled Bremer catchment exceeded the catchment-scale limit. Therefore, no new dam capacity was added to any zones, and demand was reduced in many zones. There are some zones that are still over-allocated for Scenario 5, after the 'full development' process above was applied. For example:
  - Option A for the Bremer ends up with some zones that are still over-allocated, as for some zones, the total capacity of non-scope dams exceeds the dam capacity limit – but these dams are not reduced under the rules of option A.
  - The minimum demand factor of 0.3 (assumed stock and domestic use) that is applied when reducing demand meant that, for some zones, demand from the already reduced dam capacity in the zone was still over the zone's take limit.

The analysis for this investigation used full development option B for the Onkaparinga zones, and full development option C for the Bremer and Carrickalinga zones. This approach was taken because:

- Full development option A only adjusts the size of scope dams, which can significantly skew the original distribution of dam capacities in a zone (for example all the licensed dams and large stock and domestic dams get reduced, but the stock and domestic dams under 5 ML do not get reduced – so the zone originally had a spread of large and small dams but ends up with only small dams). This change to the distribution of dam capacities is likely to affect the way that water is captured, and hence the EWR metric results, compared to the other scenarios.
- Full development options B and C avoid the problem above by adjusting the size of all dams proportionally, and so were considered to be a lower approach.
- Full development option C retains the same number of scope dams, and so the results are likely to be more comparable with other modelling projects such as strategic location modelling done for LFR implementation projects. So, this option was used for the analysis where possible.
- Full development option C was not calculated for the Onkaparinga catchment, and so full development option B is used for the analysis instead. The differences between full development options B and C are small for the Onkaparinga zones, as they are generally small with few dams, with only a few cases where a dam changes status from scope to non-scope, or vice versa occur.

7.3 Notes on unexpected metric results

This section briefly describes some of the unexpected metric results found for 2 zones where full implementation increased the risk for a zone (that is failed more metrics), without demand increasing. In most cases, examination of the results showed that the unexpected result was likely to be a calculation artefact, often caused by very small flows and a high proportion of zero flows.

Zone BR044

This is a small headwater zone ion a southern tributary of Mt Barker Creek in the Bremer catchment. This zone is quite dry – the mean annual adjusted runoff depth is 24 mm (compared to 87mm for the zone containing Mt Barker).

For the full implementation scenario, low flows are passed at 6 sites (none for current implementation scenario); and water demand and dam capacity are reduced (for example demand from 114% to 100% of take limit for the zone).

This zone fails one more metric for the full implementation scenario compared to the current implementation scenario, which is unexpected given more sites pass low flows for the full implementation scenario.

Examination of the metric data shows that 2 extra metrics fail, and one extra metric passes, for the full implementation scenario (that is net effect is one extra metric failing).

High flow season freshes

One of the extra metrics that fails is the average number of fresh spells in the High flow season (HFS), which decreases from 5.2 freshes/year for the current implementation scenario to 4.6 freshes/year for the full implementation scenario. When considered in isolation, this seems like a negative environmental impact. However, the average duration of freshes for this season increases at the same time, with the net result that the total duration of HFS freshes stays about the same. That is, for the full implementation scenario, longer freshes occur less often, but the total duration across all fresh events is about the same as for the current implementation scenario.

This effect is likely to occur as a result of low flows being passed for the full implementation scenario. The presence of dams has probably disrupted fresh events in the HFS and may have split longer fresh events into several shorter ones – increasing the frequency but reducing the duration of individual fresh events, which would likely have an overall effect of increasing risk to environmental objectives. Passing low flows may restore sufficient flow to join some of these shortened events back together again, decreasing the frequency but increasing the duration of individual fresh events, for a net environmental benefit. However, in this case, the decreasing frequency of freshes causes that metric to fail, but the corresponding increase in duration of individual events is not assessed, and the total duration of freshes (which is assessed) does not change. So, it registers as an increase in risk to environmental objectives when it actually is not.

A similar situation can occur with the zero-flow metrics, when multiple short zero flow events, split up by flow events in the No development scenario, may become one very long zero flow event under water resource development when the flow events get intercepted/removed by dams and watercourse diversions. So, the frequency of individual zero flow events decrease. This looks better when considered in isolation (that is decreased risk); but the duration of individual zero flow events increase, which is worse (increased level of risk to environmental objectives).

This effect is a known issue with the EWR metric calculations. It is most likely to occur in response to water management rules that return water (for example passing low flows or reducing demand or dam capacity), so if this unexpected outcome is not detected, it would underestimate the benefit of implementing that rule.

This effect could be reduced by only assessing the metric for total duration of freshes in a season, which probably provides the most information of the available metrics. It may be useful to still calculate the frequency and duration of individual events for information, without using that data to determine change in risk to environmental objectives. For example, one fresh event of 10 days is likely to have different ecological effects compared to 10 freshes of one day each, but both have the same total duration.

T2 season low flows

The other extra metric that fails is the low flow metric for the T2 flow season. This metric is the daily flow rate that represents low flow for the season. It is calculated as the 80th percentile non-zero flow rate for the season, that is, for all of the days that there is flow in a flow season, 80% of those days have a flow rate that is higher than the low flow rate, and 20% of those days have a daily flow rate that is lower.

The T2 low flow rate for the No development scenario is 0.05 ML/day, and the value for the full implementation scenario is 0.03 ML/day, which is enough of a decrease to cause that metric to fail. The T2 low flow rate for the current implementation scenario is 0.09 ML/day. This is higher than for the No development period, which is unexpected, as the presence of dams and watercourse diversions would be expected to reduce the low flow rate rather than increase it. The metric calculations deal with this type of unexpected result by assigning that metric as passing, which in general is a reasonable outcome (that is having a higher low flow rate is generally better).

However, in this case, it is likely that the low flow rate for the current implementation period is artificially inflated as a result of the high proportion of zero flow days for this season and scenario.

The T2 flow season is 30 days long (November). For the No development scenario, the T2 average total duration of zero flows is 7.5 days. For the current implementation scenario, this increases to 22.9 days, which is most of the flow season. That is, many of the low flow days are removed, and become zero flow days instead. The flow rate on the remaining days is likely to be higher, as the smaller events get intercepted by dams, which means the data available to calculate the low flow rate consists of higher flow values. So, the calculated low flow rate increases, when in reality low flows are at higher risk because they occur less often.

When low flows are passed for the full implementation scenario, the average duration of zero flows decreases to 17.4 days – that is, new low flow days are created. The flow rates for the days that there is flow are more skewed towards lower values, compared to the current implementation scenario, and so the calculated low flow rate is lower. But in reality, the risk to environmental objectives is less, because low flow occurs more often.

This effect is also a known issue with the EWR metrics. It tends to occur in very dry zones with a naturally high proportion of zero flows. It is most likely to occur in response to water management rules that return water (for example passing low flows or reducing demand or dam capacity), so if this unexpected outcome is not detected, it would underestimate the benefit of implementing that rule.

There are a range of calculation issues around very small values and small datasets. The approach for calculating the metrics includes some processes that reduce these effects in many cases (as outlined in VanLaarhoven and van der Wielen 2009), but they do not work in all cases. These issues are inherent to small numbers and small datasets, and it is unlikely that they can be avoided in all cases. It is useful to be cautious in interpreting metric results for very dry zones, and to manually assess the outcomes where practical to determine if calculated changes to metrics are likely to cause changes to risk on-ground. The two cases outlined for this zone generally occur in response to management actions that improve flow, and result in extra metrics failing; that is, they underestimate the benefit of the management action.

Zone BR059

This is a small zone in the headwaters of Red Creek in the Bremer catchment. This zone is very dry – the mean annual adjusted runoff depth is 12 mm (compared to 87mm for the zone containing Mt Barker).

For the full implementation scenario, low flows are not passed at any sites, as there are no scope sites in this zone; and water demand and dam capacity are significantly reduced (demand is reduced from 163% to 100% of take limit for the zone).

This zone fails 2 more metrics for the full implementation scenario compared to the current implementation scenario, which is unexpected given more sites pass low flows for the full implementation scenario.

T1 zero flow duration

One of the extra metrics that fails for the full implementation scenario but not the current implementation scenario is the average duration of individual zero flow events in the T1 flow season. The average duration of a zero flow event is 13.2 days for the current implementation scenario and 13.3 days for the full implementation scenario. The difference between the values is very small but is right on the boundary of the acceptable target range for this metric, and so it passes for the current implementation scenario, and fails for the full implementation scenario. The average number of zero flow events for the season decreases slightly for the full implementation scenario without changing metric pass/fail status, with the net effect being that the total duration of zero flows for the season is slightly shorter (lower risk) for the full implementation scenario (50.7 days, instead of 51.1 days for the current implementation scenario).

In reality, the very minor increase in duration of individual zero flow events is unlikely to increase risk to environmental objectives, particularly given that the total duration of zero flow days for the season slightly decreases. This situation illustrates the occasional issue that arises with the metrics around very small changes occurring in the vicinity of the target or boundary. This occasionally occurring issue is difficult to completely avoid for any situation where a numerical target or limit is set.

High flow season, low flow metric

The other extra metric that fails for the full implementation scenario but not the current implementation scenario is the low flow metric for the High flow season. This low flow rate is 0.012 ML/day for the current implementation scenario decreases to 0.008 ML/day for the current implementation scenario. The comparison low flow rate for the No development scenario is 0.013 ML/day. The absolute difference between the values is very small for the full implementation scenario compared with the No development scenario, but the percentage difference is quite large (40%). Metric success is assessed based on the percentage change between the No development value and the value for the scenario of interest, and so the metric fails for the full implementation case. It seems unlikely that a change of this magnitude is likely to change risk to environmental objectives on average but is still indicative that the different scenarios are having different effects. This is another example of calculation issues when small values are involved and is difficult to avoid.

It is not certain why the low flow rate is decreasing in this case. It is unlikely to be the same effect outlined above for T2 season low flows for zone BR044. This reduction is occurring in the High flow season, which is much longer, and the proportion of zero flows does not change much between scenarios.

7.4 Ready reckoner of scenario terminology

Through the course of this investigation, different terminology has been used for different scenarios, and the modelling parameters and their configurations. Table 28 aims to summarise the different terms used for items over time, so that datasets can be matched up with each other and this report.

Table 25. Table showing various terminology used for scenarios during this investigation

Name in report for scenarios	Alternative names used during investigation
1 No development	**Scn1_No-Dams**
2 Pre-WAP	**Scn2_Asm-Use-NoLFR**
3 Current implementation	**Scn3_Asm-Use-LFR**
4 Current allocation	**Scn4_Alc-Use-NoLFR**
5 Full implementation	**Scn5_Alc-Use-LFR**
Full development options and associated full implementation scenarios	
Option A Scenario 5_A	1 5_1
Option B Scenario 5_B	2 5_2
Option C Scenario 5_C	4 5_4 Note that the third option that was originally considered was discarded, hence there was no Option 3 calculated. The options were renamed A-C for the report.

8 References

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