TECHNICAL REPORT

STRATEGIC APPROACH TO LOCATION OF LOW FLOW RELEASES IN THE MOUNT LOFTY RANGES

– FEASIBILITY STUDY

Government of South Australia
Department of Environment, Water and Natural Resources

STRATEGIC APPROACH TO LOCATION OF LOW FLOW RELEASES IN THE MOUNT LOFTY RANGES

– Feasibility Study

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Science, Monitoring and Knowledge Branch

Department of Environment, Water and Natural Resources

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FOREWORD

The Department of Environment, Water and Natural Resources (DEWNR) 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 provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEWNR's strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management 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.

Allan Holmes
CHIEF EXECUTIVE
DEPARTMENT OF ENVIRONMENT, WATER AND NATURAL RESOURCES

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EXECUTIVE SUMMARY

This report describes the methodology and results of the investigation undertaken to assess the feasibility of strategic placement of Low Flow Releases (LFRs) in the three[1] Prescribed Water Resources Areas (PWRAs) of the Mount Lofty Ranges (MLRs).

Water management in the project area is underpinned by extraction or use limits that rely on restoring suitable low flows in order to meet environmental water targets. Restoring suitable low flows helps to maximise provisions of water for consumptive use while maintaining water-dependent ecosystems at an acceptable level of risk, supporting businesses and communities that rely on the ecosystem services provided by a healthy environment.

One way to restore suitable low flows is via low flow releases (LFRs) at selected dams and watercourse diversions, where steps are taken to return or not capture low flows at or below the threshold flow rate. A primary aim of this project is to determine whether the environmental water targets underpinning the water allocation plans (WAPs) and existing user allocation processes in the project area can be achieved with LFRs at strategic points in the landscape, rather than at all 'scope' dams and watercourse diversions as assumed by the original work to determine the extraction or use limits.

The study was phased in two distinct units to investigate:

1. The strategic location of LFRs within surface water management zones (surface water zones) that could minimise the total number of locations required to restore low flows across the MLRs, whilst still meeting environmental targets.
2. The estimation of volumes of water that would be returned to the system after implementation of a potential LFR program.

Strategic Location

Ten surface water zones were selected across the three PWRAs for investigation of strategic placement options. These zones were chosen to represent a wide variety of landscape conditions, rainfall distribution, water resource development levels and geography.

A total of nine LFR placement options were investigated for each of the ten zones.

In addition to the three different "base" scenarios, six other scenarios were investigated to determine the feasibility of achieving a more strategic placement of LFRs while satisfying as near as possibly the environmental water targets. Comparison of scenarios in most areas of the study is with the "Base-WAP" scenario (Scenario 3). This scenario assumes that LFRs are implemented on a combination of all dams scoped in this study (scope dams)[2] .

Hydrological models of each test zone were built using the eWater Source IMS modelling platform and a purpose-built farm dam plug-in allowing the assessment of LFRs from individual farm dams in a catchment.

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[1] Three Prescribed Areas – (i) the Western Mount Lofty Ranges Prescribed Water Resources Area (WMLR PWRA), (ii) the Eastern Mount Lofty Ranges Prescribed Water Resources Area (EMLR PWRA) and (iii) the Marne Saunders Prescribed Water Resources Area (MS PWRA)

[2] 'scope dam ' a dam where low flows may be required to be returned. In the Marne Saunders PWRA, this includes licensed dams only. In the EMLR and WMLR PWRAs, this includes licensed dams, and also all other dams with a capacity of 5 ML or more (including stock and domestic dams). Note that stock and domestic dams with a capacity of 5 ML or more are licensed in the WMLR; and that such dams are not licensed in the EMLR but may be required to return low flows.

The daily and seasonal flow regime was assessed using the environmental water targets from the existing environmental water requirement (EWR) assessment method and results between each scenario compared.

Volumes Returned to the System

In addition, the total volumes for each scenario subsequent to Scenario 3 were compared to determine the likely total volume of water that could be returned to the system under each scenario.

KEY FINDINGS

Phase 1: Strategic Location

This project demonstrates that it is feasible to place LFRs strategically within a surface water zone, such that fewer LFRs are required to achieve a similar outcome in terms of the environmental water targets, when compared to the "Base-WAP" scenario. However, there can be more than one suitable (or near-suitable) location strategy for a given surface water zone, and a strategy suitable for one surface water zone is not necessarily suitable for others. This lack of a “stand-out” location strategy presents a significant challenge for any potential LFR implementation program.

For nine of the ten surface water zones examined in detail as part of this project, at least one of the six location strategies (or scenarios) trialled was able to approximately meet the environmental water targets while reducing the number of LFRs required (when compared to the “Base WAP” scenario). For most of these zones, there were also one or more location strategies that compromised the achievement of environmental water requirements targets. However, not only did the suitable (or near-suitable) location strategies differ between surface water zones, but a strategy which compromised existing environmental water targets for one zone, could be one of the more suitable strategies for another zone (and vice versa). This also presents a significant challenge for any potential LFR implementation program.

The maximum reduction in number of LFRs (whilst still approximately maintaining achievement of existing environmental water targets) ranges from 6% in the zone with the minimum possible reduction, to 52% in the zone with the maximum possible reduction in LFR numbers. As such, if a strategic location approach is adopted as part of an implementation program to return low flows, careful consideration should be given to ensure the program takes an approach that minimises the chances of adopting a strategy that compromises existing environmental water targets, while maintaining the opportunity to realise a reduction in LFRs that is as high as possible.

Phase 2: Calculation of returned flows

Calculation of possible return flows was carried out for each management zone using a regression derived from the 10 test zones. As difference in the percentage of flow returned between scenarios was minimal, a single regression relationship was derived and applied across the three PWRAs.

The total possible volumes of returned mean annual flow (1974 - 2006) for the Marne Saunders (MS), EMLR and WMLR were; 160, 650 and 1510 ML respectively. This represents approximately 1.6% of natural[3] flows for the Marne Saunders which was higher than that recovered for the EMLR (0.6%) and the WMLR (0.4%). This difference was found to be due to a more uniform distribution of highly developed surface water zones in the MS PWRA.

Although the volume of flows returned to the system may appear small, it is important to note that the benefits of LFRs are not just related to a notion of 'volume of water saved for the environment'. Rather, the primary benefit of restoring suitable low flows is to help provide water to the environment at the right times in the right amounts. Returning natural low flows that are otherwise intercepted by dams and diversions supports critical ecological functions, such as maintaining key aquatic refuge habitats in streams during the drier seasons. It is also important to get flows back into the system sooner at the break of season, giving water-dependent plants and animals the right length and pattern of flow to go through their life cycles, and to provide access to different habitats needed for feeding, breeding and shelter.

Applicability and limitations

The ten surface water zones used in this study were selected to represent a wide variety of landscape conditions, rainfall distribution, water resource development levels and geography across the MLR. However, they represent only a small sample of the 584 surface water zones in the highly hydrologically variable MLR study area. Hence, the quantitative elements of the results presented can be considered only as indicative estimates for the entire MLR. Further investigation would be required to extend the methodology presented in this report to other surface water zones. Also, the results presented in this report need to be used with caution when considered in isolation, as the likely impacts on the EWRs of downstream surface water zones needs further investigation.

While there are limitations, as discussed in the previous paragraph, in application of the results of this report across the MLR, the analysis and the modelling methodology used in this investigation align with current best practise modelling guidelines (Black et al., 2011), and hence considered scientifically robust and appropriate for this investigation, and importantly, for further investigations if required.

[3] Natural flows – Modelled flows with the impacts of farm dams and forestry removed.

1.INTRODUCTION

1.1. BACKGROUND

The provision of suitable low flows,, in conjunction with optimising the use of water for consumptive use purposes, is fundamentally important in maintaining healthy water dependent ecosystems in the Mount Lofty Ranges (MLRs).

Water management in the project area is underpinned by extraction or use limits that rely on securing suitable low flows in order to meet environmental water targets. Securing suitable low flows helps to maximise provisions of water for consumptive use while maintaining water-dependent ecosystems at an acceptable level of risk, supporting businesses and communities that rely on the ecosystem services provided by a healthy environment.

One way to secure suitable low flows is via low flow releases (LFRs) at selected dams and watercourse diversions, where steps are taken to return or not capture low flows at or below the threshold flow rate. A primary aim of this project is to determine whether the environmental water targets underpinning the water allocation plans (WAPs) and existing user allocation processes in the project area can be achieved with LFRs at strategic points in the landscape, rather than at all 'scope' dams and watercourse diversions as assumed by the original work to determine the extraction or use limits.

There are three prescribed areas within the project area:

- Marne Saunders (MS) Prescribed Water Resources Area
- Eastern Mount Lofty Ranges (EMLR) Prescribed Water Resources Area
- Western Mount Lofty Ranges (WMLR) Prescribed Water Resources Area.

The Prescribed Water Resource Areas (PWRAs) for the MS and the EMLR both lie within the Murray-Darling Basin (MDB), and therefore have a direct connection to the policy framework applied at a Basin-scale, including the Basin Plan under the Commonwealth Water Act, 2007.

The WMLR PWRA, while not within the MDB, is dominated by the catchments of Adelaide's reservoirs, which are operated by SA Water. SA Water also operates the pumping mains which link Adelaide's reservoirs to the River Murray, so that MDB water can be used when there is a short-fall of runoff from the WMLR catchments. As such, the sustainability of supply to reservoirs from the WMLR catchments is directly related to how much water needs to be extracted from the MDB for Adelaide's needs.

1.2. OBJECTIVES

This project, "*Strategic approach to location of Low Flow Releases in The Mount Lofty Ranges – Feasibility Study*", forms part of a broader initiative that seeks to restore low flows in the MLRs, and has the following aims:

1. Assessment of the feasibility of different scenarios for the optimisation of LFR placement, in terms of the total number of releases required (Cost) and the environmental targets likely to be met by these scenarios (Benefit).
2. Estimation of the likely volumes of water that are to be returned to the system(s) through the implementation of the most preferable scenario(s).

1.3. PROJECT AREA

This project covers the geographical region described by the Marne Saunders PWRA, the WMLR PWRA and the EMLR PWRA (Figure 1).

The Marne Saunders PWRA is part of the South Australian Murray-Darling Basin and covers an area of 743 km^2. It lies in the EMLR approximately 70 km north east of Adelaide and includes the townships of Springton, Eden Valley, Keyneton and Cambrai. The surface water, watercourse water and wells within the Marne Saunders PWRA were prescribed on 20 March 2003.

The WMLR PWRA cover a total area of approximately 2750 km^2 from Gawler in the north, to Middleton, and across to Cape Jervis on the south coast.

The EMLR PWRA, which includes the Angas Bremer Prescribed Wells Area, is located approximately 50 km to the east of Adelaide and occupies an area of 2845 km^2. The area incorporates the eastern slopes of the Mount Lofty Ranges and the Murray Plains and lies within the Murray-Darling Basin. The EMLR PWRA extends from the Milendella Creek catchment in the north to Currency Creek catchment in the south and contains sixteen surface water catchments. Eleven of the catchments have watercourses that drain from the eastern side of the Mount Lofty Ranges to the River Murray and Lake Alexandrina, with the Bremer, Angas and Finniss Rivers being some of the larger watercourses.

1.4. MOUNT LOFTY RANGES PRESCRIPTION AND LOW FLOW RELEASES

All three areas described in this report are areas where surface and groundwater resources are prescribed, with Water Allocation Plans (WAP) being required to be written, which in broad terms provides for the water needs of the environment and other consumptive requirements.

The Marne Saunders WAP has been in place since 2010, while the EMLR and WMLR WAPs were adopted in 2013.

1.4.1. ECOLOGICALLY SUSTAINABLE LIMITS

The definition of extraction and use limits in the WAPs and existing user processes includes the returning of flows at or below the threshold flow rate around or from existing and new licensed dams and watercourse diversions and non-licensed dams of 5 ML capacity or more in the Eastern and Western Mt Lofty Ranges PWRAs, and around existing and new licensed dams and watercourse diversions in the Marne Saunders PWRA. These dams are referred to as ‘scope dams’ in this report, as they are in-scope for returning low flows.

Securing suitable low flows helps to provide water to the environment at the right times and in the right amounts. Returning natural low flows that are otherwise intercepted by dams and diversions supports critical ecological functions, such as maintaining key aquatic refuge habitats in streams during the drier seasons. It is also important to get flows back into the system sooner at the break of season, giving water-dependent plants and animals the right length and pattern of flow to go through their life cycles, and to provide access to different habitats needed for feeding, breeding and shelter.

Returning low flows in this way is expected to “provide sufficient flow and a flow regime that provides an acceptable level of risk to the water-dependent ecosystems” according to the EMLR WAP (SAMDB NRM Board, 2013). The benefits of returning low flows are also described as “reducing impacts on the measurable indicators and therefore allows a larger percentage of the surface water resource capacity to be allocated, while maintaining an acceptable level of risk to the water-dependent ecosystems”(AMLRNRMB, 2013 All three WAPs, through a detailed assessment of Environmental Water Requirements (EWRs), identified the critical need for low flows to pass through the system and that this part of the flow regime is currently the most impacted, particularly in the early flow seasons from around May-July and also during the summer low flow season.

The EWRs for the Marne Saunders are described in (MREFTP, 2003) and Doeg and van der Wielen (2007), while for the EMLR and WMLR, they are described by Vanlaarhoven and van Der Wielen (2009).

The current estimate of dams that would require some system to release low flows over the three prescribed areas is approximately 2500. Whilst extensive modelling of varying water usage rates from dams was explored during the determination of sustainable extraction and use rates for the prescription process, only a single scenario was investigated for placement of Low Flow releases. This study will investigate other strategic placement options that may achieve the same or similar environmental targets.

1.4.2. LOW FLOW RELEASE RATES

Low flow release rates (termed as ‘threshold flow rates’ in the WAPs) are the minimum flow rate that must be returned or allowed to pass by a diversion or dam before capture or extraction or diversion may occur.

For the Marne Saunders PWRA, the defined low-flow release rates are varied based on climate zones within the area, and are generally derived from the daily flow statistic of 10^{th} Percentile Time Exceeded. These unit threshold flow rates are generally between 1 and 2 L/sec/km^2.

For the EMLR and WMLR the defined low flow release rates are defined as the 20^{th} percentile exceedence daily flows for the flowing period (i.e. non zero flow period). In practice this is calculated using a relationship between watershed average rainfall and calculated statistic values for various stream flow gauges through the Mount Lofty Ranges. These rates are generally between 1 and 4 L/sec/km^2.

1.5. BEST-PRACTICE PROJECT

Some of the key features of this project, which have demonstrated its adherence to current best-practise, include:

- Aligning the project methodology and modelling platform with current National best-practice, as detailed in the ‘Guidelines for Water Management Modelling’ (Black et al., 2011).
- External peer review of the project methodology prior to commencement of project roll-out.
- Completion of an uncertainty and parameter sensitivity analysis, which incorporated a Principal Component Analysis and a Monte Carlo Analysis.
- External peer review of this report.
- Engagement throughout the project with the likely end-users of the project findings.

1.6. PROJECT GOVERNANCE

This project is one of a suite of matters being progressed by a steering committee focussing on “Restoring low flows in the MLRs”. A technical reference group reports to this committee on the scientific and technical detail relating to this project.

INTRODUCTION

For the delivery of the project summarised by this report, a project working group was established (by the aforementioned technical reference group), which included representatives from the relevant NRM Regions (Adelaide Mount Lofty Ranges and South Australian Murray-Darling Basin).

The groups mentioned above have been engaged at key junctures during commencement and completion of this project.

Figure 1. Location map: WMLR, EMLR and MS PWRAs

2. METHODOLOGY

The overall methodology adopted for this project is described in Figure 2 below, followed by a detailed description of each phase.

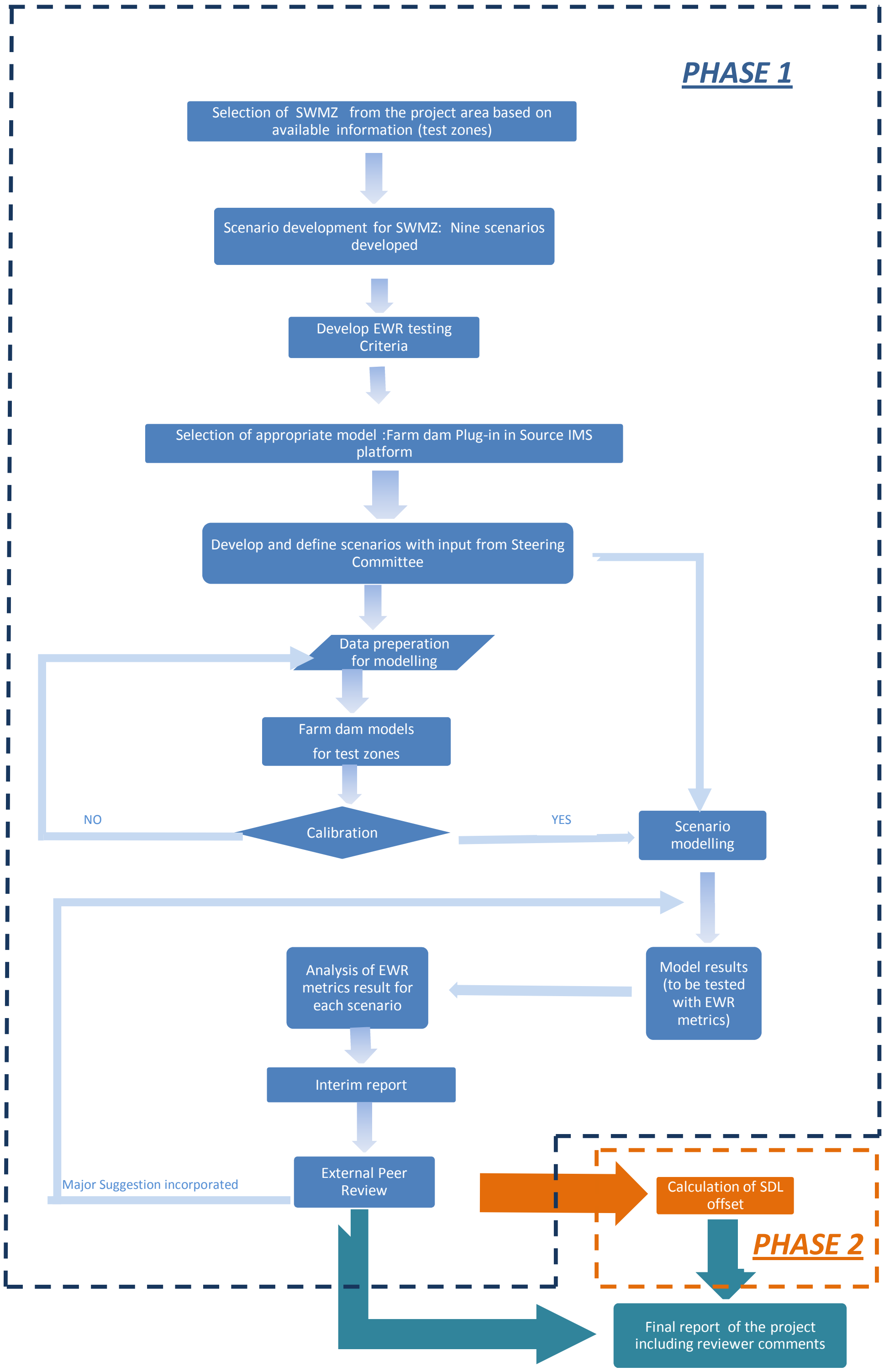


Figure 2. Flowchart showing project methodology

2.1. PHASE 1

The objective of Phase 1 is to explore various options for the strategic placement of LFRs within the surface water zones, i.e. to explore options for the least number of LFRs, while aiming to achieve the environmental targets that underpin the determination of extraction/use limits used in the existing user allocation process and the WAPs. These processes have largely limited the intention to include Stock and Domestic Dams smaller than 5 ML as part of the potential program to return low flows, and as such these dams have not been considered here.

The Phase 1 method included an initial stage of visual and numerical data exploration, with the aim of yielding a set of placement strategies (scenarios) for further consideration by the steering committee. This was followed by analysis of the hydrological outcomes of the different scenarios, with interpretation of environmental implications of different flow regimes. It was not intended, within the current project timelines, to undertake on-site or localised assessments, or consider social and economic factors (i.e. economic factors beyond the costs saved by reducing the number of LFR's required).

The main steps involved in Phase 1 were (Figure 3):

1. **Zone Selection and Exploration:** Selection of 10 surface water management zones ('test zones') for testing and exploration of optimisation scenarios.
2. **Scenario Definition:** Assessment of the feasibility of different scenarios for the optimisation of LFRs, in terms of the total number of releases required and the environmental benefit likely to be gained by these options.
3. **EWR Testing Criteria:** Determine the methods and metrics that will be used to assess the relative success or otherwise of each of the scenario options.
4. **Model Selection:** Selection of a method for hydrological representation of the zones that is consistent with work previously completed during the Water Allocation Planning process
5. **Model Build and Run**: Build each of the 10 test zones into the selected model platform (eWater Source), code in the various scenario options and run.
6. **Analyse the results:** Evaluating the EWR Testing Criteria (metrics) and estimating the total flow returned to the system; assessment of parameter sensitivity and areas of model uncertainty.
7. **Compare** the results of the different scenarios with the base scenario in regards to the number of LFRs required.

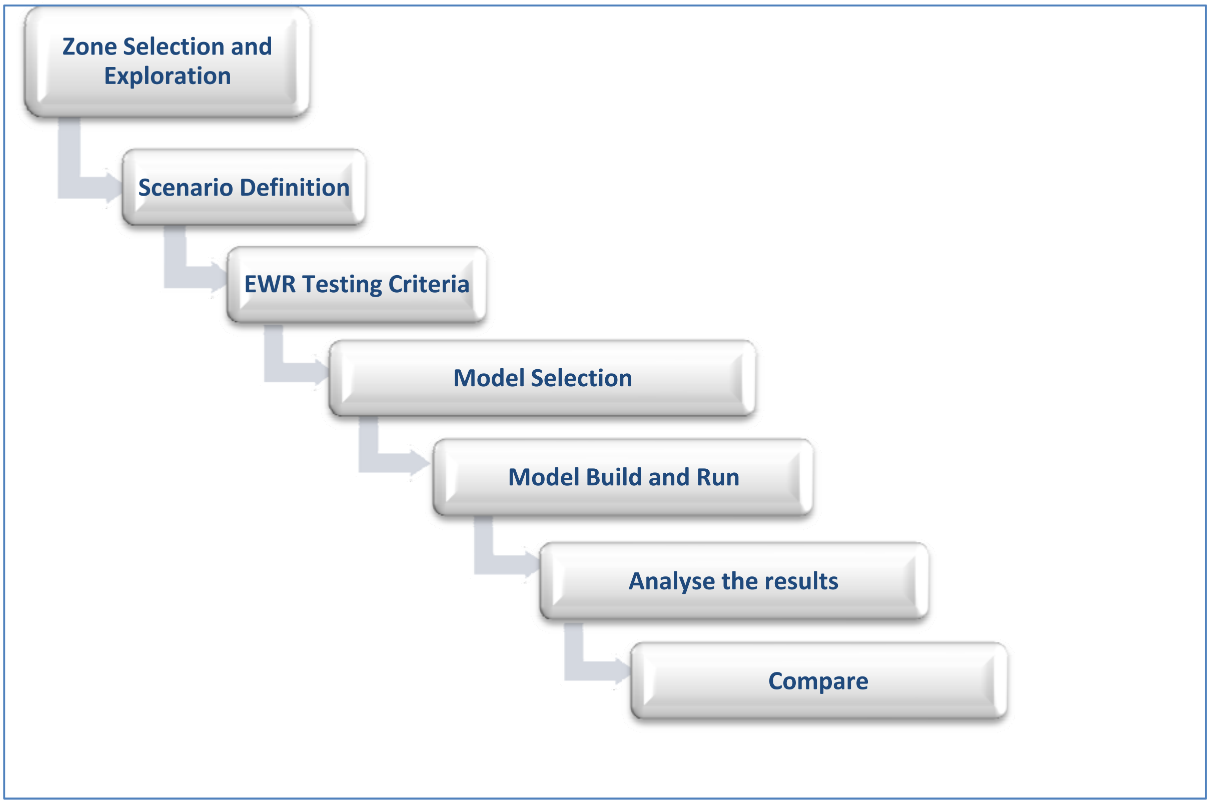


Figure 3. Process for Phase 1

2.1.1. ZONE SELECTION AND EXPLORATION

There are 584 zones in the study area (Figure 1) and the level and pattern of farm dam development varies widely across the area. A detailed analysis of the entire region was considered outside the scope of this project. However, it was considered a requirement that the zones selected for scenario modelling represent a wide range of zones within the region. Given the duration of the project and the time required to model different scenarios for each zone, the project working group decided to select a maximum of ten zones as 'test zones' using the following criteria:

- **Location** - The test zones are to be representative of the entire region that includes the WMLR PWRA, the EMLR PWRA, the Fleurieu region (also within the WMLR PWRA) and the Marne Saunders PWRA, and in particular the highly developed catchments therein.
- **Development level** - Headwater zones to be selected as test zones due to their higher level of development (farm dam density) in comparison to receiving zones. While headwater zones with higher development level were considered as the highest priority for LFR implementation, zones with lower level of development were also included as test zones, to represent the variable level of development across the region.
- **Impact visibility /sensitivity -** From a modelling perspective, it was considered more appropriate to select headwater zones for testing, as the impact of different LFR scenarios on different sections of the flow regime would be more visible in these areas in comparison to modelling receiving zones, where the results would potentially be 'masked' by the cumulative effect of flows from its contributing headwater zones.

- **Development distribution –** In addition to the 'development level' criteria discussed earlier, the variable pattern of the distribution of licensable and non-licensable dams within zones were also considered during the selection process. While no definite patterns were identified, it was decided to investigate the distributions for the higher proportion of large dams in comparison to smaller dams, presence of a majority of the larger dams on lower streams, uniform distribution of dams across the zone and the vice versa of those patterns.
- **Data confidence –** Preference was given to headwater zones that were either within a gauged sub-catchment (or in the vicinity of the flow monitoring site) or with a hydrological model available for the zone.

Maps of the ten testing zones were sent out to members of the technical working group with the aim of allowing input from various stakeholders. The ten test zones selected for this investigation and the criteria used for their selection are presented and further discussed in Section 3.1.1.

2.1.2. SCENARIO DEFINITIONS

With the aim of an optimised and strategic placement of LFRs, the scenarios that were explored considered how the number of low-flow releases required could be effectively reduced while at the same time still achieving acceptable levels of risk. In addition, it was considered essential that the process to define this optimisation be transparent and repeatable, and where possible be a rules-based approach.

After discussion with the project working group at a workshop, the following scenarios were agreed upon for further analysis (Table 1):

Table 1. Scenario description

Number	Title	Description
Scenario 1	No dams	Flows derived from modelling with the effect of farm dams removed. This gives the nil disturbance flow dataset from which to compare the various scenarios below.
Scenario 2	Current (no LFR)	Flows with the impacts of farm dams modelled.
Scenario 3	Base (or "Base WAP")	Flows with the impacts of farm dams modelled, and low flow releases applied to all scope dams. This scenario represents the currently proposed WAP policies.
Scenario 4	≥ 10 ML	All dams 10 ML (Including S&D) or above releasing low flows
Scenario 5	≥ 10 ML + blocking	10 ML or above + scope dams on third order streams or in a major blocking location. This extra condition would ensure that where a scope dam was in a position to block released flows from 10ML dams higher in the catchment, these flows would be also be released.
Scenario 6a	Base - 1st order	In addition to LFRs applied to scope dams, this scenario investigates the exclusion of required LFRs on 1st order streams on the larger scale flow regime.
Scenario 6b	Base - < 10 ha	In addition to LFRs to scope dams, this scenario investigates the exclusion of required LFRs on headwater dams with small watersheds (<10ha) on the larger scale flow regime.
Scenario 7a	≥ 10 ML + blocking - 1st order	In addition to LFRs to dams defined in Scenario 5; this scenario investigates the exclusion of required LFRs on 1st order streams on the larger scale flow regime.
Scenario 7b	≥ 10 ML + blocking - < 10 ha	In addition to LFRs to dams defined in Scenario 5, this scenario investigates the exclusion of required LFRs on headwater dams with small watersheds (<10 ha) on the larger scale flow regime.

Scenario 3, the "Base" scenario is the scenario with which the results of the Environmental Metrics testing of subsequent scenarios were compared. Scenarios 1 and 2 were not compared directly with other scenarios, but are included for comparison purposes to help provide further insight into catchment responses if necessary.

2.1.3. ENVIRONMENTAL WATER REQUIREMENTS TESTING CRITERIA

The EMLR, WMLR and MS Environmental Water Requirements were tested for the prescription process through the modelling of various water usage and low flow scenarios by the use of environmental water targets based on a set of Environmental Flow Metrics. These metrics rely on hydrological models and various assumptions relating to the flow regimes, on-farm water usage, dam volumes, and low flow release rates in each of the catchments investigated. A similar approach has been adopted to rank and assess the various scenarios described above (Table 1).

At an early stage of this project, an external peer review of the proposed methodology was completed. This review was supportive of the proposed methodology, with a key suggestion being a more detailed investigation of the importance and correlation of the individual metrics. This was tested using a Principal Components Analysis (see Section 2.1.7 for details).

The configurations and scenarios were tested using the eWater Source model (v3.0.7.31) with a custom built farm dam plug-in (courtesy of Sinclair Knight Merz (SKM) and Western Australia's Dept. of Water). The Farm Dam Analysis Tool plug-in (Fowler et al., 2012) allows each farm dam in the test catchment to be configured in their spatial location for low flow release scenarios. Each dam is assigned an inflow derived from the outlet of the catchment and proportioned by area. A daily water balance is performed on each farm dam and spills are passed down through the network to the next dam or to the catchment outlet.

Outputs from the end (outlet) of each of the test zones were analysed for each scenario with the daily flow series used for the period 1974 - 2006. This period was chosen as it was used previously as the period of analysis for the EMLR and WMLR EWR studies.

2.1.4. ENVIRONMENTAL FLOW METRICS AND MEASURES OF "SUCCESS"

A key component of the environmental water targets set out in the EMLR and WMLR environmental water provisions report (Vanlaarhoven 2012, Vanlaarhoven and van der Wielen 2012) is the overall requirement at a site to pass a certain proportion of the tested environmental flow metrics, as the environmental water requirements (EWRs) involve the calculation of around 40 different flow metrics across four flow seasons and four annual flow metrics. Based on relationships comparing the proportion of metrics passed with observed condition of fish populations and macro-invertebrates, the desired condition of the indicator was found to correspond to the passing of 85% of the defined metrics for that site. Thus, for this study the 'target' threshold is to pass at least 85% of metrics where possible, which is equivalent to failing no more than 15% of the metrics where possible.

The Base scenario, with its requirement to release low flows from all scope dams, is generally very effective at meeting the 85% target threshold. It is possible however, that in some of the ten study zones, a number of metrics are not passing this target threshold, even for the Base scenario. The nominal target for scenarios in this situation is that the percentage of metrics failed does not increase. For example, if a zone under the Base scenario were to register a level of 88% metrics passed, it is proposed that this level under a scenario (with possibly fewer dams returning low flows) could be reduced to a level of 85% and be considered acceptable. However, if a zone under the Base scenario were to register a level of 75% metrics passed, it is then unacceptable that any other scenario should further reduce this level to below 75% passed.

Whilst it would seem likely that by removing some of the low flow releases required under the Base scenario that the pass/fail score would be reduced, this is not necessarily the case, due to the threshold nature of the pass/fail mechanism of the individual metrics themselves. The metrics pass/fail score is determined by a level of deviation from the no-dams scenario and only 'tip over' from passing to failing at specified intervals based on priority groupings (Table 2). Depending on the priority level of the metric, there is a varying level of accepted deviation allowed.

Table 2. Mount Lofty Ranges EWR Metrics Deviation Index

Priority Level	% Deviation	
Decrease	From	To
1	1	0.8
2	1	0.7
3	1	0.5
Increase		
1	1	1.25
2	1	1.5
3	1	2

2.1.5. MODEL SELECTION

Selection of a hydrological model to represent the changes in flow regime due to different levels of low flow releases was based on the following requirements:

1. The ability to represent the flow regime on a daily time step
2. The ability to bypass a specified flow rate (Low Flow Release)
3. The ability to represent the water balance of individual dams within a catchment or sub-catchment, including the following elements:
    a. Rainfall and evaporation
    b. Catchment inflows
    c. Dam outflows
    d. Internal water demand.

Previous studies by the Department (Alcorn, 2010; Savadamuthu, 2004; Teoh, 2008) have used the WaterCRESS modelling framework with success. However under the National Hydrological Modelling Platform/Strategy, there is an ongoing transition to a more standardised and National model platform. For catchment and River System Modelling, this platform is currently the eWater Source modelling platform (Welsh, et al., 2012), which is a comprehensive and extensible modelling environment that supports water resource planning and management in complex regulated and unregulated river systems. A river system can be configured as a node-link network where flow and constituents are routed through the system. Upstream catchments can be spatially configured to enable processes such as rainfall-runoff and constituent generation to deliver flow and loads to the river network (for more details refer to Welsh et al., 2012).

Fundamental to this design is the flexibility which makes Source readily customisable as new science and information becomes available. New capabilities can be incorporated via plug-ins developed to suit particular needs. Whilst the currently available beta version of Source IMS does not have the ability to model an explicit, spatial representation of farm dams, work conducted jointly between SKM and Western Australia's Department of Water has resulted in the development of the Farm Dam Analysis Tool plug-in (Fowler, et al., 2012). The plug-in meets all the requirements to model the spatial representation of farm dams configured with low flow releases and the affects these dams will have on end of catchment flows. The advantage of using Source with the Farm Dam Analysis Tool plug-in is the ability to collaborate with interstate peers on this project, and also the ease with which the model itself can be set up, parameterised and shared.

2.1.6. MODEL BUILD AND RUN

A hydrological model for each test zone was constructed to model each farm dam within the zone. The eWater Source modelling platform version 3.0.7.31 was used to build on the existing hydrological model for the selected zones. The simulation of individual farm dams in this model platform is possible through the Farm Dam Analysis Tool plug-in.

Input Data requirements

The Source model and associated farm dam plug-in required the following basic data to derive a watershed node-link model:

1. ASCII-formatted digital elevation model (DEM), hydrologically corrected for pits and sinks. A 10 metre pre-processed DEM was used for this project
2. GIS shape-file of Farm Dams with minimum attributes being maximum storage capacity and unique identifier (DamID)
3. GIS shape-file of observations points used to compare flows at various points in the catchment. This node model was not employed in this case, as flows were compared at the outlet of each catchment.
4. Dam sub-catchment inflow data
5. A temporal pattern for extractions from the farm dam and an estimate of the demand that would be placed on the dam each year. This is represented as a proportion of the dam capacity.
6. Time series of rainfall data for the farm dam water balance calculation
7. Time series of evaporation data for the farm dam water balance calculation
8. Estimate of the rate of seepage from the farm dam.

An artificial dam (dummy) was created such that the catchment of this dummy dam extends to match the hydrological boundary of the zone. This ensures that all the area in the zone was used in the model. A new model was created with this new hydrological boundary. Figure 4 shows the model of one of the test zones (MP01) and its hydrological boundary as created in the model.

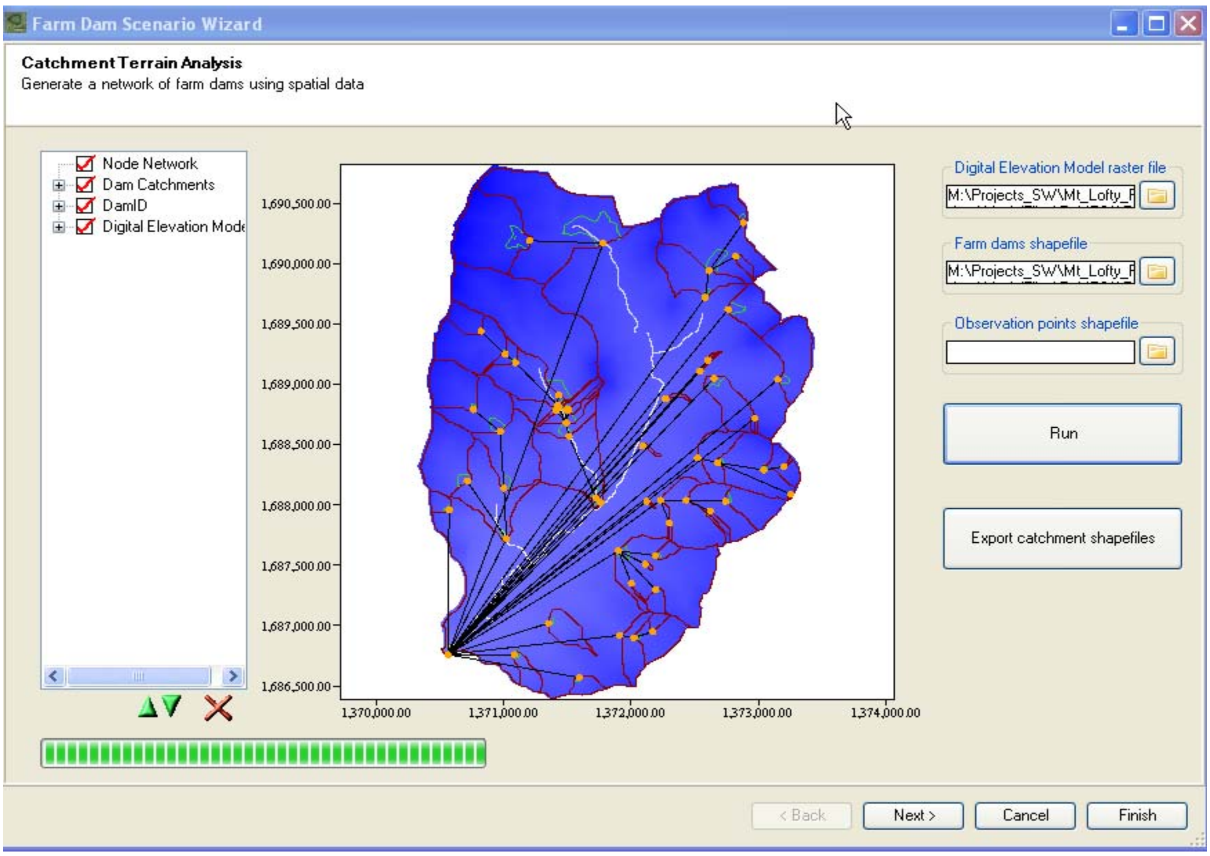
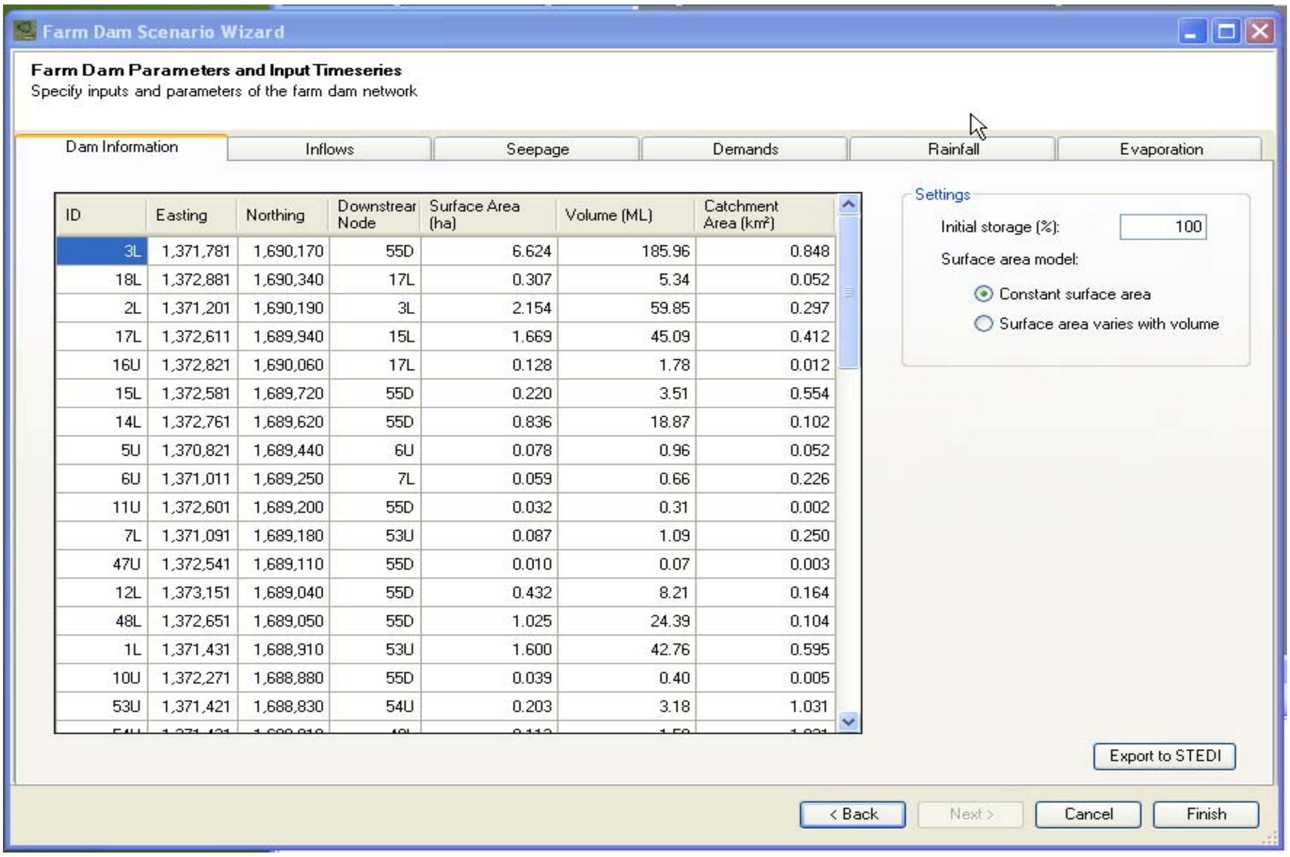


Figure 4. Delineating individual dam watersheds in Source IMS

Required data input were loaded independently in the model under the related heading. This was then applied to an individual dam. The most important input in the model is the inflow. Inflows in the model were selected from previously modelled flow representing natural flow conditions. Inflows in the model were proportionally distributed to each farm dam as a contribution from the local catchment area. Figure 5 shows the model window for input parameters.

Demands from each dam were input as internal demand factor (0.3 for Stock and Domestic and 0.5 for other licensable dams). Relevant rainfall and evaporation data were another input in the model. For this modelling, the spatial variation of rainfall and evaporation within a model was averaged. The models were then run for the period of 1974 - 2006 to match the modelling period of previous EWR analysis for the MLR (VanLaarhoven & van der Wielen, 2012).



ID	Easting	Northing	Downstream Node	Surface Area (ha)	Volume (ML)	Catchment Area (km²)
3L	1,371,781	1,690,170	55D	6.624	185.96	0.848
18L	1,372,881	1,690,340	17L	0.307	5.34	0.052
2L	1,371,201	1,690,190	3L	2.154	59.85	0.297
17L	1,372,611	1,689,940	15L	1.669	45.09	0.412
16U	1,372,821	1,690,060	17L	0.128	1.78	0.012
15L	1,372,581	1,689,720	55D	0.220	3.51	0.554
14L	1,372,761	1,689,620	55D	0.836	18.87	0.102
5U	1,370,821	1,689,440	6U	0.078	0.96	0.052
6U	1,371,011	1,689,250	7L	0.059	0.66	0.226
11U	1,372,601	1,689,200	55D	0.032	0.31	0.002
7L	1,371,091	1,689,180	53U	0.087	1.09	0.250
47U	1,372,541	1,689,110	55D	0.010	0.07	0.003
12L	1,373,151	1,689,040	55D	0.432	8.21	0.164
48L	1,372,651	1,689,050	55D	1.025	24.39	0.104
1L	1,371,431	1,688,910	53U	1.600	42.76	0.595
10U	1,372,271	1,688,880	55D	0.039	0.40	0.005
53U	1,371,421	1,688,830	54U	0.203	3.18	1.031

Figure 5. Model window for parameter input

2.1.7. UNCERTAINTY AND PARAMETER SENSITIVITY ANALYSIS

Consideration of the uncertainties associated with a model can determine which parameters or relationships are sensitive to model outputs, give an indication of confidence (or lack thereof) in the model's performance and assist in exploring solution options. As such, uncertainties may alter methodology choices or initiate new investigations. Uncertainty analysis is an important aspect of any modelling exercise and should be undertaken in conjunction with the calibration and validation process (Black et al., 2011).

There will always be some degree of uncertainty in models as they are a simplification of reality. Uncertainties in model outputs can arise from conceptualization of the processes modelled, quality and quantity of data, constraints of the modelling technology, and assumptions used in the model algorithms and the configuration of the scenarios tested (Caminiti, 2004; Van Dijk et al., 2008).

There are numerous methods and tools available to test the uncertainty within a model (structural uncertainty) and within parameter sets (parameter uncertainty and sensitivity), which are the two areas of uncertainty that are of interest in this project. The eWater “Guidelines for Water Management Modelling” give a comprehensive overview of uncertainty analysis and options modelling, and questions or strategies that the modeller should consider when performing scenario modelling (Black et al., 2011). As such, this project has taken guidance from the eWater Guidelines for Water Management Modelling (Black et al., 2011) and the project’s external peer reviewer (Dr Justin Costelloe, University of Melbourne) in order to scope a suitable uncertainty analysis. Accordingly, an uncertainty analysis was undertaken on some of the key factors in the water balance methodology of the modelling platform.

Data from the model setup for the surface water zone AR002 were used for this analysis. The aims of this uncertainty analysis were to:

1. Understand the sensitivity of key farm dam model parameters on the outcomes of each scenario based on the environmental flow metrics and the volume of water recovered from low flow releases
2. Determine the differences between scenarios based on the “threshold change” pass/fail score of environmental flow metrics in order to make a fact-based decision as to the best scenario outcome
3. Determine if certain environmental flow metrics are more important than others in providing information on the outcomes of the low flow release scenarios.

The methodology followed by the uncertainty analysis is shown in Figure 6.

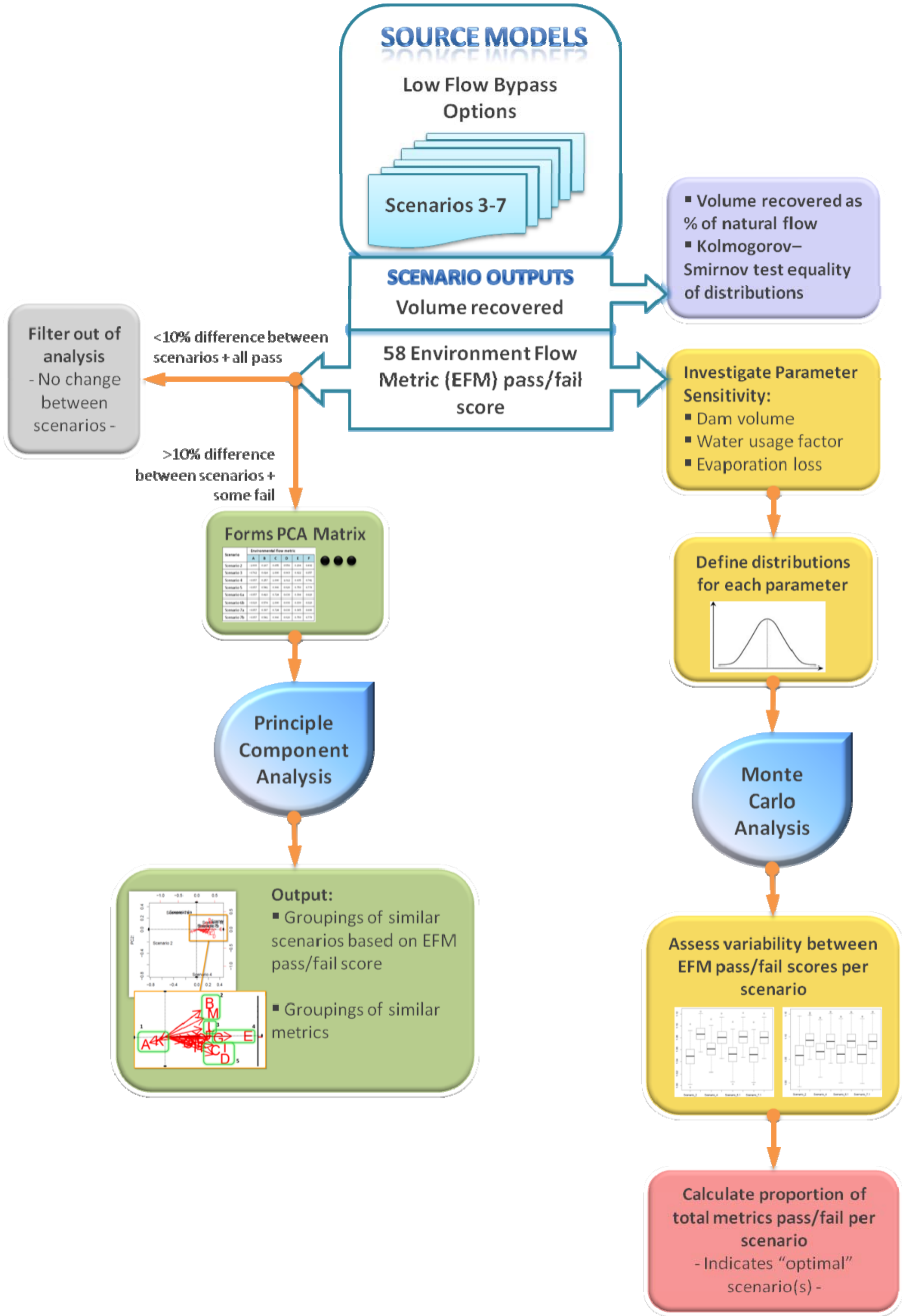


Figure 6. **Uncertainty analysis methodology flow chart**

2.1.7.1. Variability between environmental flow metrics

The first area of focus for the uncertainty analysis was to explore the inter-relationships between environmental flow metrics. As there are a total of 58 individual environmental flow metrics, it was important to understand and identify which metrics were the most sensitive to changes between scenarios. Therefore, a principal component analysis (PCA) was performed to differentiate between the most critical metrics. Although various flow metrics describe different aspects of the flow regime, most of them are strongly inter-correlated (Smakhtin, 2001). PCA is a mathematical method that transforms a complex matrix of possibly correlated variables into a set of linearly uncorrelated variables (called principal components). Each principal component is a measure of the variability within the matrix, where the first principal component will account for as much of the variability in these data as possible. PCA is a way of identifying patterns in data, and expressing these data in such a way as to highlight their similarities and differences, by reducing the number of dimensions, without significant loss of information (i.e., the variability between variables).

In order to narrow down which metrics to analyse using the PCA, the individual metric's "threshold change" pass/fail score for each scenario for the surface water zone AR002 was examined. The "threshold change" score refers to the percentage difference in calculated flow metric for a given scenario from the "no-dams" or "natural" flow regime. Those metrics that did not change substantially (±10%) between each scenario when compared to scenario 2 (Current-NoLFR) and all passed the environmental flow metric pass/fail criteria, were filtered out of the analysis. For example, the environmental flow metric "Number of years with one or more T1 freshes" pass/fail score was consistently above 0.91% for all scenarios and thus met the environmental flow requirement (pass = 85% for priority 1 metric). The remaining metrics were processed to form a matrix for the PCA (Table 3). The PCA was performed using the R statistical software (specifically the `prcomp()` function).

The PCA results were examined using:

- *2-dimensional biplots*, which seek to support the visual identification of similarities in variances between environmental flow metrics and between scenarios
- Summary statistics for each principal component.

Table 3. Variable matrix for PCA: the environmental flow metric pass threshold (%) for each scenario

Scenario	Environmental flow metric (short name – see Table 4)																
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Scenario 2	1.000	0.167	0.655	0.556	0.284	0.492	0.406	0.714	0.473	0.503	0.822	0.403	0.267	0.640	0.857	0.722	0.672
Scenario 3	0.762	0.614	1.000	0.963	0.922	0.857	0.909	0.992	0.941	0.864	0.754	0.805	0.718	0.840	1.000	0.972	0.971
Scenario 4	0.857	0.257	1.000	1.012	0.635	0.741	0.758	0.970	0.840	0.735	0.795	0.623	0.436	0.840	1.000	0.889	0.880
Scenario 5	0.857	0.541	0.966	0.926	0.750	0.779	0.727	0.887	0.818	0.779	0.775	0.731	0.646	0.840	1.000	0.917	0.896
Scenario 6a	0.857	0.418	0.724	0.630	0.394	0.619	0.594	0.797	0.576	0.627	0.780	0.575	0.500	0.720	0.893	0.736	0.755
Scenario 6b	0.810	0.574	1.000	0.938	0.839	0.810	0.788	0.925	0.850	0.810	0.768	0.764	0.682	0.840	1.000	0.917	0.909
Scenario 7a	0.857	0.397	0.724	0.630	0.365	0.600	0.563	0.752	0.542	0.608	0.783	0.554	0.480	0.720	0.857	0.708	0.743
Scenario 7b	0.857	0.541	0.966	0.926	0.750	0.779	0.727	0.887	0.818	0.779	0.775	0.731	0.646	0.840	1.000	0.917	0.896

Table 4. List and description of the environmental flow metrics that were analysed in the PCA.[4]

Short Name	Flow Season	Flow component	Metric	Statistic
A	Annual	Bankfull	Ann_Bankfull_NumYr	Number of years with one or more flow component
B	Low flow	Low flow	LFS_80pc	80 percentile exceedence non-zero flow
C	Low flow	Freshes	LFS_Fresh_NumYr	Number of years with one or more flow component
D	Low flow	Freshes	LFS_Fresh_AveYr	Average number of flow component per year
E	Low flow	Freshes	LFS_Fresh_AveDuration	Average total duration of flow component per year
F	T1 - Transitional (Low-High)	Low flow	TLF_80pc	80 percentile exceedence non-zero flow
G	T1 - Transitional (Low-High)	Low flow	T1_LF_Delay	Current month reaching median flow of natural T1 median (delay)
H	T1 - Transitional (Low-High)	Freshes	T1_Fresh_AveYr	Average number of flow component per year
I	T1 - Transitional (Low-High)	Freshes	T1_Fresh_AveDuration	Average total duration of flow component per year
J	HFS – High flow	Low flow	HFS_80pc	80 percentile exceedence non-zero flow
K	HFS – High flow	Freshes	HFS_Fresh_AveDuration	Average total duration of flow component per year
L	T2 - Transitional (High-Low)	Low flow	T2_LF_MedianDailyQ	Median non-zero daily T2 flow
M	T2 - Transitional (High-Low)	Low flow	T2_TLF_80pc	80 percentile exceedence non-zero flow
N	T2 - Transitional (High-Low)	Low flow	T2_TLF_Early	Current month reaching median flow of natural T2 median (early onset)
O	T2 - Transitional (High-Low)	Freshes	T2_Fresh_NumYr	Number of years with one or more flow component
P	T2 - Transitional (High-Low)	Freshes	T2_Fresh_AveYr	Average number of flow component per year
Q	T2 - Transitional (High-Low)	Freshes	T2_Fresh_AveDuration	Average total duration of flow component per year

2.1.7.2. Parameter sensitivity analysis

Uncertainty analysis of complex mathematical models often involves the use of Monte Carlo methods to analyse the sensitivity of parameters and model algorithms on overall model performance (Smith, 2002; Black, et al., 2011 and references within). Understanding which parameters cause a large degree of change in model outputs can give insight into where areas of uncertainty lie within the model structure or data used to parameterise the model.

[4] (List after filtering out those that did not change substantially between scenarios and that all passed the pass/fail criteria)

Monte Carlo analysis is a method of quantifying uncertainty in a model by considering the sensitivity or variation in key model parameters, inputs and algorithms. The sensitivity of a parameter is determined by specifying parameter bounds or distributions that describe the range in possible values, and then running the model multiple times (often thousands of runs) with a different parameter value selected from the distribution using probability methods. The results of the Monte Carlo analysis are a distribution of output estimates that reflect the uncertainties in model inputs.

A number of studies have investigated the uncertainty of parameters and algorithms of the Source farm dam plug-in (previously as the stand-alone TEDI/CHEAT farm dam model and as the farm dam plug-in for Source) (Lowe & Nathan, 2008; Fowler, et al., 2012; Fowler, et al., 2011). Lowe and Nathan (2008) demonstrated that the volume of farm dams in the Werribee catchment (Vic) varied by ±11% of the mean and the overall catchment-scale impacts on runoff varied by ±29% of the mean. The most sensitive farm dam model parameter that contributed the most to overall model uncertainty was the farm dam catchment area. Fowler et al. (2012) found that uncertainties in the spatial variation of flow generation as an input to the Source farm dam plug-in were the greatest source of uncertainty in model outputs and that seepage may have a significant effect on the farm dam water balance. In a South Australian context, the studies conducted by McMurray (McMurray, 2003; McMurray, 2004) on dams in the Mount Lofty Ranges indicate that potential sources of error in farm dam parameters and relationships are the digitising errors that occurred in defining the dam water outline from aerial photography, farm dam water use fraction, evaporation loss and the errors associated with the farm dam volume-surface area regression relationship.

As a result of previous studies on farm dam model uncertainty, for this project the water use fraction parameter, evaporation loss and dam volume relationship was subjected to an uncertainty analysis using a Monte Carlo approach.

Normal distributions for each of the three farm dam parameters were sourced from the literature based on previous studies on uncertainties in farm dam model parameterisation (Figure 7):

- **Dam Volume:** One of the largest sources of uncertainty, dam volumes are derived from a relationship to surface area (McMurray, 2004). As dam volume is a relationship, a scaling factor was used to linearly scale the dam volume for each iteration of the Monte Carlo runs. The scaling factor was given a normal distribution with a mean of 1 and standard deviation of 0.25, representing the degree of error associated with this relationship as given by McMurray (2004).
- **Evaporation loss:** The rate of evaporation from the farm dams' surface area (itself related to surface area volume relationship at less than full capacity) was modified with a linear scaling factor that was applied to the evaporation time series for each Monte Carlo iteration. The linear scaling factor represents the degree of variability associated with evaporation loss from farm dam surface area as given by McMurray (2003), and was given a mean of 1 and standard deviation of 0.2.
- **Dam usage fraction:** Demand from farm dams is assumed based on dam size and purpose. It was assumed that large or irrigation dams will demand a larger proportion (50%) than smaller dams used for stock and domestic purposes. For each Monte Carlo run, the dam usage fraction was modified based on a normal distribution with a mean of 0.46 and standard deviation of 0.25. This is consistent with the distribution for dam use given by Fowler et al. (2012).

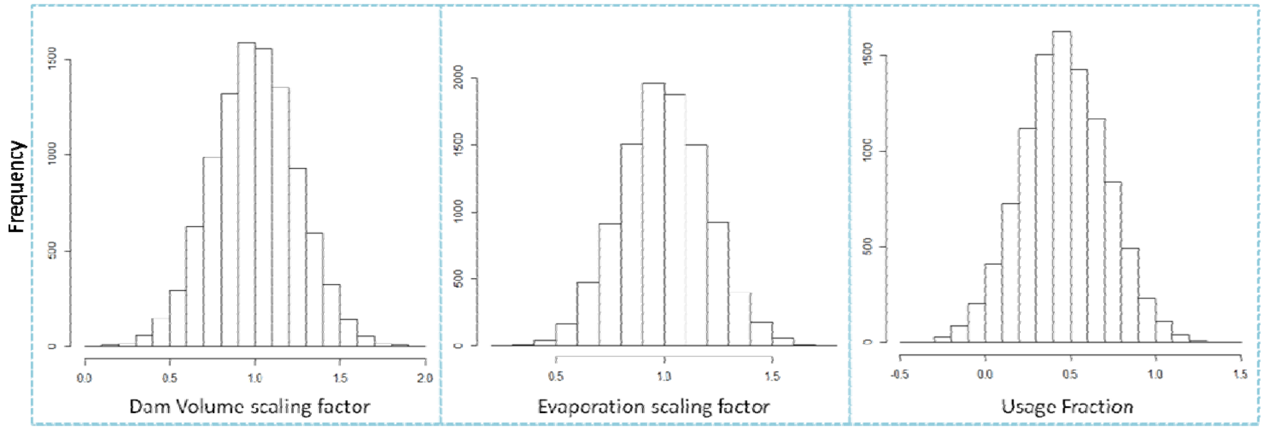


Figure 7. Normal distributions for farm dam parameters (Dam Volume, Evaporation loss, Usage Fraction) used in the Monte Carlo analysis

A Monte Carlo simulator was configured using the R programming language and Source Command Line. A single Source project for surface water zone AR002 was configured with global variables for the dam volume and evaporation loss scaling factors and the usage fraction parameter. These global variables are accessible from the Command Line and can be read in by the R code that has been set up with a Monte Carlo simulator. Initially, 1000 Monte Carlo runs of each farm dam parameter were undertaken, but due to computational issues were reduced to 300 runs for each farm dam parameter. Although this is generally a very low number of runs to generate sufficient replicates to capture the sensitivity range of each parameter, comparison of the 1000 runs and 300 runs for evaporation loss shows that the effect on the results is minimal (Figure 8).

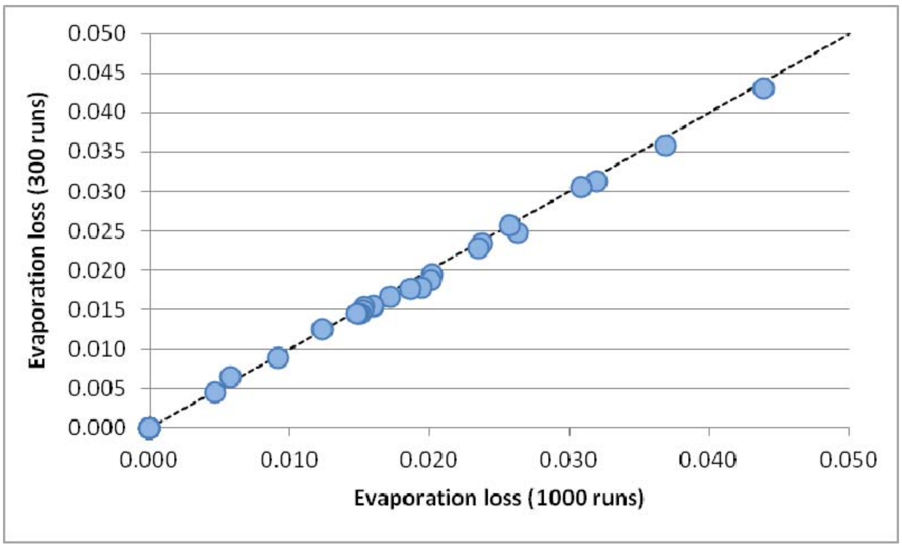


Figure 8. Comparison of evaporation loss replicates (300 vs. 1000 runs) for Monte Carlo analysis

2.2. PHASE 2

Phase 2 of the report builds on the results and outputs of Phase 1. The aim of Phase 1 is to:

- Identify the different volumes of water that might be returned to the system as a result of the implementation of any particular scenario
- Identify the volumes of water returned through the provision of these low flows that might be considered as a potential Murray-Darling Basin Plan Sustainable Diversion Limit (SDL) Offset.

As this study only investigates the impacts of scenarios on 10 surface water zones spread across the MLRs, a scaling methodology was required to estimate the full level of returned flow.

Flows at the end of each zone were calculated and compared to the “Current” case or Scenario 2 (no low flow releases currently occurring).

The returns occurring were then analysed and compared to catchment characteristics, to determine if there were any factors that would allow ‘scaling up’ of the results based on easily measurable or derivable quantities.

Factors investigated included:

- Low Flow unimpeded area (% of zone area)
- Mean Annual Runoff (mm)
- Dam Density (ML/km^2)
- Number of Dams Requiring Low Flow Releases (% of Total, % of Volume Bypassed)
- Dam development level (Total Dam Volume/ Mean Annual Runoff).

3. RESULTS

3.1. PHASE 1

This section presents the results and some discussion around the results of Phase 1 of this study, which includes the “Test zones” selected for modelling, scenario modelling and the uncertainty analysis. Due to the repetitive nature of the results, only one test zone is presented in full within this section of the report, with the results for the remaining nine test zones presented as Appendices to this report.

3.1.1. ZONE SELECTION

Ten zones from across the region were selected as ‘test zones’ (Figure 10) based on the criteria described in Section 2.1.1 and they are distributed as follows:

- Six zones were selected in the WMLR PWRA, with three of them located in the central WMLR and three from the Fleurieu region, including one from the Southern Fleurieu
- Three zones were selected in the EMLR PWRA
- One zone in the Marne Saunders PWRA.

A brief description of one test zone is provided below. Table 5 summarises the key characteristics of all ten test zones. A detailed description of the other nine test zones is provided in Appendix A.

Mount Pleasant: MP01

This is a headwater zone located in the Mt Pleasant Sub-catchment of the Torrens River Catchment (Figure 9). It has a catchment area of 10.98 km^2. The mean annual rainfall for the zone is 677 mm with its resource capacity[5] being 106 mm. The stream flow gauging station (A5041046) is located at the outlet of this zone.

There are 61 farm dams in this zone with a total dam capacity of 571 ML. 30% (18 dams) of those are currently considered scope dams and they account for 33% of the zone’s total dam capacity. The scope dams are distributed across the zone and located mostly on the 1st and 2nd order streams, with no blocking dams on the 3rd order. The development level[6] in this zone is 55% and is rated as a ‘high development’ zone.

3.1.2. DISCUSSION

The ten test zones selected, while being representative of their regions, indicate both, a lack of pattern in certain aspects of farm dam development while indicating a pattern in other aspects. One example is with reference to development level:

- **Development level:** Varies widely, ranging from a very high 55% for the zone MP01 in the Upper Torrens catchment, to as low as 4% and 7% in the zones in the Hindmarsh and Deep Creek catchments in the Fleurieu region (Hind01, Deep01 respectively).

[5] Resource Capacity is defined as the mean annual runoff with the impact of dams removed, also widely referred to as “No-dams flow” or “Pre-development flow” or “Natural Flow”.
[6] Development level = Total dam capacity divided by resource capacity

One of the possible reasons for the wide range in development level could be related to water security, which is related to both reliability of supply and the variability of this supply, with the southern Fleurieu region having a wetter and less variable climate that the Marne. Another possible reasons could be the influence of policy framework, for example the Barossa, which is to the north of the Marne, being prescribed earlier, influencing rapid farm dam development in the neighbouring Marne catchment. Further analysis of periodical farm dam datasets would enhance further understanding of temporal patterns of farm development, if any, across the region.

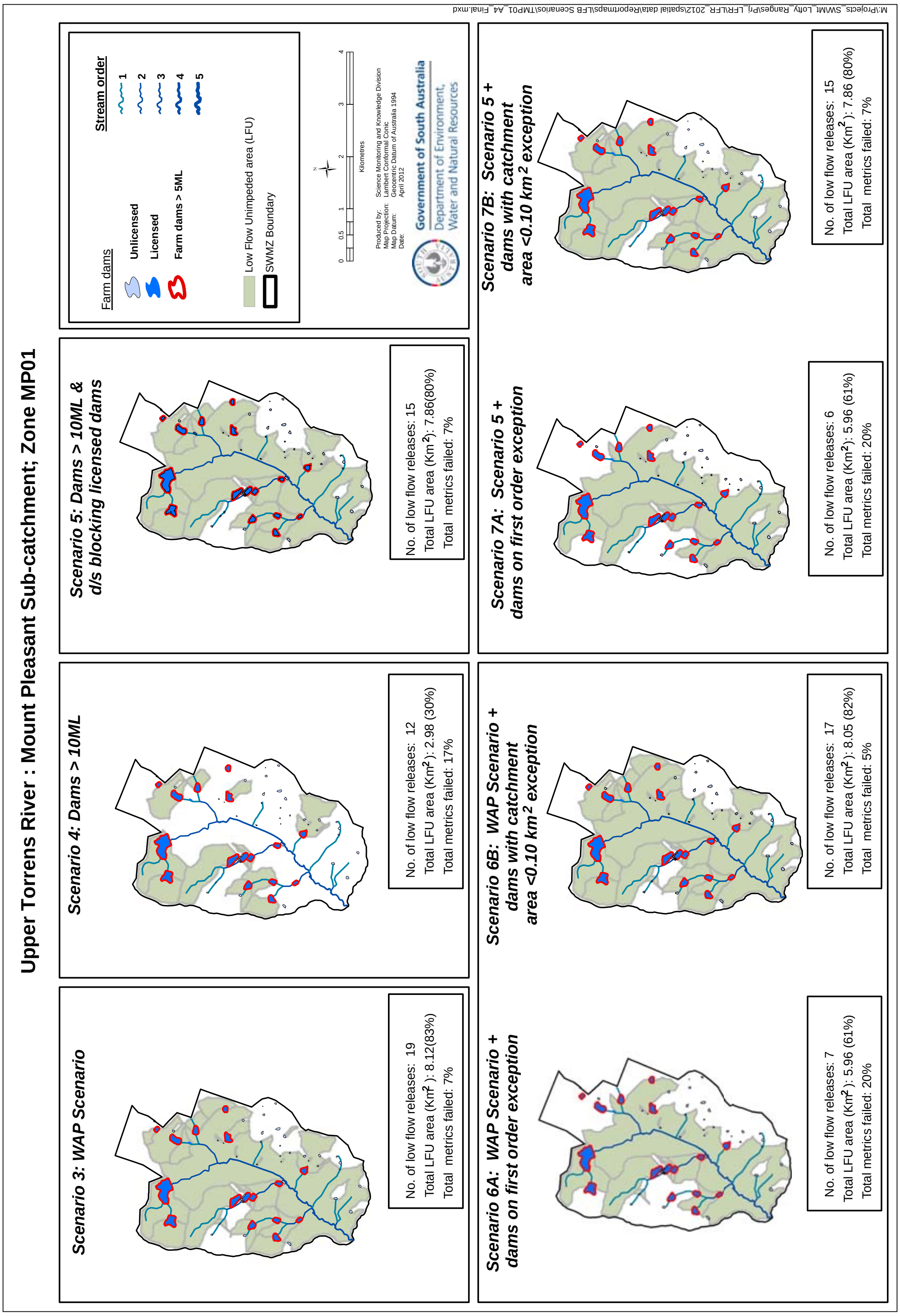


Figure 9. **Test Zone MP01, Upper Torrens River showing scenario definitions**

Table 5. Test Zones – Key characteristics

Zone	Catchment	PWRA	Modelled Area (km^2)	Mean annual rain (mm)	Modelled Natural Runoff (mm)	No. of dams	Total dam capacity (ML)	Dam density (ML/km^2)	Scope dam capacity (% of total)	Development level	Comments
AR002	Angas River	EMLR	4	828	127	32	160	43	32%	34%	Larger dams located on low order streams; lesser no of dams
BR038[7]	Bremer River	EMLR	19	782	92	110	776	42	40%	45%	Dams distributed all over the zone
Deep01	Deep Creek	WMLR	12	840	125	37	49	4	8%	4%	Smaller number of dams, very few licensed dam and plantation forestry as a major land use
FR005	Finniss River	EMLR	15	870	144	178	445	31	15%	21%	Larger dams located on low order streams; similar patterns observed in most headwater zones of Finniss Catchment
Hind01	Hindmarsh River	WMLR	56	879	174	324	496	9	6%	5%	Low development level , lesser number of licensed dams
IV01	Onkaparinga River	WMLR	11	807	119	104	461	41	25%	34%	Clustered dams, large dams located in series
LW04	Onkaparinga River	WMLR	2	944	313	18	73	48	44%	15%	More free to flow area, high proportion of licensed dams
M1_01	Marne River	MS	18	747	97	74	759	44	23%	45%	Development level more than resource capacity; includes large stock and domestic dams
MP01	Torrens River	WMLR	10	677	106	56	571	58	33%	55%	Scattered dams, high proportion licensed dams
Myp01	Myponga River	WMLR	74	863	138	462	1124	16	13%	11%	Licensed dams concentrated on low order streams, high proportion of unlicensed dams

[7] The selected study area is a part of Bremer SWMZ BR038

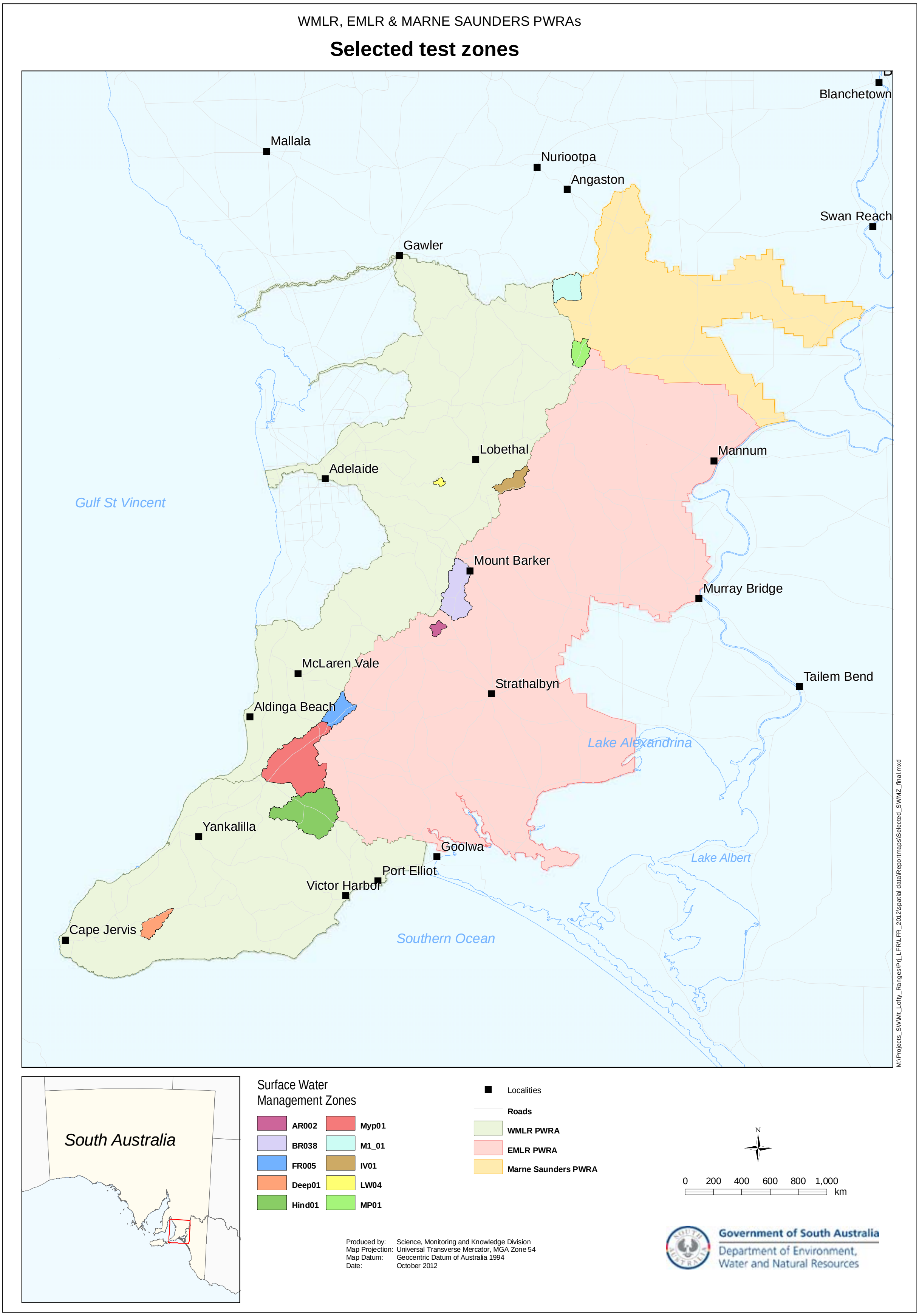


Figure 10. Selected test zones from three prescribed areas for the project

3.1.3. SCENARIO RESULTS

As described in the methodology, a total of nine scenarios were modelled for each test zone. The scenarios identified the dams requiring LFRs and their respective low flow unimpeded (LFU) areas, which were estimated using GIS analysis. The scenario definition result showing which dams would return low flows under each scenario for one of the test zones (MP01) is presented in Figure 9 and other test zones results are attached as Appendix B.

It needs to noted that this study looked at the impact of dams on the flow regime, as opposed to other interception activities like plantation forestry.

The total number of dams in each test zone and the number of dams requiring low flow release are tabulated in Table 6 below. The table shows the percentage reduction in the number of LFRs for each scenario subsequent to Scenario 3 for each of the test zone.

Table 6. Results of scenario modelling for each test zone and summary of required number of LFRs for each scenario

Zone	Total Dams in Zone	Number of LFRs required for Scenario 3	Percentage reductions in numbers of dams requiring LFRs compared to Scenario 3					
			S4	S5	S6a	S6b	S7a	S7b
AR002	32	10	60%	40%	70%	30%	80%	40%
BR038	110	44	48%	34%	41%	7%	55%	34%
Deep01	37	3	67%	67%	100%	67%	100%	67%
FR005	178	27	67%	52%	78%	26%	74%	52%
Hind01	324	20	60%	45%	40%	10%	55%	45%
M101	74	17	41%	35%	71%	41%	71%	47%
Myp01	462	61	72%	28%	39%	16%	61%	38%
OIV01	104	26	42%	27%	42%	19%	38%	27%
OLW04	18	8	63%	50%	75%	38%	88%	50%
TMP01	56	18	33%	17%	61%	6%	67%	17%
Area Weighted Average	-	-	59%	36%	50%	19%	61%	41%

The data indicates that the largest average reductions in the number of LFRs required are for Scenarios 4 and 7a, followed by 6a, 7b, 5 and 6b. Further analysis of these results is discussed below.

Comparison of scenarios through EWR metrics

Table 7 summarises the variation in number of dams requiring low flow release and the corresponding percentage of EWR metrics not met for different scenarios in all ten “test zones”.

Table 7. Scenarios showing number of LFRs required and percentage of metrics failed

SURFACE WATER ZONES	*Scn3*		Scn4		Scn5		Scn6a		Scn6b		Scn7a		Scn7b	
	A	*B*	A	B	A	B	A	B	A	B	A	B	A	B
MP01	*18*	*7%*	12	17%	15*	7%	7	20%	17	5%	6	20%	15*	7%
IV01	*26*	*21%*	15	36%	19	21%	15*	21%	21	21%	16	21%	19	21%
LW04	*8*	*9%*	3	16%	4	16%	2	23%	5*	11%	1	27%	4	16%
Hind01[1]	*20*	*3%*	8	3%	11	3%	12	3%	18	3%	9	3%	11	3%
Deep01 [1]	*3*	*2%*	1	2%	1	2%	0	2%	1	2%	0	2%	1	2%
Myp01[1]	*61*	*8%*	17	8%	44	8%	37	8%	51	8%	24	8%	38	8%
FR005	*27*	*11%*	9	16%	13*	14%	6	18%	20*	11%	7	18%	13*	14%
AR002	*10*	*5%*	4	17%	6*	12%	3	32%	7*	7%	2	32%	6*	12%
BR038	*44*	*17%*	23	24%	29*	17%	26	29%	41*	15%	20	32%	29*	17%
M101	*17*	*15%*	10	20%	11	17%	5	17%	10	17%	5	17%	9	17%

A : number of dams requiring LFR

B : % EWR metrics not met in the scenario

* (green) Rated best scenario(s) for zone, due to reduced number of LFRs with 'metrics not met' remaining 15% or less (or not increasing 'metrics not met' where Scn3 already exceeded 15%) – refer to Section 2.1.4 for full details.

(orange) Scenario(s) which appear unsuitable for zone, due to 'metrics not met' exceeding 15% (or increasing 'metrics not met' figure where Scn3 already exceeded 15%) – refer to Section 2.1.4 for full details.

1: No scenarios have been highlighted as 'successful' or otherwise for "Hind01", "Deep01" and "Myp01" – refer Section 3.1.4 for details.

3.1.4. COST BENEFIT ANALYSIS

A cost benefit analysis is described in this section for each of the scenarios subsequent to Scenario 3 (WAP Scenario), to determine possible alternatives and their pros and cons.

The "cost" function is simplified here to the percentage possible reduction in numbers of LFRs that would be required under each scenario. That is, the change from Scenario 3. The "benefit" function is analysed using the "total percentage of metrics not met" parameter.

In describing the benefit of each scenario it should be noted that each test zone will begin at a different level of 'metrics not met'. Given that a threshold of acceptable level of failure is set at 15% (VanLaarhoven & Van der Wielen, 2009), any given scenario should not exceed this level. This is not possible at all times however, as metric success or failure is dependent on various factors including:

- the existing level of farm dam development
- the proximity of large dams to the point of testing the metrics
- the location or distribution of farm dams though the zone or catchment
- the proportion of potential dams requiring LFRs compared to those that will not.

As outlined previously in Section 2.1.4, if a test zone is already failing more than 15% of total metrics, then the benchmark for "success" is that under any scenario, the zone should not fail any more metrics. Where a zone is failing less than 15% of metrics under Scenario 3, any further scenario should not cause that rate to go above the 15% level.

The results shown in Table 8 indicate a variety of possible solutions that fit these criteria. Table 7 shows that some zones (Myp01, Deep01, and Hind01) exhibit no change in the level of metrics failed between scenarios. In the case of Deep Creek (Deep01) this can be attributed to the low number of dams requiring LFRs under Scenario 3 (“BaseWAP”) and the relative position of those dams high in the catchment. The Myponga (Myp01) and Hindmarsh (Hind01) zones both exhibit no change in metrics also. This is largely due to the size of the zones and the large areas of unimpeded flow upstream of the testing point at the end of the zone. From Table 5 we note that these three zones have the lowest level of scope dams at between 6 - 13% of the total volume.

This project assesses the benefits of returning low flows at the scale of the end of the management zone. However, it is important to note that environmental benefits occurring at the local scale (e.g. immediately downstream of a dam) do not necessarily change the performance of the metrics at the end of the zone because of the influence of free-to-flow areas lower in the zone. This situation may occur in zones like Hind01, Deep01 and Myp01, which have low development levels and/or are large zones with large areas of free-to-flow catchment. The scale of assessment is an important factor to consider in making decisions on strategic location approaches.

The Finniss River zone (FR005) is the next lowest in this measure with 15% of dam capacity being in-scope to return low flows. At this level there begins to be some difference in the scenarios. This zone also illustrates the need to consider the impacts of strategic location options on downstream zones. Scenarios 5 and 7b fail more metrics than the base scenario 3, although the percentage of metrics failed in these scenarios is still within the acceptable threshold of 15%. This result must be used with caution when considered in isolation, as the likely on-ground reality is that zones such as this partially offset hydrological deficiencies in downstream zones that do not meet EWR targets. A similar situation is observed for zone AR002 as well.

Scenario 3 (base) is the only scenario that meets the environmental targets for zone M1-01, and none of the strategic location options provide a successful outcome (in accordance with 2.1.4).

While there is no single scenario that stands out as the preferred one across all the surface water zones, the scenarios 5, 6b and 7b provide acceptable outcomes for the three zones (AR002, BR038 and FR005) in the EMLR PWRA. (Table 7 and Table 8). However, it needs to be noted that the absence of any dams in the headwaters with catchment areas less than 10 ha, makes scenario 7b the same as scenario 5.

Scenario 4 always provides an unacceptable outcome in those zones where an assessment of suitable options has been made. Scenarios 6a and 7a provide an unacceptable outcome in 6 of the 10 zones tested. As outlined above, there is no single scenario that stands out as the preferred scenario across all test zones. Furthermore, a preferred scenario in one zone can lead to an unacceptable result in another. For example, scenarios 5 and 7b are preferred in a number of test zones, but lead to an unacceptable result in zone LW04.

These selections should be used with caution as the value of the cost/benefit function is neither normalised nor indicative of other values which may be of value such as the social or economic value of water released.

Table 8. Discussion of cost/benefit for each test zone

Zone	Preferred Scenarios (From Table 7)	Comments
AR002	6b, 5 and 7b	Scenario 4 whilst yielding a greater reduction in LFRs, goes over the EWR Threshold of 15% failed. All preferred scenarios fail more metrics than Scenario 3, but the percentage failed is within the acceptable threshold of 15%.
BR038	6b, 5 and 7b	Scenarios 5 and 7b pass the same percentage of metrics as the Scenario 3. Scenario 6b, although failing 2% fewer metrics than Scenario 3, yields the least reductions in number of LFR required.
Deep01	No preferred option	Not enough data. Metrics do not change.
FR005	6b, 5 and 7b	Scenarios 5 and 7b fail more metrics than Scenario 3, but the percentage failed is within the acceptable threshold of 15%.
Hind01	No preferred option	Not enough data. Metrics do not change.
M1-01	No preferred option	Scenario 3 results in an acceptable outcome, but all strategic location options (scenario 4 onwards) do not.
Myp01	No preferred option	Not enough data. Metrics do not change.
IV01	6a	Scenarios 5, 6a, 6b, 7a and 7b yield identical metric results with 6a yielding the greatest reductions in LFRs required
LW04	6b	This zone is small in size and dominated by large dams.
MP01	5 and 7b	Scenarios 5 and 7b yield reasonable reduction in LFRs required while still passing the 15% EWR threshold. Scenario 6B gives an acceptable outcome but a smaller reduction in LFRs required.

3.1.5. IDENTIFICATION OF KEY ENVIRONMENTAL FLOW METRICS USING PRINCIPAL COMPONENT ANALYSIS

The results of the analysis undertaken to assess the correlation between the environmental flow metrics and scenarios modelled, as described in Section 2.1.7, are presented in this section. Eight principal components in all were determined from the PCA, with 91% of the variance in the data matrix attributed to the first principal component and 98% (cumulative for the first and second components) attributed to the second principal component (Table 9). Therefore, the first two principal components are a good representation of the co-linearity between variables. As a result, a biplot of the first two principal components can be calculated and the correlation between scenarios and environmental flow metrics can be analysed (Figure 11 and Figure 12).

Table 9. Importance of principal components (PC) that attribute to the variance of each object (scenario) and each variable (environmental flow metric)

PCA statistics	Principal Components							
	PC 1	*PC 2*	*PC 3*	*PC 4*	*PC 5*	*PC 6*	*PC 7*	*PC 8*
Standard Deviation	0.5335	0.15235	0.06120	0.04645	0.01682	0.01058	9.052e-17	1.197e-18
Proportion of Variance	0.9061	0.07388	0.01192	0.00687	0.00090	0.00036	0.000e+00	0.000e+00
Cumulative Proportion	0.9061	0.97995	0.99188	0.99874	0.99964	1.00000	1.000e+00	1.000e+00

3.1.5.1. Correlation between scenarios

In a PCA biplot, the distance of each object (scenario) and each variable (metric) from the origin (0, 0 coordinate) is the deviation from its mean; thus a large distance from the origin means a higher variance from the mean. Four distinct groupings of scenarios can be seen in the biplot in Figure 11. Scenario 2 and Scenario 4 are not correlated with each other or any of the other scenarios, and their distance from the origin (0, 0 coordinate) is larger than the other scenarios, suggesting that these two scenarios contribute to a high degree of variability in the overall data matrix.

Scenarios 3, 5, 6b and 7b form another correlated group, and are the closest grouping to the origin coordinate, suggesting the lowest variance between variables. As Scenario 4-7 will be assessed against Scenario 3 outputs, it can be concluded that Scenarios 5, 6b and 7b are not substantially different to Scenario 3 and will effectively produce similar outcomes with less low flow releases.

In addition, Scenarios 3, 5, 6b and 7b have the most similar interaction with all metric variables, compared to all other Scenarios. This means that these scenarios have a greater association with the pass/fail criteria of each environmental flow metric, and can be assessed together.

Scenarios 6a and 7a are similar to each other, which is not surprising as both these scenarios investigate the exclusion of low flow releases on dams on first order streams. However, these scenarios are substantially different from Scenario 3 and have been further analysed in the next section with a focus on the pass score of the environmental flow metrics and the volume of water recovered from the low flow releases.

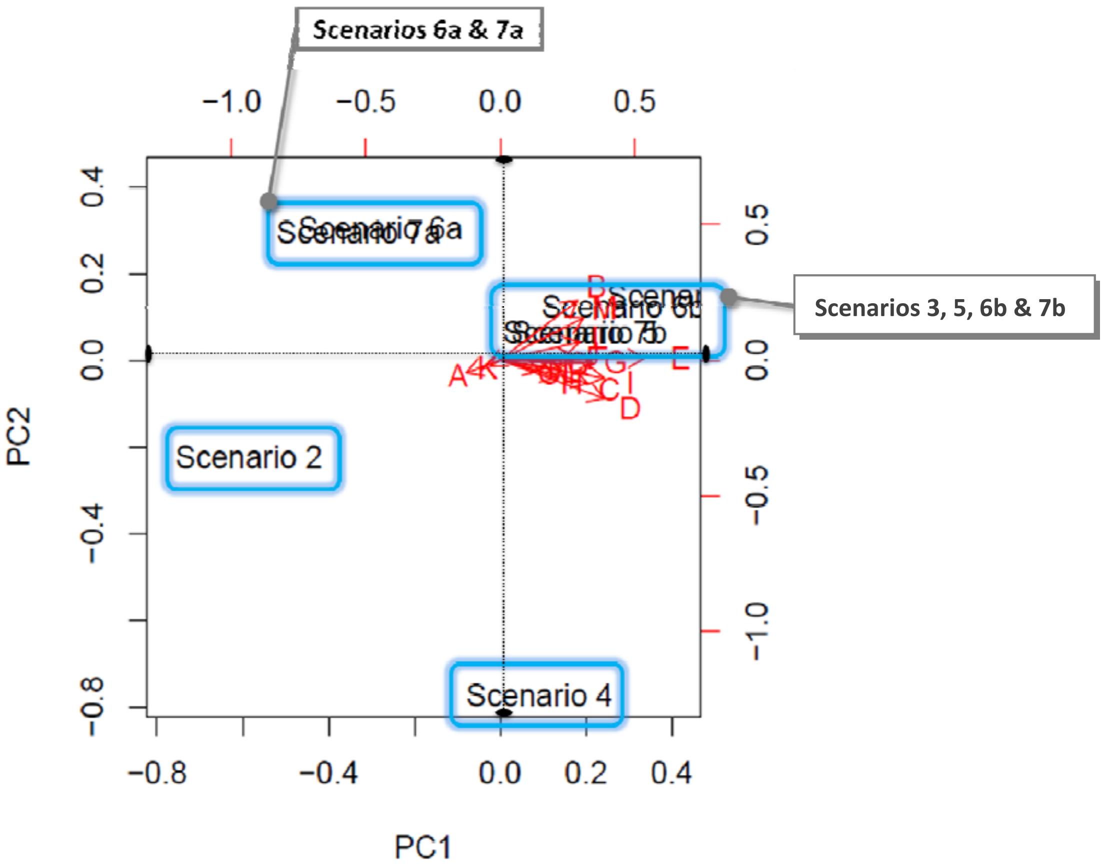


Figure 11. PCA biplot distinguishing between scenarios based on their environmental flow metric scores. Dotted intersecting lines show the 0,0 origin.

3.1.5.2. Correlation between metrics

The key measures of the degree of correlation (or variance) between environmental flow metrics are the length of the vectors (the red arrows) and the angle of the vectors (Figure 12). The length of the vector shows the degree of variance associated with an individual metric – the longer the vector (thus, the furthest away from the 0, 0 origin) the higher the variance. The angle between two vectors illustrates the degree of correlation.

For example, environmental flow metric E (Average total duration of Low Flow Season freshes per year) has the highest variance, whilst metric K (Average total duration of High Flow Season freshes per year) has the lowest. Metrics A (Number of years with one or more bankfull flow event) and K are strongly correlated as the vectors point in the same direction, and are negatively correlated to many of the other metrics, as the vectors point in the opposite direction. Metrics B (Low Flow Season 80 percentile exceedence non-zero flow) and D (Average number of Low Flow Season freshes per year) are not correlated (or are dissimilar), as the vectors are close to 90 degrees apart.

Five groupings of environmental flow metrics can be delineated from the biplot in Figure 12. Table 10 shows the different correlation groups for all the environmental flow metrics analysed in the PCA. Metrics A and K are strongly correlated in a negative direction to many of the other metrics. Groupings are further outlined in Table 10. Those with the longest vectors account for the highest degree of variability in the data matrix and thus should be considered the most critical metrics for the Monte Carlo analysis in assessing parameter uncertainty on the outcomes of each scenario.

The main outcome of the PCA analysis is to aid the interpretation of, and distinguish between metrics which may be representative of the overall outcome.

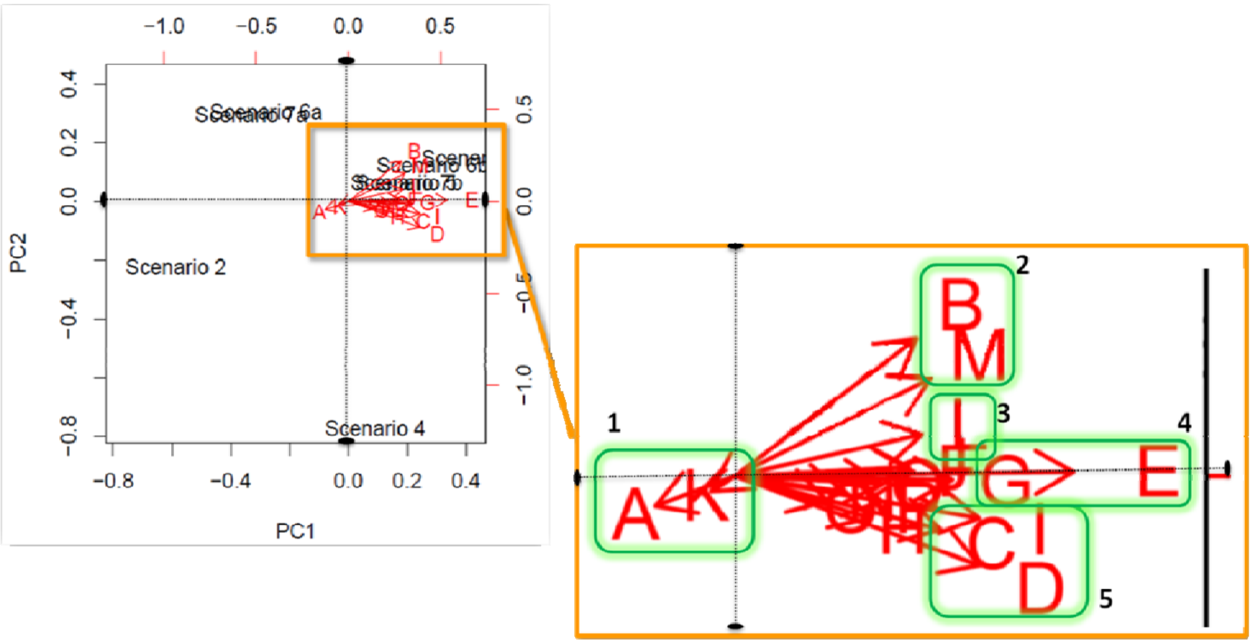


Figure 12. PCA biplot distinguishing between environmental flow metric pass/fail score variables. Dotted intersecting lines show the 0, 0.

Table 10. Correlated groupings of environmental flow metric variables from the PCA

Correlation group	Metric (short name)	Metric Description
1	A	Number of years with one or more bankfull event
	K	Average total duration of high flow season freshes per year
2	B	Low flow season 80 percentile exceedence non-zero flow
	M	T2 low flow season 80 percentile exceedence non-zero flow
3	L	Median non-zero daily T2 low flow
4	E	Average total duration of low flow season freshes per year
	F	T1 low flow 80 percentile exceedence non-zero flow
	G	Current month reaching median flow of natural T1 median (delay)
	Q	Average total duration of T2 freshes per year
5	D	Average number of low flow season freshes per year
	C	Number of years with one or more low flow season freshes
	N	Current month reaching median flow of natural T2 median (early onset)
	O	Number of years with one or more T2 freshes
	P	Average number of T2 freshes per year

Table 11. Key environmental flow metrics that account for the greatest degree of variability between metrics for each scenario

Metric (short name)	Metric Description
A	Number of years with one or more bankfull event
B	Low flow season 80 percentile exceedence non-zero flow
L	Median non-zero daily T2 low flow
D	Average number of low flow season freshes per year
E	Average total duration of low flow season freshes per year

3.1.6. MONTE CARLO PARAMETER SENSITIVITY ANALYSIS

Figures 13 - 15 show the outcomes of the Monte Carlo analysis for farm dam parameters (Dam Volume, Evaporation Loss and Usage Fraction) for Scenario 3 environmental flow metric threshold change (pass/fail) scores. Scenario 3 has the most LFRs and represents the 'best case' scenario in terms of recovering the greatest volume of water.

Overall, the variability in metric pass/fail score for each farm dam parameter analysed was not large, with standard deviations generally between 0.004–0.05. The exception is for the annual total duration of bankfull flows metric that showed the greatest variability for each farm dam parameter.

Across all Environmental flow metrics, the evaporation loss parameter was the most sensitive (Figure 14), with the usage fraction parameter producing the least sensitive response. Those metrics that showed the most sensitivity to each of the farm dam parameters tested were predominantly metrics associated with the Low Flow Season and Transitional 2 (High to Low) flow season, particularly the 80th percentile non-zero flows and the mean number of years with 1 or more freshes.

Understanding the degree of variability of each farm dam parameter on each environmental flow metric can give an indication on which metrics might be close to "tipping over or under" the pass/fail threshold due to changes in farm dam inputs. With respect to priority 1 metrics (indicated by orange squares in Figures 13 to 15, and requiring a 75% threshold change pass score), there are no instances where a metric may switch from pass to fail, or vice versa. This suggests that although there is variability in the metric threshold change score caused by the farm dam parameters analysed, the variability is not of sufficient magnitude to influence the overall end results of the scenario analysis. This indicates a robustness in the use of the EWR Metrics as a decision making tool.

Further results for all scenarios for zone AR002 are presented in Appendix C.

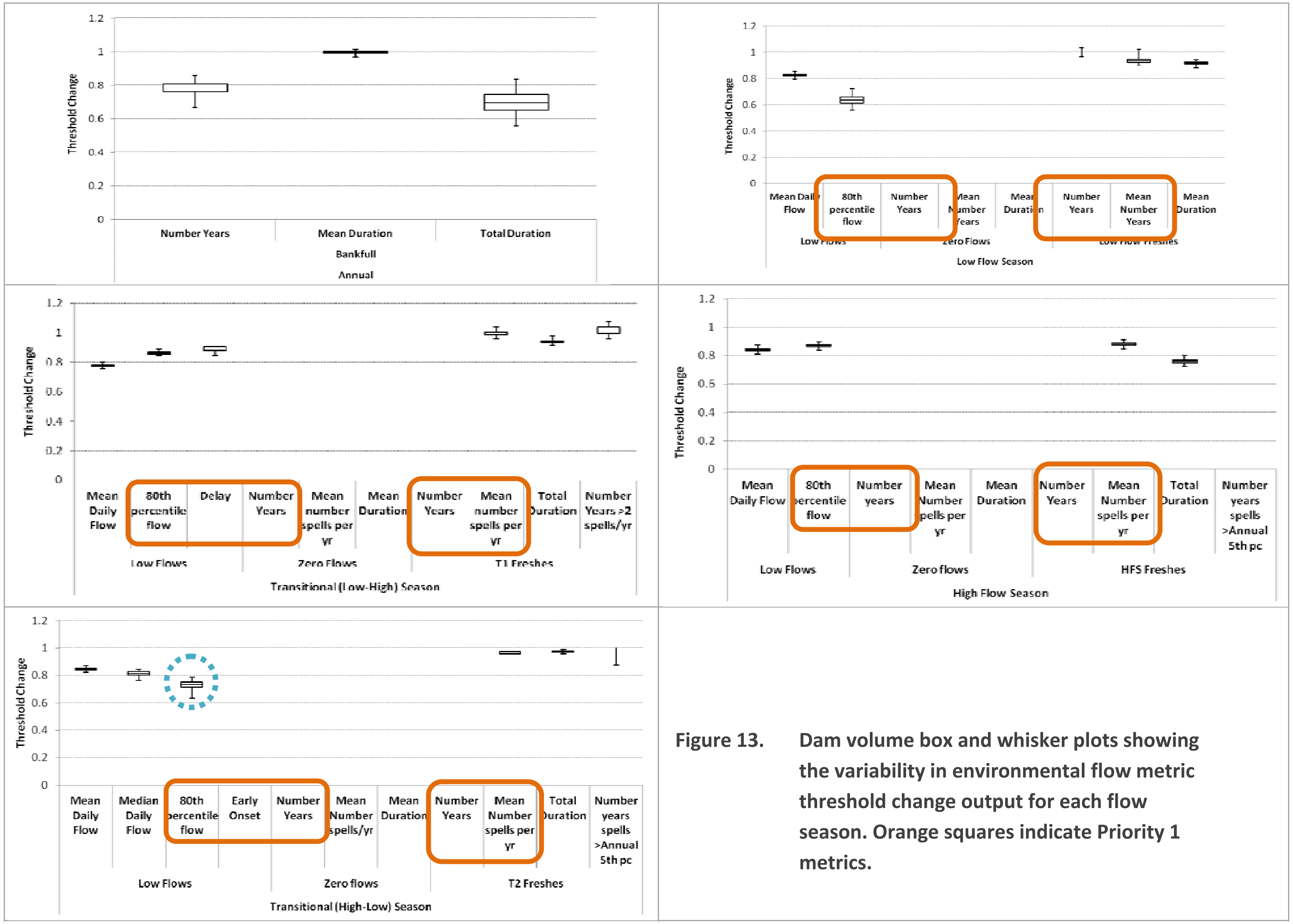


Figure 13. **Dam volume box and whisker plots showing the variability in environmental flow metric threshold change output for each flow season. Orange squares indicate Priority 1 metrics.**

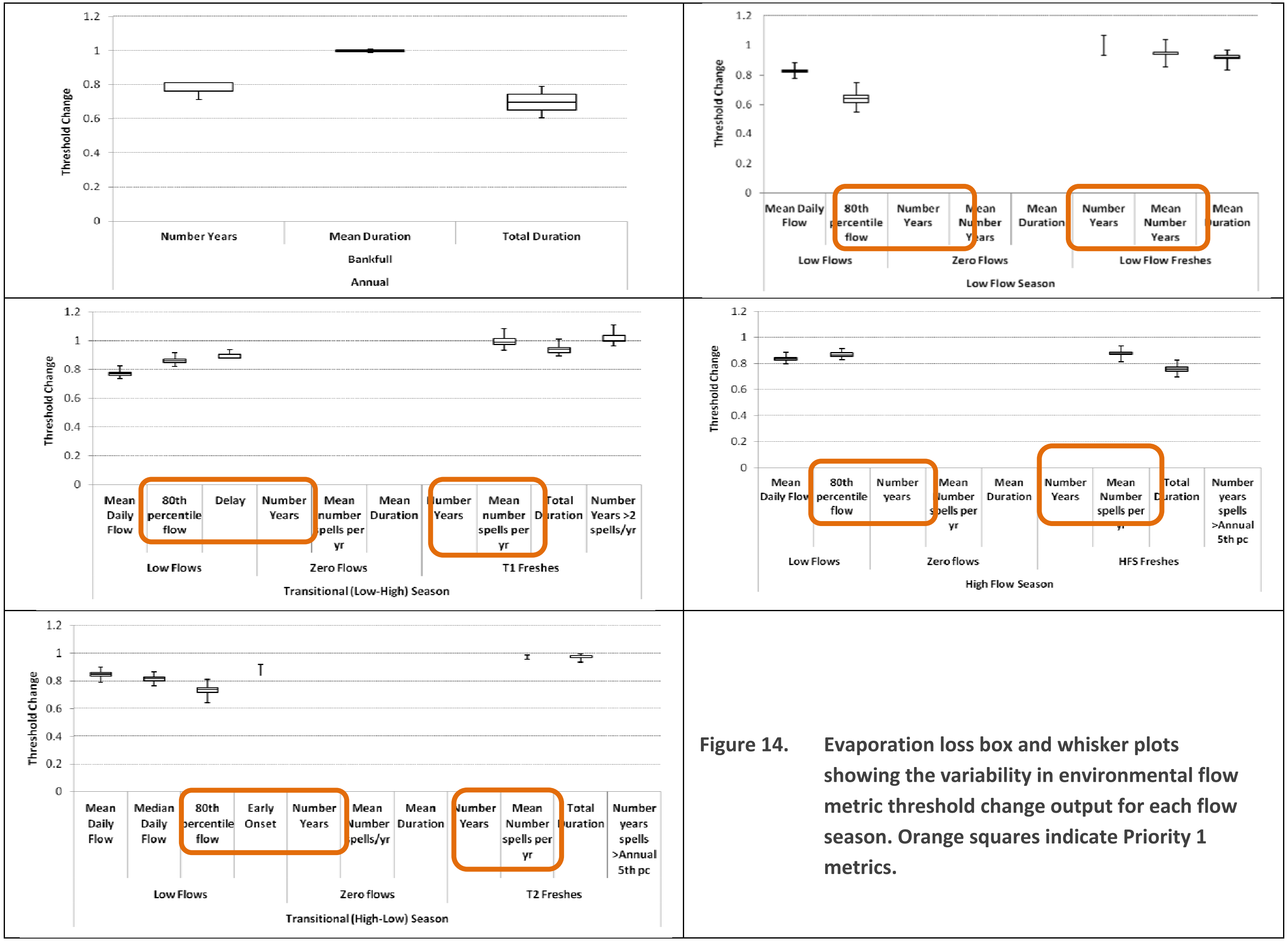
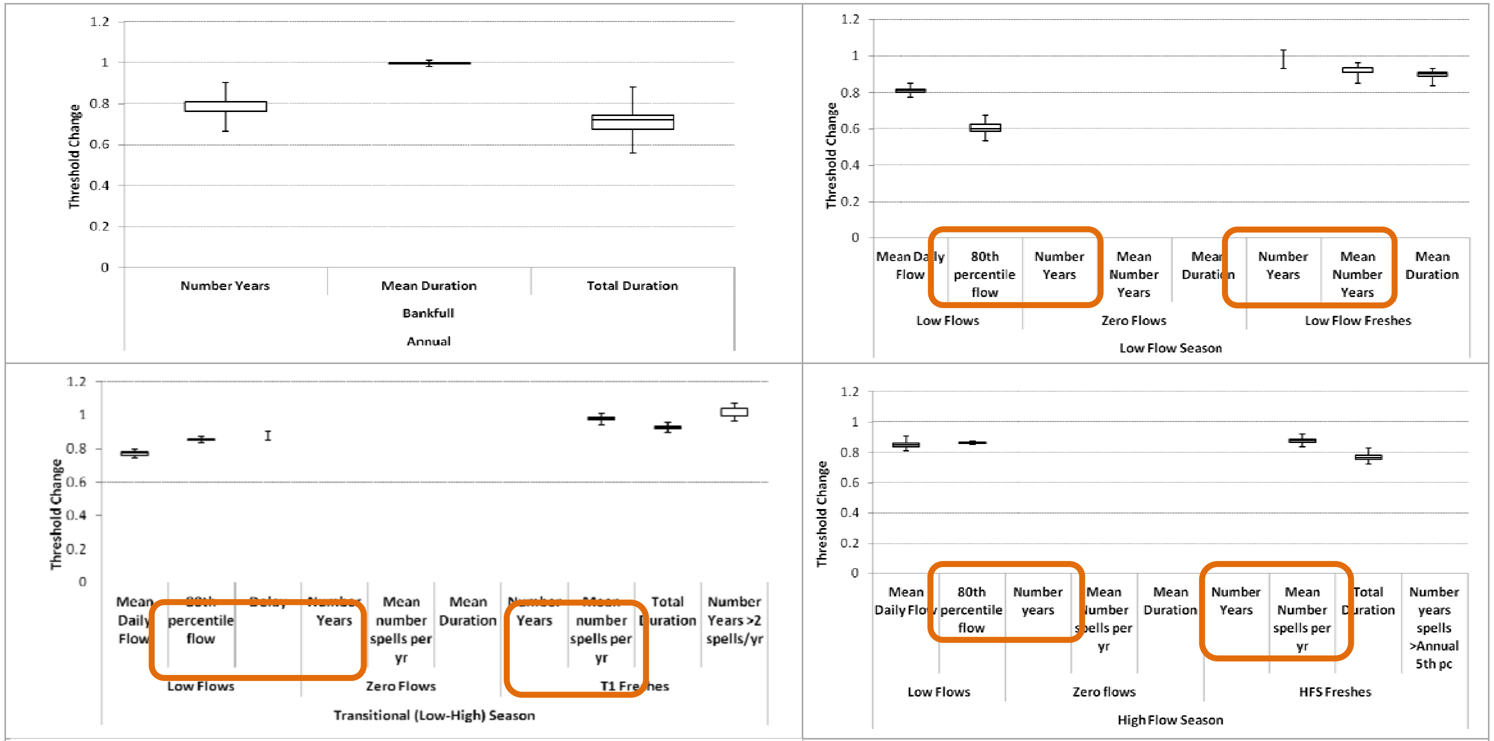


Figure 14. Evaporation loss box and whisker plots showing the variability in environmental flow metric threshold change output for each flow season. Orange squares indicate Priority 1 metrics.



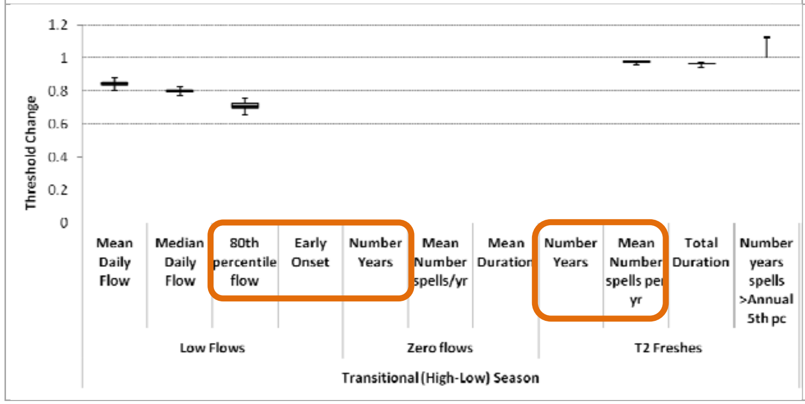


Figure 15. **Usage factor box and whisker plots showing the variability in environmental flow metric threshold change output for each flow season. Orange squares indicate Priority 1 metrics.**

3.2. PHASE 2

The primary benefit of restoring suitable low flows is to help provide water to the environment at the times and flow rates necessary to support critical ecological functions. This investigation has also estimated the total volume of water that may be returned to the system, which may be considered as a potential Murray-Darling Basin Plan Sustainable Diversion Limit offset.

For each scenario, the annual flow results were analysed for each test zone.

In addition, the total volume recovered for each scenario is compared to Scenario 2 to determine the likely low flow returns for any given scenario against the current situation of no LFRs on farm dams.

The results for the mean annual flows returned are shown in Table 12 below.

Table 12. Volume recovered as a % of "current flow" (Scenario 2 – Current (No LFR))

Test zone	Scenario 3	Scenario 4	Scenario 5	Scenario 6a	Scenario 6b	Scenario 7a	Scenario 7b
AR002	2.8%	2.2%	2.4%	0.2%	2.4%	0.2%	2.4%
BR038	2.2%	1.8%	2.0%	1.4%	2.2%	1.3%	2.0%
FR005	1.0%	0.7%	0.8%	0.2%	0.9%	0.2%	0.8%
OLW04	0.04%	0.00%	0.00%	0.03%	0.03%	0.01%	0.00%
OIV01	0.8%	0.6%	0.7%	0.5%	0.8%	0.6%	0.7%
Deep01	0.1%	0.1%	0.1%	0.0%	0.1%	0.0%	0.1%
TMP01	2.2%	2.1%	2.2%	1.3%	2.2%	1.3%	2.2%
Myp01	0.4%	0.2%	0.4%	0.3%	0.3%	0.2%	0.3%
Hind01	0.1%	0.1%	0.1%	0.0%	0.1%	0.0%	0.1%
M101	2.2%	2.1%	2.1%	0.9%	2.0%	0.9%	2.0%

As can be seen from Table 12, the variability of recovered flows is small, ranging between 0 and 2.8% across the different test zones. It is also clear from this table that there is little difference between several of the scenario options within a given zone. As identified in the previous section on grouping of scenarios through the Principal Component Analysis, there exist differences only in three groups of scenarios when considering Scenario 3 onwards.

When compared with Scenario 3, Scenarios 4, 5, 6b and 7b all exhibit similar recovery rates of total volume, while Scenarios 6a and 7a deliver a lesser amount of total water recovered through the use of LFRs.

Scenarios 5, 6b and 7b commonly provide an acceptable outcome, while Scenarios 6a and 7a commonly result in an unacceptable outcome (as per Table 7). Given this and the similarity in volume returned between scenarios 3, 4, 5, 6b and 7b, the total possible water delivery will be estimated using the average of Scenarios 3, 4, 5, 6b and 7b.

Modelled range of recovered volumes

Using the Monte Carlo Analysis described in Section 3.1.6, the uncertainty in the model prediction of recovered volumes was investigated with regard to three key parameters in the model; Evaporation Rates, Usage Rates from farm dams, and estimated farm dam volumes. This analysis was only conducted on one of the selected test zones; AR002 in the Angas River catchment of the EMLR.

Of these three parameters it was found that evaporation rates have the greatest impact on the certainty of the results. A box plot showing the inter-quartile Range, the median and extreme values is shown in **Figure** 16, which illustrates the uncertainty for each scenario and the scenarios identified above.

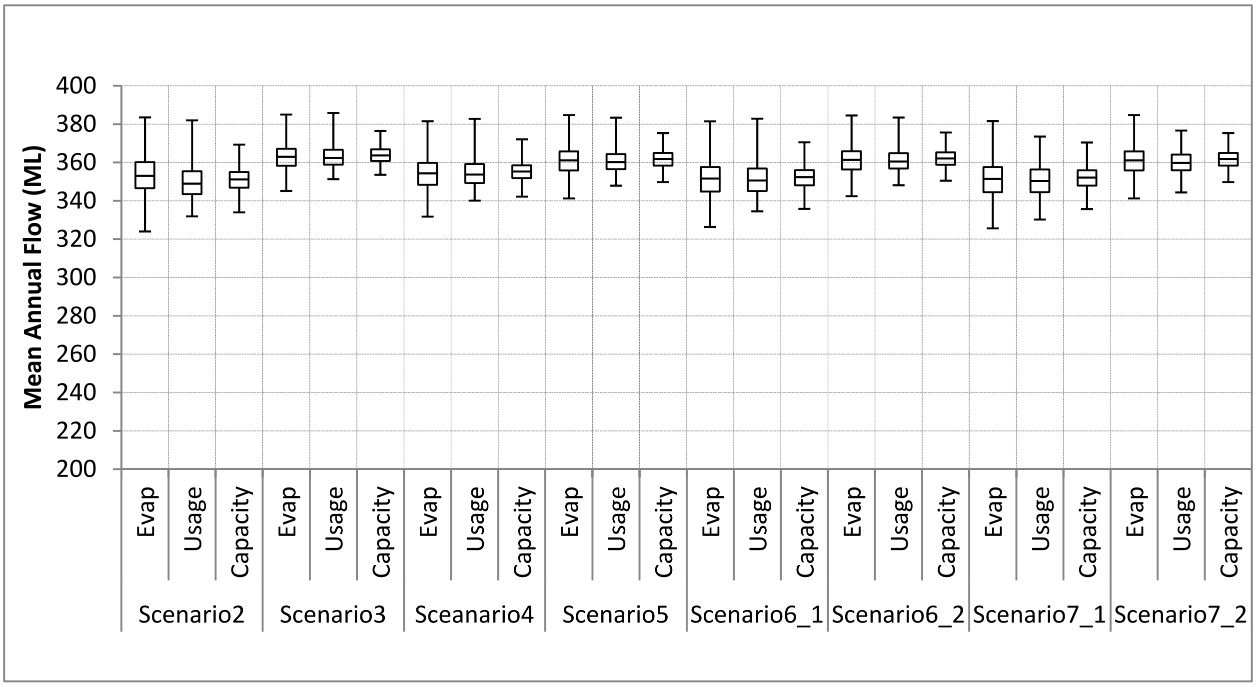


Figure 16. Box Plots showing variance of flows delivered for Test Zone AR002 between scenarios

As can be seen in the charts for the flow variance values, the differences in variation within a parameter such as evaporation between the scenarios is negligible. In fact when tested using the Kolmorigov Smirnov Test (which compares the distributions for differences) the result of the H0 null hypothesis is true at the 0.05 level of significance. This means that, in terms of volumes returned, there is no statistically significant difference between the scenarios. However, due to the targeted scope of this project, when scaled up to entire prescribed areas, the results should be taken to be indicative estimates only.

3.2.1. REGRESSION ANALYSIS OF RECOVERED VOLUMES

To enable estimation of the expected recovered volume across the region, several factors were investigated to determine whether a relationship could be derived between zone characteristics and the volume recovered (as a percentage of natural flow) for the ten test zones. Such a relationship could then be applied to the remaining zones in the region. The zone characteristics investigated were:

1. Total Runoff from the Zone (Runoff ML)
2. The total capacity of dams in the zone (DAMVOL)
3. Development Level: the total capacity of dams divided by the total natural runoff in the zone (PCDev).

The results of a correlation analysis are shown in Table 13, which indicates that the strongest correlation of 0.82 is the level of development in the zone.

This result appears reasonable, as zones with very high dam capacities are most likely to be required to release low flows as the first factor in LFR selection is related to dam capacity (5 ML and above for Scenarios 3, 6a, 7a; and 10 ML and above for 4, 5, 6b and 7b). The total volume of large dams make up the largest proportion of dam volumes in the vast majority of catchments. For example, across the EMLR and WMLR PWRAs, dams above 5ML make up around 70% of the total volume.

Table 13. Correlation table

	PFR	*Runoff (ML)*	*DAMVOL*	*PCDev*
PFR*	1			
RunoffML	-0.40	1		
DAMVOL	0.22	0.57	1	
PCDev	0.82	-0.52	0.28	1

*Percentage of natural flow recovered

Further analysis of the Development Level (PCDev) factor for each test zone reveals that a positive relationship exists between Percentage Development and the volume of water recovered for each scenario. The differences between each scenario however are very small, and given the range of uncertainty determined by the Monte Carlo Analysis, there appears to be no case for using a distinct regression for each modelled scenario.

As such a generalised regression has been selected for scaling the results from the 10 Test Zones to the remaining Surface Water Management Zones based on Scenarios 3, 5, 6b and 7b as discussed in Section 3.2 above. This regression is shown in Figure 17, which indicates the expected percentage of returned low flows for a given development level.

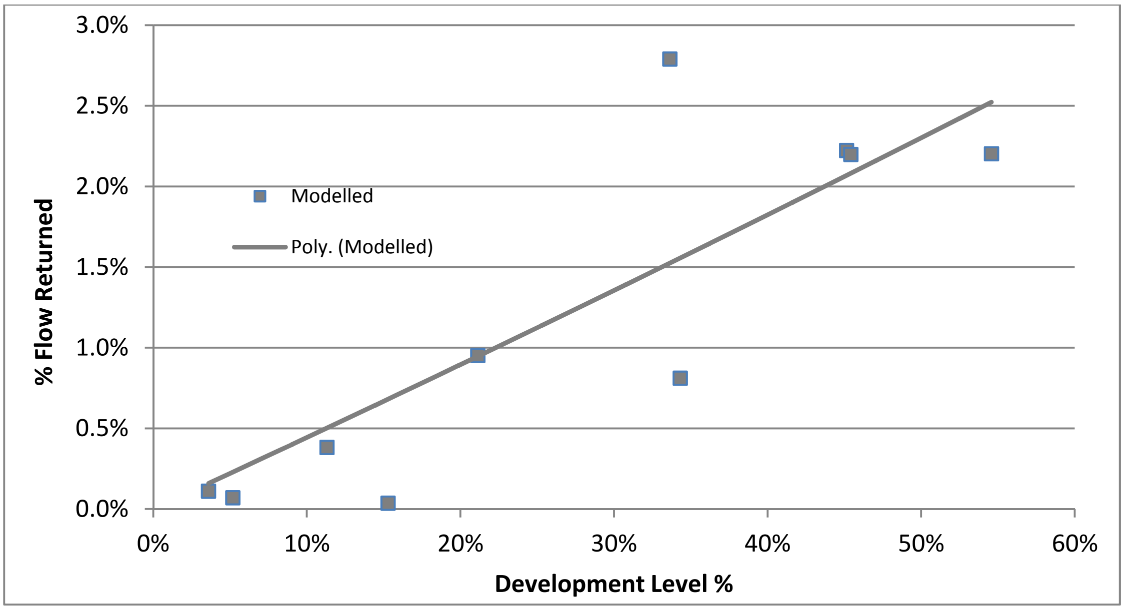


Figure 17. Relationship between level of development and % flow recovered by LFR implementation

Equation 1

$$PFR = 0.018PCDev^2 - 0.035 \times PCDev$$

Where:

PFR = Percentage of Adjusted Flow Recovered

PCDev = the level of development of the Zone calculated by dividing the total dam volume by the adjusted Runoff

3.2.2. CALCULATION OF THE POSSIBLE RECOVERABLE VOLUME

Given that the range (the difference between scenarios) of volumes returned under each scenario is insignificant, we can assume that estimates of the total volume recovered can be summarised by Equation 1.

The distributions of development level for zones within each PWRA give some indication of the level of expected recoverable volume. These distributions are shown in Figure 18 to Figure 20 below.

Distributions of Development Level in each Prescribed Area

The distribution in the Marne Saunders PWRA (Figure 18) appears to be more uniform than either the EMLR or WMLR. This indicates that there will likely be a higher level of returned flows in this area due to the positive exponential relationship shown in Figure 17 above.

The distribution in the EMLR PWRA (Figure 19) is more skewed, with most values being below 0.2 development level. This indicates that the likely average level of returns per zone would be lower than that for the Marne Saunders PWRA.

The distribution shown for the WMLR PWRA (Figure 20) zones indicates a higher proportion of zones with a low level of development.

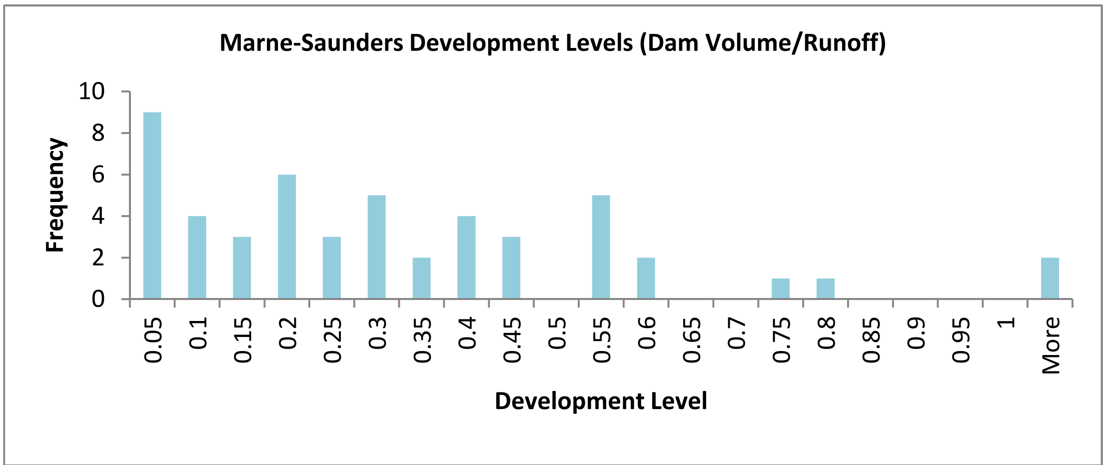


Figure 18. Distribution of dam volumes in Marne Saunders PWRA

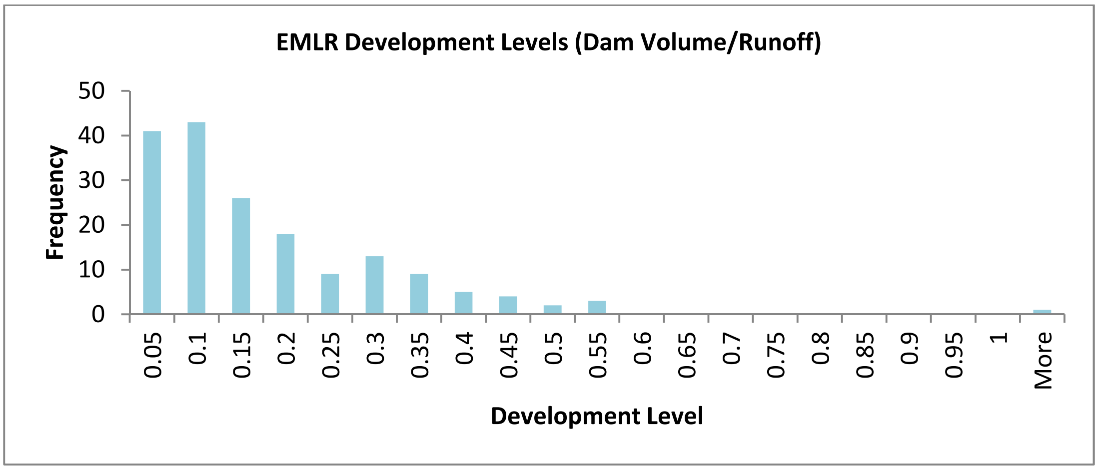


Figure 19. Distribution of dam volumes in EMLR PWRA

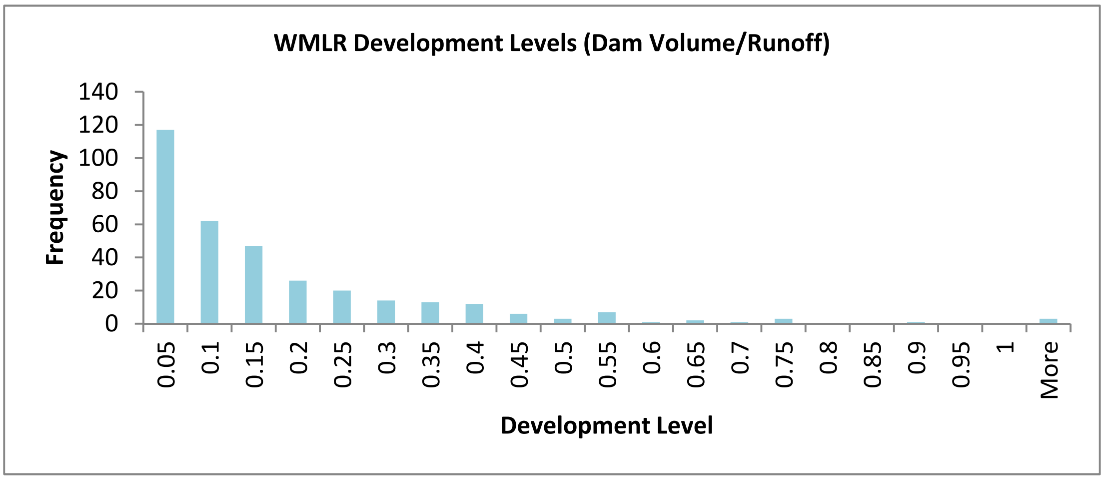


Figure 20. Distribution of dam volumes in WMLR PWRA

Using the relationship derived in the previous section (Equation 1), the results for each PWRA are given in Table 14 below. This was calculated using the development level for each zone to derive the percentage of returned flow. This percentage is then multiplied by the runoff for each zone to arrive at a volume. By way of comparison, previous estimates of this volume have typically been in the order of 0.5-2% of "natural" flow in the EMLR PWRA (Alcorn, 2010).

Table 14. Low flow volumes returned to the system under Scenario 3

PWRA	Volume Recovered (ML)	Percentage of "Natural" Flow recovered
Marne Saunders	160	1.6%
EMLR	650	0.6%
WMLR	1510	0.4%
Total	2320	0.5%

4. CONCLUSIONS

This report describes the methodology and results of the investigation undertaken to assess the feasibility of strategic placement of low flow releases in the three Prescribed Water Resources Areas of the Mount Lofty Ranges.

Phase 1: Strategic Location

Ten focus surface water management zones were selected across the three PWRAs. These zones were selected to represent as wide a variety of landscape conditions as possible, taking in a range of rainfall, water resource development levels and geography. A total of nine modelling scenarios were defined.

In addition to the three Base scenarios of; “No Dams Flow”, “Current Dams with no LFR” and “Base WAP” scenarios, six other scenarios were investigated to determine the feasibility of reducing the number of LFRs required while satisfying as near as possibly the existing environmental requirements:

- Scenario 4 investigated the possibility of placing LFRs only on dams of 10 ML or greater capacity
- Scenario 5 built on Scenario 4 by adding additional LFRs on strategically located “blocking dams” that are also scope dams under the current or proposed legislative framework
- Scenario 6a removed LFRs from headwater dams in Scenario 3 which were located on 1st order streams
- Scenario 6b removed LFRs from headwater dams in Scenario 3 which had an upstream area of less than 10 ha
- Scenario 7a removed LFRs from headwater dams in Scenario 5 which were located on 1st order streams
- Scenario 7b removed LFRs from headwater dams in Scenario 5 which had an upstream area of less than 10 ha.

Hydrological models of each test zone were built using the eWater Source IMS modelling platform and a purpose built farm dam plug-in allowing the assessment of low flow releases from individual farm dams in a catchment. These models were run with the various scenario data input to each farm dam (LFRs switched on or off for each scenario) and outflows at the end of each zone were saved and analysed.

The daily and seasonal flow regime was assessed using the existing environmental water targets from the existing Environmental Water Requirements assessment method (as used for the relevant WAPs) and results between each scenario compared.

Based on this approach and analysis of the subsequent results, this project has demonstrated that it is feasible to place LFRs strategically within a surface water zone, such that fewer LFRs are required to achieve a similar outcome in terms of the environmental water targets, when compared to the "Base-WAP" scenario. However, there can be more than one suitable (or near-suitable) location strategy for a given surface water zone, and a strategy suitable for one surface water zone is not necessarily suitable for others. This lack of a “stand-out” location strategy presents a significant challenge for any potential LFR implementation program.

For nine of the ten surface water zones examined in detail as part of this project, at least one of the six location strategies (or scenarios) trialled was able to approximately meet the environmental water targets while reducing the number of LFRs required (when compared to the “Base WAP” scenario). For most of these zones, there were also one or more location strategies that compromised the achievement of EWR metrics. However, not only did the suitable (or near-suitable) location strategies differ between surface water zones, but a strategy which compromised existing environmental water targets for one zone, could be one of the more suitable strategies for another zone (and vice versa). This also presents a significant challenge for any potential LFR implementation program.

The maximum reduction in number of LFRs (whilst still approximately maintaining achievement of existing environmental water targets) ranges from 6% in the zone with the minimum possible reduction, to 52% in the zone with the maximum possible reduction in LFR numbers. As such, if a strategic location approach is adopted as part of an implementation program to return low flows, careful consideration should be given to ensure the program takes an approach that minimises the chances of adopting a strategy that compromises existing environmental water targets; while maintaining the opportunity to realise a reduction in LFRs that is as high as possible.

Phase 2: Calculation of returned flows

Calculation of possible return flows was carried out for each management zone using a regression derived from the 10 test zones. As difference in the percentage of flow returned between scenarios was small, a single regression relationship was derived and applied across the three PWRAs.

The total possible volumes of mean annual returned flow for the Marne Saunders, EMLR and WMLR were; 160, 650 and 1510 ML respectively. This represents approximately 1.6% of natural flows for the Marne Saunders. This is higher than that recovered for the EMLR (0.6%) and the WMLR (0.4%). This difference was found to be due to the higher proportion of highly developed surface water zones in the MS PWRA.

Although the volume of flows returned to the system may appear small, it is important to note that the benefits of LFRs are not just related to a notion of 'volume of water saved for the environment'. Rather, the primary benefit of securing suitable low flows is to help provide water to the environment at the right times in the right amounts. Returning natural low flows that are otherwise intercepted by dams and diversions supports critical ecological functions, such as maintaining key aquatic refuge habitats in streams during the drier seasons. It is also important to get flows back into the system sooner at the break of season, giving water-dependent plants and animals the right length and pattern of flow to go through their life cycles, and to provide access to different habitats needed for feeding, breeding and shelter.

Uncertainty Analysis

A Monte Carlo analysis was conducted to assess the uncertainty around parameters in the Source IMS hydrological models. The analysis was carried by selecting and varying parameters within the model according to their known or estimated uncertainty distributions. Of the three parameters – evaporation, estimated dam capacity and dam usage fraction – evaporation was found to be the largest source of model uncertainty.

Despite this uncertainty, an assessment of the threshold change value of individual environmental flow metrics revealed that this had little impact on the outcome of the metrics as a decision making tool.

Applicability and Limitations

The ten surface water zones used in this study were selected to represent a wide variety of landscape conditions, rainfall distribution, water resource development levels and geography across the MLR. However, they represent only a small sample of the 584 surface water zones in the highly hydrologically variable MLR. Hence, the quantitative elements of the results presented can be considered only as indicative estimates for the entire MLR. Further investigation would be required to extend the methodology presented in this report to other surface water zones across the MLR.

One possibility of extending the results could be to use the ten zones modelled in by this project as “reference zones” against which newly considered zones could be compared. The modelling undertaken as part of this project could provide valuable insight to the types of LFR location strategies that are likely to be suitable for a newly considered zone that is similar in characteristics to a “reference zone”. Further work may be required to identify the zone characteristics that support different strategic location options, and also to minimise the potential of unintended adverse impacts of strategic location approaches on downstream zones. Additional targeted examination at a greater level of detail (eg. zone-scale modelling) may also be required to assist identification of suitable location strategies for zones that differ markedly from all ten “reference zones”.

While there are limitations, as discussed in the previous paragraph, in application of the results of this report across the MLR, the analysis and the modelling methodology used in this investigation align with current best practise modelling guidelines (Black et al., 2011), and hence are considered scientifically robust and appropriate for this investigation, and importantly, for further investigations if required.

APPENDICES

A. DESCRIPTION OF TEST ZONES

This section includes description of the sample surface water zones, with information on zone MP01 provided in Section 3.1.1. It includes information on location and catchment area, the rainfall and resource capacity data for each zone, and land use in the area. Dam information for the zone and, information on the stream record are also included in the description. The reason of selecting the zone as a sample case is also discussed for each selected zone.

SURFACE WATER ZONE LW04

Figure 21. Zone LW04: Dams and stream network details

This zone lies in the Lenswood Creek Sub-catchment of Onkaparinga River catchment. It is the smallest (catchment area: 1.7 km^2) of the test zones selected for the project. The annual average rainfall for the zone is 944 mm while the resource capacity is 313 mm. The major land use is the irrigated agriculture tree fruits while other land uses are native cover and grazing modified pasture.

There are 20 farm dams in the zone, with a total dam capacity is 73 ML. Majority of the dams are used for stock and domestic purpose. There are only eight dams which are currently considered scope dams and they hold more than 44% of dam capacity. Most of the dams are in first order streams and more areas of the zone contribute to free to flow rather than an intercepted flow by dam development. There are a number of off-stream dams in the zone. The water resource development level for this zone is around 15%.

No gauging station exists in this zone, hence flow from the zone is estimated using gauging station (A5030507; Lenswood Creek at Lenswood) from a neighbouring catchment. Since the land use pattern and rainfall of the two areas are similar, the proportional flow is calculated using the area of the zone and the contributing area of the gauging station.

This zone was selected as a test zone due to the following reasons:

- It has a higher proportion of scope dam, and all those large dams are located in series
- There is also a large proportion of free- to-flow area within the zone.

SURFACE WATER ZONE IV01

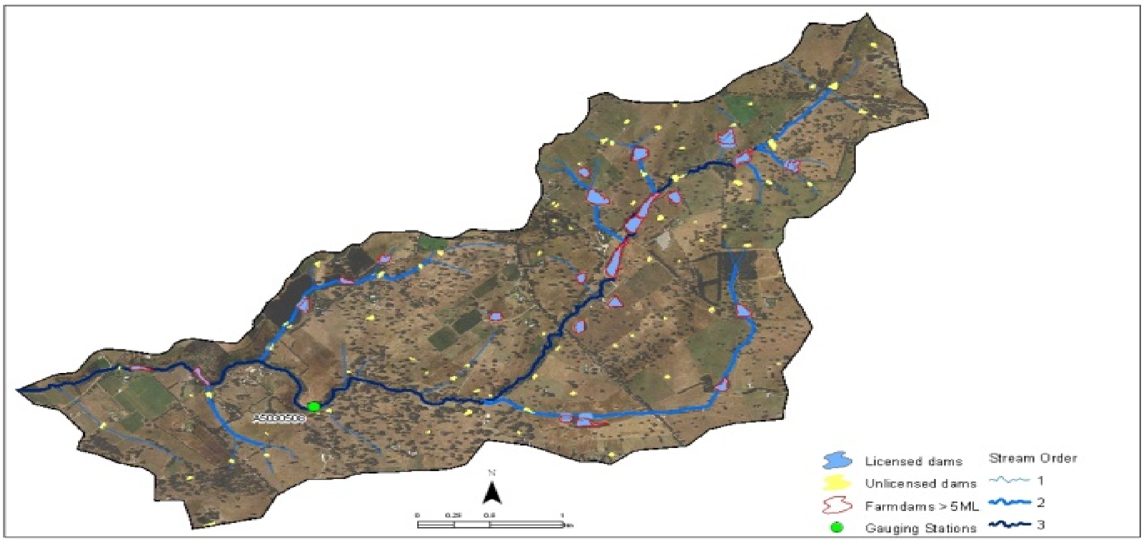


Figure 22. Zone IV01: Dams and stream network details

The zone lies in the Inverbrackie Creek sub-catchment of Onkaparinga River catchment. It has an area of 11.72 km^2. The average annual rainfall in this zone is 807 mm and the annual adjusted runoff (resource capacity) volume is 1495 ML, which equates to 119 mm runoff. Majority of the land is used for grazing modified pasture, with other minor uses being natural environment and conservation area and some irrigated horticulture areas.

Although there are lots of dams (103 dams) in the zone, only 22% of them are scope dams. The total capacity of dams is 461 ML, with 25% of them being held in scope dams. Water resource development level in this zone is 34%.

Gauging station (A5030508; Inverbrackie Creek- Craigbank) is the flow measuring station in the zone, but it is upstream of the zone outlet, not at the outlet. The catchment area of the gauging station is 8.4 km^2. The measurement at this station was used to estimate the flow at the zone outlet.

The zone was selected as a test zone as:

- Most licensed dams are clustered in the upper part of the catchment and the bigger dams are located in a row
- A long record of stream flow data is available for this zone.

SURFACE WATER ZONE HIND01

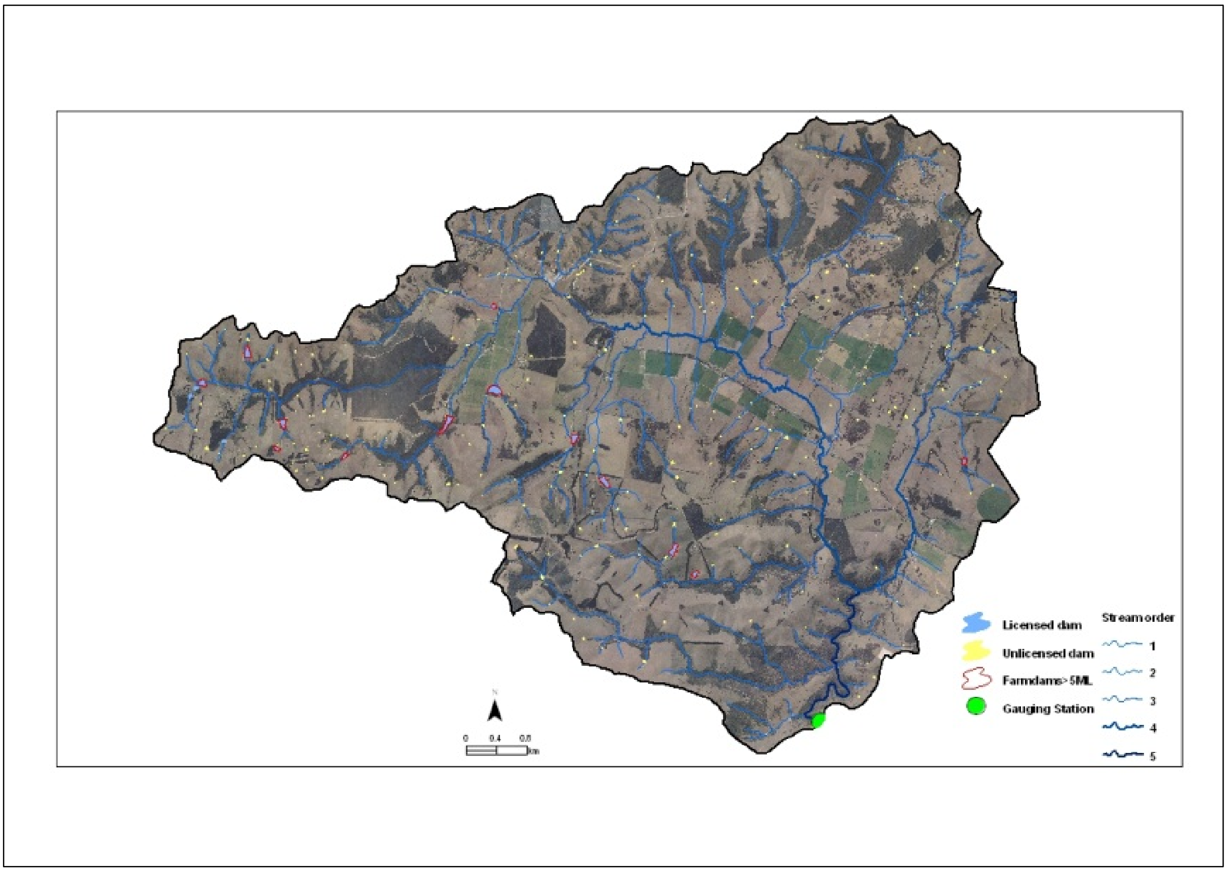


Figure 23. Zone Hind01: Dams and stream network details

This is one of the surface water zones in Fleurieu region within the WMLR PWRA. It lies in Hindmarsh catchment and is a upstream sub-catchment with a catchment area of 56.1 km^2. The average annual rainfall of the zone is 879 mm while the resource capacity of the zone is 174 mm. Grazing pasture is the main land use in this zone and native cover and irrigated pastures cover minimal areas.

The farm dam development in the zone is low while compared with resource capacity but the number of farm dams is high. Total number of farm dams in the zone is 337 with a total dam capacity of 496 ML and 6% of them are scope dams.

Flow from the zone is measured at the long term Gauging station (A5010500; Hindmarsh River at Hindmarsh Valley Res Offtake Weir). This has a long term record and was converted to telemetry in 2010 to have a continuous record.

The reason for selecting this zone for scenario development is the larger number of dams are unlicensed and only 4% of dams are licensed, the distribution of dams across the catchment, and availability of long term gauging record.

SURFACE WATER ZONE DEEP01

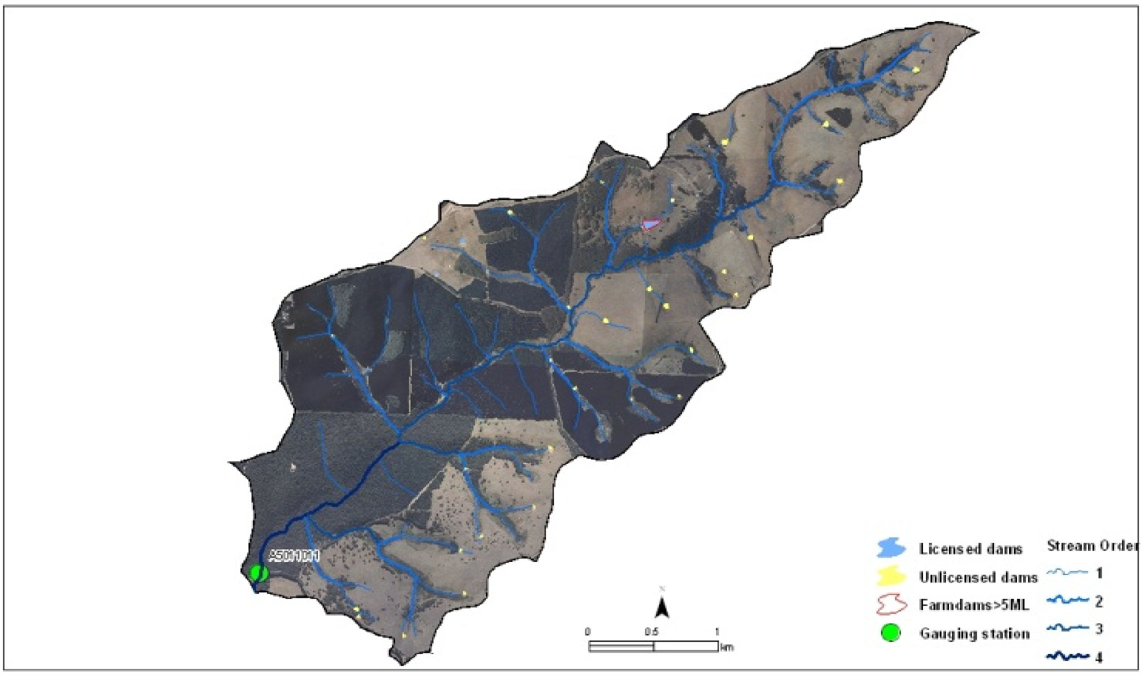


Figure 24. Zone Deep01: Dams and stream network details

This is one of the zones in Fleurieu region which lies in the Southern Fleurieu. It is the upstream area of the Deep Creek catchment and has a catchment area of 11.2 km2. The average annual rainfall in the area is 840 mm and the resource capacity of the area is approx. 1300 ML (125mm). Plantation forestry and grazing modified pasture are the major land uses in the zone.

There are fewer farm dams in this surface water zone compared to other zones in the region. Out of 37 farm dams, just three of them are licensed and only one dam is greater than 5 ML. The water resource development level is just 4%.

A gauging station A5011011 (Deep Creek near Tappanappa Road) was established at the outlet of this zone in 2006. Hence, this station has a very short period of record (around 4 years). This station in now under the custody of Forestry SA.

This zone is selected for scenario development as it has very few licensed dam and has only a dam which can provide the project some highlights on exclusion rules for strategic location of low flow release.

SURFACE WATER ZONE MYP01

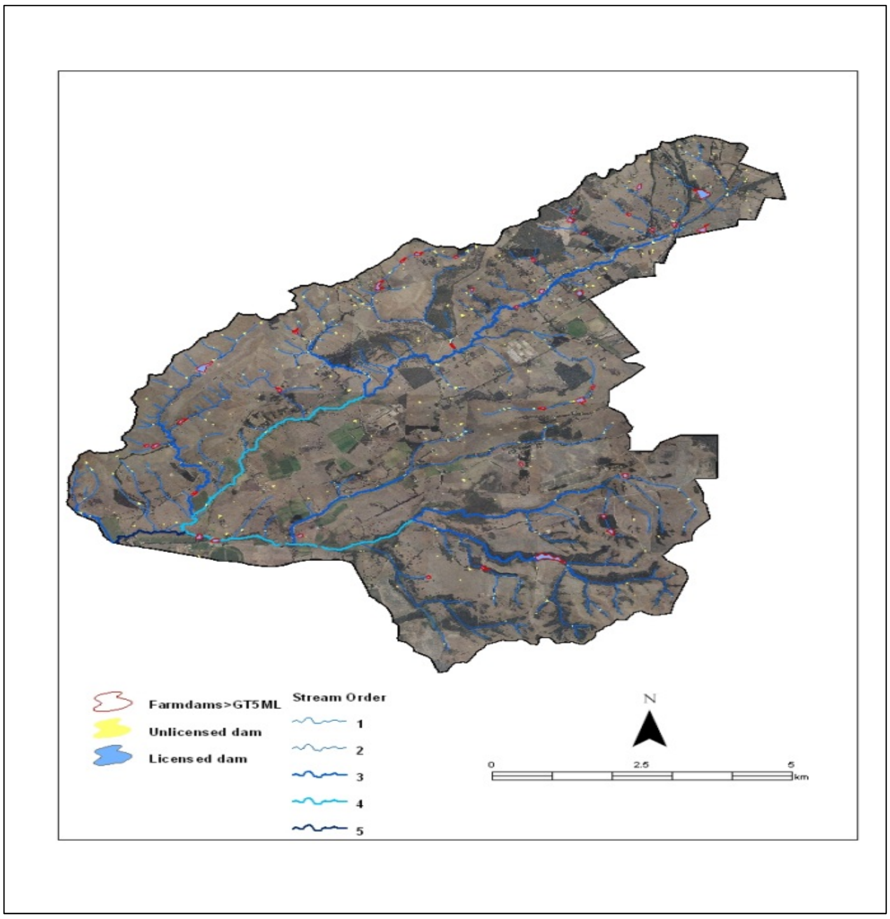


Figure 25. Zone Myp01: Dams and stream network details

This is an upstream zone in the Myponga River catchment and one of the largest surface water zones (catchment area: 74.4 km2) selected for scenario development. The average rainfall for this area is 863 mm and the resource capacity is 138 mm. The major land use of this zone is grazing modified pasture as in most of the selected zones.

This zone has a large number of farm dams (total: 474 farm dams) which makes a total dam capacity of 1124 ML. Forty dams in this zone are licensed and the capacity of these licensed dams is 13% of total dam capacity. There is a long term flow record for this zone. The gauging station (A5020502; Myponga River upstream dam and road bridge) doesn’t lie on this zone itself but it lies at the top of downstream catchment, hence the record of this station is the flow record from this zone only.

The reason for selecting zone is there are significant number of licensed farm dams and these dams are concentrated on low order streams rather than scattered.

SURFACE WATER ZONE FR005

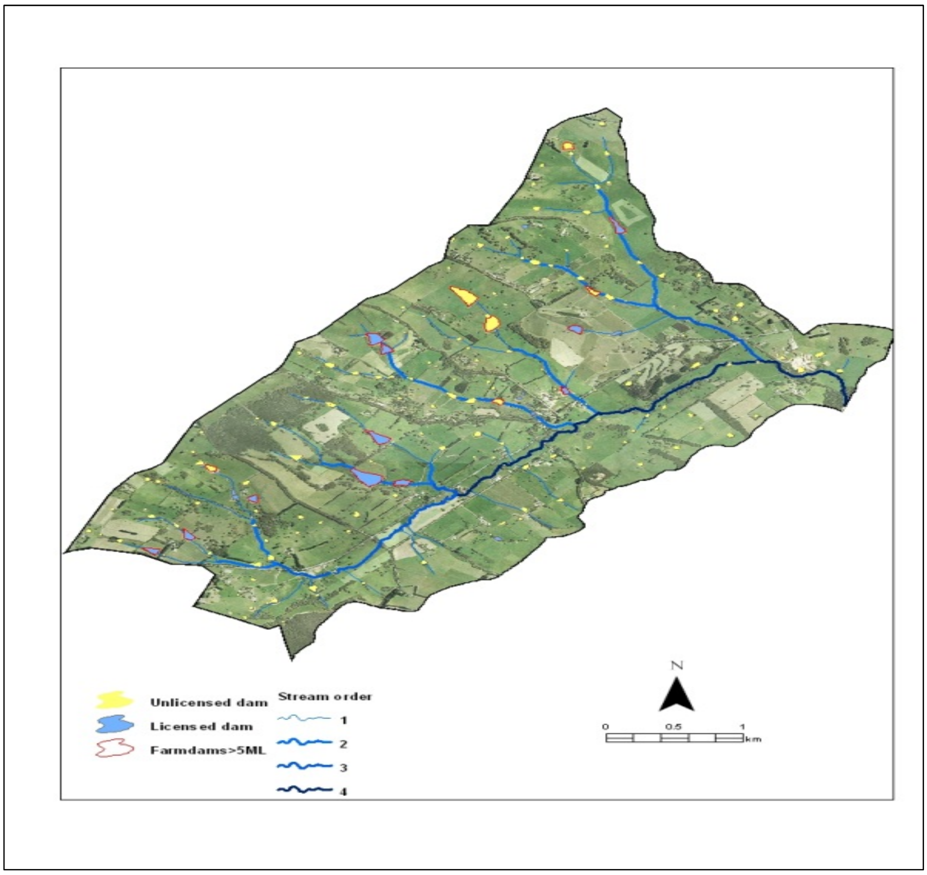


Figure 26. Zone FR005: Dams and stream network details

This zone is in the Meadows Creek sub-catchment of the Finniss River within the EMLR PWRA . The catchment area of this zone is 15 km2. The average rainfall in the area is 870 mm and the resource capacity is 144 mm. The major land use of the area is grazing pasture.

There are 184 farm dams with total dam capacity of 445 ML in the zone, out of which only 17 dams are scope dams (total capacity of scope dams is 15% of the total dam capacity).There is no stream flow gauging site in this zone.

The zone is selected for scenario development because the similar pattern of dam distribution is observed in most headwater zones of Finniss River.

SURFACE WATER ZONE AR002

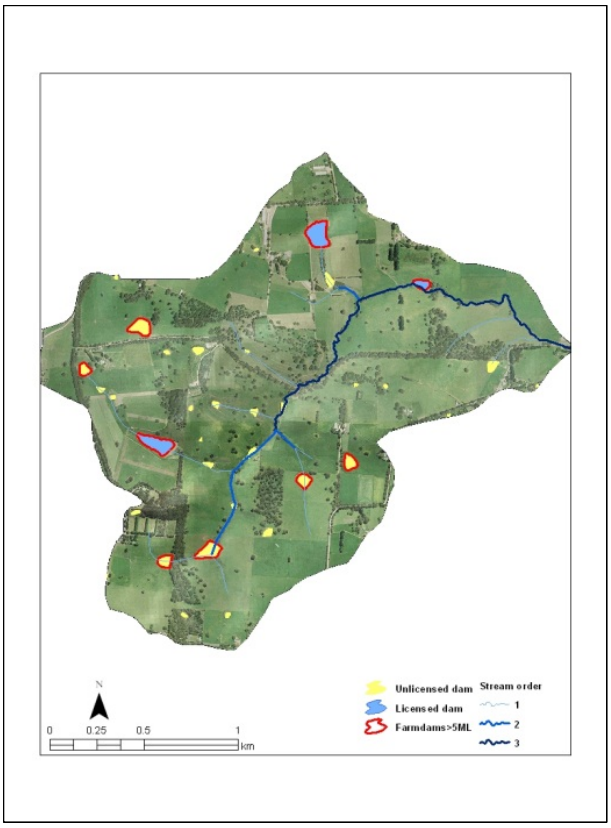


Figure 27. Zone AR002: Dams and stream network details

The zone lies in the Upper Angas River sub-catchment of the Angas River Catchment. This is the smallest zone (catchment area: 4 km2) selected in the EMLR prescribed area. The mean annual rainfall for the zone is 828mm and the resource capacity is 127 mm. The general (primary) land use in the area is grazing and irrigated pastures.

There are 35 farm dams present in this zone with a total capacity of 160 ML, with 32% of that being held in licensed dams.

The zone was selected for scenario development owing to the existence of many dams greater than 5 ML and those dams being located on low order streams.

SURFACE WATER ZONE BR038

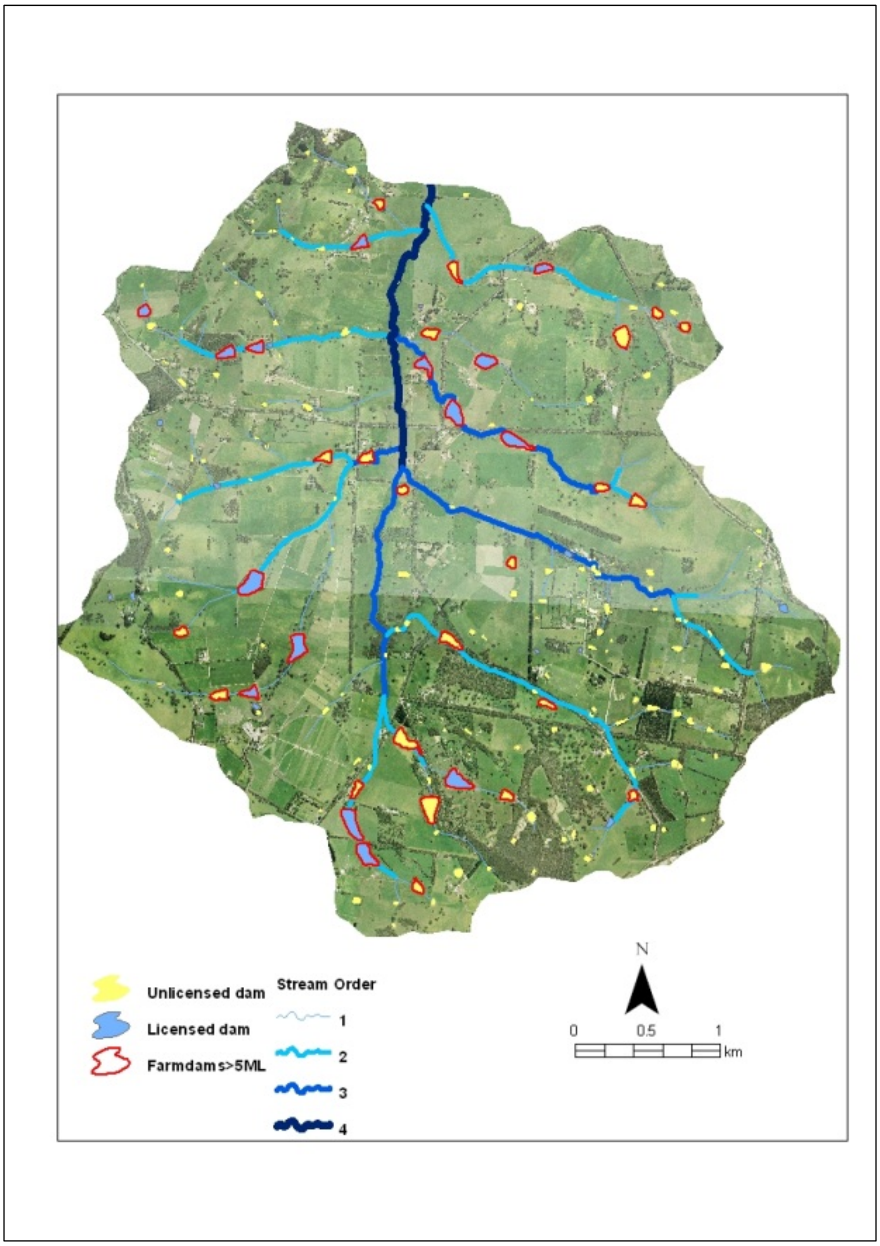


Figure 28. Zone BR038: Dams and stream network details

This is another zone selected in the EMLR PWRA . This zone lies in Mt Barker Creek sub-catchment in Bremer river catchment. The selected area (catchment area 19 km2) is only an upper portion of this zone. The average rainfall of the selected area is 782 mm and the resource capacity is approximately 92 mm.

There are 191 farm dams in the zone with a total capacity of 776 ML, with 40% of that capacity being held in licensed dams. The zone is selected for scenario development due to the large number of dams greater than 5 ML, and the dams being uniformly distributed across the zone.

SURFACE WATER ZONE M101

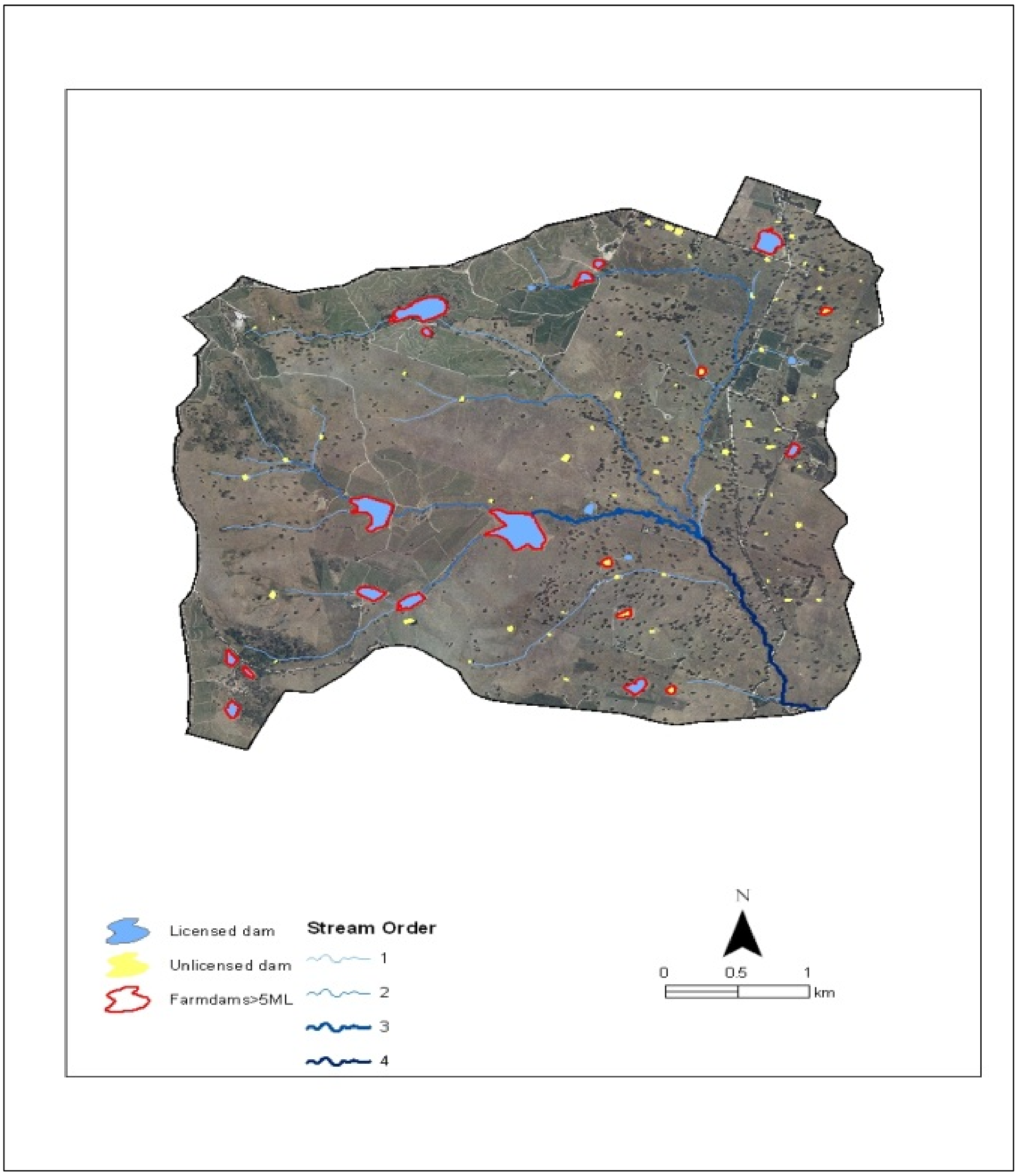


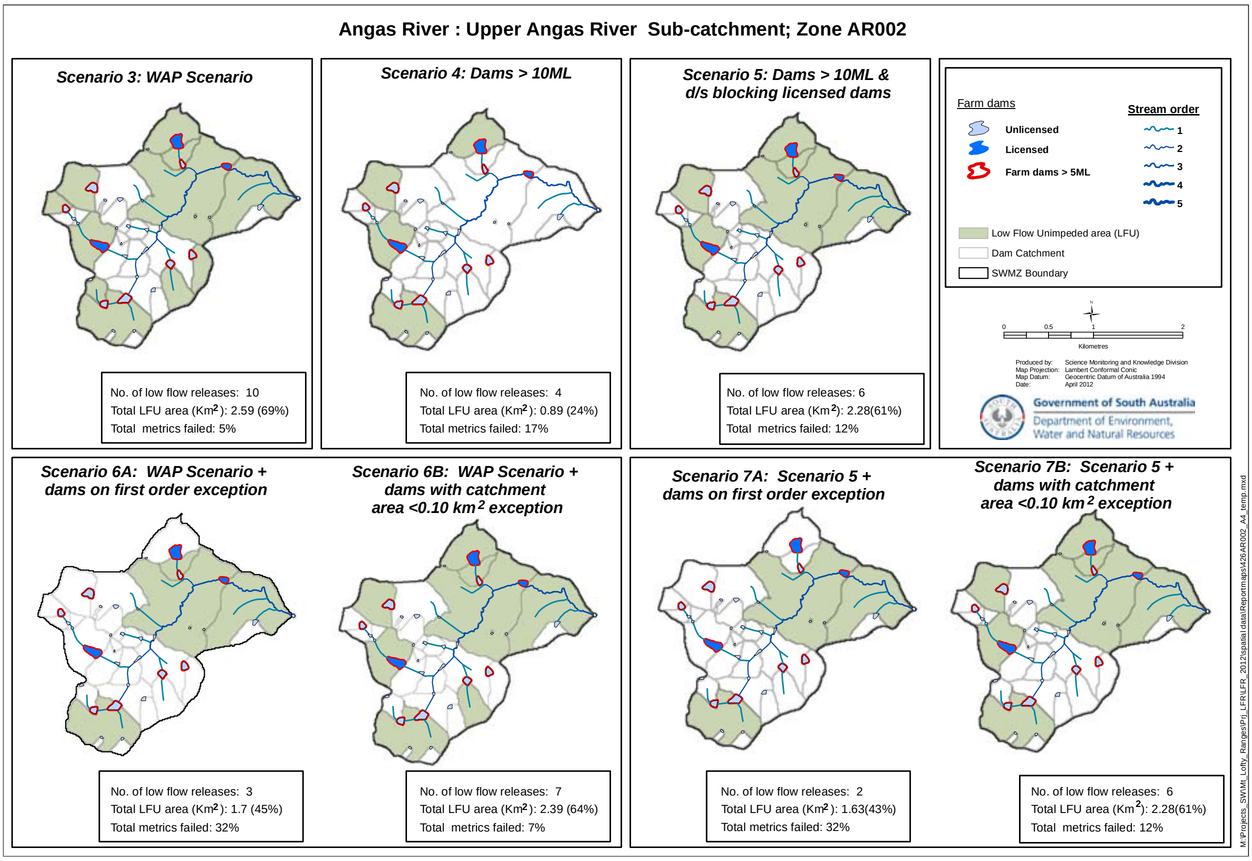
Figure 29. Zone M101: Dams and stream network details

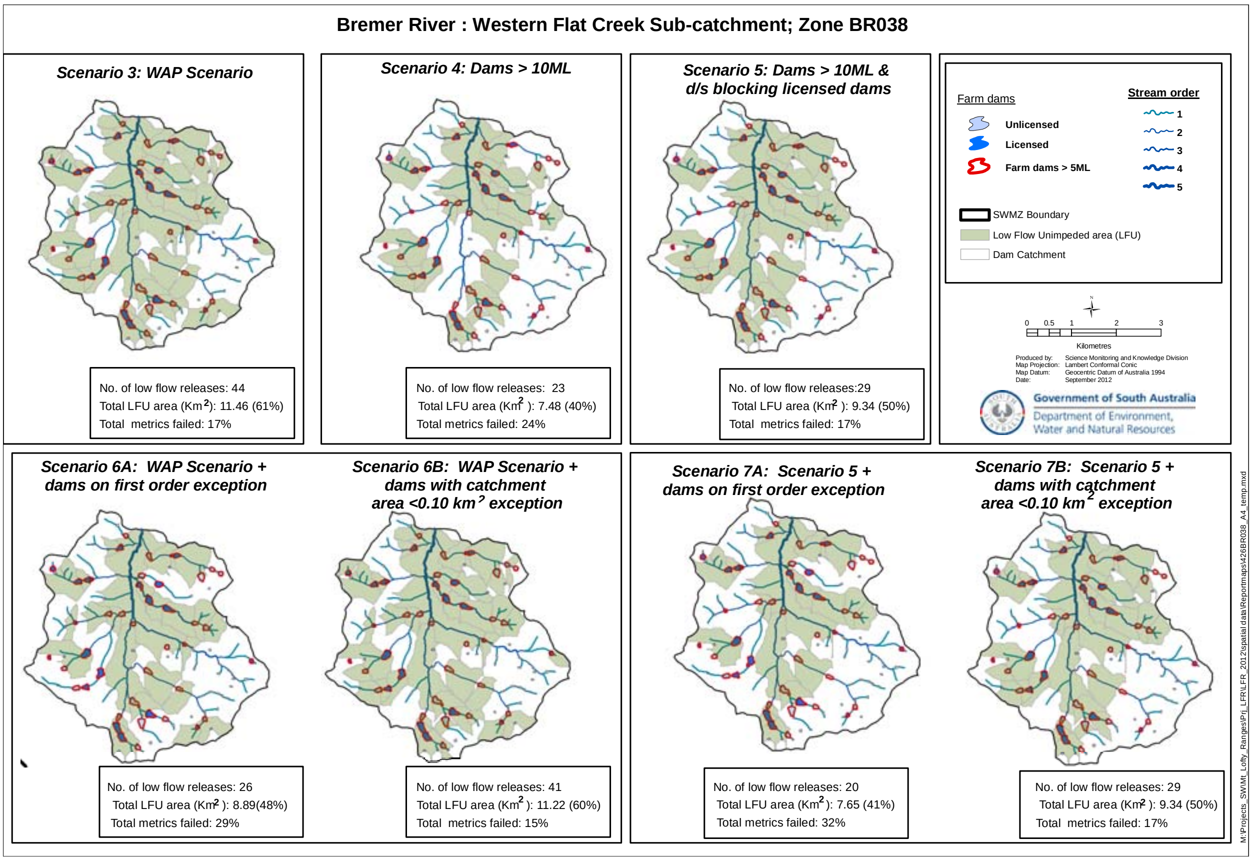
This is the only zone selected from Marne Saunders PWRA. Its catchment area is 18.2 km2. The average annual rainfall in this area is 747 mm, the mean winter rainfall is 574 mm and the resource capacity for this area is 97 mm.

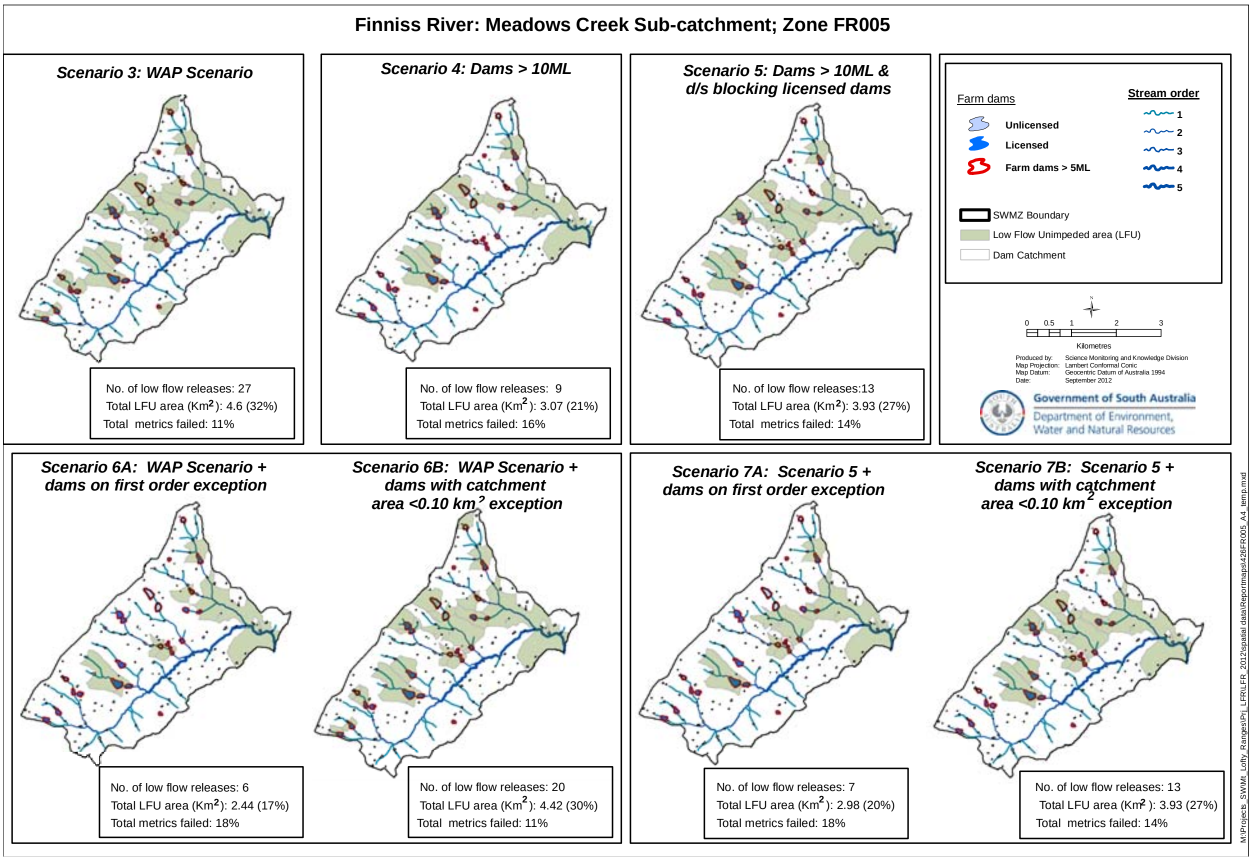
There are 85 farm dams in this zone with total dam capacity of 759 ML, 23% of which is held in licensed dams.

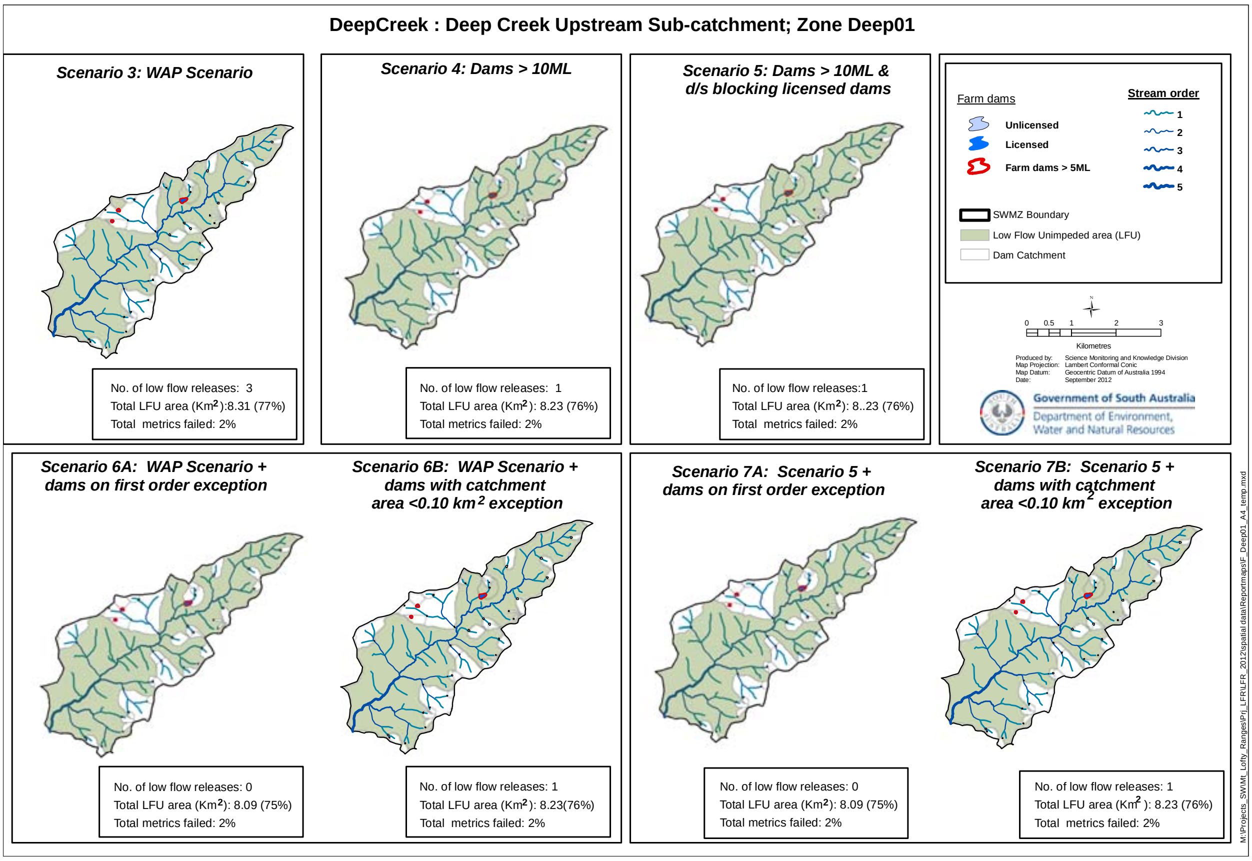
There is no stream gauging station to record the flow at the outlet of this zone.

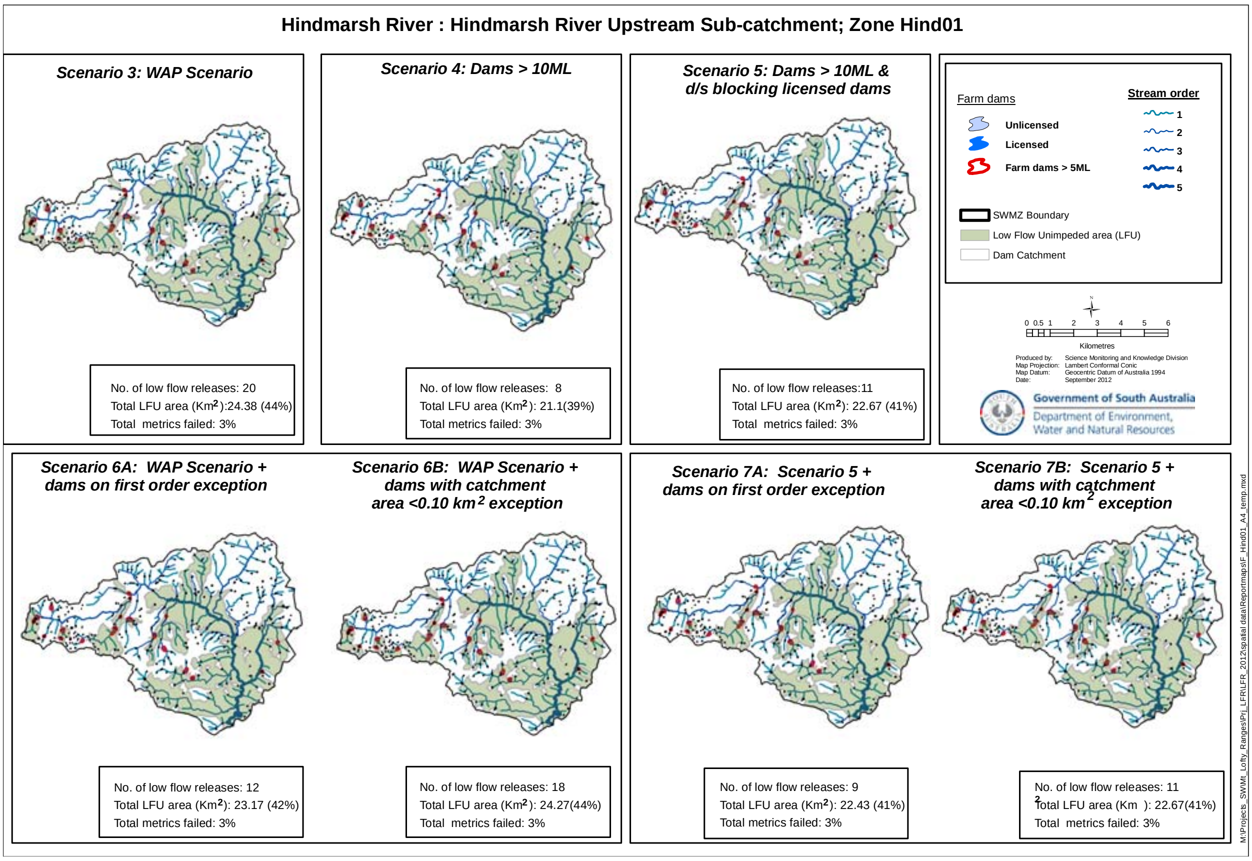
B. MAPS SHOWING SCENARIO DEFINITION RESULTS

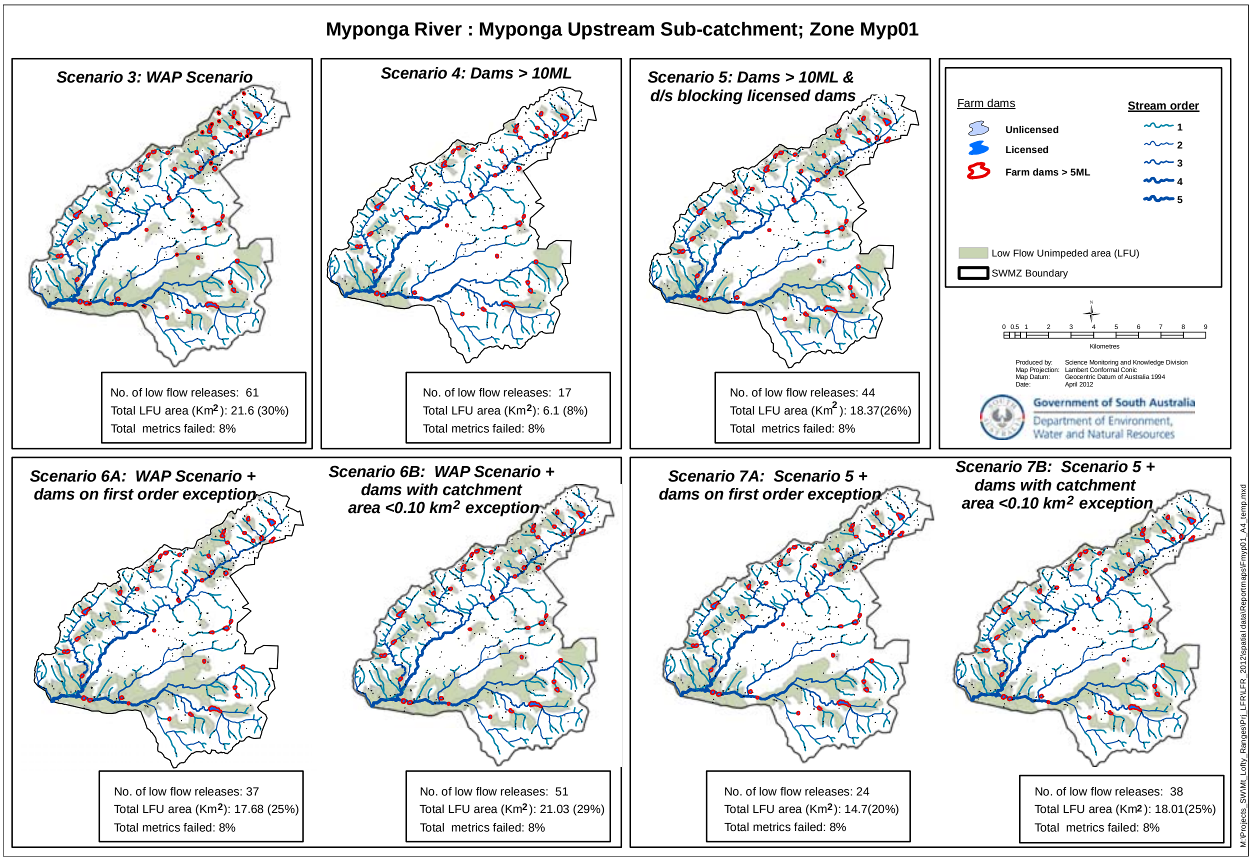


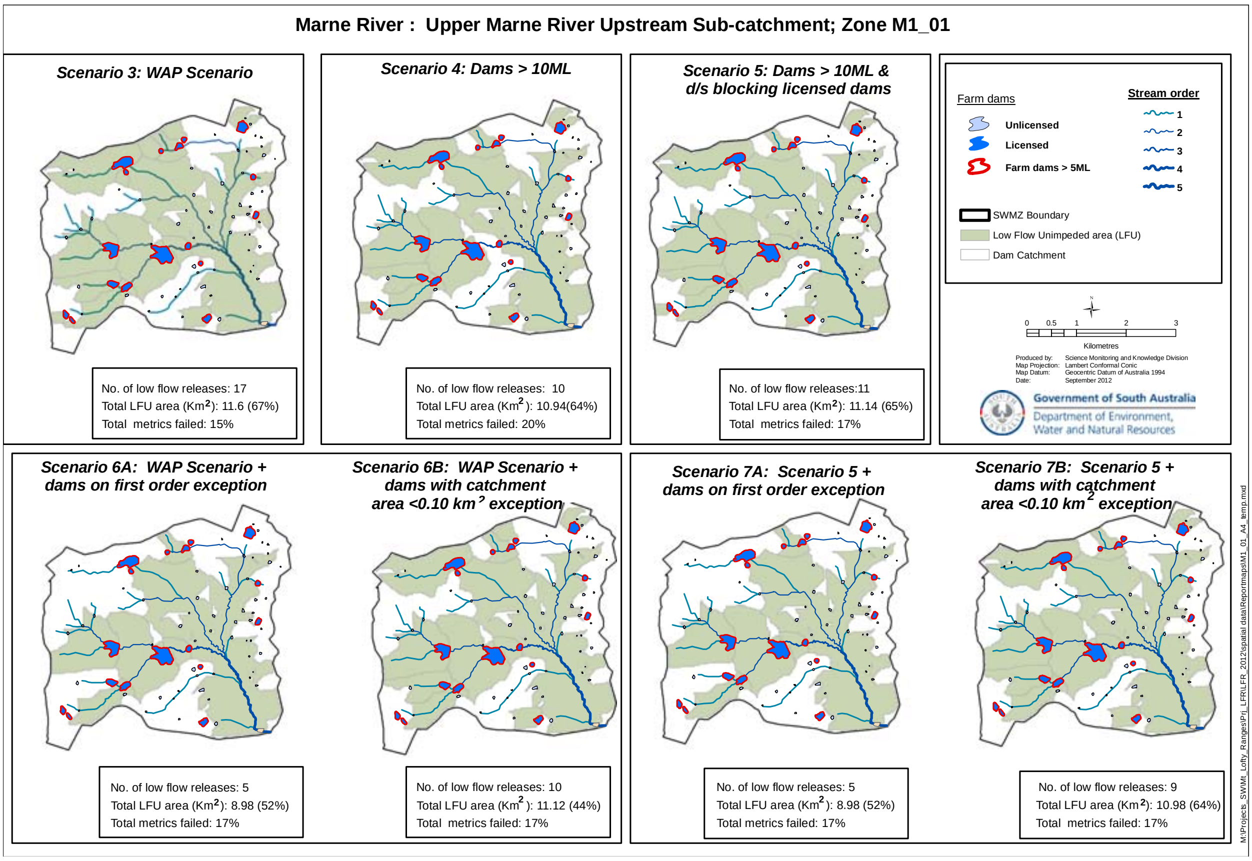


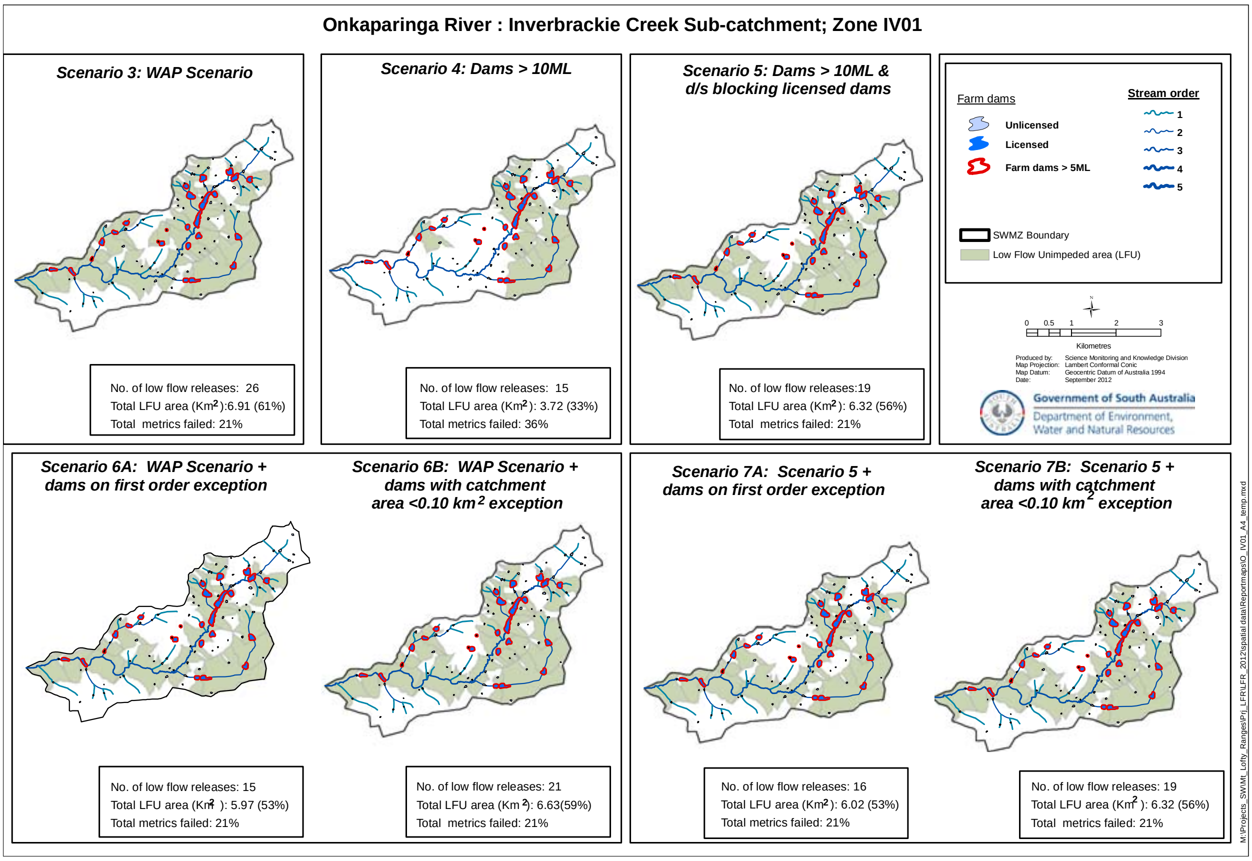

Finniss River: Meadows Creek Sub-catchment; Zone FR005
Scenario 3: WAP Scenario
No. of low flow releases: 27
Total LFU area (Km^2): 4.6 (32%)
Total metrics failed: 11%
Scenario 4: Dams > 10ML
No. of low flow releases: 9
Total LFU area (Km^2): 3.07 (21%)
Total metrics failed: 16%
Scenario 5: Dams > 10ML & d/s blocking licensed dams
No. of low flow releases:13
Total LFU area (Km^2): 3.93 (27%)
Total metrics failed: 14%
Farm dams
Unlicensed
Licensed
Farm dams > 5ML
Stream order
1
2
3
4
5
SWMZ Boundary
Low Flow Unimpeded area (LFU)
Dam Catchment
0 0.5 1 2 3
Kilometres
Produced by: Science Monitoring and Knowledge Division
Map Projection: Lambert Conformal Conic
Map Datum: Geocentric Datum of Australia 1994
Date: September 2012
Government of South Australia
Department of Environment, Water and Natural Resources
Scenario 6A: WAP Scenario + dams on first order exception
No. of low flow releases: 6
Total LFU area (Km^2): 2.44 (17%)
Total metrics failed: 18%
Scenario 6B: WAP Scenario + dams with catchment area <0.10 km^2 exception
No. of low flow releases: 20
Total LFU area (Km^2): 4.42 (30%)
Total metrics failed: 11%
Scenario 7A: Scenario 5 + dams on first order exception
No. of low flow releases: 7
Total LFU area (Km^2): 2.98 (20%)
Total metrics failed: 18%
Scenario 7B: Scenario 5 + dams with catchment area <0.10 km^2 exception
No. of low flow releases: 13
Total LFU area (Km^2): 3.93 (27%)
Total metrics failed: 14%

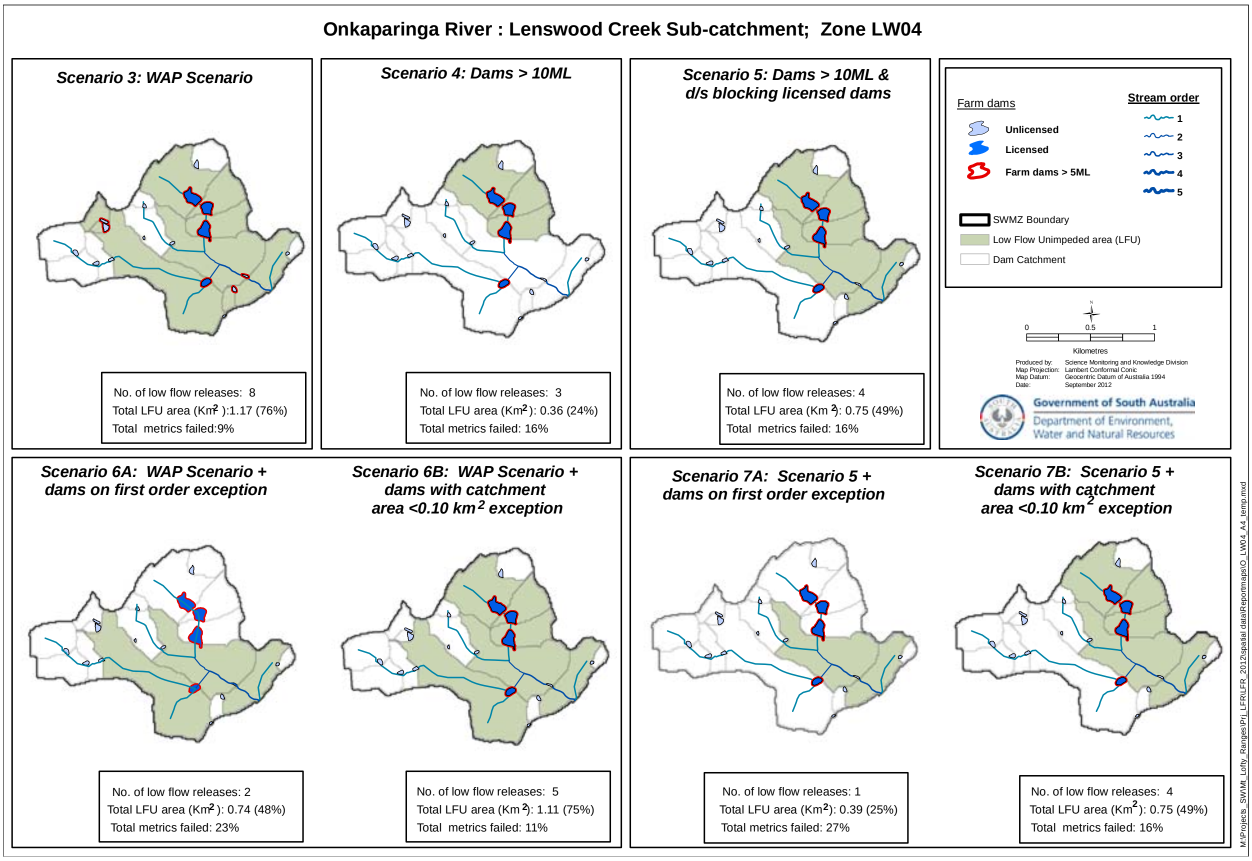

DeepCreek : Deep Creek Upstream Sub-catchment; Zone Deep01
Scenario 3: WAP Scenario
No. of low flow releases: 3
Total LFU area (Km^2):8.31 (77%)
Total metrics failed: 2%
Scenario 4: Dams > 10ML
No. of low flow releases: 1
Total LFU area (Km^2): 8.23 (76%)
Total metrics failed: 2%
Scenario 5: Dams > 10ML & d/s blocking licensed dams
No. of low flow releases:1
Total LFU area (Km^2): 8..23 (76%)
Total metrics failed: 2%
Farm dams
Unlicensed
Licensed
Farm dams > 5ML
Stream order
1
2
3
4
5
SWMZ Boundary
Low Flow Unimpeded area (LFU)
Dam Catchment
0 0.5 1 2 3
Kilometres
Produced by: Science Monitoring and Knowledge Division
Map Projection: Lambert Conformal Conic
Map Datum: Geocentric Datum of Australia 1994
Date: September 2012
Government of South Australia
Department of Environment, Water and Natural Resources
Scenario 6A: WAP Scenario + dams on first order exception
No. of low flow releases: 0
Total LFU area (Km^2): 8.09 (75%)
Total metrics failed: 2%
Scenario 6B: WAP Scenario + dams with catchment area <0.10 km^2 exception
No. of low flow releases: 1
Total LFU area (Km^2): 8.23(76%)
Total metrics failed: 2%
Scenario 7A: Scenario 5 + dams on first order exception
No. of low flow releases: 0
Total LFU area (Km^2): 8.09 (75%)
Total metrics failed: 2%
Scenario 7B: Scenario 5 + dams with catchment area <0.10 km^2 exception
No. of low flow releases: 1
Total LFU area (Km^2): 8.23 (76%)
Total metrics failed: 2%


Hindmarsh River : Hindmarsh River Upstream Sub-catchment; Zone Hind01
Scenario 3: WAP Scenario
No. of low flow releases: 20
Total LFU area (Km2):24.38 (44%)
Total metrics failed: 3%
Scenario 4: Dams > 10ML
No. of low flow releases: 8
Total LFU area (Km2): 21.1(39%)
Total metrics failed: 3%
Scenario 5: Dams > 10ML & d/s blocking licensed dams
No. of low flow releases:11
Total LFU area (Km2): 22.67 (41%)
Total metrics failed: 3%
Farm dams
Unlicensed
Licensed
Farm dams > 5ML
Stream order
1
2
3
4
5
SWMZ Boundary
Low Flow Unimpeded area (LFU)
Dam Catchment
N
0 0.5 1 2 3 4 5 6
Kilometres
Produced by: Science Monitoring and Knowledge Division
Map Projection: Lambert Conformal Conic
Map Datum: Geocentric Datum of Australia 1994
Date: September 2012
Government of South Australia
Department of Environment, Water and Natural Resources
Scenario 6A: WAP Scenario + dams on first order exception
No. of low flow releases: 12
Total LFU area (Km2): 23.17 (42%)
Total metrics failed: 3%
Scenario 6B: WAP Scenario + dams with catchment area <0.10 km2 exception
No. of low flow releases: 18
Total LFU area (Km2): 24.27(44%)
Total metrics failed: 3%
Scenario 7A: Scenario 5 + dams on first order exception
No. of low flow releases: 9
Total LFU area (Km2): 22.43 (41%)
Total metrics failed: 3%
Scenario 7B: Scenario 5 + dams with catchment area <0.10 km2 exception
No. of low flow releases: 11
Total LFU area (Km2): 22.67(41%)
Total metrics failed: 3%

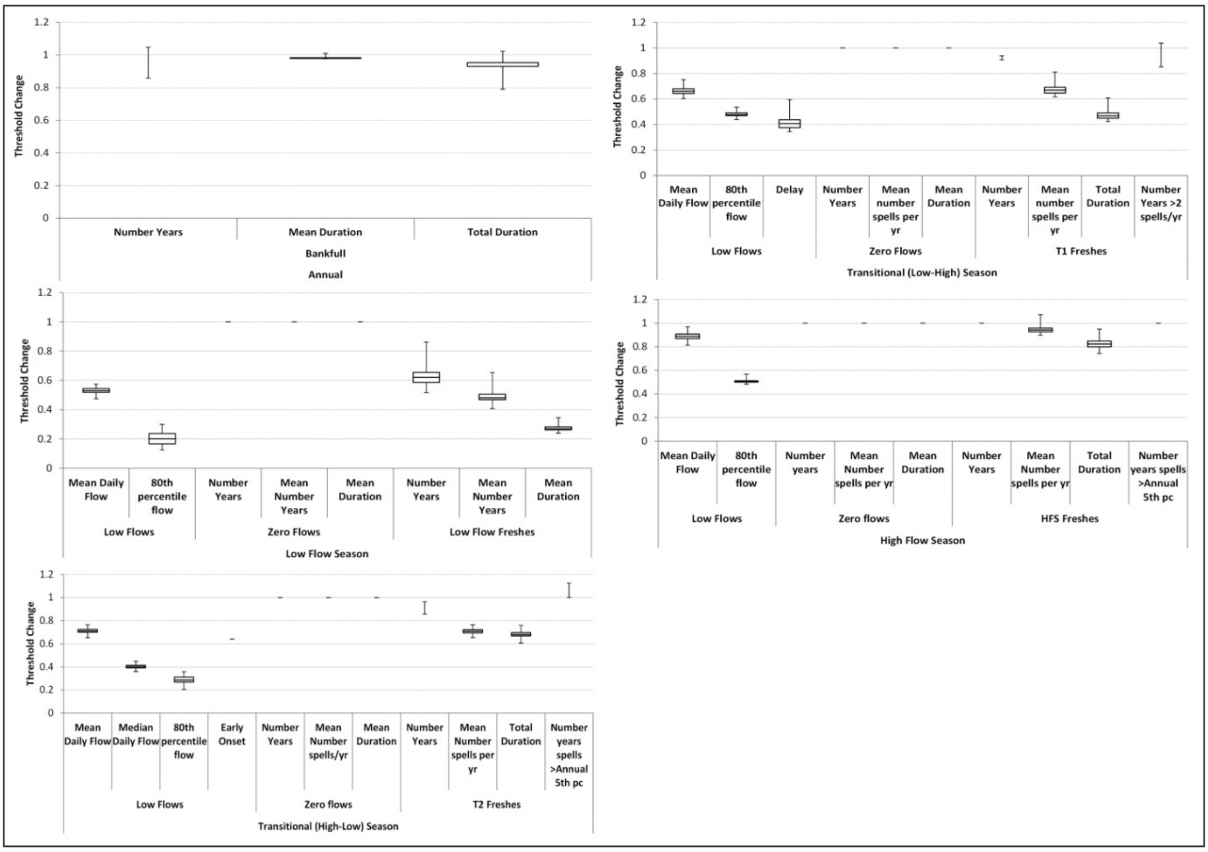

Myponga River : Myponga Upstream Sub-catchment; Zone Myp01
Scenario 3: WAP Scenario
No. of low flow releases: 61
Total LFU area (Km2): 21.6 (30%)
Total metrics failed: 8%
Scenario 4: Dams > 10ML
No. of low flow releases: 17
Total LFU area (Km2): 6.1 (8%)
Total metrics failed: 8%
Scenario 5: Dams > 10ML & d/s blocking licensed dams
No. of low flow releases: 44
Total LFU area (Km2): 18.37(26%)
Total metrics failed: 8%
Farm dams
Unlicensed
Licensed
Farm dams > 5ML
Stream order
1
2
3
4
5
Low Flow Unimpeded area (LFU)
SWMZ Boundary
0 0.5 1 2 3 4 5 6 7 8 9
Kilometres
Produced by: Science Monitoring and Knowledge Division
Map Projection: Lambert Conformal Conic
Map Datum: Geocentric Datum of Australia 1994
Date: April 2012
Government of South Australia
Department of Environment, Water and Natural Resources
Scenario 6A: WAP Scenario + dams on first order exception
No. of low flow releases: 37
Total LFU area (Km2): 17.68 (25%)
Total metrics failed: 8%
Scenario 6B: WAP Scenario + dams with catchment area <0.10 km2 exception
No. of low flow releases: 51
Total LFU area (Km2): 21.03 (29%)
Total metrics failed: 8%
Scenario 7A: Scenario 5 + dams on first order exception
No. of low flow releases: 24
Total LFU area (Km2): 14.7(20%)
Total metrics failed: 8%
Scenario 7B: Scenario 5 + dams with catchment area <0.10 km2 exception
No. of low flow releases: 38
Total LFU area (Km2): 18.01(25%)
Total metrics failed: 8%

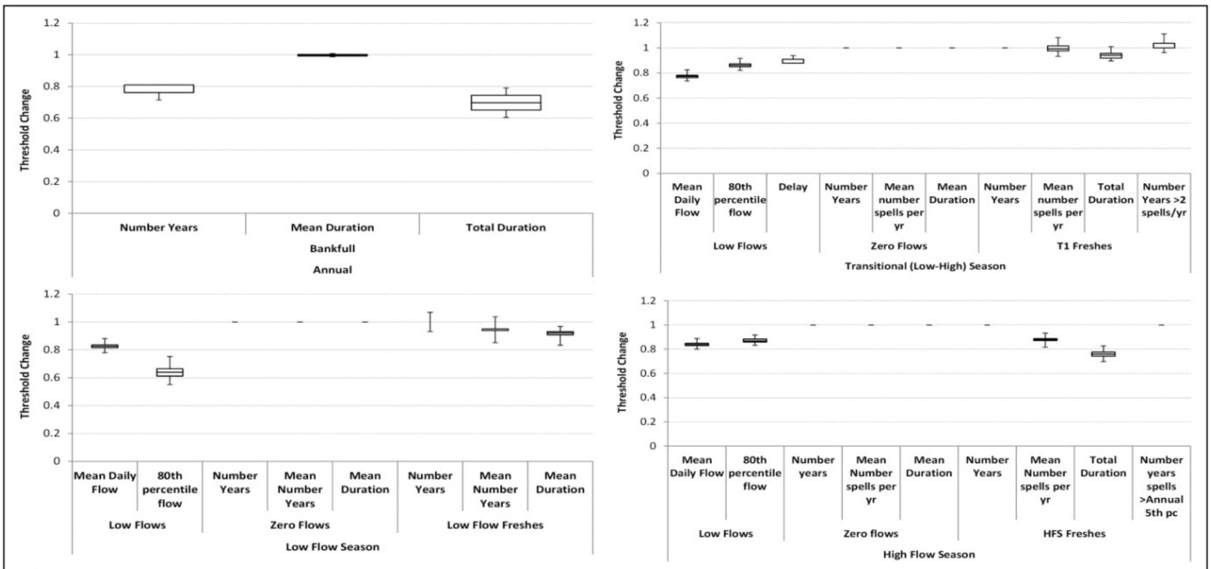

Marne River : Upper Marne River Upstream Sub-catchment; Zone M1_01
Scenario 3: WAP Scenario
No. of low flow releases: 17
Total LFU area (Km2): 11.6 (67%)
Total metrics failed: 15%
Scenario 4: Dams > 10ML
No. of low flow releases: 10
Total LFU area (Km2): 10.94(64%)
Total metrics failed: 20%
Scenario 5: Dams > 10ML & d/s blocking licensed dams
No. of low flow releases:11
Total LFU area (Km2): 11.14 (65%)
Total metrics failed: 17%
Farm dams
Unlicensed
Licensed
Farm dams > 5ML
Stream order
1
2
3
4
5
SWMZ Boundary
Low Flow Unimpeded area (LFU)
Dam Catchment
0 0.5 1 2 3
Kilometres
Produced by: Science Monitoring and Knowledge Division
Map Projection: Lambert Conformal Conic
Map Datum: Geocentric Datum of Australia 1994
Date: September 2012
Government of South Australia
Department of Environment, Water and Natural Resources
Scenario 6A: WAP Scenario + dams on first order exception
No. of low flow releases: 5
Total LFU area (Km2): 8.98 (52%)
Total metrics failed: 17%
Scenario 6B: WAP Scenario + dams with catchment area <0.10 km2 exception
No. of low flow releases: 10
Total LFU area (Km2): 11.12 (44%)
Total metrics failed: 17%
Scenario 7A: Scenario 5 + dams on first order exception
No. of low flow releases: 5
Total LFU area (Km2): 8.98 (52%)
Total metrics failed: 17%
Scenario 7B: Scenario 5 + dams with catchment area <0.10 km2 exception
No. of low flow releases: 9
Total LFU area (Km2): 10.98 (64%)
Total metrics failed: 17%


Onkaparinga River : Inverbrackie Creek Sub-catchment; Zone IV01
Scenario 3: WAP Scenario
No. of low flow releases: 26
Total LFU area (Km2):6.91 (61%)
Total metrics failed: 21%
Scenario 4: Dams > 10ML
No. of low flow releases: 15
Total LFU area (Km2): 3.72 (33%)
Total metrics failed: 36%
Scenario 5: Dams > 10ML & d/s blocking licensed dams
No. of low flow releases:19
Total LFU area (Km2): 6.32 (56%)
Total metrics failed: 21%
Farm dams
Unlicensed
Licensed
Farm dams > 5ML
Stream order
1
2
3
4
5
SWMZ Boundary
Low Flow Unimpeded area (LFU)
0 0.5 1 2 3
Kilometres
Produced by: Science Monitoring and Knowledge Division
Map Projection: Lambert Conformal Conic
Map Datum: Geocentric Datum of Australia 1994
Date: September 2012
Government of South Australia
Department of Environment, Water and Natural Resources
Scenario 6A: WAP Scenario + dams on first order exception
No. of low flow releases: 15
Total LFU area (Km2): 5.97 (53%)
Total metrics failed: 21%
Scenario 6B: WAP Scenario + dams with catchment area <0.10 km2 exception
No. of low flow releases: 21
Total LFU area (Km 2): 6.63(59%)
Total metrics failed: 21%
Scenario 7A: Scenario 5 + dams on first order exception
No. of low flow releases: 16
Total LFU area (Km2): 6.02 (53%)
Total metrics failed: 21%
Scenario 7B: Scenario 5 + dams with catchment area <0.10 km2 exception
No. of low flow releases: 19
Total LFU area (Km2): 6.32 (56%)
Total metrics failed: 21%


Onkaparinga River : Lenswood Creek Sub-catchment; Zone LW04
Scenario 3: WAP Scenario
No. of low flow releases: 8
Total LFU area (Km2):1.17 (76%)
Total metrics failed:9%
Scenario 4: Dams > 10ML
No. of low flow releases: 3
Total LFU area (Km2): 0.36 (24%)
Total metrics failed: 16%
Scenario 5: Dams > 10ML & d/s blocking licensed dams
No. of low flow releases: 4
Total LFU area (Km 2): 0.75 (49%)
Total metrics failed: 16%
Farm dams
Unlicensed
Licensed
Farm dams > 5ML
Stream order
1
2
3
4
5
SWMZ Boundary
Low Flow Unimpeded area (LFU)
Dam Catchment
0
0.5
1
Kilometres
Produced by: Science Monitoring and Knowledge Division
Map Projection: Lambert Conformal Conic
Map Datum: Geocentric Datum of Australia 1994
Date: September 2012
Government of South Australia
Department of Environment, Water and Natural Resources
Scenario 6A: WAP Scenario + dams on first order exception
No. of low flow releases: 2
Total LFU area (Km2): 0.74 (48%)
Total metrics failed: 23%
Scenario 6B: WAP Scenario + dams with catchment area <0.10 km2 exception
No. of low flow releases: 5
Total LFU area (Km 2): 1.11 (75%)
Total metrics failed: 11%
Scenario 7A: Scenario 5 + dams on first order exception
No. of low flow releases: 1
Total LFU area (Km2): 0.39 (25%)
Total metrics failed: 27%
Scenario 7B: Scenario 5 + dams with catchment area <0.10 km2 exception
No. of low flow releases: 4
Total LFU area (Km2): 0.75 (49%)
Total metrics failed: 16%

C. ZONE AR002: MONTE CARLO RESULTS FOR EACH SCENARIO





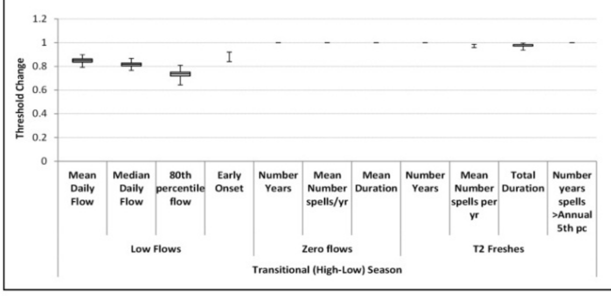
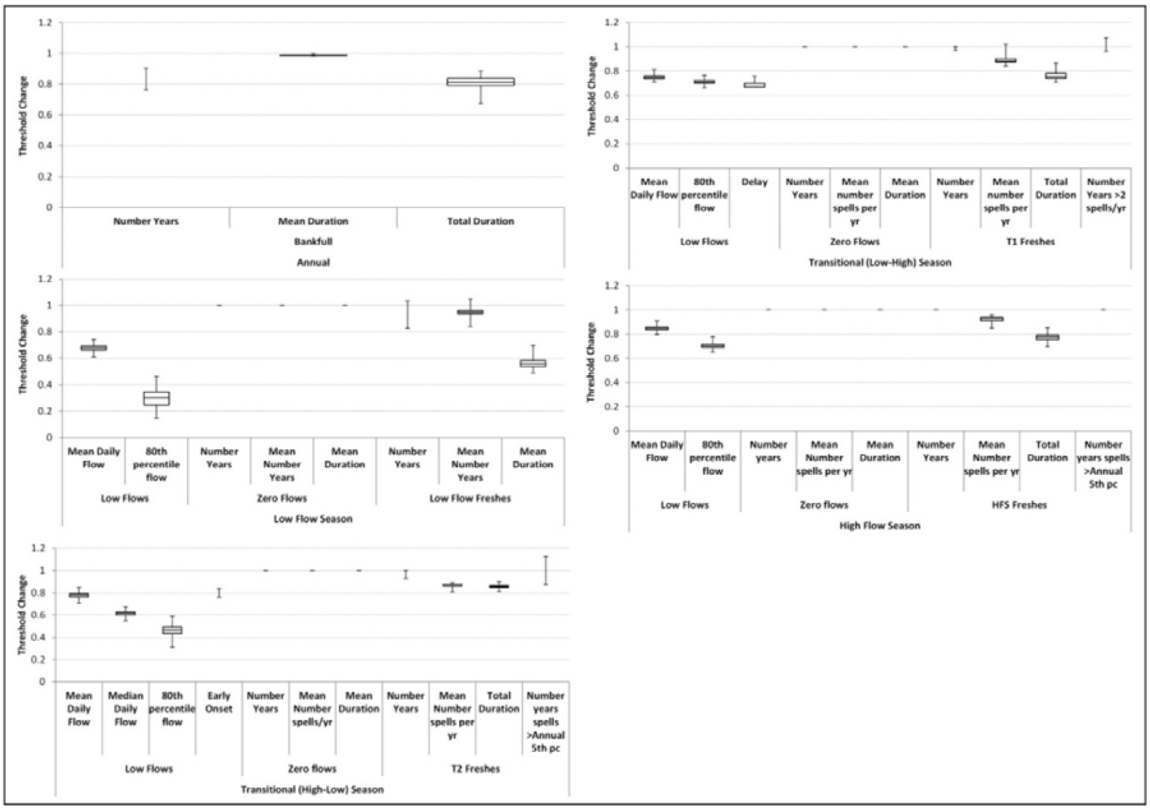


Figure 30. Evaporation factor box and whisker plots showing the variability in environmental flow metric threshold change output for each flow season. Scenario 2 Top, Scenario 3 Bottom



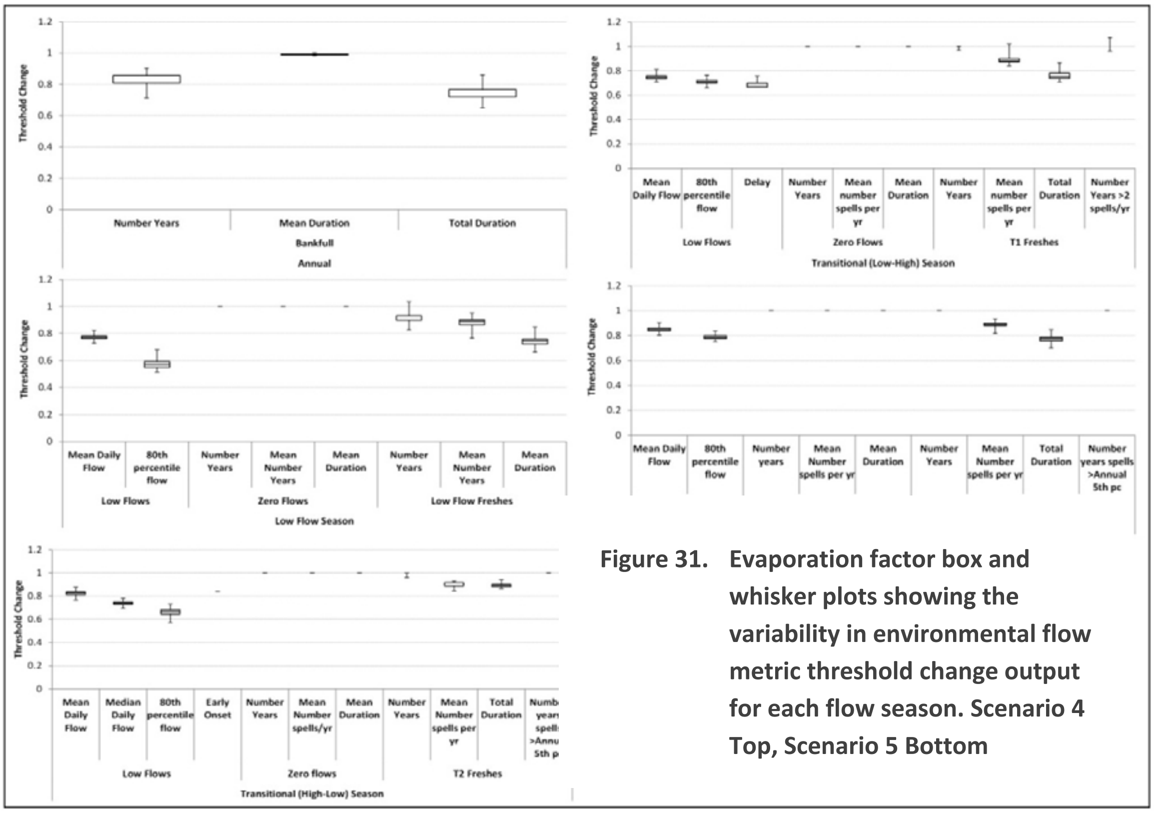
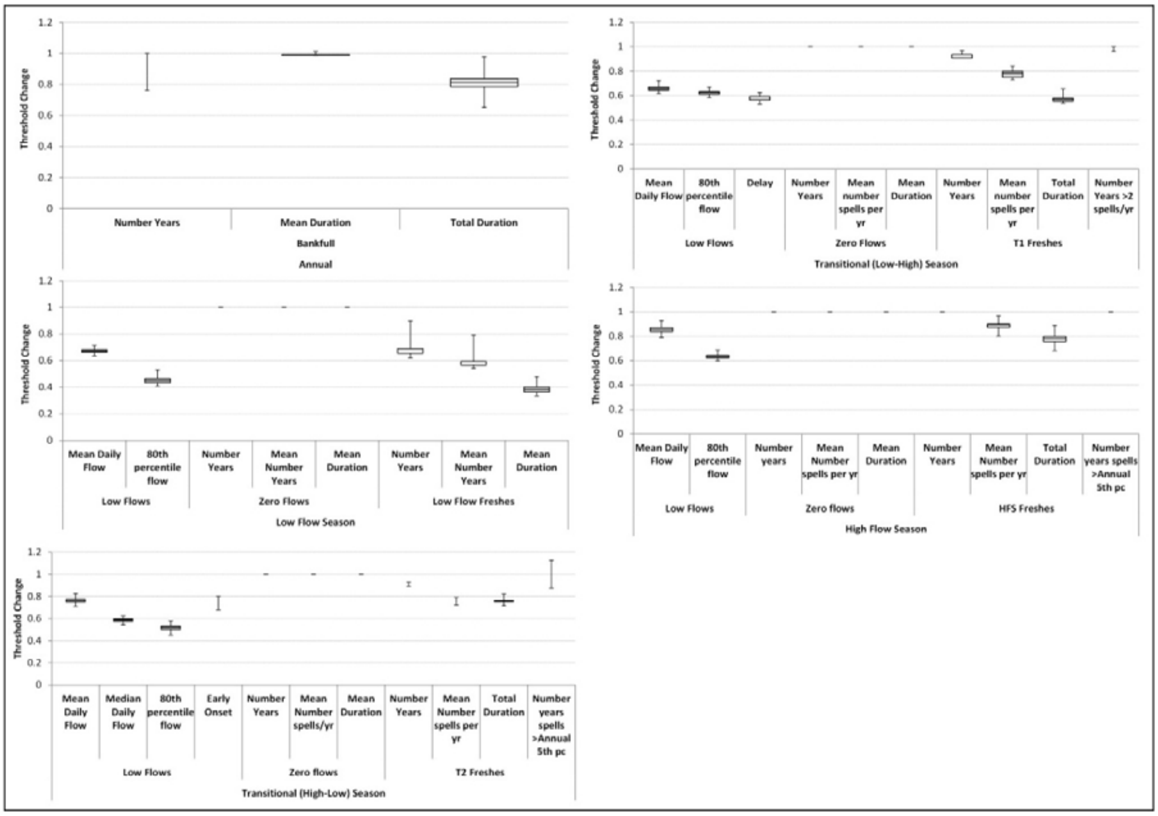
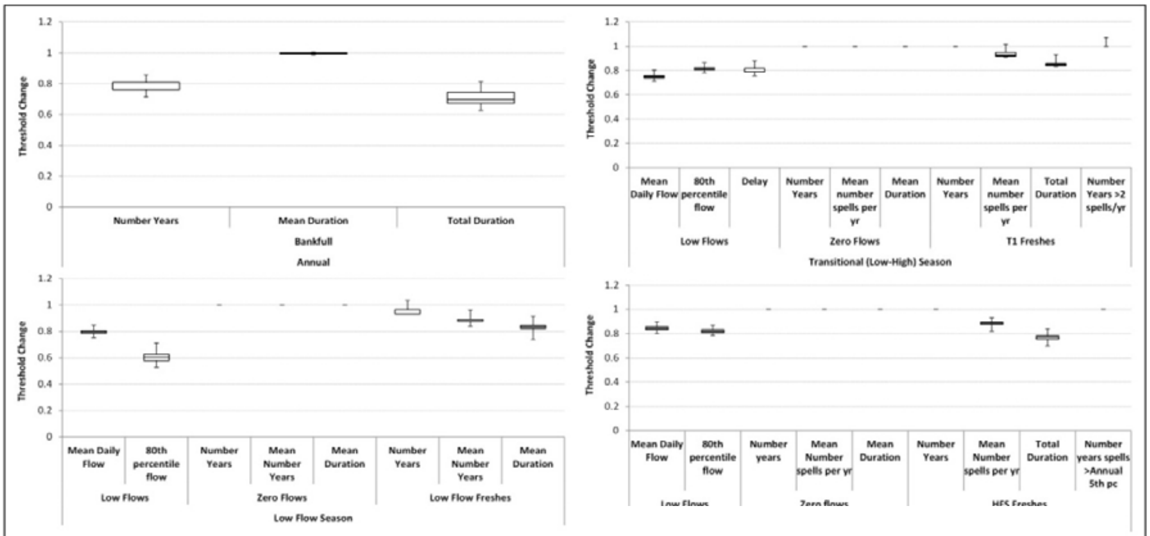


Figure 31. Evaporation factor box and whisker plots showing the variability in environmental flow metric threshold change output for each flow season. Scenario 4 Top, Scenario 5 Bottom





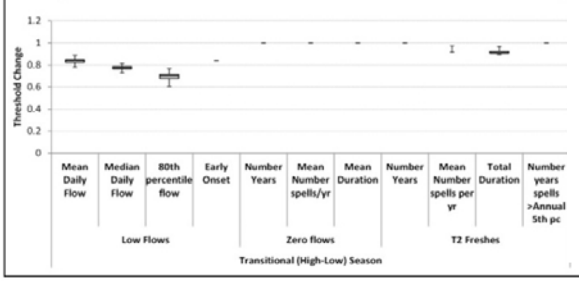
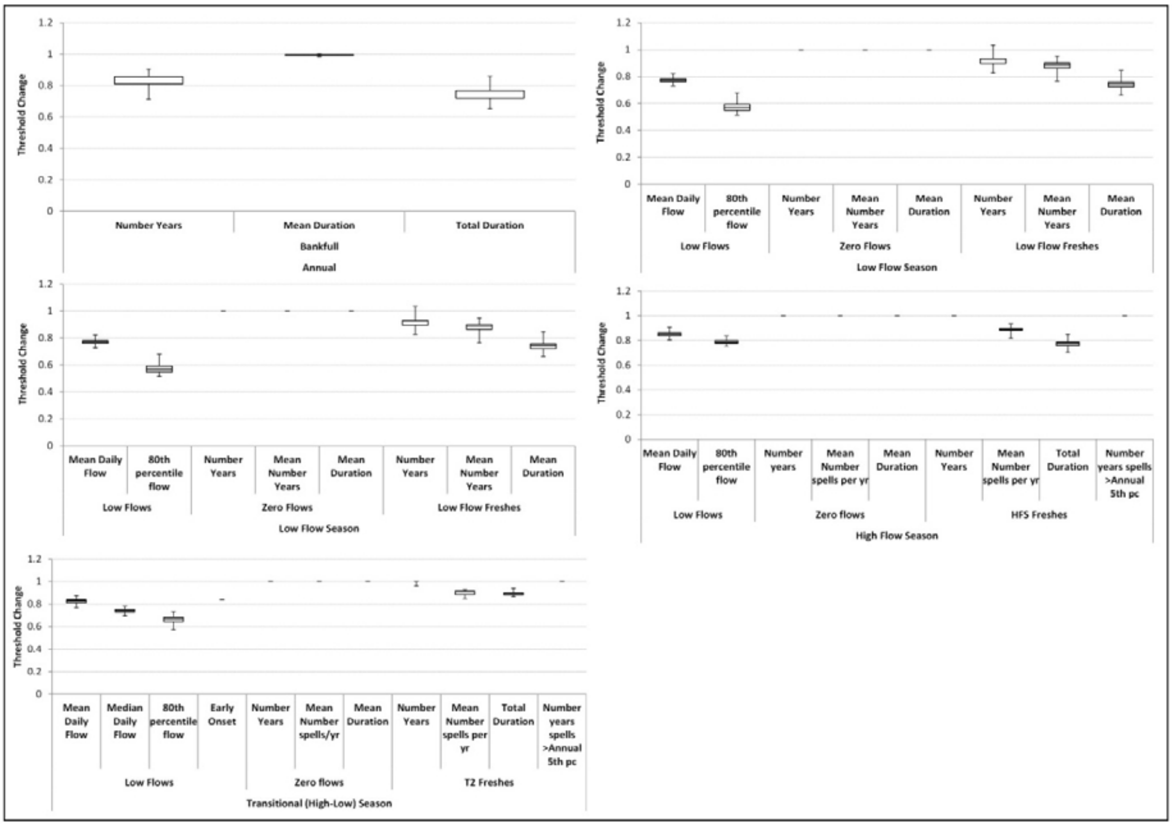
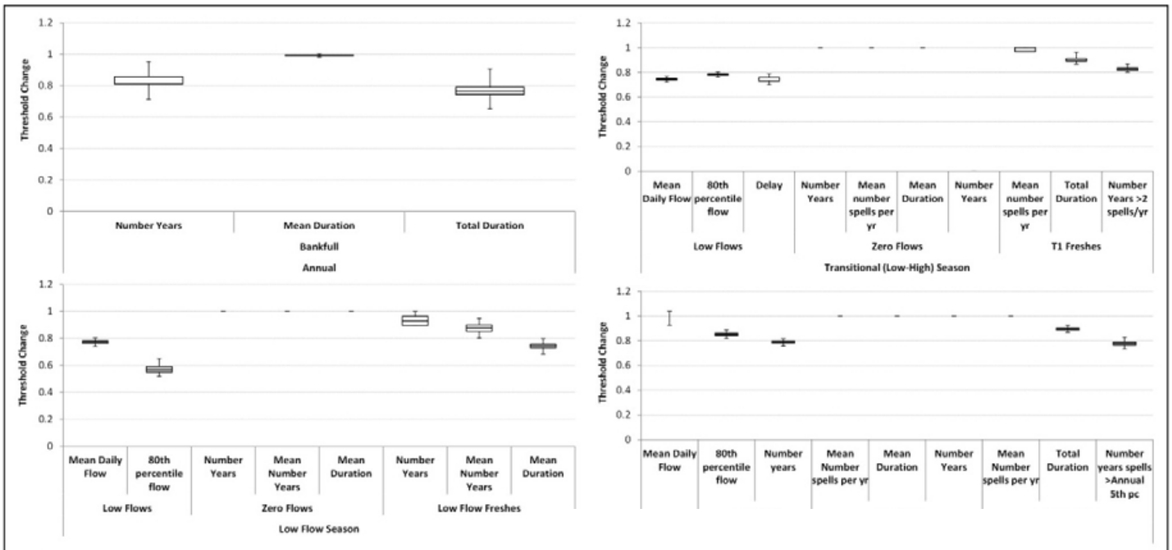


Figure 32. Evaporation factor box and whisker plots showing the variability in environmental flow metric threshold change output for each flow season. Scenario 6a Top, Scenario 6b Bottom





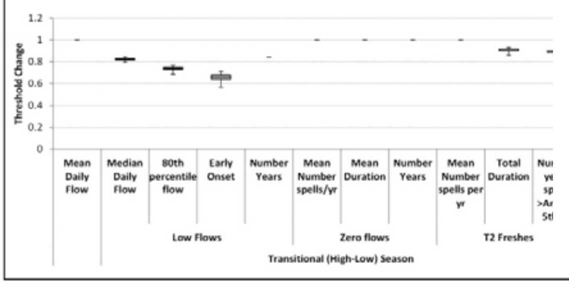
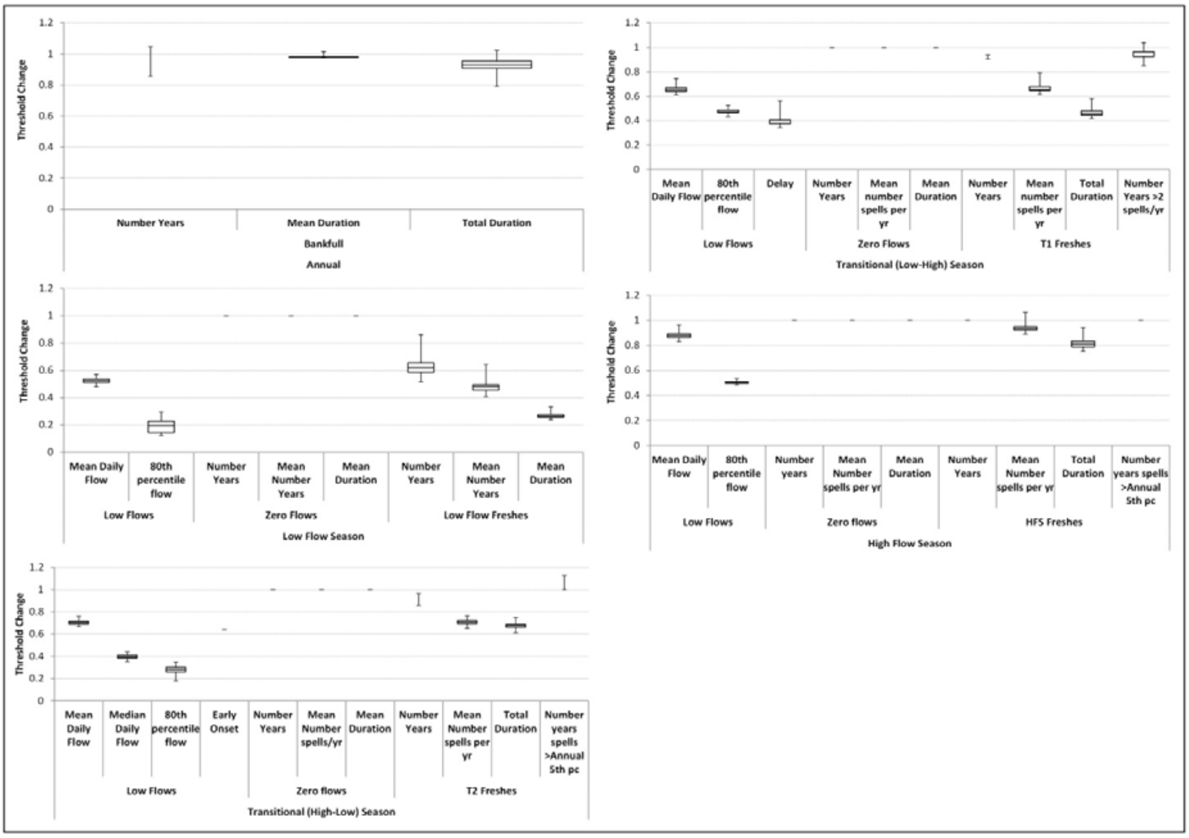
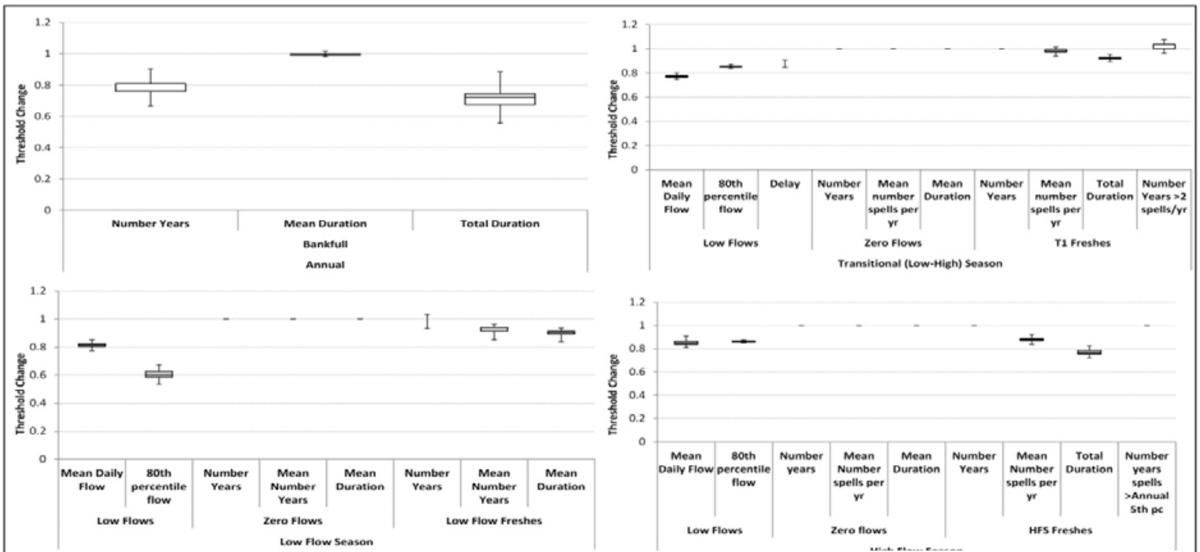


Figure 33. **Evaporation factor box and whisker plots showing the variability in environmental flow metric threshold change output for each flow season. Scenario 7a Top, Scenario 7b Bottom**





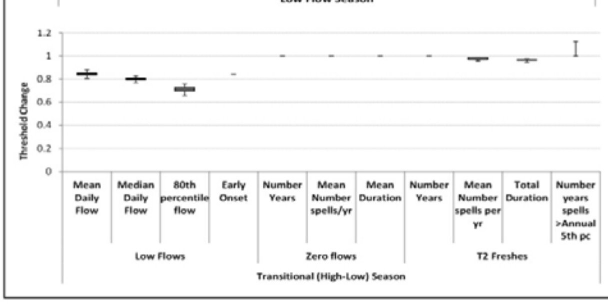
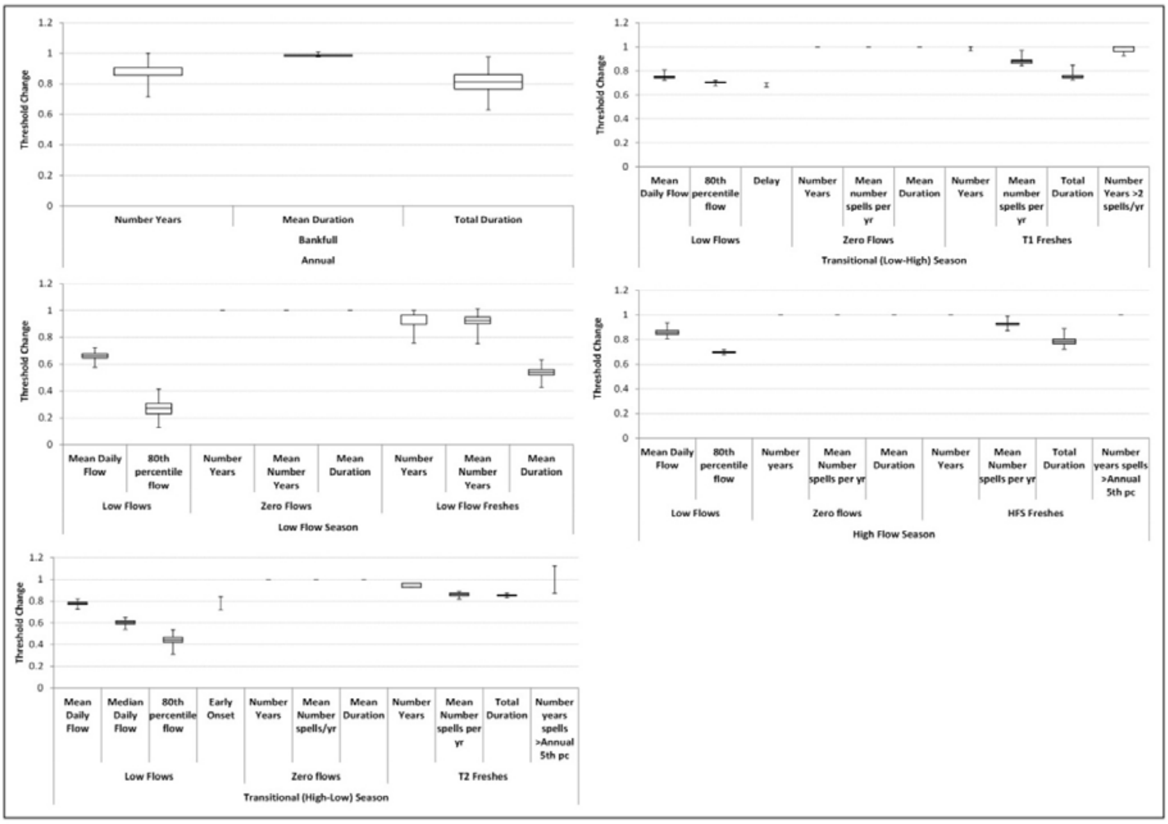
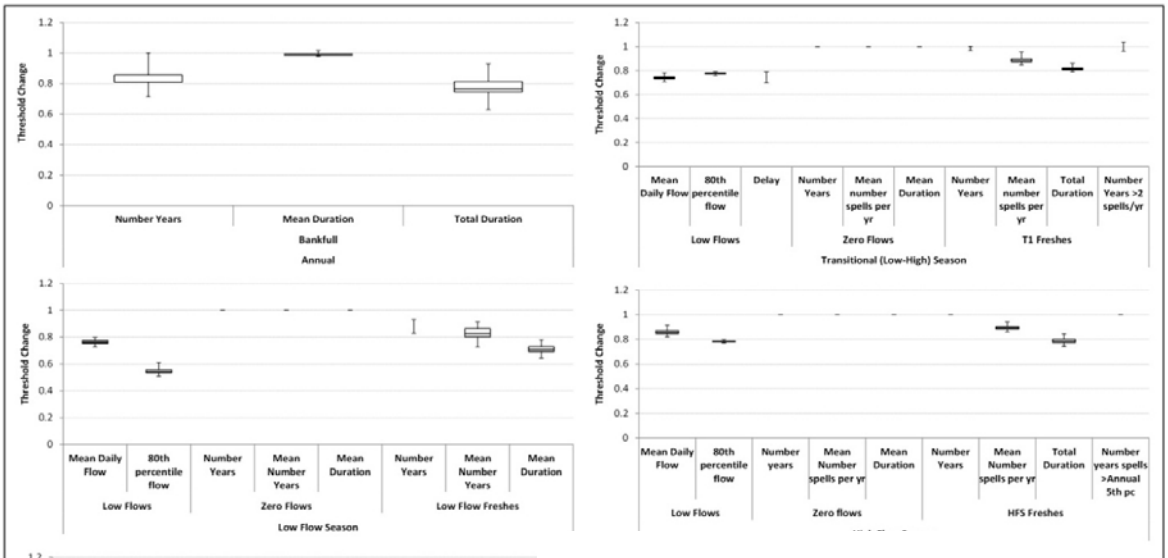


Figure 34. Usage factor box and whisker plots showing the variability in environmental flow metric threshold change output for each flow season. Scenario 2 Top, Scenario 3 Bottom





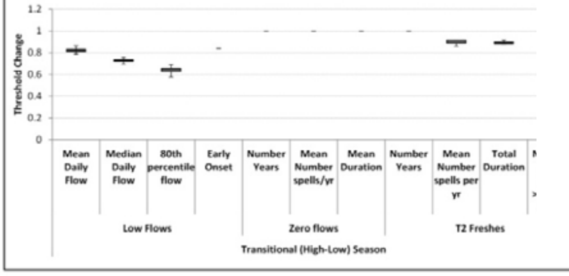
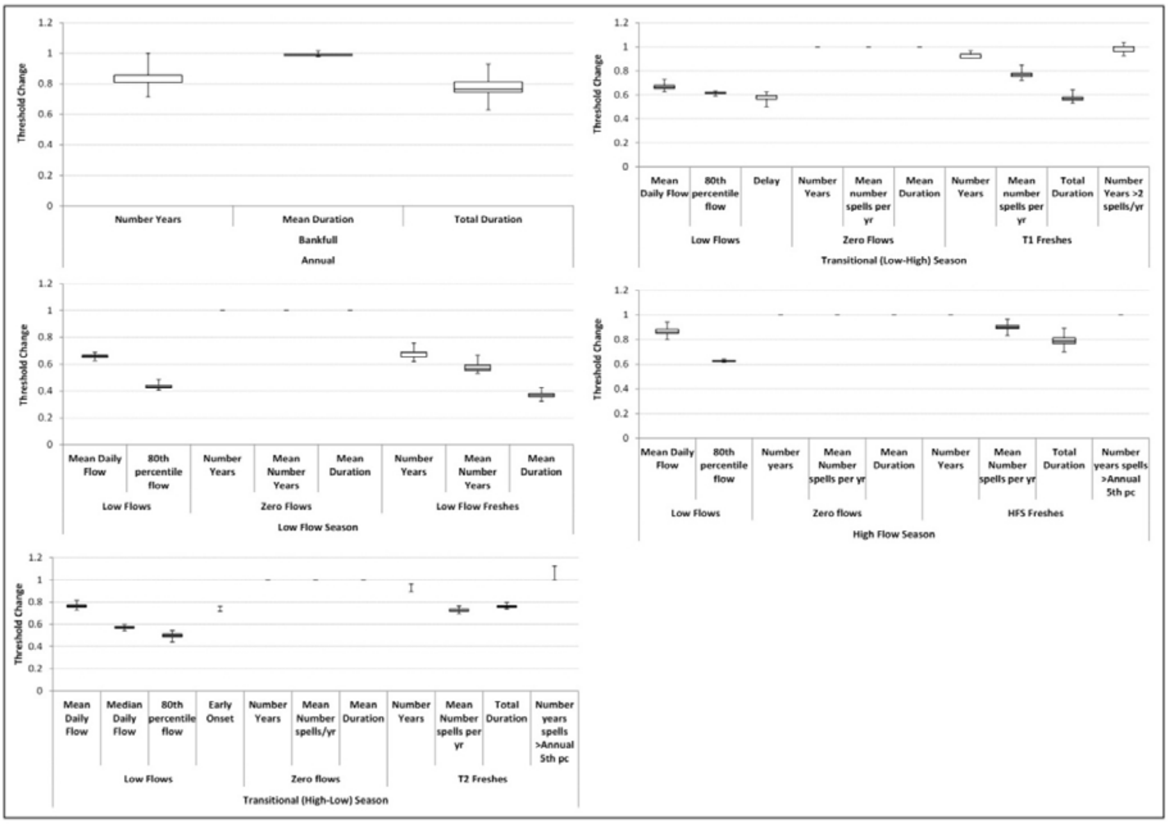
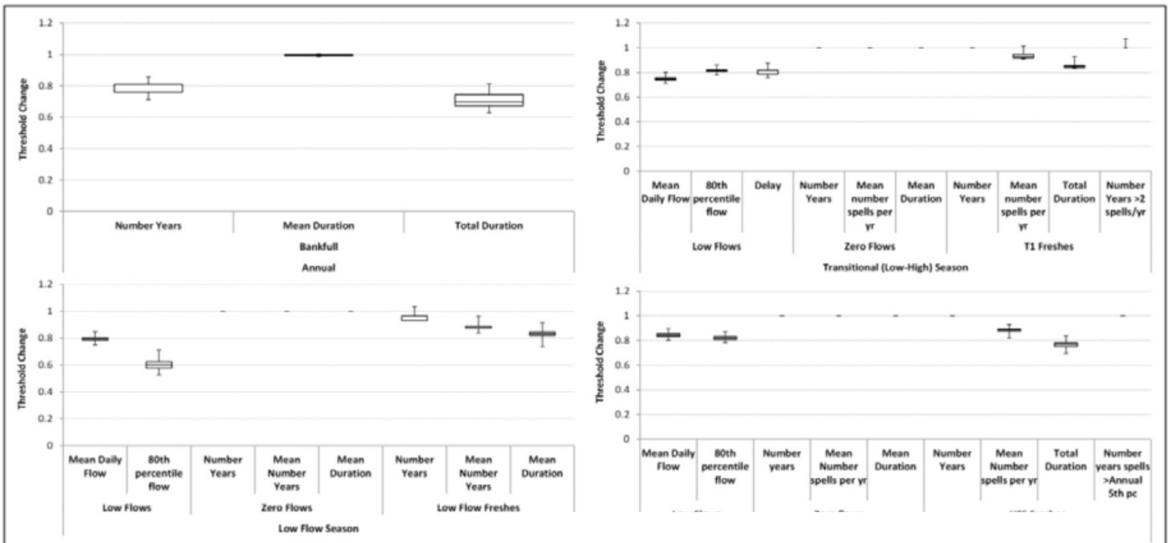


Figure 35. Usage factor box and whisker plots showing the variability in environmental flow metric threshold change output for each flow season. Scenario 4 Top, Scenario 5 Bottom





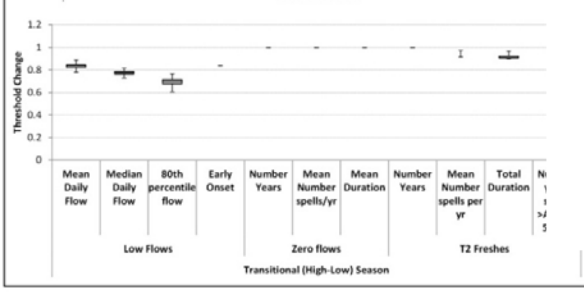
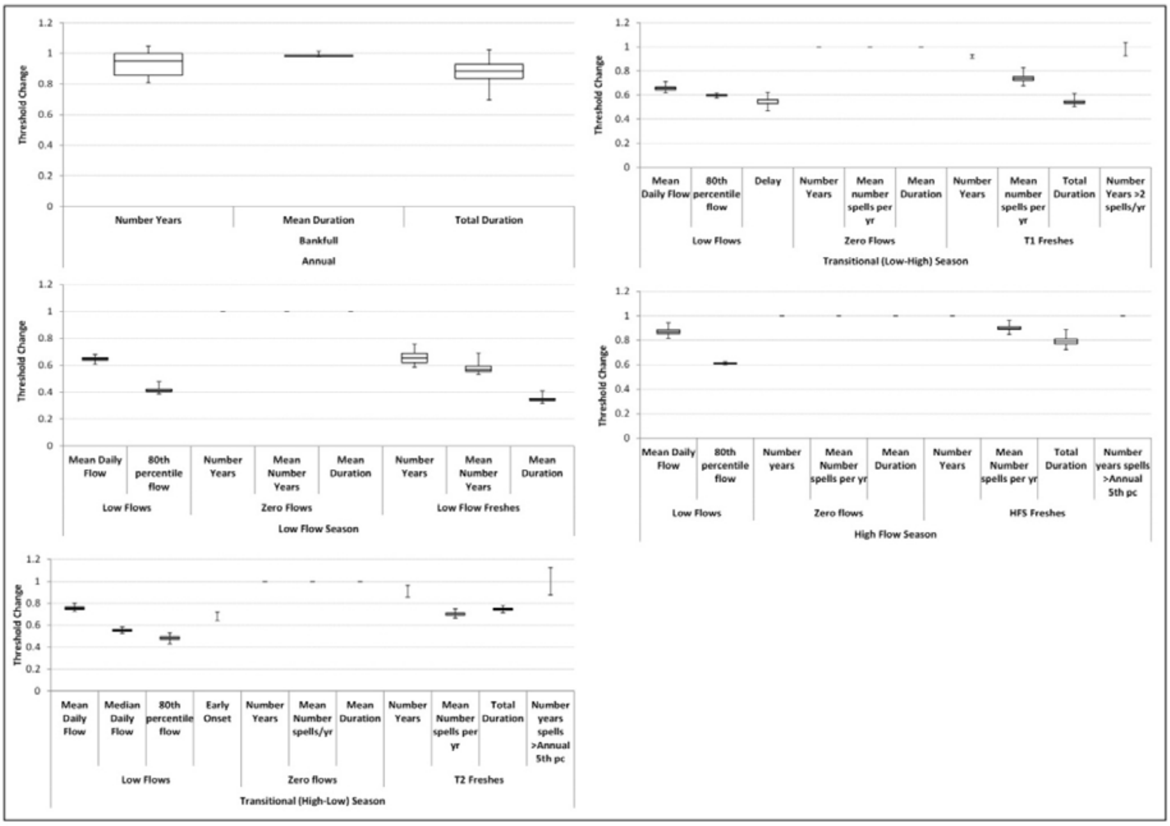


Figure 36. Usage factor box and whisker plots showing the variability in environmental flow metric threshold change output for each flow season. Scenario 6a Top, Scenario 6b Bottom



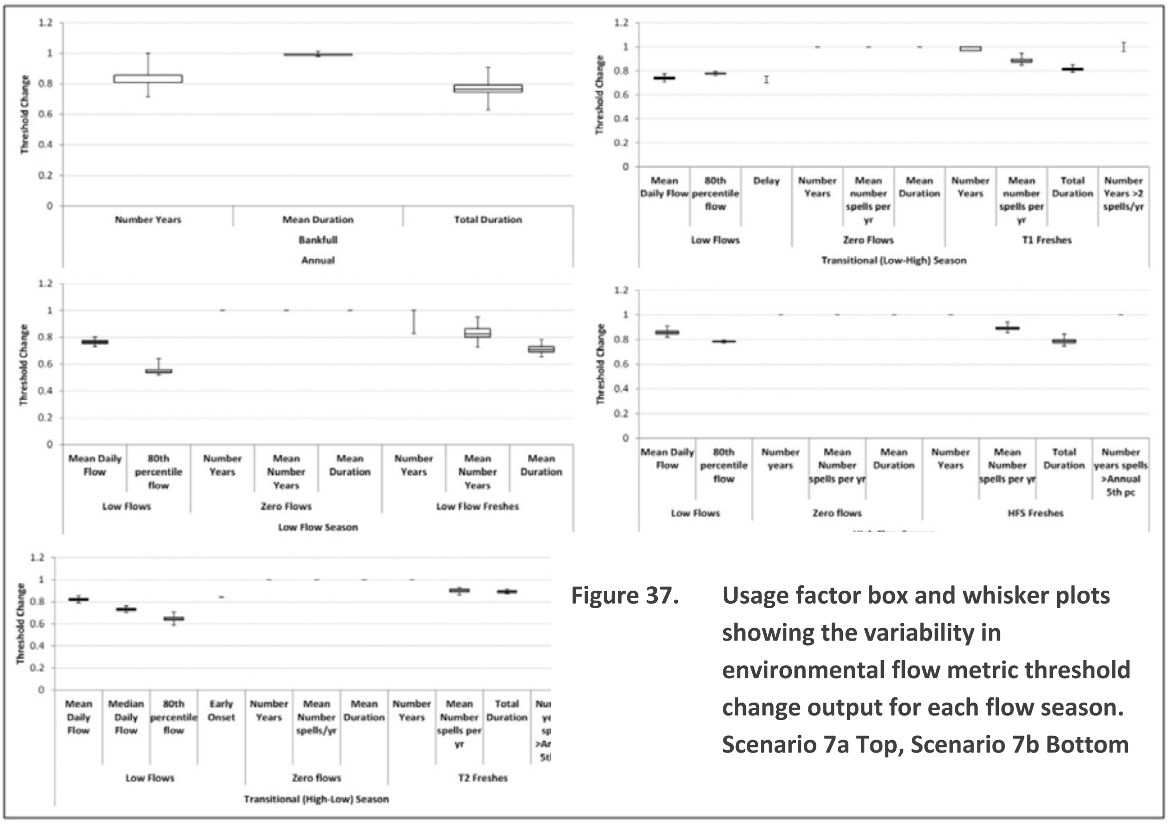
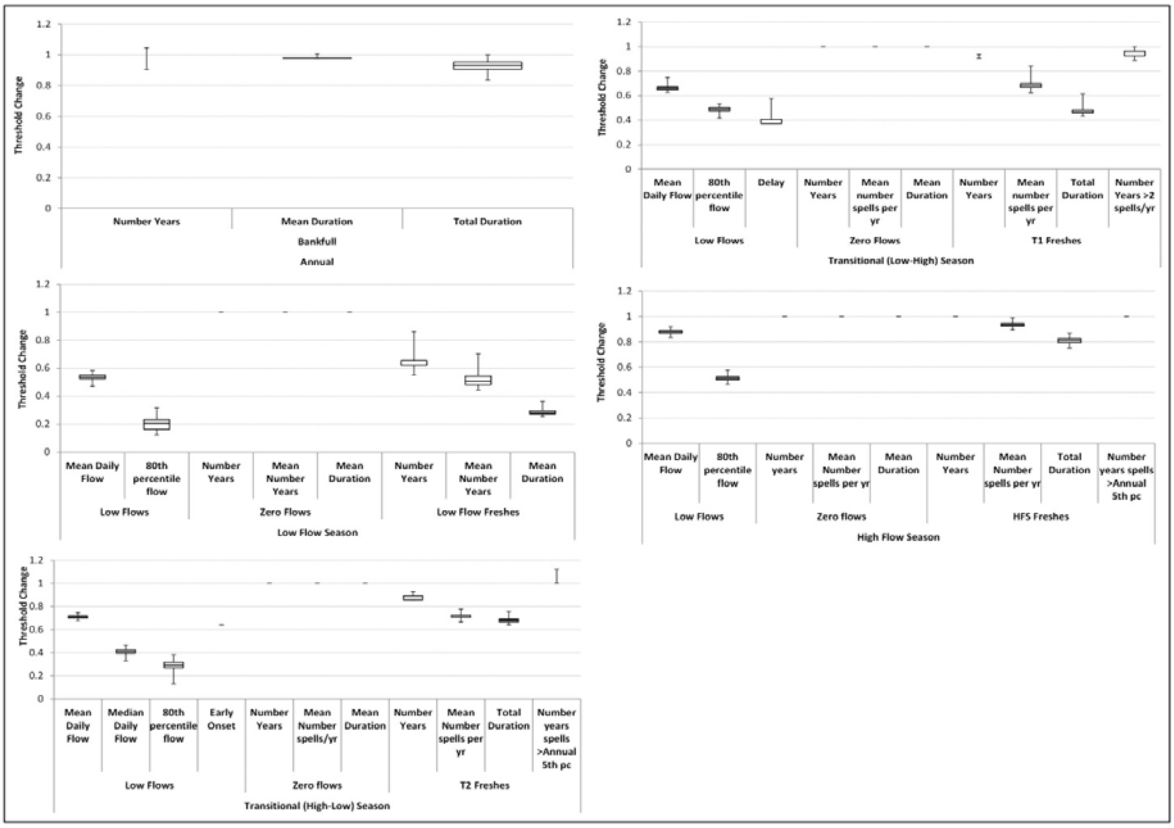
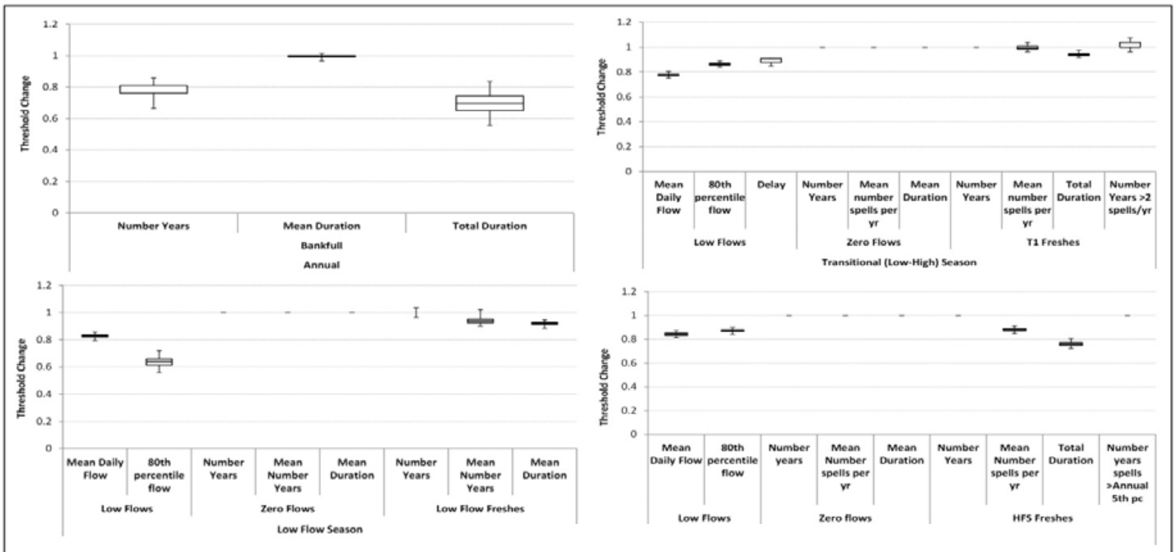


Figure 37. Usage factor box and whisker plots showing the variability in environmental flow metric threshold change output for each flow season. Scenario 7a Top, Scenario 7b Bottom





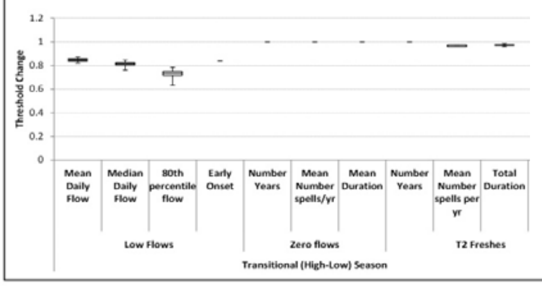
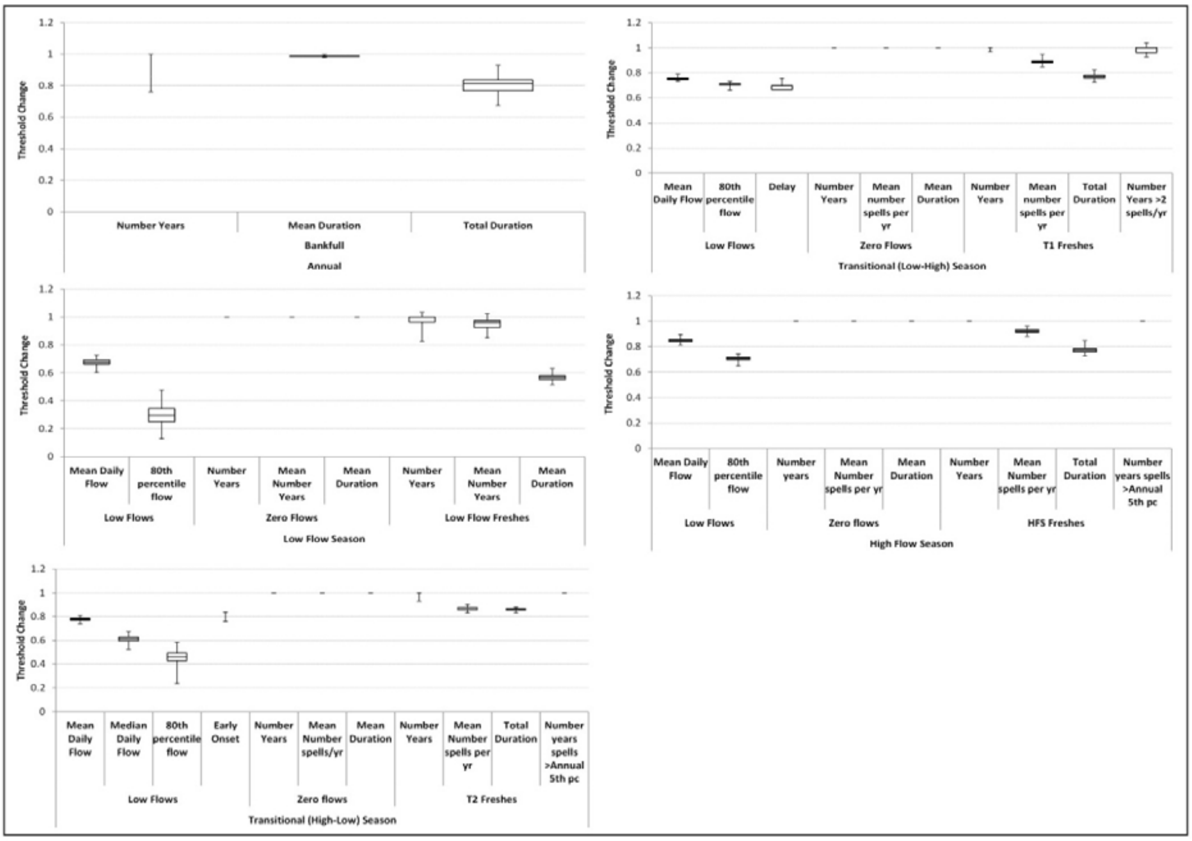
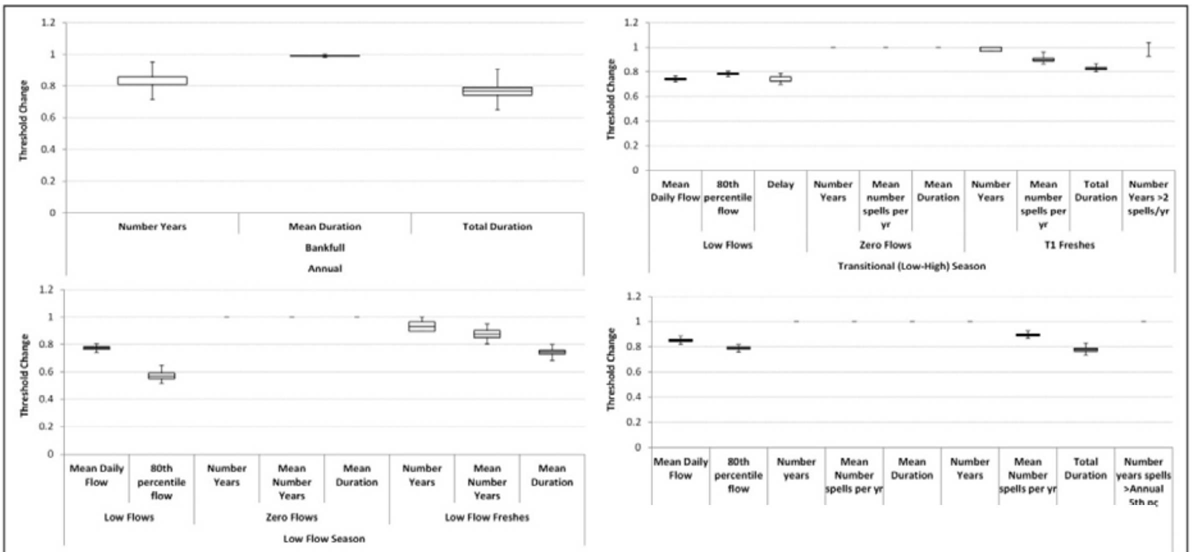


Figure 38. Capacity factor box and whisker plots showing the variability in environmental flow metric threshold change output for each flow season. Scenario 2 Top, Scenario 3 Bottom





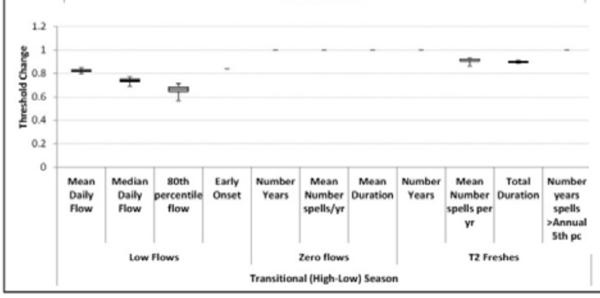
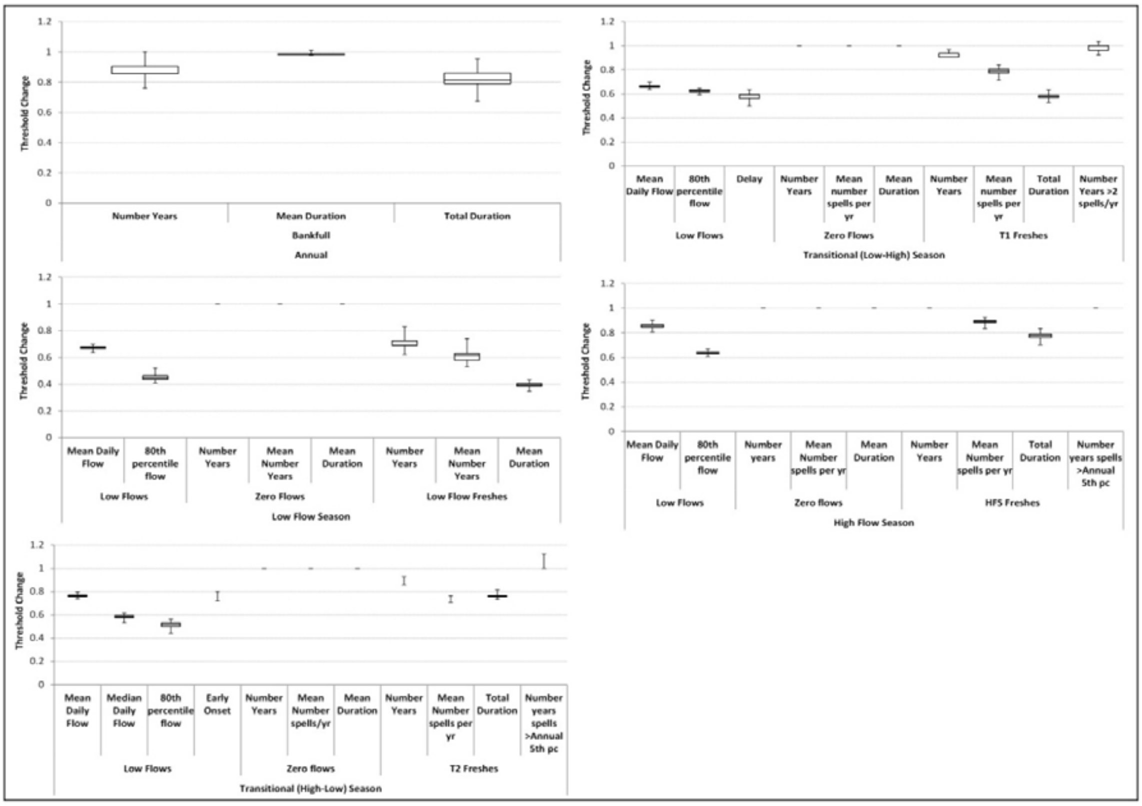


Figure 39. **Capacity factor box and whisker plots showing the variability in environmental flow metric threshold change output for each flow season. Scenario 4 Top, Scenario 5 Bottom**



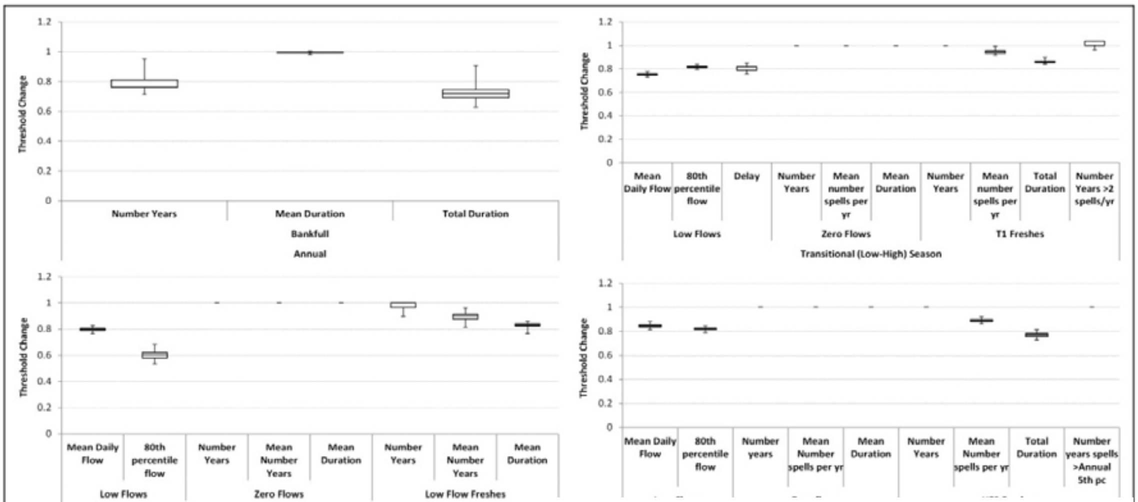
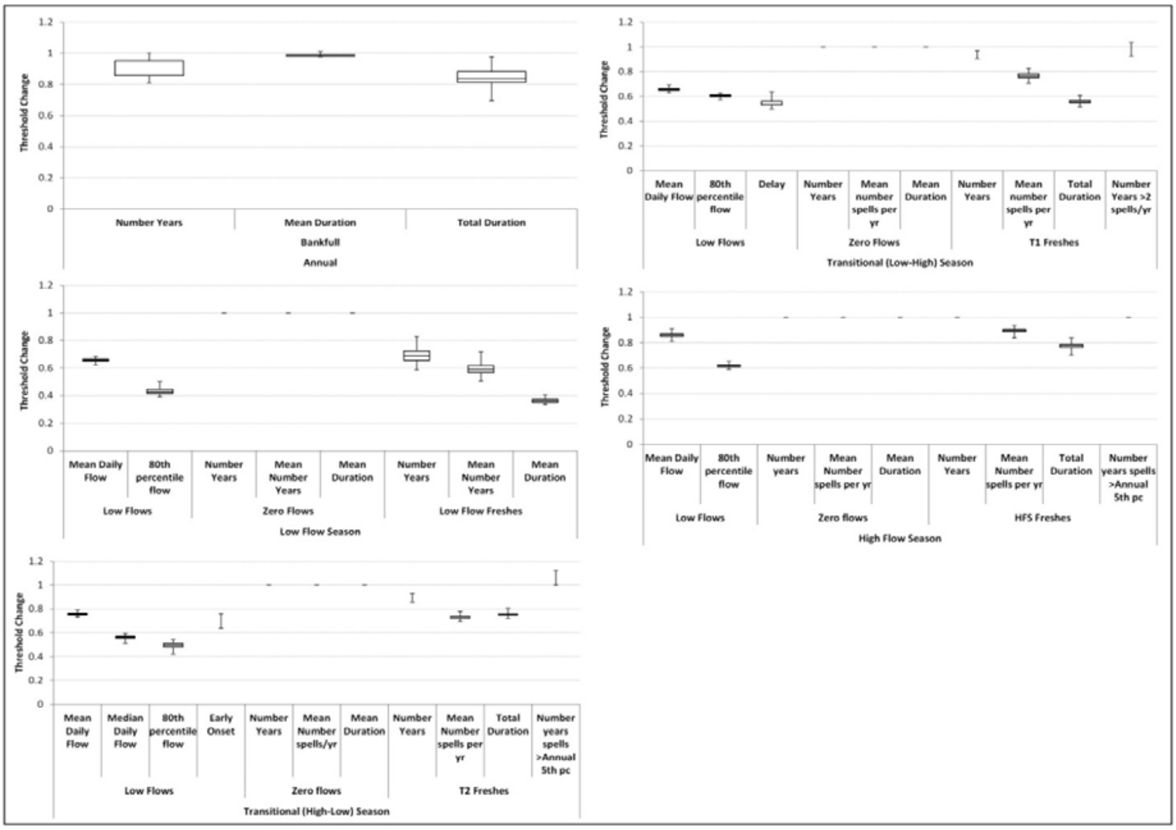
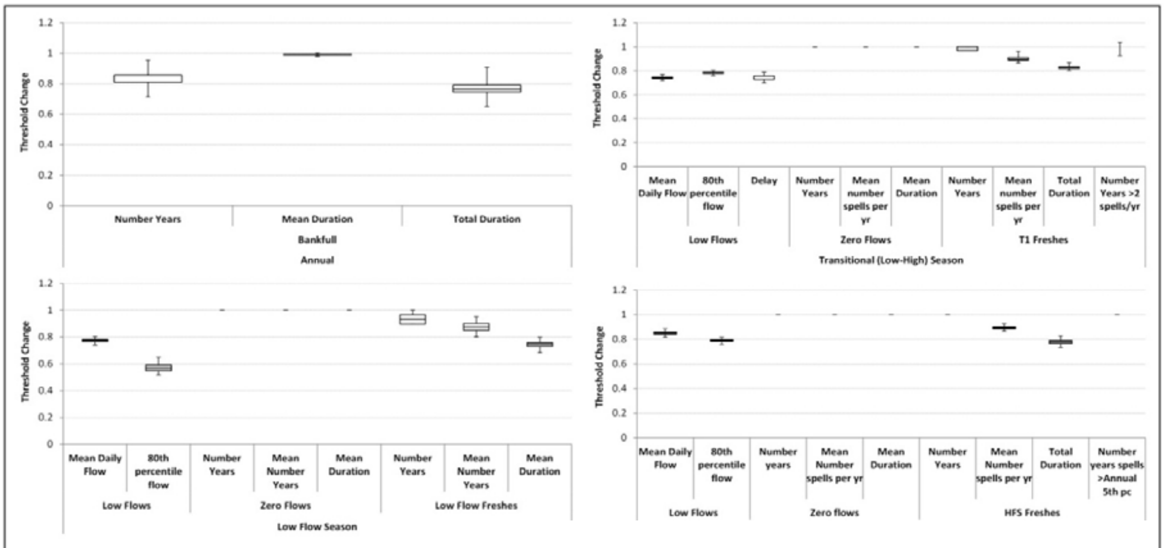


Figure 40. Capacity factor box and whisker plots showing the variability in environmental flow metric threshold change output for each flow season. Scenario 6a Top, Scenario 6b Bottom





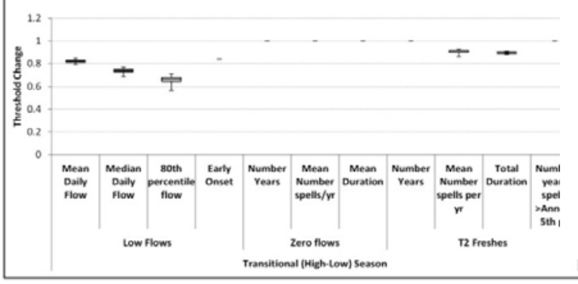


Figure 41. Capacity factor box and whisker plots showing the variability in environmental flow metric threshold change output for each flow season. Scenario 7a Top, Scenario 7b Bottom

UNITS OF MEASUREMENT

Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^6 m^3	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^4 m^2	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^3	volume
kilometre	km	10^3 m	length
litre	L	10^{-3} m^3	volume
megalitre	ML	10^3 m^3	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^3	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^3	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

GLOSSARY

Act (the) — In this document, refers to the *Natural Resources Management (SA) Act 2004,* which supersedes the *Water Resources (SA) Act 1997*

Annual adjusted catchment yield — Annual catchment yield with the impact of dams removed

Aquatic community — An association of interacting populations of aquatic organisms in a given water body or habitat

Aquatic ecosystem — The stream channel, lake or estuary bed, water and/or biotic communities and the habitat features that occur therein

Aquatic habitat — Environments characterised by the presence of standing or flowing water

Baseflow — The water in a stream that results from groundwater discharge to the stream; often maintains flows during seasonal dry periods and has important ecological functions

Basin — The area drained by a major river and its tributaries

Benchmark condition — Points of reference from which change can be measured

Biodiversity — (1) The number and variety of organisms found within a specified geographic region. (2) The variability among living organisms on the earth, including the variability within and between species and within and between ecosystems

Biological diversity — See 'biodiversity'

BoM — Bureau of Meteorology, Australia

Catchment — That area of land determined by topographic features within which rainfall will contribute to run-off at a particular point

Conjunctive use — The utilisation of more than one source of water to satisfy a single demand

Critical habitat — Those areas designated as critical for the survival and recovery of threatened or endangered species

Dams, off-stream dam — A dam, wall or other structure that is not constructed across a watercourse or drainage path and is designed to hold water diverted or pumped from a watercourse, a drainage path, an aquifer or from another source; may capture a limited volume of surface water from the catchment above the dam

Dams, on-stream dam — A dam, wall or other structure placed or constructed on, in or across a watercourse or drainage path for the purpose of holding and storing the natural flow of that watercourse or the surface water

Dams, turkey nest dam — An off-stream dam that does not capture any surface water from the catchment above the dam

Data comparability — The characteristics that allow information from many sources to be of definable or equivalent quality, so that this information can be used to address program objectives not necessarily related to those for which the data were collected. These characteristics need to be defined but would likely include detection limit precision, accuracy, bias, etc

DENR — former Department of Environment and Natural Resources (Government of South Australia)

DEWNR — Department of Environment, Water and Natural Resources (Government of South Australia)

DFW — former Department for Water (Government of South Australia)

Domestic purpose — The taking of water for ordinary household purposes; includes the watering of land in conjunction with a dwelling not exceeding 0.4 hectares

d/s — Downstream

DWLBC — former Department of Water, Land and Biodiversity Conservation (Government of South Australia)

Ecological indicators — Plant or animal species, communities, or special habitats with a narrow range of ecological tolerance; for example, in forest areas, such indicators may be selected for emphasis and monitored during forest plan implementation because their presence and abundance serve as a barometer of ecological conditions within a management unit

Ecological processes — All biological, physical or chemical processes that maintain an ecosystem

Ecological values — The habitats, natural ecological processes and biodiversity of ecosystems

Ecology — The study of the relationships between living organisms and their environment

Ecosystem — Any system in which there is an interdependence upon, and interaction between, living organisms and their immediate physical, chemical and biological environment

Ecosystem services — All biological, physical or chemical processes that maintain ecosystems and biodiversity and provide inputs and waste treatment services that support human activities

Effectiveness monitoring — Documents how well management practices meet intended objectives for the riparian area. Monitoring evaluates the cause and effect relations between management activities and conditions of the riparian-dependent resources. Terrestrial and in-stream methods constitute monitoring that evaluates and documents the total effectiveness of site-specific actions.

EMLR — Eastern Mount Lofty Ranges

Endangered species — (1) Any species in danger of extinction throughout all or a significant portion of its range

Endemic — A plant or animal restricted to a certain locality or region

Environmental values — The uses of the environment that are recognised as being of value to the community. This concept is used in setting water quality objectives under the Environment Protection (Water Quality) Policy, which recognises five environmental values — protection of aquatic ecosystems, recreational water use and aesthetics, potable (drinking water) use, agricultural and aquaculture use, and industrial use. It is not the same as ecological values, which are about the elements and functions of ecosystems.

Environmental water provisions — That part of environmental water requirements that can be met; what can be provided at a particular time after consideration of existing users' rights, and social and economic impacts

Environmental water requirements — The water regimes needed to sustain the ecological values of aquatic ecosystems, including their processes and biological diversity, at a low level of risk

Ephemeral streams or wetlands — Those streams or wetlands that usually contain water only on an occasional basis after rainfall events. Many arid zone streams and wetlands are ephemeral.

Evapotranspiration — The total loss of water as a result of transpiration from plants and evaporation from land, and surface water bodies

Floodout — An area where channelised flow ceases and floodwaters spill across adjacent alluvial plains

Floodplain — Of a watercourse means: (1) floodplain (if any) of the watercourse identified in a catchment water management plan or a local water management plan; adopted under the Act; or (2) where (1) does not apply — the floodplain (if any) of the watercourse identified in a development plan under the *Development (SA) Act 1993*; or (3) where neither (1) nor (2) applies — the land adjoining the watercourse that is periodically subject to flooding from the watercourse

Flow bands — Flows of different frequency, volume and duration

Flow regime — The character of the timing and amount of flow in a stream

Fresh — A short duration, small volume pulse of streamflow generated by a rainfall event that temporarily, but noticeably, increases stream discharge above ambient levels

GIS — Geographic Information System; computer software linking geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis

Hydrography — The discipline related to the measurement and recording of parameters associated with the hydrological cycle, both historic and real time

Hydrology — The study of the characteristics, occurrence, movement and utilisation of water on and below the Earth's surface and within its atmosphere; see also 'hydrogeology'

Hydrometric — Literally relating to water measurement, from the Greek words 'hydro' (water) and metrikos (measurement)

Hydstra — A time series data management system that stores continuously recorded water-related data such as water level, salinity and temperature; it provides a powerful data analysis, modelling and simulation system; contains details of site locations, setup and other supporting information

Impact — A change in the chemical, physical, or biological quality or condition of a water body caused by external sources

Impairment — A detrimental effect on the biological integrity of a water body caused by impact that prevents attainment of the designated use

Infrastructure — Artificial lakes; dams or reservoirs; embankments, walls, channels or other works; buildings or structures; or pipes, machinery or other equipment

Irrigation — Watering land by any means for the purpose of growing plants

Irrigation season — The period in which major irrigation diversions occur, usually starting in August–September and ending in April–May

Lake — A natural lake, pond, lagoon, wetland or spring (whether modified or not) that includes part of a lake and a body of water declared by regulation to be a lake. A reference to a lake is a reference to either the bed, banks and shores of the lake or the water for the time being held by the bed, banks and shores of the lake, or both, depending on the context.

Land — Whether under water or not, and includes an interest in land and any building or structure fixed to the land

Land capability — The ability of the land to accept a type and intensity of use without sustaining long-term damage

Licence — A licence to take water in accordance with the Act; see also 'water licence'

Licensee — A person who holds a water licence

Macro-invertebrates — Aquatic invertebrates visible to the naked eye including insects, crustaceans, molluscs and worms that inhabit a river channel, pond, lake, wetland or ocean

m AHD — Defines elevation in metres (m) according to the Australian Height Datum (AHD)

MDBA — Murray-Darling Basin Authority

MDBC — former Murray-Darling Basin Commission

Metadata — Information that describes the content, quality, condition, and other characteristics of data, maintained by the Federal Geographic Data Committee

MLR — Mount Lofty Ranges

Model — A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions. Examples include estimating storm run-off, assessing the impacts of dams or predicting ecological response to environmental change

Native species — Any animal and plant species originally in Australia; see also 'indigenous species'

Natural resources — Soil, water resources, geological features and landscapes, native vegetation, native animals and other native organisms, ecosystems

NRM — Natural Resources Management; all activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively

Percentile — A way of describing sets of data by ranking the dataset and establishing the value for each percentage of the total number of data records. The 90th percentile of the distribution is the value such that 90% of the observations fall at or below it.

Perennial streams — Permanently inundated surface stream courses. Surface water flows throughout the year except in years of infrequent drought.

Prescribed area, surface water — Part of the state declared to be a surface water prescribed area under the Act

Prescribed lake — A lake declared to be a prescribed lake under the Act

Prescribed watercourse — A watercourse declared to be a prescribed watercourse under the Act

Prescribed water resource — A water resource declared by the Governor to be prescribed under the Act and includes underground water to which access is obtained by prescribed wells. Prescription of a water resource requires that future management of the resource be regulated via a licensing system.

Prescribed well — A well declared to be a prescribed well under the Act

PWA — Prescribed Wells Area

PWCA — Prescribed Watercourse Area

PWRA — Prescribed Water Resources Area

Quickflow — Also known as direct run-off or event flow, refers to that portion of streamflow generated during a storm event that enters the watercourse via direct run-off. It is defined as that volume of total observed streamflow for a given day that remains following subtraction of the volume identified as baseflow by the digital baseflow filter.

Riffles — Shallow stream section with fast and turbulent flow

Riparian — Of, pertaining to, or situated or dwelling on the bank of a river or other water body

Riparian areas — Geographically delineable areas with distinctive resource values and characteristics that comprise the aquatic and riparian ecosystems

Riparian-dependent resources — Resources that owe their existence to a riparian area

Riparian ecosystems — A transition between the aquatic ecosystem and the adjacent terrestrial ecosystem; these are identified by soil characteristics or distinctive vegetation communities that require free or unbound water

Riparian habitat — The transition zone between aquatic and upland habitat. These habitats are related to and influenced by surface or subsurface waters, especially the margins of streams, lakes, ponds, wetlands, seeps, and ditches

Scope dams - A dam where low flows may be required to be returned. In the Marne Saunders PWRA, this includes licensed dams only. In the EMLR and WMLR PWRAs, this includes licensed dams, and also all other dams with a capacity of 5 ML or more (including stock and domestic dams). Note that stock and domestic dams with a capacity of 5 ML or more are licensed in the WMLR; and that such dams are not licensed in the EMLR but may be required to return low flows

Seasonal watercourses or wetlands — Those watercourses or wetlands that contain water on a seasonal basis, usually over the winter–spring period, although there may be some flow or standing water at other times

Stock use — The taking of water to provide drinking water for stock other than stock subject to intensive farming (as defined by the Act)

Sub-catchment — The area of land determined by topographical features within which rainfall will contribute to run-off at a particular point

Surface water — (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir

Surface Water Archive — An internet-based database linked to Hydstra and operated by DEWNR. It contains rainfall, water level, stream flow and salinity data collected from a network of surface water monitoring sites located throughout South Australia

Sustainability — The ability of an ecosystem to maintain ecological processes and functions, biological diversity, and productivity over time

To take water — From a water resource includes (a) to take water by pumping or siphoning the water; (b) to stop, impede or divert the flow of water over land (whether in a watercourse or not) for the purpose of collecting the water; (c) to divert the flow of water from the watercourse; (d) to release water from a lake; (e) to permit water to flow under natural pressure from a well; (f) to permit stock to drink from a watercourse, a natural or artificial lake, a dam or reservoir

Tributary — A river or creek that flows into a larger river

u/s — Upstream

Water affecting activities — Activities referred to in Chapter 7, Part 42, Division 1, s. 127 of the Act

Water allocation — (1) In respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence. (2) In respect of water taken pursuant to an authorisation under s.11 means the maximum quantity of water that can be taken and used pursuant to the authorisation

Water allocation, area based — An allocation of water that entitles the licensee to irrigate a specified area of land for a specified period of time usually per water–use year

WAP — Water Allocation Plan; a plan prepared by an NRM Board

Water body — Includes watercourses, riparian zones, floodplains, wetlands, estuaries, lakes and groundwater aquifers

Watercourse — A river, creek or other natural watercourse (whether modified or not) and includes: a dam or reservoir that collects water flowing in a watercourse; a lake through which water flows; a channel (but not a channel declared by regulation to be excluded from the this definition) into which the water of a watercourse has been diverted; and part of a watercourse

Water dependent ecosystems — Those parts of the environment, the species composition and natural ecological processes, that are determined by the permanent or temporary presence of flowing or standing water, above or below ground; the in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries and lakes are all water-dependent ecosystems

Water licence — A licence granted under the Act entitling the holder to take water from a prescribed watercourse, lake or well or to take surface water from a surface water prescribed area; this grants the licensee a right to take an allocation of water specified on the licence, which may also include conditions on the taking and use of that water; a water licence confers a property right on the holder of the licence and this right is separate from land title

Watershed — The land area that drains into a stream, river, lake, estuary, or coastal zone

Water-use year — The period between 1 July in any given calendar year and 30 June the following calendar year; also called a licensing year

WDE — Water dependent ecosystem

Wetlands — Defined by the Act as a swamp or marsh and includes any land that is seasonally inundated with water. This definition encompasses a number of concepts that are more specifically described in the definition used in the Ramsar Convention on Wetlands of International Importance. This describes wetlands as areas of permanent or periodic to intermittent inundation, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tides does not exceed six metres.

WMLR — Western Mount Lofty Ranges

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