Environmental water requirements for the Mount Lofty Ranges prescribed water resources areas

2009

Government of South Australia

Environmental water requirements for the Mount Lofty Ranges prescribed water resources areas

Jason VanLaarhoven and Mardi van der Wielen

Science, Monitoring and Information Division
Department of Water, Land and Biodiversity Conservation

South Australian Murray-Darling Basin Natural Resources Management Board

December 2009

Report DWLBC 2009/29

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Science, Monitoring and Information Division

Department of Water, Land and Biodiversity Conservation

25 Grenfell Street, Adelaide

GPO Box 2834, Adelaide SA 5001

Telephone	National	(08) 8463 6946
	International	+61 8 8463 6946
Fax	National	(08) 8463 6999
	International	+61 8 8463 6999
Website	www.dwlbc.sa.gov.au	

ISBN 978-1-921528-63-7

VanLaarhoven, JM and van der Wielen, M. 2009. *Environmental water requirements for the Mount Lofty Ranges prescribed water resources areas.* DWLBC Report 2009/29, Department of Water, Land and Biodiversity Conservation & South Australian Murray-Darling Basin NRM Board, Adelaide.

Download this document at: www.dwlbc.sa.gov.au/publications/reports/html

FOREWORD

South Australia's unique and precious natural resources are fundamental to the economic and social wellbeing of the State. It is critical that these resources are managed in a sustainable manner to safeguard them both for current users and for future generations.

The Department of Water, Land and Biodiversity Conservation (DWLBC) strives to ensure that our natural resources are managed so that they are available for all users, including the environment.

In order for us to best manage these natural resources it is imperative that we have a sound knowledge of their condition and how they are likely to respond to management changes. DWLBC scientific and technical staff continues to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

Scott Ashby
CHIEF EXECUTIVE
DEPARTMENT OF WATER, LAND AND BIODIVERSITY CONSERVATION

ACKNOWLEDGEMENTS

The authors would like to acknowledge the invaluable input of many individuals and organisations that have made this project possible.

- The funding bodies: Commonwealth National Water Initiative, Adelaide and Mount Lofty Ranges Natural Resources Management Board and the Government of South Australia as facilitated through the Department of Water, Land and Biodiversity Conservation's Mount Lofty Ranges Program, and the South Australian Murray-Darling Basin Natural Resources Management Board.
- Michelle Bald for her work in the initial stages of the project in the development of the methodology.
- The Expert Panel for their work in their documentation of environmental water requirements for the biota in the study area and providing advice on the thresholds for changes in the flow regime resulting in impacts upon the aquatic environment.
- Department of Water, Land and Biodiversity Conservation hydrologists (Kumar Savadamuthu, Mark Alcorn, Bruce Murdoch and Daniel Penney) for their assistance in scenario testing, cross-section surveys, ratings and gaugings.

A special acknowledgement goes to ecological consultant Tim Doeg for his invaluable assistance in facilitating and documenting the outcomes of expert panel workshops and in the development of the environmental water requirement metric scenario testing tool.

CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

Catchments of the Mount Lofty Ranges (MLR) straddle two drainage basins: the Western (WMLR) catchments that drain into the sea west and south of Adelaide; and the Eastern (EMLR) catchments, part of the Murray-Darling Basin, which drain into the River Murray and Lake Alexandrina.

The water resources of the MLR, including surface water, watercourse water and groundwater, were prescribed on 8 September 2005 (EMLR) and 20 October 2005 (WMLR). Local natural resources management boards are required to prepare a water allocation plan (WAP) for prescribed resources, which sets sustainable limits for allocation of water and provides for ongoing water management. The South Australian Murray-Darling Basin Natural Resources Management (SAMDB NRM) Board is responsible for developing the EMLR WAP and the Adelaide and Mount Lofty Ranges (AMLR) NRM Board for developing the WMLR WAP, both assisted by the Department for Water, Land and Biodiversity Conservation (DWLBC).

The prescription process identifies the quantity, quality and regime of water required to sustain water-dependent ecosystems, and gathers information on water resources and social demands. All information is used to set sustainable extraction limits and other water management policies. These extraction limits and management policies need to recognise the legitimate right of the environment to water, and equitably balances social, economic and environmental water requirements.

The goal of this study is to define the level of deviation from the natural flow regime within which populations of aquatic animals and plants can be maintained and/or restored to a self-sustaining state and can withstand times of (natural) sub-optimal conditions such as drought.

The environmental water requirements of water-dependent flora and fauna inhabiting the watercourses and associated habitats in the eastern and western Mount Lofty Ranges have been determined by an expert panel, based on knowledge of local ecology, hydrology and geomorphology.

A series of expert panel workshops in late 2007 were attended by state and national experts in ecology, hydrology, hydrogeology and geomorphology. They identified priority water-dependent biota and physical processes of the Mount Lofty Ranges, and determined their environmental water requirements.

Water-dependent biota were divided into groups with similar life histories and flow requirements (functional groups). The ecological processes required to support self-sustaining populations of each functional group were identified, as were the components of the flow regime required to support those processes.

The distribution of biotic functional groups and physical processes across the Mount Lofty Ranges was identified by conceptually matching them to generic river reach types. Reach types represent watercourses with similar structure, ecology and hydrology, and are expected to support similar water-dependent ecosystems. The environmental water requirements of a reach type could then be expressed by aggregating the environmental water requirements of the biotic functional groups known or expected to be found there.

The 'natural flow paradigm', which considers that water-dependent ecosystems have evolved in response to the flow regime that they experience, was adopted as a guiding principle. It is well established that changes to the flow regime can lead to changes in the structure and function of the dependent ecosystem.

Environmental water requirements were translated into measurable hydrologic 'metrics' that correspond to key parts of the flow regime. (e.g. duration of zero flow events in the Low Flow Season). Limits were set for each metric in terms of how far it could deviate from its value under natural conditions while still maintaining the ecological process supported by that flow component at low risk. A metric that remains within these limits is considered to 'pass' while a metric that exceeds these limits is considered to 'fail' to provide an adequate environmental water requirement. Comparison of ecological monitoring data with the percentage of metrics passed at a site showed a good correlation between increasing ecological condition and increasing percentage of metrics passed.

An assessment of whether environmental water requirements are currently being met across the Mount Lofty Ranges showed that, of the 135 sites tested, only two sites passed all metrics, and 50% of sites passed less than 75% of the metrics. Metrics associated with low flows had very high failure rates in each of the flow seasons; larger bankfull flows were only marginally impacted. Fresh flows (shorter-term small increases in flow that remain in the channel) fell between these in the proportion of metrics met.

Meeting environmental water requirements in the Low Flow Season is likely to be the most critical in supporting the continuing presence of aquatic biota in the environment, largely due to the importance of maintaining viable aquatic habitat in the absence of (or with reduced) water inputs.

It is likely that given historical and current impacts (e.g. water resource development, land use change, land management practices) on the environment that some biotic species have experienced localised extinctions, and therefore environmental water requirements in those areas may be superfluous at this time. However, suitable environmental water requirements provide the capacity for successful restoration work, including biota reintroduction.

The next step in the process is to use the metrics and limits to assess the hydrological impacts of different management actions, such as varying dam capacity limits, extraction limits, or allowing threshold flows to bypass dams. The impact on metrics due to varying levels of water resource development can be expressed as varying levels of 'stress', for which targets can be set to environmentally acceptable levels, and consequently inform the development of environmental water provisions (van der Wielen in prep; VanLaarhoven 2009).

1. INTRODUCTION

Understanding environmental water requirements (EWR) is a key part of water allocation planning and licensing for the Mount Lofty Ranges (MLR) in South Australia. This report details the environmental water requirements of the catchments of the MLR and outlines the process that determined these EWRs.

More detail on this project can be found in the workshop report (MLR EWR Expert Panel in prep).

While informing water allocation planning for the MLR, the work within this report also informs or contributes significantly to the following resource condition targets outlined in the State NRM Plan (DWLBC 2006):

- W1: By 2011, all ecosystems dependent on prescribed water resources have improved ecological health compared with 2006
- W2: By 2020, all aquatic ecosystems have improved ecological health compared with 2006
- W3: By 2015, no further net loss of wetland or estuary extent or condition, compared to 2006
- B3: By 2011, no further net loss of natural habitat (terrestrial, marine and aquatic) extent and condition below that of 2006
- B4: By 2020, a net increase in ecological connectivity across all terrestrial, marine and aquatic ecosystems compared to the 2006 values.

1.1 STUDY AREA

Catchments of the Mount Lofty Ranges (MLR) straddle two drainage basins: the Western (WMLR) catchments that drain into the sea west and south of Adelaide; and the Eastern (EMLR) catchments, part of the Murray-Darling Basin, which drain into the River Murray and Lake Alexandrina (Figure 1). The common landscape and climate range means that catchments in the two basins have strong physical and biological similarities, and have thus been treated collectively. There are 72 catchments that cover 5600 km^2 and drain 10,422 km of mostly seasonal watercourses in the study area. An estimated 20,000 dams in the region have a total capacity of close to 55,000 ML.

1.2 WATER RESOURCE MANAGEMENT IN THE MLR

The water resources of the MLR, including surface water, watercourse water and groundwater, were prescribed on 8 September 2005 (EMLR) and 20 October 2005 (WMLR). Local natural resources management boards are required to prepare a water allocation plan (WAP) for prescribed resources, which sets sustainable limits for allocation of water and provides for ongoing water management. The South Australian Murray-Darling Basin Natural Resources Management (SAMDB NRM) Board is responsible for developing the EMLR WAP and the Adelaide and Mount Lofty Ranges (AMLR) NRM Board for developing the WMLR WAP, both assisted by the Department for Water, Land and Biodiversity Conservation

(DWLBC). DWLBC is also responsible for the overall water licensing process, and for allocating water to existing users at the time the prescription process started.

The prescription process identifies the quantity, quality and regime of water required to sustain water-dependent ecosystems, and gathers information on water resources and social demands. All information is used to set sustainable extraction limits and other water management policies. These extraction limits and management policies need to recognise the legitimate right of the environment to water, and equitably balances social, economic and environmental water requirements.

1.3 ENVIRONMENTAL WATER REQUIREMENTS AND PROVISIONS

Environmental water requirements have been defined as 'the water regime needed to sustain the ecological values of ecosystems, including their processes and biological biodiversity, at a low level of risk' (DWLBC 2006).

Aquatic and riparian biota have evolved life-history strategies based on the spatial and temporal presence of suitable habitats (Poff et al. 1997; Casanova and Brock 2000; Bunn and Arthington 2002). Water regime is a major determinant of the presence, quality and availability of these habitats. A number of key components in the water regime support these evolved biological responses, for example:

- flows that provide in-channel habitat
- flows that stimulate fish spawning
- flows that flush excess sediment from the stream bed
- groundwater levels that are accessible to vegetation
- flows that entrain organic material from the floodplain
- flows that maintain channel forms.

Changes to important elements of the water regime are likely to lead to changes in aquatic habitats, and subsequently the condition and composition of water-dependent ecosystems (e.g. Lloyd et al. 2004).

Environmental water provisions (EWPs) have been defined as 'those parts of environmental water requirements that can be met at any given time. This is what can be provided at that time with consideration of existing users' rights, social and economic impacts.' (DWLBC 2006). This report focuses on environmental water requirements; the approach to developing potential environmental water provisions for the MLR is outlined in separate reports (van der Wielen in prep; VanLaarhoven 2009).

Figure 1: Mount Lofty Ranges Prescribed Water Resources Areas

Prescribed Water Resources Areas

Eastern Mount Lofty Ranges PWRA

Western Mount Lofty Ranges PWRA

Catchments

Major Watercourse

Road

N

0 9 18 27

Kilometres

Government of South Australia
Department of Water, Land and Biodiversity Conservation

DISCLAIMER: The Department of Water, Land and Biodiversity Conservation, its Employees and servants do not warrant or make any representation regarding the use, or results of use of the information contained herein as to its correctness, accuracy, currency or otherwise. The Department of Water, Land and Biodiversity Conservation, its employees and servants expressly disclaim all liability or responsibility to any person using the information or advice contained herein.

Produced by: DWLBC Science, Monitoring and Information
Map Projection: Lambert Conformal Conic
Map Datum: Geocentric Datum of Australia 1994
Date: June 2009

M:\Projects_SWM\Mt_Lofty_Ranges\EWR_Project\Ouputs\EWR_report_maps\GeneralDescriptionMap.mxd LewisM01

2. PROJECT AIMS

The major aim of this project is to develop a methodology that can be used to determine the EWRs of water-dependent ecosystems and biota in the Mount Lofty Ranges, and to develop a tool that can report on the levels of stress placed on these environments by current and projected future water resource development.

For the purposes of this project, the major goal for EWRs is to promote self sustaining populations of aquatic and riparian flora and fauna, which are resilient in times of drought. To this end the project focuses on conserving biota and ecosystems currently present in the region through the establishment of suitable hydrological conditions. This will promote resilience through maintaining or increasing species population numbers and spatial extent.

EWRs are often expressed in absolute statements, with limited scope for assessing the effect of incremental deviations from the natural flow regime, and the consequent increase in 'stress' levels placed on water-dependent biota. For example, an EWR assessment for a given watercourse may state that flows are required to reach the top of the bank once every 2 years to maintain the channel form and scour sediments from the system. This statement suggests that if this doesn't happen, then the EWR is not met regardless of resilience inherent in this water requirement. It does not make known the risk associated with a change in either the frequency or magnitude of this event. For example, what is the increased risk to the watercourse if a bankfull flow event does not occur over a period of 3 or 4 years?

This report outlines a methodology that overcomes this problem by determining EWRs, and then translating them into terms that can be quantitatively assessed against changes in the flow regime brought about by water resource development. They are used in conjunction with deviation threshold limits (indicating increases in water-dependent ecosystem stress) to determine the current state of EWRs in the MLR.

Likens et al. (2009) states that quantifiable goals focused on specific, measurable ecosystem responses and outcomes have been poorly articulated in determining EWRs. This project overcomes this problem through the development of a hydro-ecological relationship between the condition of key biota and the success of EWRs.

The outcomes of this report will also inform water prescription processes with tools to help set sustainable water resource extraction limits and diversion rules that will meet environmental targets. An accompanying document will outline how the product of this report can be used to quantitatively report on increasing stress levels in water-dependent ecosystems because of flow regime deviation caused by surface water resource development. It also recommends sustainable diversion limits.

3. METHODS

3.1 OVERVIEW OF THE PROCESS

The process for determining EWRs for the MLR has been adapted from the methodologies used for the Marne EWR Project (MREFTP 2003), and the Victorian FLOWS process (SKM et al. 2002).

The study area (Figure 1) covers the EMLR and WMLR Prescribed Water Resources areas. Biological surveys in the region have revealed a wide diversity of water-dependent ecosystems and species, although there is limited information on their distribution at the stream scale (e.g. Casanova 2004; Hammer 2004, 2007; Harding 2005; Biological Database of South Australia (Department for Environment and Heritage), databases held by South Australian Research and Development Institute on fish, and by the EPA and Australian Water Quality Centre on aquatic macroinvertebrates). This project describes the likely EWRs of the entire prescribed water resources areas. In the absence of more spatially comprehensive survey data, the process relies on the use of an expert panel approach, coupled with conceptual mapping of water-dependent biota throughout the region.

3.1.1 EXPERT PANEL METHOD OF DETERMINING EWRS

The ‘expert panel’ approach of determining EWRs is a recognised and widely used methodology for use in systems with limited ecological data (e.g. Arthington et al. 1998; Cottingham et al. 2001; Doeg et al. 2008; Earth Tech 2003a, 2006; Favier et al. 2000, 2004; LREFSP 2002; LREFTP 2003; LYDEFTP 2004; SKM 2005, 2006; VanLaarhoven et al. 2004).

The approach uses a multidisciplinary expert panel to review available data, and use their professional, expert knowledge and experience to determine critical water requirements for the biota or ecosystems of interest. For the purposes of this study experts in hydrology, hydrogeology, geomorphology and ecology (see Appendix A) were gathered to interpret the available life-history, habitat and water requirement data for the study region.

3.1.2 PROCESS SUMMARY

Water-dependent ecosystem structure and function are considered to have strong similarities in similar landscape settings across the MLR. These similarities were used to classify watercourses and water-dependent biota into like groups by determining generic:

- functional groups of aquatic and riparian flora and fauna in the MLR that have similar life-cycles, habitat requirements and hence EWRs
- watercourse reach types (including groups of watercourses with similar physical form, ecology and hydrology) that represent the major types of water-dependent habitats across the study area.

EWRs were described for each biotic functional group by determining the flow-dependent ecological processes required to support each group, and the water regime components required to support those processes.

Biotic functional groups were matched to generic reach types based on the types of habitats present, creating a conceptual model for each reach type of the biotic groups likely to be present, their interactions and the collective EWRs of the reach type. Reach types were mapped over the MLR, allowing identification of EWRs for different locations.

EWRs were quantified by identifying hydrological metrics to act as a surrogate measurement for each of the identified water requirements (two examples of metrics are duration and frequency of zero flow events in the low-flow season – Section 4.1.1 describes MLR flow seasons). Limits of acceptable deviation from 'natural' values for these metrics were then set (see Section 6.3.1) to allow assessment of the level of environmental stress or risk likely to be associated with different levels of water resource development, including current development.

Steps in the EWR process

1. Determine EWRs for water-dependent ecosystems of the MLR (Section 4):
    a. Collate existing information on the presence and distribution of water-dependent ecosystems and biota.
    b. Group species into 'functional groups' with similar life histories, habitat niches and water requirements.
    c. Set environmental water regime objectives for water-dependent ecological assets.
    d. Determine EWRs for identified 'functional groups' (1a).
2. Map the distribution of water-dependent ecosystems and EWRs across the MLR (Section 5):
    a. Collate existing data on the distribution of water-dependent ecosystems and biota in the MLR.
    b. Define generic watercourse 'reach types' that describe major habitat types across the MLR, based on the characteristics of the physical form across the area (i.e. group watercourses with 'like' major habitat types).
    c. Assign functional groups of organisms (1a) and their EWRs (1c) to the generic reach types identified in (2b).
3. Quantify EWRs to allow testing of water management policies against resulting environmental stress (Section 6):
    a. Determine standard hydrological definitions for flow components.
    b. Develop measurable hydrological 'metrics' to represent EWRs (1c).
    c. Determine acceptable deviation in 'metrics' to maintain 'functional groups' (1a) at a low level of risk of degradation.
4. Determine the deviation in EWR metrics (3b) between current and 'natural' flow (flow with the effects of dams removed) (Section 7).
5. Determine EWPs, or environmentally sustainable diversion from EWRs (reported separately (van der Wielen in prep; VanLaarhoven 2009))

The outcomes for steps 1–4 are outlined in the following chapters. The process and outcomes are described in detail in a report on the two expert panel workshops and on work carried out before and after the workshops for this project (MLR EWR Expert Panel in prep).

The steps in the EWR process are illustrated in Figure 2.

Flow focus of the project

Both surface water (including flows in watercourses) and groundwater play important roles in meeting the EWRs in the MLR. Groundwater may contribute to surface flows by discharging to the surface as springs or baseflow. Organisms, such as stygofauna (fauna that live in groundwater systems, including caves and aquifers) and phreatophytic vegetation (plants that draw water from the groundwater table to maintain vigour and function), may also utilise groundwater while it is below the surface.

The focus of this report is on water on the surface, and on the impacts of surface water resource development on EWRs.

Information on presence, distribution and water requirements of stygofauna and phreatophytic vegetation in the MLR is currently very limited, and there is insufficient information to make an assessment of their EWRs at this point.

This project uses surface water flow modelling developed for the MLR catchments using the WaterCress platform (e.g. Alcorn et al. 2008; Heneker 2003; Teoh 2006). The modelling accounts for the component of surface flow derived from groundwater (baseflow) under current conditions by calibrating the surface water models with real flow data, which includes the baseflow (Teoh in prep). The surface water modelling can be used to assess the impacts of different surface water capture scenarios (including current conditions) on the flow pattern and hence EWRs. However, the impact of groundwater extraction on baseflow is not well described at a local scale and has not been incorporated into surface water modelling. Therefore assessment of groundwater extraction on EWRs can only currently be considered at a coarse (aquifer) scale.

The dependency of ecosystems on direct groundwater inputs at a local scale is largely unknown in the study area, although investigations show that it is likely that a significant proportion of wetlands and pools in the region are at least partially maintained through direct groundwater inputs (e.g. Barnett and Rix 2006; Green and Stewart 2008). Groundwater contributions to the environment can be protected by controlling groundwater extraction volumes, maintaining groundwater level gradients and managing the location where extractions occur.

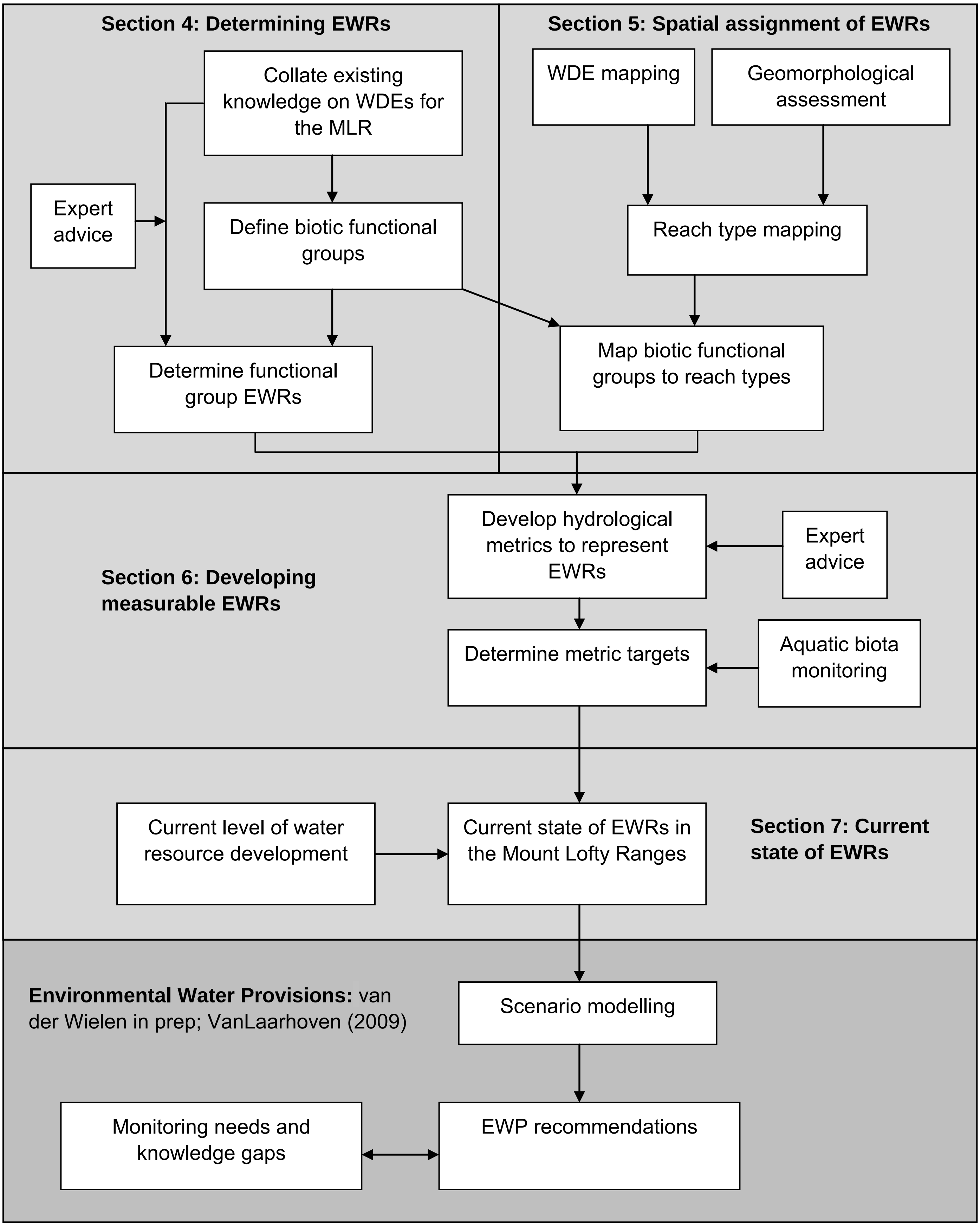


Figure 2. Overview of EWR process for Mount Lofty Ranges (WDE: water-dependent ecosystems)

4. DETERMINING EWRS

This chapter describes the EWRs for key biotic functional groups across the MLR. The terms used to describe EWRs and an overview of a typical EWR cycle in the MLR are given in Section 4.1. Section 4.2.1 describes the EWRs for functional groups of three key biotic groups of organisms: fish, aquatic macroinvertebrates and vegetation.

4.1 DESCRIBING ENVIRONMENTAL WATER REQUIREMENTS

The aspects of the flow regime used to describe an environmentally relevant flow are seasonality, magnitude (flow depth), frequency and duration.

4.1.1 SEASONALITY

Environmental water requirements, particularly those associated with biological responses, can be tied to particular ‘flow seasons’ during the year. These seasons do not always equate strictly to the traditional summer, autumn, winter or spring; they are based on natural flow distribution during the year. The 4 flow seasons identified for the MLR (Figure 3), and used in this report, are:

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

4.1.2 FLOW COMPONENTS

Within the natural flow seasons, EWRs can be described in terms of a number of different flow components:

- **Cease-to-flows** or zero flows – no flows are recorded in the channel and during these periods, the stream may contract to a series of pools or ponds, or may dry completely
- **Low flows (Low Flow Season)** – the low level of persistent baseflow during the Low Flow Season that maintains water flowing through the channel, keeping in-stream habitats wet and pools full; the permanence of flow in a stream is a product of the combination of low flows and cease-to-flows

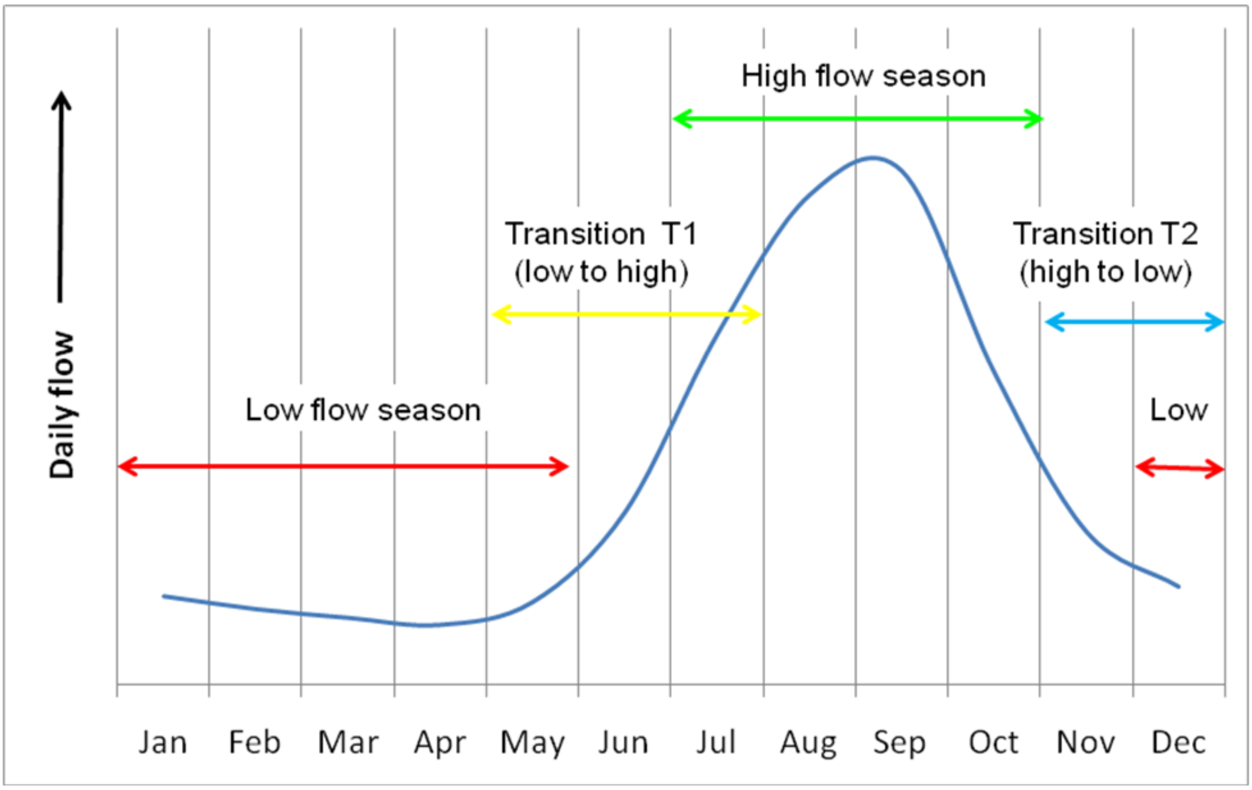


Figure 3. Typical range of flow seasons in the MLR against relative daily flow

- **Low flow freshes** – relatively small and short duration high flow events that last for one to several days as a result of localised rainfall during the Low Flow Season
- **Low flows (High Flow Season)** – the persistent increase in baseflow with the onset of the wet season (beginning in T1), often lasting through to the end of T2
- **High flow freshes** – long, sustained increases in flow during Transitional and High Flow seasons as a result of heavy rainfall events; may last for a number of weeks but are still contained in the channel
- **Bankfull flows** – flows that fill the channel but do not spill on to the floodplain (can occur any time but more commonly associated with High Flow Season)
- **Overbank flows** – higher flows that spill out of the channel on to the floodplain (can occur any time but more commonly associated with High Flow Season).

4.1.3 FREQUENCY AND DURATION

In the context of EWRs, frequency refers to how often an event such as a fresh, bankfull or overbank flow occurs each year or each flow season. Duration refers to how long an event is maintained over a particular flow rate threshold (e.g. how long an overbank flow remains over the bank level).

In general, absolute flow duration or frequency requirements have not been stipulated in this project. The duration and frequency of flow components will vary between streams, subcatchments and catchments depending on local geomorphic and climatic conditions, creating a variety of hydrologically controlled habitats. These habitats will support a range of population sizes and diversity of taxa largely determined by the range of hydrological conditions. Some habitats will naturally be more diverse and support larger populations than others due to more optimal hydrological conditions for a given taxonomic group (Poff et al. 1997). The duration and frequency components of EWRs were assessed as acceptable deviation from the 'natural' flow regime in a particular catchment (see Section 6.3).

4.1.4 TYPICAL FLOW REGIME IN THE MOUNT LOFTY RANGES

The different aspects of the flow regime make up a typical, generic annual environmental water cycle in the MLR (Figure 4).

Low Flow Season is characterised by relatively constant low flow rates and cease-to-flow events that are common in the MLR. Over time, between rainfall events, flows gradually decline and the amount of flowing water habitat decreases or disappears altogether. Permanent water habitats remain in individual pools that act as refugia where aquatic and semi-aquatic species persist over the drier months. Groundwater inflow, and occasional rainfall-driven low flow fresh events, maintain pool volume and water quality by flushing the system.

Transitional Flow Season 1, from low to high flows, begins with the increase in westerly cold fronts. The additional rainfall creates flowing water habitat, filling pools and delivering water to habitats that have persisted through the summer months with little water input. As local groundwater supplies are replenished, baseflow gradually increases over the season.

The High Flow Season is characterised by higher, more permanent baseflows as catchments wet up under more rainfall. Larger rainfall-driven flows can trigger breeding events for many aquatic animals and plants, and allow movement throughout the catchment, including migration to the sea for many fish species. Higher flows (bankfull and overbank) are more common in this season.

Flow rates begin to decrease in Transitional Flow Season 2 with the onset of weather dominated by high pressure systems. The flow reduction exposes substrates for many plant species to germinate, while maintaining sufficient depth to allow the continuing movement and migration of aquatic animal species.

4.2 EWRS OF BIOTIC FUNCTIONAL GROUPS

The water-dependent ecosystems of the MLR support a diverse range of fauna and flora with EWRs. Three well-studied priority biotic groups have been selected to represent the wider range of animals and plants in the region:

- fish
- aquatic macroinvertebrates
- water-dependent plants.

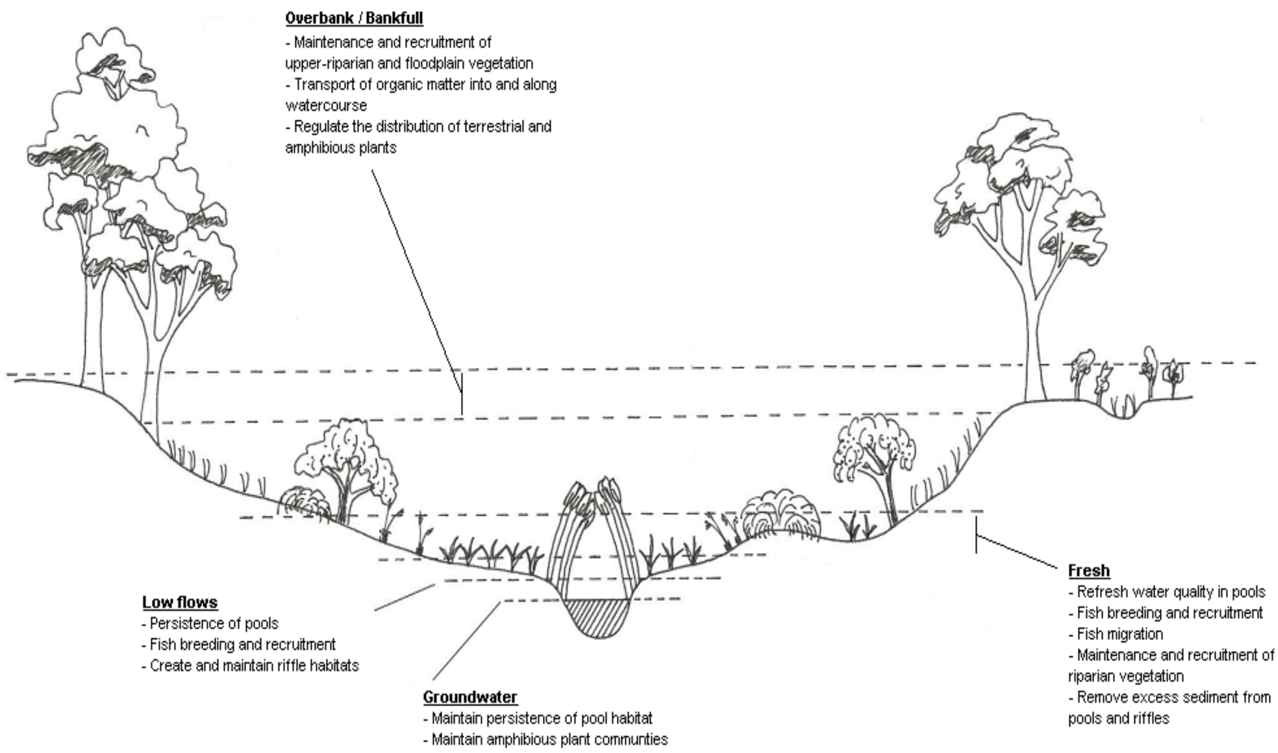


Figure 4. Common environmental water requirement processes linked to flow magnitudes (Favier et al. 2004)

Geomorphic processes that maintain suitable physical habitats have also been identified for these groups.

It is assumed that if EWRs are met for these representative key groups, then they will also be met for the other water-dependent biota and ecosystems in the MLR (e.g. birds, frogs, mammals).

Given the richness of water-dependent plants and animals inhabiting the watercourses and wetlands of the MLR, functional groups within the three major biotic groups were developed to group organisms with similar life-cycles and habitat requirements, and hence similar EWRs. Functional groups were developed by relevant members of the expert panel based on expert and literature knowledge on life-histories, habitat preferences and distribution of different species.

The major goal for EWRs for this project is to promote self sustaining populations of aquatic and riparian flora and fauna, which are resilient in times of drought. To this end the project focuses on conserving biota and ecosystems currently present in the region through the establishment of suitable hydrological conditions. This will promote resilience through increasing species population numbers and spatial extent.

Environmental water requirements were described by the expert panel for each functional group by determining the flow-dependent ecological processes required to meet the above objective for each group, and the water regime components required to support those processes.

4.2.1 FISH

In the MLR, 30 native and 9 exotic freshwater fish species have been recorded (Figure 5; Appendix B). Three of the native species have conservation significance on a national scale, and 20 have conservation significance at the state scale. McNeil and Hammer (2007) have comprehensively reviewed fish of the MLR and their distribution.

Native freshwater fish of the MLR are of two broad types: resident freshwater species (remain in a small range in a catchment throughout their life); and migratory species (require extensive migration in a waterway, or from the waterway to the sea or estuary at some stage of their life-cycle). Within these two broad types, five primary functional groups of native fish have been identified in the MLR (outlined in Appendix B) (Hammer 2007a; McNeil and Hammer 2007).

Resident freshwater species

Obligate freshwater, stream specialised: Species that have particular habitat or environmental requirements for survival, and are specialised to live in stream habitats; often found as the only species in a reach but are restricted to specific habitats; includes southern pygmy perch, mountain galaxias and river blackfish.

Obligate freshwater, wetland specialised: Species that require particular habitats or environments for survival, and are specialised to live in wetland habitats; often found as rare species in diverse fish assemblages, being restricted to specific habitats in lowland or terminal stream reaches; includes Yarra pygmy perch, Murray hardyhead, chanda perch and southern purple-spotted gudgeon.

Obligate freshwater, generalists: Mostly found in association with other species and occupy multiple habitats in a reach; the types of habitats present determine community composition and structure (and therefore water requirements); includes gudgeon species, numerous species from terminal wetlands and euryhaline species like gobies.

Migratory freshwater species

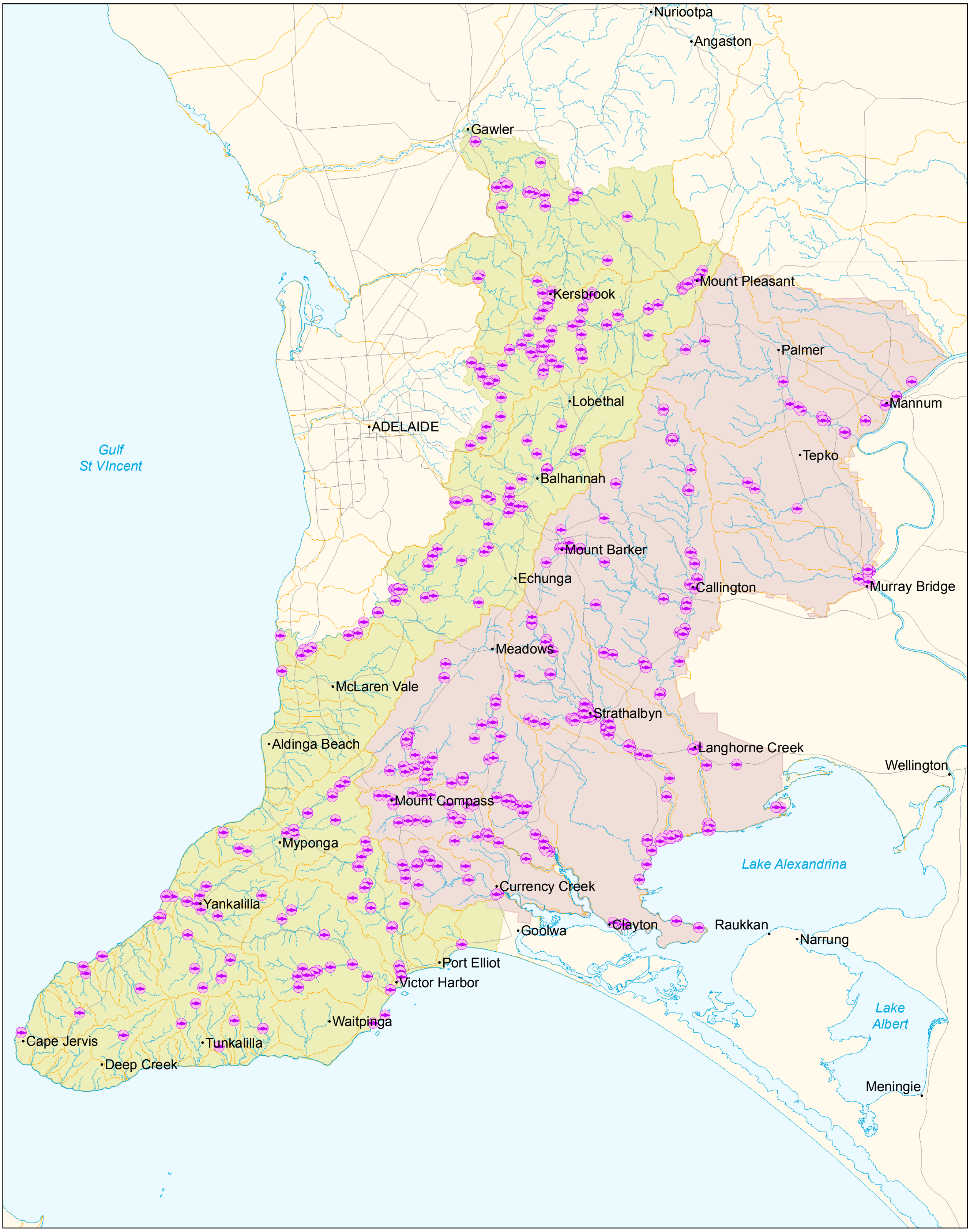
Migratory, diadromous species: Species that require migration to and from the sea or estuary as part of their life-cycle such as climbing galaxias, congolli, common galaxias and lampreys.

Migratory, potamodromous species: Species known to make extensive movements but remain within freshwater systems for all life-cycle stages (Murray–Darling golden perch).

A habitat-based group has also been described for the Fleurieu wetlands. Species in this group come from the different functional groups but the specific low energy nature of the habitat means that the water requirements are slightly different from the general functional group requirements. Species include southern pygmy perch, river blackfish and potentially climbing galaxias.

Appendix C outlines the ecological processes, grouped by flow season and flow component, required to support self-sustaining populations of these functional groups of fish, and the EWRs that support these processes (MLR EWR Expert Panel in prep).

Figure 5: Fish survey sites in the Mount Lofty Ranges



Prescribed Water Resources Areas

- Eastern Mount Lofty Ranges PWRA
- Western Mount Lofty Ranges PWRA

Catchment

- Major Watercourse
- Road
- Fish Survey Sites

N

0 9 18 27

Kilometres

Government of South Australia

Department of Water, Land and Biodiversity Conservation

DISCLAIMER: The Department of Water, Land and Biodiversity Conservation, its Employees and servants do not warrant or make any representation regarding the use, or results of use of the information contained herein as to its correctness, accuracy, currency or otherwise. The Department of Water, Land and Biodiversity Conservation, its employees and servants expressly disclaim all liability or responsibility to any person using the information or advice contained herein.

Produced by: DWLBC Science, Monitoring and Information
Data Source:
Map Projection: Lambert Conformal Conic
Map Datum: Geocentric Datum of Australia 1994
Date: June 2009

Fish are reliant on other biotic groups and so the EWRs for these groups (shown in Appendixes D and E) are also part of the requirements for fish. For example, many fish are reliant on macroinvertebrates as a food source (e.g. Lloyd 1987). Aquatic, in-stream, riparian and floodplain vegetation provide shade and habitat for fish survival, sources of terrestrial and aquatic macroinvertebrates (food), shelter during floods, and sites for spawning and recruitment (including indirectly through input of woody debris and leaf litter).

4.2.2 AQUATIC MACROINVERTEBRATES

A variety of programs have collected 338 aquatic macroinvertebrate taxa from the MLR at sites shown in Figure 6.

In the broadest sense, aquatic macroinvertebrates in the MLR belong to two functional groups – those that require flowing water (found in riffles, runs and cascades) and those with a distinct preference for still or very slow flowing water (found in pond or pool habitats, and slow flowing lowland streams) (MLR EWR Expert Panel in prep).

Within these two broad groups, six different community types can be identified, depending on the type of habitats and persistence of flow regime (wet or dry climate). The same species can be found in a number of different community types and it is difficult to identify specific indicator taxa that are restricted to just one community. Often, the difference between types is in degrees of species diversity and relative abundance of different species from each group, with fewer or more still water or flowing water taxa found in particular habitat types (MLR EWR Expert Panel in prep).

Flowing water (permanent or seasonal flow) species

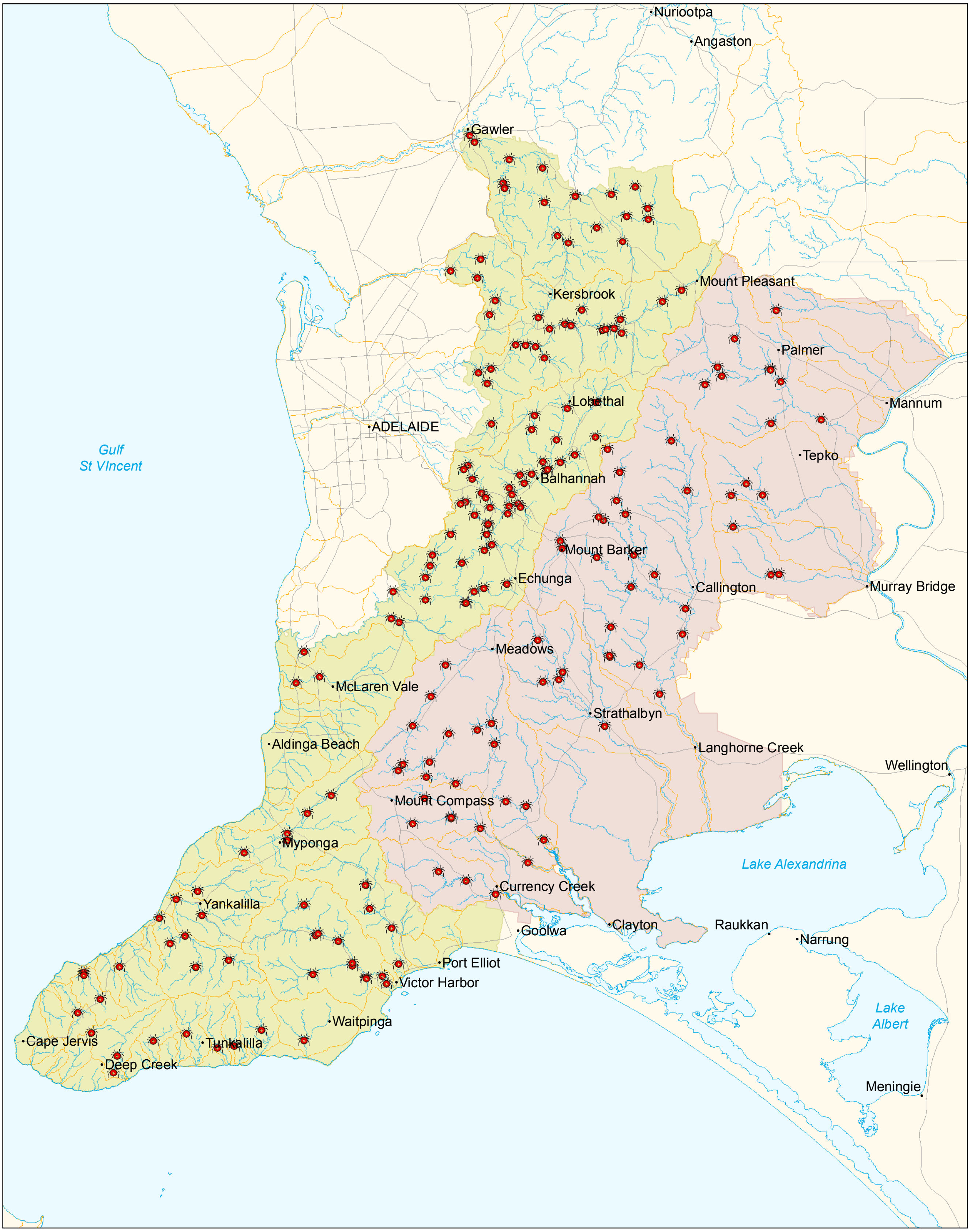
Flowing water, cascade: Macroinvertebrates in these habitats tend to live on the surface of the bedrock, and have adapted to withstand high flows during floods by evolving secure attachment mechanisms. Overall diversity is relatively low, as the number of species that require access to subsurface habitats at various times during their life-cycle (e.g. juveniles migrating into the stream bed, species that use the subsurface habitats as refuges during floods) is small. These species are not well adapted to dry periods, as refuges in these habitats are limited.

Flowing water, riffle: The cobble/boulder habitats of riffles or the gravel habitats that characterise runs provide a wide diversity of microhabitats, so that these areas are generally the most diverse communities in stream systems. Cascade species are still present in riffles, living on the upper surfaces of rocks but other taxa present can use other microhabitats. With significant subsurface refuge habitats, most species can survive short periods of no flow (although diversity is highest in permanently flowing streams).

Still water (permanent or seasonal water) species

Still water, persistent ponds and pools: The diversity of macroinvertebrates is highest among the still-water communities in ponds or pools where water is present throughout the year. The diversity and abundance of plants in permanent ponds and pools ensure a wide range of microhabitats.

Figure 6: Macroinvertebrate survey sites in the Mount Lofty Ranges



Prescribed Water Resources Areas

Eastern Mount Lofty Ranges PWRA

Western Mount Lofty Ranges PWRA

Catchment

Major Watercourse

Road

Macroinvertebrate Survey Sites

N

0 9 18 27

Kilometres

Government of South Australia
Department of Water, Land and Biodiversity Conservation

DISCLAIMER: The Department of Water, Land and Biodiversity Conservation, its Employees and servants do not warrant or make any representation regarding the use, or results of use of the information contained herein as to its correctness, accuracy, currency or otherwise. The Department of Water, Land and Biodiversity Conservation, its employees and servants expressly disclaim all liability or responsibility to any person using the information or advice contained herein.

Produced by: DWLBC Science, Monitoring and Information
Data Source:
Map Projection: Lambert Conformal Conic
Map Datum: Geocentric Datum of Australia 1994
Date: June 2009

M:\Projects_SW\Mt_Lofty_Ranges\EWR_Project\Ouputs\EWR_report_maps\FishSites.mxd LewitM01

Still water, lowland streams: In the main, lowland stream macroinvertebrate communities reflect the types of taxa present in persistent ponds and pools. However, available habitats tend to be different, including the surfaces of woody debris (where species that are not present in persistent ponds and pools can be found) and the root zone of trees present on the water's edge, as well as in-stream vegetation.

Still water (temporary water) species

Still water, temporary pools: Some of the species found in persistent ponds and pools can be found in temporary pools in the river channel. However, the drying period restricts the diversity of macroinvertebrates to those that are adapted to dry habitats – through characteristics like higher resistance to poor water quality, resistant egg stages, ability to survive in damp mud on the bottom of pools, or the ability to move out of the habitat and colonise other waterbodies nearby (returning when water is present again).

Still water, floodplain wetlands: In wetlands disconnected from the groundwater and relying on stream floods, the macroinvertebrate community is determined by the frequency of the filling of wetlands and the subsequent persistence of the water. In general, the same species are present in all cases. The main differences are the diversity of the community, with lower diversity related to less frequent filling and lower levels of persistence. The EWRs of this group are very similar to those of the still water, temporary pools group so EWRs for the two groups are described together.

Appendix D outlines the EWRs, grouped by flow season and flow component, of these functional groups of aquatic macroinvertebrates and the ecological processes the EWRs support.

4.2.3 VEGETATION

In the MLR, 510 plant species have been identified that require the presence of surface water at some stage of their life-cycle. The South Australian Aquatic Biodiversity database was used to determine which of these plant species was considered to be water-dependent. Databases used to find records of water-dependent plant species in the MLR included Casanova (2004), data collected during the EMLR Fish Inventory (Hammer 2004), during the Wetland Inventory of the Fleurieu Peninsula (Harding 2005), and the Biological Database of South Australia held by the Department of Environment and Heritage (which includes records from the South Australian Herbarium).

Functional groups for water-dependent vegetation were developed and refined from the work of Brock and Casanova (1997), Casanova and Brock (2000) and Leck and Brock (2000). Taxa were assigned to functional groups by plant ecologists on the expert panel, based on expertise and with reference to a range of botanical textbooks and databases.

Three broad groups of vegetation types can be identified in the MLR: terrestrial species associated with waterways and wetlands; amphibious species that require or tolerate the presence of surface water at some stage of their life-cycle; and submerged species that require extended periods of free surface water. Within these three broad vegetation types, 10 functional groups can be identified (Casanova in prep).

Terrestrial species

Many members of these groups are annual herbaceous species. The terrestrial group includes a large proportion of exotic species such as grasses and clovers that are often associated with watercourses. Soil disturbance associated with watercourses provides open habitat for these ruderal species to colonise.

Terrestrial dry (Tdr): Desiccation tolerant species that are intolerant of flooding but will persist in damper parts of the landscape and can invade or persist in riparian zones and the edges of wetlands. They do not have a flow requirement and are not considered further.

Terrestrial damp (Tda): These species germinate and establish on saturated or damp ground but cannot tolerate extended flooding in the vegetative state. They can persist in the environment in puddles as they dry, table drains etc. To persist in riparian zones and wetlands they need high water events, where water spreads out over the landscape long enough to saturate the soil profile, and then retreats. The soil profile needs to remain damp for around 3 months. In this climatic zone (cool wet winters, hot dry summers) the timing should be brief spring flooding, allowing maturation in the late spring and early summer. Examples include some *Allocasuarina*, *Centipeda* and *Chenopodium* species as well as a range of grasses.

Amphibious species

Amphibious fluctuation tolerator, low growing (ATl): This functional group can germinate either on saturated soil or under water, and grow totally submerged, as long as they are not inundated by the time they start to flower and set seed. They require shallow flooding for around 3 months in the spring. Shorter flooding times may eventually deplete the seed bank. Examples include *Isolepis, Elatine* and *Glossostigma* species.

Amphibious fluctuation tolerator, emergent (ATe): This functional group of emergent sedges and rushes has a wide tolerance to water presence. They survive in saturated soil or shallow water (unlike Tda) but also require their photosynthetic parts to remain above water (be emergent). The fluctuation toleration refers to the depth of water, as well as the presence of water. They prefer to keep their roots wet (damp soil to shallow surface water present), although the preferred duration varies widely between species (average of 6 months). They tolerate dry times as adults, preferably in the late summer to autumn. Examples include many *Eleocharis, Juncus* and *Cyperus* species.

Amphibious fluctuation tolerator, woody (ATw): This functional group of woody perennial species that hold their seeds on their branches, requires water to be present in the root zone but will germinate in shallow water or on a drying profile. Generally restricted to permanently saturated areas, that don't dry out over summer, or if so, for short periods of time or areas in which they can access groundwater most or all of the time. Examples include some *Eucalyptus*, *Leptospermum* and *Melaleuca* species.

Amphibious fluctuation responder, plastic (ARp): This functional group occupies a similar zone to the ATl group, except that they have a physical response to water level changes such as rapid shoot elongation or a change in leaf type. They can persist on damp and drying ground because of their morphological flexibility but can flower even if the site does not dry out. They occupy a slightly deeper/wet for longer site than the ATl group. Examples include *Myriophyllum* and *Persicaria* species.

Amphibious fluctuation responder, floating (ARf): These species grow under water or float on the top of the water, and require the year-round presence of free surface water of some depth. Many of them can survive and complete their life-cycle stranded on the mud, but they reach maximum biomass growing in free water all year round. They require the presence of permanent pools of water. Examples include *Azolla, Lemna* and *Nymphoides* species.

Submerged species

Submerged r-selected (Sr): Species that colonise recently flooded areas. Many require drying to stimulate high germination percentages, and they can complete their life-cycle quickly and die off naturally. They persist via a dormant, long-lived bank of seeds or spores in the soil. They prefer habitats that are flooded once a year or so, to a depth of more than 10 cm. If they don't receive flooding, they can persist in the seed bank and recover when water becomes available. Examples include annual *Chara* and *Nitella* as well as *Lepilaena* species.

Submerged emergent (Se): Species that require permanent saturated soil or surface water, but they need to remain emergent. Many of the swamp cyperaceous and restionaceous species belong to this group. They require permanent shallow water or saturated root-zone for germination, growth and reproduction and freshes during the Low Flow Season to maintain water presence and quality. Examples include *Typha*, *Phragmites* and *Bolboschoenus* species and *Triglochin procerum*.

Submerged k-selected (Sk): Species require that a site be flooded to >10 cm for more than a year for them to either germinate or reach sufficient biomass to start reproducing. Completely water-dependent, true aquatic species. Essentially restricted to permanent pools and ponds. Examples include *Vallisneria* and some *Potamogeton*, *Chara* and *Nitella* species.

Appendix E outlines the EWRs, grouped by flow season and flow component, of these functional groups of vegetation and the ecological processes the EWRs support. The flow component associated with a particular ecological process for a function group can vary depending on which habitat the plant is found in. For example, water for germination of river red gums on a floodplain would need to be an overbank flow, while the same process on an in-stream bench would require a fresh. Appendix E refers broadly to habitats as aquatic (wetted at cease-to-flow to low flow in a season); in-stream (from edge of pools to top of bank, including riffles, runs, benches, bars and stream bank); riparian (top of bank); and floodplain.

The particular water requirements between species in a group are variable in preferred timing, depth, duration and frequency of wetting. Maintaining a naturally variable water regime over time will help promote a diversity of species over time and space, including at different heights from the stream bed up to the floodplain. Appendix E summarises the most common seasonal patterns for groups in the MLR, although some species may germinate and reproduce at different times or opportunistically when the appropriate flow regime occurs.

5. SPATIAL ASSIGNMENT OF ENVIRONMENTAL WATER REQUIREMENTS

Biological surveys in the region have shown that there is a wide diversity of water-dependent ecosystems and species (Chapter 1) in the 72 catchments of the study area. However, distribution information is limited. This study aims to determine the likely EWRs for the whole of the study area, and in the absence of more comprehensive survey data, relies on the use of conceptual mapping of water-dependent biota throughout the region.

The strong similarities in structure and function of water-dependent ecosystems over similar landscape settings across the MLR have allowed generic reach types to be determined. They represent the major types of water-dependent habitats and have been mapped across the study area. The biotic functional groups identified in Chapter 4 have been matched to these generic reach types based on local and expert knowledge, hydrology and the types of habitats present in a reach type.

The EWRs for a generic reach type can therefore be determined by aggregating the EWRs of all functional groups found in a reach type, and considering interactions between functional groups and the geomorphic processes required to maintain relevant habitats. The mapping allows likely EWRs of a location to be stated based on the EWRs for that generic reach type.

5.1 DEVELOPMENT OF GENERIC REACH TYPES

The generic reach types were developed by the expert panel on the basis of local and expert knowledge of the distribution and grouping of geomorphic units and habitats (e.g. pools, riffles, levees), species and/or ecological groups, and hydrological characteristics across the MLR.

5.1.1 GEOMORPHOLOGY (PHYSICAL FORM AND HABITATS)

River geomorphological classifications include an assessment of the features and processes that determine the physical form and habitats of watercourses. These processes are strongly influenced by local geology, hydrology and vegetation structure.

The watercourses of the MLR were classified into similar physical categories using the River Styles® geomorphic framework, based on valley setting (level of watercourse confinement) and the presence of different geomorphic units (e.g. pools, riffles, levees) (see Fryirs and Brierley 2005). Existing geomorphic mapping by Earth Tech Engineering (2003b, 2004) was used to identify relevant geomorphic units and their groupings in the development of reach types.

5.1.2 HYDROLOGY (AQUATIC HABITAT)

Flow, driven by local hydrology, is a major determinant of habitat type by providing surface water, and by driving processes like scouring sediments and mobilising substrates. For the purposes of a classification system of reach types, the influences of hydrology have been taken into account through the relative catchment size contributing to flow in each watercourse system, which was estimated using stream ordering (Strahler 1952).

Stream order is also an indication of position in the catchment. When coupled with hydrology, it is an influencing factor on the presence of certain biota. The uppermost watercourses of a catchment (first and second order streams), with a few spring fed exceptions, are generally dominated by terrestrial ecosystems with no strong water requirements, with more strongly driven hydrological conditions becoming increasingly prevalent further down the catchment in higher order streams. Therefore, position in the catchment was used to help classify the location of river reach types. For example, streams in the upper catchment (e.g. third order streams) are more likely to support freshwater obligate fish species than diadromous fish species due to the increased distance required for the diadromous fish species to migrate, and the likelihood of barriers to migration along the length of watercourse between the upper catchment and the sea/estuary.

Two key aspects driving local hydrology are climate and presence of significant groundwater inflow. The EMLR was divided into wet and dry subcatchments on the basis of a threshold of 500 mm annual rainfall. This threshold was chosen by the panel on the basis of observed differences in species presence, particularly fish, and on hydrology advice on the extent of rainfall derived surface flow (Alcorn et al. 2008). Some dry areas have regular inflow of groundwater over the Low Flow Season, allowing obligate aquatic species like fish to persist in dry areas that would otherwise be unlikely to occur there.

5.1.3 HABITAT MAPPING

Existing habitat mapping for the MLR on the presence of wetlands, baseflow and permanent pools was used to inform reach type mapping by indicating the presence of aquatic habitat which is inferred to support aquatic biota.

5.2 RIVER REACH TYPES

Seven major reach types were identified in the MLR after combining geomorphology, habitat characteristics and position within the catchment (Figure 7a-b). Some have been further subdivided based on variations in geomorphology and/or hydrology. The methodology for mapping reach types is documented in the MLR EWR Expert Panel report (in prep).

The expert panel matched the fish, macroinvertebrate and plant functional groups to each of the generic reach types based on:

- the likely presence of different habitat types/geomorphic units
- appropriate hydrology
- known distribution of functional groups and field knowledge of streams in different parts of the landscape
- access to the necessary life-history processes (e.g. diadromous fish species need suitable connectivity to the sea/estuary).

Figure 7a: Reach Types in the northern Mount Lofty Ranges

Reach Type
- Headwater
- Upper pool-riffle channel
- Mid pool-riffle channel
- Lowland
- Tidal
- Gorge
- Reservoir
- Wetland
- Terminal wetland

Prescribed Water Resources Areas
- Eastern Mount Lofty Ranges PWRA
- Western Mount Lofty Ranges PWRA

Catchment

Road

N

0 5 10 15

Kilometres

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Produced by: DWLBC Science, Monitoring and Information
Map Projection: Lambert Conformal Conic
Map Datum: Geocentric Datum of Australia 1994
Date: June 2009

M:\Projects_SWM\Mt_Lofty_Ranges\EWR_Project\Ouputs\EWR_report_maps\ReachTypes.mxd LewisM01

Figure 7b: Reach Types in the southern Mount Lofty Ranges

Produced by: DWLBC Science, Monitoring and Information
Map Projection: Lambert Conformal Conic
Map Datum: Geocentric Datum of Australia 1994
Date: June 2009

5.2.1 HEADWATERS

Subgroups: rocky headwaters (with or without springs); alluvial (intact discontinuous channel or channelised); chain of ponds

This reach type (Figure 8) is located higher in the catchments in rocky or alluvial headwaters of first and second order streams. Rocky headwaters generally have a bedrock, cobble or gravel bed in steep areas. Alluvial headwaters are generally featureless valley floors of mud or sand in lower energy systems. Channels may or may not exist, and may be swampy, or contain fresh water meadows. Alluvial headwaters can also include floodouts where a channel disperses on to a floodplain at a decrease in gradient or where a stream emerges from a much more confined valley. Alluvial headwaters may also be channelised through vegetation clearance, physical disturbance (e.g. stock grazing), drainage works or increased catchment runoff. Habitat types generally include temporary cascades (rocky headwaters only), pools, runs and riffles, valley fill, remnant ponds (in chain of ponds), and in-channel surfaces (benches and bars), generally providing a marginal aquatic habitat.

Figure 8. Headwater channel in the South Para catchment

Typical flow regimes are seasonal short-term flows following rainfall events with some overland flows. Ponds and some pools can retain water between events, which may persist (in wetter catchments or where spring fed) or dry out completely (in drier catchments).

Headwaters can have damp or swampy areas persisting over wetter seasons or in association with groundwater seepage and may provide baseflow or throughflow to downstream reaches, although in channelised areas this may be reduced.

Functional groups present

Vegetation

- ATe and ATw in pools, riffles and damp areas
- ATw in cascades
- Se in pools in wetter areas
- Tda around channel edges

Macroinvertebrates

- Still water, temporary pools
- Still water, persistent ponds and pools in wetter areas
- Flowing water cascade (rarely but with low diversity if present)
- Flowing water riffle (rarely but with low diversity if present)

Fish

- Most often headwaters do not support fish species but in areas with groundwater input, pools may support populations of freshwater obligate stream specialists.

5.2.2 UPPER POOL–RIFFLE CHANNEL

Subgroups: ephemeral; dry with persistent pools; wet

This reach type (Figure 9) is characterised by sequences of small to large pools connected by short riffles or long runs in the upper catchments. In drier catchments (<500 mm rainfall), the typical flow regime consists of occasional flows over riffles and runs during and after rain events supporting semi-permanent water in some pools. In wetter catchments the flow regime is characterised by persistent surface water in pools and several months of flows across riffles and runs. Higher flows generally occur in the High Flow Season and Transitional seasons. Freshes and bankfull flows associated with rainfall extend the surface water extent and depth, and occasional overbank flows spill out into the limited floodplain. Habitat types include permanent or semi-permanent pools, moderate to high-energy cascades, riffle and run habitats, benches and bars, and floodplain pockets.

Functional groups present

Wet catchments

Vegetation

- Sr, Se, Sk, ARf, ATl, ATw and ATe in pools
- Se, ATe, ATw and ARp in riffles and runs
- Se and ATw in cascades

- Tda, ATe, ATl and ATw around channel edges up to the top of bank
- ATe, ATw, and Tda on floodplain pockets

Macroinvertebrates

- Still water, temporary pools
- Still water invertebrates, persistent ponds and pools (high diversity)
- Flowing water, riffles and runs (medium diversity)

Fish

- Freshwater obligate (stream specialist) – mountain galaxias, river blackfish (marginal without significant springs), marginal habitat for southern pygmy perch if sufficiently wet
- Freshwater (generalist)
- Diadromous/migratory species – climbing galaxias

Figure 9. Upper pool–riffle channel in the Myponga catchment

Ephemeral and dry reaches

Vegetation

- Sr, ATe and ATe in temporary pools
- Se, Sr, ARf, Arp, Ate and ATw in persistent pools (not ephemeral reaches)
- ATe, ATw and ARp in riffles and runs
- ATw in cascades
- Tda, ATe and ATw around channel edges up to top of bank
- ATe, ATw, and Tda on floodplain pockets

Macroinvertebrates

- Still water, temporary pools
- May be still water invertebrates, persistent ponds and pools (not ephemeral reaches)

Fish

- Freshwater obligate (stream specialist) – mountain galaxias where sufficient water of suitable quality persists (absent or only periodically (opportunistically) present in ephemeral reaches)

5.2.3 MID POOL–RIFFLE CHANNEL

This reach type (Figure 10) is characterised by larger trunk streams in the upper to mid catchments with sequences of small to large pools connected by short riffles or long runs. Flow regimes are similar to upper pool–riffle channel but with higher flow rates due to the larger catchment area. In drier catchments, the typical flow regime is persistent to semi-persistent water with occasional flows over riffles and runs during and after rain events. In wetter catchments, or catchments with associated groundwater springs, the typical flow regime is persistent surface water in pools and semi permanent flows across riffles and runs (short cease-to-flow events). Habitat types include temporary and permanent pools, high to moderate-energy riffle and run habitats, benches and bars, and larger floodplain pockets.

Functional groups present

Vegetation

- Se, Sk, ATe, ATw and ARf in permanent pools
- Sr, Ate and ATw in temporary pools
- Se, ATe, ATw and ARp in riffles and runs
- Tda, ATl, ATe and ATw around channel edges to top of bank
- ATe, ATw, and Tda further up the slope on floodplain pockets

Macroinvertebrates

- Still water, persistent ponds and pools (high diversity)
- Flowing water, riffle (high diversity)

Figure 10. Mid pool–riffle channel in the Hindmarsh catchment

Fish

- Freshwater obligate (stream specialist) – mountain galaxias, river blackfish, southern pygmy perch
- Freshwater (generalist) – gudgeons
- Diadromous/migratory species – including climbing galaxias and occasionally common galaxias

Note: only mountain galaxias and gudgeons in drier catchments

5.2.4 GORGE

Subgroups: dry; wet or dry with springs

This reach type (Figure 11) is typically associated with steeper tributary streams in the upper to mid catchment and comprises relatively coarse substrates (bedrock, cobble, gravel, sand) and a higher energy flow environment. Habitat types include cascades, riffles, pools and runs. In drier catchments, typical flow regimes are persistent to semi-persistent water in pools with occasional flows over riffles and runs during and after rain events. In wetter catchments, typical flow regimes are persistent surface water in pools and near permanent fast flows across riffles and runs (short cease-to-flow events). A distinct seasonal regime is often observed with higher baseflows in the High Flow Season. Freshes and bankfull flows associated with rainfall extend the surface water extent and depth.

Functional groups present

Vegetation

- Se, ATw and ATe in pools
- ATw and ATe in riffles
- ATw in cascades – also Se in wetter catchments
- Tda, ATe and ATw around channel edges to top of bank

Macroinvertebrates

- Still water, temporary pools (medium diversity)
- Still water, persistent ponds and pools (medium diversity)
- Flowing water, riffles (medium diversity)
- Flowing water, cascades (medium diversity)

Figure 11. Gorge in the South Para catchment

Fish

- Freshwater obligate (stream specialist) – mountain galaxias
- Freshwater (generalist) – gudgeons
- Diadromous/migratory species – climbing galaxias; likely to be more common where a gorge is accessible to reaches lower in the landscape

5.2.5 LOWLAND

Subgroups: ephemeral; dry with springs or wet with limited floodplain; dry with springs or wet with extensive floodplain

This reach type (Figure 12) is associated with a low-gradient large channel breaking or broken out of hills, consisting of sequences of large and long pools separated by short-run segments and occasional riffles. In losing reaches (which recharge groundwater) or very dry catchments, it may simply consist of a small channel with few in-stream features (ephemeral lowland channel). More confined or incised lowlands with limited floodplains often have pools, runs, riffles and in-channel surfaces such as bars and benches. Extensive floodplains can also include floodplain features such as flood-runners and wetlands/billabongs, many of which are paleo-channels (old/former channels).

In ephemeral lowlands, flow occurs as occasional ephemeral flows over winter–spring in response to upstream flooding or high flows. In wetter catchments with a more substantial channel and baseflow, typical water habitats are persistent to semi-persistent water in large pools to semi-persistent water in small shallow pools, with occasional flows over riffles and runs during and after rain events. In wetter catchments, typical flow regimes are persistent surface water in pools and near permanent flows across riffles and runs (short cease-to-flow events). In the High Flow Season, higher baseflows show a distinct seasonal regime. Freshes and bankfull flows associated with rainfall extend the surface water width and depth, and occasional overbank flows can spill out into floodplains (where they exist).

Functional groups present

Vegetation

- Se, Sk, ATe, ATl, ARf and ARp in more permanent pools, ponds and floodplain wetlands
- Tda, Se, Sr, ATl, ATe, ATw, ARp and ARf in temporary pools, ponds and floodplain wetlands
- Tda, Se, ATe and ARp in riffles and runs
- Se, Sk, ATe in billabongs and floodplain ponds
- Tda, ATl, ATe and ATw around channel edges, in-channel surfaces, top of bank and around ponds, billabongs and wetlands

Macroinvertebrates

- Still water, persistent ponds and pools (seasonal) (medium to low diversity)
- Flowing water, riffles (seasonal)

Figure 12. Lowland channel in the South Para catchment

Fish

Ephemeral

- Diadromous/migratory species, including potadromous – no permanent populations but use these opportunistically for migration and colonisation when wet

Dry catchments

- Freshwater (generalist) – gudgeons
- Diadromous/migratory species, including potadromous

Wet catchments

- Freshwater (generalist)
- Freshwater (wetland specialist)
- Freshwater (stream specialist) – mountain galaxias, river blackfish, s outhern pygmy perch
- Diadromous/migratory species, including potadromous

5.2.6 TERMINAL WETLANDS

Terminal wetlands (Figure 13) are largely freshwater wetland habitats linking the stream with the discharge environment (estuary, ocean, River Murray or Lake Alexandrina). They can have a complex array of aquatic, semi-aquatic to terrestrial habitats, often including a deeper, open channel with shallower, well vegetated, low-energy benches and a variably inundated bank.

The water regime will depend on the upstream catchment rainfall and flow regime. Those that discharge to a freshwater environment will have relatively permanent freshwater due to back-filling from the River Murray/Lake Alexandrina under normal circumstances. Drier catchments will provide episodic flooding whereas wetter catchments or those with significant baseflow in the area will experience seasonal baseflow of fresher, clearer catchment water as well as occasional floods.

Figure 13: Terminal wetland in the Tookayerta catchment

Functional groups present

Vegetation

- Se, S k, S r, A Te, A Tl, A Rf and A Rp in open water with distribution dependent on topography
- Se often lining the main channel of flow

- ARf, ARp, ATl, ATe, ATw, Se and Sr in shallow areas and temporary margins
- Tda, ATe and ATw around edges and on floodplain

Macroinvertebrates

- Still water, persistent ponds and pools

Fish

- Freshwater (generalist).
- Freshwater (wetland specialist) – including Yarra pygmy perch and Murray hardyhead
- Freshwater (stream specialist) – southern pygmy perch
- Diadromous/migratory species, including potadromous

5.2.7 WETLANDS OF THE FLEURIEU PENINSULA

A total of 858 wetland bodies have been mapped from aerial photography on the Southern Fleurieu Peninsula as part of the wetland inventory of the Fleurieu Peninsula (Harding 2005). Wetlands in the WMLR area have been groundtruthed by the AMLR NRM Board and DWLBC between 2006 and 2008. Swamps of the Fleurieu Peninsula are a subset of wetland on the Fleurieu Peninsula that are recognised as a critically endangered ecological community, and are protected under the federal *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

Wetlands on the Fleurieu Peninsula (Figure 14) have been recorded as supporting 742 plant species, of which 139 have conservation status, including 73 species with status under the state *National Parks and Wildlife Act 1972*, and 6 species under the EPBC Act. These wetlands have also been recorded as supporting 183 vertebrate species. Of these, 22 species have conservation status under the National Parks and Wildlife Act, and 3 species are protected under the EPBC Act. Additionally, 3 of the bird species recorded are protected under international migratory bird treaties (JAMBA, CAMBA).

Wetlands are permanently or periodically inundated with water that may be static or flowing and may range from fresh to saline; the inundation with water influences the organisms or ecological processes. This very broad definition captures a wide variety of wetlands with varying habitat types, including freshwater swamps and marshes, estuaries, floodplains, artificial wetlands (including dams), watercourses, pools and baseflow systems. For the purpose of this report, streams, pools, baseflow systems and estuaries are separated from the general wetland definition.

Typical flow regimes are generally low energy flow, continuously wet, with a seasonal increase in baseflow. Flow may be provided by rainfall and interflow (perched wetlands), streamflow or groundwater (Permian Sands wetlands, fractured rock wetlands) or a combination. Habitat types include permanently damp–wet environments, with or without standing water.

Figure 14 Wetland on the Fleurieu Peninsula

Functional groups present

Vegetation

- ATl, ARf, ARp, ATe, ATw, Se, Sk and Sr in open water aquatic zone
- ATl, ARf, ARp, ATe, ATw, Se and Tda in emergent zone
- ATe, ATw, and Tda in bank and shore

Macroinvertebrates

- Still water, persistent ponds and pools (seasonal)

Fish

- Fleurieu wetland fish habitat community (southern pygmy perch, mountain galaxias, climbing galaxias, river blackfish)

6. DEVELOPING MEASUREABLE EWRS

Environmental water requirements need to be described in hydrological terms if they are to be used for testing the hydrological impacts of different actions under water resource management policies. The approach of this project is to express EWRs as hydrological metrics that represent important parts of the flow regime (e.g. the duration and frequency of freshes in the High Flow Season). The impacts of water resource development on these metrics can be expressed in terms of varying levels of ‘stress’, for which targets or limits can be set to represent levels of acceptable environmental impacts.

The absolute magnitude of flow components and the value of flow metrics to meet ecological requirements at a single site can be determined only with multiple years of detailed monitoring data on flow and ecological responses, because the variables of each flow component (e.g. low flow depth) vary from place to place depending on stream morphology and flow pattern. Also, the value of a flow metric that will promote a particular ecological outcome (e.g. the duration of freshes required to allow fish to access emergent vegetation for spawning in the Transitional Flow seasons) vary from site to site depending on a number of factors, such as stream morphology, flow pattern and species present.

Monitoring data is only available for a limited number of sites and it is beyond the scope and timeframe of this project to collect more. Therefore this project needs to define relative metrics and limits or targets for metric values that can be calculated and assessed at sites across the MLR.

Section 6.1 outlines the approach used to quantify measures to represent different flow components; Section 6.2 the final list of metrics selected to represent EWRs in the MLR; and Section 6.3 the approach used to identify whether an EWR has been met, and to assess the level of stress that may be associated with the impact of water resource development on metric values.

6.1 QUANTIFYING FLOW COMPONENTS

The absolute magnitude of each flow component (see section 4.1.2) required to achieve ecological objectives varies between catchments in the MLR. If these magnitudes are described by standard hydrological measures, a single ecologically relevant hydrological descriptor can be used for a flow component, regardless of where it is located.

The relationship between flow and habitat characteristics (e.g. depth) have been determined for a number of sites across the MLR. At these sites, cross-sections with important habitat components (deep pools, shallow riffles, bank benches, bankfull) have been established and rating curves determined that give the relationship between flow depth and flow rate. The flow rate was calculated for a large range of potential hydrological measures that could represent each flow component.

The flow depth associated with each potential hydrological measure was then compared against the cross-sections using photographs and notes from site visits by members of the expert panel to identify which flow level was the best fit for supporting relevant ecological processes. For example, the depth of the different potential measures of the ‘low flow’ component in each season was checked against the depth inundated on the cross-sections to see which would support persistence of water in pools, wetting up riffles, and allowing localised or extensive fish movement.

The hydrological measures found to be suitable surrogates for flow components across all flow seasons and reach types are shown in Table 1.

Table 1. Hydrological measures or flow descriptors that represent flow components across reach types and flow seasons in the MLR

Component	Hydrological measure
Low flow	80^{th} percentile exceedence flow for the flow season of interest (calculated on non-zero flows)
Fresh	2 times the median of all non-zero flows in the flow season of interest
Bankfull/overbank	1.5 annual return interval flow (based on annual maximum flows)

Many streams in the MLR have incised since European settlement, largely due to vegetation clearance, increased peak flow events and drainage works. In these situations it is probable that the 1.5 annual return interval will no longer reach the top of bank. However, without comprehensive mapping of stream condition, this is not able to be taken into account and will be accepted as a known issue with this methodology.

6.2 FINAL SET OF EWR METRICS

From the measures used to describe the different flow components, the expert panel developed a set of flow metrics that best represent the EWRs identified in section 4.2 and appendixes C-E. The set of metrics examined included:

- core metrics based on the flow descriptors identified in Table 1
- metrics identified by panel members that showed correlation between annual metric value and ecological condition or responses (e.g. fish recruitment and survivorship) in different years from monitoring data.
- metrics developed by panel members to represent key parts of the flow regime that were not covered by the core metrics.

The final list of metrics selected is shown in Appendix F (EWR Metric column) along with the intended function of the metric in meeting environmental objectives (Flow purpose column), grouped by flow season and component. Some metrics are only relevant for particular reach types (Reach type column). The ‘Priority group’ and ‘Threshold’ columns are explained in the following section.

6.3 EVALUATION OF METRIC SUCCESS

The natural flow paradigm (Poff et al. 1997) states that the integrity of water-dependent ecosystems depends largely on the dynamics of the natural flow regime. The natural flow regime influences the spatial and temporal diversity of in-channel and floodplain habitats which the present taxa have evolved life-history strategies to utilise, and in turn have become dependent upon. An altered flow regime can change the spatial and temporal availability of habitats and form an environment to which the native taxa may be poorly adapted (Bunn and Arthington 2002).

The goal of this study is to help define the level of deviation from the natural flow regime that is acceptable with the aim of maintaining/restoring populations to a state where they are self-sustaining and able to withstand times of (natural) sub-optimal conditions such as droughts.

6.3.1 SETTING METRIC LIMITS OR TARGETS

A quantitative understanding of how far a regime can deviate from the natural flow before it starts to impact significantly on water-dependent ecosystems is ideally required for determining limits or targets for EWR metrics. The tolerance levels and threshold limits to flow variation for each of the priority taxa groups in each watercourse, and the spatial interaction of these flows with resource availability (e.g. habitat, food), needed to do this are not currently available and collecting them is outside the scope of this project.

In absence of this data, it is necessary to use generic principles on the likely impact of variation in the flow regime on water-dependent ecosystems, which presents its own challenges. The negative ecological impacts of flow modification have been demonstrated many times; however, there is no clear relationship between the level of impact and the degree of change in the natural flow regime (Lloyd et al. 2004).

Priority flow metrics

The environment will be more sensitive to changes in some EWR measures (as represented by metrics) than others, depending on the resilience of the variable that the metric is representing. To represent this, EWR metrics for the study area have been split into 3 priority groups (Table 2), where Priority 1 metrics represent ecological functions that are critical for maintaining habitats or biological processes, and Priority 3 metrics are more general or more resilient to change. The column ‘Priority group’ in Appendix F shows which metric has been assigned to each priority group.

An acceptable level of deviation has been defined as the proportional change in an EWR metric (comparing its value between current and natural flow) that will limit the risk of degradation to the environment to a low level. These numbers have been developed in consultation with the expert panel, and are considered to be a ‘first cut’ with a need to monitor the system to ensure they are accurate. A low level of risk is expected to maintain self-sustaining populations of water-dependent taxa that are resilient to times of drought.

The percentage deviation that a metric can have from natural values and still be associated with low ecological risk is shown under ‘Low risk deviation’ in Table 2. The acceptable level of deviation from the natural value for the metrics in each priority group was developed from expert opinion of relevant ecologists with experience in freshwater fish, aquatic macroinvertebrate and vegetation natural history.

Therefore, for example, a Priority 1 flow metric can be reduced by up to 20% (e.g. low flow rate) or increased by up to 25% (e.g. average duration of zero flow spells) of the natural value and be considered a low-risk change.

Table 2. Priority groups for metrics and percentage deviation from the natural value associated with low ecological risk

Priority	Functions	Low risk deviation from natural	
		Decrease	Increase
1	Maintenance of core refuge habitat, or critical life-cycle processes	20%	25%
2	Promote resilience in the long term (e.g. large breeding events)	30%	50%
3	General information or metrics that represent resilient water requirements	50%	100%

Priority metrics by reach

Different habitats and biota have been matched to different reach types (Section 5). The distribution of these habitat types will also influence the priority rating of a metric for that zone, so the priority rating for a metric may vary between different reach types (see 'Priority group' column of Appendix F). For example, bankfull flows are likely to be more important in lowland reach types with significant floodplains than for the generally more confined upper pool–riffle or mid pool–riffle reach types.

Input data – current vs 'natural' flow

The metric system employed to indicate relative stress levels of the environment relies on comparing 'current' to 'natural' flows with the understanding that the greater the deviation from natural flow, the greater the stress the environment is likely to experience, under the principles of the natural flow paradigm (Poff et al. 1997).

Current flow is either actual gauged data, or flow modelled for a given water resource development scenario using the WaterCress hydrology modelling platform, which has been calibrated to gauged data.

Natural flow has been calculated as the flow with the impacts of the 2005 level of dam development removed as modelled using the WaterCress platform (e.g. Alcorn et al. 2008; Teoh in prep) and references therein) but accepting that some irreversible changes from pre-European flows have occurred due to land clearance and other water resource developments. It may be more accurately termed the 'adjusted' flow, as there is little scope to determine or model the natural pre-European flow regime due to the confounding interactions between land-use change and water resource development on both the surface and groundwater systems, and the relationships/connections between the two.

Using adjusted flow has a number of advantages:

- Given that it is unlikely that the landscape will return to pre-European settlement conditions, it provides a realistic flow regime for the 'best' that could be anticipated, and is the flow regime that the flora and fauna will be exposed to in the future.
- It can be determined reliably using a defined method, based on a model calibrated with actual flow data (when constructing the model to represent current flow).

The adjusted flow will be somewhat different from the pre-European natural flow regime under which water-dependent ecosystems evolved but it most reliably represents flows without the effects of water resource development. This issue has been accounted for through correlating current ecological monitoring data against metric scores calculated using natural or adjusted flow (Section 7.3).

The project aims to describe the EWRs of the biota expected to be present in the current landscape in the absence of water resource development, rather than expected under pre-European settlement conditions. The distribution of water-dependent habitats and species has changed since pre-European settlement as a result of factors including vegetation clearance, incision of watercourses and land management practices. Adjusted flow better represents the water regime that the current or likely distribution of species and habitats has adapted to since European settlement.

Thresholds for metrics – the small number problem

EWRs are assessed as the percentage or proportional change of a metric between current and natural flow. This means that there may be an issue where large proportional percentage changes are recorded for small absolute changes when dealing with small numbers. For example, if the value of the zero flow duration metric under natural conditions is 0.5 of a day and this increases to 0.75 of a day under current conditions, the result will be a proportional increase of 50%. This increase is beyond acceptable change for a priority 1 metric (Table 2), but in reality will result in a negligible increase in risk to the environment.

This problem has been dealt with by setting low-value thresholds for selected metrics. The threshold represents the value of a metric below which variations should not affect environmental risk. If the natural value of the metric is below the low-value threshold, then the current value of the metric can vary up to the low-value threshold without causing a change in environmental quality.

Metrics can vary in two directions in response to extraction of water. For some metrics, the current value will increase over the natural value (e.g. frequency or duration of zero flow events) – an 'increasing metric'. In other cases, the current value will decrease below the natural value (e.g. frequency or duration of low flow freshes) – a 'decreasing metric'. The treatment of metrics under the low-value threshold differs somewhat between the two types.

Whether the low-value threshold is incorporated in the assessment is determined by the following rules:

1. If both the natural and current values of an increasing metric are below or equal to the low-value threshold, then the metric is deemed to pass, irrespective of the proportional change. This applies to zero flow spell metrics (e.g. if there are on average 2 zero flow spells per year for a given site in the Low Flow Season under natural conditions, and this increases to an average of 4 spells per year under current conditions the metric is deemed to have passed as both scores are under the threshold of 4, even though it is equivalent to a 100% increase measured against an allowable 25% increase for a Priority 1 metric).

2. If both the natural and current values of a decreasing metric are below or equal to the low-value threshold, then the metric priority group changes to 3 and the proportional deviation is calculated as normal (current value divided by natural value). This applies to the bankfull metrics, as even small changes were considered to be ecologically important. Changing the metric priority group to 3 allows a higher deviation while still passing, which helps to address the small number problem.

3. If the natural value of the metric is less than or equal to the low-value threshold and the current value is higher than the threshold (only likely to happen for increasing metrics), then the proportional change is compared to the threshold value (current value divided by the low-value threshold). This avoids large proportional changes when the natural value is very low but the current value is just above the threshold. In this case, the current value is compared to a value of the metric deemed to be ecologically acceptable.
4. If the natural value of the metric is greater than the low-value threshold, then the proportional deviation is calculated as normal (current value divided by natural value).

Unexpected results

In some cases such as the following examples, the value of a metric under current conditions changes in an unexpected direction:

- Modelled bankfull and fresh spells in the High Flow Season and Transitional Flow Season 2 may be more likely under current than natural conditions. Dams are generally full at this time and are effectively impervious surfaces, which increase the proportion of rainfall that runs off compared with the no-dams situation where all of the catchment has some degree of permeability. This effect may push a flow event that is just under the flow threshold under natural conditions to be slightly over the flow threshold under current conditions, and hence is recorded as a bankfull or fresh spell.
- The measure of low flows (80th percentile exceedence non-zero daily flow rate – a decreasing metric) may go up under current conditions because there may be extra zero flow days under current conditions. This means that there are fewer non-zero flow days from which to calculate the 80th percentile exceedence non-zero daily flow rate, and so this value is more likely to be skewed by remaining non-zero flow days with higher daily flow rates.

The preferred approach would be to exclude such metrics when this occurs as the change is not likely to represent an ecologically significant outcome. However, different water management scenarios are assessed as the percentage of metrics passed or failed. Excluding metrics with unexpected results means that the number of metrics tested could change between scenarios because of excluded metrics but the number of metrics failed could stay the same. In this case, the percentage of metrics failing would change between the scenarios with no real ecological difference. Hence a metric is deemed to pass if the current value of a metric changed by more than 20% in an unexpected direction.

6.4 SUMMARY – DETERMINING IF ENVIRONMENTAL WATER REQUIREMENTS HAVE BEEN MET

The aim of providing EWRs is to maintain water-dependent ecosystems at a low level of risk. A set of flow metrics has been selected to represent ecologically important parts of the flow regime for different reaches and the different biotic groups they contain (Appendix F). Each part of the flow regime is assessed by comparing the value for the metric under current conditions with the value of the metric under natural conditions. The proportional deviation from current to natural is assessed in accordance with Table 2. If the deviation is within the acceptable range for that metric and priority group, then the metric 'passes'; if it is outside the acceptable limits then the metric 'fails'.

A passing metric score allows a level of deviation in accordance with its priority rating, with a maximum deviation of a reduction of 50% or an increase of 100% for a priority 3 metric. Metrics are surrogate measures for EWRs and reflect the environment's needs for water. If an EWR metric fails, the biota that depend on the aspect of the flow regime represented by the particular metric will be at an increased risk of degradation. Fewer passing metrics will correspond with an increased risk of environmental degradation. Environmental water requirements are considered to have been fully met if all metrics pass.

7. CURRENT STATE OF ENVIRONMENTAL WATER REQUIREMENTS

The integrity of water-dependent ecosystems depends largely on the dynamics of the natural flow regime (Poff et al. 1997). An altered flow regime can alter the spatial and temporal availability of habitats, forming an environment to which the native taxa may be poorly adapted (Bunn and Arthington 2002).

Bunn and Arthington (2002) suggest that four key principles link hydrology and aquatic biodiversity, and can be used to infer consequential impacts from altered flow regimes:

1. Flow is a major determinant of physical habitat in streams, which in turn is a major determinant of biotic composition.
2. Aquatic species have evolved life-history strategies primarily in direct response to their natural flow regimes.
3. Maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of populations of many riverine species.
4. The invasion and success of exotic and introduced species in rivers is facilitated by the alteration of flow regimes.

The system of metrics (Chapter 6) has been designed to demonstrate ecologically relevant changes from the natural flow regime, and can be used to assess:

- whether EWRs are currently being met in the MLR
- which parts of the flow regime have been affected by surface water resource development.

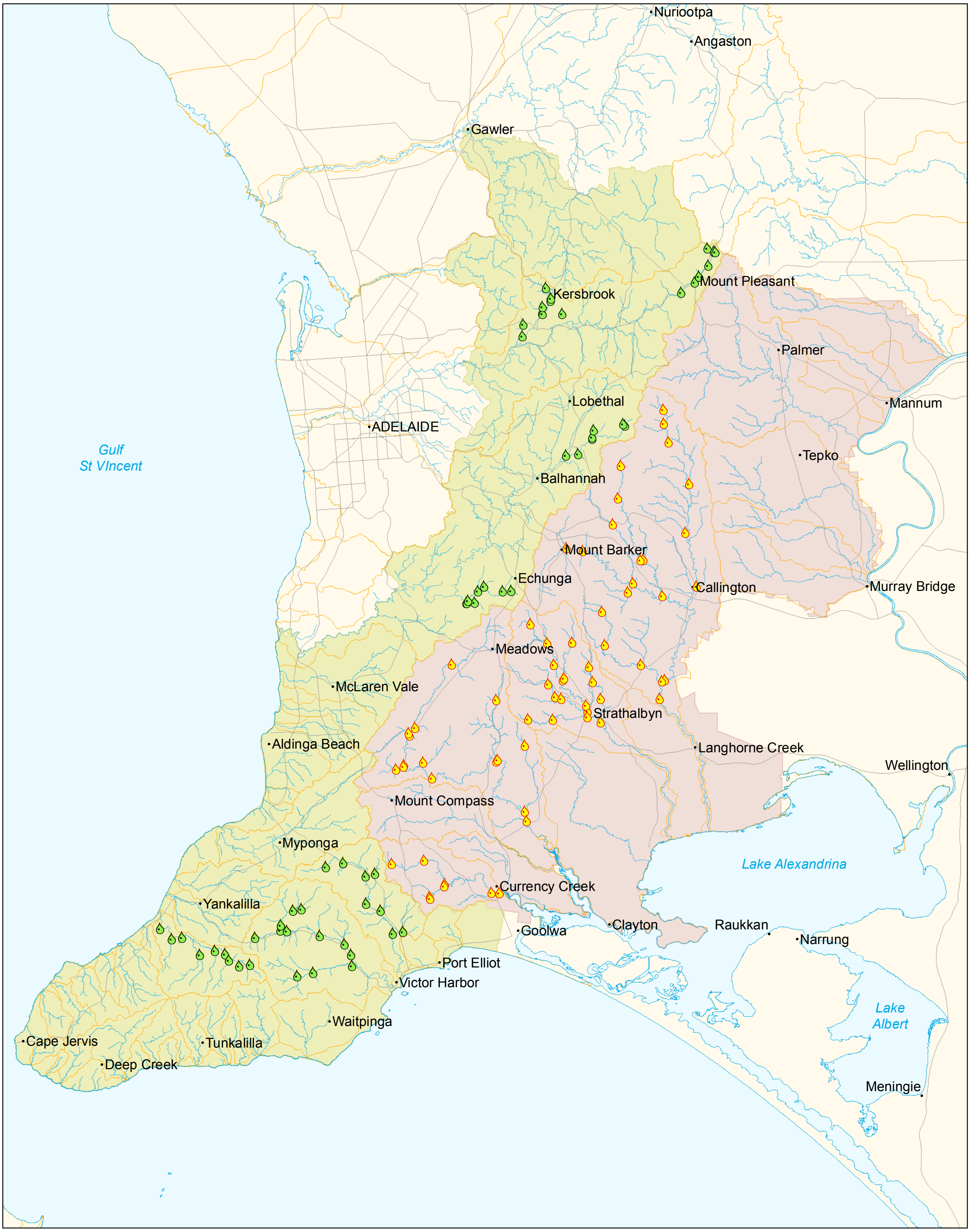
7.1 METHOD

Across the MLR, 135 sites were selected for testing whether EWRs are currently being met, based on location (to represent the different catchments and reach types) and availability of accurate flow data (Figure 15).

For each site, daily flow data was modelled under current and natural conditions for the period of 1974–2006 using the WaterCress platform (see Alcorn et al. (2008) and Teoh (in prep) for modelling process and assumptions). This period represents a range of wet and dry years, and corresponds to periods for which flow gauging data is available for most catchments. Current conditions were modelled assuming that usage from irrigation dams is up to 50% of dam capacity over October–March, while usage from stock and domestic dams was assumed to be up to 30% of dam capacity. Natural flow was considered to be adjusted flow (Section 6.3.1).

The two sets of daily flow were used to calculate the long-term average values of each metric under current and natural conditions. The metric value for current conditions was then expressed as a proportion of the natural value and assessed against the relevant deviation limit as set out in Table 2.

Figure 15: EWR test sites in the Mount Lofty Ranges



Prescribed Water Resources Areas

- Eastern Mount Lofty Ranges PWRA
- Western Mount Lofty Ranges PWRA

Catchment

- Major Watercourse
- Road

- Eastern MLR EWR test sites
- Western MLR EWR test sites

N

0 9 18 27

Kilometres

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Produced by: DWLBC Science, Monitoring and Information
Data Source:
Map Projection: Lambert Conformal Conic
Map Datum: Geocentric Datum of Australia 1994
Date: June 2009

M:\Projects_SW\Mt_Lofty_Ranges\EWR_Project\Ouputs\EWR_report_maps\FishSites.mxd LewitM01

A metric was considered to fail if the deviation from the natural value exceeded the relevant deviation limit (Table 2). This means that a priority 1 metric that passes may still deviate from the natural value by 25%, and that a passing priority 3 metric may still deviate from the natural value by 100%.

The number of metrics passed and failed under current conditions was then added for each site to give an indication of whether EWRs are being met across the MLR.

The percentage of sites that passed each metric was then examined to assess which parts of the flow regime have been particularly affected by development of the surface water resources (including extraction from watercourses and interception by dams) (Table 3).

7.2 RESULTS

7.2.1 ARE EWRS BEING MET ACROSS THE MLR?

Only 2 of the 135 test sites passed all metrics, and more than half the sites passed less than 75% of EWR metrics (Figure 16), suggesting that water-dependent ecosystems in almost all sites are at an elevated risk of degradation.

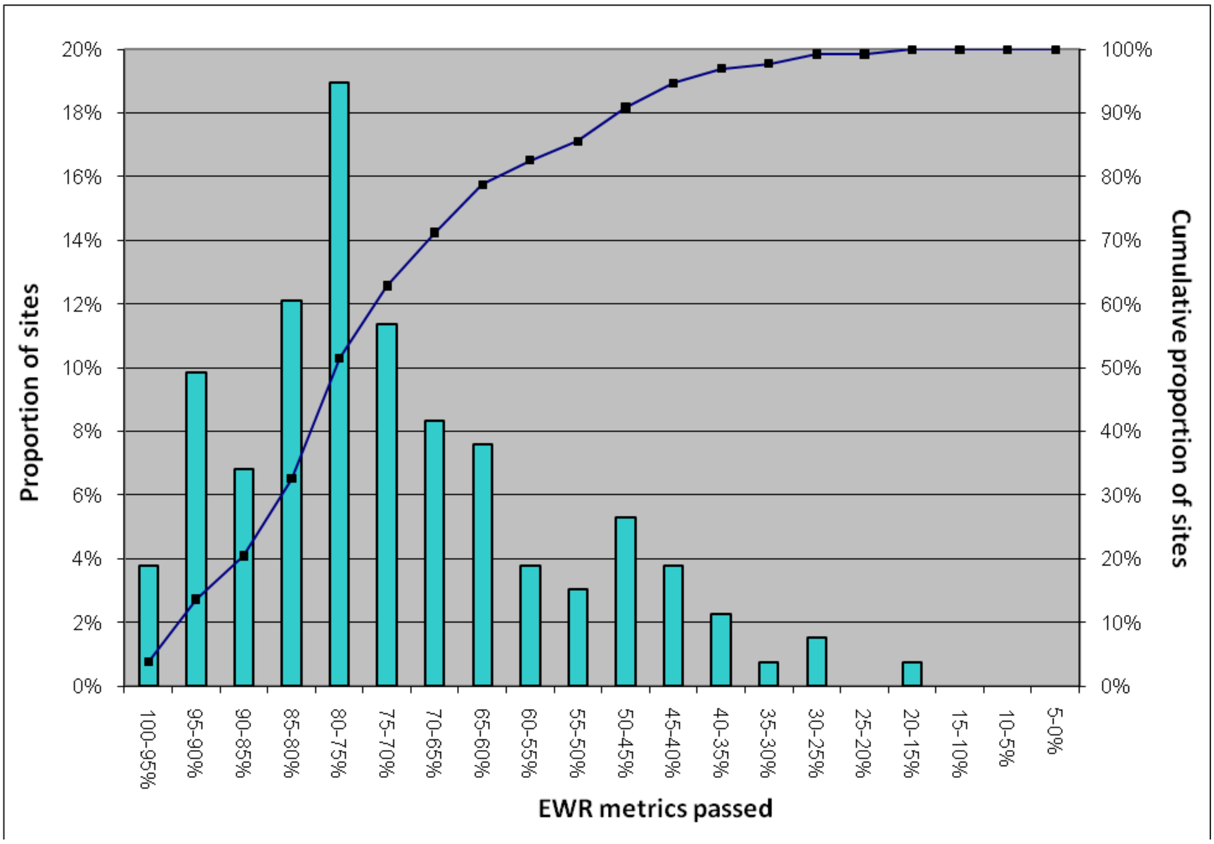


Figure 16. Proportion of sites passing EWR metrics

7.2.2 RELATIONSHIP BETWEEN DAM WATER USE AND EWRS

Environmental water requirements, through the use of EWR metrics, have been tested at 135 representative sites that have good flow data, showing varying levels of stress on the environment and corresponding varying levels of risk of environmental degradation. This data can be extrapolated to estimate risks to the environment in untested areas of the MLR.

Levels of water use in these 135 sites (extracted from dams or pumped from watercourses) can be correlated to the success of EWR metrics (Figure 17). This correlation has been used to infer the likely success of EWR metrics and hence the level of risk to water-dependent ecosystems in other areas of the MLR where water use is known or has been estimated (Figure 18). Water use in these remaining, largely ungauged, MLR areas has been estimated through hydrological modelling using dam locations and estimated volumes mapped from 2005 aerial photography, and assuming 50% usage from irrigation dams and 30% from stock and domestic dams.

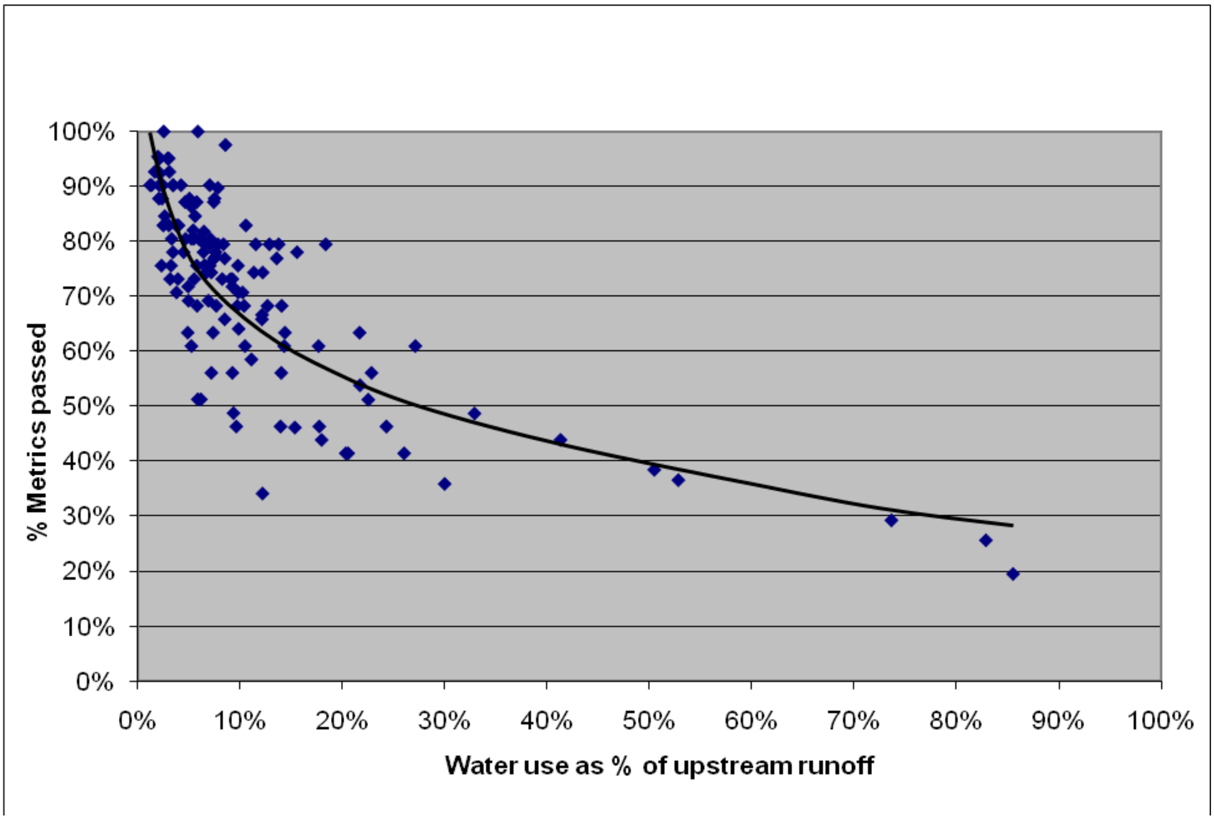
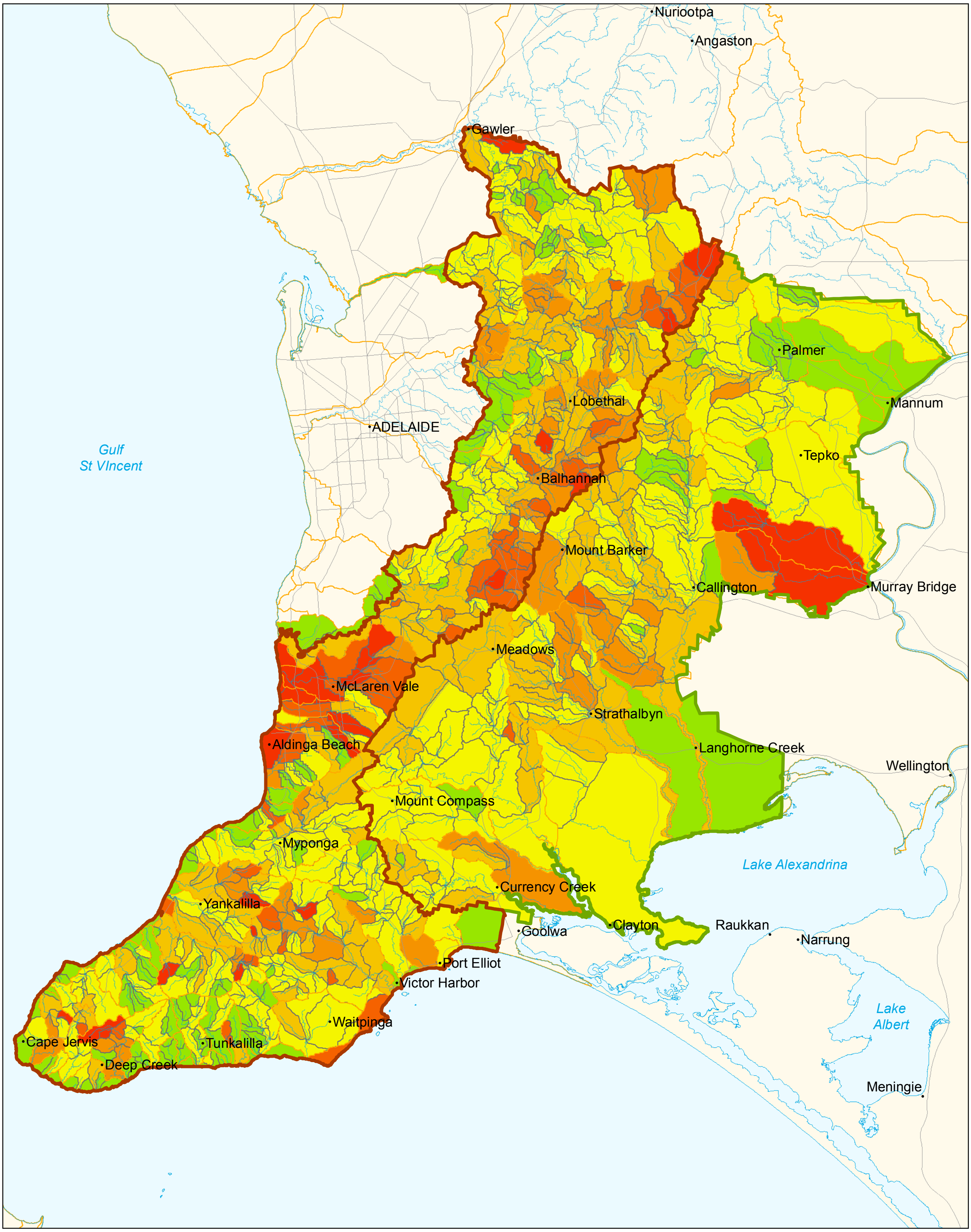


Figure 17. Comparison of percentage of metrics passed against water usage at 135 sites across the MLR (r squared=0.6328; F=227.4 (P<0.0001))

7.2.3 PARTS OF THE FLOW REGIME BEING AFFECTED BY WATER RESOURCE DEVELOPMENT

The impacts on the flow regime that are accounted for in this analysis are due to dam development and extraction from watercourses. Generally, most surface water is captured in dams in the MLR rather than through direct watercourse diversions.

Figure 18: % EWR metrics met in the MLR
(estimated using deemed current water use as % of upstream runoff)



% of metrics met

- 0 - 50
- 50 - 60
- 60 - 70
- 70 - 80
- 80 - 90
- 90 - 100

- Western Mount Lofty Ranges Prescribed Water Resources Area
- Eastern Mount Lofty Ranges Prescribed Water Resources Area
- Catchments
- Major Watercourse
- Road

N

0 9 18 27
Kilometres

Government of South Australia
Department of Water, Land and Biodiversity Conservation

DISCLAIMER: The Department of Water, Land and Biodiversity Conservation, its Employees and servants do not warrant or make any representation regarding the use, or results of use of the information contained herein as to its correctness, accuracy, currency or otherwise. The Department of Water, Land and Biodiversity Conservation, its employees and servants expressly disclaim all liability or responsibility to any person using the information or advice contained herein.

Produced by: DWLBC Science, Monitoring and Information
Map Projection: Lambert Conformal Conic
Map Datum: Geocentric Datum of Australia 1994
Date: June 2009

M:\Projects_SWMt_Lofty_Ranges\EWR_Project\Ouputs\EWR_report_maps\% EWR metrics MLR.mxd LewitM01

Dams change the flow regime by both reducing total volume of flow, and delaying flow events by holding back flows until they fill and begin to spill. This delay causes proportionally larger impacts when dams are not at capacity such as during the irrigation period of October to March (Figure 19). Smaller flows are proportionally more impacted than higher flows, as larger flows will cause dams to fill and spill much quicker.

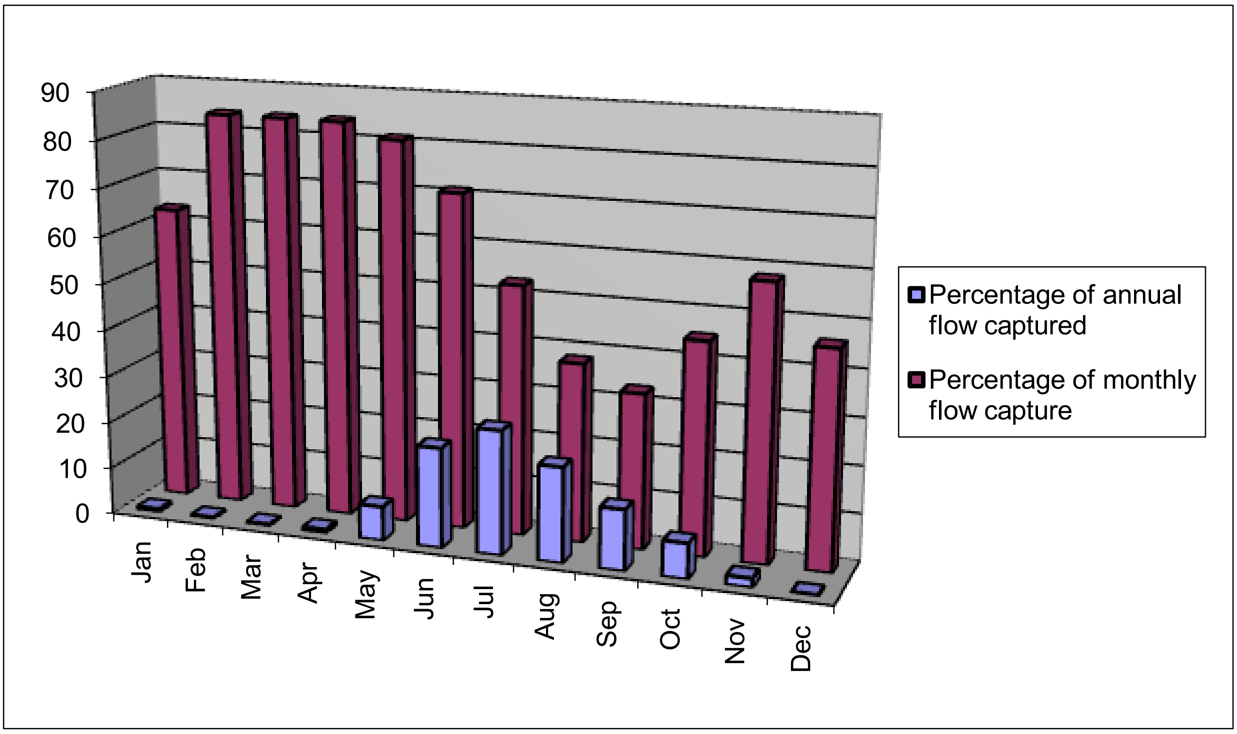


Figure 19. Generic impact of dams on annual and monthly flow in a single year

This pattern of impact on the flow regime from dams is well reflected in the performance of EWR metrics (Table 3). Measures of low flow (80th percentile exceedence non-zero flow) had very low pass rates in each of the flow seasons, whereas larger bankfull flows were only marginally impacted. Fresh flows that fall between these two extremes, also fall between these in the proportion of EWR metrics met.

Metrics in the Low Flow Season generally performed worse than metrics in Transitional Flow seasons, which in turn performed worse than the High Flow Season. This is well reflected in the proportion of sites that pass the low flow metric (80^{th} percentile exceedence non-zero flow): 9.6% in the Low Flow Season and 31.9% in the High Flow Season. Similar patterns can be seen in other metrics, including the duration of zero-flow spells (67% vs 82%) and frequency of fresh flows (31% vs 85%).

Table 3. Number of tested sites in the MLR passing each metric

Metric	Number of sites tested	Number of sites passed	% sites passed
Low Flow Season			
Average daily LFS flow	135	99	73.3
80th percentile exceedence non-zero flow [low flow]	135	13	9.6
Number of years with LFS zero flow spells	135	101	74.8
Average number of LFS zero flow spells per year	135	125	92.6
Average duration of LFS zero flow spells	135	91	67.4
Number of years with one or more LFS freshes	135	72	53.3
Average number of LFS freshes per year	135	42	31.1
Average total duration of LFS freshes per year	135	8	5.9
Transition Flow Season 1 (low to high)			
Average daily T1 flow	135	107	79.3
80th percentile exceedence non-zero flow [low flow]	135	22	16.3
Current month reaching median flow of natural T1 median (delay)	98	27	27.6
Number of years with T1 zero flow spells	135	105	77.8
Average number of T1 zero flow spells per year	135	134	99.3
Average duration of T1 zero flow spells	135	108	80.0
Number of years with one or more T1 freshes	135	103	76.3
Average number of T1 freshes per year	135	78	57.8
Average total duration of T1 freshes per year	135	81	60.0
Number of years with 2 or more T1 freshes	126	90	71.4
Frequency of spells higher than LFS fresh level	8	7	87.5
High Flow Season			
Average daily HFS flow	135	131	97.0
80th percentile exceedence non-zero flow [low flow]	135	43	31.9
Number of years with HFS zero flow spells	135	100	74.1
Average number of HFS zero flow spells per year	135	134	99.3
Average duration of HFS zero flow spells	135	111	82.2
Number of years with one or more HFS freshes	135	126	93.3
Average number of HFS freshes per year	135	115	85.2
Average total duration of HFS freshes per year	135	122	90.4
Number of years with 1 or more spell greater than the annual 5th percentile exceedence flow in HFS	89	86	96.6
Number of years with 2 or more freshes early in the season (Jul, Aug)	37	36	97.3
Transition Flow Season 2 (high to low)			
Average daily T2 flow	135	125	92.6
Median non-zero daily T2 flow	126	33	26.2
80th percentile exceedence non-zero flow [low flow]	135	11	8.1
Current month reaching median flow of natural T2 median (early onset)	135	63	46.7

Number of years with T2 zero flow spells	135	90	66.7
Average number of T2 zero flow spells per year	135	135	100.0
Average duration of T2 zero flow spells	135	106	78.5
Number of years with one or more T2 freshes	135	102	75.6
Average number of T2 freshes per year	135	99	73.3
Average total duration of T2 freshes per year	135	70	51.9
Frequency of spells higher than LFS fresh level	8	6	75.0
Number of years with 1 or more spell greater than the annual 5th percentile exceedence flow	98	86	87.8
Number of consecutive years with no T2 fresh	9	4	44.4
Annual: at any time of the year			
Number of years with 1 or more bankfull flows	135	129	95.6
Average duration of bankfull flow spells	135	134	99.3
Average total duration of bankfull flow per year	135	127	94.1

7.3 RELATIONSHIP BETWEEN METRICS AND ACTUAL ENVIRONMENTAL HEALTH

Ecological monitoring data was compared with the proportion of metrics passed at a number of monitoring site to assess the usefulness of the metric tool compared to real data on ecological condition. Adequate monitoring data was available only for fish and aquatic macroinvertebrates.

7.3.1 FISH

Fish have been monitored at a range of sites in the MLR on behalf of the NRM Boards. The abundance and size distribution of two key species that have a strong ecological response to flow (southern pygmy perch and mountain galaxias) have been monitored annually in autumn at a range of sites for 1–7 years (Conallin and Hammer 2003; Hammer 2007b).

Sites were selected that had at least 4 years of monitoring data up to 2006. Sites from the Tookayerta catchment were excluded, as the high level of year-round baseflow means that fish there have a different life-history pattern than elsewhere in the MLR (i.e. regular low level recruitment throughout the year in Tookayerta; episodic flow triggered responses elsewhere (M Hammer, AquaSave Consultants pers. comm.)).

Population models were developed for southern pygmy perch and mountain galaxias linking fish length to fish age (Hammer 2005, 2007c). These models allowed annual fish counts to be broken down into fish spawned that flow season (recruitment) and adults surviving from previous years (survivorship). Annual data were used to assess whether the key ecological processes of recruitment and survivorship for any year at any site had been excellent, good, marginal or poor (including failure), in relation to what would reasonably be expected for that site. If data was not available to split the population into recruits and adult survivors then a general assessment of the population was made using these terms (M Hammer, Aquasave Consultants pers. comm.).

Recruitment was considered to be the most flow sensitive process. Therefore recruitment data (or general data if recruitment data was not available) was examined to identify the percentage of time that recruitment was marginal or poor (i.e. number of years with marginal or poor recruitment out of the number of years that monitoring data was collected). The proportion of years with marginal or poor recruitment at a monitoring site was compared to the proportion of flow metrics passed for that site for mountain galaxias (Figure 20) and southern pygmy perch (Figure 21).

It can be seen that poorer ecological condition (i.e. a higher proportion of time where recruitment is marginal or poor) is generally correlated with a lower number of metrics passing at a site. Southern pygmy perch appears to be particularly sensitive to changes in flow regime, which corresponds to the relatively short lifespan and high dependence on different aspects of the flow regime (e.g. to allow access to emergent vegetation for successful recruitment (Hammer 2001)).

A range of other processes will also affect ecological condition, including habitat quality (e.g. degradation by stock access, clearance of vegetation), water quality and predation by feral fish. They may account for some of the scatter apparent in Figure 20 and Figure 21. However, as land use at most sites is stable, and the flow pattern is a key driver in the structure and function of ecological communities, it is reasonable to assume that part of the relationship between fish recruitment and changes to the flow regime is driven by changes to the flow regime.

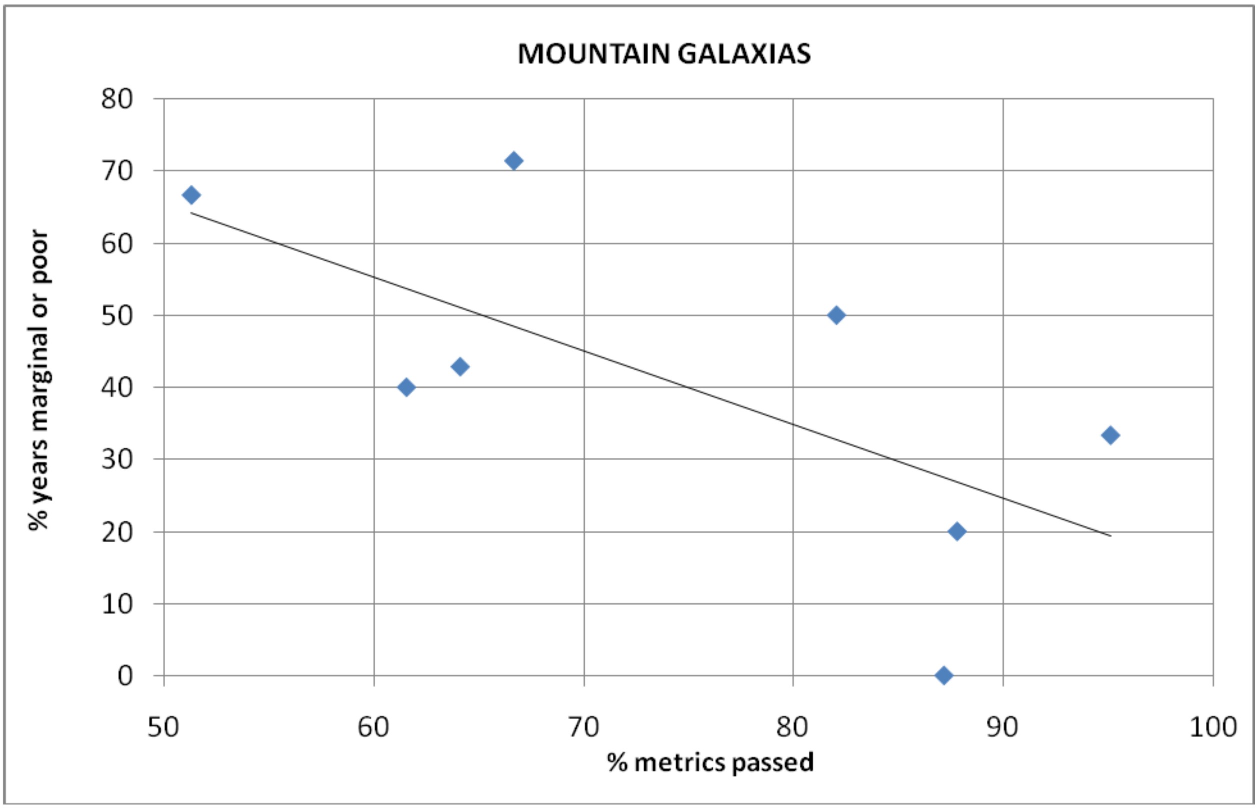


Figure 20. Proportion of time that mountain galaxias recruitment was marginal or poor compared with percentage of metrics passed at each site; each point represents a single fish monitoring site (adjusted r squared=0.37; F=5.078 (P=0.0651))

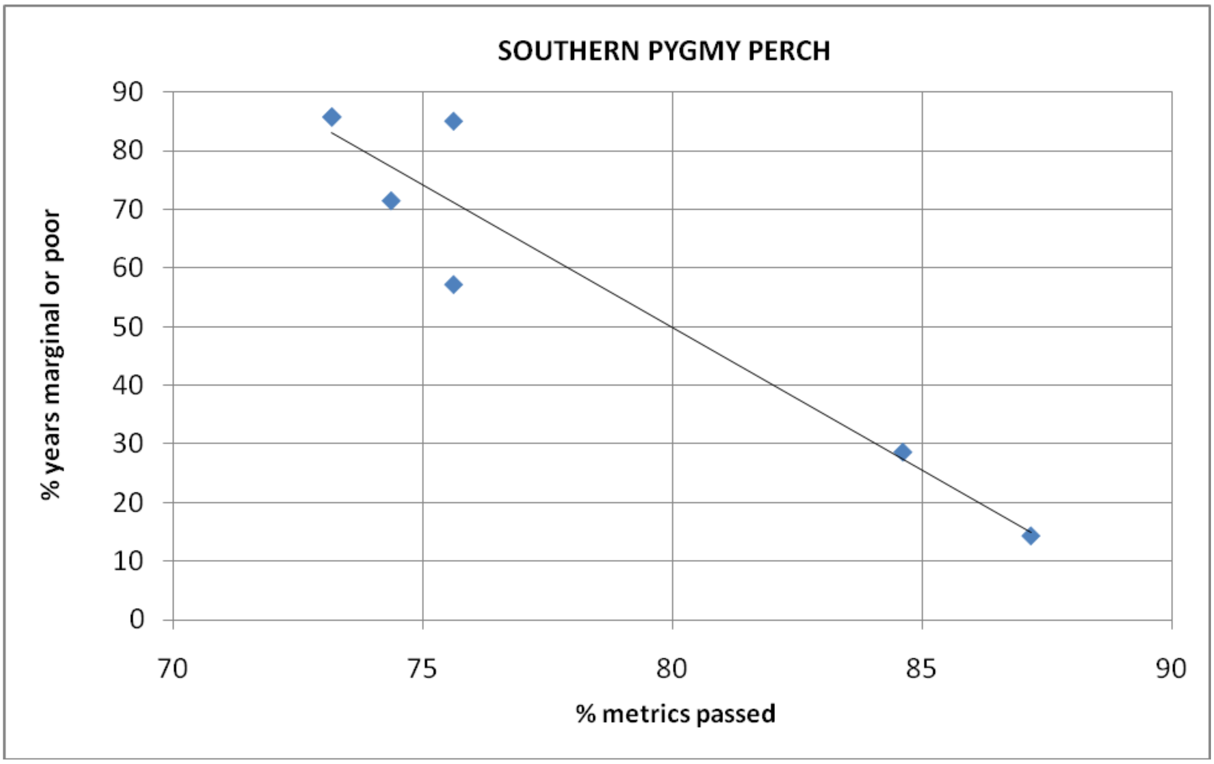


Figure 21. Proportion of time that recruitment is marginal or poor compared with percentage of metrics passed for southern pygmy perch; each point represents a single fish monitoring site (adjusted r squared=0.90; F=53.83 (P=0.0007))

7.3.2 AQUATIC MACROINVERTEBRATES

Macroinvertebrate monitoring data has been collected at a range of sites throughout the MLR, primarily under the auspices of the AusRivAS protocol on behalf of organisations such as the Environment Protection Authority and NRM Boards.

Data has generally been collected in spring and autumn each year, and for up to 13 years at some sites (as at 2006). The AusRivAS protocol allows assessment of the condition of the aquatic macroinvertebrate community in relation to the 'reference' community that would be expected at that site based on water quality and habitat characteristics (see ausrivas.canberra.edu.au/Bioassessment/Macroinvertebrates/).

Sites with a long-term data set were selected. Sites that had an unusual influence, different from other sites and likely to affect the macroinvertebrate community (e.g. tidal influence, signficant urban influence), were excluded. The condition of the macroinvertebrate community was rated as good, medium, marginal or poor based on a combination of factors including expert opinion of community health over time for different habitats (pools and riffles), and the presence of different habitats over time. For example, a site with riffles frequently missing had the condition downgraded.

The average percentage of metrics passed for sites in each of the condition rating groups (Figure 22) shows that poorer condition is generally correlated with a lower percentage of metrics passing at a site.

As for fish, a range of other processes will also affect condition of the macroinvertebrate community, including habitat quality (e.g. degradation by stock access, clearance of vegetation), water quality and predation.

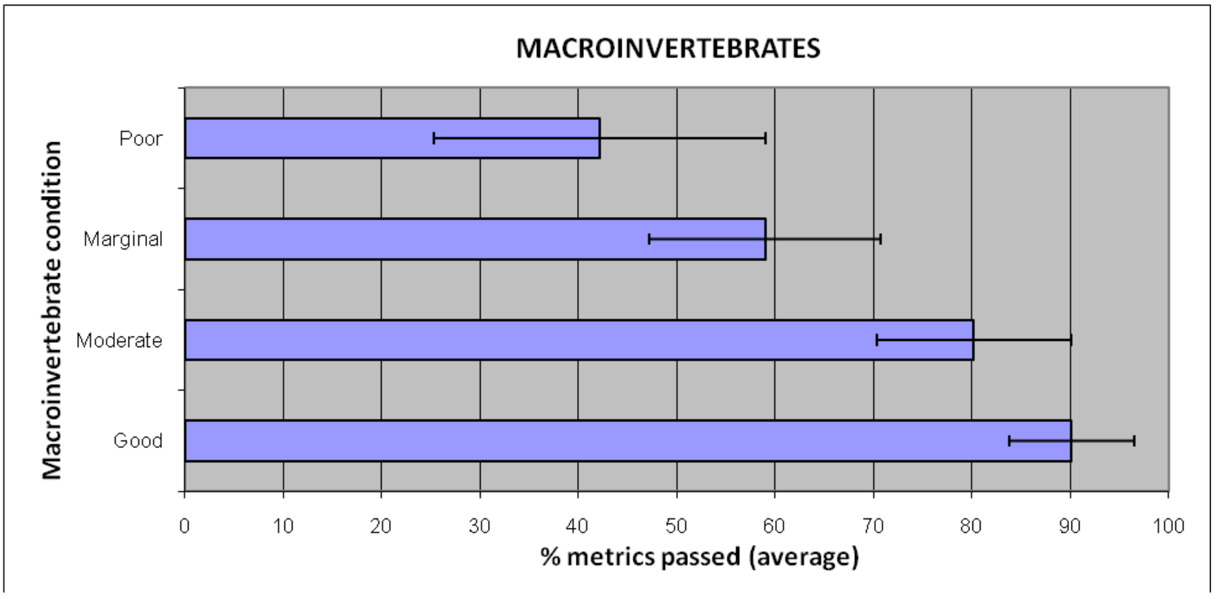


Figure 22. Average percentage of metrics passed for sites in each condition rating group for long-term condition of the macroinvertebrate community at monitoring sites; blue bars show average percentage metrics passed for sites in the group, and error bar shows standard deviation (Spearman's Rank: rho=0.87, P=0.0003)

7.4 DISCUSSION

The natural flow paradigm states that the endemic biota within an ecosystem have evolved to fill the ecosystem niches created through the dynamics of the natural flow regime and its relationship with the spatial and temporal distribution of habitat (Poff et al. 1997; Bunn and Arthington 2002). Changes in the natural flow regime can create conditions to which the native biota are poorly adapted, resulting in ecosystem degradation. However, given the natural variation (seasonal, annual and inter-annual) in the flow regime, aquatic biota evolve tolerances to some level of deviation (Jowett and Biggs 2008).

It is beyond the scope and ability of this project to determine the quantitative deviation for each priority biotic group (for each reach type in each catchment) that will lead to a given level of impact. Instead, this study uses expert opinion to determine acceptable deviations in the flow regime, how the deviation relates to EWR metrics, and is tested against available fish and macroinvertebrate monitoring data.

The major goal for EWRs is to promote self sustaining populations of aquatic and riparian flora and fauna, which are resilient in times of drought. To this end the project focuses on conserving biota and ecosystems currently present in the region through the establishment of suitable hydrological conditions. This will promote resilience through increasing species population numbers and spatial extent.

7.4.1 STATE OF EWRS IN THE MLR

Only 2 out of 135 sites within the MLR were found to meet 100% of the EWRs required to maintain the environment at a low level of risk, with approximately 50% of sites passing less than 75% of metrics. This suggests that MLR water-dependent ecosystems are at an elevated level of risk of degradation due to the current level of water resource development, and are unlikely to be sustainable in the long term.

When comparing the relationship between the proportion of EWR metrics passed to the level of water use (annual volume extracted from dams), small deviations in water use were found to have a wide range of impacts on EWRs as measured by metrics; relatively small levels of use (~5% of runoff) could cause the failure of 10–50% of metrics. This is likely to be due to a combination of real world dam positioning, and the method by which the metrics are calculated. EWR metrics are calculated as a binary pass/fail measure, with no account being taken of how 'close' an EWR is to being met – a metric failing by 1% is given the same weight as a metric failing by 90%. The wide range of EWR metrics being met at low usage levels is likely caused by a threshold being passed where metrics are 'tipping' over the edge into failure caused by specific dam positioning configurations in the landscape.

The majority of EWR impacts occur in the Low Flow Season when flows are delayed until empty dams fill and spill. Metrics tended to be less impacted in the higher flow seasons when dams tend to be fuller, and therefore spill more often in response to rainfall events. In terms of flow components, low flow measures are most affected by current development, with bankfull metrics least affected.

7.4.2 IMPACT ON WATER-DEPENDENT ECOSYSTEMS AND BIOTA

All aspects of the flow regime have been impacted by water resource development in the MLR, resulting in an increased risk of degradation to processes that maintain water-dependent ecosystems. These at-risk processes include maintenance of suitable habitat (including refugia), provision of adequate connectivity to allow localised or large-scale movement and migration, and provision of suitable conditions to promote breeding, recruitment and survivorship.

Increasing stress on refuges in Low Flow Season

Environmental water requirements in the Low Flow Season are often the most critical in supporting the continuing presence of aquatic biota in the environment, largely due to the importance of maintaining viable aquatic habitat in the absence of (or with reduced) water inputs.

One of the critical functions of flow in the Low Flow Season is maintenance of refuge habitat. The persistence of many aquatic species in the MLR depends on the presence of permanent aquatic habitat, especially for obligate aquatic species such as fish. One of the most critical habitats are permanent pools that retain water over the drier months. They maintain core populations of aquatic biota and act as refugia during droughts from which species can recolonise other areas of the catchment when favourable conditions return.

During Low Flow Season, permanent pools are generally maintained by a combination of groundwater connection, and periods of surface water flow after rainfall events (freshes). Groundwater connection is important in maintaining the presence of water in a pool over dry periods, although large pools can be maintained simply by sufficient volume despite losses due to evaporation and/or seepage. In either scenario (except for very large pools where loss is a small proportion of the total pool volume) surface water flow is important in maintaining pool viability as aquatic habitat by supplementing pool volume and refreshing water quality by flushing or diluting pollutants such as salt.

According to the EWR metric testing, the largest impacts of water resource development occur in the Low Flow Season, followed by the Transitional Flow seasons, with the least impact in the High Flow Season. Both Low Flow Season low flows and low flow freshes have been significantly impacted by dam construction and extraction of water from the system: 90% of sites have less than the desirable low flow rate; 69% of sites have much fewer freshes; and 33% of sites have much longer zero flow periods.

Truncation of higher flow period

Another factor exacerbating stress on water-dependent ecosystems is the effective extension of the Low Flow Season into Transitional Flow Season 1 (low–high (T1)) and the early onset of the Low Flow Season during Transitional Flow Season 2 (high–low (T2)). This effect is represented by the metrics ‘Current month reaching median flow of natural T1 median (delay)’ (passed at 28% of sites) and ‘Current month reaching median flow of natural T2 median (early onset)’ (passed at 47% of sites). This extension has two key effects. Firstly, it extends the naturally stressful period of very low to zero flows, which exacerbates the effects of the Low Flow Season and places permanent refuges at even higher risk. Secondly, the period of higher flow (T1–T2) is truncated at both ends, reducing the time available for organisms to complete their life-cycle and carry out key ecological processes such as recolonisation and reproduction. This means that communities will be less resilient to the stresses of the Low Flow Season. Repeated failures to recruit or contribute to the seedbank as a result of a truncated higher flow period may lead to extinctions of local populations.

Reduction in connectivity and access to habitats

Of the sites, 32% passed the metric representing low flows in the High Flow Season. Reduction in low flows in the High Flow Season is likely to reduce the extent, frequency and duration of inundation of in-stream habitats such as riffles, bars, benches and edge vegetation. Some functional groups are primarily found in such habitats, such as the flowing water macroinvertebrate groups. Reduced inundation of these habitats is likely to lead to reduced diversity of such groups. Many stream-specialist fish also require access to these habitats for feeding, spawning, juvenile habitat, adult conditioning and predator avoidance. Reduced opportunity for conditioning, recruitment and predator avoidance make such populations less resilient to stress.

The current level of water resource development has also detrimentally affected the frequency and duration of freshes in the T1 and T2 seasons (52–76% of sites passing these metrics). Together with the reduction in low flows in the High Flow Season, this is likely to have reduced the opportunity for organisms to move around the catchments as propagules, juveniles or adults. Some species, including many diadromous fish species, need to migrate between different habitats in order to breed or recruit. Migration also increases the resilience of populations by allowing recolonisation of habitats where species have been lost or greatly reduced through water regime stress or other factors. Maintaining multiple populations of a species across a landscape means that the species can persist even if individual populations are lost in the short term. Reducing the opportunities for migration means that local losses are less likely to be replaced.

7.4.3 OTHER FACTORS AFFECTING WATER-DEPENDENT ECOSYSTEM CONDITION

The goal of this study is to determine the flow regime required to maintain the environment at a low level of risk of degradation. However, an appropriate water regime to meet the needs of water-dependent ecosystems is only one aspect of the requirements for sustainable ecosystem functioning. Ecosystems and populations will not recover to their full potential until all limiting factors are removed. Some other factors are discussed below.

Water quality

Increased periods of zero flow, reduced low flow rates, and less frequent flushing fresh flows can allow pollutants to build up in pools, and increase in concentration with evaporative losses. All water quality factors can be improved in an appropriate water regime. However, point source pollutants can still have significant impacts on ecosystems if introduced to an isolated habitat (e.g. pool during Low Flow Season) at a time of no flushing flows.

Large scale diffuse source pollutants can still also have significant effects by 'saturating' a watercourse to a point where incoming flushing flows have similar poor water quality attributes as the water it is entering (e.g. large scale sediment inputs).

Connectivity

On-stream dams, bridges, culverts and fords have all restricted the ability of biota to move through the watercourse landscape, reducing the potential for recolonisation and migration. This situation is likely to have proportionally higher impacts on fish species and increased the risk of localised/regional extinctions of water-dependent biota throughout the MLR. Species have less chance to recolonise habitats that have undergone localised extinctions during dry periods. The distribution of species is thus restricted and regional populations are more susceptible to localised impacts.

A number of diadromous fish species in the MLR require migration in their life-cycle. Barriers preventing fish species from migrating to and from the estuary during their breeding cycle, place pressure on breeding and recruitment success, and likely reduce population numbers.

Habitat disturbance

The transformation of the MLR natural landscape into a largely agricultural and urban landscape, with associated land use impacts, has had a significant impact on habitat quality for native biota. Historical clearance of floodplain and riparian vegetation, works in watercourses and instream impacts from stock grazing and watering has often resulted in a degraded landscape with reduced habitat values, and has likely caused a corresponding reduced native population carrying capacity.

Exotic species

The introduction of exotic species (competitors, predators, diseases) to MLR ecosystems has placed additional pressures on native biota, and is likely to have restricted population size or excluded species from their natural locations (McNeil and Hammer 2007).

7.4.4 RESTORING EWRS – NEXT STEPS

Impacts on EWRs, as measured through metrics, were largely caused by both the influence of dams in reducing runoff volumes by capturing water, and delayed flows due to fill and spill times.

With this in mind, the impacts of surface water resource development can be reduced through mechanisms including management of:

- the volume extracted from watercourses and dams
- the capacity of dams
- the pattern in which water is captured (e.g. allowing low flows to return to the environment while higher flows can be harvested).

The metrics and limits on acceptable deviation from 'natural' presented in this report provide a tool for assessing the impacts of these different management options on EWRs. Such work can be used in combination with assessment of social and economic impacts to set environmental water provisions for the MLR.

An accompanying report contributes to this process by:

- considering the spatial scales at which environmental water should be provided
- considering ecological risk associated with different levels of water resource development
- exploring the impacts of different management scenarios on metrics and likely ecological risk
- developing recommendations on environmental water provisions that result in an acceptable level of risk to the environment.

7.4.5 GAPS AND FURTHER WORK

Testing EWR hypotheses

In determining limits or targets for EWRs, and targets for EWPs, a quantitative understanding of how far a regime can deviate from the natural flow before beginning to significantly impact on water-dependent ecosystems is ideally required. To achieve this, it would be necessary to understand the tolerance levels and threshold limits to flow variation for each priority taxa group, and the spatial interaction of these flows with resource availability (e.g. habitat, food), which may vary from watercourse to watercourse across the whole of the study area.

This detail is not currently available and collecting it is outside the capacity of this project, so a best-practice framework has been used that instead uses generic principles for the likely impact of variation in the flow regime on water-dependent ecosystems. The use of this data presents its own challenges: it is known that there are negative ecological impacts from flow modification but there is no clear standard relationship between the level of impact and the degree of change in the natural flow regime (Lloyd et al. 2004).

Suitable ecological monitoring data, where it exists, has been used to validate EWRs as described but sites with sufficient information are few and not well distributed throughout the study area. In light of this, and although best-practice methods have been used, the work presented in this report is based on best available but limited information and, in the absence of data, makes use of expert opinion and knowledge. The outcomes of this project must thus be considered as the first step in an adaptive management regime.

It will be important to implement a robust monitoring program to test the hypothesised relationships between flow and ecological condition or processes, and to ensure that the stated EWPs with the objective of *maintaining self-sustaining populations, resilient to times of drought* are achieved, as hypothesised.

Impacts of groundwater use

This project has focused on the impacts of surface water resource development, with little consideration of the impact of groundwater resource development on the availability of environmental water (Section 3.1.2). Further work is required to better understand:

- the impacts of groundwater extraction on the flow regime from the local to the catchment scale
- presence and water requirements of other groundwater-dependent ecosystems such as phreatophytic vegetation and stygofauna.

Species distribution

Our limited understanding of the full distribution of water-dependent species across the MLR has necessitated the use of conceptual models (Section 5) to suggest where these species are likely to occur. Environmental water requirements have been determined and assigned across the MLR on the outcomes of this conceptual mapping of biota distributions. It is likely that, given historical and current impacts on the environment, some species have suffered localised extinctions. Therefore EWRs in those areas may be superfluous at this time. However, suitable EWRs provide the capacity for successful environmental restoration work and biota reintroduction.

It may be also be the case in some areas that certain species, which have been conceptually mapped to an area, have never existed in that location due to unknown historical factors. It is expected that these areas are likely to represent only a small proportion of the study area.

Further work is required to assess the distribution of species over the MLR. Species that are mobile (e.g. many fish species) or highly localised (e.g. river blackfish) may be overlooked or only become apparent under certain conditions (e.g. seed germination under appropriate conditions only). Therefore survey work is recommended to continue over time to pick up such spatial and temporal variability in presence.

APPENDICES

A. MEMBERS OF THE MLR EWR EXPERT PANEL

Name	Affiliation
Michelle Bald	DWLBC
Steve Barnett	DWLBC
Michelle Casanova	Charophyte Services
David Cresswell	DWLBC
David Deane	DWLBC
Brian Deegan	University of Adelaide
Tim Doeg	Private consultant
Ben Fee	DWLBC
Graham Green	DWLBC
Ashley Greenwood	DWLBC
Michael Hammer	Aquasave Consultants
Rohan Lucas	Alluvium
Paul McEvoy	Australian Water Quality Centre
Dale McNeil	South Australian Research and Development Institute
Bruce Murdoch	DWLBC
Jason Nicol	South Australian Research and Development Institute
Daniel Penney	DWLBC
Alys Stevens	Southern Emu Wren and Fleurieu Peninsula Swamp Recovery Team
Mardi van der Wielen	SAMDB NRMB
Jason VanLaarhoven	DWLBC
Geoff Vietz	Alluvium

B. MOUNT LOFTY RANGES FISH SPECIES AND FUNCTIONAL GROUPS

List of native and exotic species recorded in the MLR by region

Functional group	Species	Scientific name	Cons. status		Record type		
			Nat.	State	EMLR	SF	WMLR
D	Pouched lamprey	*Geotria australis*		EN	1	0	3
D	Shortheaded lamprey	*Mordacia mordax*		EN	1	0	3
D	Shortfinned eel	*Anguilla australis*		R	1	0	0
Fw	Freshwater catfish	*Tandanus tandanus*		P, V	1		3*
Fg	Bony herring	*Nematalosa erebi*			3		
Fg	Smelt	*Retropinna semoni*			3	0	
D	Climbing galaxias	*Galaxias brevipinnis*		V	1	3	3
D	Common galaxias	*Galaxias maculatus*			3	3	3
Fs	Mountain galaxias 1	*Galaxias olidus*		R	3	0	3
Fs	Mountain galaxias 2	*Galaxias* sp. 1		R	3	3	
Fg	Murray rainbowfish	*Melanotaenia fluviatilis*		R	2/3		3*
Fg	Smallmouthed hardyhead	*Atherinosoma microstoma*			3	3	3
Fw	Murray hardyhead	*Craterocephalus fluviatilis*	VU	E	2		
Fg	Unspecked hardyhead	*Craterocephalus stercusmuscarum fulvus*		R	3		
Fw	Chanda perch	*Ambassis agassizii*		P, E	2		
Fs	River blackfish	*Gadopsis marmoratus*		P, E	3	0	0
Fg	Murray cod	*Maccullochella peelii peelii*	VU	R	2		1*
Fp	Murray–Darling golden perch	*Macquaria ambigua ambigua*			2/3		1*
Fs	Southern pygmy perch	*Nannoperca australis*		P, E	3	3	
Fw	Yarra pygmy perch	*Nannoperca obscura*	VU	P, E	3		
Fg	Silver perch	*Bidyanus bidyanus*		P, V	2		1*
D	Congolli	*Pseudaphritis urvillii*		R	3	3	3
Fg	Midgley's carp gudgeon	*Hypseleotris* sp. 1			3		3*
Fg	Murray–Darling carp gudgeon	*Hypseleotris* sp. 3		R	3	3	
Fg	Hybrid forms	*Hypseleotris* spp.			3	3	
Fw	Southern purple-spotted gudgeon	*Mogurnda adspersa*		P, E	2		2
Fg	Flathead gudgeon	*Philypnodon grandiceps*			3	3	3
Fg	Dwarf flathead gudgeon	*Philypnodon* sp. 1		R	3	3	3?
Fg	Western bluespot goby	*Pseudogobius olorum*			3	3	3
Fg	Lagoon goby	*Tasmanogobius lasti*			3		
Ex	Common carp	*Cyprinus carpio*			3	1	3
Ex	Tench	*Tinca tinca*			3		3
Ex	Rainbow trout	*Oncorhynchus mykiss*			3	3	3
Ex	Brown trout	*Salmo trutta*			3	3	3
Ex	Brook trout	*Salvelinus fontinalis*					1

Functional group	Species	Scientific name	Cons. status		Record type		
			Nat.	State	EMLR	SF	WMLR
Ex	Gambusia	*Gambusia holbrooki*			3	3	3
Ex	Redfin	*Perca fluviatilis*			3	3	3
Ex	Barramundi	*Lates calcarifer*					1

- Region: EMLR = Eastern Mount Lofty Ranges; SFP = Southern Fleurieu Peninsula, Goolwa to Cape Jervis; WMLR = Western Mount Lofty Ranges north of Cape Jervis
- MLR Functional Group: D = diadromous; Fs = obligate freshwater, specialists stream; Fw = obligate freshwater, specialists wetland; Fg = obligate freshwater, generalist; Fp = obligate freshwater, potamodromous generalist; Ex = exotic
- Record type: 1 = verified records, limited in number; 2 = species present but no recent records; 3 = recent records at a few or more locations; 0 = presumed to exist based on unverified records or nearby records plus suitable habitat; * = translocated; ? = unknown if native or translocated (or both)
- Conservation status: National (Nat.): VU=Vulnerable (EPBC Act 1999); State: P = protected (Fisheries Act 1982), E = Endangered, V = Vulnerable, R = Rare (DEH 2004)

C. ENVIRONMENTAL WATER REQUIREMENTS FOR FISH IN THE MOUNT LOFTY RANGES

Some groups have species with specific requirements, identified in table for river blackfish (RB), southern pygmy perch (SPP), mountain galaxias (MG) and Yarra pygmy perch (YPP); requirements for diadromous and potadromous fish grouped together in 'diadromous/migratory' column (MLR EWR Expert Panel in prep)

Flow season	Flow component	Ecological process supported by EWR				
		Freshwater obligate (stream specialist)	**Freshwater obligate (wetland specialist)**	**Freshwater obligate (generalist)**	**Diadromous/migratory**	**Fleurieu wetland**
Low Flow Season	**Zero flow**	Maintain persistent aquatic conditions through combination of zero flows, low flows and channel shape				
		Discourage exotic fish		Discourage exotic fish	Discourage exotic fish	
	Low flow	Persistent water in pools throughout season (base flow ideal); cool and well oxygenated (RB), well vegetated (SPP) Maintain shallower sub-optimal habitats and pool margins when exotic predatory fishes occur Maintain shallows (larval habitat) for spawning and recruitment (RB, SPP)	Persistent cool, well-oxygenated, tolerable salinity water in wetlands, channel, riffles, anabranches and refuges (pools, billabongs) throughout season (base flow ideal); tannin-reach, clearer water (YPP) Promote successful spawning events Continuously flowing cool water discourages exotic fish in these habitats	Persistent water in pools throughout season (base flow ideal) Maintain shallower sub-optimal habitats and pool margins when exotic predatory fishes occur Promote successful spawning events	Persistent water in pools throughout season (base flow ideal) Maintain shallower sub-optimal habitats and pool margins when exotic predatory fishes occur Sustained flow to allow upstream migration	Persistent water in wetlands throughout season (base flow ideal) Cool flowing conditions discourage exotic fish Access to shallows (larval habitat) for spawning and recruitment
	Fresh	Refill pools, maintain water quality Prevent vegetation encroachment Clean substrates for egg deposition (MG, RB) and feeding (RB) Allow movement between pools	Refill pools, maintain water quality Prevent vegetation encroachment Maintain water in a range of habitats at different elevations to allow co-existence of species with different requirements	Refill pools, maintain water quality, and prevent vegetation encroachment Variable flows discourage exotic fish	Refill pools, maintain water quality (particularly pools and migration barriers) Prevent vegetation encroachment Variable flows discourage exotic fish	Low energy freshes that refill wetlands and maintain water quality Allow localised movement between wetlands Variable flows discourage exotic fish

Flow season	Flow component	Ecological process supported by EWR				
		Freshwater obligate (stream specialist)	**Freshwater obligate (wetland specialist)**	**Freshwater obligate (generalist)**	**Diadromous/migratory**	**Fleurieu wetland**
		Maintain submerged aquatic vegetation habitat (SPP) Variable flows discourage exotic fish	Variable flows discourage exotic fish			
Trans-itional Flow Season 1	**Zero flow**	Maintain persistent aquatic conditions through combination of zero flows, low flows and channel shape				
		Discourage exotic fish		Discourage exotic fish	Discourage exotic fish	
	Low flow	Persistent water in pools; cool and well oxygenated (RB), well vegetated (SPP) Trigger spawning, oxygenate riffles and allow access to new habitats (spawning sites) (MG) Localised movement between pools (RB, SPP) Maintain water quality Maintain shallower sub-optimal habitats and pool margins when exotic predatory fishes occur Maintain shallows for juveniles and young fish (RB) Promote successful spawning	Persistent cool, well oxygenated, tolerable salinity water in wetlands, channel, riffles, anabranches and refuges (pools, billabongs); tannin-reach, clearer water (YPP) Continuously flowing cool water discourages exotic fish in these habitats	Persistent water in pools Maintain shallower sub-optimal habitats and pool margins when exotic predatory fishes occur	Persistent water in pools Maintenance of permanent water in slow flow areas (larval lampreys) Maintain shallower sub-optimal habitats and pool margins when exotic predatory fishes occur Sustained flow to allow upstream and downstream migration	Persistent water in wetlands throughout the season (base flow ideal) Cool flowing conditions discourage exotic fish Allow localised movement between wetlands Access to shallows for juveniles and young fish
	Fresh	Trigger spawning, oxygenate riffles and allow access to new habitats (spawning sites) (MG) Allow movement between pools Variable flows discourage exotic fish	Allow fish movement to recolonise vacant habitats Variable flows discourage exotic fish	Allow fish movement to recolonise vacant habitats Variable flows discourage exotic fish	Promote spawning success (raise water levels to allow access to emergent vegetation (e.g. common galaxias spawning lower stream reaches), appropriate water quality, permanence and access where species congregate)	Allow movement between wetlands Variable flows discourage exotic fish

Flow season	Flow component	Freshwater obligate (stream specialist)	Freshwater obligate (wetland specialist)	Freshwater obligate (generalist)	Diadromous/migratory	Fleurieu wetland
		Ecological process supported by EWR				
					Trigger spawning, oxygenate riffles (CG) and successive access to riparian spawning habitat Allow fish movement to recolonise vacant habitats Variable flows discourage exotic fish	
High Flow Season	**Zero flow**	Maintain persistent aquatic conditions through combination of zero flows, low flows and channel shape				
		Discourage exotic fish		Discourage exotic fish	Discourage exotic fish	
	Low flow	Persistent water in pools; cool and well oxygenated (RB), well vegetated (SPP) Allow movement between pools over local and relatively long distances Maintain shallower sub-optimal habitats and pool margins when exotic predatory fishes occur Maintain water quality Maintain shallows, hollows and cavities (larval habitat) with low salinity water for spawning and recruitment (RB) Access to emergent and edge vegetation for spawning and recruitment (SPP)	Persistent cool, well-oxygenated, tolerable salinity water in wetlands, channel, riffles, anabranches and refuges (pools, billabongs); tannin-reach, clearer water (YPP) Sustain flows to provide access to off-channel habitat for adult conditioning, spawning sites and larval habitat Continuously flowing cool water discourages exotic fish in these habitats	Persistent water in pools Maintain shallower sub-optimal habitats and pool margins when exotic predatory fishes occur Allow fish movement to recolonise vacant habitats Sustain flows to provide access to off-channel habitat for larger species (e.g. Murray cod, golden perch) for adult conditioning, spawning sites and larval habitat in lowland/floodplain reaches	Persistent water in pools Maintain shallower sub-optimal habitats and pool margins when exotic predatory fishes occur Sustain flow to allow upstream and downstream migration Allow fish movement to recolonise vacant habitats	Persistent water in wetlands throughout season (base flow ideal) Cool flowing conditions discourage exotic fish Increase seasonal flow to prevent vegetation encroachment of open water Allow movement between wetlands Sustained flow between wetlands to allow connectivity with stream reaches for colonisation by climbing galaxias Access to shallows for spawning and recruitment
	Fresh	Allow movement between pools over relatively long distances Maintain water quality	Flows to provide access to off-channel habitat for adult conditioning, spawning sites and larval habitat	Allow fish movement to recolonise vacant habitats Flows to provide access to off-channel habitat for	Promote spawning success (raise water levels to allow access to emergent vegetation (e.g. common galaxias	Increase seasonal flow to prevent vegetation encroachment of open water Allow movement between

Flow season	Flow component	Ecological process supported by EWR				
		Freshwater obligate (stream specialist)	**Freshwater obligate (wetland specialist)**	**Freshwater obligate (generalist)**	**Diadromous/migratory**	**Fleurieu wetland**
		Access to emergent and edge vegetation for spawning and recruitment (SPP) Variable flows discourage exotic fish	Variable flows discourage exotic fish	larger species (e.g. Murray cod, golden perch) for adult conditioning, spawning sites and larval habitat in lowland/ floodplain reaches Variable flows discourage exotic fish	spawning lower stream reaches), appropriate water quality, permanence and access where species congregate) Attractant flow to trigger upstream migration Trigger spawning, and successive access to riparian spawning habitat Variable flows discourage exotic fish	wetlands Sustain flow between wetlands to allow connectivity with stream reaches for colonisation by climbing galaxias Flow related disturbance to maintain a mosaic of habitats to allow species coexistence Access to shallows for spawning and recruitment Variable flows discourage exotic fish
Trans-itional Flow Season 2	**Zero flow**	Maintain persistent aquatic conditions through combination of zero flows, low flows and channel shape				
		Discourage exotic fish		Discourage exotic fish	Discourage exotic fish	
	Low flow	Persistent water in pools; cool and well oxygenated (RB), well vegetated (SPP) Localised movement between pools (RB, SPP) Maintain shallower sub-optimal habitats and pool margins when exotic predatory fishes occur Maintain water quality Maintain shallows, hollows and cavities (larval habitat) with low salinity water for spawning and recruitment (RB) Access to emergent and edge vegetation for spawning and recruitment (SPP)	Persistent cool, well oxygenated, tolerable salinity water in wetlands, channel, riffles, anabranches and refuges (pools, billabongs); tannin-reach, clearer water (YPP) Sustain flows to provide access to off-channel habitat for adult conditioning, spawning sites and larval habitat Continuously flowing cool water discourages exotic fish in these habitats	Persistent water in pools Maintain shallower sub-optimal habitats and pool margins when exotic predatory fishes occur Allow fish movement to recolonise vacant habitats Sustain flows to provide access to off-channel habitat for larger species (e.g. Murray cod, golden perch) for adult conditioning, spawning sites and larval habitat in lowland / floodplain reaches	Persistent water in pools Maintain shallower sub-optimal habitats and pool margins when exotic predatory fishes occur Sustained flow to allow upstream and downstream migration Allow fish movement to recolonise vacant habitats	Persistent water in wetlands throughout the season (base flow ideal) Cool flowing conditions discourage exotic fish Seasonal flow increase to prevent vegetation encroachment of open water Sustain flow between wetlands to allow connectivity with stream reaches for colonisation by climbing galaxias Access to shallows for spawning and recruitment
	Fresh	Allow movement between	Flows to provide access to	Flows to provide access to	Promote spawning	Seasonal flow increase to

Flow season	Flow component	Ecological process supported by EWR				
		Freshwater obligate (stream specialist)	**Freshwater obligate (wetland specialist)**	**Freshwater obligate (generalist)**	**Diadromous/migratory**	**Fleurieu wetland**
		pools Maintain water quality Variable flows discourage exotic fish	off-channel habitat for adult conditioning, spawning sites and larval habitat Variable flows discourage exotic fish	off-channel habitat for larger species (e.g. Murray cod, golden perch) for adult conditioning, spawning sites and larval habitat in lowland / floodplain reaches Variable flows discourage exotic fish	success (raises water levels to allow access to emergent vegetation (e.g. common galaxias spawning lower stream reaches), appropriate water quality, permanence and access where species congregate) Flow to allow upstream and downstream migration Variable flows discourage exotic fish	prevent vegetation encroachment of open water Allow movement between wetlands Sustained flow between wetlands to allow connectivity with stream reaches for colonisation by climbing galaxias Variable flows discourage exotic fish
	Bankfull/ overbank	Maintain shallows (larval habitat) for spawning and recruitment	Flows to provide access to off-channel habitat for larger species (e.g. Murray cod, golden perch) for adult conditioning, spawning sites and larval habitat	Flows to provide access to off-channel habitat for larger species (e.g. Murray cod, golden perch) for adult conditioning, spawning sites and larval habitat in lowland/ floodplain reaches		
Any season	**Bankfull/ overbank**	Maintain deep pool structure (scour sediment, prevent vegetation encroachment) Channel forming flows to maintain habitat diversity Discourage exotic fish (flushing)	Channel forming flows to maintain wide range of habitat diversity (regional-scale mosaic), including physical habitat and vegetation Maintain deep pool structure (scour sediment, prevent vegetation encroachment) Discourage exotic fish (flushing)	Maintain deep pool structure (scour sediment, prevent vegetation encroachment) Channel forming flows to maintain habitat diversity Discourage exotic fish (flushing)	Maintain deep pool structure (scour sediment, prevent vegetation encroachment) Scour in channel cease to flow points to improve connectivity Channel forming flows to maintain habitat diversity Discourage exotic fish (flushing)	

D. ENVIRONMENTAL WATER REQUIREMENTS FOR MACROINVERTEBRATES IN THE MOUNT LOFTY RANGES

Flow season	Flow component	Ecological process supported by EWR				
		Flowing water, cascade	**Flowing water, riffle**	**Still water, persistent pools and ponds**	**Still water, lowland streams**	**Still water, temporary pools**
Low Flow Season	**Zero flow**					Maintain habitat quality (determines conditions for temporary water specialists)
	Low flow	Maintain persistent aquatic habitat conditions	Maintain persistent aquatic habitat conditions	Maintain persistent aquatic habitat conditions (pool habitat)	Maintain persistent aquatic habitat conditions (pool habitat)	Maintain persistent aquatic habitat conditions (pool habitat)
	Fresh	Maintain habitat quality (clean surface habitats)	Maintain habitat quality (clean surface habitats)	Refill pools, maintain water quality	Maintain habitat quality (flush pools – water quality)	Maintain habitat quality (flush pools – water quality)
T1	**Zero flow**					Maintain habitat quality (determines conditions for temporary water specialists)
	Low flow	Maintain persistent aquatic habitat conditions Allow movement to recolonise vacant habitats	Maintain persistent aquatic habitat conditions Allow movement to recolonise vacant habitats	Maintain persistent aquatic habitat conditions (pool habitat) Allow movement to recolonise vacant habitats	Maintain persistent aquatic habitat conditions (pool habitat) Allow movement to recolonise vacant habitats	Maintain persistent aquatic habitat conditions (pool habitat) Allow movement to recolonise vacant habitats
	Fresh			Maintain habitat quality (flush pools – water quality)	Maintain habitat quality (flush pools – water quality)	Maintain habitat quality (flush pools – water quality)
High Flow Season	**Zero flow**					Maintain habitat quality (determines conditions for temporary water specialists)

Flow season	Flow component	Ecological process supported by EWR				
		Flowing water, cascade	**Flowing water, riffle**	**Still water, persistent pools and ponds**	**Still water, lowland streams**	**Still water, temporary pools**
	Low flow	Maintain persistent aquatic habitat conditions Allow movement to recolonise vacant habitats	Maintain persistent aquatic habitat conditions Allow movement to recolonise vacant habitats	Maintain persistent aquatic habitat conditions (pool habitat) Allow movement to recolonise vacant habitats	Maintain persistent aquatic habitat conditions (pool habitat) Allow movement to recolonise vacant habitats	Maintain persistent aquatic habitat conditions (pool habitat) Allow movement to recolonise vacant habitats
	Fresh	Maintain habitat quality (overturn cobbles and clean riffles)	Maintain habitat quality (overturn cobbles and clean riffles) Entrain organic material from banks	Entrain organic material from banks	Entrain organic material from banks	
T2	**Zero flow**					Maintain habitat quality (determines conditions for temporary water specialists)
	Low flow	Maintain persistent aquatic habitat conditions Allow movement to recolonise vacant habitats	Maintain persistent aquatic habitat conditions Allow movement to recolonise vacant habitats	Maintain persistent aquatic habitat conditions (pool habitat) Allow movement to recolonise vacant habitats	Maintain persistent aquatic habitat conditions (pool habitat) Allow movement to recolonise vacant habitats	Maintain persistent aquatic habitat conditions (pool habitat) Allow movement to recolonise vacant habitats
	Fresh	Maintain habitat quality (overturn cobbles and clean riffles)	Maintain habitat quality (overturn cobbles and clean riffles)			
Any season	**Bankfull**	Maintain channel morphology – habitat resetting	Maintain channel morphology – habitat resetting Entrain organic material from banks	Maintain channel morphology – habitat resetting Maintain pool habitat – Scour sediments Entrain organic material from banks	Maintain channel morphology – habitat resetting Maintain pool habitat – Scour sediments Entrain organic material from banks	Maintain channel morphology – habitat resetting Maintain pool habitat - Scour sediments

Flow season	Flow component	Ecological process supported by EWR				
		Flowing water, cascade	**Flowing water, riffle**	**Still water, persistent pools and ponds**	**Still water, lowland streams**	**Still water, temporary pools**
	Overbank					Maintain persistent aquatic habitat conditions (pool habitat for still water floodplain wetland species)

E. EWRS FOR PLANTS IN THE MOUNT LOFTY RANGES

Two-part table: 1 semi-aquatic functional groups; 2 aquatic functional groups

Part 1

Tda = terrestrial damp; ATl = amphibious fluctuation tolerator, low growing; ATe = amphibious fluctuation tolerator, emergent; ATw = amphibious fluctuation tolerator, woody

Season	Component	Tda	ATl	ATe	ATw
Low Flow Season	**Zero flow**		Reproduction – needs to be exposed – gradual seasonal decline in water level (in-stream)		
	Low flow		Establishment and growth (damp soil to shallow water – in-stream) Reproduction – gradual seasonal decline in water level (in-stream)	Establishment and growth (damp soil to shallow water – in-stream)	Establishment and growth (damp soil to shallow water – in-stream)
	Fresh	Establishment (damp soil – in-stream and riparian) Preferred time for dispersal of newly produced propagules late in season	Establishment and growth (damp soil to shallow water – in-stream) Preferred time for dispersal of newly produced propagules late in season	Establishment and growth (damp soil to shallow water – in-stream) Preferred time for dispersal of newly produced propagules late in season	Establishment and growth (damp soil to shallow water – in-stream) Preferred time for dispersal of newly produced propagules late in season
	Bankfull/ overbank	Establishment (dampen soil – riparian and floodplain)	Establishment and growth (dampen soil – riparian and floodplain)	Establishment and growth (dampen soil – riparian and floodplain)	Establishment and growth (dampen soil for pairs of years – riparian and floodplain)
Transitional Flow Season 1	**Zero flow**				
	Low flow		Growth (damp soil to shallow water – in-stream)	Growth (damp soil to shallow water – aquatic and low in-stream)	Growth (damp soil to shallow water – aquatic and low in-stream)
	Fresh		Growth (damp soil to shallow water – in-stream)	Growth (damp soil to shallow water – in-stream)	Growth (damp soil to shallow water – in-stream)

Season	Component	Tda	ATl	ATe	ATw
	Bankfull/ overbank		Growth (damp soil – riparian and floodplain)	Growth (damp soil to shallow water – riparian and floodplain)	Growth (damp soil to shallow water – riparian and floodplain)
High Flow Season	**Zero flow**				
	Low flow		Germination, establishment and growth (saturated soil to shallow water – aquatic and in-stream)	Germination, establishment and growth (saturated soil to shallow water – aquatic and in-stream)	Germination, establishment and growth (saturated soil to shallow water – aquatic and in-stream)
	Fresh	Germination, establishment and growth (damp soil – in-stream and riparian) Promote community diversity over time by maintaining diversity of habitats (e.g. scour pools, shape in-channel features)	Germination, establishment and growth (saturated soil to shallow water – in-stream and riparian) Promote community diversity over time by removal of competitive dominants and terrestrial competitors through high flow disturbance Promote community diversity over time by maintaining diversity of habitats (e.g. scour pools, shape in-channel features)	Germination, establishment and growth (saturated soil to shallow water – in-stream and riparian) Regulates distribution of shorter species by inundating photosynthetic parts that need to remain emergent Promote community diversity over time by removal of competitive dominants and terrestrial competitors through high flow disturbance Promote community diversity over time by maintaining diversity of habitats (e.g. scour pools, shape in-channel features)	Germination, establishment and growth (saturated soil to shallow water – in-stream and riparian) Promote community diversity over time by removal of competitive dominants and terrestrial competitors through high flow disturbance Promote community diversity over time by maintaining diversity of habitats (e.g. scour pools, shape in-channel features)
	Bankfull/ overbank	Germination, establishment and growth (damp soil – riparian and floodplain)	Germination, establishment and growth (saturated soil to shallow water – riparian and floodplain) Reproduction – exposed on recession of overbank flows	Germination, establishment and growth (saturated soil to shallow water – riparian and floodplain)	Germination, establishment and growth (saturated soil to shallow water – riparian and floodplain)
Transitional Flow Season 2	**Zero flow**		Reproduction – needs to be exposed – gradual seasonal decline in water level (aquatic and in-stream)		

Season	Component	Tda	ATl	ATe	ATw
	Low flow		Germination, establishment and growth (saturated soil to shallow water – aquatic and in-stream) Reproduction – needs to be exposed – gradual seasonal decline in water level (aquatic and in-stream)	Germination, establishment and growth (saturated soil to shallow water – aquatic and in-stream)	Germination, establishment and growth (saturated soil to shallow water – aquatic and in-stream)
	Fresh	Germination, establishment and growth (damp soil – in-stream and riparian)	Germination, establishment and growth (saturated soil to shallow water – in-stream and riparian) Reproduction –needs to be exposed – gradual seasonal decline in water level (aquatic and in-stream)	Germination, establishment and growth (saturated soil to shallow water – in-stream and riparian)	Germination, establishment and growth (saturated soil to shallow water – in-stream and riparian)
	Bankfull/ overbank	Germination, establishment and growth (damp soil – riparian and floodplain)	Germination, establishment and growth (saturated soil to shallow water – riparian and floodplain) Reproduction – exposed on recession of overbank flows	Germination, establishment and growth (saturated soil to shallow water – riparian and floodplain)	Germination, establishment and growth (saturated soil to shallow water – riparian and floodplain)
All	**All**	Promote community diversity over time by retaining flow variability to provide a variety of depth/duration/frequency over time and space to meet requirements of different species (within and between functional groups)			
	Low flow	Prevent terrestrial invasion of aquatic habitat (where appropriate)			
Any time	**Fresh**	Dispersal of propagules			
	Bankfull/ overbank	Dispersal of propagules Promote community diversity over time by maintaining diversity of habitats (e.g. shape in-channel and floodplain features) and by removing competitive dominants and terrestrial (dry) competitors through high flow disturbance			

Part 2

ARp = amphibious fluctuation responder, plastic; ARf = amphibious fluctuation responder, floating; Sr = submerged r-selected; Se = submerged emergent; Sk = submerged k-selected

Season	Component	ARp	ARf	Sr	Se	Sk
Low Flow Season	**Zero flow**		Maintain persistent aquatic conditions through combination of low flows, zero flows and channel morphology Commonly reproduce on gradually declining seasonal water level (aquatic and in-stream)	Maintain persistent aquatic conditions through combination of low flows, zero flows and channel morphology Drying stimulates germination for some species Commonly reproduce on gradually declining seasonal water level (aquatic and in-stream)	Maintain persistent saturated or aquatic conditions through combination of low flows, zero flows and channel morphology	Maintain persistent aquatic conditions through combination of low flows, zero flows and channel morphology Commonly reproduce on gradually declining seasonal water level (aquatic and in-stream)
	Low flow	Establishment and growth (damp soil to shallow water – in-stream)	Establishment and growth (saturated soil to shallow water – aquatic) Commonly reproduce on gradually declining seasonal water level (aquatic)	Establishment and growth (surface water – aquatic) Drying by seasonal decline in water level stimulates germination in some species Commonly reproduce on gradually declining seasonal water level (surface water – aquatic)	Establishment and growth (saturated soil to shallow water – aquatic)	Establishment and growth (surface water - aquatic) Commonly reproduce on gradually declining seasonal water level (surface water – aquatic)
	Fresh	Establishment and growth (damp soil to shallow water – in-stream) Preferred time for dispersal of newly produced propagules late in season	Maintain water in aquatic habitats Preferred time for dispersal of newly produced propagules late in season Maintain water quality (aquatic habitats)	Maintain water in aquatic habitats Preferred time for dispersal of newly produced propagules late in season Maintain water quality (aquatic habitats)	Maintain water in aquatic habitats Preferred time for dispersal of newly produced propagules late in season Maintain water quality (aquatic habitats)	Maintain water in aquatic habitats Preferred time for dispersal of newly produced propagules late in season Maintain water quality (aquatic habitats)

Season	Component	ARp	ARf	Sr	Se	Sk
	Bankfull/ overbank	Establishment and growth (dampen soil –floodplain wetlands)	Establishment and growth (saturated soil to shallow water -floodplain wetlands)	Establishment and growth (surface water -floodplain wetlands)	Establishment and growth (saturated soil to shallow water – floodplain wetlands)	Establishment and growth (surface water – permanent floodplain wetlands)
Transitional Flow Season 1	**Zero flow**		Maintenance of persistent aquatic conditions through combination of low and zero flows		Maintenance of persistent saturated or aquatic conditions through combination of low flows, zero flows and channel morphology	Maintenance of persistent saturated or aquatic conditions through combination of low flows, zero flows and channel morphology
	Low flow	Growth (damp soil to shallow water – aquatic and low in-stream)	Growth (saturated soil to shallow water – aquatic)		Growth (saturated soil to shallow water – aquatic)	Growth (surface water – aquatic)
	Fresh	Growth (damp soil to shallow water – in-stream)				
	Bankfull/ overbank	Growth (damp soil to shallow water – floodplain wetlands)	Growth (saturated soil to shallow water – floodplain wetlands)		Growth (saturated soil to shallow water – floodplain wetlands)	Growth (surface water – permanent floodplain wetlands)
High Flow Season	**Zero flow**		Maintenance of persistent aquatic conditions through combination of low flows, zero flows and channel morphology	Maintenance of persistent aquatic conditions through combination of low flows, zero flows and channel morphology	Maintenance of persistent saturated or aquatic conditions through combination of low flows, zero flows and channel morphology	Maintenance of persistent aquatic conditions through combination of low flows, zero flows and channel morphology
	Low flow	Germination, establishment and growth (saturated soil to shallow water – aquatic and in-stream)	Germination, establishment and growth (saturated soil to shallow water – aquatic)	Germination, establishment and growth (surface water – aquatic)	Germination, establishment and growth (saturated soil to shallow water – aquatic)	Germination, establishment and growth (surface water – aquatic)

Season	Component	ARp	ARf	Sr	Se	Sk
	Fresh	Germination, establishment and growth (saturated soil to shallow water – in-stream) Promote community diversity over time by removal of competitive dominants and terrestrial competitors through high flow disturbance Promote community diversity over time by maintaining diversity of habitats (scour pools, create undercut banks, deposit bars and benches etc)	Promote community diversity over time by removal of competitive dominants and terrestrial competitors through high flow disturbance Promote community diversity over time by maintaining diversity of habitats (scour pools, create undercut banks, deposit bars and benches etc)	Germination, establishment and growth (surface water – in-stream habitats that stay inundated for at least 4 months) Promote community diversity over time by removal of competitive dominants and terrestrial competitors through high flow disturbance Promote community diversity over time by maintaining diversity of habitats (scour pools, create undercut banks, deposit bars and benches etc)	Promote community diversity over time by removal of competitive dominants and terrestrial competitors through high flow disturbance Promote community diversity over time by maintaining diversity of habitats (scour pools, create undercut banks, deposit bars and benches etc)	Promote community diversity over time by removal of competitive dominants and terrestrial competitors through high flow disturbance Promote community diversity over time by maintaining diversity of habitats (scour pools, create undercut banks, deposit bars and benches etc)
	Bankfull/ overbank	Germination, establishment and growth (saturated soil to shallow water – floodplain wetlands)	Germination, establishment and growth (saturated soil to shallow water – floodplain wetlands)	Germination, establishment and growth (surface water – floodplain wetlands)	Germination, establishment and growth (saturated soil to shallow water – floodplain wetlands)	Germination, establishment and growth (surface water – permanent floodplain wetlands)
Transitional Flow Season 2	**Zero flow**		Maintenance of persistent aquatic conditions through combination of low flows, zero flows and channel morphology Commonly reproduce on gradually declining seasonal water level (aquatic)	Maintenance of persistent aquatic conditions through combination of low flows, zero flows and channel morphology Commonly reproduce on gradually declining seasonal water level (aquatic)	Maintenance of persistent saturated or aquatic conditions through combination of low flows, zero flows and channel morphology	Maintenance of persistent aquatic conditions through combination of low flows, zero flows and channel morphology Commonly reproduce on gradually declining seasonal water level (aquatic)

Season	Component	ARp	ARf	Sr	Se	Sk
	Low flow	Germination, establishment and growth (saturated soil to shallow water – aquatic and in-stream) Commonly reproduce on gradually declining seasonal water level (aquatic and in-stream)	Germination, establishment and growth (saturated soil to shallow water – aquatic) Commonly reproduce on gradually declining seasonal water level (aquatic)	Germination, establishment and growth (surface water – aquatic) Drying by seasonal decline in water level stimulates germination in some species Commonly reproduce on gradually declining seasonal water level (aquatic)	Germination, establishment and growth (saturated soil to shallow water – aquatic)	Germination, establishment and growth (surface water – aquatic) Commonly reproduce on gradually declining seasonal water level (aquatic)
	Fresh	Germination, establishment and growth (saturated soil to shallow water – in-stream) Commonly reproduce on gradually declining seasonal water level (in-stream)		Germination, establishment and growth (surface water – in-stream habitats that stay inundated for at least 4 months)		
	Bankfull/ overbank	Germination, establishment and growth (saturated soil to shallow water – floodplain wetlands) Commonly reproduce on gradually declining seasonal water level (flood recession in floodplain wetlands)	Germination, establishment and growth (saturated soil to shallow water – floodplain wetlands) Commonly reproduce on gradually declining seasonal water level (flood recession in floodplain wetlands)	Germination, establishment and growth (surface water – floodplain wetlands) Commonly reproduce on gradually declining seasonal water level (flood recession in floodplain wetlands)	Germination, establishment and growth (saturated soil to shallow water – floodplain wetlands)	Germination, establishment and growth (surface water – permanent floodplain wetlands) Commonly reproduce on gradually declining seasonal water level (flood recession in floodplain wetlands)
All	**All**	Promote community diversity over time by retaining flow variability to provide a variety of depth/duration/frequency over time and space to meet requirements of different species (within and between functional groups)				
	Low flow	Prevent terrestrial invasion of aquatic habitat (where appropriate)				
Any time	**Fresh**	Dispersal of propagules				
	Bankfull/ overbank	Dispersal of propagules Promote community diversity over time by maintaining diversity of habitats (scour pools, create undercut banks, deposit bars and benches etc) Promote community diversity over time by removal of competitive dominants and terrestrial competitors through high flow disturbance				

F. METRICS REPRESENTING EWRS IN THE MOUNT LOFTY RANGES

Note: threshold values are those used if calculating metric values using 33 years of flow data (as for this project)

Season and flow component	EWR metric	Measurement unit	Reach type	Flow purpose	Priority group (see Section 6.3)	Threshold (see Section 6.3)
Low Flow Season						
Low flows	Average daily LFS flow	ML/day	All	• Correlated with macroinvertebrate health • General measure of seasonal discharge – indicator of habitat persistence, recharge to groundwater where relevant	3	n.a.
	80th percentile exceedence non-zero flow	ML/day	All	• Maintenance of core aquatic habitat (refugia) • Flows to prepare climbing galaxias breeding • Promote flowering and seed set of some aquatic plant species (ARp)	1	n.a.
Zero flows	Number of years with LFS zero flow spells	# years	All	• Correlated with the viability of core aquatic habitat (refugia) • Promote flowering and seed set of some aquatic plant species (ATl) • Discourage exotic fish species	1	4
	Average number of LFS zero flow spells per year	events/ season	All	• Can cause 'false start' breeding events for plants • Determines habitat quality for temporary still-water macroinvertebrate species	2	4
	Average duration of LFS zero flow spells	days/spell	All	• Correlated with the viability of core aquatic habitat (refugia) • Promote flowering and seed set of some aquatic plant species (ATl) • Discourage exotic fish species	If threshold = 15 then priority = 3 otherwise priority =1	Threshold = 15 if natural and current number of years with LFS zero flow spells are <= 4

Season and flow component	EWR metric	Measurement unit	Reach type	Flow purpose	Priority group (see Section 6.3)	Threshold (see Section 6.3)
						otherwise threshold = 4
Low flow freshes	Number of years with one or more LFS freshes	# years	All	• Flush mountain galaxias spawning sites • Maintain damp conditions on banks for plant establishment • Transport plant propagules	1	n.a.
	Average number of LFS freshes per year	events/ season	All	• Maintenance of core aquatic habitat (refugia) • Flush mountain galaxias spawning sites • Allow localised fish movement • Transport plant propagules • Refresh pool water quality	1	n.a.
	Average total duration of LFS freshes per year	days/season	All	• Maintenance of core aquatic habitat (refugia) • Flush mountain galaxias spawning sites • Allow localised fish movement • Transport plant propagules	2	n.a.
Transitional Flow Season 1 (low–high, T1)						
Low flows	Average daily T1 flow	ML/day	All	• General measure of seasonal discharge – indicator of habitat persistence, recharge to groundwater where relevant	3	n.a.
	80th percentile exceedence non-zero flow	ML/day	All	• Maintain core aquatic habitat (refugia) • Stimulate mountain galaxias breeding • Prepare climbing galaxias breeding • Open common galaxias migration to sea • Allow localised fish movement • Extend habitat to riffles for	1	n.a.

Season and flow component	EWR metric	Measurement unit	Reach type	Flow purpose	Priority group (see Section 6.3)	Threshold (see Section 6.3)
				macroinvertebrates		
	Current month reaching median flow of natural T1 median (delay in onset)	# years	Upper pool riffle only	• Delayed onset of T1 means longer low flow stress for refuges and shorter flow period • Important for fish survival • Ensure sufficient duration of habitat availability for plants	1	n.a.
Zero flows	Number of years with T1 zero flow spells	# years	All	• Correlated with the viability of core aquatic habitat (refugia) • Discourage exotic fish species	1	4
	Average number of T1 zero flow spells per year	events/ season	All	• Determines habitat quality for temporary still-water macroinvertebrate species	2	4
	Average duration of T1 zero flow spells	days/spell	All	• Correlated with the viability of core aquatic habitat (refugia) • Discourage exotic fish species	If threshold = 15 then priority = 3 Otherwise priority =1	Threshold = 15 if natural and current number of years with T1 zero flow spells are <= 4 Otherwise threshold = 4
T1 freshes	Number of years with one or more T1 freshes	# years	All	• Enhance movement of common galaxias to sea • Transport plant propagules	1	n.a.
	Average number of T1 freshes per year	events/ season	All	• Enhance movement of common galaxias to sea	1	n.a.
	Average total duration of T1 freshes per year	days/season	All	• Maintain core aquatic habitat (refugia) • Enhance movement of common galaxias to sea • Transport plant propagules	2	n.a.

Season and flow component	EWR metric	Measurement unit	Reach type	Flow purpose	Priority group (see Section 6.3)	Threshold (see Section 6.3)
	Number of years with 2 or more T1 freshes	# years	n.a. for upper pool riffle dry	• Promote successful climbing galaxias breeding	2	n.a.
	Frequency of spells higher than LFS fresh level	events/ season	Lowland only (not ephemeral)	• Localised fish movement	2	n.a.
High Flow Season						
Low flows	Average daily HFS flow	ML/day	All	• Correlated with macroinvertebrate health • General measure of seasonal discharge – indicator of habitat persistence, recharge to groundwater where relevant	3	n.a.
	80th percentile exceedence non-zero flow	ML/day	All	• Maintenance of core aquatic habitat (refugia) • Localised movement of macroinvertebrate and fish species (recolonise vacant habitats) • Breeding and movement for diadromous fish • Regulate terrestrial and amphibious plant distribution • Extend habitat availability for plants (MPR), including amphibious (lowland & MPR)	1	n.a.
Zero flows	Number of years with HFS zero flow spells	# years	All	• Correlated with the viability of core aquatic habitat (refugia) • Discourage exotic fish species	1	4
	Average number of HFS zero flow spells per year	events/season	All	• Determines habitat quality for temporary still-water macroinvertebrate species	2	4
	Average duration of HFS	days/spell	All	• Correlated with the viability of core	If threshold = 15	Threshold = 15 if

Season and flow component	EWR metric	Measurement unit	Reach type	Flow purpose	Priority group (see Section 6.3)	Threshold (see Section 6.3)
	zero flow spells			aquatic habitat (refugia) • Discourage exotic fish species	then priority = 3 Otherwise priority =1	natural and current number of years with HFS zero flow spells are <= 4 Otherwise threshold = 4
HFS freshes	Number of years with one or more HFS freshes	# years	All	• Promote fish spawning success • Promote large-scale fish movement • Trigger upstream fish migration • Transport plant propagules • Dampen bank soils for plant germination and establishment (Tda) • Maintain habitat (overturn substrates and scour pools) • Regulate terrestrial/amphibious plant distribution • Entrain organic material from banks	1	n.a.
	Average number of HFS freshes per year	events/ season	All	• Discourage exotic fish (Gambusia) • Promote fish spawning success • Promote large-scale fish movement • Trigger upstream fish migration • Transport plant propagules • Dampen bank soils for plant germination and establishment (Tda) • Habitat maintenance (overturn substrates and scour pools) • Regulate terrestrial/amphibious plant distribution	1	n.a.

Season and flow component	EWR metric	Measurement unit	Reach type	Flow purpose	Priority group (see Section 6.3)	Threshold (see Section 6.3)
	Average total duration of HFS freshes per year	days/season	All	• Entrain organic material from banks • Expand riffles for macroinvertebrates • Discourage exotic fish (Gambusia) • Promote fish spawning success • Promote large-scale fish movement • Trigger upstream fish migration • Transport plant propagules • Dampen bank soils for plant germination and establishment (Tda) • Maintain habitat (overturn substrates and scour pools) • Regulate terrestrial/amphibious plant distribution • Entrain organic material from banks • Expand riffles for macroinvertebrates	2	n.a.
	Number of years with 1 or more spell greater than the annual 5th percentile exceedence flow in HFS	# years	Upper pool riffle wet only	• Correlate with large-scale fish movement	2	n.a.
	Number of years with 2 or more freshes early in the season (Jul, Aug)	# years	All but upper pool riffle and lowland ephemeral	• Stimulate successful climbing galaxias breeding	2	n.a.
Transitional Flow Season 2 (high–low, T2)						
Low flows	Average daily T2 flow	ML/day	All	• General measure of seasonal discharge – indicator of habitat persistence, recharge to groundwater where relevant	3	n.a.

Season and flow component	EWR metric	Measurement unit	Reach type	Flow purpose	Priority group (see Section 6.3)	Threshold (see Section 6.3)
	Median non-zero daily T2 flow	ML/day	All but upper pool riffle dry	• Promote resilience in fish populations leading into the subsequent LFS • Access to spawning habitats for southern pygmy perch • Prime gudgeon spawning	2	n.a.
	80th percentile exceedence non-zero flow	ML/day	All	• Maintenance of core aquatic habitat (refugia) • Localised movement of macroinvertebrate and fish species (recolonise vacant habitats) • Breeding and movement for diadromous fish • Promote plant reproduction (ARf, Sk)	1	n.a.
	Current month reaching median flow of natural T2 median (early onset)	# years	All	• Early onset of Low Flow Season means longer low flow stress for refuges and shorter flow period • Promote survival of fish • Support gudgeon spawning • Support reproduction of some amphibious plants (ATl)	1	n.a.
Zero flows	Number of years with T2 zero flow spells	# years	All	• Correlate with the viability of core aquatic habitat (refugia) • Discourage exotic fish species • Promote germination of some amphibious plants (Sr)	1	4
	Average number of T2 zero flow spells per year	events/ season	All	• Determine habitat quality for temporary still-water macroinvertebrate species	2	4
	Average duration of T2 zero flow spells	days/spell	All	• Correlate with viability of core aquatic habitat (refugia)	If threshold = 15 then priority = 3	Threshold = 15 if natural and current

Season and flow component	EWR metric	Measurement unit	Reach type	Flow purpose	Priority group (see Section 6.3)	Threshold (see Section 6.3)
				• Discourage exotic fish species • Promote germination of some amphibious plants (Sr)	Otherwise priority =1	number of years with T2 zero flow spells are <= 4 Otherwise threshold = 4
T2 freshes	Number of years with one or more T2 freshes	# years	All	• Maintain core aquatic habitat (refugia) • Maintain habitat (overturn substrates, scour algae for macroinvertebrates) • Provide fish edge habitat (esp southern pygmy perch) • Scour algae to provide macroinvertebrate habitat and food • Transport plant propagules • Promote establishment of instream vegetation	1	n.a.
	Average number of T2 freshes per year	events/ season	All	• Maintain core aquatic habitat (refugia) • Amount of flow related edge habitat for southern pygmy perch • Attractant flow for migratory fish	1	n.a.
	Average total duration of T2 freshes per year	days/season	All	• Maintain core aquatic habitat (refugia) • Maintain habitat (overturn substrates) • Amount of flow related edge habitat for southern pygmy perch • Transport plant propagules • Promote establishment of instream vegetation	2	n.a.
	Frequency of spells higher than LFS fresh level	events/ season	Lowland only (not ephemeral)	• Enhance localised fish movement (pool to pool)	2	n.a.
	Number of years with 1 or more spell greater than	# years	Upper pool riffle only	• Large scale fish movement	2	n.a.

Season and flow component	EWR metric	Measurement unit	Reach type	Flow purpose	Priority group (see Section 6.3)	Threshold (see Section 6.3)
	the annual 5th percentile exceedence flow					
	Number of consecutive years with no T2 fresh	# years	Upper pool riffle dry only	• Maintain core aquatic habitat (refugia)	1	n.a.
Any time of year						
Bankfull	Number of years with 1 or more bankfull flows	# years	All	• Maintain floodplain vegetation (recruitment and survivorship – pairs of years) • Fill floodplain wetlands • Regulate distribution of terrestrial plant competitors • Regulate plant distribution • Maintain channel morphology	2	n.a.
	Average duration of bankfull flow spells	days	All	• Fill floodplain wetlands • Promote fish recruitment (access to flood-runners) • Correlate fish recruitment (dry upper pool riffle)	**If less than 2 for current and 'natural'** 1 – Lowland 2 – all other zones **If greater than 2 for current or 'natural'** 3	**2**
	Average total duration of bankfull flow per year	days/year	All	• Fill floodplain wetlands • Promote fish recruitment (access to flood-runners) • Correlate to fish recruitment (dry upper pool riffle)	**If less than 2 for current and 'natural'** 1 – Lowland 2 – all other zones **If greater than 2 for current or 'natural'** 3	**2**

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

Adjusted flow

Calculated volume of water that flows over land with the presence of dams removed.

Aquatic macroinvertebrates

Animals without backbones that spend all or part of their life-cycle in water. They are large enough to be seen with the naked eye and include insects, crustaceans, snails, worms, mites and sponges. Included are the larvae of flying insects (e.g. midges, two-winged flies, dragonflies, mayflies, stoneflies and caddisflies) as well as the adults of some groups (e.g. waterbugs, beetles, springtails).

Aquifer

A permeable zone of rock or sediment in which underground water is stored and moves.

Baseflow

The component of flow in a watercourse that is driven from the discharge of underground water.

Cascade

A series of shallow or step-like waterfalls.

Catchment

The area of land determined by topographic features within which rainfall contributes to runoff at a particular point.

Current flow

Gauged or modeled flow using 2005 dam development levels.

Diadromous

Fish that need to travel between salt and fresh water as part of their life-cycle.

Ecosystem

A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit.

Environmental water provision

Those parts of environmental water requirements that can be met at any given time, considering existing users' rights, as well as social and economic interests. Environmental water provisions do not necessarily aim to return water-dependent ecosystems to a pristine condition but rather to ensure that they are sustained (and restored, where achievable) as close as possible to the natural condition, while considering social and economic interests in the area.

Environmental water requirement

The water regime needed to sustain the ecological values of aquatic ecosystems, including their processes and biological diversity, at a low level of risk.

Euryhaline

Able to adapt to a wide range of salinities.

Floodplain

An area of land adjacent to a watercourse, lake or estuary that is periodically inundated with water derived from flow from the adjacent watercourse.

Flow regime

The magnitude, timing, duration and frequency of water flow events.

Flow seasons

Low Flow Season, Transitional Flow Season 1 (low–high), High Flow Season, Transitional Flow Season 2 (high–low) – see Figure 3; seasons defined by the natural flow distribution, rather than the traditional seasons of summer, autumn, winter and spring

Gaining stream

A stream in which groundwater discharges contribute significantly to the streamflow volume.

Losing stream

A stream that is losing water to (or recharging) the groundwater system.

Metric

Hydrological terms used to quantify the environmental water requirements of water-dependent ecosystems (e.g. 80th percentile exceedence non-zero flow is a metric that represents low flows).

Natural flow

For the purposes of this project, the flow with the impacts of the 2005 level of dam development removed as modelled using the WaterCress platform (e.g. Alcorn et al. 2008; Teoh in prep) and accepting that some irreversible changes from pre-European flows have occurred due to land clearance and other water resource developments. It is more accurately termed the 'adjusted' flow, as there is little scope to determine or model the natural pre-European flow regime due to the confounding interactions between land-use change and water resource development on both the surface and groundwater systems, and the relationships/connections between the two.

Phreatophytic

A plant (often deep-rooted) that obtains a significant portion of the water it needs from the watertable or other permanent ground supply.

Potadromous

Fish that migrate within fresh water only.

Prescribed Area

Comprises the Western Mount Lofty Ranges Prescribed Water Resources Area and Eastern Mount Lofty Ranges Prescribed Water Resources Area (see Figure 1).

Reach type

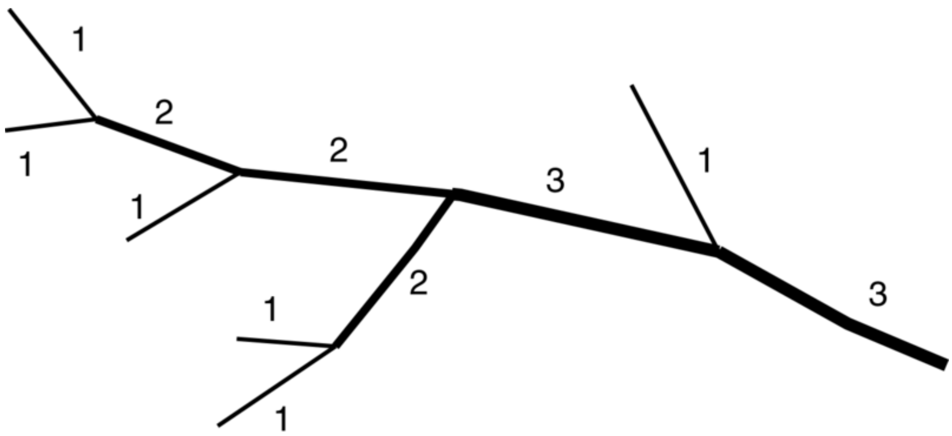
Watercourses with similar structure, ecology and hydrology expected to support similar water-dependent ecosystems

Riffle

A reach of stream characterised by shallow, fast moving water broken by the presence of rocks and boulders

Strahler stream ordering

The beginnings of a watercourse in headwaters are **first-order** streams. When two **first-order** streams come together, they form a **second-order** stream. When two second-order streams come together, they form a **third-order** stream. Streams of lower order joining a higher order stream do not change the order of the higher stream. Thus, if a first-order stream joins a second-order stream, it remains a second-order stream. It is not until a second-order stream combines with another second-order stream that it becomes a third-order stream.



Stygofauna

Animals that live in groundwater systems, including caves and aquifers.

Surface water

As in section 3(1) of the Natural Resources Management Act –

- water flowing over land (except in a watercourse) –
- after having fallen as rain or hail or having precipitated in any other manner; or
- after rising to the surface naturally from underground;
- water of the kind referred to above that has been collected in a dam or reservoir;
- water of the kind referred to in the first dot point above that is contained in any stormwater infrastructure (as that term is defined in the Act).

Swamps of the Fleurieu Peninsula

Wetlands on the Fleurieu Peninsula listed as critically endangered threatened ecological communities under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.

Watercourse

As in section 3(1) of the Act, a river, creek or other natural watercourse (whether modified or not) in which water is contained or flows whether permanently or from time to time 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 ambit of this definition) into which the water of a watercourse has been diverted;
- part of a watercourse;
- an estuary through which water flows; and
- any other natural resource or class of natural resource, designated as a watercourse for the purposes of the Act by an NRM Plan.

Water-dependent ecosystem(s)

Those parts of the environment, the species composition and natural ecological processes of which, which 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, permanent pools, floodplains, estuaries and lakes are all water-dependent ecosystems.

Water resource

As in section 3(1) of the Act –

- a watercourse or lake, surface water, underground water, stormwater (to the extent that it is not within a preceding item) and effluent
- an opening in the ground excavated for some other purpose but that gives access to underground water
- a natural opening in the ground that gives access to underground water.

Wetland

As in section 3(1) of the Act, an area that comprises land that is permanently or periodically inundated with water (whether through a natural or artificial process) where the water may be static or flowing and may range from fresh water to saline water and where the inundation with water influences the biota or ecological processes (whether permanently or from time to time) and includes any other area designated as a wetland –

- by an NRM plan; or
- by a Development Plan under the *Development Act 1993*.

For the purposes of this report, dams and well-defined, channelised watercourses are exempt from this definition.

ABBREVIATIONS

AMLR NRM Board	Adelaide and Mount Lofty Ranges Natural Resources Management Board
CAMBA	China–Australia Migratory Bird Agreement
DWLBC	Department for Water, Land and Biodiversity Conservation
EMLR	Eastern Mount Lofty Ranges
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
EWP	environmental water provisions
EWR	environmental water requirements
JAMBA	Japan–Australia Migratory Bird Agreement
MLR	Mount Lofty Ranges
NRM	natural resources management
SAMDB NRM Board	South Australian Murray–Darling Basin Natural Resources Management Board
WDE	water-dependent ecosystems
WMLR	Western Mount Lofty Ranges

BIBLIOGRAPHY

Alcorn M, Savadamuthu K and Murdoch B. 2008. Capacity of the surface water resources of the Eastern Mount Lofty Ranges. DWLBC Technical Note 2008/23. Department of Water, Land and Biodiversity Conservation, Adelaide.

Arthington AH, Brizga SO, Pusey BJ, McCosker RO, Bunn SE, Loneragan N, Growns IO and Yeates M. 1998. Comparative evaluation of environmental flow assessment techniques: review of methods. LWRRDC Occasional Paper 27/98. Land and Water Resources Research and Development Corporation,

Barnett S and Rix R. 2006. Southern Fleurieu Groundwater assessment. Report DWLBC 2006/24. Department of Water, Land and Biodiversity Conservation, Adelaide.

Brock MA and Casanova MT. 1997. Plant life at the edges of wetlands: ecological responses to wetting and drying patterns. In N Klomp and I Lunt (eds) Frontiers in ecology: building the links. Elsevier Science, Oxford.

Bunn S and Arthington A. 2002 Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management*, 30, 492–507.

Casanova MT. 2004. A census of submerged plants of the Angas River and Tookayerta Creek catchments. Unpublished report for the River Murray Catchment Water Management Board.

Casanova MT. in prep. Using plant functional groups to investigate environmental water requirements of a catchment.

Casanova MT and Brock MA. 2000. How do depth, duration and frequency of flooding influence the establishment of wetland plant communities? *Plant Ecology*, 147: 237–250.

Conallin A and Hammer M. 2003. Fish surveys of selected streams in the Eastern Mount Lofty Ranges, South Australia. MDFRC Report No. 7/2003. The Murray–Darling Freshwater Research Centre, Mildura.

Cottingham P, Stewardson M, Roberts J, Metzeling L, Humphries P, Hillman T and Hannan G. 2001. Report of the Broken River scientific panel on the environmental condition and flows of the Broken River and Broken Creek. Technical Report 10/2001. Cooperative Research Centre for Freshwater Ecology, University of Canberra, Canberra.

Doeg TJ, Vietz GJ and Boon PI. 2008. Painkalac Creek environmental flow investigation: recommendations paper. Prepared for Corangamite Catchment Management Authority, Colac.

Earth Tech. 2003a. Thomson River environmental water requirements: Part B – Final Recommendations. Unpublished report to the West Gippsland Catchment Management Authority by the Thomson River Environmental Water Requirements Technical Panel.

Earth Tech. 2003b. Watercourse rehabilitation priority setting process. Final report for the Northern Adelaide and Barossa, Patawalonga and Torrens Catchment Water Management Boards.

Earth Tech. 2004. Watercourse Risk Assessment – Geomorphology and Vegetation, Angas and Tookayerta Catchments. For the River Murray Catchment Water Management Board.

Earth Tech. 2006. Environmental Flow Determination for the Maribyrnong – Draft Final Recommendations Paper. Unpublished report to Melbourne Water Corporation by the Maribyrnong River Environmental Water Requirements Technical Panel.

Favier D, Rixon S and Scholz G. 2000. A river management plan for the Wakefield Catchment. Department for Environment and Heritage, Adelaide.

Favier D, Scholz G, VanLaarhoven JM and Bradley J. 2004. A river management plan for the Broughton Catchment. Department of Water, Land and Biodiversity Conservation. Report DWLBC 2004/16.

Fryirs K and Brierley G. 2005. Practical application of the River Styles (R) framework as a tool for catchment-wide river management: a case study from Bega catchment, New South Wales. Macquarie University.

Green G and Stewart S. 2008. Interactions between groundwater and surface water systems in the Eastern Mount Lofty Ranges. DWLBC Report 2008/27

DWLBC (Department of Water, Land and Biodiversity Conservation). 2006. State natural resources management plan. Government of South Australia, Adelaide.

Hammer M. 2001. Molecular systematics and conservation biology of the southern pygmy perch Nannoperca australis (Günther, 1861) (Teleostei: Percichthyidae) in south-eastern Australia. B. Sc. (Honours) thesis, Adelaide University.

Hammer M. 2004. The Eastern Mount Lofty Ranges fish inventory: distribution and conservation of freshwater fishes of tributaries in the Lower River Murray, South Australia. Native Fish Australia (SA) Inc, Adelaide.

Hammer M. 2005. Recovery monitoring for the southern pygmy perch in the Mount Lofty Ranges South Australia, 2001–2005 review: confidential technical document. Native Fish Australia (SA) Inc, Adelaide.

Hammer M. 2007a. Freshwater fish monitoring for threatened species and environmental water requirements in the Eastern Mount Lofty Ranges. Aquasave Consultants report to the SA Murray-Darling Basin NRM Board, Murray Bridge.

Hammer M. 2007b. Data summary and 2006 performance of fish indicators for environmental water requirements of the Marne River Catchment, South Australia. Aquasave Consultants, Adelaide.

Hammer M. 2007c. A preliminary population model for mountain galaxias in the Eastern Mount Lofty Ranges, South Australia based on 2002–2006 monitoring data. Aquasave Consultants, Adelaide.

Harding CL. 2005. Wetland inventory for the Fleurieu Peninsula, South Australia. Department for Environment and Heritage, Adelaide.

Heneker TM. 2003. Surface water assessment of the Upper River Torrens catchment. Report DWLBC 2003/24. Department of Water, Land and Biodiversity Conservation, Adelaide.

Jowett IG and Biggs BJF. 2008. Application of the 'natural flow paradigm' in a New Zealand context. *River Research and Applications,* 25(9): 1126-1135

Leck MA and Brock MA. 2000. Ecological and evolutionary trends in wetlands: evidence from seeds and seed banks in New South Wales, Australia and New Jersey, USA. *Plant Species Biology*, 15: 97-112.

Likens GE, Walker KF, Davies PE, Brookes J, Olley J, Young WJ, Thoms MC, Lake PS, Gawne B, Davis J, Arthington AH, Thompson R and Oliver RL. 2009. Ecosystem science: toward a new paradigm for managing Australia's inland aquatic ecosystems. *Marine and Freshwater Research*, 60, 271-279.

Lloyd LN. 1987. Ecology and distribution of the small native fish of the lower River Murray, South Australia and their interactions with the exotic mosquitofish, *Gambusia affinis holbrooki*. MSc. thesis, The University of Adelaide.

Lloyd N, Quinn G, Thoms M, Arthington A, Gawne B, Humphries P and Walker K. 2004. Does flow modification cause geomorphological and ecological response in rivers? A literature review from an Australian perspective. Technical report 1/2004, CRCFE, Canberra.

LREFSP. 2002. Environmental flow determination of the Loddon River catchment: final report. Unpublished report to the North Central Catchment Management Authority and Department of Natural Resources and Environment, Melbourne.

LREFTP (Lerderderg River Environmental Flows Technical Panel). 2003. Environmental flow determination of the Lerderderg River Catchment: Part B – Final Recommendations. Unpublished report for the Port Phillip and Westernport Catchment Management Authority and Department of Sustainability and Environment, Melbourne.

LYDEFTP (Little Yarra and Don Rivers Environmental Flow Technical Panel). 2004. Environmental flow determination for the Little Yarra and Don rivers: final recommendations. Prepared for Melbourne Water Corporation, Melbourne.

MREFTP (Marne River Environmental Flows Technical Panel). 2003. Environmental water requirements of the ephemeral Marne River system, South Australia. River Murray Catchment Water Management Board.

McEvoy P, Goonan P and Madden C. 2003. Aquatic macroinvertebrates. In DM Armstrong, SJ Croft and JN Foulkes (eds) A biological survey of the southern Mount Lofty Ranges, South Australia, 2000–2001. Department for Environment and Heritage, Adelaide. pp 219–227.

McNeil DG and Hammer M. 2007. Biological review of the freshwater fishes of the Mount Lofty Ranges. SARDI publication: F2006/000335. South Australian Research and Development Institute (Aquatic Sciences), Adelaide.

MLR EWR Expert Panel (Mount Lofty Ranges Environmental Water Requirements Expert Panel). in preparation. Environmental water requirements for the Mount Lofty Ranges prescribed water resources areas: Technical background report.

Poff NL, Allan JD, Bain MB, Karr JR, Prestegaard KL, Richter BD, Sparks RE and Stromberg J. 1997. The natural flow regime: a paradigm for river conservation and restoration. *Bioscience*, 47: 769-784.

Savadamuthu K. 2003. Surface water assessment of the Upper Finniss catchment. Report DWLBC 2003/18. Department of Water, Land and Biodiversity Conservation, Adelaide.

SKM. 2005. Determination of an environmental water reserve recommendation and complementary waterway works for the Yarra River: flow and non-flow related environmental and social issues associated with the Yarra River. Report prepared for Melbourne Water.

SKM. 2006. Seven Creeks environmental flows assessment. Unpublished report for the Goulburn Broken Catchment Management Authority.

SKM, CRC for Freshwater Ecology, Freshwater Ecology (NRE) and Lloyd Environmental Consultants. 2002. FLOWS – A method for determining environmental water requirements in Victoria. Report prepared for Department of Natural Resources and Environment, Melbourne.

Strahler A N. 1952. Hypsometric (area-altitude) analysis of erosional topology, *Geological Society of America Bulletin*, 63(11): 1117–1142.

Teoh K. in preparation. Capacity of surface water resources in the Western Mount Lofty Ranges – Methodology and results. Technical Note DWLBC.

Teoh K. 2006. The impact of farm dam development on the surface water resources of the South Para River catchment. Report DWLBC 2003/19.

van der Wielen M. in preparation. Environmental water provisions for the Eastern Mount Lofty Ranges prescribed water resources area.

VanLaarhoven JM. 2009. Environmental water provisions for the Western Mount Lofty Ranges prescribed water resources areas. DWLBC Report 2009/30. Department of Water, Land and Biodiversity Conservation, Adelaide.

VanLaarhoven JM, Scholz G, Phipps L and Favier D. 2004. A river management plan for the Light Catchment. Report DWLBC 2004/17. Department of Water, Land and Biodiversity Conservation., Adelaide.