ASSESSMENT OF THE NEEDS OF WATER DEPENDENT ECOSYSTEMS FOR THE EASTERN MOUNT LOFTY RANGES PRESCRIBED WATER RESOURCES AREA

Government of South Australia
Department for Water

ASSESSMENT OF THE NEEDS OF WATER DEPENDENT ECOSYSTEMS FOR THE EASTERN MOUNT LOFTY RANGES PRESCRIBED WATER RESOURCES AREA

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Under delegation of the Minister for Sustainability, Environment and Conservation pursuant to Section 164N(4) of the *Natural Resources Management Act 2004*

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FOREWORD

South Australia's Department for Water leads the management of our most valuable resource—water.

Water is fundamental to our health, our way of life and our environment. It underpins growth in population and our economy—and these are critical to South Australia's future prosperity.

High quality science and monitoring of our State's natural water resources is central to the work that we do. This will ensure we have a better understanding of our surface and underground water resources so that there is sustainable allocation of water between communities, industry and the environment.

Department for Water scientific and technical staff continue to expand their knowledge of our water resources through undertaking investigations, technical reviews and resource modelling.

Allan Holmes
CHIEF EXECUTIVE
DEPARTMENT FOR WATER

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SUMMARY

In accordance with Section 164N(4) of the *Natural Resources Management Act 2004*, before determining the capacity of a prescribed water resource, the Minister responsible for the administration of that Act must prepare a report assessing the needs of ecosystems that depend on the prescribed resource.

An assessment was undertaken to determine the existence and water needs of the water dependent ecosystems in the Eastern Mount Lofty Ranges Prescribed Water Resources Area.

This report provides a framework to inform the environmentally sustainable development of water resources in the Eastern Mount Lofty Ranges Prescribed Water Resources Area, with the goal of maintaining aquatic ecosystems at an 'acceptable' level of risk through meeting the objective of maintaining self-sustaining populations that are resilient to times of drought.

An 'acceptable' level of risk was determined through correlating the success of environmental water requirement measures with the condition of aquatic ecosystems in the Mount Lofty Ranges that is expected to be sustainable (this is termed 'environmental needs' for the remainder of the report). The resulting level of risk equated to a level of water use that will provide for environmental needs was determined to be 5% of upstream runoff. This level of water use is unlikely to be socially or economically acceptable.

The flow regime is most impacted in the Low Flow Season, as are environmental water requirements relating to low and fresh (pulse) flows. These parts of the water regime may be more practically managed through water-taking rules on how water is captured by dams and watercourse diversions, rather than through influencing the pattern of dam filling and spilling by managing the volume of use from dams. Hence investigations were made into the influence of providing flows around, or from, existing dams and watercourse diversions under different scenarios.

This alteration in when and how water is taken from the system has a significant influence on the success of environmental water requirement measures, increasing the level of consumptive water loss that will provide for environmental needs from 5% to 20% of upstream runoff.

The lower Angas and Bremer Rivers across the plains are sufficiently different to warrant a modified approach to determining levels of water use that meet environmental needs which can be met through a set of water taking rules that aim to maintain existing aquatic ecosystems, such as red gum swamps and fish species, at an acceptable level of risk.

The estimated levels of water use outlined in this report must be considered as the first stage of an adaptive management regime. A robust monitoring program should be implemented to test the hypothesised relationships between flow and ecological condition or processes. This will help to ensure that the stated level of water use that will maintain self-sustaining populations that are resilient to times of drought is achieved.

1. INTRODUCTION

In accordance with Section 164N(4) of the *Natural Resources Management Act 2004* (the Act), before the capacity of a water resource can be determined, the Minister responsible for the administration of the Act must prepare a report to assess the needs of ecosystems that depend on the water resource.

This report outlines the current knowledge on the distribution of three of the major aquatic biotic components—fish, macroinvertebrates and vegetation—of the Eastern Mount Lofty Ranges (EMLR) and conceptually maps the distribution of these groups where existing survey data does not exist (Sections 2 and 3). Water requirements for these groups are then documented (Section 4) and translated into hydrological metrics which can be used to test the likely ecological implications of various water use scenarios (Section 5). Existing monitoring data are used to determine likely levels of water use beyond which the long term persistence of aquatic ecosystems may be compromised (Sections 6 and 7).

1.1. LOCATION

The Eastern Mount Lofty Ranges PWRA[1] extends from the Milendella Creek catchment in the north to Currency Creek catchment in the south and contains sixteen surface water catchments. Eleven of the catchments have watercourses that drain from the eastern side of the Mount Lofty Ranges to the River Murray and Lake Alexandrina, with the Bremer, Angas and Finniss Rivers being some of the larger watercourses. There are also a number of catchments that have streams that rise in the ranges but do not persist and contribute little water into the River Murray (Figure 1).

1.2. MANAGEMENT OF WATER IN THE EASTERN MOUNT LOFTY RANGES PRESCRIBED WATER RESOURCES AREA

The water resources of the Eastern Mount Lofty Ranges (EMLR), including surface water, watercourse water and underground water, were prescribed on 8 September 2005. The South Australian Murray-Darling Basin Natural Resources Management Board is developing a Water Allocation Plan (WAP) for the region. The Department for Water is undertaking a process to allocate water to existing users in the region.

A key component of the water prescription process is the identification of the quantity, quality and regime of water required to sustain water dependent ecosystems. This and other information on the water resources and social demands is used to set levels of water use that will provide for environmental needs and develop other water management policies, such as permitting for dam and well construction. These levels of water use and management policies aim to provide an equitable balance between meeting social, economic and environmental water requirements.

1.3. SURFACE VS. UNDERGROUND WATER REQUIREMENTS

Both surface water (including flows in watercourses) and underground water play important roles in meeting the Environmental Water Requirements (EWRs) in the EMLR. Underground water may contribute to surface flows by discharging to the surface as springs or baseflow. Organisms, such as

[1] Eastern Mount Lofty Ranges Prescribed Water Resources Area means the following areas:

- Eastern Mount Lofty Ranges Water Resources Area (the area bounded by the bold red line in GRO Plan No 422/2003)
- Eastern Mount Lofty Ranges Prescribed Wells Area (the area bounded by the bold red line in GRO Plan No 423/2003)
- Angas-Bremer Prescribed Wells Area (as described in the Government Gazette published on 23 October 1980 (p. 1192) pursuant to the *Water Resources Act 1976*).

stygofauna (fauna that live in underground water systems, including caves and aquifers) and phreatophytic vegetation (plants that draw water from the underground water table to maintain vigour and function), may also utilise underground water while it is below the surface.

This project uses surface water flow modelling developed for the EMLR catchments using the WaterCRESS platform (e.g. Heneker 2003; Teoh 2006; Alcorn *et al.* 2008). The modelling accounts for the component of surface flow derived from underground water (baseflow) under current conditions by calibrating the surface water models with actual flow data, which includes the baseflow. 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 underground water extraction on baseflow is not well described at a local scale and has not been incorporated into surface water modelling. Therefore assessment of underground water extraction on EWRs can only currently be considered at a coarse (aquifer) scale.

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

While the dependency of ecosystems on direct underground water inputs at a local scale is largely unknown in the study area, investigations show that it is likely that a significant proportion of watercourses, wetlands and pools in the region are at least partially maintained through direct underground water inputs (e.g. Barnett and Rix 2006; Green and Stewart 2008). Environmental underground water requirements can be met through a combination of 1) reserving the quantity of water expected to be contributing to baseflow in the underground water budget; and 2) the development of appropriate buffer zones to manage new underground water extractions close to watercourses, with the aim of providing underground water to these ecosystems. Underground water extraction by existing users within these buffer zones may influence the delivery of water to ecosystems dependent on underground water.

Figure 1: Eastern Mount Lofty Ranges Prescribed Water Resources Area

2. WATER DEPENDENT ECOSYSTEMS

The water dependent ecosystems of the EMLR support a diverse range of aquatic fauna and flora. 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.

2.1. FISH

In the EMLR, 30 native and seven exotic freshwater fish species have been recorded (Figure 2; Appendix A). Twenty of the endemic species have conservation significance at the state scale (McNeil and Hammer, 2007) and three species at the national scale.

Native freshwater fish of the EMLR 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 EMLR (Hammer 2007a; McNeil and Hammer 2007).

2.1.1. 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.

2.1.2. 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 and potentially river blackfish and climbing galaxias.

Appendix B 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.

Fish are reliant on other biotic groups and so the EWRs for these other groups (shown in Appendixes C and D) 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).

2.2. MACROINVERTEBRATES

A variety of programs have recorded 338 aquatic macroinvertebrate taxa from the MLR. The majority of these species are expected to be represented across the EMLR – survey sites are shown in Figure 3.

In the broadest sense, aquatic macroinvertebrates in the EMLR 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).

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.

2.2.1. 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).

Figure 2: Distribution of sites sampled for fish in the EMLR

2.2.2. 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.

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.

2.2.3. 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 underground water 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 C outlines the EWRs, grouped by flow season and flow component, of these functional groups of aquatic macroinvertebrates and the ecological processes the EWRs support.

Figure 3: Distribution of sites sampled for aquatic macroinvertebrates in the EMLR

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 majority of these species are expected to be represented in the EMLR. 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 EMLR included Casanova (2004), data collected during the EMLR Fish Inventory (Hammer 2004), the Wetland Inventory of the Fleurieu Peninsula (Harding 2005) and the Biological Database of South Australia held by the Department of Environment and Natural Resources (which includes records from the South Australian Herbarium).

Taxa were assigned to functional groups as developed and refined from the work of Brock and Casanova (1997), Casanova and Brock (2000) and Leck and Brock (2000).

Three broad groups of vegetation types can be identified in the EMLR:

1. Terrestrial species associated with waterways and wetlands
2. Amphibious species that require or tolerate the presence of surface water at some stage of their life cycle
3. Submerged species that require extended periods of free surface water.

Ten functional groups can be identified within these three broad vegetation types.

2.3.1. 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 three 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.

2.3.2. 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 three 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 -oleration 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 six 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 underground water 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 underwater 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.

2.3.3. 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 100 mm. 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 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 >100 mm 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 D outlines the EWRs, grouped by flow season and flow component, of these functional groups of vegetation and the ecological processes that 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 D 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 D summarises the most common seasonal patterns for groups in the EMLR, although some species may germinate and reproduce at different times or opportunistically when the appropriate flow regime occurs.

3. 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 in the EMLR, however, distribution information is limited. This report outlines 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 EMLR have allowed generic reach types to be determined. They represent the major types of water dependent habitats and have been mapped across the EMLR PWRA. The biotic functional groups identified in Section 2 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.

3.1. DEVELOPMENT OF GENERIC REACH TYPES

The generic reach types were developed by an expert panel using 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 EMLR.

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 EMLR 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 (2004) was used to identify relevant geomorphic units and their groupings in the development of reach types.

Hydrology (aquatic habitat)

Flow, driven by local hydrology, is a major determinant of habitat type by providing surface water and by driving processes such as 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 and when coupled with hydrology, 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.

Habitat mapping

Existing habitat mapping for the EMLR 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.

3.2. RIVER REACH TYPES

Eight major reach types were identified in the EMLR after combining geomorphology, habitat characteristics and position within the catchment (Figure 4). Some have been further subdivided based on variations in geomorphology and/or hydrology.

An 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 4: Distribution of reach types across the EMLR

3.2.1. HEADWATERS

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

This reach type (Figure 5) 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 5: Headwater channel in the Tookayerta 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 underground water 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 underground water input, pools may support populations of freshwater obligate stream specialists.

3.2.2. UPPER POOL-RIFFLE CHANNEL

Subgroups: ephemeral; dry with persistent pools; wet

This reach type (Figure 6) 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 (see Section 4). Freshes and bankfull flows associated with rainfall extend the surface water extent and depth and overbank flows occasionally 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 6: Upper pool-riffle channel in the Bremer 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)

3.2.3. MID POOL-RIFFLE CHANNEL

This reach type (Figure 7) 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 underground water 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)

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

Figure 7: Mid pool-riffle channel in the Angas catchment

3.2.4. GORGE

Subgroups: dry; wet or dry with springs

This reach type (Figure 8) 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)

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

Figure 8: Gorge in the Reedy Creek catchment

3.2.5. LOWLAND

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

This reach type (Figure 9) 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 underground water) 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 overbank flows can occasionally 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)

Fish

Ephemeral

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

Dry catchments

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

Wet catchments

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

Figure 9: Lowland channel in the Finniss catchment

3.2.6. TERMINAL WETLAND

Terminal wetlands (Figure 10) are largely freshwater wetland habitats linking the stream with the discharge environment (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.

FUNCTIONAL GROUPS PRESENT

Vegetation

- Se, Sk, Sr, ATe, ATl, ARf and ARp 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 potamodromous

Figure 10: Terminal wetland in the Tookayerta catchment

3.2.7. WETLANDS

A total of 448 wetland bodies have been mapped from aerial photography for the EMLR PWRA (Harding 2005; AWE 2010). 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 11) have been recorded as supporting 742 plant species, of which 139 have conservation status, including 73 species with status under the *National Parks and Wildlife Act 1972* and six 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 three species are protected under the EPBC Act. Additionally, three of the bird species recorded are protected under international migratory bird treaties (Japan-Australia Migratory Birds Agreement, China-Australia Migratory Birds Agreement).

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 underground water (Permian Sands wetlands, fractured rock wetlands) or a combination. Habitat types include permanently damp–wet environments, with or without standing water.

Figure 11: Fleurieu wetlands in the Tookayerta catchment

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)

4. ENVIRONMENTAL WATER REQUIREMENTS

This section summarises the way in which environmental water requirements are described. Actual environmental water requirements for fish, macroinvertebrates and vegetation are described in Appendixes B–D.

Environmental water requirements are 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
- underground water 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).

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 (Figure 12). The four flow seasons identified for the EMLR 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.
- 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).

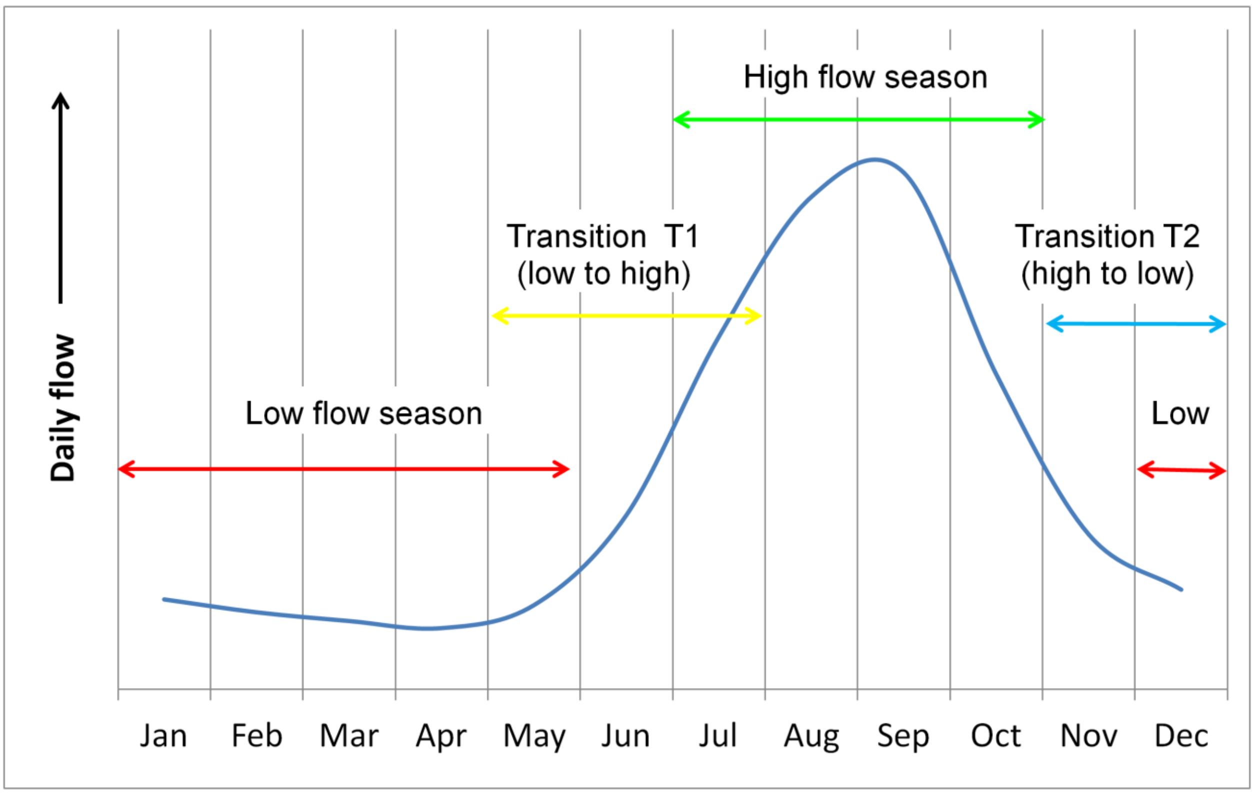


Figure 12: Typical range of flow seasons in the EMLR against relative daily flow

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 experienced. 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). In light of this heterogeneity of driving hydrological processes, duration and frequency components of EWRs are instead assessed as acceptable deviation from the 'natural' flow regime.

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 EMLR (Figure 13).

Low Flow Season is characterised by relatively constant low flow rates and cease-to-flow events that are common in the EMLR. 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. Underground water 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 underground water 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.

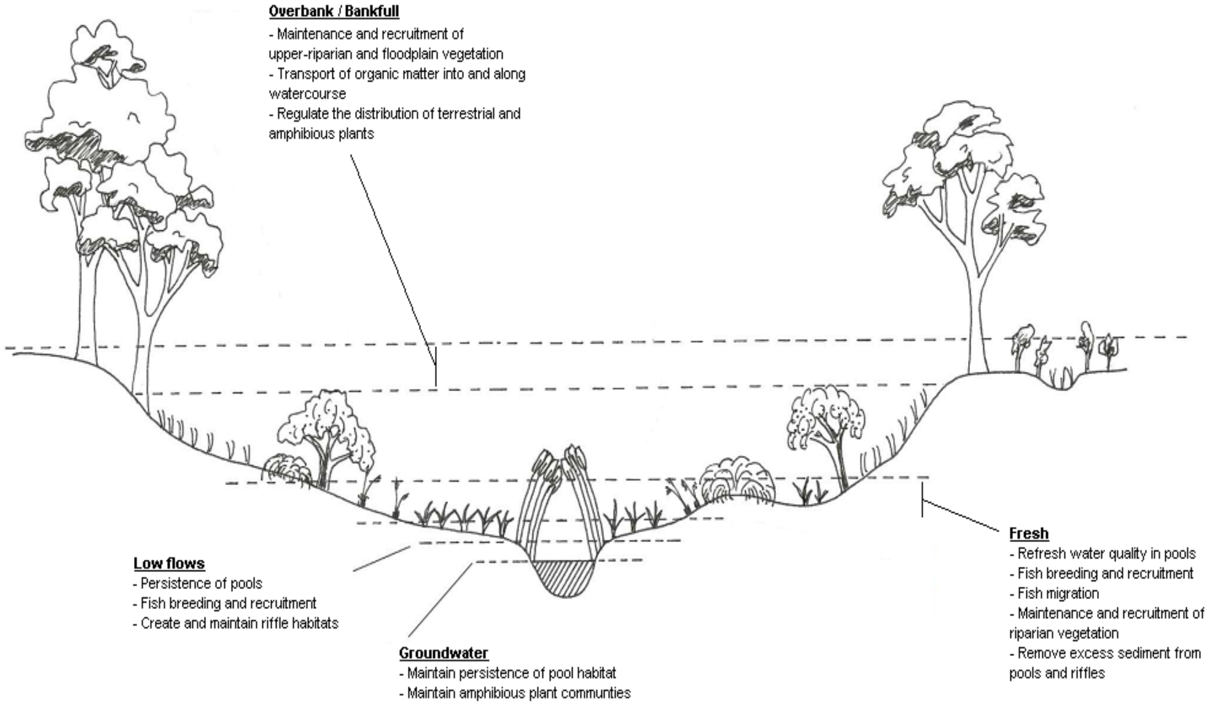


Figure 13: Common environmental water requirement processes linked to flow magnitudes (Favier *et al.* 2004)

5. 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 taken has been 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.

Section 5.1 outlines the approach used to quantify measures to represent different flow components; Section 5.2 the final list of metrics selected to represent EWRs in the MLR and Section 5.3 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.

5.1. 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 EMLR. 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 EMLR

Component	Hydrological measure
Low flow	80th 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 EMLR 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.

5.2. 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 shown in Appendixes B–D. The set of metrics examined include:

- core metrics based on the flow descriptors identified in Table 1
- metrics identified by panel members that show 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 E (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.

5.3. 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, on 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 report 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.

5.3.1. SETTING METRIC 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 these 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).

5.3.2. 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 water requirement that the metric is representing. To represent this, EWR metrics for the study area have been split into three 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 are expected to be more resilient to change. The column ‘Priority group’ in Appendix E 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 the best available with the current limited data, with a need to monitor the system to improve the available data set. A low level of risk is expected to maintain self-sustaining populations of water dependent taxa that are resilient to times of drought.

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%

5.3.3. PRIORITY METRICS BY REACH

Different habitats and biota have been matched to different reach types (Section 3). 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 E). 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.

5.3.4. 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 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 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 underground water 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).

Environmental water requirements 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, are described in this report. This is because 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.

5.3.5. 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 (Section 5.3.2), 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 levels of water use. 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 two zero flow spells per year for a given site in the Low Flow Season under natural conditions and this increases to an average of four spells per year under current conditions the metric is deemed to have passed as both scores are under the threshold of four, 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 three 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).

5.3.6. 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 (80^{th} 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 80^{th} 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.

5.4. OVERVIEW – 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 (Appendix E) to represent ecologically important parts of the flow regime for different reaches and the different biotic groups they contain. 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.

The success of EWR metrics have been tested at a number of sites across the EMLR to better understand the components of the flow regime that are most impacted under the current water management regime (Table 3). Only two out of the 69 sites tested passed all of the metrics.

Table 3: Number of tested sites in the EMLR passing each metric

Metric	Number of sites tested	Sites passed	% Sites passed
Annual: can occur at any time of the year			
Number of years with 1 or more bankfull flows	69	69	100.0
Average duration of bankfull flow spells	69	69	100.0
Average total duration of bankfull flow per year	69	67	97.1
Low flow season			
Average daily LFS flow	69	49	71.0
80th per cent exceedence non-zero flow [low flow]	69	9	13.0
Number of years with LFS zero flow spells	69	44	63.8
Average number of LFS zero flow spells per year	69	64	92.8
Average duration of LFS zero flow spells	69	46	66.7
Number of years with one or more LFS freshes	69	43	62.3
Average number of LFS freshes per year	69	22	31.9
Average total duration of LFS freshes per year	69	4	5.8
Transition 1: Low to high flow season			
Average daily T1 flow	69	61	88.4
80th per cent exceedence non-zero flow [low flow]	69	11	15.9
Current month reaching median flow of natural T1 median (delay)	51	8	15.7
Number of years with T1 zero flow spells	69	48	69.6
Average number of T1 zero flow spells per year	69	69	100.0
Average duration of T1 zero flow spells	69	57	82.6
Number of years with one or more T1 freshes	69	57	82.6
Average number of T1 freshes per year	69	45	65.2
Average total duration of T1 freshes per year	69	54	78.3
Number of years with 2 or more T1 Freshes	66	56	84.8
Frequency of spells higher than LFS fresh level	6	6	100.0
High flow season			
Average daily HFS flow	69	69	100.0
80th per cent exceedence non-zero flow [low flow]	69	24	34.8
Number of years with HFS zero flow spells	69	50	72.5
Average number of HFS zero flow spells per year	69	69	100.0
Average duration of HFS zero flow spells	69	59	85.5
Number of years with one or more HFS freshes	69	68	98.6
Average number of HFS freshes per year	69	61	88.4
Average total duration of HFS freshes per year	69	65	94.2
Number of years with 1 or more spell greater than the annual 5th p.e. flow in HFS	48	48	100.0
Number of years with 2 or more freshes early in the season (Jul, Aug)	18	18	100.0
Transition 2: High to low flow season			
Average daily T2 flow	69	65	94.2
Median non-zero daily T2 flow	66	18	27.3
80th per cent exceedence non-zero flow [low flow]	69	6	8.7
Current month reaching median flow of natural T2 median (early onset)	69	34	49.3
Number of years with T2 zero flow spells	69	44	63.8
Average number of T2 zero flow spells per year	69	69	100.0
Average duration of T2 zero flow spells	69	58	84.1
Number of years with one or more T2 freshes	69	58	84.1
Average number of T2 freshes per year	69	51	73.9
Average total duration of T2 freshes per year	69	37	53.6
Frequency of spells higher than LFS fresh level	6	5	83.3
Number of years with 1 or more spell greater than the annual 5th p.e. flow	51	49	96.1
Number of consecutive years with no T2 fresh	3	2	66.7

6. DEFINING AN ECOLOGICAL TARGET

Environmental water requirements identify the flow regime required to maintain the aquatic ecosystems, biota and processes in the EMLR at a low level of risk of degradation. Within this report, EWRs are considered to have been met if 100% of metrics pass (Section 5). Developing a process by which levels of water use that meet environmental needs can be derived will provide a baseline against which Environmental Water Provisions (EWPs) can be developed. Environmental Water Provisions are those parts of EWRs that can be met after consideration of existing users rights and social and economic impacts.

6.1. ACCEPTABLE LEVEL OF RISK TO MEETING ENVIRONMENTAL NEEDS

An EWP that transparently balances water between environmental, social and economic needs depends on defining a relationship between aquatic ecosystem condition and the level of water resource development.

A relationship between breeding and survivorship success of two fish species, macroinvertebrate population condition and the success of EWRs is reported in VanLaarhoven and van der Wielen (2009). Based on the ecological objective of 'self sustaining populations, resilient to times of drought', these relationships can be used as a decision point beyond which the risks to meeting the objective are considered to be too great. Once a decision point has been reached (i.e. % of years successful recruitment events for fish, or a given macroinvertebrate population condition), a corresponding level of metric success is noted (Sections 6.1.1 and 6.1.2).

For the purposes of this report, only the expected risks with regard to ecological condition and processes are assessed. Risks with regard to the methodology (e.g. uncertainty around metric deviation limits, flow as the major driver of condition, future flow) are not explicitly assessed, but are acknowledged and are expected to be addressed through the implementation of the recommended monitoring and evaluation program.

6.1.1. FISH

The abundance and size distribution of southern pygmy perch and mountain galaxias populations have been monitored annually in autumn for 3–7 years at a range of sites in the eastern MLR and the Fleurieu Peninsula. These monitoring data can be used to develop the hydro-ecological relationships required to inform levels of water use that will provide for the environment.

Recruitment was considered to be the most flow-sensitive process and one of the most important processes in promoting population resilience. Therefore, recruitment data were 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 monitoring data were 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 15) and southern pygmy perch (Figure 16). Poorer ecological condition (i.e. a higher proportion of time when recruitment is marginal or poor) was found to correlate with fewer metrics passing at a site.

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. These other aspects may account for some of the scatter apparent in Figures 15 and 16. However, as flow pattern is a key driver in the structure and function of ecological communities, it is assumed that the observed relationship between fish recruitment and changes to flow regime can largely be attributed to changes to flow regime.

Acceptable ecological target – fish

Mountain galaxias and southern pygmy perch are relatively short lived (~ three years) species. Suitable breeding conditions are needed often enough to build population numbers and promote resilience to withstand poorer flow years and ensure the survival of these species.

Consecutive years of poor to marginal breeding events occur under natural conditions and native fish species have developed strategies to persist through these periods. Sufficient recruitment is expected in the marginal years to maintain sustainable population numbers for these species to recover in subsequent years once improved hydrological conditions prevail.

Expert opinion suggests better-than-marginal recruitment events are needed in at least seven years out of every ten (M Hammer [AquaSave Consultants] 2009, pers. comm.; D McNeil [SARDI] 2009, pers. comm.) to maintain sufficient population numbers of these species, but that three marginal recruitment events should not occur sequentially. Assuming that the climate patterns used in the development of this relationship (1974–2006) are indicative of future conditions, then the probability of a run of three consecutive years of poor to marginal fish breeding is once in 37 years (Figure 14). These events are likely to result in population crashes for fish species with relatively short life cycles. More conservative targets (i.e. a requirement for more frequent better-than-marginal recruitment events) will reduce the probability of such crashes.

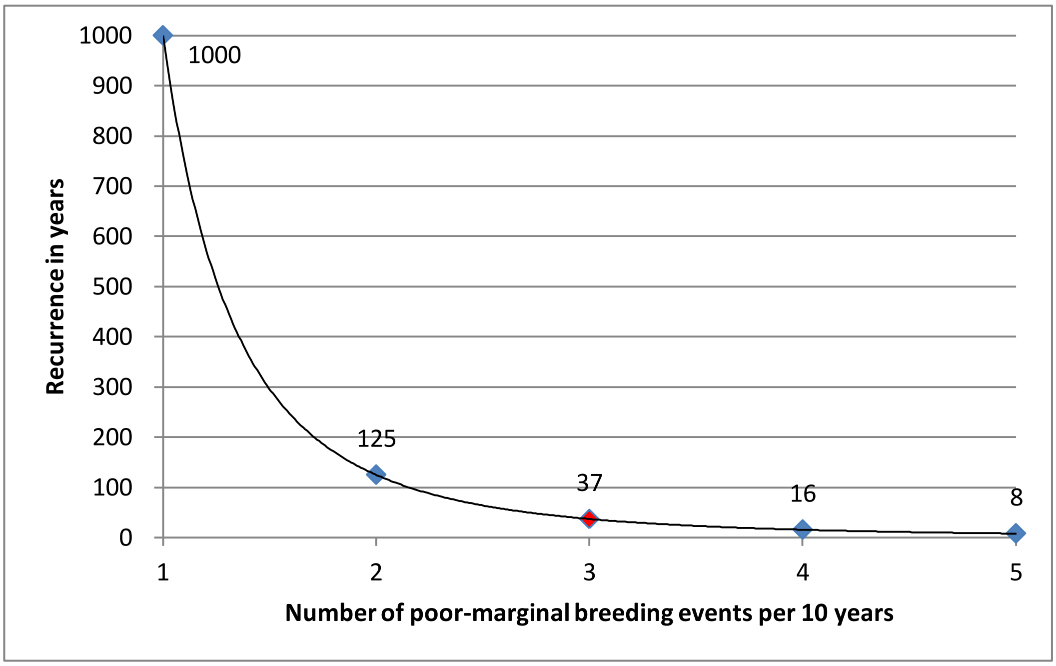


Figure 14: Return period (in years) for three sequential years not meeting the acceptable number of poor–marginal breeding events per 10 years target (as shown on the X-axis). (e.g. the probability of three successive years not meeting a 1 year in 10 'better than marginal breeding' target is 1 in 1000 years; the probability for three successive years not meeting a 2 in 10 target is 1 in 125 years)

The ecological target of 7 out of 10 years having better than marginal recruitment, equates approximately to an EWR metric success rate of 85% (i.e. 85% of the 45 metrics listed in Appendix E are passed) (Figures 15 and 16).

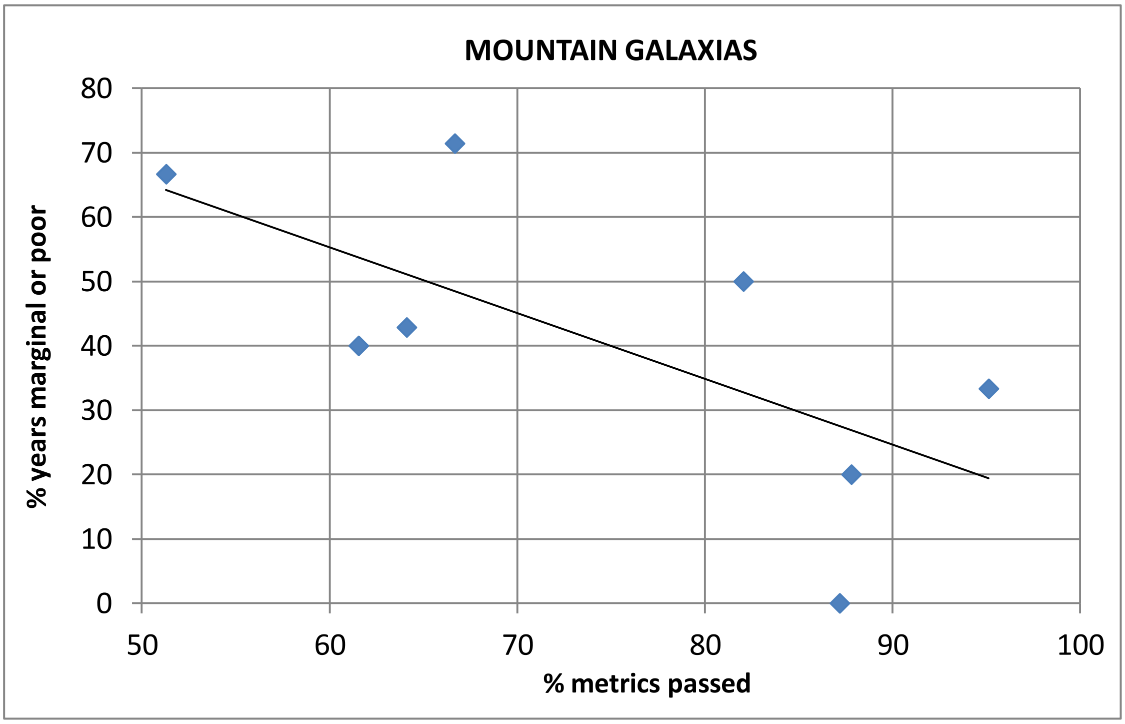


Figure 15: **Relationship of mountain galaxias recruitment to percentage of metrics passed at each site ; each point represents a single fish monitoring site (adjusted r2=0.37; F=5.078 (P=0.0651))**

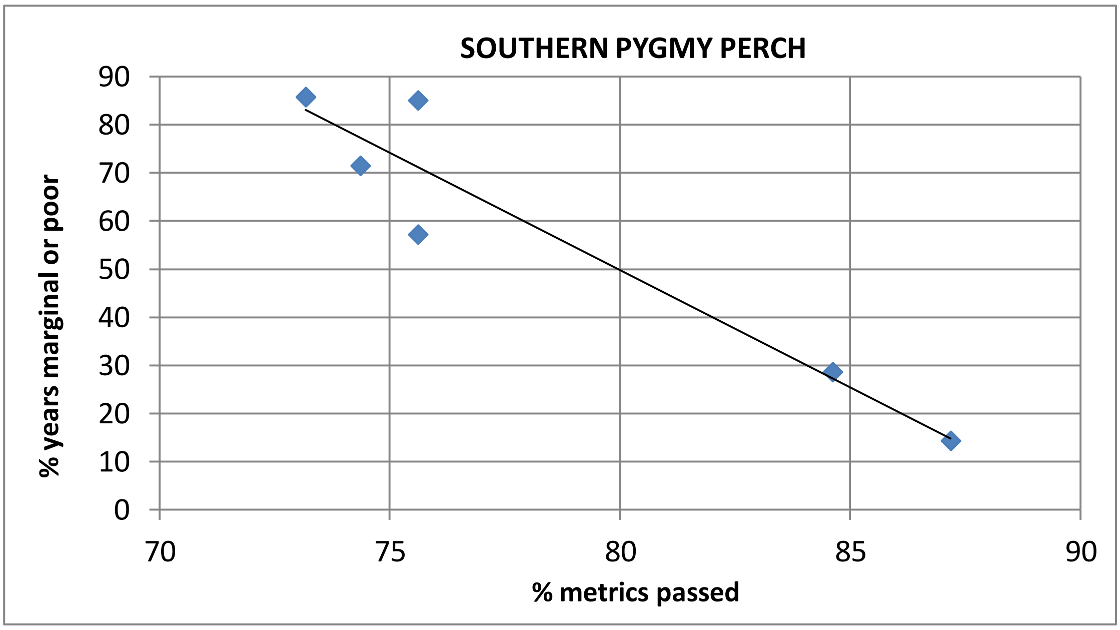


Figure 16: **Relationship of southern pygmy perch recruitment to percentage of metrics passed for; each point represents a single fish monitoring site (adjusted r2 =0.90; F=53.83 (P=0.0007))**

6.1.2. MACROINVERTEBRATES

Macroinvertebrate monitoring data have 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 regional NRM Boards. Twelve sites were selected for analysis based on representativeness, length of record and access to adequate flow data.

The average percentage of metrics passed for sites in each of the macroinvertebrate condition rating groups is shown in Figure 17. Poorer condition is 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. However, as flow pattern is a key driver in the structure and function of ecological communities, it is assumed that the observed relationship between macroinvertebrate population condition and changes to flow regime can be attributed to changes to flow regime.

Acceptable ecological target – macroinvertebrates

Expert opinion recommends that a target of macroinvertebrate population condition between moderate and good is likely to promote resilience and allow populations to be sustainable in the long term (P McEvoy [Australian Water Quality Centre], pers. comm.). This ecological target equates to an EWR metric success rate of between 80–90% (i.e. 80–90% of the 45 metrics listed in Appendix E are passed) (Figure 17).

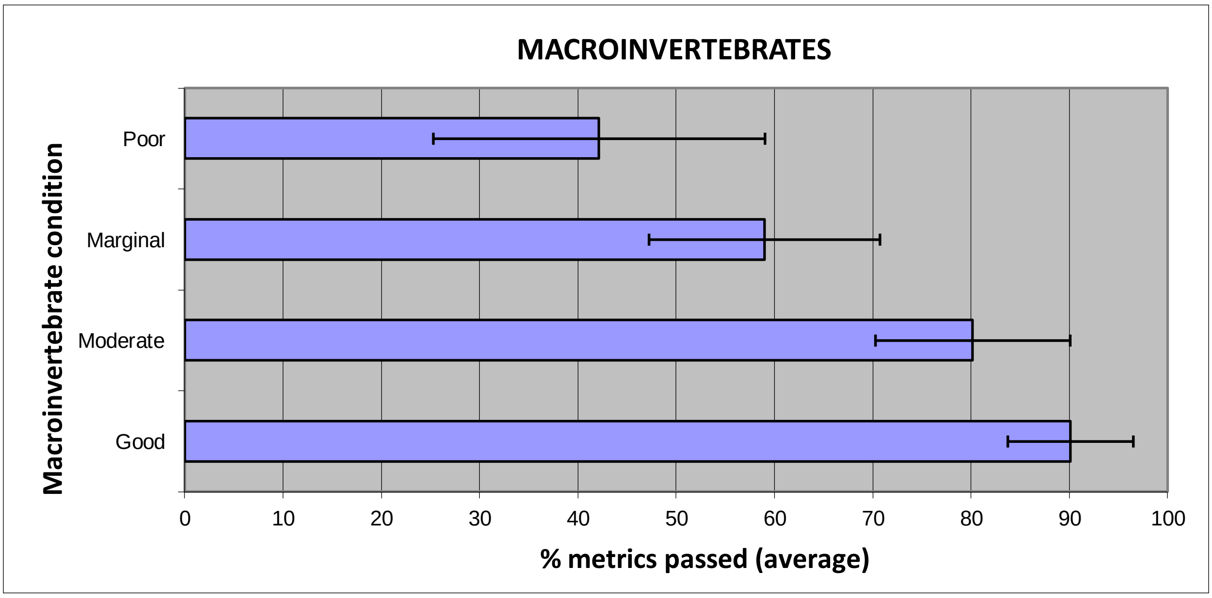


Figure 17: Metrics passed for monitoring sites in each condition rating group for long-term condition of the macroinvertebrate community; error bars: standard deviation (Spearman's Rank: rho=0.87, P=0.0003)

6.2. SUMMARY

The success of EWR metrics in the EMLR varies according to upstream level of water use and provides an indication on relative levels of risk to the aquatic environment. A 100% metric pass rate indicates a high probability that the aquatic environment will be sustainable in the long term.

To meet EWRs (i.e. meeting 100% of metrics), there will be a need to significantly cut the current level of water use given that only two out of 69 testing sites passed 100% of the metrics under current conditions. This is unlikely to be economically sustainable or socially acceptable. Therefore, there is a need to define an alternative, ecologically acceptable target other than meeting 100% of metrics. The target would involve accepting a higher risk of degradation that still has an acceptable probability of maintaining aquatic ecosystems in a sustainable state in the long term.

The correlations of proportion of EWR metrics passed at a site with the recruitment success of mountain galaxias and southern pygmy perch; and with macroinvertebrate population condition, can be used to define an alternative, acceptable level of metric success.

Expert opinion based on fish life-history and macroinvertebrate population composition was used to define an acceptable level of fish recruitment success (better than marginal in no less than seven years in 10) and macroinvertebrate population condition (good–moderate health), that will maintain an acceptable probability that these populations will be sustainable in the long term.

Based on the correlations (Figures 15, 16 and 17), a site that passes 85% of EWR metrics will meet this level of risk.

7. LEVELS OF USE THAT WILL PROVIDE FOR ENVIRONMENTAL NEEDS

Recommended levels of water use that meet environmental needs will inform the development of EWPs, which like EWRs, are more than just a volume of water that must be set aside for the environment. Aquatic and riparian biota have evolved life-history strategies based on the spatial and temporal presence of habitat (Poff *et al.* 1997; Bunn and Arthington 2002), of which the water regime is a major determinant. Therefore, changes to components of the water regime are likely to lead to changes in the presence and condition of aquatic habitats and subsequently the condition and composition of water dependent ecosystems (e.g. Lloyd *et al.* 2004).

7.1. SPATIAL SCALE

Water resource development has a proportionally greater impact on the flow regime and therefore EWRs, immediately downstream of the point of development. The level of impact decreases further downstream as other sources contribute to flow. This has consequences for the scale at which water use limits are applied to development to meet environmental needs.

Surface water management zones (Figure 18) have been developed on the basis of reach types (Section 3), each of which represents a length of river with similar ecosystems, habitats, processes and biota. Therefore, each reach type will have a different EWR driven by differences in the presence of varying biota, ecosystems and processes. As a general rule, the confluence of reach types (not including headwaters which are not considered to have significant EWRs in most cases) has been used to differentiate each surface water management zone. This ensures that each stretch of watercourse will have its water needs met without being compromised by development in adjacent watercourses.

Figure 18: Surface water management zones in the EMLR

7.2. LEVEL OF WATER USE AND ENVIRONMENTAL NEEDS

The surface water models were used to test the environmental water requirements metric success rate (i.e. % metrics passed) of a range of water management options at 69 test sites throughout the EMLR PWRA (Figure 19). These sites were selected to cover a range of reach types, catchment conditions and combinations of water-taking infrastructure (e.g. low to high development, dams and watercourse diversions, proportion of licensed and non-licensed extraction). Surface water modelling used for this scenario testing is described in Alcorn (2011).

Environmental water requirements are expected to be met if 100% of metrics are passed, which is expected to maintain the environment at a low level of risk. Further work to determine an alternative, ecologically sustainable level of risk (Section 6) has indicated that passing 85% of EWR metrics increases the risk of ecological degradation but it is considered to be within acceptable limits. It was considered that success would be measured through the proportion of sites that meet this alternative level of metric success – ecological objectives are considered met where 85% of metrics are passed at the majority (at least 50%) of test cases (usage scenarios at each test site – varying from 0-100% use at 10% increments) within a management scenario. All water management scenarios tested were based on the current level and distribution of dams and watercourse diversions as represented in the surface water models.

7.2.1. MANAGING THE VOLUME TAKEN FROM DAMS AND WATERCOURSE DIVERSIONS

One set of water management scenarios tested the effects of varying the volume of water taken from licensed dams and watercourse diversions. The assumed volume taken for non-licensed purposes was held constant as the volume of water taken from dams and watercourses for non-licensed purposes can’t be managed through the prescription process. The volume taken for licensed use was varied between different scenarios. The total volume lost from the resource due to consumptive purposes (licensed plus non-licensed use) for each scenario was expressed as a percentage of mean annual adjusted runoff from the catchment area upstream of the test site. The total volume lost includes:

1. consumptive demand (maximum volume that could be extracted from dams and watercourse diversions for a given scenario)
2. net evaporative loss from dams.

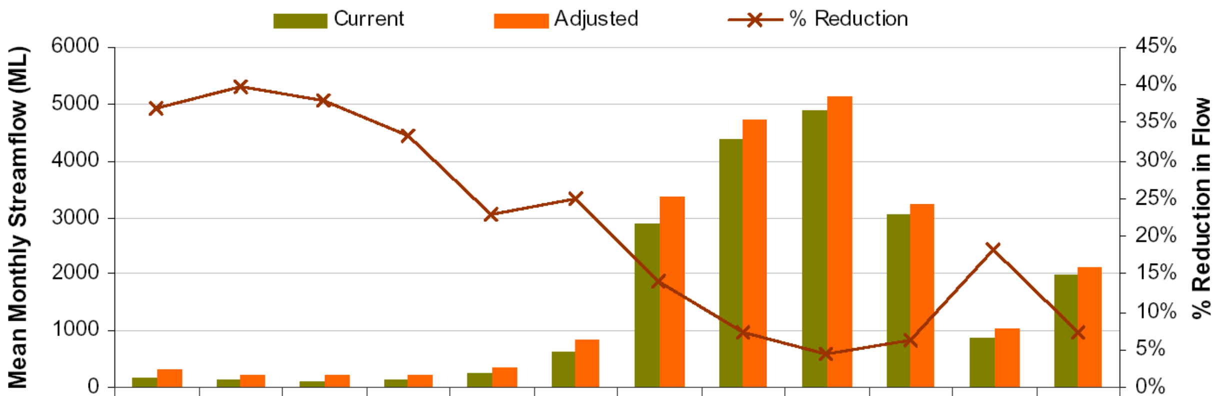
This water is no longer available for downstream users and the environment and so, is accounted for when determining levels of water use that will need environmental needs.

It was found that the environmental target of passing at least 85% of the metrics could only be met in the majority of test cases if total consumptive loss (demand + evaporation from dams) was below 5% of the upstream mean annual adjusted runoff. Alternative water management scenarios involving diversion rules as well as consumptive loss limits are investigated in Section 7.3.

Figure 19: EWR test sites in the Eastern Mount Lofty Ranges

7.3. INFLUENCE OF RESTORING THRESHOLD FLOWS

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. The delay in flows is most noticeable when dams are not at capacity, which is generally the case during the irrigation period (October–March) and continuing into the break-of-season. Figure 20 shows that while the percentage of annual flow captured during the drier months is minimal, the percentage of flow captured in each of these months is very large. For example, the proportion of annual flow captured in February is ~0.6% but over 40% of the flow for that month is captured. Smaller flows are proportionally more impacted than higher flows, as larger flows will cause dams to fill and spill much quicker. Direct extraction from watercourses during periods of low flow is likely to exacerbate this effect.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Current	188.9	124.0	118.8	138.4	259.9	633.0	2881.5	4380.5	4906.8	3036.3	852.7	1972.2
Adjusted	299.4	205.5	191.9	207.2	336.7	842.7	3356.6	4721.7	5130.8	3241.9	1041.2	2127.6
% Reduction	37%	40%	38%	33%	23%	25%	14%	7%	4%	6%	18%	7%

Figure 20: Impact of dams on monthly flow in a single year (Alcorn 2008).

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 had very low pass rates in each of the flow seasons and 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. This is well reflected in the proportion of sites that pass the low flow metric (80^{th} per cent exceedence non-zero flow), which passed at only 9.6% of sites in the Low Flow Season and 31.9% of sites in the High Flow Season. Similar patterns can be seen in other metrics, including average duration of zero-flow spells (67.4% vs. 82.2%) and average number of fresh flows (31.1% vs. 85.2%).

If these lower flows were allowed to bypass dams or not be captured, it may be possible to allocate larger volumes while still meeting the needs of the environment.

7.3.1. THRESHOLD FLOW RATE

The use of threshold flow rates is a method by which water can be shared between consumptive users and the environment. Under this management approach, only flows above a given threshold flow rate may be captured, while those at or below are not captured or are otherwise allowed to flow into the downstream watercourse.

Freshes in the two transitional flow seasons are the largest of the flow components that have been significantly impacted by surface water resource development and therefore, have been used as the basis for setting the threshold flow rate. By using freshes to determine a threshold flow, the impact to low flows will also be minimised. Flow exceedence percentiles (i.e. the percentage of time that a particular flow rate is exceeded) were used to determine a consistent and easily calculated way of setting a threshold flow rate that would encompass these flow levels.

The 34 sites selected across the Mount Lofty Ranges for analysis were selected as being representative of different climate conditions and reach types. The daily flow rates (in ML/d) considered to represent a fresh in each of the two transitional flow seasons (two times the median non-zero flow in the flow season of interest; as discussed in Section 4.1.2), were determined for each site. The higher of these fresh flow rates at a site was then expressed as a per cent exceedence value for the flowing period using natural flows for 1974–2006. For example, at a given site:

1. Calculate the flowing period
    - Example: Flows occur on 8000 out of the total of 12 053 days between 1974 and 2006
2. Determine the natural fresh flow rate
    - Example: 2 ML/d
3. Determine the number of days that the fresh flow rate (2a) is exceeded
    - Example: 2400 d
4. Determine the number of days that the fresh flow rate is exceeded (3a) as a percentage of the total flowing period (1a)
    - 2400 d/8000 d = 30%.
5. In this scenario, a flow rate of 2 ML/d is equivalent to the 30th per cent exceedence non zero flow, as daily flows are higher than this flow rate in 30% of days with flow.

Calculations for the threshold flow rate were also performed using the whole period, not just the flowing period. However, results were much more variable and showed no consistent trend by which a single threshold flow rate could be determined.

Using the flowing period only, the majority of test sites showed that the fresh flow rate was exceeded in 15–25% of days. As such the threshold flow rate has been defined as the 20th per cent exceedence non-zero flow (i.e. flows that occur for 20% of the flowing period can be captured – note that these are higher flow events and generally account for 80–95% of the total annual flow volume). The application of this threshold flow rate is considered to improve the flows most affected by water resource development for the majority of sites.

The recommended, ecologically significant threshold flow rate is the 20th per cent exceedence non-zero flow.

7.3.2. INFLUENCE OF THRESHOLD FLOWS ON EWR METRICS

Providing threshold flows is expected to have a significant influence on the success of EWR metrics based on the proportion of dams and watercourse diversions from which they are provided.

7.3.2.1. Providing threshold flows – licensed infrastructure only

Scenario testing was undertaken to test the effects of a combination of varying licensed water use volumes, together with a diversion rule that flows at or below the threshold flow rate are returned to the system for existing licensed dams and watercourse diversions.

For these scenarios, it was found that environmental needs are met for the majority of test cases if the total volume of consumptive loss was below 5% of upstream mean annual adjusted runoff.

7.3.2.2. Providing threshold flows – licensed infrastructure and non-licensed dams ≥5ML

Scenario testing was undertaken to test the effects of a combination of varying licensed water use volumes, together with a diversion rule that flows at or below the threshold flow rate are returned to the system for existing licensed dams and watercourse diversion structures, as well as existing dams used only for non-licensed purposes with a capacity of 5 ML or greater.

For these scenarios, it was found that environmental needs are met at the majority of test cases if the total volume of consumptive loss was up to 20% of upstream mean annual adjusted runoff. It is possible that a strategic approach may reduce the number of dams required to return threshold flows when considering site specific issues.

7.3.3. SUMMARY

Passing 85% of EWR metrics is an alternative ecological target that relates to an increased, but acceptable, level of risk of degradation to the aquatic environment in the Eastern Mount Lofty Ranges. Passing 85% of metrics is expected to maintain the environment dependent upon the prescribed resource at an acceptable level of risk.

Water resource development through the construction of dams and watercourse diversions has resulted in a change in the flow regime for which endemic biota and ecosystems have evolved life-history strategies. Capture of water in dams and extraction of low flows has had the largest impacts in the Low Flow season and in metrics which relate to low flows. The introduction of a threshold flow rate below which water cannot be captured or diverted was found to ameliorate many of the water regime impacts caused by water interception and extraction. An ecologically significant threshold flow rate of the 20th per cent exceedence non-zero flow was developed based on being equivalent to the most impacted components of the flow regime.

A level of consumptive water loss (demand plus evaporation) that meets environmental needs at the majority of test cases is 5% when flows at or below the threshold flow rate are returned or not taken by licensed infrastructure and 20% when returned or not taken by licensed infrastructure and non-licensed dams ≥5ML in capacity.

7.4. INTERCEPTION LIMIT

The impact of dams on the water resources, users and the environment is not limited to the volume extracted from dams and watercourses. Dams trap all of the runoff from the upstream catchment area until they fill and spill. The presence of the dam as a physical barrier to water movement and the capacity of the dam have a key influence on the volume and pattern of downstream flow. The level of usage, evaporation and seepage from the dam will also affect how soon the dam fills and spills. Therefore it is important that both dam capacity and usage are managed to meet environmental needs.

It was found that the environmental needs are met in the majority of test cases if the total volume of dam capacity was up to 30% of upstream mean annual adjusted runoff, provided that flows at or below the threshold flow rate are bypassed or not taken by licensed infrastructure and non-licensed dams ≥5 ML in capacity.

7.5. ANGAS AND BREMER RIVERS ACROSS THE PLAINS

The earlier part of this section describes levels of water use that meet environmental needs for the majority of the Eastern Mount Lofty Ranges PWRA where the hydrology, ecology and method of water capture have reasonable similarities. However, the lower Angas and Bremer Rivers across the plains are sufficiently different to warrant a modified approach to determining levels of water use that meet environmental needs.

The Angas and Bremer Rivers descend from the relatively wet hills down to the low rainfall Murray Plains and Lake Alexandrina, with the lower sections crossing a relatively flat floodplain with important water-dependent red gum swamps. The lower sections flow in winter and spring most years, often at quite high levels due to rainfall in the wet upper catchments. However, the watercourse is otherwise dry except for permanent pools in the upstream parts of the plains, small wetlands at the mouths that are usually kept wet via water from Lake Alexandrina and at least one semi-permanent pool on a blind tributary (Mosquito Creek) that is likely to be maintained by shallow underground water. Parts of the watercourse lose flow to the underlying Quaternary aquifer.

The flow pattern and flat topography means that water capture in the area is from direct extraction from the watercourse, rather than via interception of runoff by dams. Much of the infrastructure in the area is capable of extracting water at a high rate, to allow water to be captured during the intermittent periods of flow. The nature and operation of the infrastructure means that water capture is likely to have a different impact on the flow pattern compared to elsewhere in the EMLR.

The consumptive loss limit of 20% of mean annual adjusted runoff has been derived from modelling the impact of water capture, largely by dams, on the flow patterns experienced in the hills areas and in plains areas where there is not significant loss of flow to underground water. This means that this limit is less applicable to the lower Angas Bremer area, as the flow pattern and water extraction practices are somewhat different.

Much of the watercourse is incised (cut down into the ground) and/or lined with levee banks and therefore, the delivery of water through natural processes occurs rarely and only in large flood events. However the water requirements for a number of floodplain red gum swamps in the area appear to be largely met through the passage of unused flood irrigation water that has been pumped onto the floodplain. Reliance solely on infrequent flood events for the delivery of water to red gums swamps will likely lead to a significant increase in risk of tree degradation and loss. The current landscape of levee banks and water movement means that the red gum swamp communities are likely to be at risk of degradation if water is not provided to them as a result of the current water diversion practices.

The nature of the water-taking infrastructure in the area also means that significant volumes of water can be taken in a short period of time, which has implications for movement of water through to downstream users and systems and availability of water in the watercourse for in-stream ecosystem processes.

Fish migration upstream and downstream through the lower sections of these rivers is another locally important ecological process. Fish monitoring data have been interpreted to identify the times when fish have been likely to move through the system. This information was then linked to flow data to identify the flow depth that appears to be associated with fish movement (Hammer 2009, M. Hammer pers. comm.).

LEVELS OF USE THAT WILL PROVIDE FOR ENVIRONMENTAL NEEDS

For the Angas and Bremer Rivers across the plains, the water use scenario that will meet environmental needs are:

- Water continues to be provided to the red gum swamps.
- The first flush of flow events (at a flow rate of 1.2 m^3/s in the Bremer River or 0.6 m^3/s in the Angas River) be allowed to go all the way to the Mouth before water is diverted, so that fish moving with the event have the opportunity to move down to Lake Alexandrina and an attractant flow is provided into the lake to attract fish to move up the watercourses.
- A threshold flow level equivalent to 0.3 m depth at the widest cross-section for the Bremer River is required to allow free movement of fish along the reach. Together with considerations to meet other flow metrics this was found to be equivalent to 0.5 m^3/s.
- A threshold flow level equivalent to approximately 0.2–0.3 m depth is required for the Angas River, given the smaller size of the fish species likely to be migrating in that system. Together with considerations to meet other flow metrics, this equates to a threshold flow level of 0.2 m^3/s. This results in a flow depth of approximately 0.12 m at the widest cross-section.

8. CONCLUSION

The natural flow paradigm states that the endemic biota within an ecosystem are 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 natural flow regime can create conditions to which 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).

Environmental water requirements for the EMLR have been determined based on the needs of three priority biotic groups: fish, macroinvertebrates and plants (VanLaarhoven and van der Wielen 2009), which cover all of the physical habitats of riverine systems of the EMLR from instream to overbank. The level of deviation likely to maintain water dependent ecosystems in the EMLR PWRA at a low level of risk has been determined through the use of an expert panel, which has determined the success of EWRs by measurable metrics. Across the EMLR, 69 sites were tested using the EWRs which were found to have high failure rates, particularly in the low flow season. This indicates an elevated level of risk to the environment due to water resource development. To further define EWRs, a relationship was measured between ecological condition (fish recruitment and macroinvertebrate population condition) and the success of EWR metrics. Using expert advice on those conditions, it was found that passing 85% of EWR metrics is likely to lead to meeting the needs of the environment as measured through modelled responses in fish and macroinvertebrate populations in the area. These surrogate groups have been used on the assumption that if the EWRs for them are met, then the EWRs for the remaining water dependent biota and ecosystems are also likely to be met.

A correlation between consumptive losses and EWR metrics indicates that a consumptive loss below 5% of upstream annual adjusted flow will meet environmental needs. This is unlikely to be economically or socially sustainable.

Most EWR impacts appear to occur in the Low Flow Season and on metrics that relate to lower flow rates. The influence of restoring threshold flows from 1) all dams and watercourse diversions used for licensed purposes; and 2) dams used for non-licensed purposes only that are 5 ML or more in volume to the system was investigated and found to result in significant improvement to the success of most EWR metrics.

Through the provision of threshold flows back to the system, a revised level of consumptive loss/metric success correlation indicates that a level of consumptive loss of 20% will meet the 85% metric success target in at least 50% of test cases.

- In the absence of returning threshold flows to the system, the level of total consumptive loss that will meet environmental needs is 5% of upstream runoff.
- If threshold flows are returned to the system from licensed dams and watercourses diversions and non-licensed dams with a capacity of 5 ML or more, the level of total consumptive loss (ie total water use plus evaporative loss) that will meet environmental needs in 20% of upstream runoff.
- If threshold flows are returned to the system from licensed dams and watercourse diversion and from non-licensed dams with a capacity of 5 ML or more, the interception limit (ie total dam capacity plus interception activities such as forestry) that will meet environmental needs is 30% of upstream runoff.

The lower Angas and Bremer Rivers across the plains are sufficiently different to warrant a modified approach to determining levels of water use that meet environmental needs. Environmental needs in these areas can be maintained through targeted water management rules that:

1. continue to provide water to red gum swamps
2. allow fish to move to and from Lake Alexandrina
3. allow free movement of fish along the reach.

The consumptive water loss levels and taking rules stated in this report (in the absence of other limiting factors such as poor water quality, lack of habitat, presence of exotic species) are expected to improve components of the flow regime to levels that will support sustainable aquatic ecosystems and processes for all areas with significant (>5%) levels of water use. The expected outcomes are an increased frequency of fish breeding events and larger fish population numbers, increased health of macroinvertebrate populations and increased health and spatial extent of aquatic vegetation species.

Other aquatic animals and plants that are not part of the focus of this study are also expected to benefit and geomorphic processes relating to maintaining a diversity of physical habitats are also expected to be maintained or improved.

The recommendations of this report are based on best available knowledge and should be considered to be the first step in an adaptive management program. A monitoring program should be implemented to evaluate whether impacts to the flow regime and the resulting ecological responses occur as hypothesised. The monitoring results need to be able to be used to refine the hydro–ecological relationships outlined in this report. Subsequently, the levels of water use can be refined with consequential implications for the levels of water use that will meet environmental needs.

APPENDIXES

A. EASTERN 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	Nat.	State	*EMLR*
D	Pouched lamprey	*Geotria australis*		EN	1
D	Shortheaded lamprey	*Mordacia mordax*		EN	1
D	Shortfinned eel	*Anguilla australis*		R	1
Fw	Freshwater catfish	*Tandanus tandanus*		P, VU	1
Fg	Bony herring	*Nematalosa erebi*			3
Fg	Smelt	*Retropinna semoni*			3
D	Climbing galaxias	*Galaxias brevipinnis*		VU	1
D	Common galaxias	*Galaxias maculatus*			3
Fs	Mountain galaxias 1	*Galaxias olidus*		R	3
Fs	Mountain galaxias 2	*Galaxias* sp. 1		R	3
Fg	Murray rainbowfish	*Melanotaenia fluviatilis*		R	2/3
Fg	Smallmouthed hardyhead	*Atherinosoma microstoma*			3
Fs	Murray hardyhead	*Craterocephalus fluviatilis*	VU	EN	2
Fg	Unspecked hardyhead	*Craterocephalus sterc. fulvus*		R	3
Fw	Chanda perch	*Ambassis agassizii*		P,EN	2
Fs	River blackfish	*Gadopsis marmoratus*		P, EN	3
Fg	Murray cod	*Maccullochella peelii peelii*	VU	R	2
Fp	Murray-Darling golden perch	*Macquaria ambigua ambigua*			2/3
Fs	Southern pygmy perch	*Nannoperca australis*		P, EN	3
Fw	Yarra pygmy perch	*Nannoperca obscura*	VU	P, EN	3
Fg	Silver perch	*Bidyanus bidyanus*		P, VU	2
D	Congolli	*Pseudaphritis urvillii*		R	3
Fg	Midgley's carp gudgeon	*Hypseleotris* sp. 1			3
Fg	Murray-Darling carp gudgeon	*Hypseleotris* sp. 3		R	3
Fg	Hybrid forms	*Hypseleotris* spp.			3
Fw	Southern purple-spotted gudgeon	*Mogurnda adspersa*		P,EN	2
Fg	Flathead gudgeon	*Philypnodon grandiceps*			3
Fg	Dwarf flathead gudgeon	*Philypnodon* sp. 1		R	3
Fg	Western bluespot goby	*Pseudogobius olorum*			3
Fg	Lagoon goby	*Tasmanogobius lasti*			3

Ex	Goldfish	*Carassius auratus*			3
Ex	Common carp	*Cyprinus carpio*			3
Ex	Tench	*Tinca tinca*			3
Ex	Rainbow trout	*Oncorhynchus mykiss*			3
Ex	Brown trout	*Salmo trutta*			3
Ex	Gambusia	*Gambusia holbrooki*			3
Ex	Redfin	*Perca fluviatilis*			3
	Total native				**30**
	Total alien				**7**

- 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 Management Act 2007*), EN = Endangered, V = Vulnerable, R = Rare (McNeil & Hammer, 2007)

B. ENVIRONMENTAL WATER REQUIREMENTS OF FISH IN THE MOUNT LOFTY RANGES

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 Maintain submerged aquatic vegetation habitat (SPP) Variable flows discourage exotic fish	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 Variable flows discourage exotic fish	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

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) Trigger spawning, oxygenate riffles (CG) and successive access to riparian spawning habitat Allow fish movement to recolonise vacant habitats Variable flows discourage exotic fish	Allow movement between wetlands 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	Persistent cool, well-oxygenated, tolerable	Persistent water in pools Maintain shallower sub-	Persistent water in pools Maintain shallower sub-	Persistent water in wetlands throughout season (base

		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)	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	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	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	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 Access to emergent and edge vegetation for spawning and recruitment (SPP) Variable flows discourage exotic fish	Flows to provide access to off-channel habitat for adult conditioning, spawning sites and larval habitat Variable flows discourage exotic fish	Allow fish movement to recolonise vacant habitats 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 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) Attractant flow to trigger upstream migration Trigger spawning and successive access to riparian spawning habitat Variable flows discourage exotic fish	Increase seasonal flow to prevent vegetation encroachment of open water Allow movement between 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 pools Maintain water quality Variable flows discourage exotic fish	Flows to provide access to off-channel habitat for adult conditioning, spawning sites and larval habitat Variable flows discourage exotic fish	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 Variable flows discourage exotic fish	Promote spawning 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	Seasonal flow increase 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 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)

C. ENVIRONMENTAL WATER REQUIREMENTS OF 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
	Overbank					Maintain persistent aquatic habitat conditions (pool habitat for still water floodplain wetland species)

D. ENVIRONMENTAL WATER REQUIREMENTS OF PLANTS IN THE MOUNT LOFTY RANGES

Two-part table:

1. **Semi-aquatic functional groups**
2. **Aquatic functional groups**

Part 1

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)

Season	Component	Tda	ATl	ATe	ATw
	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)
	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)

Season	Component	Tda	ATl	ATe	ATw
Transitional Flow Season 2	**Zero flow**		Reproduction – needs to be exposed – gradual seasonal decline in water level (aquatic and in-stream)		
	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			

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

Part 2

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)
	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)

Season	Component	ARp	ARf	Sr	Se	Sk
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)
	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

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

E. METRICS REPRESENTING EWRS IN THE MOUNT LOFTY RANGES

Season and flow component	EWR metric	Measurement unit	Reach type	Flow purpose	Priority group (see Section 5.3.2)	Threshold (see Section 5.3.5)
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 underground water 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 otherwise threshold = 4
Low flow freshes	Number of years with one or more LFS freshes	# years	All	• Flush mountain galaxias spawning sites	1	n.a.

Season and flow component	EWR metric	Measurement unit	Reach type	Flow purpose	Priority group (see Section 5.3.2)	Threshold (see Section 5.3.5)
				• Maintain damp conditions on banks for plant establishment • Transport plant propagules		
	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 underground water 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 macroinvertebrates	1	n.a.
	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.

Season and flow component	EWR metric	Measurement unit	Reach type	Flow purpose	Priority group (see Section 5.3.2)	Threshold (see Section 5.3.5)
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.
	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 underground water 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 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 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)	1	n.a.

				• Maintain habitat (overturn substrates and scour pools) • Regulate terrestrial/amphibious plant distribution • Entrain organic material from banks		
	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 • Entrain organic material from banks • Expand riffles for macroinvertebrates	1	n.a.
	Average total duration of HFS freshes per year	days/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) • Maintain habitat (overturn substrates and scour pools) • Regulate terrestrial/amphibious plant distribution • Entrain organic material from banks	2	n.a.

				• Expand riffles for macroinvertebrates		
	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 underground water where relevant	3	n.a.
	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	# years	All	• Correlate with the viability of core aquatic	1	4

	zero flow spells			habitat (refugia) • Discourage exotic fish species • Promote germination of some amphibious plants (Sr)		
	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) • Discourage exotic fish species • Promote germination of some amphibious plants (Sr)	If threshold = 15 then priority = 3 Otherwise priority =1	Threshold = 15 if natural and current 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	2	n.a.

				• Promote establishment of instream vegetation		
	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 the annual 5th percentile exceedence flow	# years	Upper pool riffle only	• Large scale fish movement	2	n.a.
	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 reach types **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 reach types **If greater than 2 for current or 'natural'** 3	**2**

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

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

Shortened forms

~	approximately equal to
bgs	below ground surface
EC	electrical conductivity (µS/cm)
K	hydraulic conductivity (m/d)
pH	acidity
pMC	per cent of modern carbon
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
w/v	weight in volume
w/w	weight in weight

GLOSSARY

Adjusted flow — The 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. The insects include 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.

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

Consumptive loss – Net evaporation from dams plus consumptive use.

Current flow — Gauged or modeled flow using 2005 dam development levels.

Eastern Mount Lofty Ranges PWRA— means the following areas:

- Eastern Mount Lofty Ranges Water Resources Area (the area bounded by the bold red line in GRO Plan No 422/2003);
- Eastern Mount Lofty Ranges Prescribed Wells Area (the area bounded by the bold red line in GRO Plan No 423/2003);
- Angas-Bremer Prescribed Wells Area (as described in the Government Gazette published on 23 October 1980 (p.1192) pursuant to the *Water Resources Act 1976*).

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

Environmental needs — For the purposes of this report: Self-sustaining populations of aquatic biota, that are resilient to times of drought. For the watercourses of the EMLR, this is measured through a better than marginal fish (mountain galaxids and southern pygmy perch) recruitment frequency of greater than 7/10 years, and a macroinvertebrate population condition that is better than moderate-good. This is expected to occur when 85% of EWR metrics are passed.

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. EWPs do not necessarily aim to return water dependent ecosystems to a pristine condition but rather ensure that they are sustained (and restored, where achievable) at an acceptable level of risk, 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.

Floodplain — Any 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 — Seasons defined by the natural flow distribution, rather than the traditional seasons of summer, autumn, winter or spring. Flow seasons are: Low Flow Season, Transitional Flow Season 1 (low–high), High flow season, Transitional Flow Season 2 (high–low).

Fresh flow — Range from 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, to 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.

Level of water use – Water directly extracted from the system for consumptive use (e.g. irrigation, stock watering, domestic use). Usually expressed as a % of upstream runoff.

Licensed dam — Dam from which a licensed extraction is taken.

Metric — Hydrological terms used to quantify the environmental water requirements of water dependent ecosystems (e.g. 80th per cent 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 2006) but 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 underground water systems and the relationships/connections between the two.

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

Prescribed Area — The Eastern Mount Lofty Ranges Prescribed Water Resources Area as shown in Figure 1.

Reach type — Reach types represent watercourses with similar structure, ecology and hydrology and are expected to support similar water dependent ecosystems.

Seasonal watercourse — A watercourse that flows every year, but often ceases to flow during the drier months.

Stygofauna — Animals that live within underground water 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 federal *Environment Protection and Biodiversity Conservation Act 1999*.

Unlicensed dam — Dam from which no licensed extraction is taken.

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
- 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, which are determined by the permanent or temporary presence of flowing or standing water, above or below ground. The instream 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.

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