Hydro-Ecological modelling to support Water Allocation Planning: Environmental Water Requirements

GWAP project: Task 4

Sally Maxwell, Douglas Green, Jason Nicol, David Schmarr,
Luk Peeters, Nigel Fleming, Kate Holland and Ian Overton

Goyder Institute for Water Research
Technical Report Series No. 15/53

www.goyderinstitute.org

Goyder Institute for Water Research Technical Report Series ISSN: 1839-2725

The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department for Environment, Water and Natural Resources, CSIRO, Flinders University, the University of Adelaide and the University of South Australia. The Institute will enhance the South Australian Government's capacity to develop and deliver science-based policy solutions in water management. It brings together the best scientists and researchers across Australia to provide expert and independent scientific advice to inform good government water policy and identify future threats and opportunities to water security.

The following Associate organisations contributed to this report:

Enquires should be addressed to: Goyder Institute for Water Research
Level 4, 33 King William Street
Adelaide, SA, 5000
tel: 08-8236 5200
e-mail: enquiries@goyderinstitute.org

Citation
Maxwell SE, Green DG, Nicol J, Schmarr D, Peeters L, Holland K and Overton IC, 2015, *Water Allocation Planning: Environmental Water Requirements. GWAP Project: Task 4,* Goyder Institute for Water Research Technical Report Series No. 15/53

Executive summary

The Mount Lofty Ranges (MLR), east of Adelaide, is a vitally important region to South Australia — socially, economically and ecologically. The MLR catchments provide significant water resources for a range of stakeholders, including the general community (water for the environment and recreational activities), landholders (e.g. water for domestic, stock and intensive horticulture uses), secondary industries and potable water suppliers and consumers.

The MLR supports diverse arrays of native species and ecosystems, despite its position within a largely agricultural landscape. Native fish, invertebrates and plants are key components which supply ecosystem services through maintaining water quality, nutrient retention and cycling, sediment dynamics and food resources, which all contribute to a healthy, functioning system able to support agricultural use.

The development of land for productive use in South Australia has led to a dramatic change in the flow regime of the mostly temporary rivers that flow across the landscape. The effects have been characterised in several reports and studies, and include decreases in low to medium flows (captured by dams and watercourse diversions) and increased volume and speed of runoff (due to lack of vegetation). The combined effects of these changes, including the development of the water resource, have resulted in degradation of water-dependent ecosystems (WDEs) in these areas.

The water resources of the MLR were formally prescribed in 2005. Local natural resource management boards are required to prepare a Water Allocation Plan (WAP) for prescribed resources, setting sustainable limits for allocation of water and providing for ongoing water management. This requirement, and recognition of the need to balance social, economic and environmental water needs, culminated in release of a WAP for the western MLR and another for the eastern MLR, both formally adopted in 2013.

The Goyder Institute has identified areas to improve information to support water allocation planning in the MLR. These include the development of robust models based on better understanding of hydro-ecological processes, particularly under low-flow situations. In this regard, the present project aimed at developing a method less reliant on expert opinion, more repeatable and transparent and more strongly based on empirical evidence. Existing environmental water requirements were revised, based on a review of literature, existing and new field-based monitoring data and an assessment of the water quantity requirements of ecosystems.

The project has established a network of hydrological and ecological monitoring sites, and complements current monitoring programs of the Adelaide and Mount Lofty Ranges Natural Resource Management Board (AMLRNRMB), South Australian Murray-Darling Basin Natural Resource Management Board (SAMDBNRMB) and Environment Protection Authority (EPA) (i.e. vWASP, eFlows, EPA macroinvertebrate, hydrology and fish monitoring sites), providing scientific evidence and data to improve predictive modelling capacity.

A modelling framework was developed to assess quantitatively whether water-use scenarios maintained and/or improved current conditions. Several approaches were used in combination to develop flow-response models for vegetation, macroinvertebrates and fish under this framework. Trait-based models were developed for macroinvertebrates and fish, using multivariate statistics and generalised linear modelling to develop empirical relationships between the target biota and hydrological variables. The level of intermittency over 10 years was modelled as the key hydrological variable driving change in temporary rivers.

Modelling for macroinvertebrates suggested that reducing the level of intermittency in MLR streams would increase taxonomic diversity, promote species with resilient traits and overall would maintain a more balanced, functioning ecosystem that is resilient to future degradation. Reducing the level of intermittency corresponds to less low and no flow days and generally to an increase in flow.

Modelling for vegetation suggested that restoring low-flow components of the natural flow regime and reducing overall use may result in improvements in plant communities. However, it was recognised these may not be realised if land-management practices are not changed and complementary actions such as weed control and stock exclusion are not also undertaken.

Response models were developed also for fish, but they require optimisation and verification before being used to inform water allocation planning.

There is clear evidence that further increases in water abstraction would increase the level of intermittency in MLR streams, leading to further ecological degradation of water-dependent ecosystems.

The current project adds further weight to the evidence already identified in the current WAPs that returning low-flows and thereby reducing intermittency is an essential part of maintaining, and potentially improving healthy, resilient ecosystems in the MLR.

This work has demonstrated the use of empirical data in modelling responses to water-use scenarios and in quantifying the ‘maintain and improve’ components of water allocation planning objectives. It has consolidated datasets and knowledge from across the region and brought together multiple research agencies. Key relationships and capabilities have clearly been enhanced through this project.

Contents

Figures

Tables

Acknowledgments

Funding for this research was provided by the Goyder Institute for Water Research. The support of landowners and other stakeholders for allowing the project to conduct surveys on their properties is greatly acknowledged.

Hydrological modelling was conducted by multiple agencies including DEWNR and CSIRO. We thank Mark Alcorn for developing Source models for the Onkaparinga River, Rob Bridgart, Nick Potter, Justin Hughes and Susan Cuddy for development support and calculation of flow metrics.

We thank Peter Goonan and Steven Gatti for provision of historical macroinvertebrate data sets, collected through programs funded by a range of groups including the Environment Protection Authority and the Adelaide Mount Lofty Ranges Natural Resources Management Board. We also like to thank David Deane for technical support compiling the macroinvertebrate trait database and Darren King for GIS support.

We thank Rupert Mathwin, David Cheshire, Rod Ward, Kate Frahn, James Devenport, Thiago Vasquez-Mari, Nick Whiterod, Chris Madden and Peter Goonan for their assistance with fieldwork. Much of the autumn 2014 fish data for the EMLR used in this project was collected by Aquasave Consultants through a program funded by the South Australian Murray-Darling Basin Natural Resources Management Board.

The authors would also like to acknowledge Mardi van der Wielen, Keith Walker and Ingrid Frannsen for early review of this document which greatly improved its clarity.

1 Introduction

1.1 Mount Lofty Ranges region

The Mount Lofty Ranges (MLR), east of Adelaide, is a vitally important region to South Australia— socially, economically and ecologically. The MLR catchments provide significant water resources used by a range of stakeholders including the general community (water for the environment and recreational activities), agricultural landholders (e.g. water for domestic, stock and intensive horticulture purposes), industry and suppliers and consumers of potable water.

The MLR has an average annual rainfall of 600 mm (range 300–1000 mm), with a decline from west to east associated with local orography (Guan *et al.* 2009). It has a Mediterranean climate, with hot, dry summers and cold, wet winters. The western part of the region has an extensive network of weirs, reservoirs and pipelines in the lower catchments, forming a major part of the water supply for the city of Adelaide. The upper catchments, the focus of this study, on both the eastern and western sides of the ranges are used for horticulture, vineyards, and stock and domestic use. Abstraction from small dams is the most common form of water use, with over 15,000 farm dams in the region capturing an average 10 percent of average annual runoff, and up to 70% in some catchments (AMLRNRMB 2015). Water capture by dams and watercourse diversions has reduced average annual runoff by 20% across the Eastern Mount Lofty Ranges, with higher reductions at a local scale (Alcorn 2010).

Many of the streams in the MLR are temporary in nature. Temporary streams have been defined as “rivers which periodically cease to flow” (Larned *et al.* 2010) and therefore include any river which ceases to flow at any time or frequency. This definition includes ‘intermittent’, ‘ephemeral’ and ‘episodic’ rivers and streams—these terms being used frequently in the scientific literature (e.g. Boulton and Lake 1992, Datry *et al.* 2014a, Kennard *et al.* 2010). Temporary rivers globally are vulnerable to anthropogenic and climatic alteration (Buttle *et al.* 2012), yet their persistence is critical for productive land use in many landscapes (Bull 1997). This is particularly so in regions where most rivers are temporary (Kennard *et al.* 2010).

Development of land for productive use in South Australia has led to dramatic changes in the flow regimes of the mostly temporary rivers that flow across the landscape. The clearing of native vegetation and planting of crops and pasture, combined with the construction of dams, has irreversibly changed the flow regime, geomorphology and ecology of the rivers (e.g. Allan 2004). The effects of these changes on the flow regime have been characterised in several reports and studies (DeFries and Eshleman 2004, Quinn *et al.* 1997) and include decreases in low-flows (captured by dams) and increased volume and speed of runoff due to lack of vegetation (cf. Poff *et al.* 2007). There are also effects not directly related to flow regime (e.g. channel incision: Quinn *et al.* 1997). The combined effects of these changes to rivers, including the increasing development of the water resource, have resulted in degradation of the water dependent ecosystems (WDEs) (Allan 2004).

1.2 Influence of flow regime changes on local biota

The MLR supports diverse arrays of native species and ecosystems, despite its position within a largely agricultural landscape. Native fish, invertebrates and plants are key components which supply ecosystem services of maintaining water quality, nutrient retention and recycling, sediment dynamics and food resources, which all contribute to a healthy, functioning system that is able to support agricultural use.

Anthropogenic changes have reduced the amount of water available, increased flow intermittency and generally changed the patterns of flow (Poff *et al*. 1997). Increasing intermittency corresponds to more low and no flow days and generally to a reduction in flow. Native fish, invertebrates and plants have particular traits to persist despite this disturbance. Resistance and resilience are two mechanisms that enable ecological communities to persist at a regional scale, despite disturbance. Resistance may be defined as an organism's ability to tolerate harsh conditions, whereas resilience relates to an organism's ability to recolonise once the disturbance is no longer present (Boulton *et al.* 1992). Increasing intermittency may be considered a 'ramp' disturbance (Lake 2000) both in terms of the duration of no flow and the increase area without water. Ramp disturbances are defined as those that may steadily increase overtime without an endpoint and often simultaneously in spatial extent.

It has been proposed that the flow regime, in particular the intermittency of intermittent streams, is a 'master variable' driving community structure in ephemeral rivers (Datry *et al.* 2014b) and will likely increase under projected climate change scenarios (Bardsley and Sweeney 2010). The modifications to the rivers of the Mt Lofty Ranges has led to changes in the flow regime, and specifically increased the levels of intermittency (Alcorn 2011, Alcorn 2008). There have been several observed changes in the fish, macroinvertebrates and vegetation communities of the WDEs in the area (e.g. Whiterod & Hammer 2014, EPA 2014).

Plant communities in the MLR are currently dominated by exotic terrestrial taxa (especially in the riparian zone) and by emergent species such as cumbungi (*Typha domingensis*) and common reed (*Phragmites australis*), particularly in flowing habitats. Current stream plant communities are the product of a combination of altered flow regimes, which have changed water availability, increased disturbance regimes, and non-hydrological factors such as increased nutrient input, grazing and erosion.

Many rivers in the MLR have degraded macroinvertebrate communities (EPA 2014) due to changes in the flow regime and other factors including increased nutrient input, changes in riparian vegetation and changes in substrate.

There has been a consistent decline in the condition of the fish communities of the Mt Lofty Ranges. However, since the changes to the flow regime and the reduction in flows several species have become locally extinct while others are regionally threatened. In contrast, several species of alien species of fish have increased dramatically in numbers (e.g. redfin perch and *Gambusia*) (Schmarr *et al.* 2014, Whiterod & Hammer 2014).

1.2.1 CURRENT WATER ALLOCATION PLANNING

The current water allocation planning structure in the MLR was described by Cox *et al.* (2013):

> *Local natural resource management boards are required to prepare a WAP for prescribed resources, which sets sustainable limits for allocation of water and provides for ongoing water management (VanLaarhoven and van der Wielen 2009)… Environmental water requirements (EWRs) are defined as 'the water regime needed to sustain the ecological values of ecosystems, including their processes and biological diversity, at a low level of risk' (DWLBC, 2006). EWRs were described at the biotic functional group level (e.g. fish, macroinvertebrates and water dependent plants) by determining the flow-dependent ecological processes required to support each group, and the water regime required to support those processes (VanLaarhoven and van der Wielen, 2009).*

Opportunities for further informing WAPs

Four major research themes have been identified by the Goyder Institute as requiring investment in order to provide information to support water allocation planning in the MLR. These are:

i) Better understanding of hydrological processes, in particular rapid assessment of those parts of the landscape where groundwater contributes substantially to stream flow;
ii) Development of robust hydro-ecological thresholds based on refined understanding of hydro-ecological processes, particularly under low-flow situations (this project);
iii) The importance of land use, topography and other landform attributes for water quality, particularly in low-flow situations; and

iv) Improvements and alignment of the hydrological models and risk frameworks used in the water allocation planning process.

Given these challenges, this project provides an opportunity to test alternative methods that are less reliant on expert opinion, more repeatable and transparent and more strongly based on empirical evidence.

1.3 Overall Project objectives

This report is based on Task 4 of a larger project related to providing information to support water planning in the MLR. The overall objective was to develop an integrated catchment water planning support system based on best practice methods and modelling, to enable the evaluation and planning for risks of water extraction to catchment water resources and water-dependent ecosystems. The project was divided into five tasks:

Task 1: Project leadership and management – coordinate the efficient and timely delivery of an integrated body of research to improve future Water Allocation Planning and the Water Quality Improvement Programme (WQIP) through regular communication with stakeholders, steering committees and State Government staff throughout the life of the project.

Task 2: Integrated catchment water planning support system – to develop a base rainfall-runoff catchment model in Source. IMS for a trial catchment in the MLR, incorporating existing and developing additional 'plug-ins' that represent demand and supply functionalities (farm dams and watercourse extractions), landcover and/or soil variability.

Task 3: Low-flows hydrology – low-flows are a critical part of the flow regimes that support water - dependent ecosystems in the MLR. More research into low-flow hydrology is needed, particularly the non-stationarity of flow between and within catchments.

Task 4: Environmental Water Requirements (EWRs) – existing EWRs will be refined based on a review of literature, existing and new field-based monitoring data and an assessment of the water quantity requirements of ecosystems. This project will complement the current Adelaide and Mount Lofty Ranges Natural Resource Management Board (AMLRNRMB) and South Australian Murray-Darling Basin Natural Resource Management Board (SAMDBNRMB) monitoring programs within the MLR (i.e. vWASP, eFlows, EPA macroinvertebrate, hydrology and fish monitoring sites).

Task 5: Water quality improvement programme - A water-quality risk assessment will be undertaken to determine the MLR catchments and environmental assets that may be at risk. The risk assessment will collate available water quality data from the MLRs and conduct a tiered risk assessment within the limitations of the data availability and quality. A spatial analysis will be used to determine linkages between catchments based on catchment features, including land use, soil type, terrain etc.

1.4 Report Outline

This report provides the outcomes of Task 4 and specifically describes the methodology used to develop ecological response models for macroinvertebrates, vegetation and fish that can be used in the determination of environmental water requirements for use in water planning. Specifically the response models will provide the basis for determining levels of risk posed by various water planning scenarios and will support water allocation plans taking a risk based approach, though this was not undertaken as part of this report. The outputs of the project are contained in this report (methodology and responses from the vegetation response modelling) and two scientific papers that detail the macroinvertebrate response models (Maxwell et al. in prep.) and a novel approach of determining the relative level of risk posed to WDEs due to differing management scenarios (Green and Maxwell, in prep.). Both of these papers were prepared as part of the project which are referred to throughout.

A review of previous methods used in the MLR were undertaken with the view to review and refine existing work where possible (Section 2). Prior to the commencement of the project key sites were selected for ongoing data collection to support water allocation planning. The desire to be able to model hydrological scenarios necessitated the link between flow gauging stations and ecological collection sites. These sites were augmented to maximise the number of sites available for understanding the key linkages between hydrology and ecology at several spatial scales. The sites are presented in Section 3.

Conceptual models for each taxon group were developed for each of the major biotic groups (fish, Macroinvertebrates and vegetation) in order to understand the key drivers for each and support the choice of factors to be included in response models (Sections 4, 5 and 6). The methods used to develop ecological response models are presented in the relevant taxon section (Sections 4, 5 and 6). These response models are accompanied by a discussion of a new risk assessment framework proposed to more closely assess the risks to achieving the ecological objectives of the WAPs of the MLR (Section 7.2.4).

An overall discussion of the work identifying limitations and recommendations for future work is presented in Section 7.

2 Methodology

The first step in this section was to review existing hydrology metrics used in the current WAPs (section 2.2). The second step was to review eco-hydrological modelling approaches (section 2.3) to identify the best way forward for modelling eco-hydrology in the MLR (section 2.4).

2.1 Hydro-ecological modelling approach

2.1.1 REVIEW OF EXISTING HYDROLOGICAL METRICS

Hydro-ecological modelling to inform EWRs for the AMLRNRMB and SAMDBNRMB WAPs was based on hydrological metrics. These were related qualitatively to the EWRs of fish and vegetation in the region (VanLaarhoven and van der Wielen 2009). The WAPs used the percentage of metrics 'passed' to determine whether the environment was maintained at an acceptable level of risk, whilst providing for economic requirements related to water allocations in the area. The EWRs were determined in a series of workshops, using an 'expert knowledge' approach to develop conceptual models of environmental water requirements. These were based on identifying flow-dependent ecological processes required to meet environmental objectives, and then identifying the water regime components required to support each of those processes. These requirements were represented quantitatively by identifying hydrological metrics and targets. The environmental objective of the allocation is to 'maintain and where possible restore water-dependent ecosystems by providing their water needs'.

The EMLR WAP includes an objective to 'Maintain and where possible restore water-dependent ecosystems by providing their water needs'; and the WMLR WAP includes an objective to 'Maintain water-dependent ecosystems'. The environmental objective underpinning the work to determine environmental water requirements is to 'maintain and/or restore self- sustaining populations of aquatic and riparian flora and fauna which are resilient in times of drought'. This objective aims to conserve biota and ecosystems current or likely to be present in the region through the establishment of a suitable water regime. It is not the intention of the objective to restore the habitat and ecosystems to pre-European conditions (SAMDBNRMB 2013).

EWRs for the WAPs were based on the premise that water-dependent ecosystem structure and function are comparable within a landscape setting. Watercourses were classified into seven different reach types (including groups with similar physical form, ecology and hydrology) that represent the major types of water-dependent habitats across the study area (VanLaarhoven and van der Wielen 2009). An expert panel was used to assign the seven generic reach types, based on knowledge of the distribution and grouping of geomorphic units and habitats (e.g. pools and riffles), species and/or ecological groups and hydrological characteristics across the MLR. The seven reach types were: headwaters, upper-pool riffle, mid-pool riffle, lowland, gorge, Fleurieu Swamps and terminal wetland. Differentiation between the reach types was based on factors, including the nature and scale of riparian and aquatic habitats expected to be present in different parts of the landscape. Details are provided in VanLaarhoven and van der Wielen (2009).

The conceptual models of environmental water requirements developed as above identified flow-dependent ecological processes associated with different flow components in different flow seasons. The key flow components identified were low-flows, freshes (short pulse flows), bankfull and overbank flows. The four flow seasons were: low-flows (LFS), transitional flows (low to high, T1), high flows (HFS) and transitional flows (high to low, T2).

In order to develop a quantitative measure to represent each flow component in each flow season, cross-sections were measured at each of the reach types to determine the relationship between flow and habitat characteristics. The cross-sections were used to determine the relationship between flow depth and flow rate for important habitat components (deep pools, shallow riffles, bank benches, bankfull). These cross-sections were used to develop flow rating curves in order to calculate hydrological measures for different flow seasons. Three hydrological measures were identified: (1) low-flows (80th percentile exceedance calculated on non-zero flow); (2) freshes (two times the median of all non-zero flows in the flow season of interest) and (3) bankfull/overbank (1.5 annual return interval flow, based on annual maximum flows) in each of the four flow seasons. These three flow components were representative across all reach types and flow seasons and were considered to be necessary for the promotion of self-sustaining populations of fish, vegetation and macroinvertebrates.

The EWRs were tested using daily flow data from 135 sites in the MLR, modelled under current and adjusted conditions for 1974–2006 using the WaterCress platform. *Current* conditions were modelled assuming that usage from irrigation dams is 50% of dam capacity over October–March, and from stock and domestic dams is 30% of dam capacity spread over a pattern of seasonal demand. Adjusted flow (sometimes referred to as ‘natural’, but recognising this is not pre-European conditions) was defined as the flow modelled with the impacts of the 2005 level of dam development removed, but accepting that some irreversible changes from pre-European flows have occurred due to land clearance and other water resource developments (VanLaarhoven and van der Wielen 2009).

The long-term average values of each metric under current and adjusted flow conditions were calculated and the metric value for current conditions was expressed as a proportion of the adjusted value to determine whether the metric was within acceptable limits. Only two sites passed all metrics, 50% passed three quarters and 90% passed half of all metrics (VanLaarhoven and van der Wielen 2009). The most affected metrics were those that represented low-flows in all seasons (e.g. 80th percentile exceedance non-zero flow and duration of zero-flow spells). The proportion of hydrological metrics passed at each site was compared to data for fish and macroinvertebrates.

The abundance and size distribution of two fish species with a strong ecological response to flow (southern pygmy perch and mountain galaxias) and monitored annually, in autumn, for 4–7 years were compared to hydrological metrics at a range of sites. Annual monitoring data were separated based on if fish spawned in that flow season (recruitment) and adults survived from previous years (survivorship), using relationships between length and age. This was used to assess whether recruitment and survivorship were ‘excellent’, ‘good’, ‘marginal’ or ‘poor’ (including failure) at each site. The relationship between the proportion of years with marginal or poor recruitment and the proportion of flow metrics passed was non-significant for mountain galaxias ($n = 8$, $p = 0.065$) but significant for southern pygmy perch ($n = 6$, $p < 0.001$) (VanLaarhoven and van der Wielen 2009). In other words, the changes in the flow regime are demonstrated to be having a significant negative impact on the population of some flow dependent species of fish in the MLR.

Macroinvertebrate monitoring data collected in spring and autumn for up to 13 years, using AusRivAS methods, were compared to the proportions of hydrological metrics passed at each site. The AusRivAS protocol describes the condition of the community in relation to a 'reference' community based on taxonomic composition, water quality and habitat characteristics. Communities were rated as 'good', 'medium', 'marginal' or 'poor' for different habitats (e.g. pools, riffles) over time. Macroinvertebrate condition increased with the proportion of hydrological metrics passed (p <0.001) (VanLaarhoven and van der Wielen 2009).

Risk was assessed by determining the change in the number of metrics passing, from the modelled 'natural' to the modelled 'test' scenario for each EWR, the 'test' scenario being the modelled flow regime resulting from a set of management policies. The scenarios were used to identify which policy options (e.g. farm dams) had the highest risk by assessing how each hydrological scenario affected the metrics. Each of the metrics was assigned a priority, which determines the bounds for determining whether it passed or failed. Priority 1 metrics were acceptable within –20% and +25%, Priority 2 metrics were acceptable within –30% and +50% and Priority 3 metrics were acceptable within –50% and –100%. The risk analysis was conducted through a pass/fail process. An ecological function was considered to be at 'low risk' if the metrics were within acceptable ranges. The ecosystem was considered to be at an 'elevated level of risk' if the metrics were not within acceptable ranges.

The relationships between proportions of hydrological metrics passed at the 135 sites were used to assess the level of risk at other sites in the MLR where water use is known or estimated through hydrological modelling. This modelling was done using dam locations and estimated volumes mapped from 2005 aerial photography, and assuming 50% usage from irrigation dams and 30% from stock and domestic dams. There was a significant relationship between proportion of metrics passed and upstream water use as a proportion of runoff (p <0.001). VanLaarhoven and van der Wielen (2009) found that an extraction limit of 5% of upstream runoff was required to pass 85% of the hydrological metrics to maintain water-dependent ecosystems at an acceptable level of risk. However, this was considered unlikely to be socially or economically acceptable as estimated current water demand is higher than 5% in most cases.

The low-flow components in all flow seasons, and the fresh component in low-flow and transitional flow seasons have been most affected by current development, and are critical to WDEs. Therefore consideration was given to management scenarios that improve low-flows and freshes in the catchments, and therefore the proportion of hydrological metrics that passed in order to share water between consumptive users and the environment. Further scenarios were modelled to investigate the effects of returning or not capturing low-flows (at or below a threshold flow rate) at existing licensed dams, licensed watercourse diversions and large non-licensed dams resulted in meeting the environmental flow targets. 'Threshold flows' were defined as the 20th percentile exceedance non-zero flow, and was set to encompass the flow components most affected by water resource development for most cases.

If threshold flows were returned or not captured by licensed sources and large non-licensed dams, then 25% of the upstream runoff in the WMLR and 20% of the upstream runoff in the EMLR could be extracted, while passing at least 85% of the metrics at most testing sites (VanLaarhoven and van der Wielen 2009; VanLaarhoven and van der Wielen 2012). This scenario also met the assumed current demand at most testing sites.

2.1.2 PRELIMINARY ANALYSIS OF HYDROLOGICAL METRICS

A review of the previous metrics used to assess the deviation of sites from natural condition (described above) was undertaken to inform the appropriateness and/ or the ability of the metrics to distinguish between different reach types and modelled and measured data. The hydrological metrics of modelled and natural flows at 12 sites with macroinvertebrate data that were used in the development of EWRs for the WAPs, were analysed using Principal Components Analysis (PCA), using PRIMER version 6.1.12 software (Clarke and Gorley 2006). Sites were those that were previously used to assess macroinvertebrate responses *via* flow-band correlation with hydrological metrics (Table 1). Prior to analysis, individual metrics were checked for normality and transformed appropriately if required.

Table 1. Macroinvertebrate sites used to compare hydrological metrics

SITE NUMBER	REACH TYPE	SITE NAME
PM1-1	UPR	First Creek, Waterfall Gully
PM10-1	MPR	Onkaparinga River, u/s Brooks Rd Ford
PM11-2	Lowland channel	Onkaparinga River, Noarlunga, GS 503522
PM15-2	MPR	Torrens River, Gumeracha Weir
PM16-2	MPR	Torrens River, Cudlee Creek Conservation Park
PM17-2	MPR	Torrens River, T44 Athelstone Linear Park
PM18-2	MPR	Kersbrook Creek GS 504525
PM2-1	UPR (D)	Marne R, S of Cambrai
PM21-2	UPR (wet)	Echunga Creek, Kavanagh Rd, SW Echunga (DS Echunga, 3239)
PM28-3	MPR	Yankalilla Creek on Hay Flat Rd
PM29-3	UPR (wet)	Baker Gully, GS 503503
PM4-1	lowland channel	Bremer River, Jaensch Rd ford
PM5-1	MPR	Finniss River, E of Yundi at ford
PM6-1	unknown	Hindmarsh River GS 501500
PM8-1	UPR (wet)	Scotts Creek, near Scotts Bottom GS 503502
PM9-1	UPR (wet)	Torrens River, Carnell Boundary Road
PM10-1	MPR	Onkaparinga River, u/s Brooks Rd Ford

Do the hydrological metrics distinguish between current and modelled natural conditions?

Most sites were clearly different in terms of current and modelled natural data. Current and adjusted modelled data were plotted separately (Figure 1), with current modelled data having predominantly lower scores along PC Axis 1. PC Axes 1 and 2 explained 38.5% and 14.8% of the variance in the model, respectively. Table 2 illustrated the direction of change in each of the flow metrics under the two test scenarios.

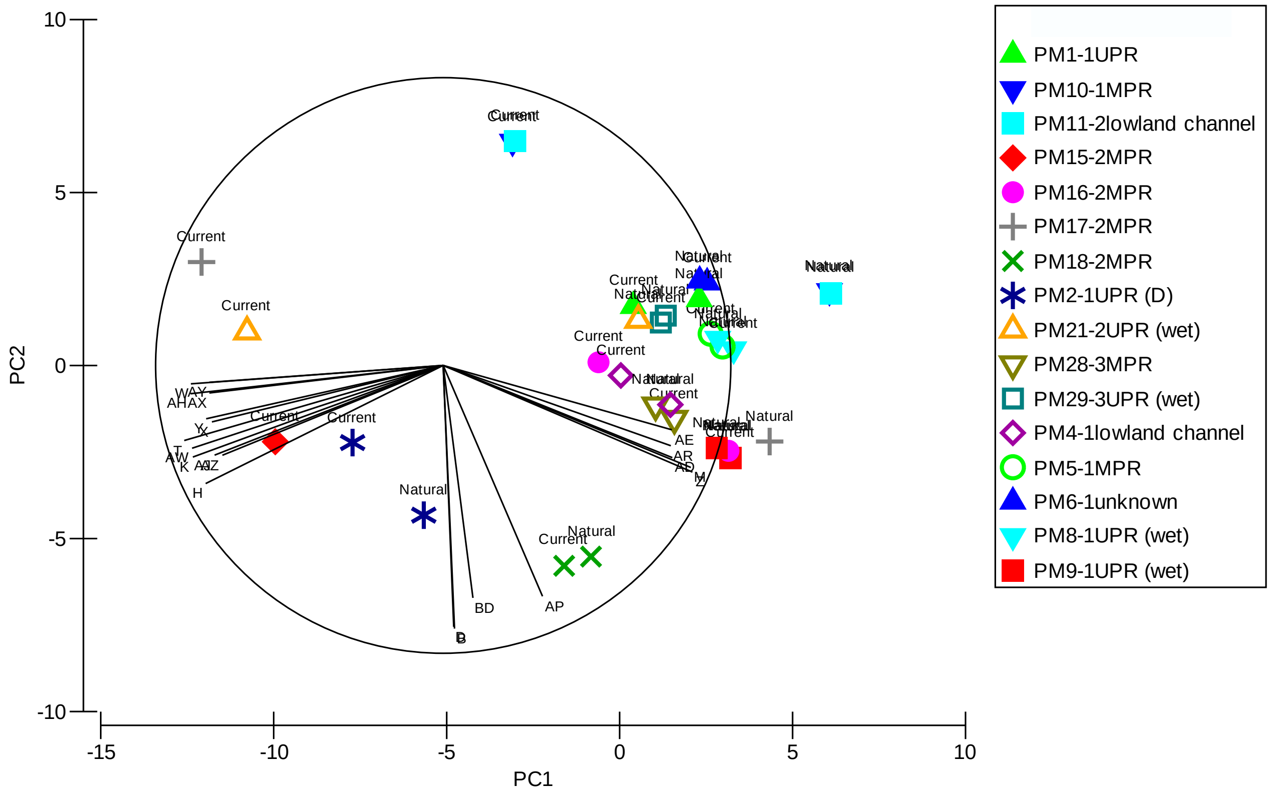


Figure 1. PCA plot of current and adjusted modelled flows for 16 test sites with macroinvertebrate data. Pearson correlations with flow metrics overlaid. Cut of at 0.8 correlation.

Table 2. Hydrological metrics driving separation between current and adjusted modelled flows. Up and down arrows indicate the direction of increase along each axis

METRIC NAMES	METRIC DESCRIPTION	AXIS 1	AXIS 2
AA	T1 - Average number of T1 freshes per year	↑	↓
AD	Number of years with 2 or more T1 freshes	↑	↓
AE	Frequency of spells higher than LFS fresh level	↑	↓
AH	Number of years with HFS zero flow spells	↓	↔
AP	HFS Average total duration of HFS freshes per year	↔	↓
AR	Number of years with 2 or more freshes early in the season (Jul, Aug)	↑	↓
AW	T2 - Number of years with T2 zero flow spells	↓	↓
AX	Average number of T2 zero flow spells per year	↓	↔
AZ	T2 - Average duration of T2 zero flow spells	↓	↓
B	Annual - Average number of bankfull flows per year	↔	↓
BA	T2 - Number of years with one or more T2 freshes	↑	↓
BB	T2 - Average number of T2 freshes per year	↑	↓
BD	Average total duration of T2 freshes per year	↔	↓
D	Average total duration of bankfull flow per year	↔	↓
M	Number of years with one or more LFS freshes	↑	↓
N	LFS - Average number of LFS freshes per year	↑	↓
T	T1 - Number of years with T1 zero flow spells	↓	↓
W	Average number of T1 zero flow spells per year	↓	↔
X	Average duration of T1 zero flow spells	↓	↓
Y	Average total duration of T1 zero flow per year	↓	↓
Z	T1 - Number of years with one or more T1 freshes	↑	↓

Patterns related to reach types

In general, there was greater separation between current and modelled data for sites lower in the catchment. The four Upper Pool Riffle (UPR) sites were less separated than Mid Pool Riffle (MPR) sites PM11. However, PM4 on the Bremer River, also a lowland channel site, showed little separation along PC Axis 1.

Correlation between metrics

A large number of metrics were highly inter-correlated, meaning that they are potentially contributing 'noise' rather than increased resolution (Table 3). Under the previous methodology, all of the 52 metrics were given equal weighting and should have an equal impact on the level of risk. However, given the correlation between metrics, some metrics are likely to not operate independently. This would likely lead to bias in the final results and risk ratings.

Generally, the metrics explaining flow frequency and duration within one season were correlated. It has been suggested that metrics which provide a measure of long term flow permanence are good for temporary rivers because they combine these inter-correlated metrics (Datry et al. 2014b).

Highly correlated pairs (*r* >.95): H,K; T,K; Y,X; AL,AK; AY,AH; AX,AI,AY,AH; AY,AU,AT

Table 3. Correlation coefficient matrix of hydrological metrics. Red denotes Pearson's r >95%, yellow denotes >90%. See Table 2 for metric codes.

	H	K	T	X	Y	AH	AI	AK	AL	AT	AU	AW	AX
K	0.96												
T	0.92	0.98											
X	0.79	0.88	0.90										
Y	0.77	0.87	0.91	0.97									
AH	0.78	0.83	0.90	0.81	0.89								
AI	0.61	0.65	0.74	0.56	0.68	0.93							
AK	0.58	0.63	0.74	0.80	0.88	0.89	0.77						
AL	0.67	0.76	0.82	0.93	0.97	0.88	0.68	0.96					
AT	-0.55	-0.58	-0.48	-0.41	-0.35	-0.29	-0.15	-0.03	-0.21				
AU	-0.63	-0.64	-0.54	-0.43	-0.37	-0.33	-0.20	-0.06	-0.22	0.99			
AW	0.91	0.92	0.94	0.81	0.86	0.95	0.84	0.79	0.82	-0.42	-0.48		
AX	0.76	0.75	0.79	0.57	0.66	0.92	0.95	0.67	0.62	-0.33	-0.39	0.91	
AY	0.68	0.70	0.80	0.65	0.76	0.95	0.95	0.87	0.78	-0.12	-0.17	0.89	0.91

2.2 Ecological modelling approaches

2.2.1 MODELLING CONSIDERATIONS

The desire for this project was to move the determination of ecological risk to WDEs to a more empirical approach, less reliant of expert opinion. The project considered a range of literature concerned with ecological modelling approaches (see Maxwell *et al.* (in prep.) and Green and Maxwell (in prep.) for details).

Several methods were identified, all methods that used ecological data to train response models, meaning that actual ecological data shaped the response model, not expert opinion. Approached ranged from simple linear modelling through to more complex multivariate modelling approaches. The models used for the fish and the macroinvertebrate response models were generalised linear models (Bolker *et al.* 2009). The reasons for using this approach are covered in Maxwell *et al.* (in prep.). The vegetation models were developed using Gaussian response curves, discussed in Section 5.

2.3 Conceptual understanding of the effect of abstraction on intermittency

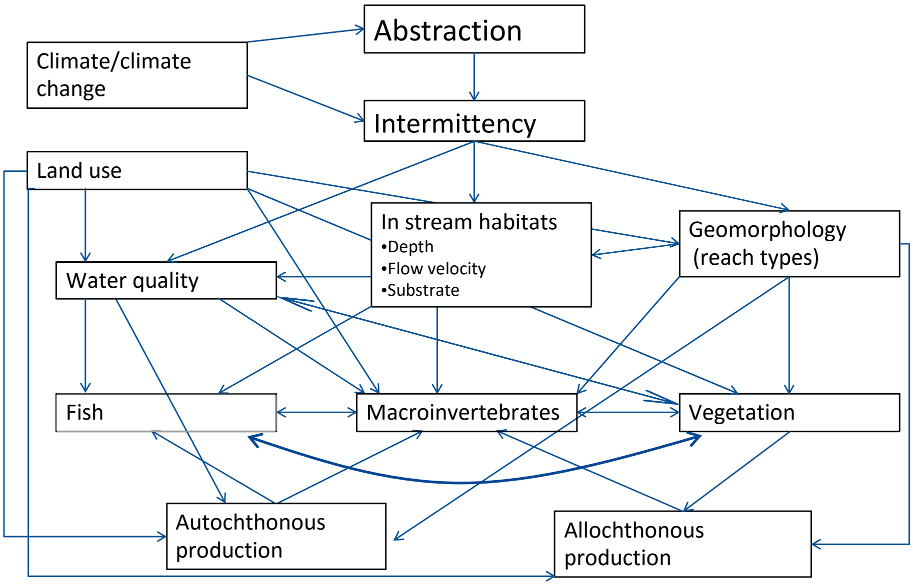


Figure 2: Overall conceptual model of the effects of abstraction (from farm dams and direct from water courses) on key ecosystem component including macroinvertebrates, fish and vegetation.

The overall project conceptual model (Figure 2) depicts the effect of abstraction on the flow regime, in stream habitats (depth, flow velocity, substrate) and fish, macroinvertebrates and vegetation. Interactions with climate and climate change, land use, geomorphology (reach types), water quality and the role of autochthonous and allochthonous production in sustaining these communities are also important and likely to occur.

Abstraction from small farm dams or water courses is likely to increase intermittency (Larned *et al*., 2010), reduce low-flows and generally alter the flow regime (Bunn and Arthington, 2002), geomorphology (Lloyd *et al.* 2004) and water quality. As a direct result of these changes, instream habitats are likely to be altered on a local scale as well as more broadly (Poff *et al.* 1997). It is well established that macroinvertebrates, fish and vegetation respond to specific flow regimes and that changes in those flow regimes can lead to degradation of the biotic community (Poff and Zimmerman, 2010). In particular, increasing intermittency is known to have negative effects on in stream biota (Benejam, *et al.* 2010). Chapters 4, 5 and 6 elaborate on these effects for each biota.

Abstraction here is defined as the ongoing extraction both direct from watercourses and from farm dams. Given the increasing demand for water resources in the Mt Lofty Ranges, here abstraction may be described as a *ramp* disturbance, increasing in intensity through time (Lake, 2000).

Water quality relationships

As in the overall model, water quality is linked to water quantity and to the persistence and survival of macroinvertebrates, vegetation and fish. Task 5 of the overall Goyder MLR project developed a tiered risk assessment for water quality across the MLR. This is likely to be useful in understanding the effects of water quality on the target biota, when combined with data to be gathered as part of the sampling program. While it was desired that predictive models would also be developed through this task, predictive modelling of water quality parameters was unsuccessful. The inability to predict water-quality parameters based on flow regime means that these parameters cannot be used in the hydro-ecological modelling.

2.5 Proposed modelling approach

Develop, validate and review hydro-ecological relationships

The measured flow data were used as part of the process to identify relationships between ecological responses and components of the flow regime, as described in chapters 4, 5 and 6 (vegetation, macroinvertebrates and fish). If flow data were not available then the ecological data were not used.

Quantify relationships between discharge and flow level – what gets wet when?

An important part of developing/reviewing hydro-ecological relationships was to be able to convert discharge (measured or modelled) into stage (water level), and to inform which parts of the stream get wet, connected or disconnected under different flow rates. Survey and flow gauging data were used to estimate the volumes of water required to achieve wetting of particular habitats and to maintain vertical and lateral connectivity.

Ecological response functions take multiple forms

In this study, ecological response functions are mathematical representations of hypothesised responses of aquatic biota to levels of flow extraction, either directly or indirectly, through parameters affected by abstraction (e.g. length of time habitats are connected).

Previous methods for assessing the impact to and developing hypotheses for the response of WDEs in the MLR have focused on flow metrics that represented ecologically relevant part of the flow regime. The conceptualisation of differing levels of connection provides an alternative approach to developing these hypotheses — one that may be more appropriate for intermittent streams of the MLR.

3 Hydrology

3.1 Introduction

Hydrological data are required for developing, verifying and refining relationships between water regime and ecological response, and determining magnitude of flow required to wet or connect different habitats.

These uses are further outlined in the sections on macroinvertebrates (section 4), vegetation (section 5), fish (section 6) and in review of previous metrics (section 2). The hydrological data used for the project includes measured and modelled flow data, and survey work to link discharge and flow level, as discussed below.

3.2 Modelled flow data

The modelled flow data came from a Source model developed for the Onkaparinga catchment as part of Task 2 of the MLR project, as well as from surface-water models developed as part of water planning processes in the region (Savadamuthu *et al.* 2011). The existing surface water models have been constructed for the catchments in the MLR with flow gauging stations, using the WaterCRESS modelling platform.

These models simulate daily flows based on rainfall, runoff, landscape characteristics and water capture, and are calibrated using data from gauging stations. The models incorporate the existing network of dams and watercourse diversions. They can be used to estimate what flows would occur under current landscape conditions, but without a number of management activities which may affect flow regime. These include water interception by dams, watercourse diversions, plantation forestry and urban development. Runoff simulated in the absence of these activities is referred to as 'adjusted' flow. The models can also be used to simulate different water management scenarios.

These models have been developed by DEWNR and its predecessors, and are described by Alcorn *et al.* (2008); Alcorn (2010); Savadamuthu (2002) and Savadamuthu and Teoh (2010) and references therein.

3.2.1 MEASURED FLOW DATA

Flow measurements came from existing monitoring stations which are managed by a range of agencies, as well as new monitoring sites installed as part of this project. Their purpose was to collect flow data at sites where ecological data also was collected.

Existing flow monitoring

Data from existing sites is stored in DEWNR's Hydstra system and is publically available on the surface water archive page of the Water Connect website:

https://www.waterconnect.sa.gov.au/Systems/SWD/Pages/Default.aspx

Gauges that were used in the project were:

A5030509	A4261208	A4261011	A4261100
A4260503	A4261076	A4260679	A5030502
A4261101	A5040517	A4260557	A5050503
A4260688	A5050510	A5050533	A5040518
A4261222	A4261103	A5050517	A5040576
A4260533	A5031001	A5050502	A5050535
A5040901	A5030537	A5050536	A4261020
A5031006	A5010503	A5031005	A5040500
A4260530	A5050518	A5030504	A5040512
A4261078	A5040525	A5030528	A5041020
A4261099	A5030507	A5031009	A5041046
A4260504	A5040541	A4261069	
A4261075	A4261007	A4261172	

New monitoring data

New flow monitoring sites have been installed, generally at locations in the vicinity of existing long-term fish monitoring sites. These sites have been chosen to represent a range of landscape/hydrological characteristics (e.g. permanent to intermittently flowing catchments), different locations in the catchment and populations of different fish species (see Figure 3).

3.2.2 DEVELOPING AND REFINING METRICS

Within sites

Ratings curves, or stage-discharge relationships, were developed for cross-sections of interest within a site, showing the relationship between water level and discharge for that location. Once a rating curve was established, derived flow rate was calculated from a simple depth measurement.

Development of theoretical rating curves using slope-area methods is a well-established hydrological practice requiring collection of cross- and long-sections and estimation of Manning's *n* (Chow 1959). Spot flow gauging can also be used to develop rating curves, and to validate or refine theoretical rating curves.

Cross sections were selected in a stratified random design incorporating five transect in pool and five in riffle environments where possible. These cross sections included a transect across the deepest cross section of the pool(s) of interest, and at the cease-to-flow point for the pool. Generally 10 cross sections were measured at each site, with a minimum of five (average of 9.6). These cross sections served multiple purposes, including:

- Development of rating curves to convert water levels measured at flow monitoring sites into discharge or flow rate,
- Forming part of the survey method for vegetation (Chapter 4), and
- Providing assistance in identifying the flow rate required to wet habitats of interest or to represent connectivity within and potentially between sites.

Rating curves were developed for cross sections, and flow gauging were measured at key cross sections to verify or refine the rating curves. Rating curves for individual cross sections can be interpreted in combination with the notes on the level or height of habitats of interest, and information on flow metrics such as frequency of different flow percentiles.

Between sites

Connection across a catchment is an important concept in the models set out in Figure 2 and in chapters 4-6. Metrics to represent connectivity are difficult to quantify in MLR catchments, given the variability of ‘gaining’ and ‘losing’ reaches. Quantifying metrics that represent how often a site is connected to another is difficult as there is often limited understanding of the watercourse between sites outside of generalised reach type and habitat.

There have been many attempts to quantify the flow regime of rivers into flow metrics. Kennard et al. (2010) developed a comprehensive list of flow metrics that are commonly referred to in Australian surface water hydrology. The MLR EWR work used 52 flow metrics (VanLaarhoven and van der Wielen 2009), with considerable overlap between the two sets of metrics. None of these metrics assess connectivity between to different sites. They instead use flow at a site to represent flow through a reach under the assumption that if it is flowing at the site then it is likely to be flowing through the whole reach.

Based on the review of the existing method (section 2.2.1), it was shown that using a larger number of flow metrics can lead to duplication of information within the data. Based on the grouping of the metrics presented in section 2.2.1 and a review of existing literature, three metrics were chosen for further analysis for the fish and the macroinvertebrate models, the level of intermittency, the mean daily flow and the variability of mean daily flow.

The vegetation models used number of days inundated and were calculated using a new method described in section 5.

3.2.3 SAMPLING METHODOLOGY

Seven new sites were installed to measure flow, specifically, these new sites were designed to measure two components of the flow regime. The first part is that of medium to high flows. This is traditionally the focus of hydrological measurement, as the vast majority of surface water in MLR catchments moves in medium to large flow events. Low-flows and cease to flow (CTF), especially in relation to ecological refuge pools, are the second area of interest, and are crucial in hydrological monitoring for ecological purposes. Traditional monitoring, however, has great difficulty measuring low-flows, and particularly the point at which flow ceases and restarts CTF.

At three of the seven new sites, the river channel at the lower edge of the water pool was suitable for both low and high flow measurement. In this case, just one water level logger was required per site. At two of the sites there are two loggers, one for the pool and one for the channel. Three loggers were required at each the two remaining sites, due to the presence of two channels as well as a pool. Site locations are shown in Figure 3 and detailed in Table 4.

Table 4. Details of GWAP hydrology monitoring sites

SITE NUMBER	WORKING NAME	WATER BODY	LATITUDE	LONGITUDE
A5030516	Aldgate Creek	Aldgate Creek	-35.039565°	138.760769°
A4261136	Braeside Road	Finniss River	-35.350912°	138.780890°
A4261226	Cleland Gully Road (pool)	Tookayerta Creek	-35.371915°	138.651194°
A4261227	Cleland Gully Road (culvert1)	Tookayerta Creek	-35.371915°	138.651194°
A4261228	Cleland Gully Road (culvert2)	Tookayerta Creek	-35.371915°	138.651194°
A4261229	Kilchoan (channel)	Currency Creek	-35.420131°	138.652493°
A4261230	Kilchoan (pool)	Currency Creek	-35.420131°	138.652493°
A4261144	Quarry Road	Angas River	-35.153613°	138.815537°
A4261139	Rodwell Creek (pool)	Rodwell Creek	-35.187858°	138.913496°
A4261234	Rodwell Creek (channel)	Rodwell Creek	-35.187858°	138.913496°
A4261231	Vigars Road (pool)	Upper Marne River	-34.669027°	139.070565°
A4261232	Vigars Road (weir)	Upper Marne River	-34.669027°	139.070565°
A4261233	Vigars Road (culverts)	unnamed creek	-34.669027°	139.070565°

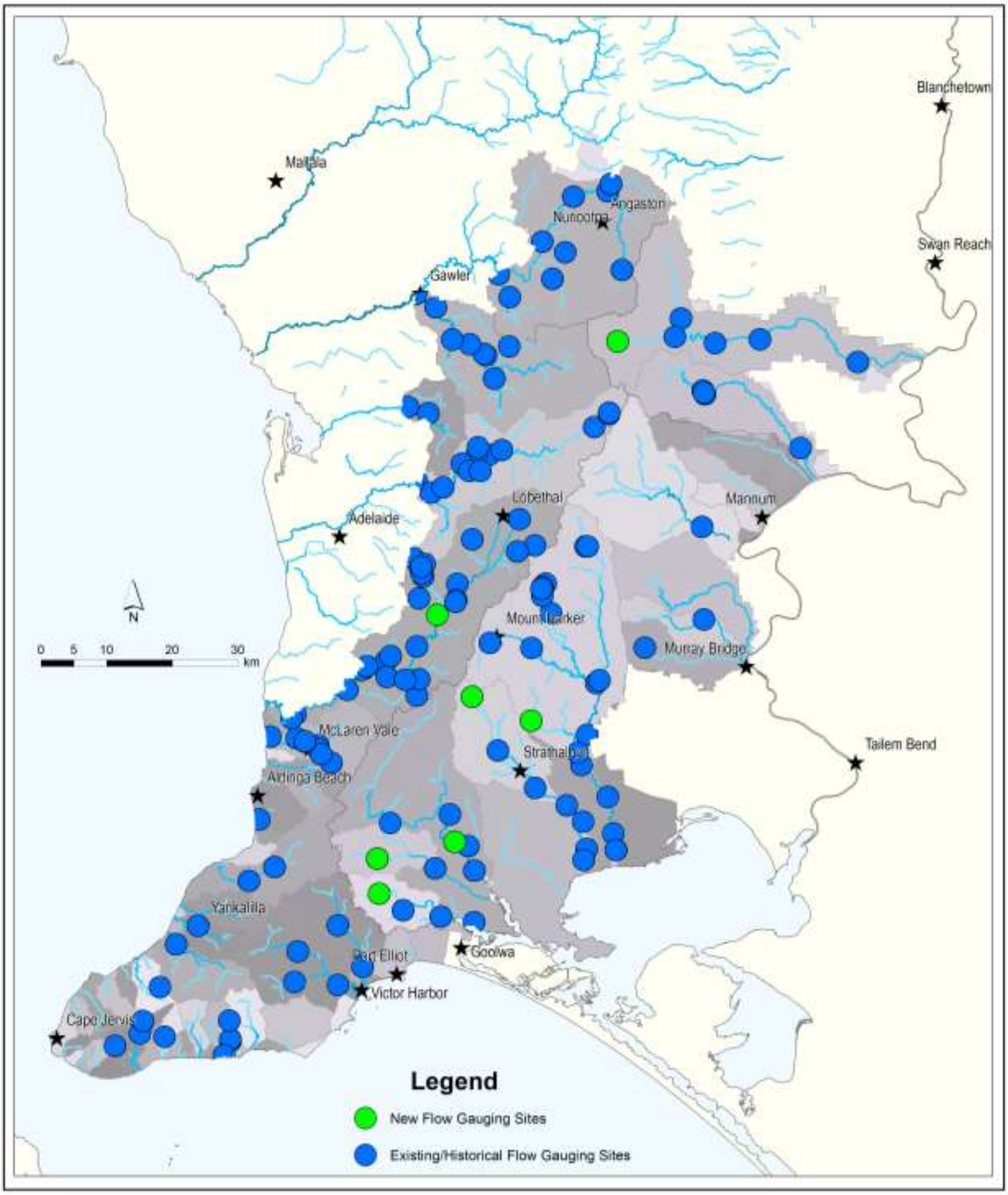


Figure 3 Locations of new GWAP hydrology monitoring sites and existing/historical monitoring sites.

All sites measure water level, and the Aldgate Creek site also measures dissolved oxygen. Data are currently recorded at 5-minute intervals, but any time interval can be programmed. All sites have solar panels and telemetry, allowing remote programming and data download.

These new sites will be used for calibrating updated surface water flow models, however, they will not be used for training the ecological models as the flow data will not cover the required time period. As the period of flow record increases it will be possible to incorporate the additional data into the hydro-ecological models.

4 Macroinvertebrates

4.1 Conceptual model

Macroinvertebrate communities are known to respond to changes in flow regime (e.g. Boulton *et al.* 1992, Growns and Davis 1994). The effects of changes in timing, magnitude, duration and variability of flow are manifest at multiple spatial scales, from landscapes to reaches to meso- and micro-habitats. Most streams in the MLR are 'intermittent' (cf. Mackay *et al.*, 2012) and prone to dry naturally in the summer months. Rivers which naturally contract to pools present challenges for organisms to complete their life cycles. Abstraction prolongs the periods of disconnection, and occurs mostly in the summer months, when there is less runoff and crops and other uses require water. Longitudinal, lateral and vertical connectivity are affected, disrupting pathways for dispersal, nutrient cycling and retention and intensifying inter- and intra-species competition (Larned *et al*. 2010).

Figure 4 shows a conceptual model described by a longitudinal gradient along the y axis and an intermittency gradient along the x axis. Increased periods of disconnection produce communities of lower diversity (alpha, beta and gamma diversity), favouring species with drought-resistant traits (e.g. multiple reproductive events per season (multivoltinism), poor water quality tolerance, aerial dispersal, rapid development, ability to tolerate high temperatures (thermophily), burrowing and resistant egg life stages. This contrasts with rivers which are at the wetter end of the gradient which are likely to favour trait such as single reproductive events per season (univoltinism), drift dispersal, slow development and an affinity for flowing environments (rheophily) (Larned *et al.* 2010, Poff *et al.* 2010).

See Maxwell *et al.* (in review) for more complete discussion of macroinvertebrate trait analysis and flow intermittency.

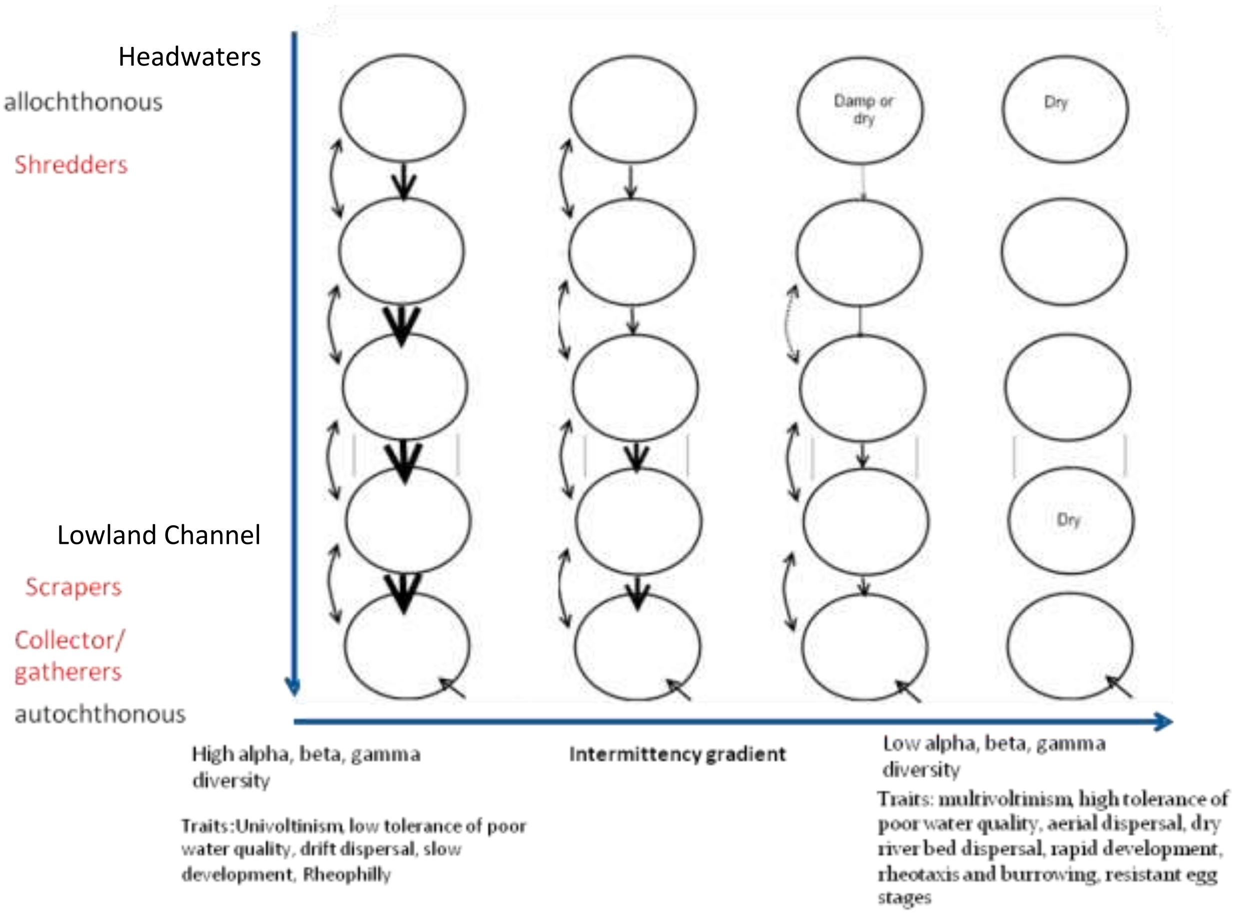


Figure 4: Macroinvertebrate conceptual model depicting trait changes with flow intermittency and longitudinal connectivity. Flow intermittency increases from left to right along x axis. Longitudinal gradient moves from top to bottom of the catchment from top to bottom along y axis.

4.2 Sampling

Previous macroinvertebrate sampling in the MLR has largely followed the AusRivAS protocol. A 10-metre sweep, maximising the coverage of microhabitats in pools and riffles over a 100 m reach has been the method of choice. Several programs of sampling have been undertaken since 1994. The EPA currently undertakes routine sampling Western every 2 years. Before 2007, the 10-m sweep sample was preserved and sorted entirely in the laboratory to the lowest possible taxonomic resolution. Since 2007, samples have been identified in the field, with voucher specimens preserved for identification. Abundance is measured by a categorical scale (1, 2-9, 10-100, 100-1000, 1000+)

Site selection for the GWAP project was targeted towards existing flow gauges in place across the MLR. The selection of the gauges was based on the presence of species of concern and to cover a gradient of abstraction. Several new sites were established to improve the coverage of several catchments, ecological communities and abstraction rates (see hydrology section and Figure 3).

4.2.1 DATA COLLECTION METHODS

Three data collection methods are referred to in this project. The single largest dataset is the EPA dataset (1994-2007) which has been collected using the EPA method. This method, a variant of the AusRivAS method, used a combination of live-pick and laboratory sorting and identification of all specimens (first method). To reduce the time and cost of analysis, the EPA in 2008 changed to a second, field sort only method, with voucher specimens sent to the lab for identification (second method). This is the method used for the rapid sampling undertaken in this project. The third method, involved sampling within sites and full lab sorting and identification of samples. Samples were collected using a 1m^2 sweep randomly located along thetransects. The data collected as part of the third method was not analysed as part of this project but remains one of the most detailed datasets of macroinvertebrates collected in the and will be used to determine fine-scale macroinvertebrate responses in up-coming projects and the WAP reviews.

EPA sampling technique

The sampling undertaken using the current EPA sampling technique was undertaken at 27 sites (Table 5) with pool and riffle sampling being undertaken at each site (where possible).

Table 5: List of the water courses and sites used for the sampling using the EPA sampling methodology.

WATER COURSE	SITE NAME
Angas River	near Willyaroo
Angas River	Quarry Rd
Angas River	u/s Strathalbyn
Boat Harbour Creek	Boat Harbour Creek
Bremer River	Hartley
Bremer River	Wirilda
Bremer River	Harrogate
Currency Ck	Lions Park
Currency Ck	Stuarts Bridge
Currency Ck	Kilchoan
Finniss River	East of Yundi
Finniss River	Lovejoy's
Finniss River	Braeside Rd
Giles Ck	opposite Signal flat rd
Hindmarsh River	Upstream falls
Hindmarsh River	Gauge
Inman River	Swains Crossing
Lenswood Ck	Onkaparinga Catchment
Marne River	south of Cambrai
Marne River	Gorge
Marne River	Gorge u/s weir
Marne River	Jutland Rd
Marne River	Vigars Rd
Rodwell Ck	Rodwell Creek
Rodwell Ck	Highland Valley
Somme Ck	Kappalunta
Tookayerta Ck	Hicks Property

Using this method 251 different taxa from 102 families were collected. This represents approximately 33% of the taxa that have been previously collected from South Australia since 1994.

The most abundant taxon was *Austrochiltonia* sp., which was collected at every sample site, with nearly 1000 individuals being recorded. This was followed by *Simulium ornatipes* and *Chironomus* spp. with 218 and 172 individuals collected, respectively.

The most diverse habitat was the edge samples. The highest diversity was recorded at Lovejoy's on the Finniss River and Hick's Property on Tookayerta Creek, with 64 taxa recorded at each site. This was followed by the Angas River upstream of Strathalbyn and the Hindmarsh River Gauge with 58 and 52 taxa, respectively. The lowest diversity was recorded in the riffle at Swains Crossing on the Inman River, with 22 taxa sampled.

There was no significant difference between the mean taxon richness of pool samples and riffle samples (t = 0.548, df = 40, p > 0.05), although this comparison is limited by the unbalanced numbers of samples of pools and riffles (37 and 18, respectively). The mean diversity of pool and riffle sites was 29.59 and 26.50, respectively.

Detailed Sampling technique

Detailed macroinvertebrate sampling was undertaken at 29 sites, with an average 8 transects sampled within each site (min 3, max 10), yielding 179 individual samples. Of these 179 sites, 110 were pools and 87 were riffles.

Table 6: Number of transects undertaken at each of the detailed sampling sites.

SITE	POOL TRANSECTS	RIFFLE TRANSECTS	TOTAL TRANSECTS
Aldgate	3	3	6
Back Valley Ck	3	3	6
Boat harbour	3	3	6
Braeside	4	3	7
Brownhill	5	3	8
Callawonga	4	3	7
Cleland Gully Rd	3	3	6
Glacier Rock	5	3	8
Harrogate	5		5
Hartley	5	3	8
Jacob Ck	3	3	6
Jutland Rd	3	0	3
Kappalunta	3	0	3
Kilchoan	3	3	6
Lenswood	5	3	8
Lion's Park	3	3	6
Lovejoys	4	3	7
Marne Gorge	3	0	3
Mt McKenzie	5	3	8
Mt Pleasant	3	3	6
Quarry Rd	4	3	7
Reedy Ck	3	0	3
Sixth Ck	5	3	8
Tanunda Gauge	4	3	7
Vigars Rd	3	0	3
Waterfall Gully	3	3	6
Willyaroo	5	3	8
Yaldara	3	3	6
Yundi	5	3	8
Grand Total	**110**	**69**	**179**

The detailed sampling collected 260 different taxa from 117 families in 26 higher taxa (order or above). This is about 34% of the species collected in South Australia since 1994, including several taxa not previously recorded. In total, about 40,000 macroinvertebrates were collected and identified.

The most abundant taxon was *Austrochiltonia* sp., collected 39,371 times in 157 sample. The macroinvertebrate group encountered at most sites were Oligochaeta, at 180 of 197 sites. Dipterans were the most commonly collected order with 136,500 individuals being collected, they were followed by amphipods (53,550 individuals), cladocerans (48,054 individuals), ostracods (37,053), gastropods (29,202 individuals) and oligochaetes (28,751 individuals). The decision to include zooplankton was to enable direct comparison with fish numbers.

The most diverse site was Transect 6 (pool) at Yundi in the Finniss Catchment, with 63 taxa . The site with the most individuals sampled was transect 1 at Lion's Park in the Currency Creek Catchment with 12,561 individuals being collected from 37 different taxa. However, it should be noted that Transect 9 (pool) at Lion's Park in the Currency Creek Catchment has the lowest number of individuals collected (90 individuals from 13 taxa), with the exception of Transect 9 (riffle) from Jacob Creek in the Barossa which had no taxa recorded, most likely due to the difficulty sampling the extremely rocky riffle habitat . The least diverse location was Transect 5 (pool) at Lenswood Creek in the Onkaparinga Catchment.

Mean species richness was higher in pool samples than in riffle samples (means 35.83 and 29.83, respectively: $t = 4.674$, df = 191, $p < 0.001$). This difference was not reflected in the mean abundances, however, where there was no significant difference (means 1985.36 and 2051.14, respectively; $t = -0.24$, df = 178, $p > 0.1$).

The abundance data showed considerably more within-site variation. Over half (15) of the pool sample data from the sites showed a standard deviation greater than half of the mean, with only five sites showing low levels of within-site variation (Aldgate Creek, Jutland Rd, Kappalunta, Tanunda Gauge and Vigars Rd). The riffle data showed similar results, with 13 of the 23 sites showing high levels of within-site variation, and a further seven showed moderate levels of variation within sites. Across both pool and riffle habitats there was almost consistently moderate or high levels of variation within sites. Only the three Marne catchment sites showed low levels of variation within sites, but these sites had no riffle habitats at the time of sampling.

Cluster analysis and non-metric multidimensional scaling did not reveal any separation of samples based on habitat. There were differences between sites and catchments, with 45 of the 121 pairwise differences being significant ($p < 0.05$, Global R = 0.116, overall $p < 0.01$). There were also pairwise differences between sites, with 146 of the 465 pairwise comparisons being significant ($p < 0.05$, Global R = 0.176, overall $p < 0.01$).

4.3 Model development

Trait analysis

A species list for the MLR was compiled using the data from previous EPA sampling as well as the two datasets compiled in for this project. This resulted in a species list of approximately 800 taxa. Traits for each of the species was compiled from a variety of sources including the literature and local experts. Cluster analysis of the traits indicated eight distinct trait groups that were used for all further work (see table 7). Predictions were made for each trait group based on the traits present. See Maxwell *et al.* in review for detailed explanation.

Table 7: Macroinvertebrate trait groups identified through trait analysis

Trait group	General Traits	Example Macroinvertebrate groups
Trait Group A	Resistant, Obligate Aquatic, Flow Avoiders	Oligochates and Hemipterans
Trait Group B	Resistant, Low dispersing, Flow Avoiders, terrestrial eggs	Coleoperans, Some Dipteran families and Collembolans
Trait Group C	Resistant, Low dispersing, flow avoiders, aquatic eggs	Gastropods, Lepidopterans
Trait Group D	Resilient/resistant, gill respiring, obligate aquatic	Amphipods, Decapods and gastropods
Trait Group E	Resistant, Predatory, Salt tolerators	Coleoptera, Odonata, Trichoptera
Trait Group F	Resilient, gill respiring, flow obligates	Ephemeroptera, Trichoptera
Trait Group G	Resistant, spiracle respiring, flow obligates	Some Dipteran families
Trait Group H	Resilient, detrital feeding, facultative flow responders	Some Dipterans, Trichoptera, Plecoptera

By splitting the macroinvertebrate community into trait groups allows for a simplified, yet effective, analysis of changes in the community structure related to changes in flow conditions, or other drivers of macroinvertebrate community structure.

Response Modelling

The response models developed for the macroinvertebrate trait groups are presented in Maxwell *et al.* (in prep.). Below is a summary of the methods used.

Response modelling was undertaken using the largest dataset available, the 1994-2007 EPA dataset. The macroinvertebrate data was paired, where possible, to flow data collected from flow monitoring stations located across the MLR. Macroinvertebrate sampling sites that were within 500m of a flow monitoring site were chosen. Beyond 500m the flow recorded was not considered to be representative of the flow at the macroinvertebrate sampling site.

Models were developed to investigate the effect of flow on the macroinvertebrate community structure. Based on the review of previous method, three main variables were identified as being important to the macroinvertebrate community, intermittency, average flow and the level of variability of flow experienced. Based on this the three flow metrics used were ‘number of zero flow days’, ‘mean daily flow’ and ‘coefficient of variation of mean daily flow’. These were calculated for the preceding 90 days, one year, 5 years and ten years.

Prior to modelling responses, the predictor variables were examined to ensure that observed effects were not confounded by inter-correlated variables. Correlations of over 90% were investigated, and one of the variables removed from the analysis.

We attempted to build response models for each of the identified trait groups as well as other, more generic measures such as species richness, trait richness, the proportion of predators in the sample and the commonly used water quality sensitive EPT taxa (Ephemeroptera, Plecoptera, Trichoptera).

Response modelling was undertaken using generalised linear models, using the lmer package in R (R Core Team 2013). Individual relationships between the response variables and the flow metrics and other predictor variables were examined using generalised linear models. For each response model the predictor variables that showed an interaction were compiled into a single response model. This large model was then simplified using the method set out in Crawley (2014) until the simplest models that explained the most variation was determined.

When used in a predictive sense, these models predict their respective response (species richness, trait richness, trait group proportion etc.) based on the flow variables inputted. In the case of the WAPs, the flow variables would be generated from modelled water management scenarios. This will allow managers to see how different management decisions will affect the macroinvertebrate community. The models all shows some response to changing flow regimes, however, the variance explained was less than expected, suggesting other factors such as water quality are also likely to be important in the macroinvertebrate response. For a full examination of the results see Maxwell *et al.* (in review).

Prediction of Macroinvertebrate Community and Summary Statistics

The prediction of the macroinvertebrate community structure based on the trait group generalised linear models could be used to establish how changes in flow regime will affect the macroinvertebrate community. This provides a method for assessing different management options under consideration for the WAPs. Ongoing monitoring will both validate the modelling and provide additional data for updating the models. An approach to do this is proposed below and presented in detail in Green and Maxwell (in prep).

Using flow modelling software it is possible to generate modelled flow data for different management scenarios. This process is currently used for assessing different policy options for WAPs. This modelled daily flow data can be used with the response models developed as part of this project to estimate the species richness, trait richness and trait group proportions, providing a modelled macroinvertebrate community.

Providing an estimate of the macroinvertebrate community under different flow regimes is of little value if there is nothing to compare it to. For this reason, the approach recommended is to use the flow modelling software to develop three flow scenarios, the modelled current flow, a modelled scenario with the effects of dams and other abstractions removed (the 'no dams' scenario) and the scenario to be tested. This approach provides two reference points to be used for comparison.

The modelled current scenario provides an indication if the planned management strategy and policy options will result in a change from the current conditions. Under the overarching ecological objective of the WAPs in the MLR, any change from current is considered not desirable, unless that change represents an improvement. To understand what represents an improvement, we need to know what the optimal macroinvertebrate community is for a given site. This is difficult to measure as there are very few 'reference condition' (natural flow and habitat) sites left in the MLR, certainly not enough to obtain a reference site for each test site.

As a surrogate, the 'no dams' scenario represents the community that would be present if the effects of water abstraction were removed. By looking at the changes between the trait groups between the three different flow scenarios it is possible to see if the test flow scenario results in a change to the macroinvertebrate community, and if that change represents an improvement.

Aligning these changes with the current objectives in the WAPs is difficult as the current ecological objective for macroinvertebrates relates to a condition gradient developed by the EPA which looks at species present and compares these to a reference condition site. Discussions with staff from the EPA should be able to align the outputs of the trait group analysis with this condition gradient.

Further development of these modelling approaches, combined with a risk assessment framework based on the outputs of the different modelled flow scenarios will provide an empirical, more rigorous and defensible approach to developing EWRs.

5 Aquatic and riparian vegetation

5.1 Conceptual model

Models of aquatic and riparian vegetation dynamics in MLR streams were developed based on reach types and plant functional groups (Casanova 2011), using expert knowledge and data on species responses to inundation and exposure. Plant functional groups provide a robust way of assessing a large number of species, where development of individual species response models is impractical. The plant species in the MLR generally are cosmopolitan or widespread in Australia, which means there is published information on the ecology and physiology from other regions for most of the common aquatic and riparian species.

Plants were classified by Casanova (2011) as 'terrestrial', 'amphibious' or 'submergent' ('amphibious' was further split into whether the species tolerate or respond anatomically to fluctuating water levels) (Table 8). Terrestrial species are intolerant of prolonged flooding and are split into terrestrial dry (e.g. *Atriplex*, which is desiccation tolerant and intolerant of flooding and water logging) and terrestrial damp (e.g. *Centipeda*, which is intolerant of extended inundation but requires high soil moisture). Terrestrial damp species are often wet season annuals. Amphibious fluctuation tolerators can tolerate inundation or exposure, but do not respond anatomically, and are split into three groups: woody (e.g. *Duma florulenta* or *Eucalyptus camaldulensis*), emergent (e.g. *Juncus usitatus* or *Cyperus gymnocaulos*) and low growing (e.g. *Lilaeopsis polyantha* or *Crassula helmsii*). Amphibious responders respond anatomically to changing water levels (e.g. *Villarsia reniformis*, leaf petioles will extend when flooded or *Azolla*, which floats on the water surface when flooded and takes root in the sediment when exposed). Submergent species are intolerant of exposure or require permanently saturated soil in the root zone, they are split into three groups: *r*-selected (e.g. *Ruppia tuberosa*, which are adapted to temporary pools growing when there is water in the pool and persisting in the seed bank as turions or seeds when conditions are dry), emergent (e.g. *Typha* spp. or *Phragmites australis*, which require permanent shallow water or permanent saturated soil in the root zone), and *K*-selected (e.g. *Vallisneria australis*, which requires permanent water).

The plot of plant functional group as a function of inundation depth and duration provides a useful way of visualizing where these functional groups sit along the inundation gradients (Figure 5). This was used to define the water requirements for each plant functional group in development of the eastern and western MLR WAPs. The plant functional group approach is robust and transferable between systems in a range of environments; there are some limitations (e.g. for floodplain species), but the method has been shown to work well for the MLR (e.g. Casanova 2011; VanLaarhoven and van der Wielen 2009).

Table 8. Functional classification of plant species based on water regime preferences (Casanova 2011).

FUNCTIONAL GROUP	ABBREVIATION	WATER REGIME PREFERENCE	EXAMPLES
Amphibious fluctuation responders floating	AFRf	Static or fluctuating water levels, responds to fluctuating water levels by having some or all organs floating on the water surface. Most species require permanent water to survive but some species will persist on mud.	*Azolla* spp., *Lemna* spp., *Potamogeton tricarinatus*
		Fluctuating water levels, plants respond morphologically to flooding and drying (e.g. increasing above to below ground biomass ratios when flooded).	*Persicaria lapathifolium,* *Ludwigia peploides,* *Rumex bidens,* *Villarsia reniformis* *Myriophyllum* spp.
		Fluctuating water levels, plants do not respond morphologically to flooding and drying and will tolerate short-term submergence (<2 weeks).	*Cyperus vaginatus,* *Juncus usitatus,* *Cyperus exaltatus*
Amphibious fluctuation tolerators low growing	ATl	Amphibious fluctuation responders plastic	AFRp
Amphibious fluctuation tolerators woody	ATw	Amphibious fluctuation tolerators emergent	ATe
Submerged Emergent	SE	Static shallow water <1 m or permanently saturated soil.	*Typha* spp., *Phragmites australis,* *Schoenoplectus validus,* *Bolboschoenus caldwellii*
Submerged k-selected	Sk	Permanent water.	*Vallisneria australis,* *Potamogeton crispus,* *Zanichellia palustris*
Submerged r-selected	Sr	Temporary wetlands that hold water for longer than 4 months.	*Ruppia tuberosa,* *Lepilaena australis,* *Chara fibrosa*
Terrestrial damp species	Tda	Will tolerate inundation for short periods (<2 weeks) but require high soil moisture throughout their life cycle.	*Centipeda minima* *Chenopodium murale*
Terrestrial dry species	Tdr	Will not tolerate inundation and tolerates low soil moisture for extended periods.	*Atriplex vesicaria*, *Rhagodia spinescens,* *Enchylaena tomentosa*

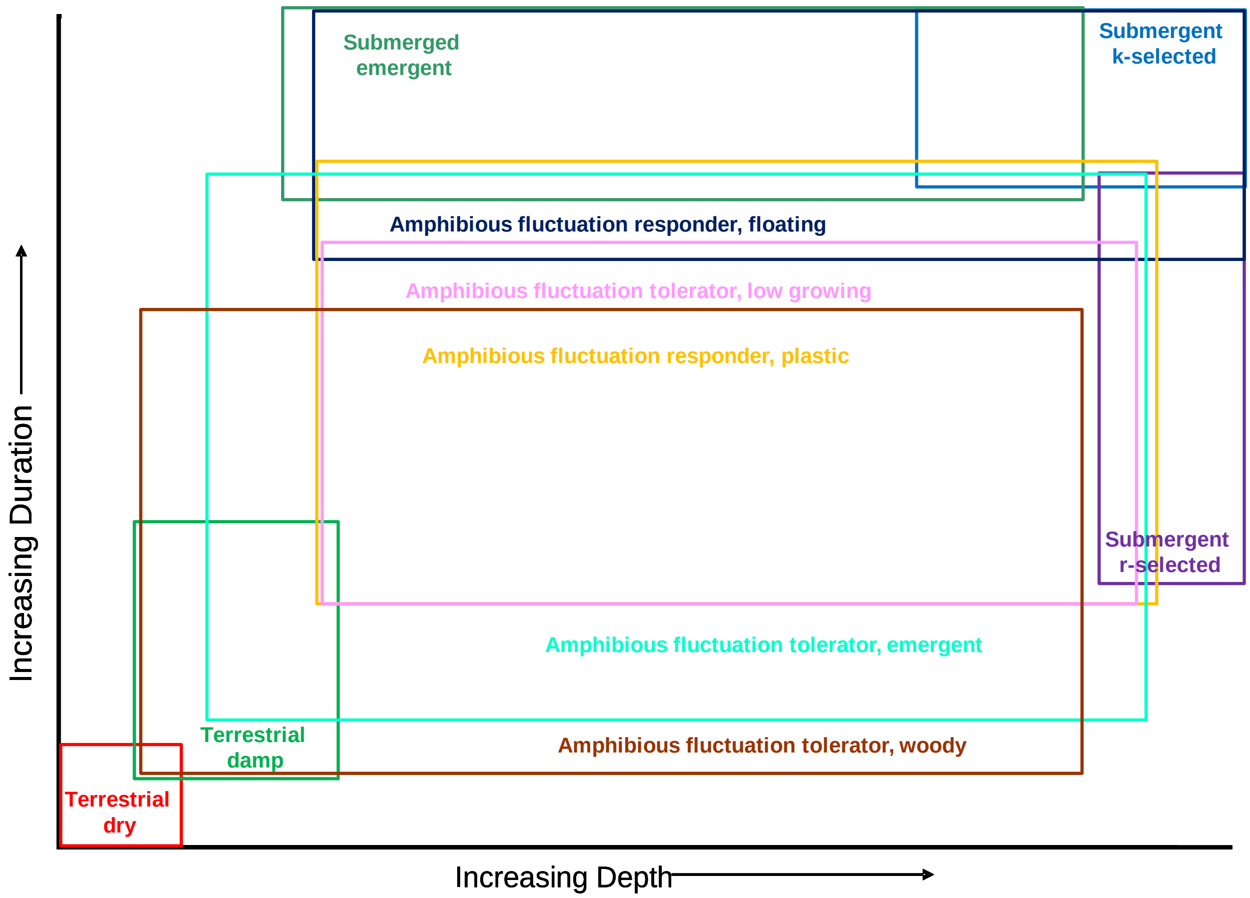


Figure 5. Plant water regime functional groups in relation to depth and duration of flooding.

The conceptual model for fish and macroinvertebrates (as per chapter 5 and 6) has been adapted for aquatic and riparian vegetation to make predictions regarding the presence or absence of functional groups in a reach type under different climatic conditions and/or levels of extraction. The model consists of four states (seasons): low/no flow, low to high flow, high flow and high to low-flow, and six reach types: headwaters, upper pool riffles, mid pool riffles, gorge, lowland and terminal wetland or estuary (Fleurieu Swamps removed from this analysis due to lack of data, Figure 6). Arrows between reach types represent surface water flow. Unlike fish and macroinvertebrates, which respond to flow and connectivity between habitats, the primary factors that influence the distribution and abundance of plant species are water level and hydroperiod (Casanova 2011).

Figure 6a represents a perennial, groundwater-fed system such as Tookayerta Creek in the eastern MLR. This system is permanently connected from the upper pool riffles to the terminal wetland, which is permanently inundated by Lake Alexandrina. Headwaters are connected during the high flow season and for parts of the low to high and high to low-flow seasons. Plant functional groups present are amphibious or submergent throughout the stream, with terrestrial dry species restricted to the headwaters and upper pool riffles during the low-flow season (Figure 6a). If abstraction increases or climate change results in reduced inflows, the low-flow season may be extended and there may be disconnection of other habitats during the low-flow season. This may result in terrestrial dry species invading other habitats and the extirpation of submerged taxa (particularly submerged *K*-selected species if permanent pools dry).

In contrast, Figure 6b represents a dry system with a losing lowland reach, such as the Marne River. There is complete disconnection between reaches during the dry season with the stream consisting of a series of disconnected pools. Flows re-establish connectivity between upper pool riffles, mid pool riffles and the gorge during the low to high, high and high to low-flow seasons. However, there is only intermittent connection with the lowland and terminal wetland during very high flows. Generally the gorge and mid-pool riffle reaches are the most permanent (except for the terminal wetland) and have more amphibious and submerged species. These are predominantly submerged, *r*-selected species, adapted to the more ephemeral nature of these systems, although there are often large stands of submerged emergent species downstream of the headwaters. Terrestrial dry species are common throughout the system even during the high flow season. The terminal wetlands are either connected to the River Murray (or Lake Alexandrina) or are estuaries, which are permanently inundated and support a large number of functional groups. These systems are particularly vulnerable to abstraction and climate change, as even small reductions of inflows can result in a large reduction of the duration of the high flow season. This has significant implications as permanent pools may become temporary and water quality can deteriorate.

The conceptual model summarises the current understanding of plant communities in MLR streams and how they may change in response to water allocation. However, its predictive capacity is limited and it is yet to be extensively tested; hence, this task aims to collect data that can be used to further develop a predictive model of vegetation in MLR streams.

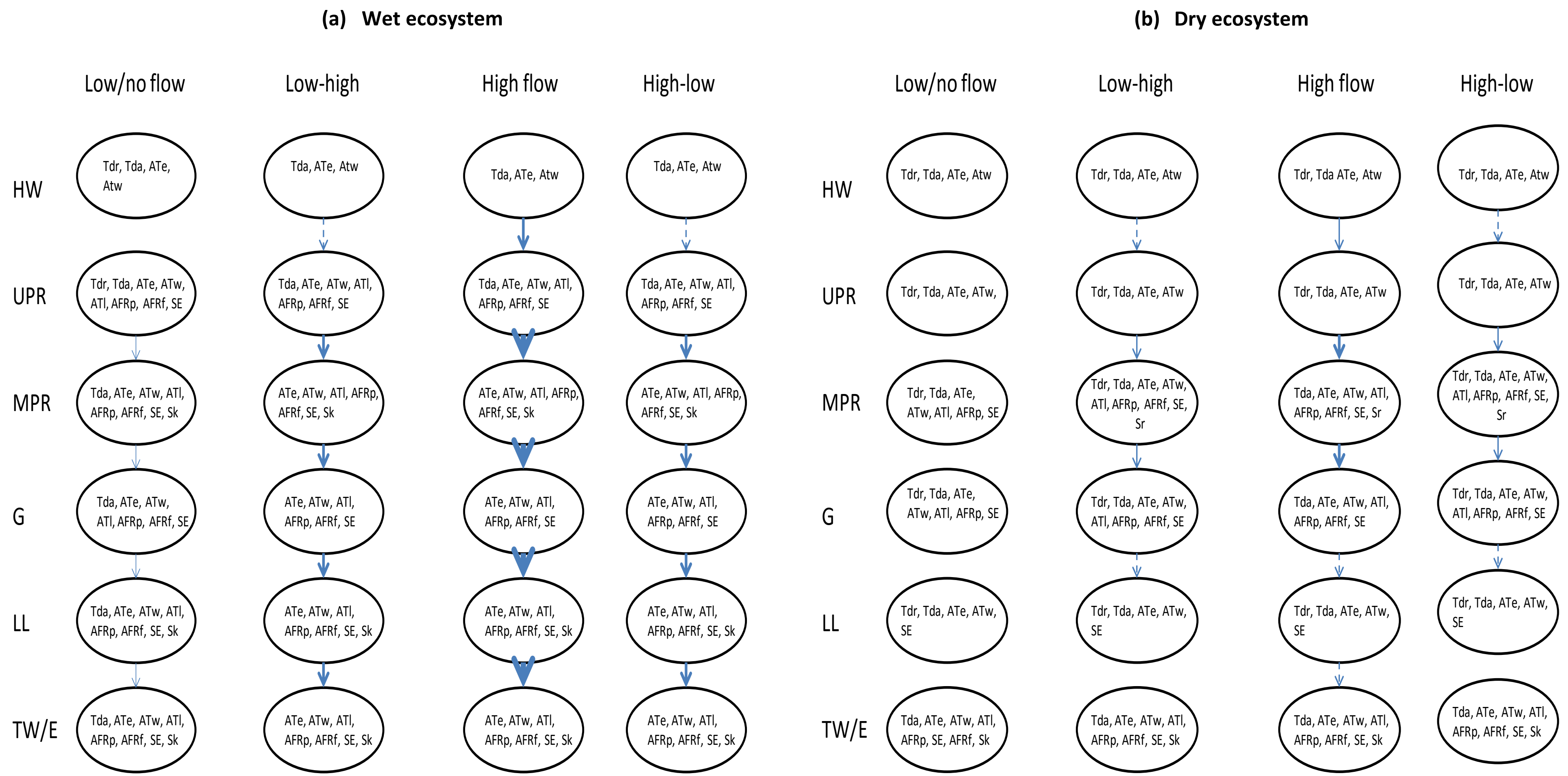


Figure 6. Conceptual model of the species of aquatic and riparian vegetation expected to be present in (a) wet ecosystems (permanent groundwater fed system, e.g. Tookayerta Creek) and a dry system (losing lowland reach, e.g. Marne River or Saunders Creek) below the normal high water level for each of the six reach types studied (Fleurieu Swamps not included). Plant functional group codes are described in Table 8.

5.2 Sampling

5.2.1 PREVIOUS STUDIES IN THE MOUNT LOFTY RANGES

Sampling in the western MLR environmental flows and the Barossa WAP projects (Nicol 2013) involved the visual estimation of percentage cover (using two observers) of all species present (including open water, bare soil, bed rock, gravel, cobbles and any other bare substrate) below the spring water level in a pool and adjacent upstream riffle, run or cascade (Figure 7). In addition, the percentage cover of overstorey (where present) is recorded separately. In the WMLR environmental flows monitoring project, series of three pools and three riffles were surveyed at each site to enable comparisons at the site scale.

The method surveys entire pools and riffles (runs or cascades); thus, there is less chance species will be missed in comparison to fixed area quadrat based surveys. The method works well for small pools and riffles, but there can be difficulties when surveying larger areas. Furthermore, this method provides no information regarding the distribution of species within sites.

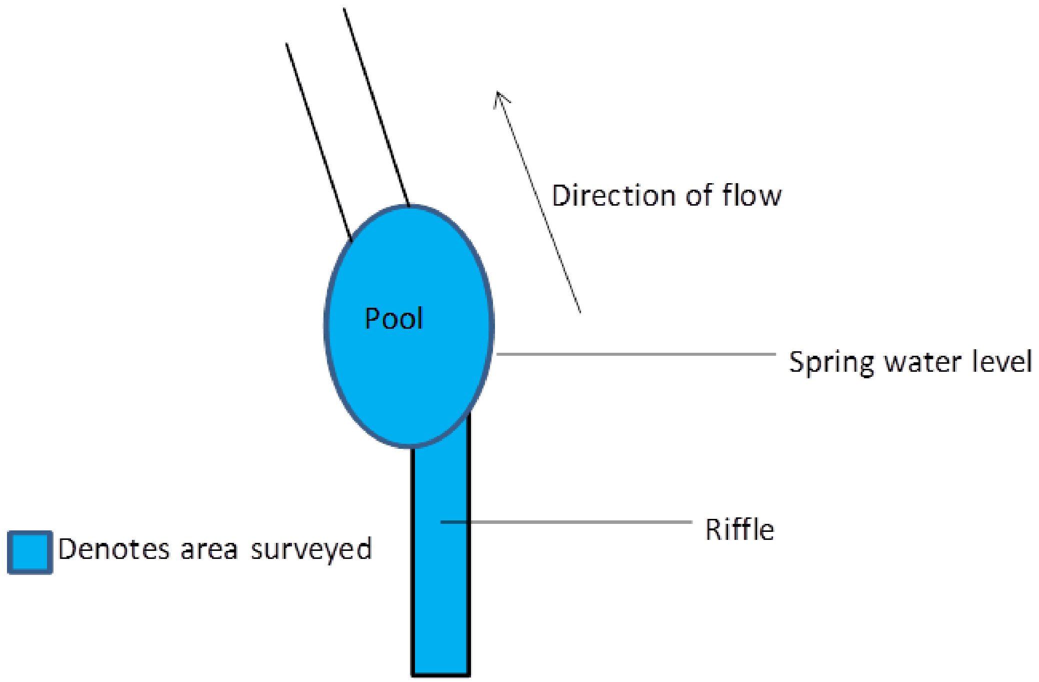
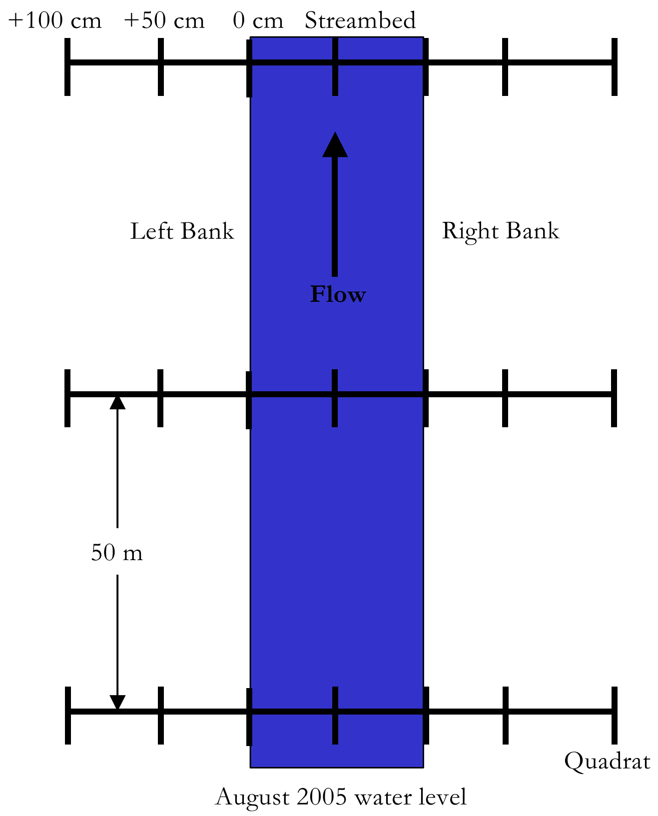


Figure 7 Plan view of an idealised survey site.

In an additional method trialled as part of the Barossa WAP project, Nicol (2013) recorded species distributions at individual sections of stream where cross-sections were recorded for hydrological measurements. This involved recording the distribution of species across the stream at each site, using a point intercept method. A measuring tape was extended horizontally across the stream at the site of the cross-section and the horizontal extent of species present was recorded. This method provided information regarding the distribution of species across a stream cross-section; however, there were problems in displaying the data and at some sites the vegetation cross-section could not be recorded at the same points as the hydrological cross-section due to uncertainty over the position of the latter. Furthermore, hydrological cross- sections were often taken where there are gauging weirs and very little vegetation, and the stream bed shape is unnatural. In the future, this type of data would be best collected at the same time as the hydrological cross-sections, or using a differential GP system (e.g. Trimble RTK™) that can accurately plot positions in three dimensions. Using such a system it would be possible to obtain the positions of plant species and communities in three dimensions, including elevation. When elevation information is obtained, where there is stream gauging information, it can then be used to determine the flow magnitude that will inundate a community and the frequency of inundation. This information can then be used to develop or refine eco-hydrological models.

Quadrat-based surveys were used by Nicol and Bald (2006) for surveys of the Onkaparinga River in 2005, to provide preliminary data for the environmental flows project. At each site (except Clarendon Oval), three transects perpendicular to the stream bank, 50 m apart were established (Figure 8a). Quadrats were established along each transect parallel to the bank in the middle of the stream bed, and on each bank at the August 2005 water level, 50 cm and 100 cm above the water level (Figure 8b). Quadrats were established on the streambed and left-hand bank at Clarendon Oval because the right-hand bank was too steep to survey. The elevation of the water level in August 2005 was measured relative to a fixed reference point, to enable the same areas to be surveyed each visit.

a.



b.

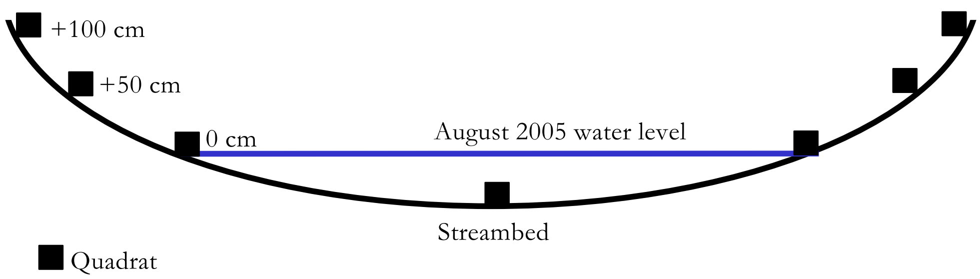


Figure 8: Vegetation surveying protocol for the initial surveys of the Onkaparinga River at Brooks Road, Sundews Track and Old Noarlunga, a. plan view and b. cross-section. The Clarendon Oval site only has quadrats in the streambed and left bank (the right bank was too steep to survey).

Quadrat dimensions were determined by species area curves (Figure 9) and the most appropriate dimensions were 1 x 20 m. This enabled narrow bands of vegetation to be surveyed at the different elevations without quadrats overlapping.

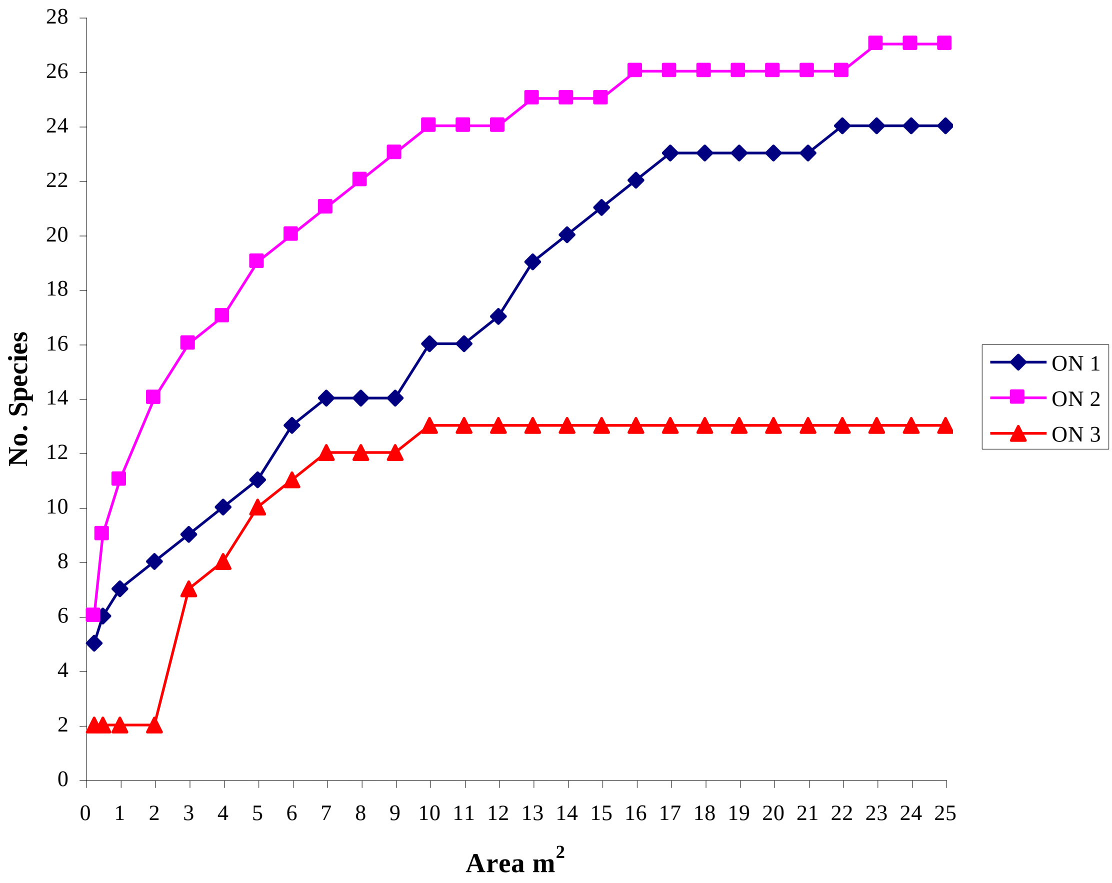


Figure 9 Species area curves from three sites at Old Noarlunga.

The floristic composition of each quadrat was determined by visually estimating the percent cover of each species, bare soil, bedrock and open water. Surveys were undertaken in August, November and December 2005. The December survey was undertaken because a large rainfall event in the catchment occurred one week after the November survey, causing Mt Bold Reservoir and the Clarendon Weir to spill, with significant flooding downstream of the weir; thus, this method was able to detected changes in floristic composition through time and in response to the flood.

5.2.2 GWAP VEGETATION SURVEYING PROTOCOL

Vegetation surveys were undertaken in spring 2013 and autumn 2014 at each site where macroinvertebrates and fish were sampled. Two survey techniques were employed:

1. Visual estimation of the percentage cover of plant species of entire pools and the adjacent upstream riffle, run or cascade, and
2. A point intercept method, used to develop response functions for the model.

Surveying Entire Pools and Riffles

Visual estimation of the percentage cover of entire pools and riffles was undertaken at each site. This enables data to be collected as part of the GWAP project, for comparison with the Barossa WAP (Nicol 2013) and environmental flows project. The technique is outlined in the previous section. These data can be used to characterise sites (if required), or used as a baseline for future monitoring, but they were not used in the response model.

Point Intercept Method

The point intercept method was used to collect the data used in development of the response model. It involved establishing 10 transects at each site, running perpendicular to the stream bank (Figure 10). Where possible, five transects were established (and marked with surveyors' pegs to ensure the physical surveys were undertaken at the same location) in the pool and in the adjacent upstream riffle, run or cascade (Figure 10), although this was not always possible due to the small size of pools and riffles at some sites. If there was insufficient space, transects were established in adjacent pools and riffles, but there were always a total of five transects in pools and five in riffles.

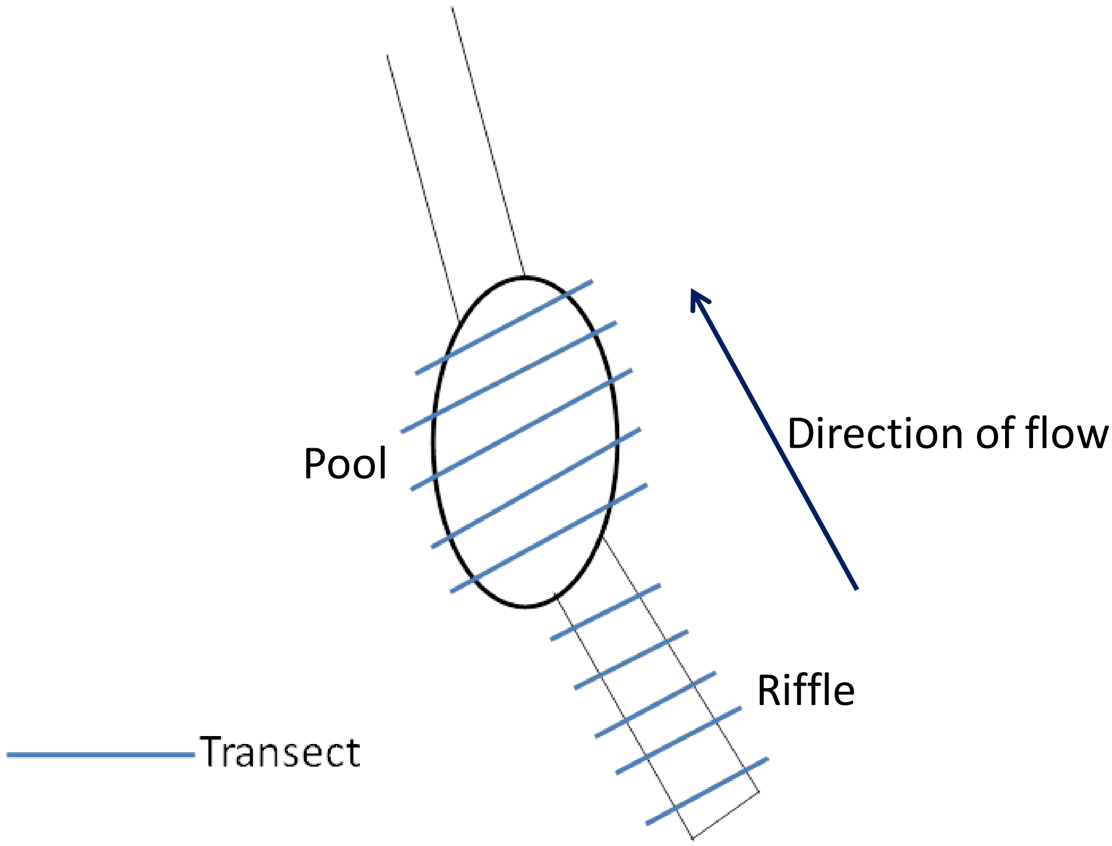


Figure 10: Plan view of an idealised survey site showing the position of transects.

A surveyor's tape was extended across the stream at each transect and at five random points, determined by a random number generator, 1 x 1 m quadrats were placed at the corresponding metre mark on the surveyor's tape and species present in each quadrat were recorded. Quadrats were placed a different points along the tape in the spring 2013 and autumn 2014 surveys to avoid repeated measurements and to increase the number of species recorded and elevations surveyed. Physical surveys were undertaken at each transect and a cross-section of the stream along each transect produced. The position of each quadrat was plotted on the cross-section and the elevation determined. Using the elevation of the quadrat and historical flow data, the number of days each quadrat was inundated was modelled for five historical time series: the previous 90 days and the previous 1, 3, 5 and 10 years.

Plant identification and nomenclature

Plants were identified using keys in Sainty and Jacobs (1981, 2003), Romanowski (1998), Jessop and Tolken (1986), Jessop *et al.* (2006), Dashorst and Jessop (1998) and Prescott (1988). Nomenclature follows the Centre for Australian National Biodiversity Research and Council of Heads of Australasian Herbaria (2015). Plants were identified to species where possible, but in some cases identification to genus only was possible. Exotic annual grasses were grouped in a single taxon called 'invasive annual grasses'. These included *Bromus* spp., *Avena* spp. *Lolium* spp. *Briza* spp., *Holcus lanatus* and *Ehrharta longiflora*.

5.2.3 DATA COLLECTION

The method used to collect information for the ecological response models was designed to collect a large amount of data across water-availability gradients in the Mount Lofty Ranges, to enable response functions to be developed (*sensu* Ganf *et al.* 2010). This resulted in a large data set and the development of response functions for 35 taxa, used in the predictive model. However, these data are not suitable for monitoring to assess change through time or the response of the plant community to management actions. Alternative techniques need to be developed for monitoring programs, dependent on program objectives. One technique that has proved appropriate for site characterisation in the Barossa catchment (Nicol 2013) and for monitoring the change in plant communities in response to the provision of environmental flows from reservoirs in the Western Mount Lofty ranges (Nicol, in prep.) is the visual estimation of percentage cover of species in entire pools and riffles below a certain elevation (e.g. the spring high-water level). This was undertaken as part of the field component of this project to characterise sites, and to compare them to other MLR sites if necessary. Another approach to monitoring vegetation is to establish quadrats across streams and catchments at elevations where the hydrology is consistent (i.e. in permanently inundated areas or at an elevation that inundated for a certain number of days each year). This avoids confounding effects of hydrology between sites and enables comparisons between sites and catchments (unlike using elevation where only comparisons within sites at different times can be made: *sensu* Nicol and Bald 2006). This technique could be useful to monitor the impacts of factors other than hydrology (e.g. grazing, riparian fencing).

5.3 Data analysis

A series of response functions that describe the relationship between the occurrence of a taxon and the number of days a quadrat was inundated (inundation history) in the previous 1, 3, 5 and 10 years form the basis of the vegetation response model (*sensu* White *et al.* 2008, Ganf *et al.* 2010). The data used to develop the response model utilise water availability gradients present in the landscape. In the MLR there is a north-south water availability gradient with the cease to flow periods being shorter in streams in the south than in the north. Furthermore, there are water-availability gradients at the catchment scale, with wetness generally increasing with stream order, except for the lowland reaches of most streams that are generally losing reaches and are drier. Finally, there is a water-availability gradient at the site scale, dependent on elevation, with water availability decreasing with increasing elevation. Sampling throughout the MLR at the landscape scale and at different elevations at the site scale resulted in a large number of points across the water-availability gradient. These range from permanently-inundated pools and flowing reaches to areas that are inundated for very short periods in large floods. By sampling across this gradient, the species that typify points on the water-availability gradient can be identified and changes in the probability of occurrence of a species caused by changes in hydrology (as a result of climate change or water allocation) can be predicted (i.e. a space-time substitution).

A total 3834 quadrats was surveyed at 42 sites in spring 2013 and autumn 2014. Of 159 taxa, 78 were recorded in 10 or more quadrats and selected to form part of the response model (

Table 9).

Table 9: List of taxa and the corresponding functional group (Casanova 2011) with 10 or more observations that were selected for analysis (*denotes exotic species).

Taxon	Functional Group
Acacia spp.	Terrestrial dry
Adiantum sp.	Terrestrial damp
*Apium graveolens**	Terrestrial damp
*Arctotheca calendula**	Terrestrial dry
*Arundo donax**	Amphibious fluctuation tolerator emergent
Baumea spp.	Amphibious fluctuation tolerator emergent
Berula erecta	Amphibious fluctuation tolerator emergent
Betula sp.*	Terrestrial dry
Bolboschoenus spp.	Submerged emergent
Callistemon sp.	Terrestrial dry
Calystegia sepium	Amphibious fluctuation tolerator emergent
Carex apressa	Amphibious fluctuation tolerator emergent
Chara spp.	Submerged r-selected
*Chenopodium album**	Terrestrial damp
Cotula spp.	Amphibious fluctuation responder plastic
*Cynara cardunculatus**	Terrestrial dry
Cyperus exaltatus	Amphibious fluctuation tolerator emergent
Cyperus gymnocaulos	Amphibious fluctuation tolerator emergent
Distichlis distichophylla	Terrestrial damp
Duma florulenta	Amphibious fluctuation tolerator woody
*Echium plantagineum**	Terrestrial dry
Eleocharis spacthaelata	Submerged emergent
*Erodium cicutarium**	Terrestrial dry
Eucalyptus camaldulensis	Amphibious fluctuation tolerator woody
*Euphorbia terracina**	Terrestrial dry
Ficinia nodosa	Amphibious fluctuation tolerator emergent
*Foeniculum vulgare**	Terrestrial damp
*Fraxinus excelsior**	Terrestrial dry
*Fumaria bastardii**	Terrestrial damp
Gahnia filum	Amphibious fluctuation tolerator emergent
*Galium murale**	Terrestrial dry
*Genista monspessulana**	Terrestrial dry
*Hedera helix**	Terrestrial dry
Hydrocotyle verticillata	Amphibious fluctuation responder plastic
Isolepis spp.	Amphibious fluctuation tolerator emergent
*Juncus acutus**	Amphibious fluctuation tolerator emergent
Juncus usitatus	Amphibious fluctuation tolerator emergent
Lactuca spp.*	Terrestrial dry
Lemna minor	Amphibious fluctuation responder floating
Leptospermum sp.	Terrestrial damp
Lobelia anceps	Terrestrial damp
Lycopus australis	Amphibious fluctuation tolerator emergent
Medicago spp.	Terrestrial dry
Mimulus repens	Amphibious fluctuation tolerator low growing
*Nephrolepis cordifolia**	Terrestrial damp
*Nothoscordum odoratum**	Terrestrial dry
*Olea europaea**	Terrestrial dry
*Oxalis pes-caprae**	Terrestrial dry
*Paspalum dilitatum**	Terrestrial damp
*Pennisetum clandestinum**	Terrestrial dry
*Pennisetum vilosum**	Terrestrial dry
Persicaria lapathifolia	Amphibious fluctuation responder plastic
*Phalaris arundinacea**	Amphibious fluctuation tolerator emergent
Phragmites australis	Submerged emergent
Pinus spp.*	Terrestrial dry
Plantago lanceolata	Terrestrial dry
Potamogeton pectinatus	Submerged k-selected
Potamogeton tricarinatus	Amphibious fluctuation responder plastic
Pteridium esculentum	Terrestrial dry
Ranunculus spp.	Amphibious fluctuation responder plastic
*Rosa canina**	Terrestrial dry
*Rubus fruticosus**	Amphibious fluctuation tolerator emergent
Rumex bidens	Amphibious fluctuation responder plastic

Taxon	Functional Group
*Salix babylonica**	Submerged emergent
*Scabiosa atropurpurea**	Terrestrial dry
Schoenoplectus pungens	Amphibious fluctuation tolerator emergent
Schoenoplectus validus	Submerged emergent
*Senecio pterophorus**	Terrestrial dry
*Solanum nigrum**	Terrestrial damp
*Sonchus oleraceus**	Terrestrial dry
Triglochin procera	Submerged emergent
Trifolium spp.*	Terrestrial dry
Typha domingensis	Submerged emergent
*Ulex europeaus**	Terrestrial dry
*Vicia sativa**	Terrestrial dry
*Vinca major**	Terrestrial dry
*Watsonia bulbilifera**	Terrestrial dry
Invasive annual grasses*	Terrestrial dry

The probability of occurrence of a species at a point in a stream was calculated by dividing the number of observations at each modelled inundation interval (the height of each quadrate relative to the cease to flow point of the pool/riffle sequence) by the total number of quadrats present at that interval. Probability of occurrence was calculated for each taxon for each of the modelled inundation histories, which were calculated by using the cross section rating curves to identify the flow required to inundate a quadrate and then using the flow data from the existing flow gauging station to identify how many days the quadrate was inundated. Non-linear regression (three parameter Gaussian curves using the equation $y= a*\exp(-0.5*((x-x0)/b)^2)$, where y=the probability of occurrence and x=the modelled number of days inundated) was applied for each taxon for each modelled inundation history (*sensu* White *et al.* 2008, Ganf *et al.* 2010) and significant relationships between modelled inundation history and probability of occurrence were detected for 48 taxa. However, after inspection of the data and curves, only 35 were chosen to be included in the model; taxa were rejected because of too few observations or outliers. If a taxon showed a significant relationship with more than one modelled inundation history the modelled inundation history with the lowest probability value was chosen for the model. The number of days a quadrat was inundated over the previous 90 days was generally not a good predictor of probability of occurrence and all taxa that showed a significant relationship had lower probability values with other inundation histories. Therefore, this inundation history was not used for the vegetation model. A list of the 35 taxa, response functions, correlation coefficient, probability values and inundation histories used in the vegetation model is in Table 10. The response functions for each inundation history are displayed in Figure 11.

Table 10: List of taxa, Global *R* values, probability values, inundation histories and response functions used in the vegetation model.

Taxon	Inundation history	Response function	Correlation Coefficient	*P*
Invasive annual grasses	1 year	$y=11.7172*\exp(-0.5*((x+1732.9409)/684.2377)^2)$	0.4481	0.0026
Calystegia sepium	1 year	$y=0.0802*\exp(-0.5*((x-7.0353)/3.1383)^2)$	0.5383	0.0001
Chara spp.	1 year	$y=0.0867*\exp(-0.5*((x-228.7625)/41.6167)^2)$	0.4243	0.0052
Foeniculum vulgare	1 year	$y=0.0457*\exp(-0.5*((x-3.0232)/1.5107)^2)$	0.6224	<0.0001
Fumaria bastardii	1 year	$y=0.0442*\exp(-0.5*((x-1.4793)/3.7183)^2)$	0.8139	<0.0001
Leptospermum sp.	1 year	$y=0.0264*\exp(-0.5*((x+0.1088)/10.4186)^2)$	0.0294	0.3530
Phalaris arundinacea	1 year	$y=0.0645*\exp(-0.5*((x-3.8389)/8.2845)^2)$	0.4723	0.0012
Trifolium spp.	1 year	$y=0.1457*\exp(-0.5*((x-43.4606)/13.8164)^2)$	0.4448	0.0029
Arctotheca calendula	3 years	$y=0.0597*\exp(-0.5*((x-43.1277)/8.1524)^2)$	0.6198	0.0001
Arundo donax	3 years	$y=0.0526*\exp(-0.5*((x-77.7713)/17.5227)^2)$	0.3990	0.0468
Bolboschoenus spp.	3 years	$y=0.0647*\exp(-0.5*((x-287.2536)/141.3912)^2)$	0.4164	0.0295
Echium plantagineum	3 years	$y=0.0713*\exp(-0.5*((x-23.2164)/16.6146)^2)$	0.5529	0.0012
Paspalum dillitatum	3 years	$y=0.0766*\exp(-0.5*((x-114.2457)/70.4262)^2)$	0.3966	0.0492
Phragmites australis	3 years	$y=0.2356*\exp(-0.5*((x-117.7135)/85.9663)^2)$	0.5442	0.0015
Plantago lanceolata	3 years	$y=0.1057*\exp(-0.5*((x+7.1721)/23.6930)^2)$	0.7004	<0.0001
Ranunculus sp.	3 years	$y=0.0687*\exp(-0.5*((x-21.8398)/9.0294)^2)$	0.5511	0.0012
Rumex bidens	3 years	$y=0.1269*\exp(-0.5*((x-20.3213)/29.1196)^2)$	0.5468	0.0014
Typha domingensis	3 years	$y=0.1081*\exp(-0.5*((x-602.4088)/374.5275)^2)$	0.4376	0.0196
Betula sp.	5 years	$y=0.0539*\exp(-0.5*((x-78.5344)/42.3157)^2)$	0.4115	0.0185
Distichlis distichophylla	5 years	$y=0.0403*\exp(-0.5*((x-158.5912)/28.4922)^2)$	0.4349	0.0110
Eucalyptus camaldulensis	5 years	$y=0.2110*\exp(-0.5*((x-301.2038)/831.7725)^2)$	0.3866	0.0437
Fraxinus excelsior	5 years	$y=0.1834*\exp(-0.5*((x-88.7348)/15.3884)^2)$	0.7063	<0.0001
Juncus acutus	5 years	$y=0.0807*\exp(-0.5*((x-81.5021)/38.6582)^2)$	0.4481	0.0081
Medicago spp.	5 years	$y=0.1239*\exp(-0.5*((x-71.1582)/72.7837)^2)$	0.6292	<0.0001
Pennisetum vilosum	5 years	$y=0.0199*\exp(-0.5*((x-20.9568)/14.5524)^2)$	0.4309	0.0121
Persicaria lapathifolia	5 years	$y=0.0561*\exp(-0.5*((x-522.8321)/236.8346)^2)$	0.4352	0.0109
Watsonia bulbilifera	5 years	$y=0.0772*\exp(-0.5*((x-18.6688)/16.1767)^2)$	0.5990	<0.0001
Baumea spp.	10 years	$y=0.0408*\exp(-0.5*((x-1649.1117)/881.6236)^2)$	0.3268	0.0357
Chenopodium album	10 years	$y=0.0166*\exp(-0.5*((x-17.0661)/11.1214)^2)$	0.3629	0.0190
Cyperus gymnocaulos	10 years	$y=0.2353*\exp(-0.5*((x-511.0583)/1402.5765)^2)$	0.3783	0.0105
Gallium murale	10 years	$y=0.1435*\exp(-0.5*((x-27.6802)/0.3701)^2)$	0.7474	<0.0001
Oxalis pes-caprae	10 years	$y=2.7210*\exp(-0.5*((x+1538.3682)/686.1759)^2)$	0.6657	<0.0001
Pennisetum clandestinum	10 years	$y=0.1369*\exp(-0.5*((x-9.8199)/776.6254)^2)$	0.4618	0.0008
Sonchus oleraceus	10 years	$y=0.4755*\exp(-0.5*((x+1932.2895)/1315.1863)^2)$	0.5332	<0.0001
Vicia sativa	10 years	$y=0.0655*\exp(-0.5*((x-438.5359)/400.9780)^2)$	0.3392	0.0270

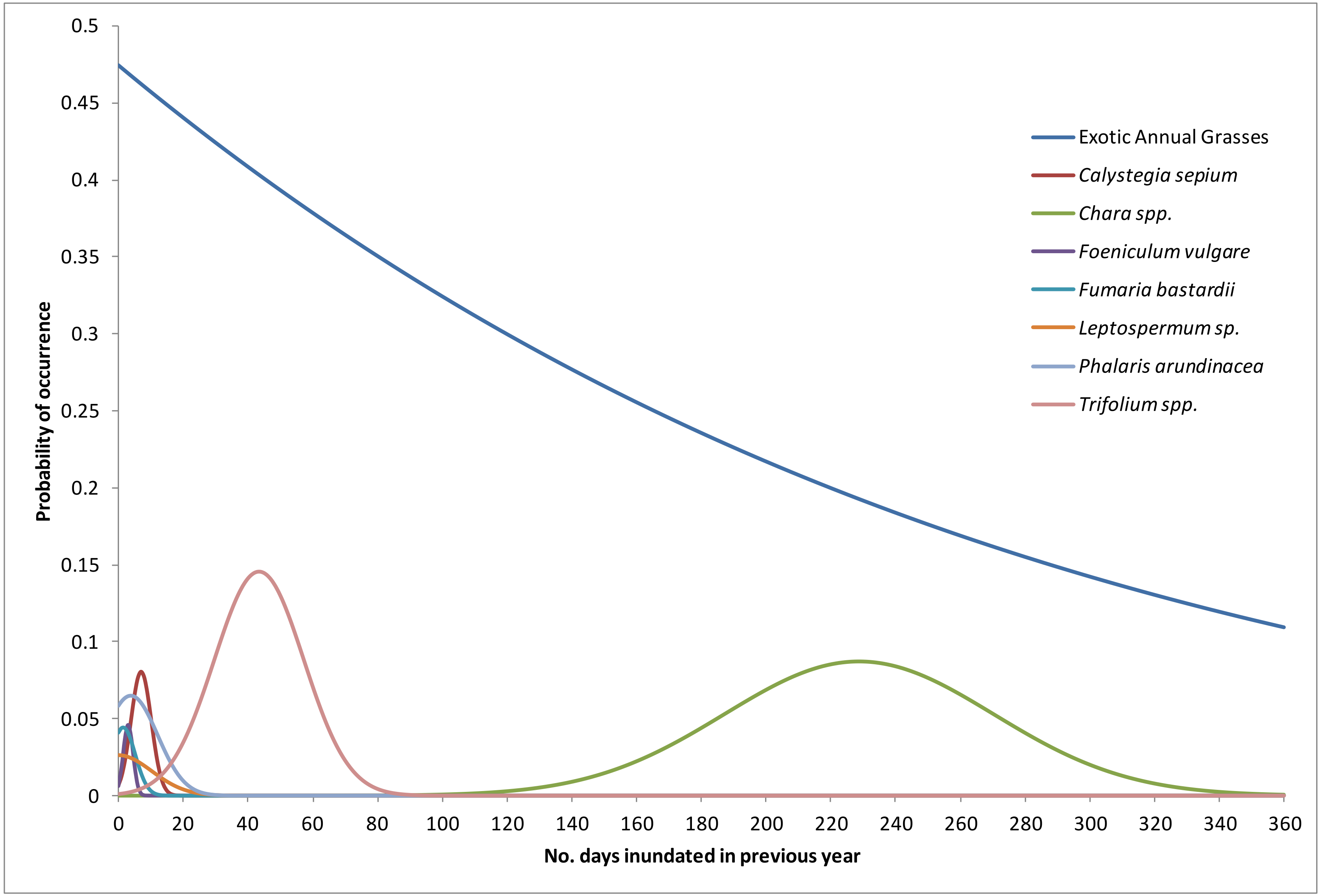


Figure 11: Modelled response functions for exotic annual grasses, *Calystegia sepium, Chara* spp., *Foeniculum vulgare, Funaria bastardii, Leptospermum* sp., *Phalaris arundinacea* and *Trifolium* spp..

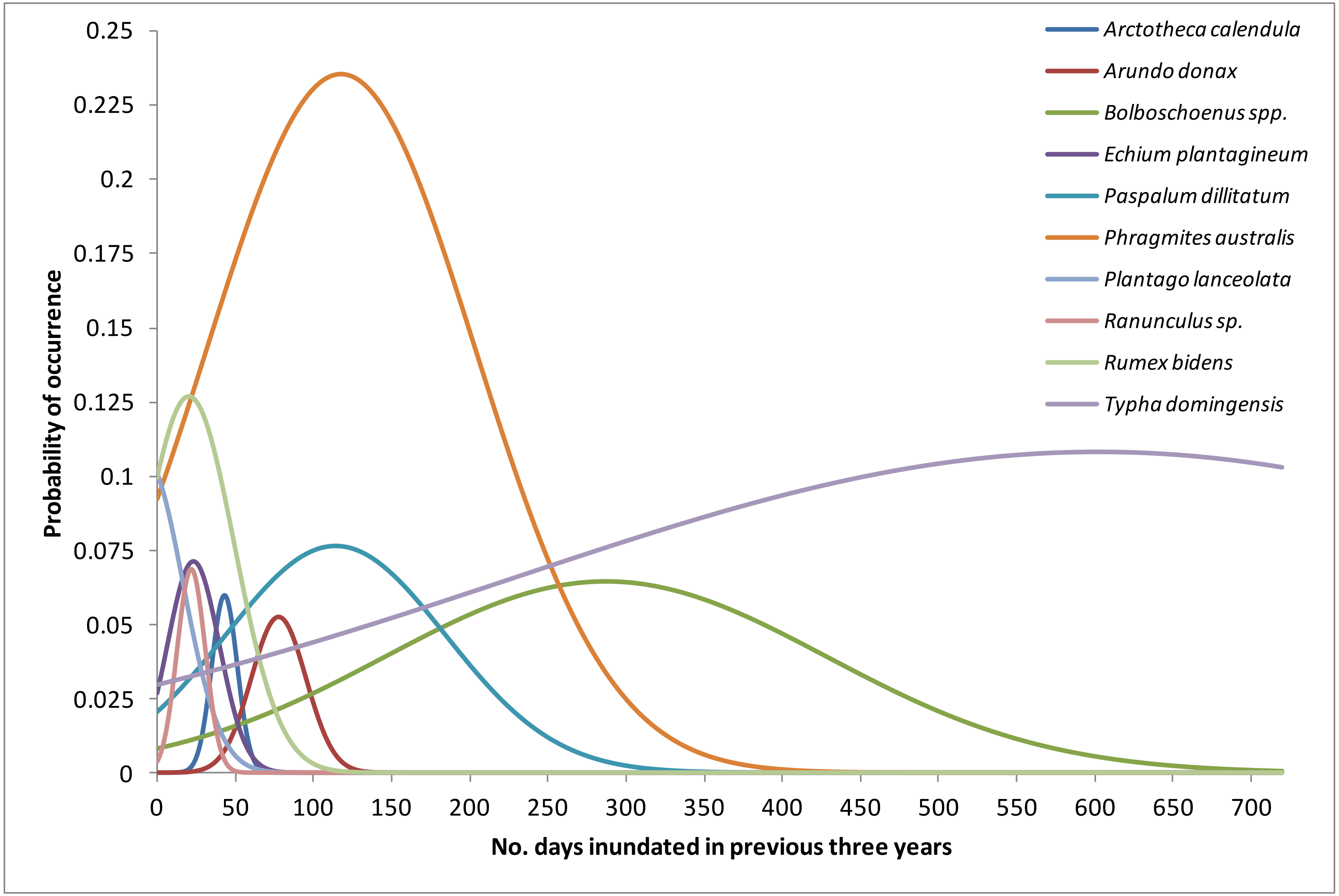


Figure 12: Modelled response functions for *Arctotheca calendula, Arundo donax, Bolboschoenus* spp.*, Echium plantagineum, Paspalum dilitatum, Phragmites australis, Plantago lanceolata, Ranunculus* sp.*, Rumex bidens and Typha domingensis*.

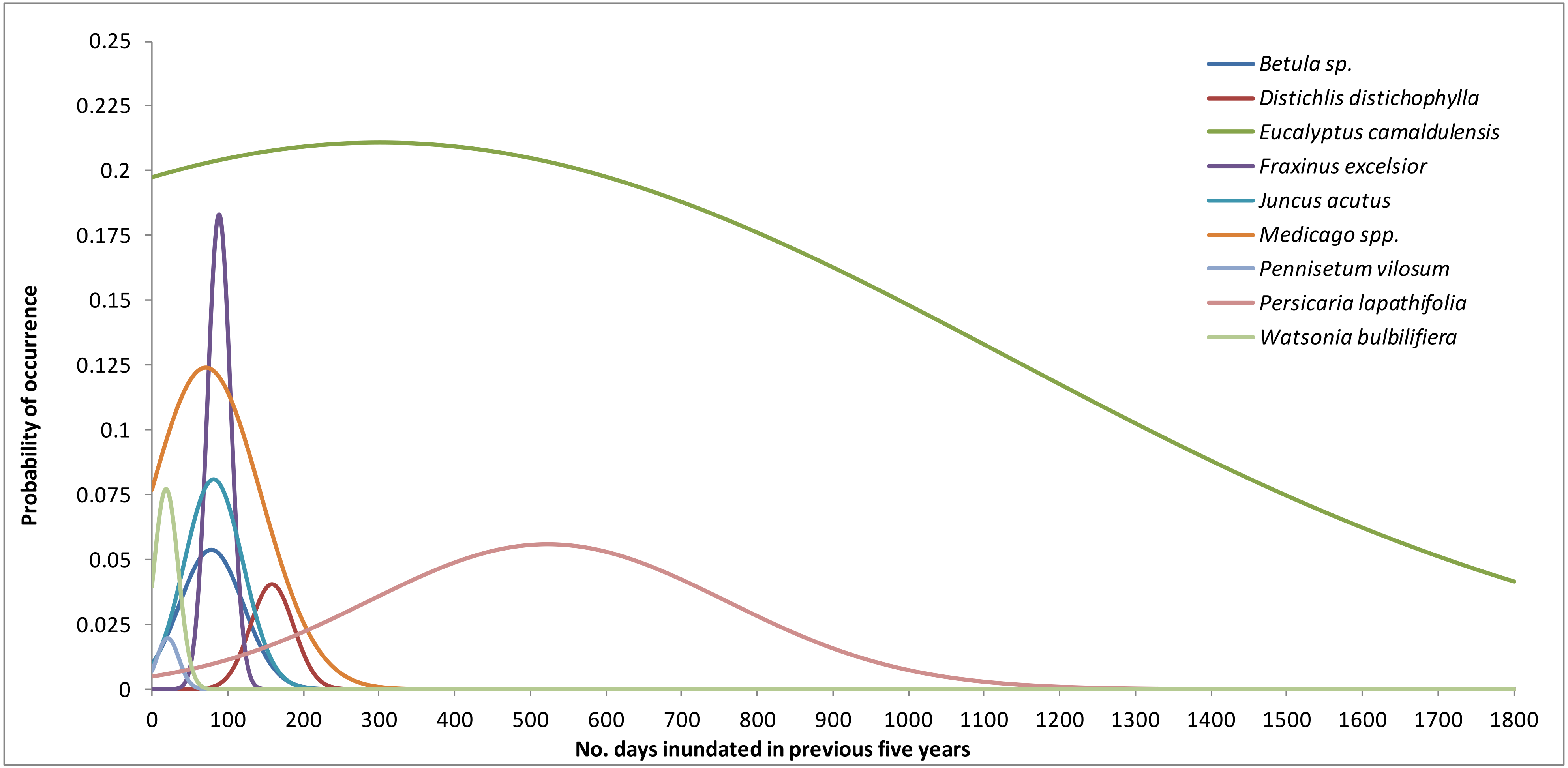


Figure 13: Modelled response functions for *Betula* sp., *Distichlis distichophylla, Eucalyptus camaldulensis, Fraxinus excelsior, Juncus acutus, Medicago* spp. *Pennisetum vilosum, Persicaria lapathifolia* and *Watsonia bulbilifera*.

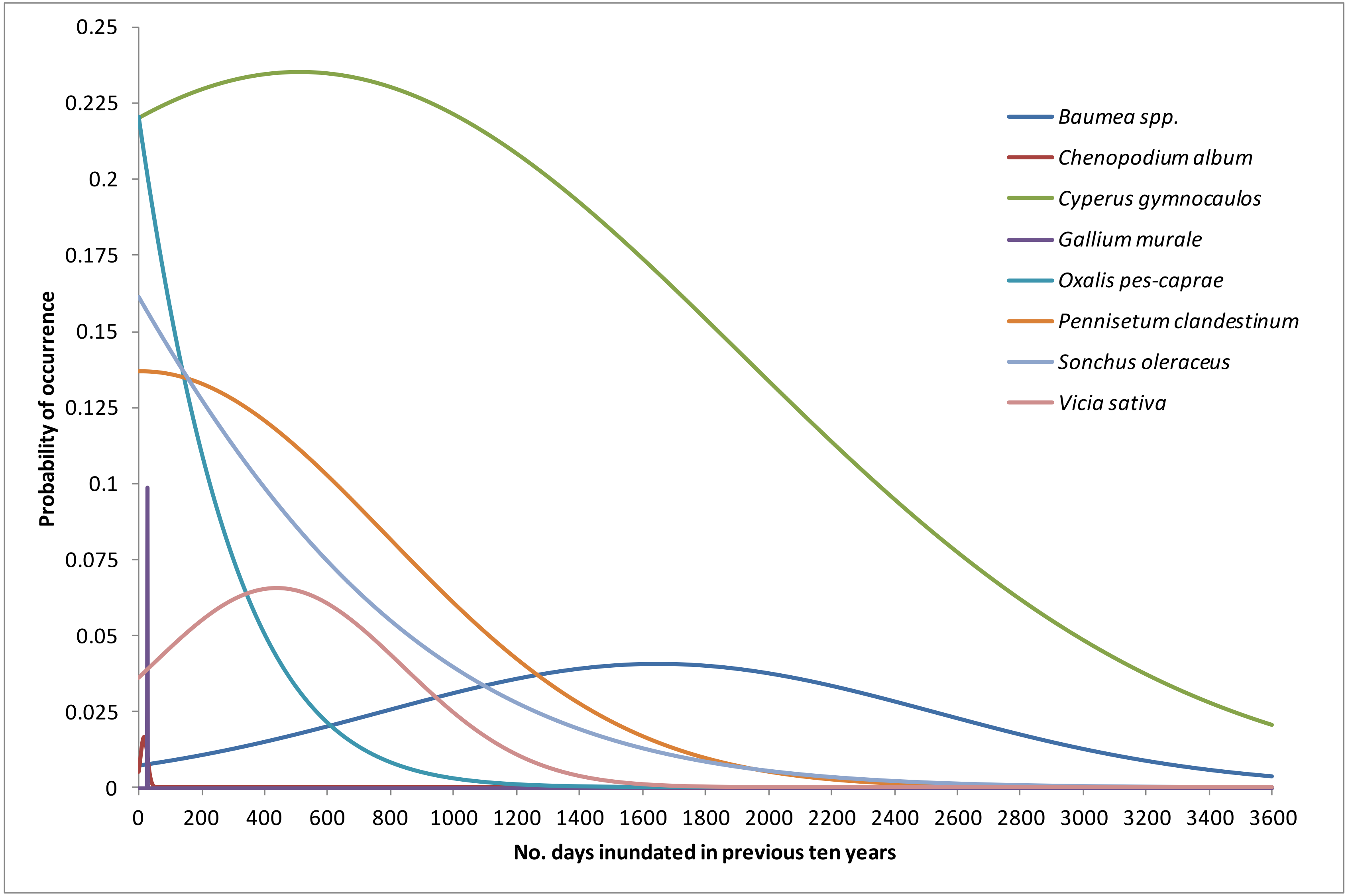


Figure 14: Modelled response functions for *Baumea* spp., *Chenopodium album, Cyperus gymnocaulos, Gallium murale, Oxalis pes-caprae, Pennisetum clandestinum, Sonchus oleraceus* and *Vicia sativa*.

5.4 Scenario testing

Probability functions for each species were collated in a Microsoft Excel spreadsheet, which allows the inundation history to be changed and the probability of occurrence for each taxa recalculated. The predicted plant community was compared for five different modelled flow scenarios: current levels of abstraction, no dams, fully allocated (all licenced users taking their full entitlement), current levels of abstraction with low-flows returned and full allocation with low-flows returned. Cross section 7 from Lenswood Creek (Figure 15) was used to test the different modelled flow scenarios, with the plant community predicted at Quadrats 2, 3 and 4 from the autumn 2014 survey for the different modelled inundation histories. The plant communities were compared by Principal Coordinates Analysis (PCO) using the package PRIMER version 6.1.12 (Clarke and Gorley 2006). Bray-Curtis similarities (Bray and Curtis 1957) were used to construct the distance matrices for all multivariate analyses.

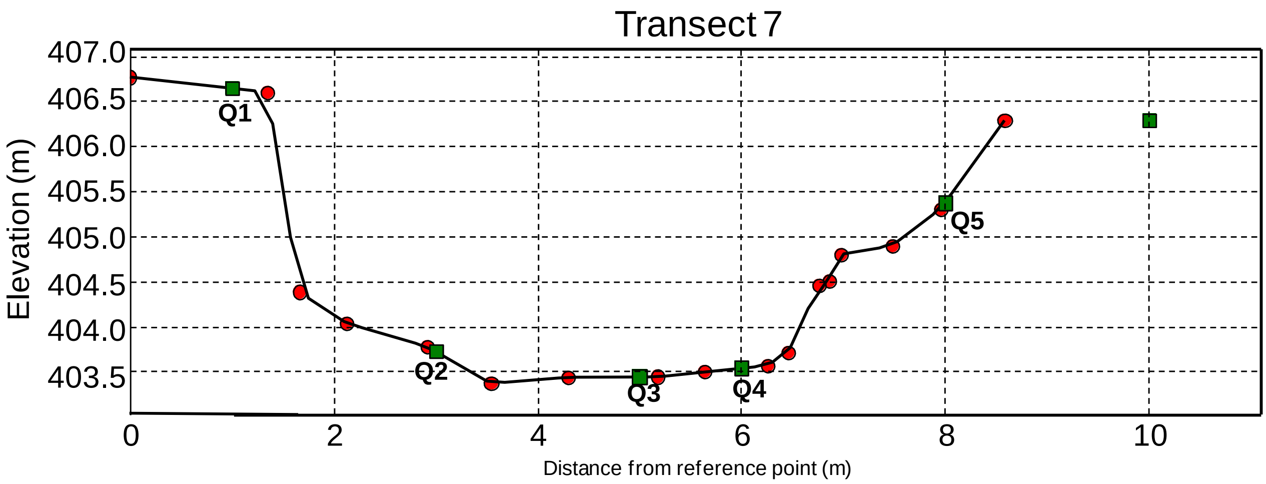


Figure 15: Transect (cross section) 7 for Lenswood Creek, showing the position of vegetation quadrats for the autumn 2014 survey.

5.5 Aquatic and riparian vegetation modelling

The pattern of the predicted response of the plant community under the different modelled flow scenarios at cross section 7 in Lenswood Creek was consistent between quadrats, but the magnitude of changes was variable (Figure 16). If modelled current flow represents the baseline, the no-dams scenario is the “best” and full allocation is the “worst” predicted plant community, there is a gradient of predicted response (Figure 16). The current consumption with low-flows returned represents the second best predicted community and an improvement on the current consumption scenario, the fully allocated with low-flows returned represents a lesser improvement (Figure 16). The fully-allocated scenario predicts a decline in the plant community compared to the current scenario (Figure 16).

The greatest predicted difference in plant community from the modelled current scenario (difference in Bray-Curtis similarity compared to the current scenario) at all quadrats was the no dams scenario (Table 11). However, the magnitude of the predicted response was greatest at the lowest elevation (Quadrat 3) and least at the highest elevation (Quadrat 2) (Figure 16, Table 11). At Quadrat 2 the model predicted almost no difference in plant community between the current, full allocation, and two low-scenarios returning low-flows (Figure 16, Table 11). At this elevation there was also very little difference between the current and no-dams scenario (Figure 16, Table 11). In contrast, the lowest elevation (Quadrat 3) showed a large difference in the predicted plant community between the current and no-dams scenarios, and predicted that there would be improvement with flows returned low-flow even if the all the water licenced for consumption is used (Figure 16, Table 11). At Quadrat 4 the response was greater than Quadrat 2 but lower than Quadrat 3, which is expected as it is at an intermediate elevation (Figure 16, Table 11).

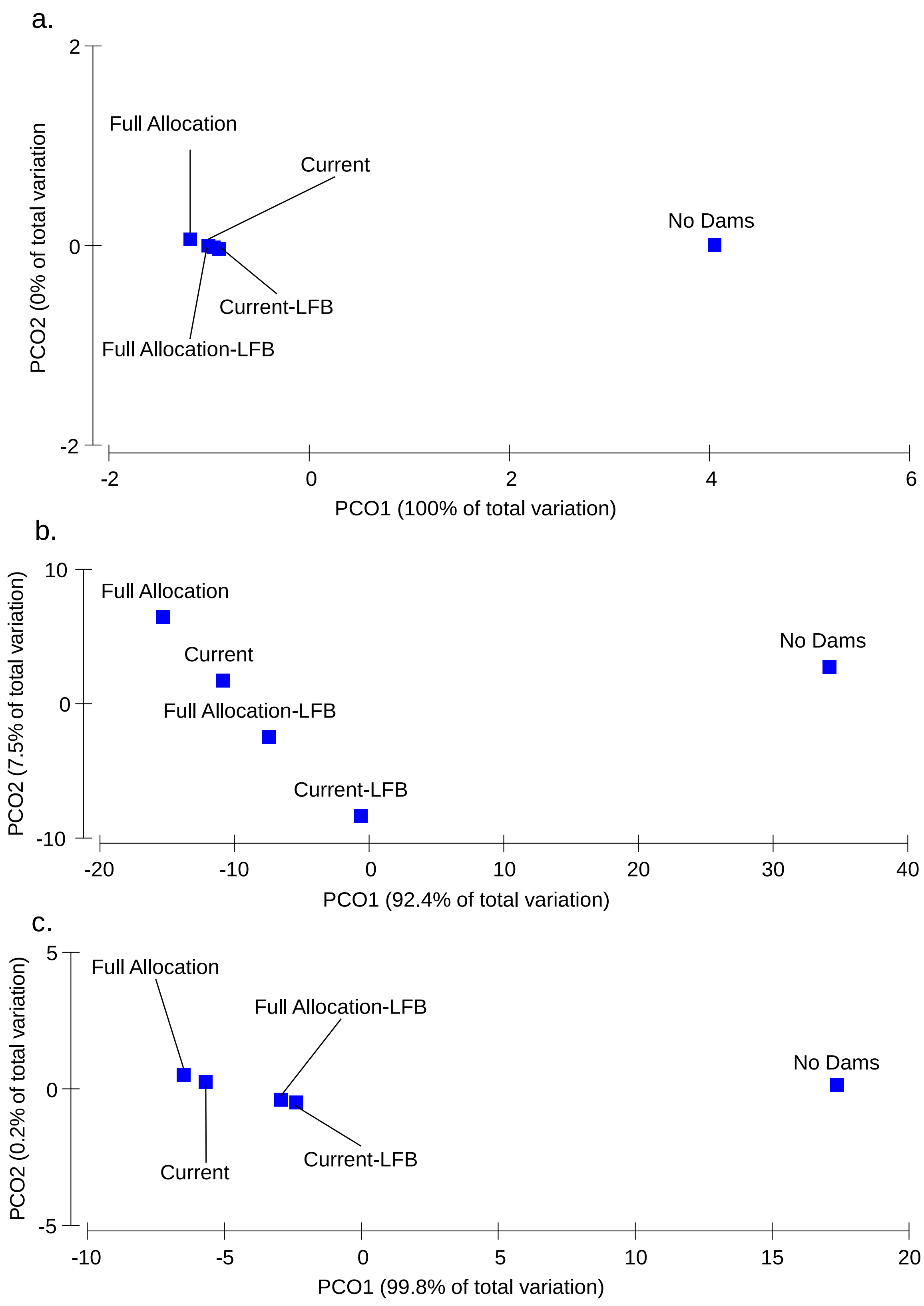


Figure 16: Principal Coordinates Analysis comparing the predicted plant communities under the different flow scenarios at a. Quadrat 2, b. Quadrat 3 and c. Quadrat 4 at cross section 7 in Lenswood Creek (LFB denotes low-flows bypassed or returned).

Table 11: Differences in Bray-Curtis similarity for the predicted plant communities compared to the current flow scenario for the modelled flow scenarios for Quadrats 2, 3 and 4 (LFB denotes low-flows bypassed or returned) at cross section 7 in Lenswood Creek (positive numbers = improvement; negative numbers = decline).

	Δ Bray-Curtis from Current Flow Scenario			
Quadrat	No Dams	Current-LFB	Full Allocation	Full Allocation-LFB
2	5.053826814	0.113306811	-0.191787573	0.057255139
3	45.0577518	14.43553629	-6.636312819	5.394872387
4	23.0606911	3.397288571	-0.840295633	2.80506277

6 Fish

6.1 Conceptual model

We created a conceptual model relating fish community response to flow. We used five functional groups to represent generalised fish community responses to flow: Obligate freshwater specialists (OFWS) (southern pygmy perch, mountain galaxias), Obligate freshwater generalists (OFWG) (flathead gudgeon, carp gudgeon spp.), Diadromous species (common galaxias, congolli, short-headed and pouched lamprey), Exotic generalists (eastern gambusia and common carp) and Exotic predators (redfin perch and brown and rainbow trout) (McNeil and Hammer 2007). The model considers the likely existence of these functional groups within the six reach types in the MLR, following the Larned *et al.* (2010) model of ecological connectivity. The Larned *et al*. (2010) model is modified slightly to describe the ecological importance of four seasonal flow bands: low-flow (including no flow), low-high transition (T1), high flow and high to low transition (T2). Freshes are considered an addition flow component within the four seasonal flow bands.

In general, the wetter flow scenario leads to improved ecological outcomes for fish with increased dispersal, better access to habitat for diadromous species and increased abundance following improved spawning and recruitment conditions. Whilst this scenario is likely to displace invasive generalist species like eastern gambusia and common carp, it is also likely to benefit invasive predators such as trout species and redfin perch. The net effect of improved native and exotic species is likely to be influenced by other factors such as habitat availability for native species to seek cover from predators and improved ability of native species to overcome barriers to dispersal.

The outcome of the driest scenario is reduced habitat availability, with some reach types drying out on an annual basis, and a concentration of obligate freshwater generalists and exotic generalists in the remaining reaches. Diadromous species would have limited access to any reaches above the lowland habitat and limited ability for juvenile dispersal. Such a scenario is likely to lead to localised depletion or local extinction of obligate freshwater specialists and diadromous species. It is likely that this has occurred already in many of the streams in the MLR (McNeil and Hammer 2007, McNeil *et al* 2011). In contrast to the wettest scenario, invasive predators (especially trout) are likely to be disadvantaged by the driest scenario due to their low tolerance of poor water quality.

These two contrasting scenarios highlight the importance of metacommunities (i.e. networks of communities maintained by dispersal between communities and interactions within communities) with variable connectivity in temporary rivers and longitudinal nesting (Larned *et al.* 2010). Under the driest scenario this may lead to limited dispersal, causing isolation of communities nested within the metacommunity, and the potential for local extinction due to competition, predation or habitat harshness. It is important to note that not only the existence of each flow band, but the timing of each part of the flow season affects fish movement and survival in the MLRs. The conceptual model presents fish community response to flow in the absence of barriers to flow and fish movement, i.e. poorly constructed road crossings, weirs, dams, strong freshes or low-flows through a steep rocky section.

Terminal wetlands are less dependent on flows coming down the system, although lack of flow in estuarine terminal wetlands can result in them becoming purely marine habitats (Zampatti *et al.* 2010). The conceptual model does not include the Fleurieu Swamps. The model is generalised, based on observation of actual conditions throughout the MLR, in the absence of knowledge of pre-development or natural conditions, so it is important to include anthropogenic factors such as barriers to dispersal and land use in the conceptual model. Whilst these factors will not be addressed by this project, they should be considered as a risk to achieving ecological outcomes from increased flows. Similarly, introduced and re-stocked fish species (trout and redfin perch) are a confounding factor, they can potentially move from where they are released and reduce the local native fish populations independent of ecological responses to flow. This can result in breaks in connectivity between the reach types, whereby the distribution of native species may be separated by exotic dominated pools. Redfin perch are considered to have a greater impact than trout particularly in upper pools. Trout are particularly susceptible to low-flow scenarios that reduce pool water quality.

Table 12. Fish community responses to the wettest and driest flow scenarios. US = upstream; DS = downstream. . Reach types are headwater (HW), upper pool-rifle (UPR), mid pool-riffle (MPR), gorge (G), lowland (LL) and terminal wetland (TW).

FLOW STATE	WETTEST FLOW SCENARIO	DRIEST FLOW SCENARIO
Low	Short or no cease to flow period	Very long cease to flow period
	All pools connected year round	Some pools permanently isolated or rarely connected, Gorge and UPR dry out (habitat loss)
	OFWS disperse to all reaches except LL and TW	OFWS isolated to MPR
	Predators access all reaches	Predators persist in MPR but no access to UPR
	Diadromous species access further US	Diadromous fish isolated to LL and TW
	Gambusia and carp displaced DS	Gambusia and carp dominate remaining pools
T1	Diadromous species move upstream	Low-flow insufficient duration and magnitude for diadromous species to move upstream
	Dispersal of OFWS and OFWG to most reaches	Low-flow insufficient duration and magnitude for dispersal of OFWS and OFWG to most reaches
High	High flows displace Gambusia and carp	High flows insufficient magnitude to displace Gambusia and carp
	Freshes prepare substrates as spawning habitat for OFWS and OFWG	Freshes eliminated – reduced spawning habitat for OFWS and OFWG
	Continued dispersal of all fish groups except Gambusia and carp	Limited dispersal of all fish groups
		Isolated populations more susceptible to predation, competition and stochastic events
T2	Diadromous species move back downstream	Reduced flow for diadromous species dispersal out to sea
	Continued dispersal of all fish groups. Gambusia and carp may recolonise US depending on flow rate and length of flow.	Reduced dispersal, increased isolation of all fish groups.
		Strong Gambusia and carp reproduction due to low-flows.
Freshes	Occur more frequently	More infrequent, only very large destructive flows persist (flash floods)
	Displace Gambusia and carp, OFWG	All species displaced by flash floods
	Provide passage over some barriers for OFWS, diadromous and predators	

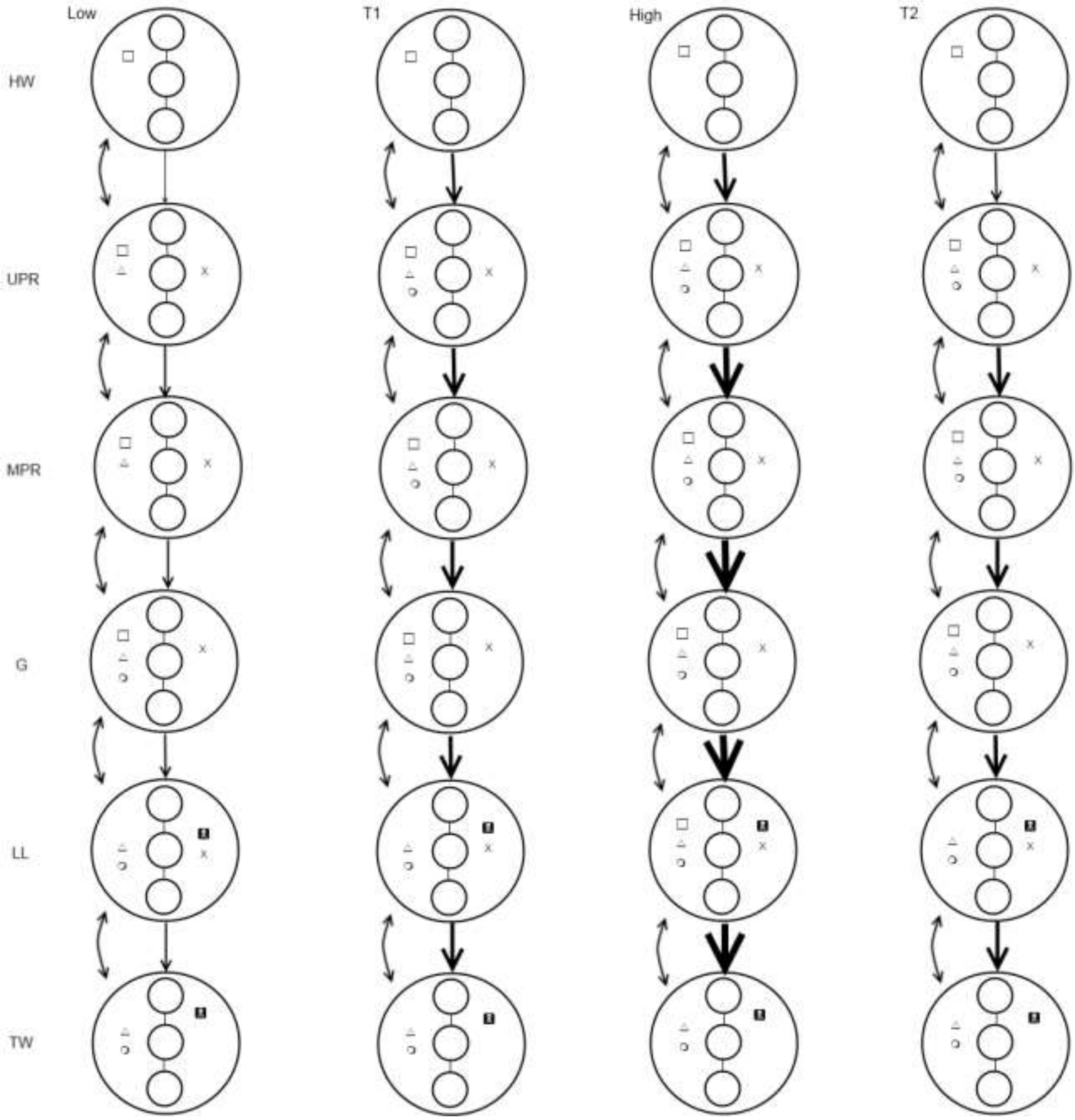


Figure 17. MLR fish conceptual model for wettest scenario. Reach types are headwater (HW), upper pool-rifle (UPR), mid pool-riffle (MPR), gorge (G), lowland (LL) and terminal wetland (TW). Flow states are low, transition from low to high (T1), high and transition from high to low (T2). Fish functional groups are (☐) Obligate freshwater specialists, (Δ) Obligate freshwater generalists, (❍) Diadromous species, (☠) Exotic generalists and (X) Exotic predators. The size of arrows between reaches indicate flow magnitude, double-headed arrows denote fish dispersal between reach types.

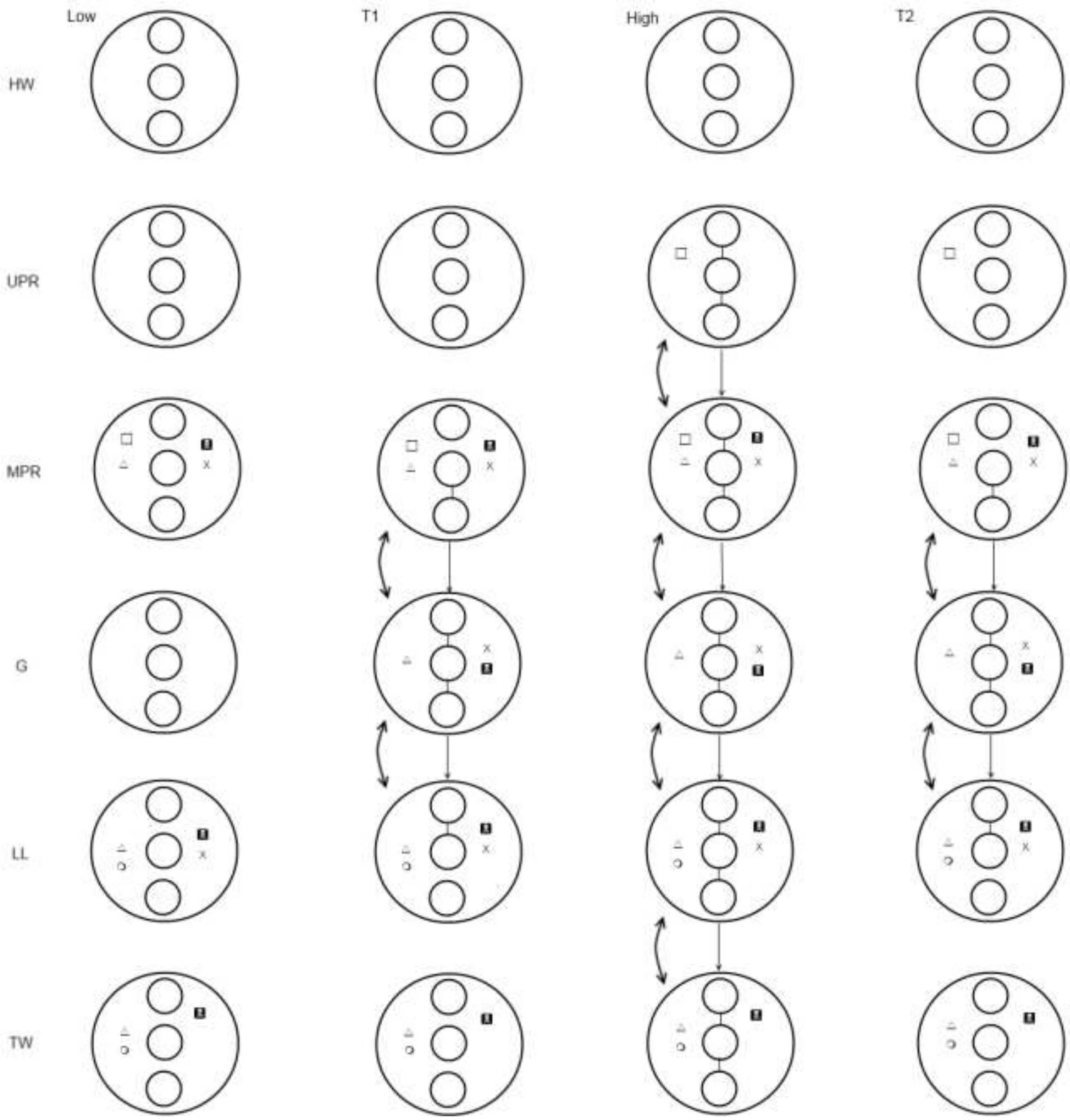


Figure 18. MLR fish conceptual model for driest scenario. Reach types are headwater (HW), upper pool-rifle (UPR), mid pool-riffle (MPR), gorge (G), lowland (LL) and terminal wetland (TW). Flow states are low, transition from low to high (T1), high and transition from high to low (T2). Fish functional groups are (☐) Obligate freshwater specialists, (Δ) Obligate freshwater generalists, (❍) Diadromous species, (☠) Exotic generalists and (X) Exotic predators. The size of arrows between reaches indicate flow magnitude, double-headed arrows denote fish dispersal between reach types.

6.2 Sampling

6.2.1 STUDY SITE SELECTION AND REACH CLASSIFICATION

The locations of sites for the fish survey were identical to those for the macroinvertebrate and aquatic vegetation surveys. In general, the pools sampled for fish were the same as those sampled for macroinvertebrates, although effort was concentrated in pools large enough to deploy the types of nets described below.

6.2.2 HABITAT ASSESSMENT AND WATER QUALITY MEASUREMENT

At each site, substrate type, in-stream structure, rate of flow and connectivity to the main channel were assessed. Percent cover of aquatic, emergent and riparian macrophytes was estimated and the dominant species for each category identified (Sainty and Jacobs 2003).

A point of maximum depth was identified within each site, where water quality was recorded. Water quality parameters including dissolved oxygen (DO), water temperature, pH and salinity, were measured on-site using an YSI 6920 Sonde (Figure 19). Measurements were recorded at the water surface and at 50-cm depth intervals to the riverbed.

Figure 19. Water quality monitoring at First Creek, Waterfall Gully

Figure 20. Buoys in cod-end of net to protect air-breathing fauna.

6.2.3 STANDARD FISH SAMPLING METHODOLOGY

The preferred methodology in the study used two fyke net designs: 'small fykes' (3-m leader, 2-m funnel, 3-mm mesh) and 'double-wing fykes' (2 x 5m wings, 3-m funnel, 3-mm mesh). Wherever pool size allowed, two double-wing and four small fykes were deployed at each site. Nets were anchored using heavy gauge chain clipped to the cod and wing ends. Two polystyrene buoys were placed in each net's cod end to force a pocket of net above the water's surface. This created a space where by-catch (birds, turtles or water rats) could take refuge until the net was processed (Figure 20). Nets were placed strategically to target distinct microhabitats within the pool, with wings tied off against natural structures or stakes. Double-wing fyke nets were deployed together and in opposition with one opening upstream and the second opening downstream. Each of the four single fykes were deployed to sample, where possible, four distinct microhabitats present in the pool (e.g. snags, reeds, bare bank). Fykes were set before dusk and collected after dawn, ensuring that each site was set for a minimum of 14 hours. This time period allowed capture during crepuscular movement and allowed adequate time for nets to perform.

In instances where sites were too small or narrow, a subset of fyke nets was deployed to best suit the characteristics of the site. In some rare instances, sites supported only one or two small fyke nets. In these instances sampling data was bolstered using baited box-style bait traps and by electrofishing. Additional seine netting was undertaken in selected sites in the eastern MLR to detect rare and threatened species with minimal impact on those populations.

Electrofishing

Where necessary a Smith-Root LR-24 backpack electrofisher was used to undertake focused sampling in marginal habitats and riffles (figure 21). Sampling was undertaken by two trained staff who fished for a total of 2,000 seconds at each site. Frequency, voltage and duty cycle settings varied between sites and were matched to local conditions. All fish collected in this manner were processed using the same methodology as for fyke nets.

Figure 21. Standard electrofishing setup. One technician operates the electrofishing unit while the other technician collects stunned fish with a dip net and transfers the fish to a bucket of water for measurement

6.2.4 FISH PROCESSING

At each site, each fish captured was identified to species, with the exception of *Hypseleotris* which exists in the MLR as a species complex. For each species at each site, total length (TL) was recorded for the first 100 fish collected. This was considered a representative subset from which to create reliable length frequency distributions. An exception was *Gambusia holbrooki,* which was measured to only 50 fish. In addition to TL, the ecologists assessed fish for the presence of disease, parasites, spawning condition and congenital abnormalities.

Fish data were collected in two seasons: spring 2013 and autumn 2014. In both seasons, 19 sites in eight catchments were sampled in the WMLR. In the EMLR, 23 sites in 10 catchments were sampled in spring and 65 samples in autumn. A total of 14,233 fish was captured for the whole project, with 8,796 captured in the WMLR and 5,437 in the EMLR. In the WMLR 6,788 fish from 12 species (9 native, 3 introduced) were captured in spring 2013 and 2,008 fish from 11 species (8 native, 3 introduced) were captured in autumn 2014. In the EMLR, 573 fish from 12 species (8 native, 4 introduced) were captured in spring 2013 and 4,864 fish from 18 species (13 native, 5 introduced) were captured in autumn 2014. Total catch data (in CPUE) for all samples are presented in Appendix A.

6.3 Data analysis

6.3.1 STANDARDISATION OF SITE DATA ACROSS THE MLR

To standardise fish sampling results to a catch per unit of effort (CPUE), the total catch data for each net from every SARDI WMLR sampling event since autumn 2006 was compiled, noting set and pull times for each event. This dataset was reviewed and events with missing data points such as unrecorded set or pulled times were eliminated, along with gear types not used in the current study. This process created a dataset tailored to compare the efficiency of double-wing and single fykes and effort ratios. Analysis in this study considered three gear types: single fykes, upstream facing double-wing fykes and downstream facing double-wing fykes.

Total catch per hour was calculated for each net and a log10 transformation was applied to normalise the data. From this, average catch for each net type was calculated using small fyke nets as the base unit producing a gear effort score for each net type. In this way a small fyke set for one hour produced one unit of effort.

Total catch for each sampling event was divided by the total gear effort (sum of all gear effort at the site) and divided by the number of hours that nets were set to produce a catch per unit effort value for each site.

6.3.2 MULTIVARIATE ANALYSIS

The PRIMER 6.1.12 statistical package (with PERMANOVA) was used to perform multivariate analysis (Clarke and Gorley 2006). Sites were characterised using species abundance. Only sites recording sufficient data to calculate CPUE were included. Temperature was excluded as an environmental variable due to the extended timeframes for sampling. The data were log transformed and analysed using group average clustering, SIMPER and indicator species analysis using PRIMER. Bray-Curtis (1957) similarities were used as a distance matrix for the cluster analysis, displayed as a dendrogram. Canonical analysis of principal components (CAP) was used to test *a priori* grouping of sites in reach types. ArcGIS was used to visually present the geographic distributions of species assemblage groups.

6.3.3 TRAIT ANALYSIS

Trait analysis was used to group of species with similar traits. This allowed the comparison of sites based upon functionally similar traits rather than comparing only sites that shared the same taxa. This also allowed a more direct link to environmental gradients and ecosystem function for the ecological response model.

In order to develop the trait groups, traits were identified from available literature (McNeil *et al*. 2011) and online databases (Fishbase, Fishes of Australia and Atlas of Living Australia). The traits used represented survival, morphology, habitat, reproductive characteristics and environmental tolerances Table 13.

Table 13 Traits used for fish analysis

Traits	Trait states				
Maximum Age	Long-lived	Medium-long	Short-lived	Short-medium	
Age at Maturity	More than 4 years	1 to 2 years	2 to 4 years	6 months to 1 year	Less than 6 months
Diadromy	Catadromous	Potomadromous	Anadromous	Facultative anadromous	
Egg Size	Small	Very large	Large	Medium	
Fecundity	Very high	Low-moderate	High	Moderate	Low
Maximum Length	Very long	Long	Short	Medium	
Reproductive Guild	Nonguarder (open substrate spawners)	Guarder (substr chooser)	Guarder (nest spawner)	Nonguarder (brood hider)	Bearer (internal)
Salinity tolerance	Euryhaline	Stenohaline			
Body form	Slender	Moderate	Deep		
Spawning Frequency	Single per lifetime	Single per season	Multiple per season		
Substrate Preference	Moderate (sand, fine gravel)	Coarse (rocks, cobble, gravel)	Fine (silt, mud)		
Trophic Guild	Omnivore	Invertivore-piscivore	Invertivore	Herbivore-detritivore	
Vertical Position	Bentho-pelagic	Benthic	Pelagic		

6.3.4 ECOLOGICAL RESPONSE MODELING

Following the same methodology as the macroinvertebrate response modelling, predictor variables were examined for correlation to ensure that observed effects were not compounded by correlating variables. Correlations of over 90% were investigated and one of the correlated variables removed from the analysis.

We attempted to build response models for each of the identified trait groups as well as other, more generic measures such as species richness and trait richness.

Response modelling was undertaken using generalised linear mixed models, using the Glmer Package in *R* (R Core Team 2014). Individual relationships between the response variables and the flow metrics and other predictor variables were examined using generalised linear models. For each response model the predictor variables that showed an interaction were compiled into a single mixed model. This large model was then simplified using the method set out in Crawley (2014) until the simplest models that explained the most variation was determined.

6.4 Fish Modelling Results

The fish response models are not presented in this report, they will be presented in a separate publication currently in preparation.

Multivariate analysis using non-metric multidimensional scaling (NMS) showed some partitioning based on reach type and region (Figures 24–25). There was a gradient of reach type across the fish population from upper pool riffle down to terminal wetland. This gradient is largely explained by the presence of mountain galaxias and brown trout in upper reaches and congolli and common galaxias in lower reaches. Differences between regions were largely due to the over-representation of lowland and terminal wetland habitats in the eastern MLR. Further multivariate analysis using CAP (Figure 26) demonstrated the strength of the reach classifications, with 62% of sites correctly classified based on fish community. Further, all misclassified sites were classified as the next nearest reach type. This demonstrates the longitudinal nesting proposed in the conceptual model of the MLR fish community.

6.4.1 TRAIT ANALYSIS

Trait analysis was conducted using 15 trait categories. Each trait category was scored using a binary score and clustered using Gower's dissimilarity index. Eight trait groups were identified with 70% similarity (Figure 21). Trait group composition was considered to be ecologically sensible based on expert opinion. Trait group A consisted of congolli and shortfin eel; group B was redfin perch and blackfish; group C was freshwater catfish; group D was brown trout and rainbow trout; group E was carp gudgeon; trait group F was flathead gudgeon, dwarf flathead gudgeon, bluespot goby, hardyhead and Australian smelt; group G was climbing galaxias, mountain galaxias, common galaxias and southern pygmy perch; and group H was common carp, tench, goldfish and eastern gambusia.

6.4.2 ECOLOGICAL RESPONSE MODELLING

Linear modelling was undertaken for all eight trait groups and two community metrics (species richness and trait richness) against three flow metrics (zero flow days, mean daily flow and coefficient of variation of daily flow, the same used in the macroinvertebrate modelling) over 90 days, 1, 2, 5 and 10 years. Due to limited hydrological data at many GWAP sites, linear modelling reduced the number of sites with valid data from 124 sites to 59. To bolster this dataset, we added all fish community data from sites sampled throughout the western MLR, where corresponding hydrological data were available. This increased the number of sites with valid hydrological data to 318.

Generalised linear modelling combined the significant factors identified with the linear modelling along with several spatial, temporal and land-use factors. Stepwise removal of factors resulted in models for each trait group and the species and trait richness measures. The factors contributing to each trait group model are presented in Table 14. In general, most trait groups were associated with at least one 5 or 10 year flow metric.

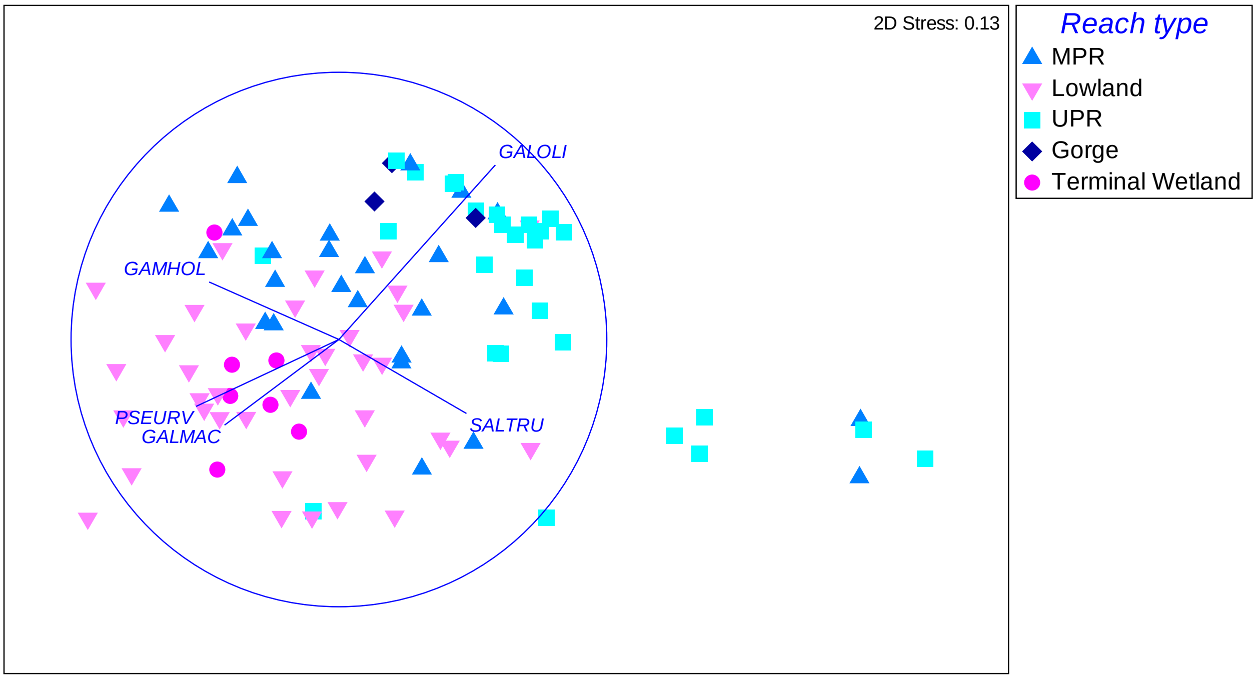


Figure 22. MDS plot of fish community labelled by reach type. Vectors display correlation with species. GALOLI = *Galaxias olidus*, SALTRU = *Salmo trutta.* GALMAC = *Galaxias maculatus*, PSEURV = *Pseudaphritis urvillii*, GAMHOL = *Gambusia holbrooki*.

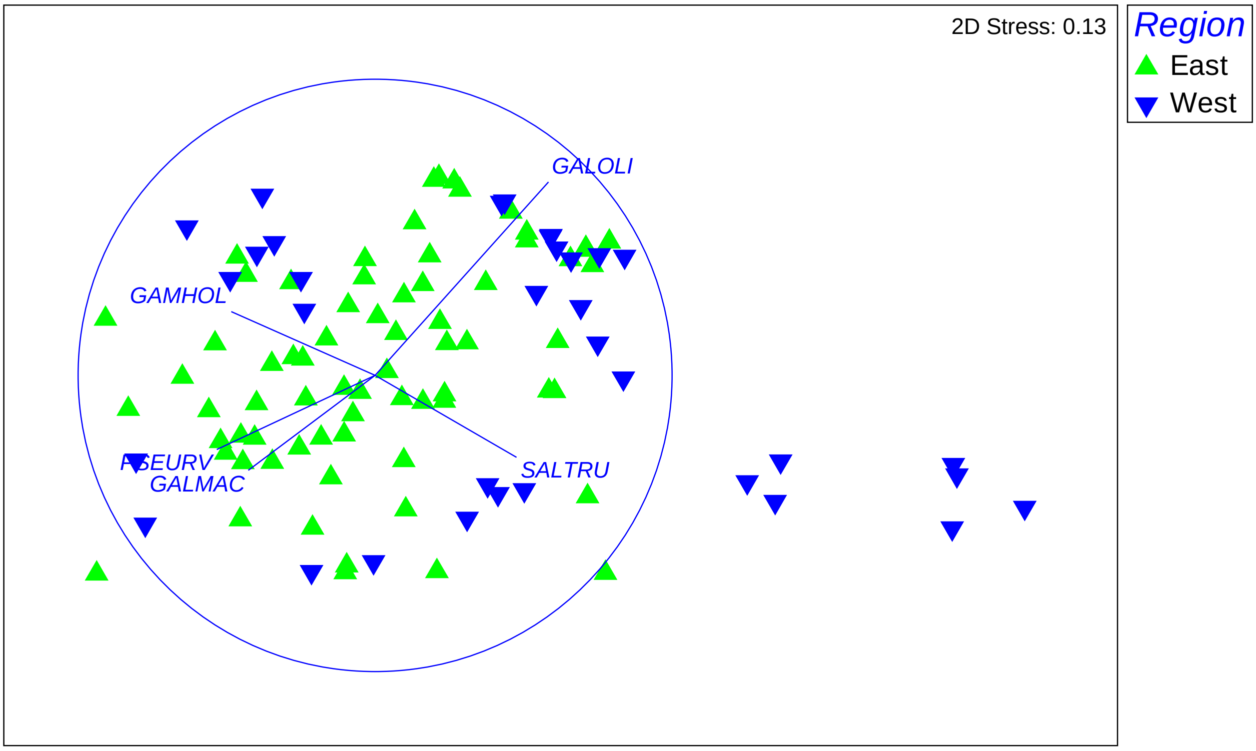


Figure 23. MDS plot of fish community labelled by region. Vectors display correlation with species. GALOLI = *Galaxias olidus*, SALTRU = *Salmo trutta.* GALMAC = *Galaxias maculatus*, PSEURV = *Pseudaphritis urvillii*, GAMHOL = *Gambusia holbrooki*.

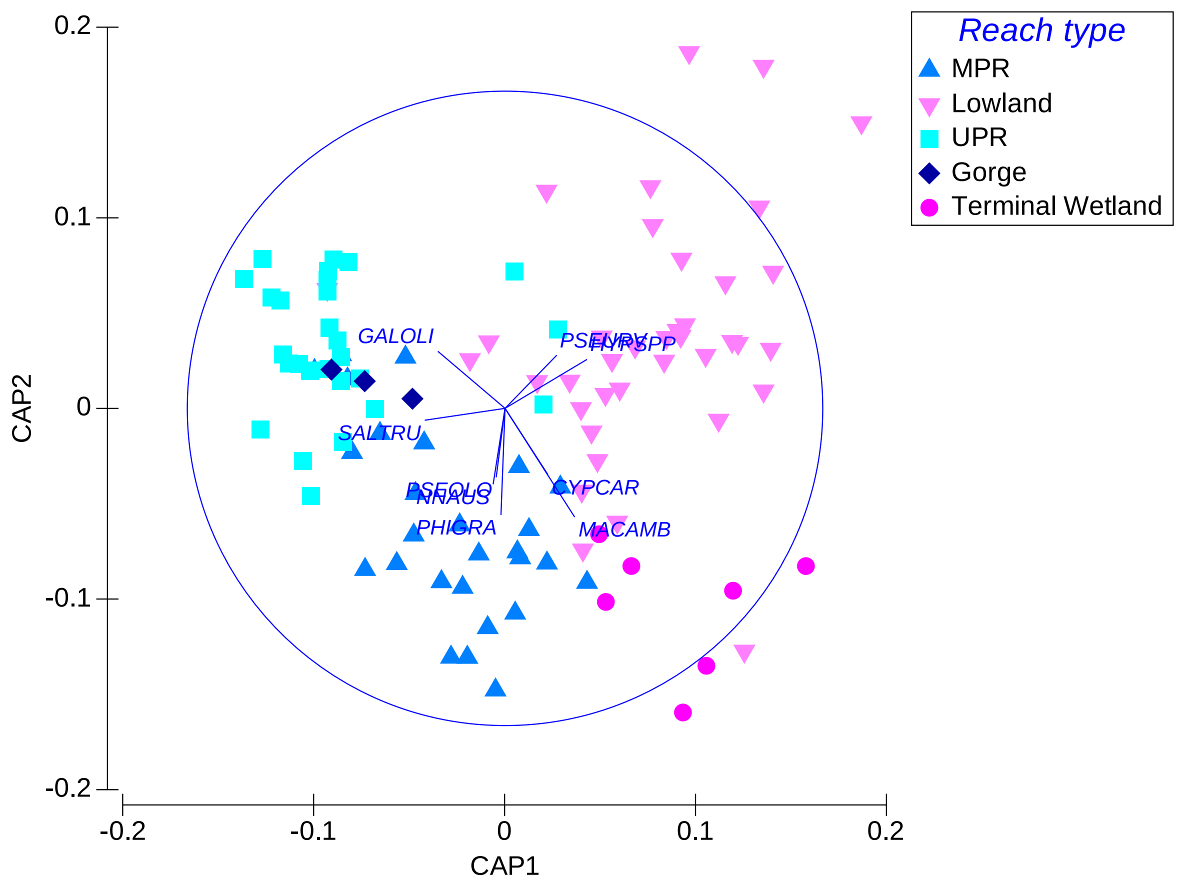


Figure 24. Canonical analysis of principal components labelled by reach type. Vectors display correlation with species.

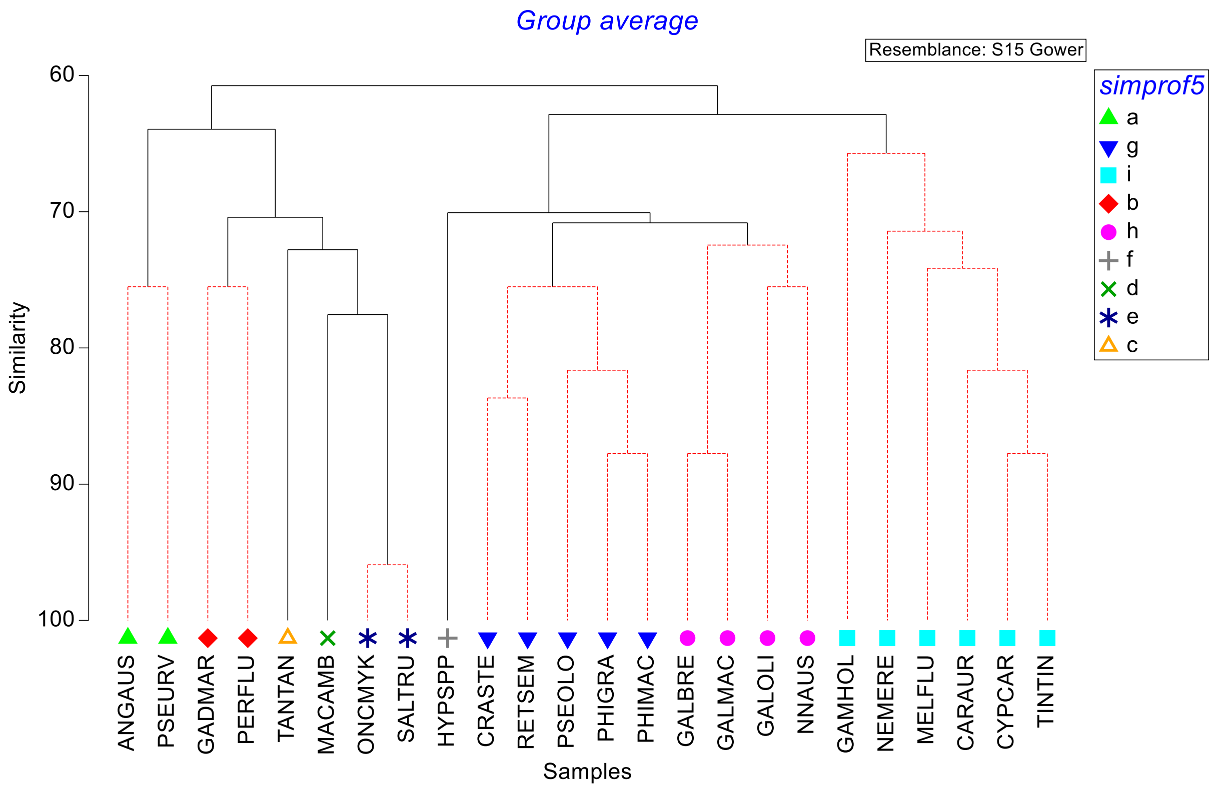


Figure 25. Dendrogram displaying hierarchical cluster analysis of species based on species traits. The red lines represent non-significant groupings (p>0.05)

Table 14. Factors contributing to fish community and trait group models.

Model	Factors
Species Richness	Zero flow days (1 Yrs), mean daily flow (5 Yrs), Catchment , River, Reach type, Regulation
Trait Richness	Zero flow days (1 Yrs), mean daily flow (0.25 Yrs), CoV (2 Yrs), River, Reach type, Regulation, Region, Season
Trait group A	Mean daily flow (5 Yrs), River, Reach type, Regulation
Trait group B	mean daily flow (5 Yrs), Reach type, Regulation
Trait group C	mean daily flow (5 Yrs), mean daily flow (2 Yrs), Region
Trait group D	mean daily flow (2 Yrs), Zero flow days (2 Yrs), Zero flow days (10 Yrs)
Trait group E	mean daily flow (5 Yrs)
Trait group F	mean daily flow (0.25 Yrs), mean daily flow (10 Yrs), Zero flow days (0.25 Yrs), Zero flow days (10 Yrs), River, Regulation, Region
Trait group G	Zero flow days (0.25 Yrs), CoV (2 Yrs), mean daily flow (0.25 Yrs), Reach type, River
Trait group H	Zero flow days (5 Yrs) mean daily flow (10 Yrs), mean daily flow (5 Yrs), Zero flow days (2 Yrs), CoV (2 Yrs), CoV (10 Yrs), Catchment, Reach type, Regulation, Season

7 Discussion

7.1 Data collection and monitoring

The project has complemented the current Adelaide and Mount Lofty Ranges Natural Resource Management Board (AMLRNRMB) and South Australian Murray-Darling Basin Natural Resource Management Board (SAMDBNRMB) monitoring programs in the MLR (i.e. vWASP, eFlows, EPA macroinvertebrate, hydrology and fish monitoring sites), providing scientific evidence to improve predictive modelling. The project has succeeded in establishing a network of hydrological and ecological monitoring sites. Future work should focus on maximising hydrological data collection and monitoring ecological assets at sites with reliable long-term hydrological data.

Seven of the sites sampled in the GWAP program had recently established flow gauges, and due to this were not used for the response modelling. This is not to say that ecological monitoring should not occur at these sites as part of annual condition monitoring. Their location in the catchment was chosen to maximise their usefulness in addressing gaps in ecological and hydrological knowledge now and in the future.

The number of sites with concurrent ecological and hydrological data should be maximised by coordinating current and future monitoring programs with water allocation priorities. It would be advantageous if projects investigating the ecosystem health in the MLR could, where possible, maximise the number of sites with “mature” hydrological data (greater than 10 years of data).

As mentioned previously, hydro-ecological monitoring is not undertaken solely for response modelling. Several sites in this project have sufficient conservation value to warrant ongoing regular monitoring despite a poor hydrological data record. In these instances, the importance of the ecological assets present, and the value of the site should outweigh the desire to pair hydrological and ecological data at all monitoring sites.

7.2 Ecological response models

Several modelling approaches were used in combination to develop response models for vegetation, macroinvertebrates and fish. Trait-based hydro-ecological models were developed using multivariate statistics combined with generalised linear modelling for both fish and macroinvertebrates. The level of intermittency was modelled as the key hydrological variable driving change in temporary rivers. A modelling framework was developed to assess quantitatively whether water use scenarios maintained or improved current conditions. The study covered a broad range of habitats and the fish community was sufficiently diverse to detect changes within the entire region.

7.2.1 MACROINVERTEBRATES

The development of trait-based functional groups of macroinvertebrates from the MLR has been a key advance in the study of the response of macroinvertebrate communities to changes in flow regime. The development of the eight trait groups defined in section 4.3 has allowed for modelling of macroinvertebrate community’s response to changes in flow to be linked to key functional attributes. It also has allowed for a clearer investigation into the different traits responses and the roles of resilience and resistance strategies in adapting to changes in the flow regimes of the rivers of the MLR.

The response modelling based on long term macroinvertebrate monitoring data was undertaken using GLM approaches. While not a new method, the application of this method is becoming increasingly acknowledged as one of the most flexible methods for modelling ecological responses (Bolker *et al.*, 2009).

The modelling undertaken against three key flow metrics identified from previous work as being important in macroinvertebrate community composition (intermittency, mean flow and variation in flow) identified that there are some links between increasing flow intermittency and the presence and abundance of macroinvertebrate trait groups. General results suggest that species richness and trait groups associated with resilience decrease with increasing intermittency, while those trait groups associated with resistance generally increased in response to increasing intermittency.

Using these models in a predictive capacity is the next step in using these models to make management decisions. While the methods for this were developed as part of this project, future monitoring data will be required to validate their predictive capacity. Current models using 1995-2007 data show the trends outlined above, however, lack sufficient data to generate consistent predictions.

7.2.2 AQUATIC AND RIPARIAN VEGETATION

The response model appears to be sufficiently sensitive to predict changes in the plant community under different modelled flow scenarios and will be useful tool for managers undertaking water allocation planning. The model was developed from field data using a published modelling technique (Ganf *et al.* 2010) and represents a logical progression from the historical approach, which was primarily based on expert opinion (VanLaarhoven and van der Wielen 2009). However, like all models it will require validation and will benefit by the inclusion of appropriate additional data.

There are limitations to the model that need to be taken into consideration. The main limitation is that it does not predict the entire plant community; rather, it predicts the probability of occurrence of a taxon at a point on a stream cross-section. A total of 159 taxa was recorded across the 42 sites and 3834 quadrats, many of which were present in low numbers (often only in one quadrat) so that meaningful relationships with hydrology could not be developed.

Of 35 taxa used for the model, 14 were terrestrial dry taxa and a further four terrestrial damp (*sensu* Casanova 2011). Furthermore, of the 159 taxa recorded throughout the surveys 29 were terrestrial dry taxa and 11 terrestrial damp. The dominance of terrestrial taxa throughout MLR streams is probably due to abstraction, with the reduced duration of inundation compared to the natural flow regime, which would favour these species over amphibious and aquatic species. The dominance of terrestrial species may also be an artefact of the way the data were collected in the field. Points randomly allocated on transects frequently missed the truly aquatic sections of streams (which are often very narrow) and more frequently sampled the wider riparian zones; however, with the large number of quadrats surveyed it was expected that a sufficient number of the truly aquatic habitats of streams would be sampled. If more data are collected to refine the model in the future, a stratified sampling design should be adopted to ensure more lower elevations are sampled (the lowest point on the cross section could be sampled on every transect) and more amphibious and submergent species included in the model. With the existing network of established sites with transects and modelled inundation histories this would relatively inexpensive and would improve the model significantly as these additional data could be included in the model to increase the number of taxa used to predict the plant community and improve the relationships of the taxa currently used in the model.

The number of terrestrial species making up the modelled plant community has resulted in there being little predicted change in plant community comparing the current, full allocation and two returning flow scenarios. The predicted plant community for the current scenarios were so dominated by terrestrial taxa that the model shows very little change in plant community when adding or taking away small volumes of water, especially at higher elevations. Furthermore, it suggests that the current level of abstraction is very close to the maximum amount of licenced abstraction. However, at the lowest elevation the greatest change (improvement) in the predicted plant community was observed for the returning low-flow scenarios, which is expected because returning low-flows will increase the duration of low-flows and increase the duration of inundation at low elevations on the stream cross section. At higher elevations returning low-flows will not greatly increase the number of days a point is inundated; therefore, little change in the plant community was predicted by the model for these quadrats.

The functional group approach developed by Casanova (2011) and used by VanLaarhoven and van der Wielen (2009) was trialled for the model; however, better model fits were obtained for individual taxa. This may be due to the wide range of water regime preferences for groups such as the amphibious fluctuation tolerator emergent and amphibious fluctuation tolerator woody groups (Casanova 2001, Figure 5). Alternatively, species may have been classified in the wrong group: for example, *Phragmites australis* is typically classified in the submerged emergent group, but inspection of the distribution of this species and the response function calculated from these data suggests that this species should be classified in the amphibious fluctuation tolerator emergent group. Data collected for this study could be used to validate the current functional classification and reclassify species if they were initially placed in the wrong group. Trait analysis, similar to that performed for macroinvertebrates and fish, could be used to regroup vegetation based on the information for individual species found through this study.

7.2.3 FISH

The ecological response modelling fish showed that medium and long term flow metrics are likely to be an important predictor of fish community structure. The models developed demonstrate that there are key links between the flow regime and the fish community that is present at a site and support the hypotheses that fish communities decline as intermittency increases and mean flow decreases. Mean daily flow and flow intermittency were both shown to be the two relatively consistent flow metrics that influenced the distribution of fish trait groups in the MLR. The models also highlight the differing responses for the different trait groups of fish. As highlighted in the conceptual model for fish (Figure 17), fish from the obligate freshwater specialists (mountain galaxias and pygmy perch) show stronger response to metrics relating to presence of flow. This is different to the exotic predators and obligate freshwater generalists that showed less response to the presence of flow, but more relation to the size of the flow. This accords with the habitat that these fish inhabit (highly, and anthropologically increased, intermittent upper catchment areas versus lower catchment areas with large bodies of permanent water).

The fish sampling that has been undertaken as part of this project has provided data in previously data poor areas of the MLR as well as demonstrated the need to match flow and ecological data collection, in line with ongoing requirements for water allocation planning. The use of data previously collected across the MLR has highlighted differences in methodology employed by different sampling agencies. While the methods employed are broadly similar, there are large differences in how site data is captured and used to develop CPUE scores. The ability to pool fish data across the MLR significantly increases the power of statistical investigations and has been highlighted as desirable by all agencies involved. The benefit of this project has been the ability to clearly identify what data is missing from each metadata collection method and encourage a more standard approach. Given time, this enhanced metadata will provide the information needed to standardise CPUE measures.

Additional benefit may be attained from investigating the possibility of using CPUE values for modelling and not trait group proportions as used in the macroinvertebrate models. This is due to the lower diversity of fish species sampled per site and in many cases sites yielding only single species. Incorporating these changes will allow improve the models facilitating the incorporation into the risk assessment framework. Modelling individual species may also provide more specific thresholds of change.

7.2.4 ECOLOGICAL RISK ASSESSMENT

A part of this project was not only to develop the response models for the different biotic groups, but also to establish a method for assessing risk to WDEs due to the development of water resources. This work is detailed in Green and Maxwell (in prep.) and summarised below.

The overarching objective of “to maintain, and improve if possible” is a common ecological objective in ecological management and features in both of the WAPs from the MLR. Despite this objective there has been no ability to assess it explicitly in response to varying management scenarios. Through this project a method was developed that uses multiple flow scenarios to quantify the metrics “maintain” and “improve” such that they can be compared in terms of the relative ecological risk each scenario imposes.

The method uses daily flow data from three modelled flow scenarios to generate modelled ecological community data using the response models developed as part of this project. The three flow scenarios used for the assessment are the modelled current scenario (model of current conditions and water use), the modelled 'no dams' scenario (model of current levels of rainfall but the effects of dams and water abstraction removed) and the test scenario (model of possible WAP policy options).

The process uses multivariate statistics to represent the communities present (as predicted by the response models) in multidimensional space. The distance between the different communities in this multidimensional space can be used to assess how different the scenarios are to each other. The difference between the current scenario and the test scenario gives an indication of how well the test scenario will maintain the current community. The difference between the distance between the 'no dams' scenario and the current scenario and the 'no dams' scenario and the test scenario provides an indication of if the changes observed represent an improvement or a degradation (under the assumption that the 'no dams' scenario represents the least impacted scenario). This is represented visually in Figure 26 (from Green and Maxwell, in prep.).

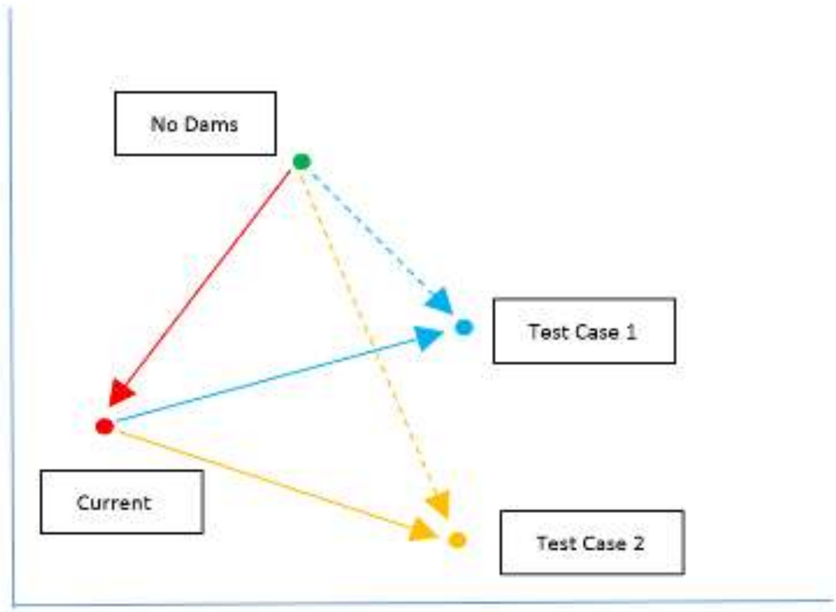


Figure 26: diagrammatic representation of the calculation of the Maintain and Improve Metrics. The arrows represent the Bray-Curtis Distance between the predicted macroinvertebrate communities from the different flow scenarios. The solid blue line represents the Maintain metric for test case one, the solid yellow line represents the maintain metric for test case two. The difference between the solid red line and the dotted blue line represents the Improve metric for Test Scenario one while the difference between the solid red line and the dotted yellow line represents the improve metric of Test Scenario two. In this case both test scenarios have changed approximately equal amounts from the current scenario. However, test case one represents and improvement, while scenario two represents a degradation. From Green and Maxwell (in prep.)

The metrics that are produced from this method represent an empirical measure of the success of the overarching WAP objectives. The utility of this method is in identifying if flow scenarios are meeting the objectives and how to objectively compare different scenarios. In order to be usable for water planning, the outputs of this process need to be translatable into the risk framework used for water planning in South Australia.

In order to achieve this, we developed a method where the relative deviations (using Bray Curtis distance) are scaled to provide a relative level for each of the metrics compared to the observable limits for each of those metrics (highest and lowest values observed for that metric for a given site) (Green and Maxwell, (in prep). This provides a ranked score comparable across all sites that can be categorised to provide relative levels of risk to WDEs.

The ultimate objective of this ongoing body of work will be to identify clear thresholds and/points of no return for the ecological assets that will allow the translation of relative levels of risk to absolute levels of risk.

7.3 Ongoing use of this work

The current project has produced several tools and datasets that will be of use to water planners and to investigations to inform water planning in the future.

7.3.1 DATASETS

There has been considerable effort extended in this project to collate existing datasets that cover the MLR. Both the fish and the macroinvertebrate modelling required existing data to be paired with data previously collected and collected by different agencies.

The modelling work has resulted in a single database of fish records for the MLR that comprises data collected by Aquasave and by SARDI. This data has been attributed with additional metadata to allow for use as a single dataset. This data is currently stored with SARDI.

The macroinvertebrate data that has been collated for this project still exists in three databases. One that represents data collected prior to 2008, one that represents post 2008 collections and one that represents data collected at a finer special scale not analysed as part of this project. The difference between the datasets is a change in the sorting methodology resulting in changes to the identification some more cryptic macroinvertebrate species. After discussions with local experts, and the chief data collector, these differences are reconcilable (P. Goonan, Pers. Comm. 2014). This is a high priority for future work as this will effectively double the available dataset for modelling. This collated data is currently sorted with SMK (DEWNR).

The sampling that was undertaken as part of this project has created a dataset of fish, macroinvertebrate, vegetation, instantaneous and continuous flow, and substrate and water quality. This dataset represents a unique dataset that provides opportunities to investigate links between biotic groups and well as interactions between biotic and abiotic factors. These links were initially envisaged to be investigated as part of this project, however, priority was given to the development of the response models and risk assessment framework. This data will be important moving forward as it provides detailed insight into WDE condition prior to the implementation of the low-flows programs across the MLR (Flows for the Future, Securing Low-flows). This data is currently stored with SMK (DEWNR) and SARDI.

7.3.2 TOOLS

The tools that have been developed as part of this program are in two broad groups. These are the scripts and codes that have been written to assist in the generation of data for analysis and the response models developed for the three biotic groups (described above).

The scripts include:

- Kennard metric calculation (R script) – this script calculates the 120 flow metrics presented in Kennard *et al.* (2010) for daily flow data.
- VanLaarhoven and van der Wielen (2009) metrics (C# script) – this script calculates the 52 metircs that were used in the determination of EWRs for the Mt Lofty ranges in VanLaarhoven and van der Wielen (2009)
- Rating curve estimation script (Python Script) – this script was developed to batch run rating curve calculations for multiple cross sections. It requires the cross section data, slope and Mannings n and will produce a theoretical rating curve (stage-discharge relationship) to predict flow.

- Inundation calculation script for vegetation quadrats (R script) – this script was developed for the vegetation response functions. It calculates the number of days in a given period that a particular location on a cross section is inundated given a provided flow record. It is paired with the rating curve estimation script to estimate stage (water level) based on a flow.
- Trait group and data manipulation scripts for fish and macroinvertebrates (R scripts) – these scripts are used for the calculation of the fish and macroinvertebrate response models. They are large and perform several functions within them including grouping data by traits, calculating flow metircs, building the response models, predicting the trait groups present based on new flow data, permuting these results to obtain confidence intervals, calculating the maintain and improvement metrics for the risk assessment and plotting the predicted community at each sites.

These scripts are variously housed with CSIRO, SMK and SARDI.

The usefulness of these tools will be ongoing as the outputs of them are required for ongoing water management in South Australia. They provide a significantly faster and effective way of generating the inputs needed for analysis.

7.4 Implications for water requirements and future use of models and review of the Mount Lofty Ranges WAP

The water resources of the MLR were prescribed in 2005. Local natural resource management boards are required to prepare a WAP for prescribed resources, which sets sustainable limits for allocation of water and provides for ongoing water management (VanLaarhoven and van der Wielen, 2009). This requirement and recognition of the need for increased environmental flows culminated in release of the WAP for the western MLR in 2010 (AMLRNRMB, 2013) and the eastern MLR in 2011 (SAMDBNRMB, 2011).

The Goyder Institute identified areas to improve water allocation planning in the MLR (Cox *et al.* 2013). These included the development of robust models based on better understanding of hydro-ecological processes, particularly under low-flow situations. Given this opportunity, this project was aimed at developing a method which is less reliant on expert opinion, more repeatable, more transparent and based on empirical evidence. Existing environmental water requirements were revised based on a review of literature, existing and new field-based monitoring data, and an assessment of the water quantity requirements of ecosystems.

Modelling results for vegetation showed that restoring components of the natural flow regime may result in an improvement in plant communities, but these improvements may not be realised if land management practices are not changed and complementary actions such as weed control and stock exclusion are not also undertaken (cf. Jansen and Robertson 2001).

Modelling results for macroinvertebrates showed that reducing the level of flow intermittency increased the diversity of taxa, promoted species with resilient traits and overall maintained a more balanced, functioning ecosystem resilient to degradation.

The response models that were developed for the fish of the MLR still require some updating before they are ready for predicative use. However, the initial outputs of the work show that the longer term changes in the flow regime are important, more so that year to year variations and that increasing levels of intermittency are having a negative impact on the fish populations of the MLR. This is important information that will enable managers to better achieve the WAP's ecological objectives pertaining to fish.

There is clear evidence that further increases in water abstraction will increase the level of intermittency in MLR streams, leading to further degradation of the water-dependent ecosystems.

This work has demonstrated the use of empirical data to model responses to proposed water-use scenarios and proposed a method to quantify the 'maintain and improve' components of water allocation planning objectives. The work has brought together multiple research agencies and has consolidated datasets and knowledge from across the region. It has helped to build the modelling capability of research organizations. It is recommended that future revisions of the MLR WAP use and enhance the predictive capability demonstrated in this project.

While the models were developed using data from the MLR, the relationships found are consistent with worldwide research on temporary rivers (Datry, *et al.* 2014b) which suggests that they may be used, with appropriate caveats, to areas beyond the MLR. Providing it can be established that the rivers of these area contain similar communities (taking into account their flow regime), they may be able to be used for water planning more broadly.

8 Outcomes

The project has resulted in several key outcomes for the progression of water resource planning in the Mt Lofty Ranges. The key aim of the project was to derive a method for assessing ecological responses that were less reliant on expert opinion, more repeatable and transparent and more strongly based on empirical evidence. The process undertaken to achieve this outcome has resulted in significant advances in both the understanding of the ecological responses of the WDEs in the Mt Lofty Ranges and the tools that can be used to assess the risks to these WDEs.

Conceptual models for each of the three main biotic groups that are referred to in the WAPs were developed (macroinvertebrates Figure 4, vegetation Figure 6, fish Figure 17). This represents a key achievement of the project as conceptual understanding of the WDEs of the Mt Lofty Ranges underpins much of the activity that is currently undertaken.

Key tools that were developed included several scripts that can be used to calculate flow metrics relating to previous work, published studies and current models, calculate theoretical rating curves and relate positions of the cross section to flow rates (section 7.3.2).

The major purpose of the project was to develop hydro-ecological relationships such that managers can relate the amount of flow through a river system to the risk to the WDEs that depend on that flow. Presented in this report are the methods (macroinvertebrates Section 4.3, vegetation Section 5.5, Fish Section 6.4) that were developed for this purpose along with the results from the vegetation response modelling (Section 5.5). The results from the macroinvertebrate modelling are being presented in a separate paper (Maxwell *et al.* in prep.), while the fish results are still being developed and will be presented in a separate publication. This work represents a key step forward in understanding the responses between flow and macroinvertebrates, fish and vegetation.

One of the final outcomes was the development of the 'Maintain' and 'Improve' metrics for use in the risk assessment process (Section 7.2.4). This work will be expanded in a separate publication (Green & Maxwell, in prep.). This work will provide managers with the ability to assess the level of risk posed to ecological communities from various management scenarios.

References

Adelaide Mount Lofty Ranges Natural Resources Management Board (AMLR NRMB) (2013) Water Allocation Plan, Western Mount Lofty Ranges. Government of South Australia, Online.

Adelaide Mount Lofty Ranges Natural Resources Management Board (AMLR NRMB) (2015) Natural Resources Adelaide and Mt Lofty Ranges. Government of South Australia, Online.

Alcorn MR (2011) Hydrological modelling of the Eastern Mount Lofty Ranges: Demand and low flow scenarios, DFW Technical Note 2011/02, Department for Water, Adelaide.

Alcorn MR (2010) Updates to the Capacity of the Surface Water Resource of the Eastern Mount Lofty Ranges: 2010, DFW Technical Note TN2010/04, Department for Water, Adelaide

Alcorn MR (2008) Restroing low flows in the Mount Lofty Ranges: Description of hydrological modelling to support the business case. DWLBC Technical Note 2008/26. Department of Water, Land and Biodiversity Conservation, Adelaide.

Alcorn MR, Savadamuthu S and Murdoch B (2008) Capacity of the Surface Water Resource of the Eastern Mount Lofty Ranges, Report DWLBC 2008/23. Department of Water land and Biodiversity Conservation, Adelaide.

Allan JD (2004) Landscapes and Riverscapes: the Influence of Land Use on Stream Ecosystems. Annual Review of Ecology, Evolution and Systematics 35: 257-284.

Bardsley D and Sweeney S (2010) Guiding Climate Change Adaptation within Vulnerable Natural Resource Management Systems. Environmental Management 45(5): 1127-1141.

Benejam L, Angermeier PL, Munne A and Garcia-Berthou EM (2010) Assessing Effects of Water Abstraction on Fish Assemblages in Mediterranean Streams. Freshwater Biology 55(3): 628-642.

Bolker BM, Brooks ME, Clark CJ, Geange SW, Poulsen JR, Stevens MH and White JS (2009) Generalized Linear Mixed Models: a Practical Guide for Ecology and Evolution. Trends in Ecology and Evolution, 24(3): 127-135.

Boulton AJ and Lake PS (1992) The Ecology of Two Intermittent Streams in Victoria, Australia. Freshwater Biology 27(1): 99-121.

Boulton AJ, Peterson CG, Grimm NB and Fisher SG (1992) Stability of an Aquatic Macroinvertebrate Community in a Multiyear Hydrologic Disturbance Regime. Ecology 73(6): 2192-2207.

Bray JR and Curtis JT (1957) An Ordination of the Upland Forest Communities of Southern Wisconsin. *Ecological Monographs* 27: 325-349.

Bull WB (1997) Discontinuous Ephemeral Streams. Geomorphology 19(3–4): 227-276.

Bunn SE and Arthington AH (2002) Basic Principles and Ecological Consequences of Altered Flow Regimes for Aquatic Biodiversity. Environmental Management, 30(4): 492-507

Buttle JM, Boon S, Peters DL, Spence C, van Meerveld HJ and Whitfield PH (2012) An Overview of Temporary Stream Hydrology in Canada. Canadian Water Resources Journal / Revue canadienne des ressources hydriques 37(4): 279-310.

Casanova MT (2011) Using water plant functional groups to investigate environmental water requirements. *Freshwater Biology* 56: 2637-2652.

Centre for Australian National Biodiversity Research and Council of Heads of Australasian Herbaria 2015. Australian Plant Census, IBIS database, http://www.chah.gov.au/apc/index.html.

Chow (1959) Open-Channel Hydraulics. McGraw-Hill. New York, United States of America.

Clarke KR and Gorley RN (2006) PRIMER version 6.1.12. PRIMER-E Ltd, Plymouth.

Cox J, Bald M, Burch M, Chittleborough D, Cuddy S, Deane D, Fleming N, Frizenschaf J, Green G, Halfyard R, Holland K, Kookana R, Lomman G, Oliver D, Rassam D, Saint C, Savadamuthu K, Skewes M, van der Weilen M, VanLaarhoven J and van Leeuwen J (2013) Water Allocation Planning and Water Quality Improvements Scoping Study – Discussion paper. Goyder Institute for Water Research Technical Report Series No. 13/8, Adelaide, Australia.

Crawley MJ (2014) Statistics: an Introduction using R. John Wiley & Sons.

Dashorst GR and Jessop JP (1998) Plants of the Adelaide Plains and Hills. The Botanic Gardens of Adelaide and State Herbarium, Adelaide.

Datry T, Larned ST and Tockner K (2014a) Intermittent rivers: a challenge for freshwater ecology. BioScience.

Datry T, Larned ST, Fritz KM, Bogan MT, Wood PJ, Meyer EI and Santos AN (2014b) Broad-scale patterns of invertebrate richness and community composition in temporary rivers: effects of flow intermittence. Ecography 37: 94-104.

DeFries R and Eshleman KN (2004) Land-use change and hydrologic processes: a major focus for the future. Hydrological Processes 18(1): 2183-2186.

EPA (2014) Aquatic ecosystem monitoring, evaluation and reporting. Goonan, P. (ed), Environmental Protection Agency, South Australia.

Ganf G, White S and Oliver R (2010) Allocating water to the wetlands of the Murray Valley to maximise aquatic plant species diversity. In 'Ecosystem Response Modelling in the Murray Darling Basin'. (Eds: Saintilan, N. and Overton, I.) pp. 279-300. CSIRO Publishing, Collingwood, Victoria.

Growns, IO and Davis JA (1994) Longitudinal Changes in Near-Bed Flows and Macroinvertebrate Communities in a Western Australian Stream. Journal of the North American Benthological Society 13(4): 417-438.

Guan H, Simmons CT and Love AJ (2009) Orographic controls on rain water isotope distribution in the Mount Lofty Ranges of South Australia. Journal of Hydrology 374(3–4): 255-264.

Jansen A and Robertson AI (2001) Relationships between livestock management and the ecological condition of riparian habitats along an Australian floodplain river. Journal of Applied Ecology 38: 63-75.

Jessop J, Dashorst GR and James FR (2006) Grasses of South Australia. An illustrated guide to the native and naturalised species. Wakefield Press, Adelaide.

Jessop JP and Tolken HR (1986) The Flora of South Australia. Government of South Australia, Adelaide.

Kennard MJ, Pusey BJ, Olden JD, Mackay SJ, Stein JL and Marsh N (2010) Classification of natural flow regimes in Australia to support environmental flow management. Freshwater Biology 55(1): 171-193.

Lake PS (2000) Disturbance, Patchiness and Diversity in Streams. Journal of the North American Benthological Society 19(4): 573-592.

Larned ST, Datry T, Arscott DB and Tockner K (2010) Emerging concepts in temporary-river ecology. Freshwater Biology 55(4): 717-738.

Lloyd N, Quinn G, Thoms M, Arthington A, Gawne B, Humphries P and Walker K (2004). Does flow modification cause geomorphological and ecological response in rivers. A literature review from an Australian perspective. CRC for Freshwater Ecology, 57.

Mackay S, Marsh N, Sheldon F and Kennard M (2012) Low-flow Hydrological Classification of Australia. National Water Commission, Canberra.

McNeil DG and Hammer M (2007) Biological Review of the Freshwater Fishes of the Mount Lofty Ranges. South Australian Research and Development Institute (Aquatic Sciences), SARDI Publication Number F2006/000335, Adelaide.

McNeil DG, Schmarr DW and Mathwin R (2011) Condition of freshwater fish communities in the Adelaide and Mount Lofty Ranges management region. F2011/000502-1: 65, Adelaide.

Nicol JM (2013) Characterisation of the in stream and riparian plant communities in the Barossa Prescribed Water Resources Area. Data and methods report. South Australian Research and Development Institute (Aquatic Sciences), SARDI Publication No. F2013/000413-1, Adelaide.

Nicol JM and Bald M (2006) In-stream and riparian vegetation of the Onkaparinga River between Clarendon Weir and Old Noarlunga. Implications for environmental water provisions. South Australian Research and Development Institute (Aquatic Sciences), SARDI Publication Number RD 04/0199, Adelaide.

Poff NL, Olden JD, Merritt DM and Pepin DM (2007) Homogenization of regional river dynamics by dams and global biodiversity implications. Proceedings of the National Academy of Sciences of the United States of America 104(14): 2732-2737.

Poff NL, Pyne MI, Bledsoe BP, Cuhaciyan CC and Carlisle DM (2010) Developing Linkages between Species Traits and Multiscaled Environmental Variation to Explore Vulnerability of Stream Benthic Communities to Climate Change. Journal of the North American Benthological Society 29(4): 1441-1458.

Poff NL and Zimmerman JK (2010) Ecological Responses to Altered Flow Regimes: a Literature Review to Inform the Science and Management of Environmental Flows. Freshwater Biology 55(1): 194-205.

Prescott A (1988) It's Blue with Five Petals. Wild Flowers of the Adelaide Region.

Quinn JM, Cooper AB, Davies-Colley RJ, Rutherford C and Williamson RB (1997) Land use effects on habitat, water quality, periphyton, and benthic invertebrates in Waikato, New Zealand, hill-country streams. New Zealand Journal of Marine and Freshwater Research 35(5): 579-597.

Romanowski N (1998) Aquatic and Wetland Plants. A Field Guide for Non-tropical Australia. University of New South Wales Press, Sydney.

Sainty GR and Jacobs SW (1981) Water Plants of New South Wales. Water Resources Commission New South Wales, Sydney.

Sainty G and Jacobs S (2003) Waterplants in Australia: A Field Guide (Expanded 4th Edition), Sainty and Associates Pty Ltd, Potts Point, New South Wales, Australia.

Savadamuthu K (2002) Impact of farm dams on streamflow in the Upper Marne Catchment. South Australia. Department for Water Resources. Report, DWR 02/01/0003.

Savadamuthu K and Teoh K (2010) Surface Water Resource Capacity Estimates for the Western Mount Lofty Ranges Prescribed Water Resources Area, DFW Technical Note 2010/05, Department for Water, Adelaide

Savadamuthu K, van der Wielen M, Alcorn MR and VanLaarhoven J (2011) Hydro-ecological modelling to establish sustainable extraction limits in unregulated catchments, 19th Internation congress on Modelling and Simulation, Perth, Australia.

Schmarr D, Mathwin R, & Cheshire D (2014) Western Mount Lofty Ranges Fish Condition Report 2012-2013 incorporating the Barossa Valley Prescribed Water Resource Area fish community study, the verification of water allocation science project (VWASP) and the Western Mount Lofty Ranges fish community monitoring, SARDI Publication No. F2014/000113-1, South Australian Research and Development Institute Aquatic Sciences, Adelaide.

South Australian Murray-Darling Basin Natural Resources Management Board (SAMDB NRMB) (2013) Water allocation plan for the Eastern Mount Lofty Ranges.

VanLaarhoven J and van der Wielen M (2009) Environmental water requirements for the Mount Lofty Ranges prescribed water resources areas, Report DWLBC 2009/29, Department of Water, Land and Biodiversity Conservation & South Australian Murray-Darling Basin Natural Resources

VanLaarhoven J and van der Wielen M (2012) Assessment of the needs of water dependent ecosystems for the Eastern Mount Lofty Ranges Prescribed Water Resources Area, Government of South Australia through Department for Water, Adelaide.

White SD, Ganf GG and Oliver RL (2008) Water allocation to River Murray wetlands: a basin-wide modelling approach. Land and Water Australia, Canberra.

Whiterod N & Hammer M (2014) The state of fish communities across the Eastern Mount Lofty Ranges: condition reporting from 2010 to 2013. Report to the South Australian Murray-Darling Basin Natural Resources Management Board. Aquasave - Nature Glenelg Trust, Goolwa Beach, South Australia.

Zampatti BP, Bice CM and Jennings PR (2010) Temporal variability in fish assemblage structure and recruitment in a freshwater-deprived estuary: The Coorong, Australia. Marine and Freshwater Research 61: 1298–1312.

Appendix A

Table 15 Fish CPUE at sites sampled for the GWAP project.

CAR AUR to NAN AUS

Site Code	East-West	DATE	River System	Waterway	Site	No fish	CAR AUR	CRA STE	CYP CAR	GAD MAR	GAL BRE	GAL MAC	GAL OLI	GAM HOL	HYP SPP	MAC AMB	NAN AUS
ML13-84	East	23-OCT-13	Angas River	Angas River	Quarry Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.033	0.000	0.000	0.000	0.000
ML13-86	East	29-OCT-13	Marne River	North Rhine River	Kappalunta	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML13-85	East	30-OCT-13	Marne River	Marne River	Cambrai	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.000	0.000	0.000	0.000	0.000
ML13-87	East	30-OCT-13	Marne River	Marne River	Jutland Rd	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML13-88	East	30-OCT-13	Marne River	Marne River	Vigars Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.920	0.000	0.000	0.000	0.000
ML13-89	East	30-OCT-13	Marne River	Marne River	Gorge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.320	0.000	0.000	0.000	0.000
ML13-90	East	30-OCT-13	Saunders Creek	Saunders Creek	Saunders Creek Gorge	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML13-91	East	31-OCT-13	Reedy Creek	Reedy Creek	ds Waterfalls	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.560	0.000	0.000
ML13-92	East	20-NOV-13	Bremer river	Bremer River	Harrogate - tennis courts	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML13-93	East	20-NOV-13	Bremer River	Bremer River	Military Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
ML13-94	East	20-NOV-13	Bremer River	Bremer River	Jaensch Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.000	0.000
ML13-95	East	20-NOV-13	Bremer River	Bremer River	Hartley Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML13-96	East	20-NOV-13	Angas River	Angas River	Gauge	0.000	0.000	0.000	0.000	0.384	0.000	0.000	0.000	0.000	1.632	0.000	0.000
ML13-97	East	21-NOV-13	Bremer River	Rodwell Creek	Belford (pool 4 & 5)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.028	0.000	0.000
ML13-98	East	21-NOV-13	Angus River	Angus River	us Development pool	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.010	0.000	0.000
ML13-99	East	02-DEC-13	Finniss River	Finniss River	Railway Bridge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML13-100	East	03-DEC-13	Finniss River	Finniss River	us Waterfalls	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.298	0.000	0.000	0.000	0.024
ML13-101	East	03-DEC-13	Currency Creek	Currency Creek	Lions Park	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000
ML13-102	East	03-DEC-13	Currency Creek	Currency Creek	Stuarts Bridge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.005	0.000	0.000	0.000
ML13-103	East	04-DEC-13	Currency Creek	Currency Creek	Kilchoan	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.287	0.000	0.000	0.000	0.000
ML13-104	East	04-DEC-13	Tookayerta Creek	Tookayerta Creek	Cleland Gully Rd	0.000	0.000	0.000	0.000	0.318	0.000	0.000	0.073	0.000	0.000	0.000	0.000
ML13-105	East	04-DEC-13	Finniss River	Finniss River	Yundi	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000

ML13-106	East	04-DEC-13	Finniss River	Giles Creek	Cross property	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.588	0.514	0.000	0.000	0.000
ML14-06	East	20-FEB-14	Reedy Creek	Reedy Creek	Lowland wetland	0.000	0.002	0.005	0.003	0.000	0.000	0.006	0.000	0.017	0.030	0.000	0.000
ML14-07	East	04-MAR-14	Finniss River	Finniss River	Lovejoys	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.018	0.000	0.000	0.000
ML14-10	East	20-MAR-14	Angas River	Angas River	Mouth	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.003	0.000	0.000	0.000
ML14-11	East	20-MAR-14	Bremer River	Bremer River	Mouth below bridge	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
ML14-08	East	01-APR-14	Lake Alexandrina	Lake Alexandrina	Turvey's Drain	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000
ML14-09	East	02-APR-14	Tookayerta Creek	Tookayerta Creek	Black Swamp	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
ML14-12	East	07-APR-14	Reedy creek	Reedy Creek	Below waterfalls	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	9.360	0.000	0.000	0.000
ML14-13	East	07-APR-14	Saunders Creek	Saunders Creek	Lenger Reserve	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	31.440	3.600	0.000	0.000
ML14-14	East	07-APR-14	Marne River	Marne River	Black Hill Springs	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.000	0.000
ML14-15	East	08-APR-14	Marne River	Marne River	Cambrai	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-16	East	08-APR-14	Marne River	Marne River	Gorge	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-17	East	09-APR-14	Saunders Creek	Saunders Creek	Saunders Creek Gorge	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-18	East	09-APR-14	Marne River	North Rhine River	Pine Hut Road	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-19	East	09-APR-14	Marne River	North Rhine River	Kappalunta	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-20	East	09-APR-14	Marne River	Marne River	Jutland Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.027	0.000	0.000	0.000	0.000
ML14-21	East	09-APR-14	Marne River	Marne River	off Vigars Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.120	0.000	0.000	0.000	0.000
ML14-23	East	09-APR-14	Bremer River	Bremer River	Harrogate - tennis courts	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-24	East	09-APR-14	Bremer River	Bremer River	Harrogate - main bridge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-25	East	10-APR-14	Currency Creek	Currency Creek	Kilchoan	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.232	0.365	0.000	0.000	0.000
ML14-26	East	10-APR-14	Tookayerta Creek	Nangkita creek	us Willowburn Rd	0.000	0.000	0.000	0.000	1.589	0.000	0.000	1.087	0.000	0.000	0.000	1.923
ML14-27	East	10-APR-14	Finniss River	Finniss River	Yundi	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.048	0.241	0.000	0.000	0.000
ML14-28	East	10-APR-14	Finniss River	Meadows Creek	Thorn Dairy	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.044	0.073	0.000	0.000	0.132
ML14-29	East	11-APR-14	Finniss River	Bull Creek	McHarg Creek Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	6.739	0.000	0.000	0.000	0.000
ML14-30	East	11-APR-14	Finniss River	Finniss River	ds Coles Crossing	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.166	0.000	0.000	0.043
ML14-31	East	11-APR-14	Tookayerta Creek	Tookayerta Creek	Cleland Gully Rd	0.000	0.000	0.000	0.000	0.160	0.000	0.000	0.053	0.000	0.000	0.000	0.000
ML14-32	East	11-APR-14	Tookayerta Creek	Swampy Creek	Brawley Swamp	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-33	East	14-APR-14	Finniss River	Finniss River	us Waterfalls	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.466	0.000	0.000	0.000	2.384
ML14-34	East	14-APR-14	Tookayerta Creek	Tookayerta Creek	us Winery Rd	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.014	0.000	0.000	0.000	0.001
ML14-35	East	14-APR-14	Finniss River	Finniss River	Railway Bridge	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
ML14-36	East	14-APR-14	Finniss River	Giles Creek	Cross property	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.028	0.000	0.000	0.000

ML14-37	East	15-APR-14	Tookayerta Creek	Tookayerta Creek	Deep Creek Rd	0.000	0.000	0.000	0.000	0.014	0.000	0.000	0.000	0.000	0.000	0.000	0.003
ML14-38	East	15-APR-14	Currency Creek	Currency Creek	Lions Park	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
ML14-39	East	15-APR-14	Currency Creek	Currency Creek	ds Goolwa Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000
ML14-40	East	15-APR-14	Currency Creek	Currency Creek	Stuarts Bridge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.000	0.000	0.000
ML14-41	East	15-APR-14	Reedy Creek	Reedy Creek	Palmer Rd bridge	0.000	4.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-42	East	15-APR-14	Reedy Creek	Reedy Creek	Delfabro property	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.000	0.000	0.000	0.000
ML14-43	East	15-APR-14	Reedy Creek	Bakers Creek	Betches pool	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.025	0.000	0.000	0.000	0.000
ML14-44	East	16-APR-14	Finniss River	Finniss River	300m ds Winery Road	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000
ML14-45	East	16-APR-14	Finniss River	Finniss River	500m ds Winery Road	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.001	0.000	0.000	0.000
ML14-46	East	16-APR-14	Finniss River	Finniss River	Murray pool (ds channel constriction)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-47	East	22-APR-14	Bremer River	Mount Barker Creek	Footbridge near bowls club	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.450	0.000	0.000	0.000	0.000
ML14-48	East	22-APR-14	Bremer River	Bremer River	Military Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-49	East	22-APR-14	Bremer River	Bremer River	Wanstead Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.440	0.000	0.000	0.000
ML14-50	East	22-APR-14	Angas River	Angas River	Development pool	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008	0.000	0.000
ML14-51	East	22-APR-14	Bremer River	Bremer River	Jaensch Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.054	0.001	0.000	0.000
ML14-76	East	22-APR-14	Bremer River	Bremer River	Hartley Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000	0.000	0.000
ML14-77	East	22-APR-14	Angas River	Angas River	Gauge	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.001	0.000	0.002	0.000	0.000
ML14-78	East	23-APR-14	Angas River	Angas River	Hospital pool	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.013	0.000	0.000
ML14-79	East	23-APR-14	Angas River	Angas River	Old swimming pool	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.000
ML14-80	East	23-APR-14	Angas River	Angas River	Town pool	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.078	0.000	0.000
ML14-81	East	23-APR-14	Angas River	Angas River	Middle Creek junction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.036	0.000	0.005	0.000	0.101
ML14-82	East	23-APR-14	Angas River	Angas River	North Parade (first weir)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.001
ML14-83	East	23-APR-14	Bremer River	Bremer River	Ballandoon Rd	0.000	0.003	0.000	0.000	0.000	0.000	0.064	0.000	0.000	0.000	0.000	0.000
ML14-92	East	23-APR-14	Bremer River	Bremer River	Davidson Rd	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-93	East	23-APR-14	Angas River	Angas River	Davidson Rd	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-94	East	23-APR-14	Angas River	Angas River	Watson Park Rd	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-95	East	23-APR-14	Bremer River	Bremer River	Ballandoon Rd	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-84	East	28-APR-14	Bremer River	Rodwell Creek	Highland Valley (b)	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-85	East	28-APR-14	Bremer River	Rodwell Creek	Highland Valley (a)	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-91	East	28-APR-14	Bremer River	Rodwell Creek	Belford (pool 4 & 5)	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

ML14-88	East	06-MAY-14	Inman River	Backvalley Creek	Kirk Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.040	0.000	0.000
ML14-89	East	06-MAY-14	Inman River	Backvalley Creek	Kirk property	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-86	East	08-MAY-14	Angas River	Angas River	Searle St	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.150	0.000	0.000	0.000	0.000
ML14-87	East	08-MAY-14	Angas River	Angas River	Quarry Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.017	0.000	0.000	0.000	0.000
ML14-90	East	08-MAY-14	Inman River	Backvalley Creek	Robertson property	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.000	0.013
WML13-1	West	5/11/2013	Gawler River	North Para River	Mt McKenzie	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.331	0.000	0.000	0.000
WML13-2	West	5/11/2013	Gawler River	North Para River	Penrice gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.058	0.000	0.000	0.000
WML13-3	West	5/11/2013	Gawler River	Tanunda Creek	Tanunda Ck Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.564	0.000	0.000	0.000	0.000
WML13-4	West	6/11/2013	Gawler River	North Para River	Penrice Quarry	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML13-5	West	7/11/2013	Gawler River	Jacob's Creek	Jacobs Creek Old Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.128	0.000	0.000	0.000	0.000
WML13-6	West	7/11/2013	Gawler River	North Para River	Yaldara	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.209	0.000	0.000	0.000
WML13-7	West	8/11/2013	Torrens	Torrens	Mt Pleasant	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML13-8	West	12/11/2013	Boat Harbour Creek	Boat Harbour Creek	Boat Harbour Gauge	0.000	0.000	0.000	0.000	0.000	0.064	0.000	0.000	0.000	0.000	0.000	0.000
WML13-9	West	12/11/2013	Callawonga Creek	Callawonga Creek	Callawonga Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML13-10	West	13/11/2013	Inman River	Back Valley Creek	BackValley Gauge	0.000	0.000	0.000	0.000	0.000	0.523	0.000	0.000	0.000	1.750	0.000	0.012
WML13-11	West	13/11/2013	Inman River	Inman River	Inman Gauge	0.000	0.000	0.000	0.000	0.000	0.343	0.000	0.000	0.000	0.023	0.000	0.000
WML13-12	West	13/11/2013	Inman River	Inman River	Swains Crossing Road	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.326	0.000	0.000
WML13-13	West	14/11/2013	Hindamarsh River	Hindamarsh River	Hindmarsh Falls	0.000	0.000	0.000	0.000	0.000	0.250	0.000	0.035	0.000	0.000	0.000	0.000
WML13-14	West	14/11/2013	Hindamarsh River	Hindamarsh River	Hindmarsh Gauge	0.000	0.000	0.000	0.000	0.000	0.000	1.483	0.000	0.000	0.000	0.000	0.000
WML13-15	West	15/11/2013	Brownhill Creek	Brownhill Creek	Brownhill Creek	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.215	0.000	0.000	0.000	0.000
WML13-16	West	15/11/2013	Onkaparinga	Aldgate Creek	Mylor Bridge	0.000	0.000	0.000	0.000	0.000	4.413	0.000	0.465	0.000	0.000	0.000	0.000
WML13-17	West	29/11/2013	Onkaparinga	Lenswood Creek	Lenswood Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	20.419	0.000	0.000	0.000	0.000
WML13-18	West	29/11/2013	Torrens	Sixth Creek	US Sixth Creek Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML13-19	West	29/11/2013	Torrens	First Creek	Waterfall Gully	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.116	0.000	0.000	0.000	0.000
WML14-1	West	27/05/2014	Brownhill Creek	Brownhill Creek	Brownhill Creek	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.180	0.000	0.000	0.000	0.000
WML14-2	West	27/05/2014	Onkaparinga	Aldgate Creek	Mylor Bridge	0.000	0.000	0.000	0.000	0.000	0.209	0.000	0.942	0.000	0.000	0.000	0.000
WML14-3	West	28/05/2014	Onkaparinga	Lenswood Creek	Lenswood Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.750	0.000	0.000	0.000	0.000
WML14-4	West	28/05/2014	Torrens	Torrens	Mt Pleasant	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML14-5	West	28/05/2014	Torrens	Sixth Creek	US Sixth Creek Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML14-6	West	28/05/2014	Gawler River	North Para River	Yaldara	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.017	0.000	0.000	0.000

WML14-7	West	30/05/2014	Gawler River	Jacob's Creek	Jacobs Creek Old Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.552	0.000	0.000	0.000	0.000
WML14-8	West	30/05/2014	Gawler River	Tanunda Creek	Tanunda Ck Gauge	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML14-9	West	2/06/2014	Gawler River	North Para River	Penrice Quarry	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.209	0.000	0.000	0.000
WML14-10	West	3/06/2014	Gawler River	North Para River	Mt McKenzie	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	4.105	0.000	0.000	0.000
WML14-11	West	3/06/2014	Torrens	First Creek	Waterfall Gully	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.110	0.000	0.000	0.000	0.000
WML14-12	West	4/06/2014	Hindamarsh River	Hindamarsh River	Hindmarsh Falls	0.000	0.000	0.000	0.000	0.000	0.047	0.000	0.000	0.000	0.000	0.000	0.000
WML14-13	West	4/06/2014	Hindamarsh River	Hindamarsh River	Hindmarsh Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.279	0.000	0.000	0.000	0.000	0.000
WML14-14	West	5/06/2014	Inman River	Back Valley Creek	BackValley Gauge	0.000	0.000	0.000	0.000	0.000	0.122	0.000	0.000	0.000	1.180	0.000	0.163
WML14-15	West	5/06/2014	Boat Harbour Creek	Boat Harbour Creek	Boat Harbour Gauge	0.000	0.000	0.000	0.000	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.000
WML14-16	West	5/06/2014	Callawonga Creek	Callawonga Creek	Callawonga Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML14-17	West	5/06/2014	Inman River	Inman River	Inman Gauge	0.000	0.000	0.000	0.000	0.000	0.087	0.006	0.000	0.000	0.000	0.000	0.000
WML14-18	West	5/06/2014	Inman River	Inman River	Swains Crossing Road	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.343	0.000	0.000

NEM ERE TO SAL TRU

Site Code	East-West	DATE	River System	Waterway	Site	No fish	NEM ERE	ONC MYK	PER FLU	PHI GRA	PHI MAC	PSE OLO	PSE URV	RET SEM	SAL TRU
ML13-84	East	23-OCT-13	Angas River	Angas River	Quarry Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML13-86	East	29-OCT-13	Marne River	North Rhine River	Kappalunta	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML13-85	East	30-OCT-13	Marne River	Marne River	Cambrai	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML13-87	East	30-OCT-13	Marne River	Marne River	Jutland Rd	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML13-88	East	30-OCT-13	Marne River	Marne River	Vigars Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML13-89	East	30-OCT-13	Marne River	Marne River	Gorge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML13-90	East	30-OCT-13	Saunders Creek	Saunders Creek	Saunders Creek Gorge	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML13-91	East	31-OCT-13	Reedy Creek	Reedy Creek	ds Waterfalls	0.000	0.000	0.000	0.000	0.000	0.080	0.000	0.240	0.000	0.000
ML13-92	East	20-NOV-13	Bremer river	Bremer River	Harrogate - tennis courts	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML13-93	East	20-NOV-13	Bremer River	Bremer River	Military Rd	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
ML13-94	East	20-NOV-13	Bremer River	Bremer River	Jaensch Rd	0.000	0.000	0.000	0.000	0.018	0.001	0.000	0.001	0.000	0.000
ML13-95	East	20-NOV-13	Bremer River	Bremer River	Hartley Gauge	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.002	0.000	0.000
ML13-96	East	20-NOV-13	Angas River	Angas River	Gauge	0.000	0.000	0.000	0.000	0.192	0.000	0.000	0.000	0.000	0.000

ML13-97	East	21-NOV-13	Bremer River	Rodwell Creek	Belford (pool 4 & 5)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML13-98	East	21-NOV-13	Angus River	Angus River	us Development pool	0.000	0.000	0.000	0.000	0.009	0.000	0.000	0.000	0.000	0.000
ML13-99	East	02-DEC-13	Finniss River	Finniss River	Railway Bridge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.011	0.000	0.000
ML13-100	East	03-DEC-13	Finniss River	Finniss River	us Waterfalls	0.000	0.000	0.000	0.000	0.000	0.012	0.000	0.000	0.000	0.000
ML13-101	East	03-DEC-13	Currency Creek	Currency Creek	Lions Park	0.000	0.000	0.000	0.003	0.001	0.000	0.000	0.011	0.000	0.000
ML13-102	East	03-DEC-13	Currency Creek	Currency Creek	Stuarts Bridge	0.000	0.000	0.000	0.000	0.059	0.000	0.000	0.000	0.000	0.000
ML13-103	East	04-DEC-13	Currency Creek	Currency Creek	Kilchoan	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML13-104	East	04-DEC-13	Tookayerta Creek	Tookayerta Creek	Cleland Gully Rd	0.000	0.000	0.024	0.024	0.000	0.000	0.000	0.000	0.000	0.049
ML13-105	East	04-DEC-13	Finniss River	Finniss River	Yundi	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML13-106	East	04-DEC-13	Finniss River	Giles Creek	Cross property	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.514	0.000	0.000
ML14-06	East	20-FEB-14	Reedy Creek	Reedy Creek	Lowland wetland	0.000	0.039	0.000	0.000	0.034	0.003	0.000	0.012	0.001	0.000
ML14-07	East	04-MAR-14	Finniss River	Finniss River	Lovejoys	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.000	0.000
ML14-10	East	20-MAR-14	Angas River	Angas River	Mouth	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.002	0.000	0.000
ML14-11	East	20-MAR-14	Bremer River	Bremer River	Mouth below bridge	0.000	0.004	0.000	0.001	0.005	0.000	0.000	0.000	0.000	0.000
ML14-08	East	01-APR-14	Lake Alexandrina	Lake Alexandrina	Turvey's Drain	0.000	0.000	0.000	0.000	0.001	0.003	0.000	0.001	0.000	0.000
ML14-09	East	02-APR-14	Tookayerta Creek	Tookayerta Creek	Black Swamp	0.000	0.000	0.000	0.001	0.002	0.000	0.000	0.000	0.000	0.000
ML14-12	East	07-APR-14	Reedy creek	Reedy Creek	Below waterfalls	0.000	0.000	0.000	0.000	0.400	0.053	0.000	0.000	0.000	0.000
ML14-13	East	07-APR-14	Saunders Creek	Saunders Creek	Lenger Reserve	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-14	East	07-APR-14	Marne River	Marne River	Black Hill Springs	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-15	East	08-APR-14	Marne River	Marne River	Cambrai	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-16	East	08-APR-14	Marne River	Marne River	Gorge	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-17	East	09-APR-14	Saunders Creek	Saunders Creek	Saunders Creek Gorge	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-18	East	09-APR-14	Marne River	North Rhine River	Pine Hut Road	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-19	East	09-APR-14	Marne River	North Rhine River	Kappalunta	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-20	East	09-APR-14	Marne River	Marne River	Jutland Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-21	East	09-APR-14	Marne River	Marne River	off Vigars Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-23	East	09-APR-14	Bremer River	Bremer River	Harrogate - tennis courts	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-24	East	09-APR-14	Bremer River	Bremer River	Harrogate - main bridge	0.000	0.000	0.000	0.000	0.240	0.000	0.000	0.000	0.000	0.000
ML14-25	East	10-APR-14	Currency Creek	Currency Creek	Kilchoan	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-26	East	10-APR-14	Tookayerta Creek	Nangkita creek	us Willowburn Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-27	East	10-APR-14	Finniss River	Finniss River	Yundi	0.000	0.000	0.000	0.000	0.555	0.000	0.000	0.000	0.000	0.000

ML14-28	East	10-APR-14	Finniss River	Meadows Creek	Thorn Dairy	0.000	0.000	0.000	0.000	0.029	0.000	0.000	0.000	0.000	0.000
ML14-29	East	11-APR-14	Finniss River	Bull Creek	McHarg Creek Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-30	East	11-APR-14	Finniss River	Finniss River	ds Coles Crossing	0.000	0.000	0.000	0.000	0.382	0.000	0.000	0.000	0.000	0.000
ML14-31	East	11-APR-14	Tookayerta Creek	Tookayerta Creek	Cleland Gully Rd	0.000	0.000	0.000	0.027	0.000	0.000	0.000	0.000	0.000	0.027
ML14-32	East	11-APR-14	Tookayerta Creek	Swampy Creek	Brawley Swamp	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-33	East	14-APR-14	Finniss River	Finniss River	us Waterfalls	0.000	0.000	0.000	0.000	0.000	0.014	0.000	0.027	0.000	0.000
ML14-34	East	14-APR-14	Tookayerta Creek	Tookayerta Creek	us Winery Rd	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
ML14-35	East	14-APR-14	Finniss River	Finniss River	Railway Bridge	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.004	0.000	0.000
ML14-36	East	14-APR-14	Finniss River	Giles Creek	Cross property	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000
ML14-37	East	15-APR-14	Tookayerta Creek	Tookayerta Creek	Deep Creek Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-38	East	15-APR-14	Currency Creek	Currency Creek	Lions Park	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.003	0.000	0.000
ML14-39	East	15-APR-14	Currency Creek	Currency Creek	ds Goolwa Rd	0.000	0.002	0.000	0.008	0.001	0.000	0.000	0.001	0.000	0.000
ML14-40	East	15-APR-14	Currency Creek	Currency Creek	Stuarts Bridge	0.000	0.000	0.000	0.000	0.013	0.003	0.000	0.000	0.000	0.000
ML14-41	East	15-APR-14	Reedy Creek	Reedy Creek	Palmer Rd bridge	0.000	0.000	0.000	0.000	0.000	0.560	0.000	0.000	0.000	0.000
ML14-42	East	15-APR-14	Reedy Creek	Reedy Creek	Delfabro property	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-43	East	15-APR-14	Reedy Creek	Bakers Creek	Betches pool	0.000	0.000	0.000	0.000	0.000	0.018	0.000	0.000	0.000	0.000
ML14-44	East	16-APR-14	Finniss River	Finniss River	300m ds Winery Road	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.001	0.000	0.000
ML14-45	East	16-APR-14	Finniss River	Finniss River	500m ds Winery Road	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.003	0.000	0.000
ML14-46	East	16-APR-14	Finniss River	Finniss River	Murray pool (ds channel constriction)	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000
ML14-47	East	22-APR-14	Bremer River	Mount Barker Creek	Footbridge near bowls club	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-48	East	22-APR-14	Bremer River	Bremer River	Military Rd	0.000	0.000	0.000	0.000	0.024	0.000	0.000	0.000	0.000	0.000
ML14-49	East	22-APR-14	Bremer River	Bremer River	Wanstead Rd	0.000	0.000	0.000	0.000	0.533	0.240	0.000	0.053	0.000	0.000
ML14-50	East	22-APR-14	Angas River	Angas River	Development pool	0.000	0.000	0.000	0.000	0.051	0.000	0.000	0.000	0.000	0.000
ML14-51	East	22-APR-14	Bremer River	Bremer River	Jaensch Rd	0.000	0.000	0.000	0.000	0.033	0.003	0.000	0.005	0.000	0.000
ML14-76	East	22-APR-14	Bremer River	Bremer River	Hartley Gauge	0.000	0.000	0.000	0.000	0.023	0.000	0.000	0.005	0.000	0.000
ML14-77	East	22-APR-14	Angas River	Angas River	Gauge	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000
ML14-78	East	23-APR-14	Angas River	Angas River	Hospital pool	0.000	0.000	0.000	0.000	0.080	0.000	0.000	0.000	0.000	0.000
ML14-79	East	23-APR-14	Angas River	Angas River	Old swimming pool	0.000	0.000	0.000	0.000	0.026	0.000	0.000	0.000	0.000	0.000
ML14-80	East	23-APR-14	Angas River	Angas River	Town pool	0.000	0.000	0.000	0.000	0.114	0.000	0.000	0.000	0.000	0.000
ML14-81	East	23-APR-14	Angas River	Angas River	Middle Creek junction	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000

ML14-82	East	23-APR-14	Angas River	Angas River	North Parade (first weir)	0.000	0.000	0.000	0.000	0.248	0.002	0.000	0.000	0.000	0.000
ML14-83	East	23-APR-14	Bremer River	Bremer River	Ballandoon Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-92	East	23-APR-14	Bremer River	Bremer River	Davidson Rd	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-93	East	23-APR-14	Angas River	Angas River	Davidson Rd	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-94	East	23-APR-14	Angas River	Angas River	Watson Park Rd	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-95	East	23-APR-14	Bremer River	Bremer River	Ballandoon Rd	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-84	East	28-APR-14	Bremer River	Rodwell Creek	Highland Valley (b)	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-85	East	28-APR-14	Bremer River	Rodwell Creek	Highland Valley (a)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-91	East	28-APR-14	Bremer River	Rodwell Creek	Belford (pool 4 & 5)	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-88	East	06-MAY-14	Inman River	Backvalley Creek	Kirk Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-89	East	06-MAY-14	Inman River	Backvalley Creek	Kirk property	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-86	East	08-MAY-14	Angas River	Angas River	Searle St	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-87	East	08-MAY-14	Angas River	Angas River	Quarry Rd	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML14-90	East	08-MAY-14	Inman River	Backvalley Creek	Robertson property	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML13-1	West	5/11/2013	Gawler River	North Para River	Mt McKenzie	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML13-2	West	5/11/2013	Gawler River	North Para River	Penrice gauge	0.000	0.000	0.000	0.000	0.058	0.000	0.000	0.000	0.000	0.000
WML13-3	West	5/11/2013	Gawler River	Tanunda Creek	Tanunda Ck Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML13-4	West	6/11/2013	Gawler River	North Para River	Penrice Quarry	0.000	0.000	0.000	0.000	1.151	0.000	0.000	0.000	0.000	0.000
WML13-5	West	7/11/2013	Gawler River	Jacob's Creek	Jacobs Creek Old Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML13-6	West	7/11/2013	Gawler River	North Para River	Yaldara	0.000	0.000	0.000	0.000	0.919	0.000	0.419	0.000	0.000	0.000
WML13-7	West	8/11/2013	Torrens	Torrens	Mt Pleasant	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML13-8	West	12/11/2013	Boat Harbour Creek	Boat Harbour Creek	Boat Harbour Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006
WML13-9	West	12/11/2013	Callawonga Creek	Callawonga Creek	Callawonga Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006
WML13-10	West	13/11/2013	Inman River	Back Valley Creek	BackValley Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML13-11	West	13/11/2013	Inman River	Inman River	Inman Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML13-12	West	13/11/2013	Inman River	Inman River	Swains Crossing Road	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000
WML13-13	West	14/11/2013	Hindamarsh River	Hindamarsh River	Hindmarsh Falls	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.023
WML13-14	West	14/11/2013	Hindamarsh River	Hindamarsh River	Hindmarsh Gauge	0.000	0.000	0.000	0.000	0.000	0.035	0.000	0.052	0.000	0.000
WML13-15	West	15/11/2013	Brownhill Creek	Brownhill Creek	Brownhill Creek	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML13-16	West	15/11/2013	Onkaparinga	Aldgate Creek	Mylor Bridge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

WML13-17	West	29/11/2013	Onkaparinga	Lenswood Creek	Lenswood Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML13-18	West	29/11/2013	Torrens	Sixth Creek	US Sixth Creek Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.052
WML13-19	West	29/11/2013	Torrens	First Creek	Waterfall Gully	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML14-1	West	27/05/2014	Brownhill Creek	Brownhill Creek	Brownhill Creek	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML14-2	West	27/05/2014	Onkaparinga	Aldgate Creek	Mylor Bridge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML14-3	West	28/05/2014	Onkaparinga	Lenswood Creek	Lenswood Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML14-4	West	28/05/2014	Torrens	Torrens	Mt Pleasant	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML14-5	West	28/05/2014	Torrens	Sixth Creek	US Sixth Creek Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.122
WML14-6	West	28/05/2014	Gawler River	North Para River	Yaldara	0.000	0.000	0.000	0.006	0.512	0.000	0.151	0.000	0.000	0.000
WML14-7	West	30/05/2014	Gawler River	Jacob's Creek	Jacobs Creek Old Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML14-8	West	30/05/2014	Gawler River	Tanunda Creek	Tanunda Ck Gauge	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML14-9	West	2/06/2014	Gawler River	North Para River	Penrice Quarry	0.000	0.000	0.000	0.000	0.192	0.000	0.000	0.000	0.000	0.000
WML14-10	West	3/06/2014	Gawler River	North Para River	Mt McKenzie	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML14-11	West	3/06/2014	Torrens	First Creek	Waterfall Gully	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML14-12	West	4/06/2014	Hindamarsh River	Hindamarsh River	Hindmarsh Falls	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.070
WML14-13	West	4/06/2014	Hindamarsh River	Hindamarsh River	Hindmarsh Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.227	0.000	0.000
WML14-14	West	5/06/2014	Inman River	Back Valley Creek	BackValley Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
WML14-15	West	5/06/2014	Boat Harbour Creek	Boat Harbour Creek	Boat Harbour Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006
WML14-16	West	5/06/2014	Callawonga Creek	Callawonga Creek	Callawonga Gauge	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.047
WML14-17	West	5/06/2014	Inman River	Inman River	Inman Gauge	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000
WML14-18	West	5/06/2014	Inman River	Inman River	Swains Crossing Road	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.000	0.000	0.000

The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department for Environment, Water and Natural Resources, CSIRO, Flinders University, the University of Adelaide and the University of South Australia.