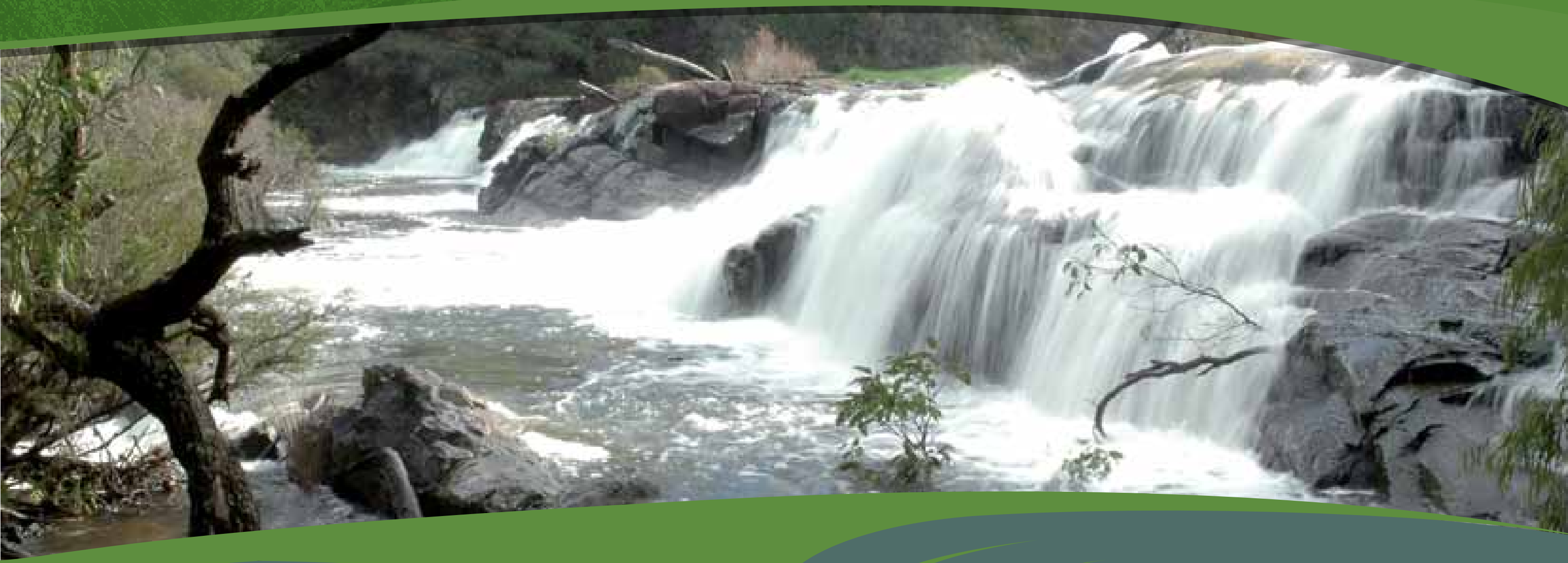
Government of **Western Australia**
Department of **Water**

Ecological water requirements of the Margaret River



Looking after all our water needs

Environmental water report series
Report no. 11
January 2011

Ecological water requirements of the Margaret River

Department of Water
Environmental water report series
Report no. 11
August 2010

Department of Water
168 St Georges Terrace
Perth Western Australia 6000
Telephone +61 8 6364 7600
Facsimile +61 8 6364 7601
www.water.wa.gov.au

August 2010

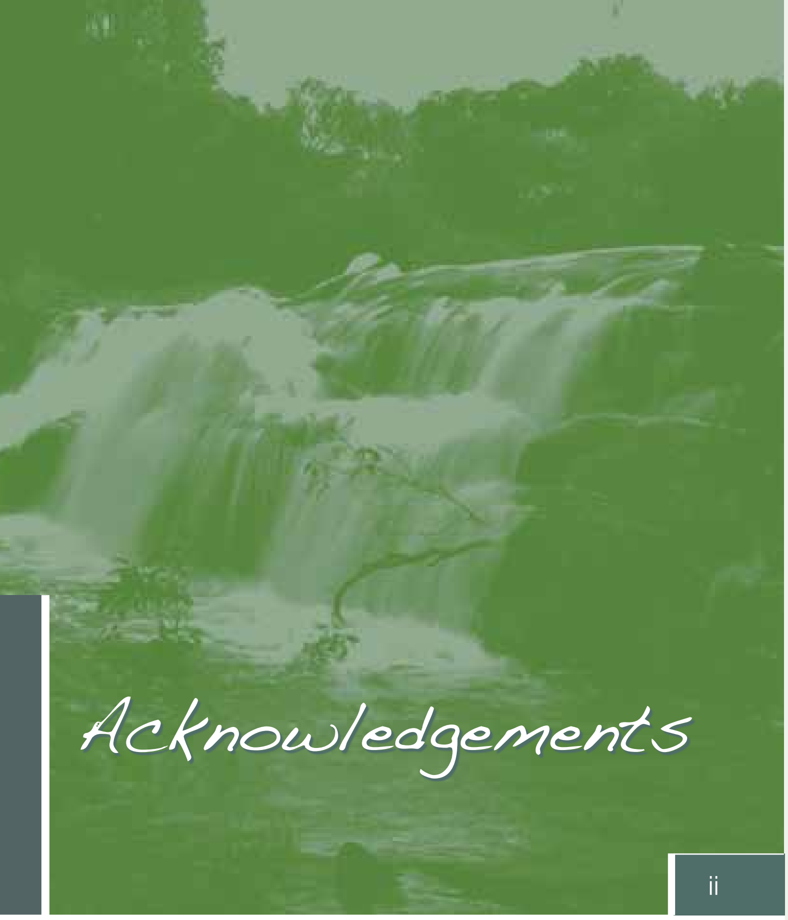
ISSN 1833-6590 (online)
ISBN 978-1-921675-49-2 (online)

This report was prepared by Adam Green and Robert Donohue of the Department of Water's Water Resource Use division.

This project is funded by the South West Catchments Council and the State and Australian Governments through the National Heritage Trust and the National Action Plan for Salinity and Water Quality.

This document is available for people with disabilities in alternative formats such as audio tape, large print and Braille on request to the Department of Water, and in electronic format from the department's website <www.water.wa.gov.au>.

Recommended reference
The recommended reference for this report is: Green, A, Donohue, R, Storey, A, Lynas, J & Pauli, N 2010, *Ecological water requirements of the Margaret River*, Environmental water report series, Report no. 11, Department of Water, Western Australia.



Acknowledgements

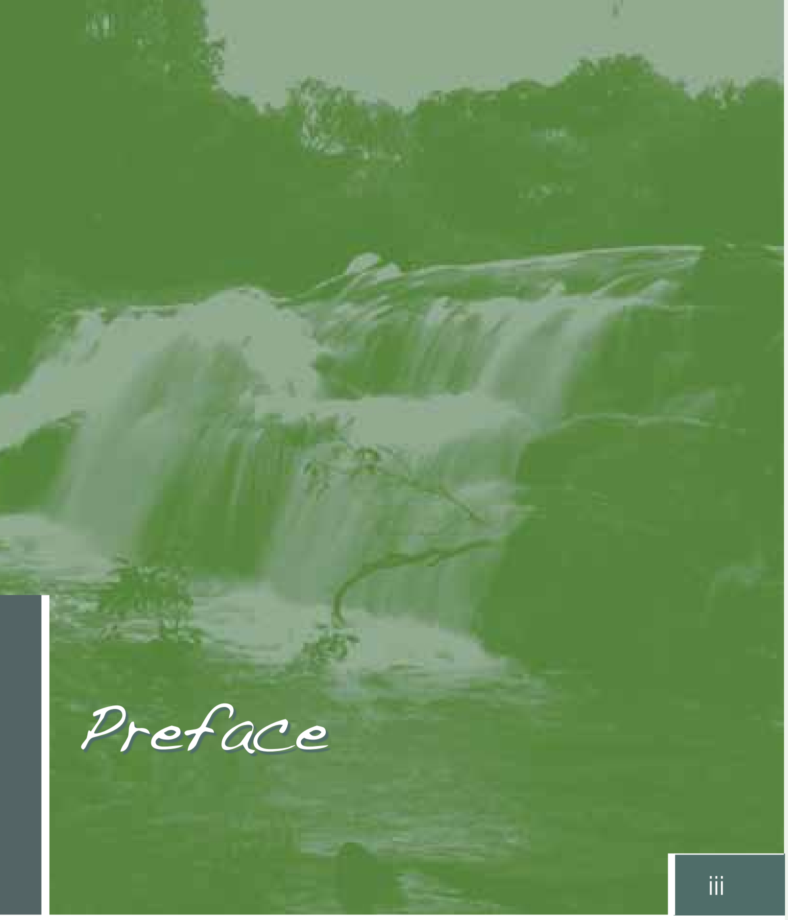
The Department of Water would like to thank the following for their contribution to this publication. Hydrological advice and support was provided by Mr Mark Pearcey, Mrs Kathryn Smith and Ms Jacqui Durrant from the department's Surface Water Hydrology section. Mr Ash Ramsay and Mr Andrew Bland from the department's South West Region provided hydrographic and hydraulic support for the project. Advice on river ecology and the modelling was also provided by Dr Paul Close from the University of Western Australia Centre of Excellence in Albany.

Wetland Research and Management contributed significantly to the final product through field work and preparation of a draft report.

The River Ecological Sustainable Yield Model (RESYM) software was coded by Mr Simon Lang from Sinclair Knight Merz (SKM) whose advice and active interest significantly improved the final product. Mr David Stephens and Mr Rory Nathan of SKM helped with developing the RESYM FORTRAN code.

This study was funded by the Natural Heritage Trust and the National Action Plan for Salinity and Water Quality, which are joint initiatives of the Australian and Western Australian governments, and administered by the South West Catchments Council (SWCC). The Department of Water and the project team thank the council for their support of surface-water resource planning in south-west Western Australia.

For more information about this report, please contact Robert Donohue.
Phone: 08 6364 6822
Email: robert.donohue@water.wa.gov.au



Preface

The purpose of this study was to determine the ecological water requirements of the Margaret River. The study is part of the South-West Environmental Water Provisions Project, which is being delivered by the Department of Water in partnership with the South West Catchments Council (SWCC). During this project, the ecological water requirements of seven river systems in south-west Western Australia will be determined. The seven waterways and their catchments, which include the Capel, Brunswick and Margaret rivers and the Wilyabrup, Cowaramup, Chapman and Lefroy brooks, are priorities for research due to the high demand for water for irrigated agriculture, mining and water supply, and declining rainfall in the state's south-west.

These studies have been funded by the Australian and Western Australian governments as part of the National Action Plan for Salinity and Water Quality and administered through the SWCC. Among others, the Margaret River study will support water resource planning in the south-west. The region's rivers have come under increasing pressure due to decreasing flows caused by below-average rainfall and increases in the abstraction and/or interception of water to meet demands for water supply and irrigated agriculture. The project's primary objective is to inform water resource planning decisions.

Contents

Ecological Water Requirements of the *Margaret River*

Contents

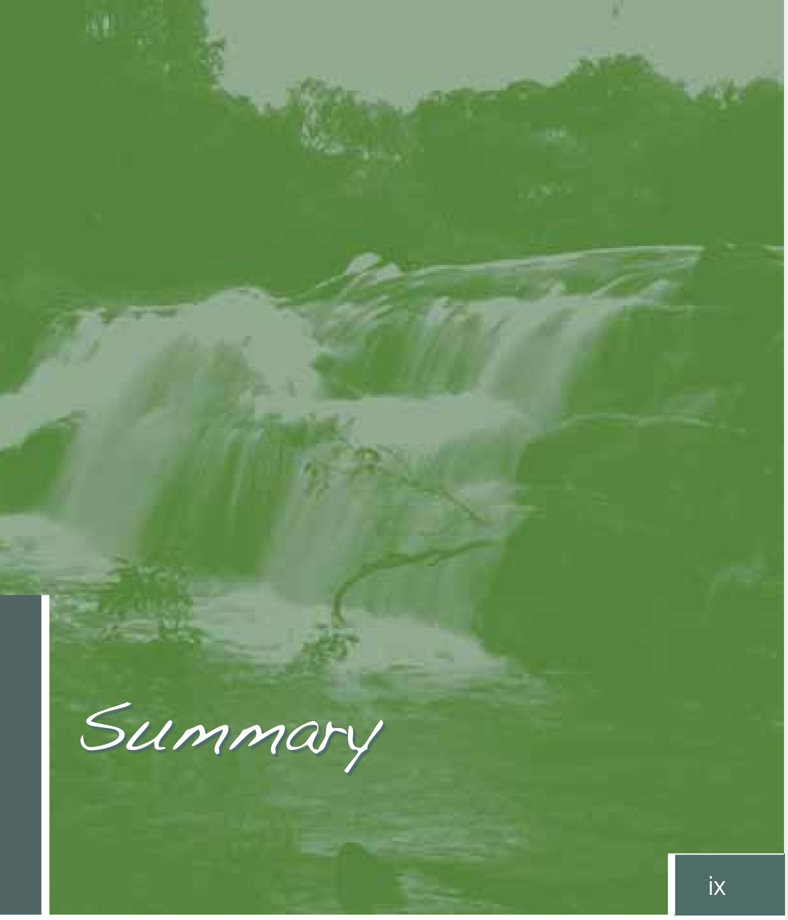
Ecological Water Requirements of the *Margaret River*

Appendices

Contents

Ecological Water Requirements of the *Margaret River*

Tables



Summary

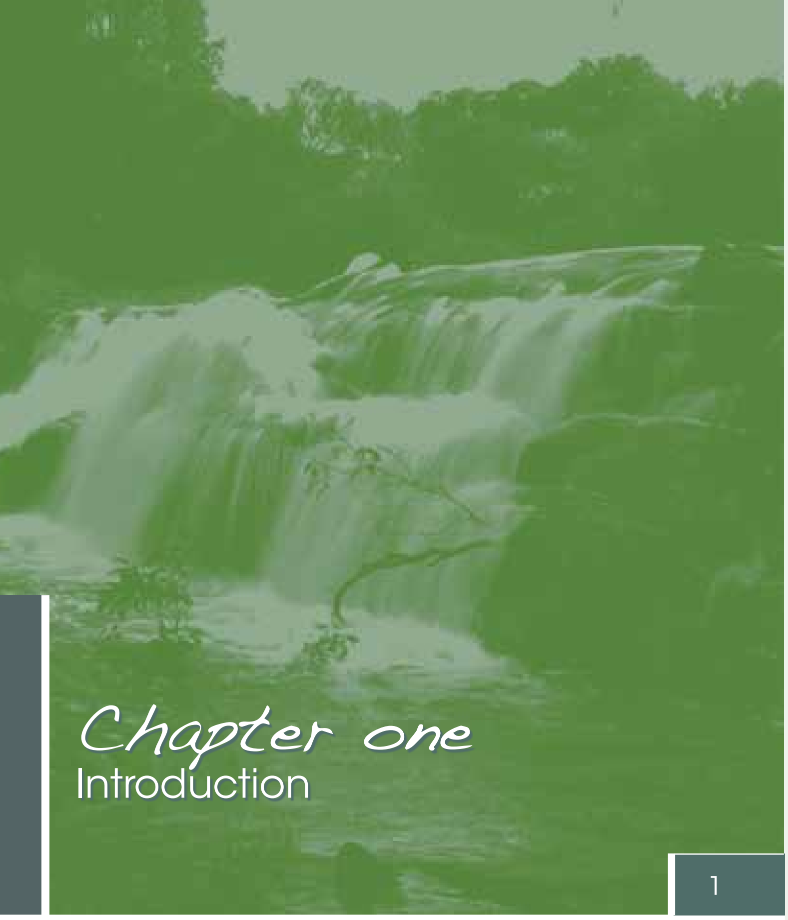
The ecological water requirement of a river is the water regime needed to maintain the ecological values of water-dependent ecosystems at a low level of risk. This report describes the development of an ecological water requirement for two representative reaches of the Margaret River in south-west Western Australia. The Margaret River ecological water requirements were generated using the Proportional Abstraction of Daily Flows (PADFLOW) method, a new approach developed by the Department of Water for the highly variable streams in the south-west region.

PADFLOW is supported by the River Ecologically Sustainable Yield Model (RESYM). RESYM progressively removes proportions of daily flow from an existing flow record until the duration and frequency of flow spells represent an ecological water requirement at a low level of risk to river ecology. The PADFLOW process increases rigour and transparency in water resource planning.

Flows to achieve the desired depth of water in key habitats and corresponding flow rates to achieve these thresholds were identified using the hydraulic analysis module in the River Analysis Package. These threshold flows provide key ecological functions, such as:

- water depth in river pools
- summer flows required to maintain pool water quality
- depths that allow for fish migration upstream
- inundation of breeding habitat
- flows needed to scour the channel of sediment and maintain a diversity of habitat.

The flow thresholds were used to produce a modelled ecological water requirement flow regime that achieves a series of ecological objectives. An expert panel evaluated the ecological water requirement by comparing the frequency and duration of flows above each threshold with that of the 'current' flow record (1975–2005). In Reach 1 of the Margaret River, the ecological water requirement was approximately 74 per cent of the current yearly flow, varying between 15 and 117 GL/year. Reach 2 had an ecological water requirement equivalent to 70 per cent of annual flow and varied between 12 and 87 GL/year. In both study reaches the ecological water requirement retained much of the variability present in the 'current' flow.



Chapter one
Introduction

The Department of Water defines the ecological water requirement (EWR) of a river as the water regime required to maintain its ecological values at a low level of risk. This study used a holistic approach to assess the EWRs of two representative reaches of the Margaret River. Holistic methods consider the aquatic and riparian ecosystem as a whole, and examine the relationships between water regime and biodiversity, riverine food-webs, ecological processes and individual species. EWR studies consider the flow-dependency of aquatic taxa such as fish, invertebrates, amphibians and aquatic plants, as well as the importance of surface water to terrestrial and riparian species.

The assessment of a waterbody's EWR is closely related to the 'natural flows paradigm'. According to the natural flows paradigm, the natural regime of flow is responsible for the evolution of the observed ecological state of a river (Poff 1997). The flow regime influences which species are present in rivers, and governs the processes that support a healthy, resilient aquatic ecosystem. The natural flows paradigm suggests that an EWR must consider the total flow environment including the natural duration and frequency of ecologically important flow events, the annual and inter-annual flow regime, seasonal patterns of flow and long-term trends in flow volume. Further information about how the flow regime's components influence ecological processes is given in Section 2.6.

This report presents the results of a study designed to determine the EWRs of the middle and lower reaches of the Margaret River in south-west Western Australia (Figure 1). The results of EWR studies allow water managers to implement an appropriate water allocation limit that takes into consideration the economic, social, cultural and ecological values of the system. The Department of Water is Western Australia's primary water resource management agency. This EWR study was undertaken with the aim to support water resource planning in the Whicher allocation area (refer to DoW 2009).

1.1 Objective of this study

This study's objective was to identify a flow regime for two representative reaches of the Magaret River that maintains the current ecological values of the aquatic and near-channel (riparian) environment at a low level of risk. A more detailed description of the EWR is provided in Section 3. EWR studies often have various aims, such as:

- maintaining current, modified ecological values
- enhancing or restoring pre-existing ecological values
- providing for a combination of key current and pre-existing ecological values.

In relatively undisturbed environments, an EWR study will be based on a natural regime, and will identify the flow regime needed to maintain the ecological values of the natural river environment. For ecosystems modified by flow regulation, catchment clearing and land-use changes, the EWR study will use a flow regime derived from existing data collected from the modified system, or from a modelled data set correlated with 'current' conditions.

The Margaret River catchment has a long history of water resource development. In addition, large areas of the catchment in the study reaches have been cleared of native vegetation. For these reasons, the aim of this study was to determine an EWR that would maintain the ecological values of the Margaret River in its present, post-development condition.

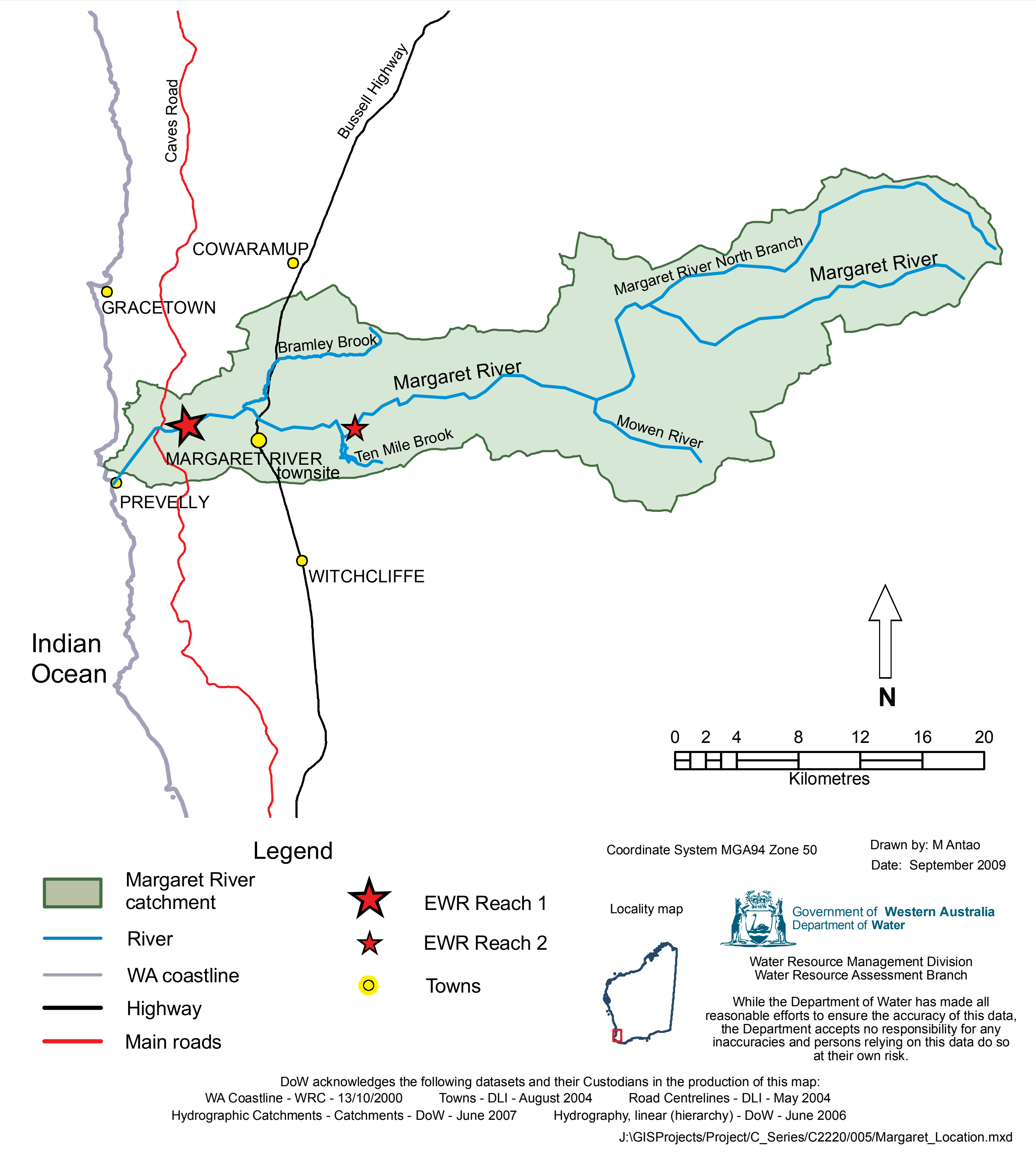
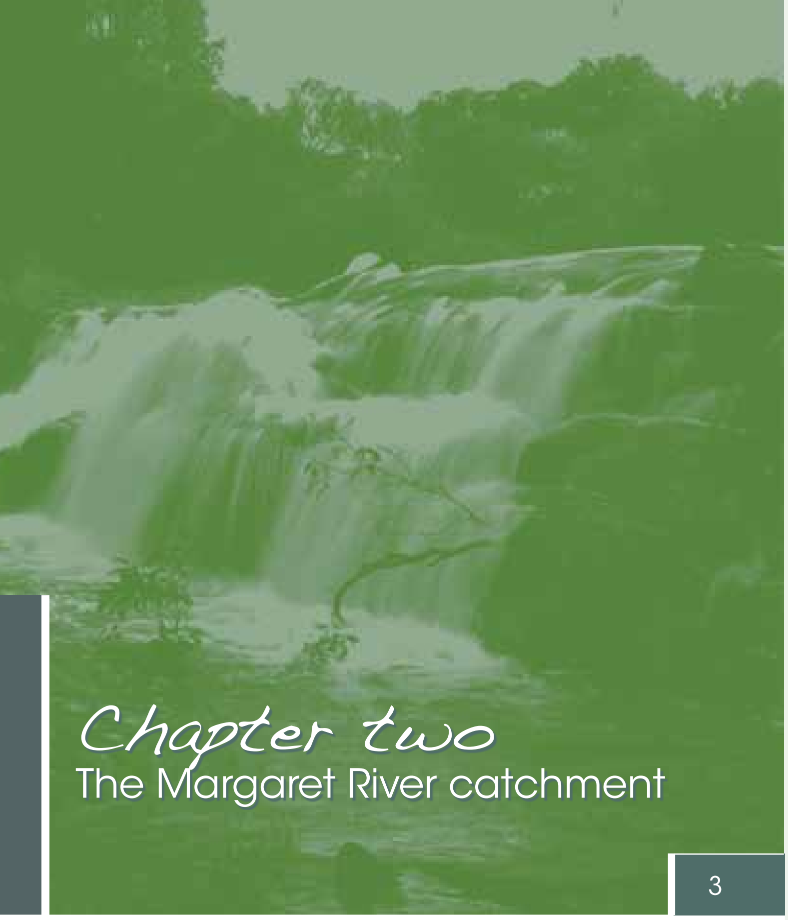


Figure 1

Location of the Margaret River and the EWR study reaches



Chapter two
The Margaret River catchment

The Margaret River is located in the Leeuwin-Naturaliste region of south-west Western Australia, approximately 230 km south-west of Perth and 40 km south-west of Busselton (Figure 1). The Margaret River catchment is part of the broader Busselton Coast Drainage Basin, which extends over 2970 km^2 (DEC 2005), and is one of 17 major watercourses draining the Leeuwin-Naturaliste Ridge. The Margaret River has a total stream length of approximately 60 km, and drains a catchment of 470 km^2. The main tributaries of the Margaret River are Mowen River, Bramely Brook and Ten Mile Brook (Figure 2). The latter is regulated, with the dam supplying water to the towns of Margaret River, Prevelly, Gnarabup and Cowaramup (DEC 2005; Crossley 2007).

The Margaret River flows across three distinct landform units: the Blackwood Plateau, the Margaret River Plateau and the Leeuwin-Naturaliste Coast (Coppolina 2006). The headwaters of the river are located on the gently undulating Blackwood Plateau, which is largely composed of laterised sedimentary rocks of the Perth Basin (Crossley 2007). The middle reaches of the river flow through the Margaret River Plateau landform, which is derived from the granitic and gneissic basement rock of the Leeuwin Block. Closer to the coast, the Margaret River flows through the Leeuwin-Naturaliste Coast landform, composed of a discontinuous limestone ridge with the underlying granite exposed in places (Marnham et al. 2000; CCG 2003).

Most of the upper catchment remains under native vegetation in State Forest reserves, with a significant area of land under pine plantations. In the middle and lower reaches, a wide range of land uses are present, including beef and dairy cattle grazing, sheep grazing, potatoes, orchards, vineyards, olives, bluegum plantations and residential subdivisions (CCG 2003). The riparian vegetation of the Margaret River is very narrow and degraded in places (CCG 2003). The loss of riparian vegetation typically results in increased surface runoff, leading to flooding and channel erosion, as well as higher nutrient and sediment loads downstream.

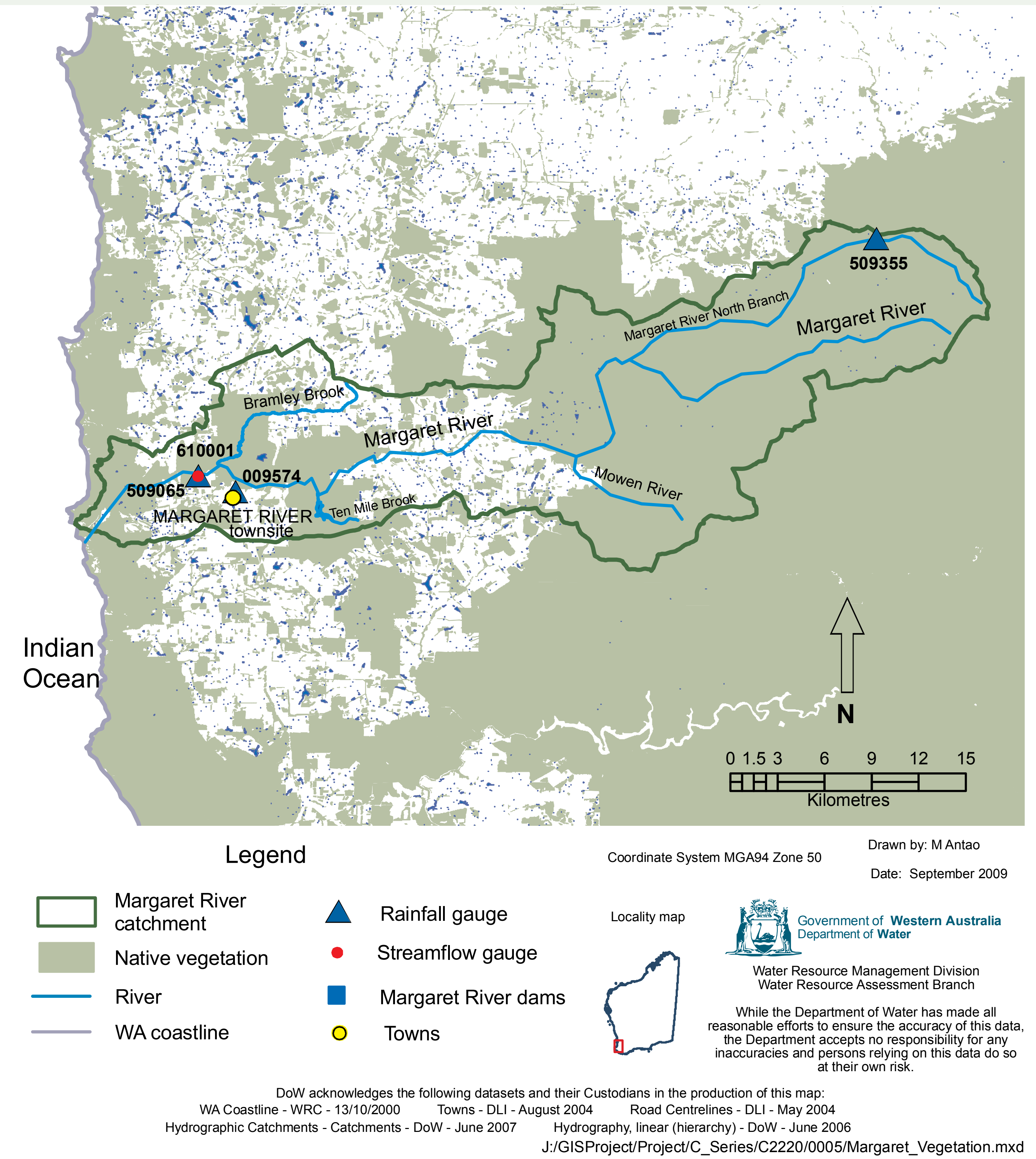


Figure 2

Map showing the area of cleared and uncleared land in the Margaret River catchment

The location of farm dams is also shown

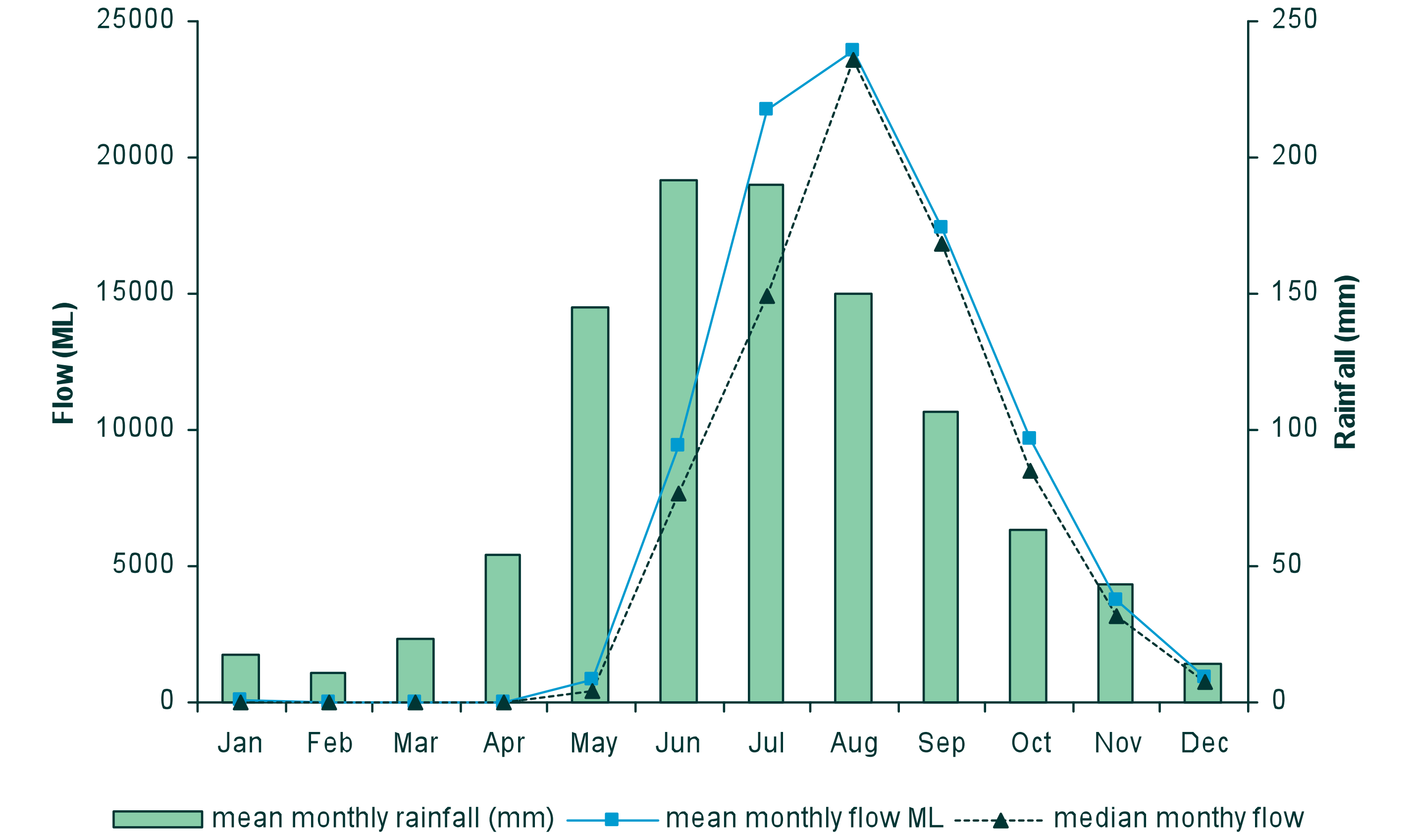


Figure 3

Mean and median monthly streamflow in the Margaret River (Willmott's Farm gauging station 610001) compared with mean monthly rainfall (Willmott's farm meteorological station 509065)

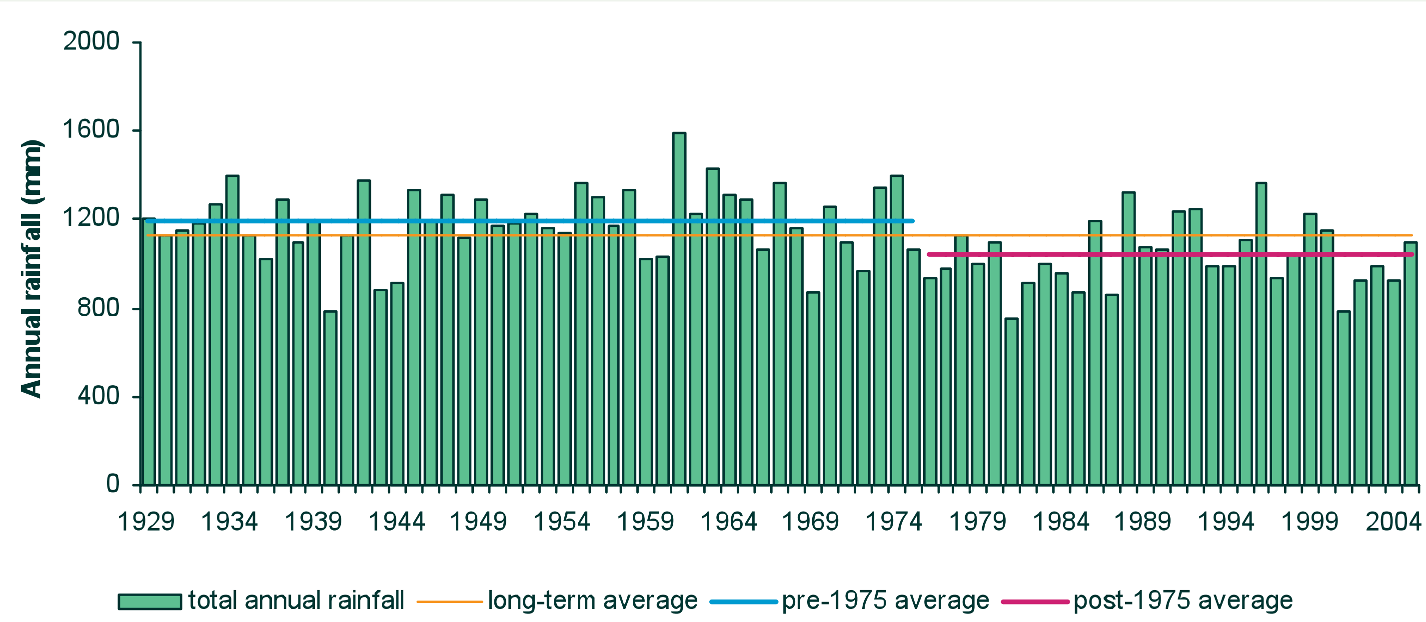


Figure 4

Total annual rainfall and long-term average for the Margaret River (Bureau of Meteorology station 009636)

2.1 Climate

The Margaret River catchment has a Mediterranean climate with hot, dry summers and mild, wet winters (CCG 2003). Average daytime temperatures can range from 15°C in winter to around 30°C during summer. Rainfall is seasonal, with around three-quarters of annual rainfall occurring between May and September (Pen 1999; Crossley 2007) (Figure 3). Winter rainfall is typically associated with the passage of cold fronts over the south-west, which bring moist air from the Southern Ocean. These fronts are blocked by high-pressure systems in summer, resulting in reduced summer rainfall. Decaying tropical cyclones from the north-west can bring occasional widespread heavy rain to the region during summer (Pen 1999).

Average annual rainfall has steadily decreased during the past four decades (Figure 4). Rainfall in the catchment increases along a gradient from north to south and from the coast inland. Mean annual rainfall for the catchment is approximately 1000 mm (Figure 4). There are three Bureau of Meteorology rainfall stations in the study area: Margaret River Post Office (009574), Whicher Range (509355) and Willmott's Farm (509065).

Current models for global warming predict a general increase in temperature for the south-west of between 0.4°C and 1.6°C by the year 2030 (CSIRO 2001). While the intensity of specific winter rainfall events may increase, their duration is expected to decrease. The total duration of drought events and rates of evaporation are also expected to increase. Overall, the south-west region has experienced a decline of approximately 20 per cent in annual rainfall during the past four decades, which has led to a corresponding decrease in annual streamflow of between 30 to 40 per cent (WRC 2000).

2.2 Hydrology

Streamflow in the Margaret River is seasonal, with 93 per cent of annual flow occurring between June and October (Figure 3). In summer and autumn (December–May), monthly rainfall can be highly variable between years due to infrequent weather events such as summer thunderstorms. The average annual streamflow in the Margaret River for the period 1975 to 2005 was 86.2 GL (WRM 2007b). The highest recorded annual flow was 190 GL, which occurred in 1973. There is a lag between peak rainfall in June or July, and peak streamflow in August (Figure 3). The lag suggests the catchment has a large soil-storage capacity (Crossley 2007). Willmott's Farm gauging station (610001, see Figure 2 for location), downstream of Margaret River township, provided streamflow data for the reference period (1975–2005) used in this report.

2.3 Hydrogeology

Seepage of groundwater into a river can be important for maintaining winter baseflow, as well as pools and flow during extended dry periods. Many aquatic plant and animal species rely on contributions from groundwater to maintain summer habitat. In the Margaret River region, a number of cave ecosystems, wetlands, rivers and some inland vegetation communities are groundwater-reliant (CSIRO 2005).

Groundwater resources within the Margaret River area include the Leederville Formation, the Yarragadee aquifer and superficial formations (CSIRO 2005). Freshwater from the Leederville Formation occurs near the surface within sand or duricrust on the Blackwood Plateau (Marnham et al. 2000). Groundwater from the Margaret River Plateau is confined to faults or fractures and is brackish to saline (Marnham et al. 2000). In the middle reaches of the Margaret River, the Yarragadee aquifer is overlain directly by superficial formations. In this area, drawdown of the Yarragadee aquifer may dry out the permanent pools that rely on groundwater resources.

2.4 Water resource development

In its middle and lower catchments, the Margaret River flows through mostly agricultural land, while a large part of the upper catchment is under native vegetation. Grazing, pasture, dairy farming, viticulture and olive production are common land uses. Most farming activities either use direct abstraction from the river, or on-stream and off-stream farm dams.

The Margaret River catchment has about 670 dams, most of which have a storage capacity of less than 8 ML and are used primarily for stock and domestic purposes (Bennett & Donohue 2009). The catchment's 43 commercial dams store between 8 and 282 ML and have a combined storage of approximately 1.7 GL (Table 1). These dams are used to irrigate crops such as olives, wine grapes and nuts. The estimated total catchment demand for crops such as these is about 2.8 GL/year (Table 1). This suggests that irrigators are most likely using water from other sources. Dam density along the Margaret River is relatively low compared with other systems in the region (Table 1).

The dams are usually completely filled by catchment runoff by mid-May to mid-June, depending on the timing and magnitude of early-season rains. Flow gauging and numerical models suggest the dams have a relatively small impact on the magnitude of mid-winter flows (Sinclair Knight Merz 2007). However, models also show that interception of catchment runoff by on-stream dams can reduce the magnitude of summer flows and flows in the seasonal 'shoulder' periods between April and June, and November and January.

The Water Corporation has a 1.7 GL capacity dam on Ten Mile Brook, which feeds into the Margaret River from the south, approximately 6 km upstream of Margaret River Township. It has a licence for 1 GL/year for public water supply and can pump water from the main Margaret River channel to supplement the Ten Mile Brook dam in dry years.

Table 1

Statistics on commercial* farm dams and water use in the Margaret River catchment compared with other catchments in the Cape to Cape region. Source: Bennett & Donohue 2009

System	Catchment area (km^2)	Mean annual flow (ML)	Runoff (ML/km^2)	Crop irrigation demand (ML/yr)	Number of dams	Storage in dams (ML)	Storage density (ML/km^2)
Wilyabrup Brook	89	23632	266	1337	66	3102	35
Cowaramup Brook	30	3356	112	227	13	300	10
Margaret River	487	84707	174	2785	43	1733	4
Chapman Brook	184	54687	297	1326	56	2297	12

* Data assume that commercial farm dams are those with a storage capacity of greater than 8 ML.
Note: Data for the Margaret River do not include the public water supply dam on Ten Mile Brook.

2.5 Ecological values of the Margaret River

This study's objective is to define a flow regime for the Margaret River to maintain its existing ecological values. It is therefore important to:

- describe the existing condition of the river ecosystem
- define how the various components of the ecosystem depend on the flow regime.

The existing environmental attributes and ecological values of the Margaret River were described by WRM (2007a, 2008) and the Cape to Cape Catchments Group (CCG) (2003). The ecological values of the Margaret River and the relationships between flow and ecological values are discussed in the following sections. These sections draw heavily on the work described in the cited reports. For detailed information about the life-history characteristics of flora and fauna species, their degree of water dependence, management options and other general biological information, please refer to these reports.

2.5.1 Vegetation

The Margaret River catchment falls within the Menzies and Warren subdistricts of the South West Botanical Province (Beard 1990). The dominant upper canopy trees of the area include jarrah (*Eucalyptus marginata*), marri (*Corymbia calophylla*), karri (*E. diversicolor*), blackbutt (*E. patens*), flooded gum (*E. rudis*) and bullich (*E. megacarpa*). The broad vegetation communities found within the catchment are described by CCG (2003). Further to the trees listed above, additional overstorey species include peppermint (*Agonis flexuosa*), *Hakea lasianthoides* and paperbark (*Melaleuca* spp.). Common heath species on rocky outcrops in the catchment include *Kunzea* spp., *Darwinia citriodora* and *H. trifurcata*.

Foreshore condition was assessed as part of the *Margaret River action plan* (CCG 2003). The downstream survey reach retained a diverse and reasonably wide band of riparian vegetation dominated by jarrah and marri, with some peppermint; although sections have been affected by erosion and weed invasion (CCG 2003) (Figure 5). The upstream survey reach contained healthy and diverse riparian vegetation with minimal weed incursion. Common species include marri, blackbutt, tea trees (*Agonis linearifolia* and *Astartea fascicularis*), bullich and numerous species of rushes and sedges. The condition of the riparian vegetation in Reach 2 is shown in Figure 6.

Environmental factors that influence plant vigour and are affected by river flow include:

- bank soil-moisture content
- the proximity of groundwater to the root zone
- the period and season of flooding that inundates the floodplain and riparian vegetation.

Figure 5
Riparian vegetation in Reach 1 of the Margaret River

Figure 6
Riparian vegetation in Reach 2 of the Margaret River

Research has found that seed set, seedling establishment and recruitment for tree species such as flooded gum (*E. rudis*), swamp paperbark (*Melaleuca rhaphiophylla*) and modong (*M. preissiana*) are closely tied to flow events. For example, germination and survival of seedlings can be influenced by infrequent winter high flows, which pick up seeds and move them to open areas in full sunlight. Year-old tree seedlings often do not survive if they are inundated in their first winter after germination.

2.5.2 Aquatic invertebrates

A targeted sampling program for macroinvertebrates was undertaken for this study in autumn and spring of 2007 (WRM 2008). A total of 75 macroinvertebrate taxa were found. Arthropod taxa (i.e. crustaceans, arachnids and insects) comprised 71 of the macroinvertebrate taxa found. Nearly 80 per cent of the individual macroinvertebrate specimens collected were insects. A list of macroinvertebrate taxa collected from the Margaret River is provided in Appendix 1; photos of some representative taxa are shown in Figure 7.

Five species of freshwater crayfish are known to occur in the rivers of south-west Western Australia, four of which have been found in the Margaret River (WRM 2008). These include the smooth marron (*Cherax cainii*), the hairy marron (*C. tenuimanus*), and two species of gilgie (*C. quinquecarinatus* and *C. crassimanus*). Marron require larger, deeper pools as refugia during summer than gilgies do (Beatty et al. 2006).

The hairy marron is endemic to the Margaret River, and is found almost exclusively in its upper reaches, although they have also been found further downstream (Morgan & Beatty 2003; WRM 2008). The species is listed as a critically endangered under the *Environment Protection and Biodiversity Conservation Act 1999* and is under threat due to competition from, and hybridisation with, the introduced smooth marron (Molony et al. 2004). The Department of Environment and Conservation (DEC) are attempting to remove the smooth marron from key areas of hairy marron habitat in the Margaret River.

Spring and summer spawning is a common life-history characteristic of aquatic invertebrates in south-west Western Australia. Very few species breed during the wetter winter months, multiple times a year, or are capable of breeding year-round. Some spring and summer flows should therefore be maintained to provide breeding habitat.

Most aquatic invertebrate species do not have physiological or life-history strategies that allow them to survive seasonal drying. As adults, many insects are capable of flying to neighbouring waterbodies. Some invertebrates are capable of burrowing into moist sediments to avoid desiccation, including oligochaetes and gilgies. Cladocerans, copepods and ostracods have some dessication-resistant stages in their life cycle (usually as an egg) and may undergo diapause during summer. Gastropods may survive drying by sealing their shell with either a mucous plug or by using their operculum.

Invertebrate diversity depends on habitat complexity and diversity, since many species are essentially restricted to particular habitats (Humphries et al. 1996; Kay et al. 2001). Aquatic invertebrates occupy a wide range of habitat types including pools, riffles and sandy runs between pools, and dams of organic debris. Riffles and sandy runs tend to support a higher density and variety of invertebrates than other aquatic habitats.

Some aquatic invertebrate species are associated with habitats such as snags, rocks, macrophyte beds and trailing riparian vegetation. They include oligochaetes, freshwater crayfish, larvae of many dragonfly and damselfly species, and most species of chironomid and caddisfly. To maintain the distribution and abundance of these taxa, it is important to maintain sufficient flows to ensure snags, rocks, macrophytes and some overhanging riparian vegetation are inundated.

Stream permanence has been found to be an overall determinant of the abundance and diversity of aquatic invertebrate fauna (e.g. Bunn et al. 1986 & 1989). Streams with intermittent flows have distinctive aquatic faunal communities compared with those of permanently flowing streams (ARL 1989; Storey et al. 1990). Some macroinvertebrate species are found only in intermittent streams, while other species show large differences in their abundance in permanent compared with intermittent streams (Bunn et al. 1989). It therefore important to maintain the natural regime of flow permanence in managed systems.

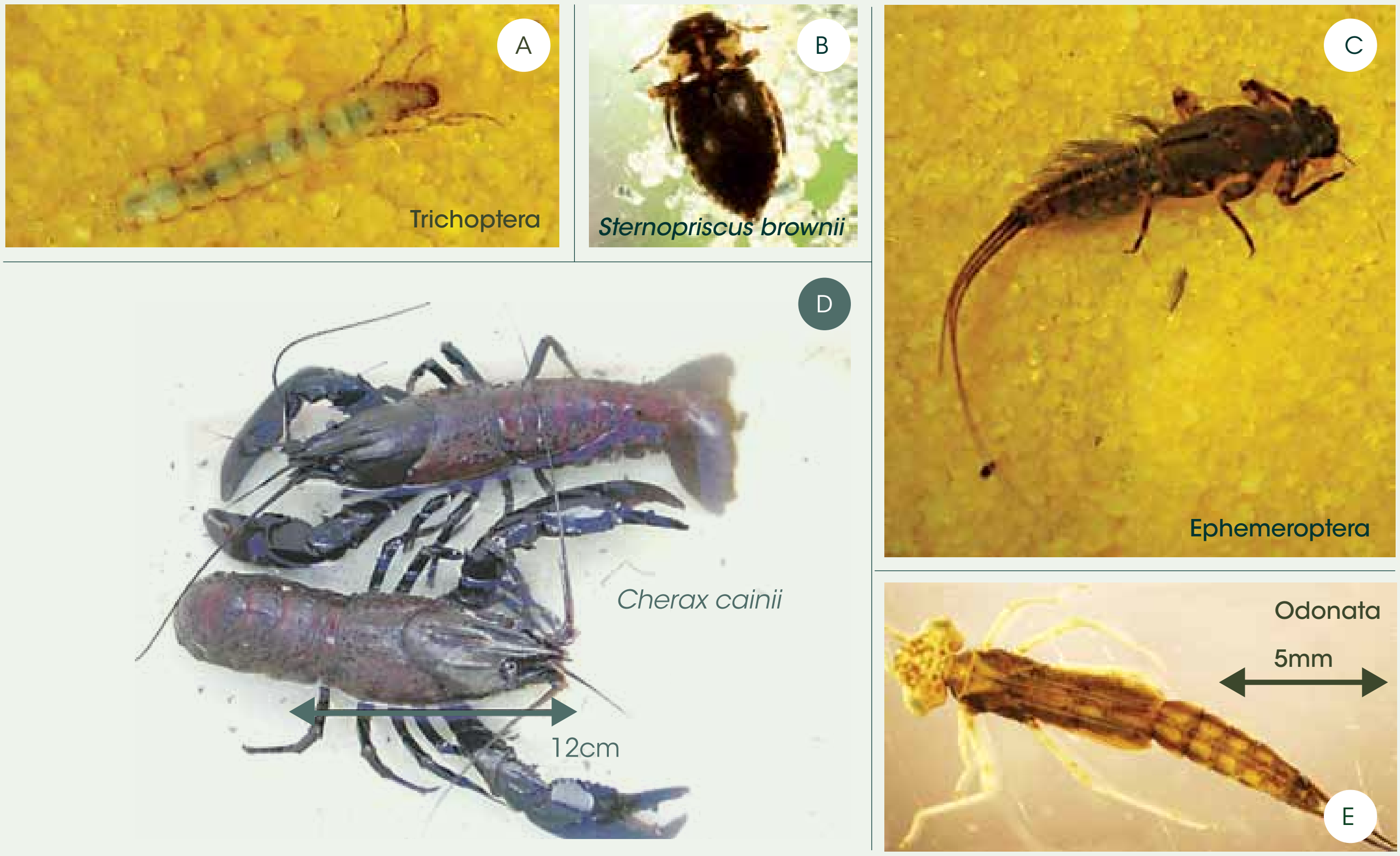


Figure 7

Macroinvertebrates of Margaret River

Source: (A, B, C, E) Wetland Research and Management (WRM). (D) John J.S. Bunn.

Figure 8

Native fish of the Margaret River. Source: (A, B) Photography by Dave Morgan. (C) Photography by Glenn Shiell.

2.5.3 Fish

South-west Western Australia has relatively few species of native freshwater fish and a high degree of endemism compared with the rest of the continent (Pusey et al. 1989). Of the endemic species, the western minnow (*Galaxias occidentalis*), western pygmy perch (*Edelia vittata*) and nightfish (*Bostockia porosa*) are the most abundant and widespread.

There is anecdotal evidence that the distributions of both pouched lamprey *(Geotria australis*) and freshwater cobbler (*Tandanus bostocki*) are becoming increasingly restricted in the south-west due to habitat loss and flow regulation (WRM 2008). Figure 8 illustrates some of the native freshwater fish species of the study area.

Nine freshwater fish species are known to occur in the Margaret River, six of which are endemic to the state's south-west (Morgan & Beatty 2003; 2004). The six native species that occur in the river are the western minnow, western pygmy perch, mud minnow (*Galaxiella munda*), Balston's pygmy perch (*Nannatherina balstoni*), nightfish and pouched lamprey. Detailed information relating to the life-history characteristics, ecology and flow requirements of the fish species can be found in WRM (2007a).

The pouched lamprey, Balston's pygmy perch and mud minnow are all of conservation significance. Balston's pygmy perch is the rarest of all south-west endemic freshwater fishes (Morgan et al. 1998), and is listed as vulnerable on the DEC list of Declared Threatened Fauna. The mud minnow is also listed as vulnerable, having undergone a considerable range contraction (Morgan & Beatty 2005). Both species are threatened by habitat alteration and exotic species. The pouched lamprey is one of only four extant lamprey species in the southern hemisphere, and the last-surviving species of the Geotriidae family (Potter 1996).

Three species of introduced freshwater fish have been found in the Margaret River, including the mosquitofish (*Gambusia holbrooki*), carp (*Carassius auratus*) and redfin perch (*Perca fluviatilis*) (WRM 2007a). Additionally, two native estuarine fish species are known to occur near the river mouth: the Swan River goby (*Pseudogobius olorum*) and the western hardyhead (*Leptatherina wallacei*).

None of the five native fish species sampled from the Margaret River have physiological adaptations to withstand desiccation. These species rely on the presence of permanent water, although it is postulated that the mud minnow can survive seasonal drying within moist mud.

The breeding ecology of native species is strongly related to river flow. At least three native fish species (pygmy perch, western minnow and nightfish) undertake upstream migrations in winter and spring for breeding (Pen 1999). With the onset of winter flows in June or July, all three species move upstream from summer pools to small side tributaries to spawn on flooded vegetation and submerged reed beds (WRM 2008).

There are many natural and artificial obstacles that can impede upstream migration of fish, such as logs, shallow riffles, rock bars, dams and weirs. Natural flow regimes include periods of high flows (also known as 'high spells') that submerge obstacles, allowing fish to move upstream. Such spells should last at least several hours to allow upstream migration of fish. Presumably, a series of winter high spells is required for fish to navigate upstream in a reach containing a series of barriers, such as a sequence of pools and riffles.

An important consideration is the length of time that elapses between the onset of cues for breeding and migration (such as changes in water temperature and day length) and the submerging of barriers to upstream migration. If flows do not drown out barriers, migrating fish will congregate downstream until the critical flow is achieved. During this time, predation on fish waiting downstream may be intense, and may particularly affect gravid females that are ready to spawn.

The duration and frequency of inundation of trailing and fringing vegetation can influence recruitment success. For example, if water levels fall too soon, or fluctuate greatly, fish eggs may be left above the water line and may dry out. Flooded vegetation and shallow, flooded off-river areas also provide sheltered, low-velocity nursery areas for growing juveniles (WRM 2008). Less successful recruitment may occur in years when reed beds and trailing vegetation are inundated for periods of less than five consecutive weeks. For fish with long life spans of three to five years, such as pygmy perch, high rates of recruitment need not occur every year to maintain healthy populations. Poor recruitment years occur naturally during periods of low rainfall. However, if conditions that are likely to result in poor recruitment occur more than three years in a row, this may lead to a population age structure skewed towards older individuals.

2.5.4 Reptiles

Figure 9 shows some of the reptiles likely to be found in the Margaret River area. The tiger snake (*Notechis scutatus*) is common in the region and is often encountered along rivers, especially in the swampier reaches where it hunts for frogs. It readily takes to water in warm weather and is a strong swimmer. The western glossy swamp skink (*Egernia luctuosa*) inhabits dense ground cover on the margins of swamps, lake and streams, while the western three-lined skink (*Acritoscincus trilineatum*) tends to inhabit areas of damp soil (Cogger 2000). These three reptile species can perhaps be regarded as semi-aquatic since they rely on riparian vegetation for survival and tend to be limited to areas of damp soil.

The long-necked tortoise (*Chelodina oblonga*) is commonly encountered in the rivers of the south-west, and is found across a range extending from Hill River in the north to the Fitzgerald River National Park east of Albany. Long-necked tortoises live in river pools, perennially flowing streams and rivers, and areas of soft soil adjacent to river banks. The diet of the long-necked tortoise includes tadpoles, fish, and aquatic invertebrates. In permanently flowing waters the long-necked tortoise has two breeding periods – in September to October and again in December to January – while in ephemeral river systems they tend to breed once a year in spring. They construct their nests in sandy soil and eggs may take up to seven months to hatch. If local conditions deteriorate, tortoises can migrate long distances overland or aestivate in-situ in burrows constructed in soft sediments. The survival of the long-necked tortoise depends on the presence of permanent water and on nearby areas of soft, damp soil in which to lay their eggs.

Many reptiles are associated with permanent and seasonal waterbodies, as these habitats provide a water source and a diverse array of prey species. However, the impact on reptile species of changes in the availability of fresh water in south-west Western Australia has not been studied, and there is little published information on reptile species' tolerance to changes in the availability of water in other geographic regions. In the absence of specific information, it is assumed that terrestrial reptiles depend on elements of the flow regime that maintain riparian vegetation and habitat, as well as ecological processes that protect aquatic biodiversity and biomass. It is also important for the survival of reptile species that permanent pools are maintained as a source of water and food during the dry summer months.

A: Photography by Andrew Storey
B: Photography by Bert and Bab Wells/DEC

Long-necked tortoise

Tiger snake

Figure 9
Reptiles of the Margaret River

2.5.5 Amphibians

South-west Western Australia is home to at least 26 frog species, of which about 20 spend a substantial part of their life cycle in moist environments adjacent to wetlands and streams. Most species require surface water during certain stages of their life cycle, such as for egg-laying and for aquatic tadpoles to develop into adult frogs. Frogs tend to be unspecialised opportunistic feeders, eating mainly insects as adults while tadpoles tend to graze on algae.

No specific studies of the frog fauna of the Margaret River were found during a literature review (WRM 2007a). DEC staff have seen some common south-west species such as the motorbike frog (*Litoria moorei*) and slender tree frog (*L. adelaidensis*). The breeding requirements and tadpole ecology of these and other species likely to occur in the study area are listed in Table 2. Some of the frog species likely to be found in the Margaret River area are shown in Figure 10.

Table 2

Habitat and breeding biology of frogs likely to occur in the Margaret River area
Information from Cogger (2000) and Tyler et al. (2000)

Species	Habitat	Spawning	Tadpole ecology
Quacking frog (*Crinia georgiana*)	Swampy areas along streams which are inundated in winter.	*Period:* July to October. *Site:* Large and separate laid in shallow seep water or wet ground that will soon be flooded.	*Habitat:* Tadpoles show lotic adaptions. *Maturation:* 45 days.
Glauert's frog (*Crinia glauerti*)	Permanent moist areas at the edges of swamps and streams.	*Period:* Mid-winter to spring following rain. *Site:* Lays in shallow water or on moist surfaces. Eggs sink to bottom.	*Habitat:* Swamps and static areas at the edge of streams. *Maturation:* >90 days.
Moaning frog (*Heleioporus eyrei*)	Swampy areas on sandy soils.	*Period:* Winter *Site:* Eggs laid in burrows excavated in sandy soils.	*Habitat:* Not known. *Maturation:* Not known.
Banjo frog (*Limnodynastes dorsalis*)	Vegetation adjacent to permanent water. Inhabits burrows during dry periods.	*Period:* Winter to spring. *Site:* Eggs in foam mass on surface of static or slowly flowing water.	*Habitat:* Not known. *Maturation:* Not known.
Slender tree frog (*Litoria adelaidensis*)	Dense vegetation in the margins of wetlands and slowly flowing streams.	*Period:* Early spring. *Site:* Eggs in mass attached to vegetation often just below the water surface.	*Habitat:* Wetlands and slowly flowing water. *Maturation:* Not known.
Motorbike frog (*Litoria moorei*)	Riparian areas of permanent wetlands and streams. Arboreal hiding beneath bark and also underneath large rocks and logs.	*Period:* Spring to summer. *Site:* Eggs laid in floating mass attached to vegetation.	*Habitat:* Permanent wetlands and slowly flowing water. *Maturation:* 60 days.

All the identified frog species are closely associated with streams and swamps. Spawning generally occurs in winter to spring, although the motorbike frog (*L. moorei*) may continue to spawn in summer if water is present. Glauert's froglet (*Crinia glauerti*) inhabits marshy areas associated with swamps and damp areas beside pools on small streams, gutters and seeps in forested areas. The froglet lays eggs in shallow water, and the tadpoles take about three months to mature in the shallow waters at the edges of rivers and swamps. The motorbike frog, Lea's frog (*C. leai*) and slender tree frog lay eggs attached to emergent and submerged vegetation (Tyler et al. 2000). Guenther's toadlet (*Pseudophryne guentheri*) lays eggs in tunnels and emerges when winter floods inundate the tunnels.

Motorbike frog

Quacking frog

Moaning frog

Slender tree frog

Glauert's froglet

Western banjo frog

Figure 10
Amphibians of the Margaret River
Source: Department of Environment and Conservation

2.5.6 Waterbirds

Waterbird species observed on the Margaret River include the dusky moorhen (*Gallinula tenebrosa*), grey teal duck (*Anas gracilis*), Pacific black duck (*Anas superciliosa*), white-faced heron (*Egretta novaehollandiae*) and cormorant (*Phalacrocorax* spp.) (CCG 2003). Other species common in the region include the black swan (*Cygnus atratus*), Australian shelduck (*Tadorna tadornoides*), Australian wood duck (*Chenonetta jubata*), Australian pelican (*Pelecanus conspicillatus*), Australian white ibis (*Threskiornis molucca*), straw neck ibis (*Threskiornis spinicollis*), red-capped plover (*Charadrius ruficapillus*), hooded plover (*Thinornis rubricollis*) and the sacred kingfisher (*Tordirhamphus sanctus*). DEC lists the hooded plover as a Priority 4 species.

Other waterbirds observed less frequently, or thought to occur in the region, are the musk duck (*Biziura lobata*), mallard duck (*Anas platyhychos*), pink-eared duck (*Malalcorhynchus membranaceus*), white-necked heron (*Ardea pacifica*), nankeen night heron (*Nycticoraz calendonicus*), glossy ibis (*Plegadis falcinellus*), royal spoonbill (*Platalea regia*), yellow-billed spoonbill (*Platalea flavipes*) and the blue-billed duck (*Oxyura australis*) (WRM 2007a). Examples of some of the waterbird species likely to inhabit the Margaret River area are shown in Figure 11.

Perhaps more than any other group of vertebrates, the ecology and habitat requirements of waterbirds must be considered at the landscape scale. River habitats are of only marginal value to most of the south-west region's waterbirds (Pen 1999), although many bushland birds use riverine habitats for nesting and as a source of water and food. Some sections of the Margaret River contain intact riparian vegetation in good condition. In south-west Western Australia, some species may depend on the habitat provided by riparian vegetation corridors for their survival (Pen 1999). Sections of the river where the banks are lined with paperbark, peppermint and eucalypts provide important breeding habitat for a limited variety of waterbirds, including tree-nesting ducks and herons.

Some birds, such as heron, egrets and ducks, use the deeper, more permanent river pools as a summer refuge or as hunting habitat. Heron, egrets and spoonbills feed almost entirely on aquatic fauna or other animals associated with waterways and wetlands. For diving birds such as cormorants and grebes, the high concentration of aquatic animals such as fish and invertebrates in permanent pools during the dry summer months provides an important seasonal source of food.

Australian Shelduck

Black Swans with cygnets

Australian Wood Duck

Pacific Black Duck

White Faced Heron

Figure 11

Waterbirds of the Margaret River

Source: Department of Environment and Conservation

In the absence of species-specific information on water-dependency, it is assumed that waterfowl associated with the Margaret River depend on the health of riparian vegetation, regular inundation of the floodplain and its wetlands, and on the ecological processes that maintain food webs and aquatic species diversity.

2.5.7 Mammals

A number of native mammal species have been seen in the study area during foreshore condition assessments (CCG 2003) and by local landholders (WRM 2007a). Positively identified species include the brushtail possum (*Trichosurus vulpecula*), water rat (*Hydromys chrysogaster*), western grey kangaroo (*Macropus fuliginosus*) and southern brown bandicoot or quenda (*Isoodon obesulus*). Other species known from the region include the western ringtail possum (*Pseudocheirus occidentalis*), brush-tailed phascogale (*Phascogale tapoatafa*), chuditch (*Dasyurus geoffroii*), quokka (*Setonix brachyurus*) and western pygmy possum (*Cercartetus concinnus*). Of these, the water rat is the most closely associated with the river system. The two possum species and the brush-tailed phascogale rely on dense vegetation and the availability of hollow-bearing trees, which often occur near rivers and streams. Quenda occur only in areas with dense covering vegetation, such as the margins of wetlands, *Banksia* woodland and jarrah forest. Examples of some of the native mammal species from the Margaret River region are shown in Figure 12.

Water rats are found in rivers, swamps, lakes and drainage channels. They have broad, partially webbed hind feet, water-repellent fur, and a thick tail. Water rats are water-dependent and are known to suffer heat stress without access to water. They construct nesting burrows in banks that are stabilised by riparian vegetation, and forage along the shoreline for food such as crayfish, mussels, fish,

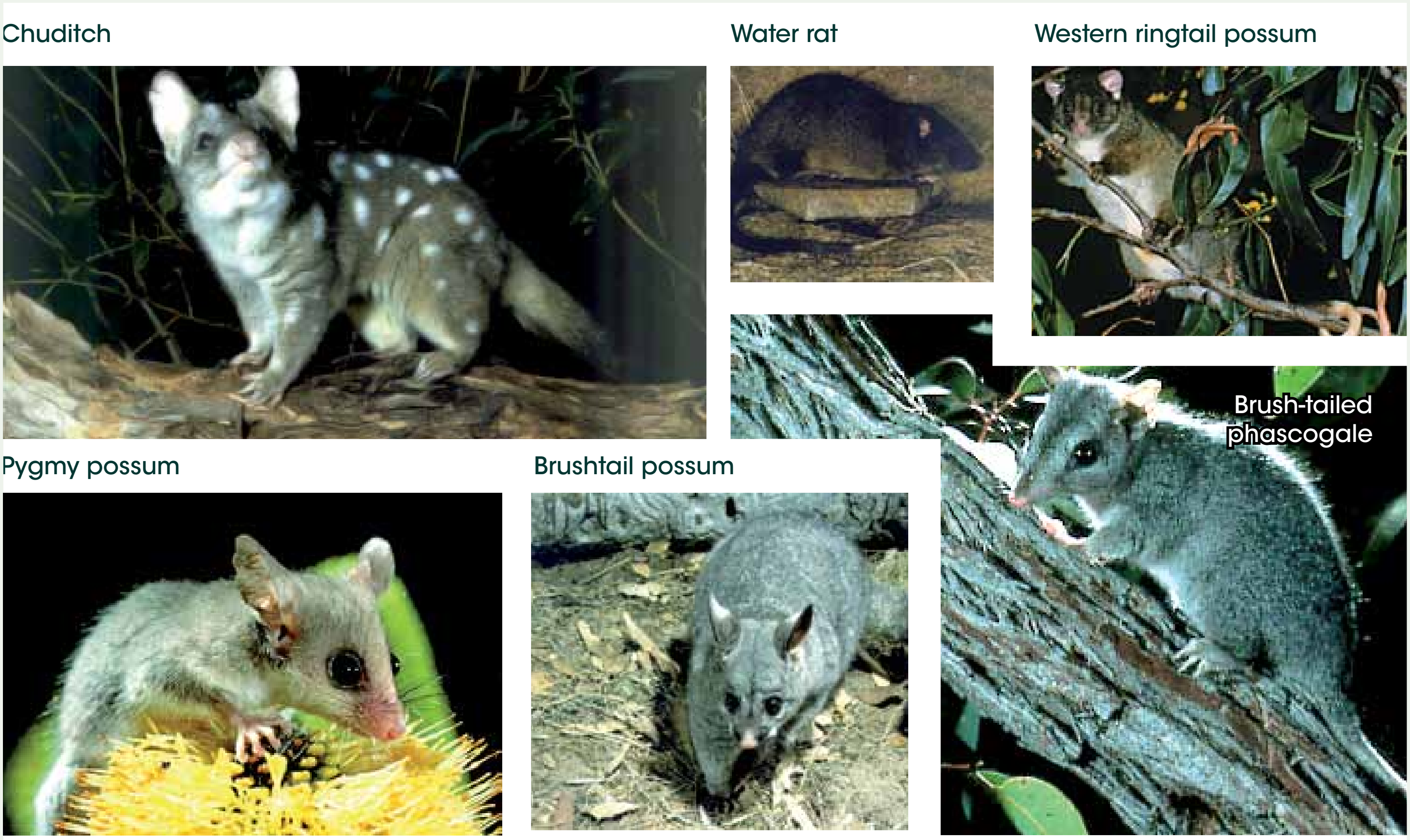


Figure 12
Mammals of the Margaret River
Source: Department of Environment and Conservation

plants, water beetles, water bugs, dragonfly nymphs and smaller mammals and birds. Water rats rely on aquatic food webs, the presence of healthy riparian vegetation and the processes that maintain them. They restrict their movements to shallower waters less than 2 m deep. The range of water rats has declined in south-west Western Australia due to salinisation and clearing of riparian vegetation (WRM 2007a).

2.5.8 Carbon sources and ecosystem productivity

Aquatic ecosystems rely on energy inputs – in the form of organic carbon – from catchments and riparian zones (WRC 2000). Flow-related processes that control the sources, fate and availability of carbon in food webs need to be considered in developing ecological water requirements (EWRs). Many factors influence the production of carbon in rivers, including light penetration, nutrient levels and flows. Human activities such as clearing of riparian vegetation and flow regulation can substantially alter aquatic life through changes to the carbon cycle.

Some carbon enters rivers as fine particulate organic matter derived from upstream terrestrial vegetation, or as woody debris washed into the river from the riparian zone. This process requires the connection of downstream and upstream river reaches (Vannote et al. 1980). Carbon may also enter river systems as dissolved organic and inorganic carbon in groundwater and soil water. Direct inputs of carbon from in-stream production (phytoplankton and benthic algae) and processing of carbon through fungal, microbial and invertebrate pathways are also important in maintaining food webs.

The mass of bio-available carbon can determine the total standing biomass of aquatic fauna, as well as the biomass of non-aquatic fauna that use river systems as a food source (such as piscivorous birds and reptiles that feed on aquatic species). The availability of different types of carbon affects the abundance and biomass of species, competition for resources and, over evolutionary time-scales, speciation and food-web relationships such as the evolution of functional feeding groups in invertebrates.

2.6 Components of the flow regime and their ecological functions

A river channel is a highly dynamic system, with a flow regime that varies seasonally and annually (Figure 13). Different components of the flow have particular ecological functions. For example, high flows scour pools and influence the distribution of sand bars, woody debris, and the complexity and distribution of habitat. As a result, high flows have a direct influence on the structure of aquatic communities and food webs in the rivers of south-west Western Australia (Pen 1999). Early-season flows relieve summer stress (high temperatures and low oxygen), provide cues for breeding migrations of native fish, and provide habitat for micro-crustaceans, aquatic insects, waterbirds, and the larval stages of some terrestrial insects. Some of the key ecologically relevant elements of the flow regime in the rivers of south-west Western Australia are detailed in the sections below, including periods of no flow, summer low flows, and high winter flows.

2.6.1 Periods of no flow

Many rivers in south-west Western Australia cease to flow in the dry period between December and April, especially during periods of below-average rainfall when regional groundwater tables fall below the base level of river channels. For example, the Margaret River regularly ceases to flow during summer, with no flow for around 20 per cent of the year. However, in periods of above-average rainfall, summer flows may be permanent.

As seasonal drying is part of the natural flow regime, endemic and other native fauna have adapted to periods when rivers recede to a series of disconnected pools. As a result, native fish have evolved to tolerate the high water temperatures and low oxygen levels that characterise the pools in late summer. Exotic species, such as mosquito fish (*Gambusia holbrooki*), are less tolerant of such conditions. In order to survive, aquatic fauna move from ephemeral tributaries and upstream reaches to river pools or perennially-flowing lower reaches of rivers. Permanent pools form critical habitat in ephemeral reaches of rivers, especially in ephemeral streams (Pen 1999).

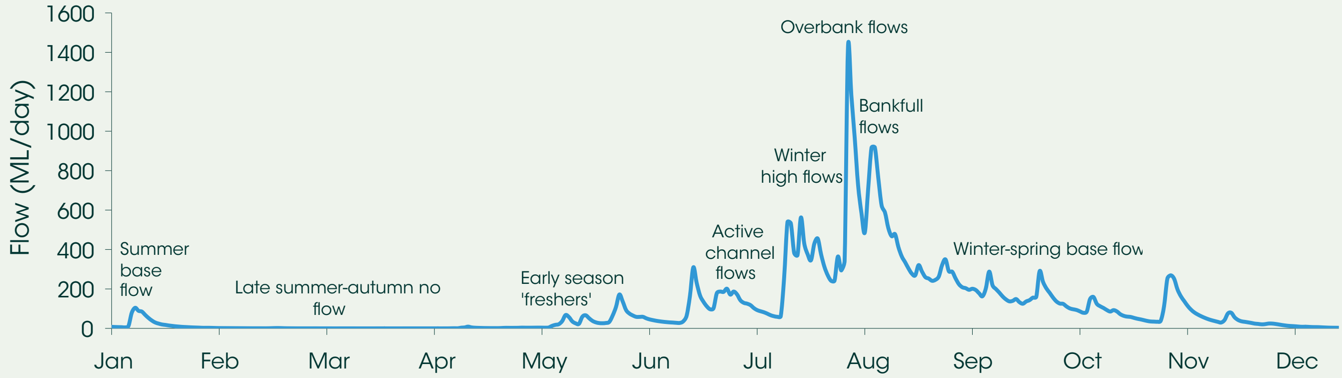


Figure 13
Representative hydrograph with different flow components labelled

To maintain the adaptive capacity of native species to variations in rainfall and flow, the EWR flow regime must include the periods of no flow that are part of the historic flow regime. These periods also help to control populations of non-native species such as *Gambusia*.

2.6.2 Summer low flows

Summer low flows, including trickle flows, can maintain water levels and depth in the dry summer period and control water temperature. Summer low flows also maintain the circulation and water movement in pools, which prevents stratification and the depletion of oxygen by respiration processes in stream sediments.

In addition, summer low flows maintain habitat in shallow areas of the river, such as riffles and sandy runs, which are important habitat for aquatic invertebrates. The turbulent flow in these areas also oxygenates flow and improves the water quality of summer refuges such as pools (Pen 1999). Finally, low flows provide a longitudinal connection between downstream and upstream reaches and pools, and provide for continued downstream carbon movement.

2.6.3 Autumn and winter low flows

Autumn and winter low flows occur in the early part of the flow season or during winter after prolonged periods of low rainfall and runoff. The magnitude of winter flow in Western Australia's south-west is variable but is highly predictable.

Early-season low flows that occur with the onset of winter rains are particularly important for aquatic fauna, as they relieve late summer stress in pool habitats. As pools dry out, water quality can deteriorate significantly as the temperature rises and oxygen levels decline. Also, as the volume of water declines, there is increased competition between species for space and resources, and predatory pressure from birds and other predators also increases owing to the greater density of fish in the remaining water (Pen 1999).

Early-season low flows are also a trigger for breeding migrations in some fish species, together with changes in day length and ambient temperature.

2.6.4 Active channel flows

The morphology of a river channel changes in response to flow events that have the energy to scour the channel, and mobilise and deposit sediment and organic debris. In describing an environmental flow regime it is important to recognise the importance of channel-forming flows and their role in maintaining a healthy and resilient ecosystem. A well-defined low-flow channel is characteristic of many rivers in south-west Western Australia and can often be seen as a 'secondary' channel within the wider river channel.

The low-flow channel is maintained by winter flows that have sufficient energy, frequency and duration to regularly scour banks. It is also known as the active channel, because the flows that maintain an open channel occur in most years and the channel is therefore actively eroding (Pen 1999).

The low-flow (or active) channel is an important structural feature of rivers and streams. The low-flow channel contains the bulk of functional habitats in rivers, such as riffles, aquatic vegetation and the pools that are so important as deep-water habitat and summer refugia.

The active channel is often overhung by fringing plants and fringing aquatic vegetation (CCG 2008). The extent of the active channel is not always obvious, but can be seen in places as a line of scoured bare earth within the low-flow channel – below which vegetation is less dense or completely absent. The flows that produce and maintain low-flow channels also tend to be those that inundate overhanging and fringing vegetation, which in turn provides cover for fauna (e.g. macroinvertebrates) and spawning habitat for native fish (e.g. pygmy perch) (Pen 1999).

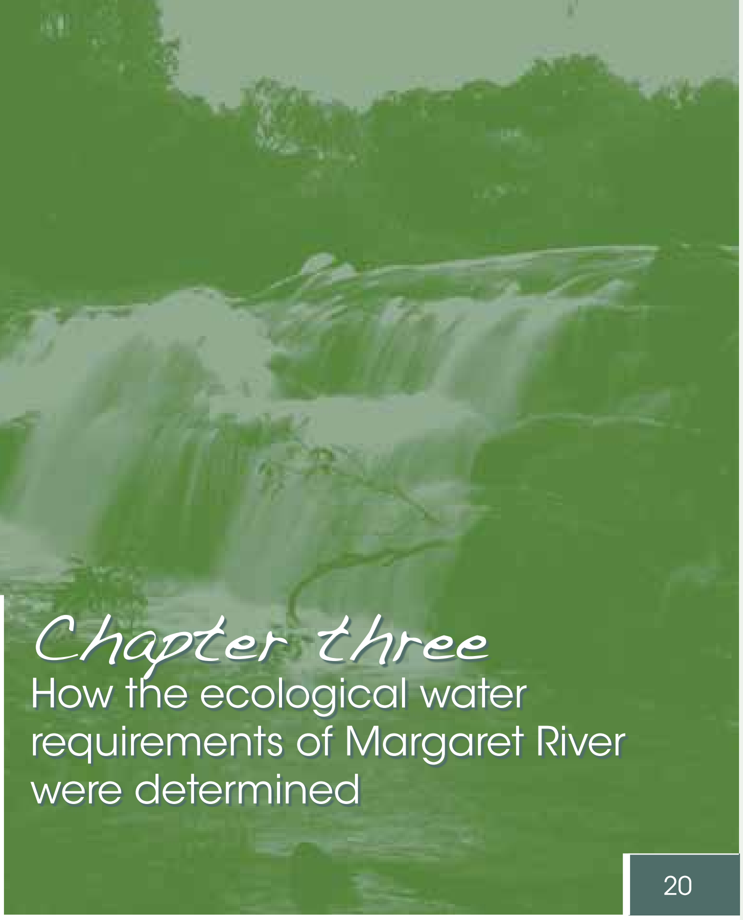
The frequency and duration of active channel flows is related to rainfall patterns. Flow events that reach the top of the active channel occur two or three times a year in south-west river systems (WRC 2000). The duration of active channel flows following rainfall is also influenced by the storage capacity of soils, soil porosity and seepage to channels from (saturated) soil profiles.

2.6.5 Winter high flows

Winter high flows include the range of flows that are responsible for creating and maintaining the morphology of the whole river channel and shape the extent of the floodplain. Winter high flows inundate the middle and higher sections of a river channel and are responsible for the creation of channel features such as benches.

Winter high flows fulfil a variety of ecological functions. By scouring channels they control encroachment of riparian vegetation into the river. They also create deep pools by scouring of sediment and organic matter to provide summer refugia for fish and other fauna as flows decline in summer (Pen 1999). The scouring of organic matter from pools also decreases biological oxygen demand, and therefore helps to maintain the oxygen levels tolerated by dependent species.

Winter high flows include flows that inundate the entire width and depth of the channel, equalling or exceeding 'bankfull' height (i.e. the highest vertical extent of the main river channel). The magnitude of a bankfull flow increases with distance downstream within a catchment, as more water is discharged into the main channel from tributaries. Flood flows (i.e. flows that reach or exceed bankfull height) occur in mid-winter due to heavy rain on saturated soils. Flood flows are generally of short duration and occur at a frequency of about one flood event every one, two or three years. Flows that result in water depths greater than the bankfull height inundate floodplains and fill wetlands that are habitat for frogs and native fish. Riparian and floodplain vegetation require occasional inundation to disperse seed, help seed-set, and soak soil profiles to promote successful germination.



Chapter three

How the ecological water requirements of Margaret River were determined

3.1 Overall approach

The ecological water requirements (EWRs) of the Margaret River were determined using an approach called the Proportional Abstraction of Daily Flows (PADFLOW). PADFLOW was developed to better define the EWR flow regime needed to maintain the ecological values of rivers (at a low level of risk). The approach evolved out of experience with using other methods, such as the 'flow events method' to determine EWRs for rivers (e.g. WRM 2005a, 2005b). The PADFLOW approach 'constructs' an EWR flow regime by removing a proportion of daily flow from an existing flow record. The volume of daily flow removed is arrived at with reference to known ecologically important flows.

PADFLOW is based around the use of the River Ecological Sustainable Yield Model (RESYM), which the Department of Water developed to estimate the EWRs of rivers. An expert panel can use RESYM in a workshop setting to assess changes in the frequency and duration of flows in a measured 'current' flow above ecologically important thresholds compared with that of a modelled EWR flow (e.g. Donohue et. al. 2009a, 2009b). For the Margaret River study, the panel included experts in water resource management, channel morphology, vegetation and aquatic ecology (Appendix 2).

The flow chart in Figure 14 shows the steps taken to generate an EWR flow for the Margaret River using the RESYM and PADFLOW approach. Tasks set out from steps 1 to 8 are the same as for the flow events method (e.g. WRM 2005b; Stewardson & Cottingham

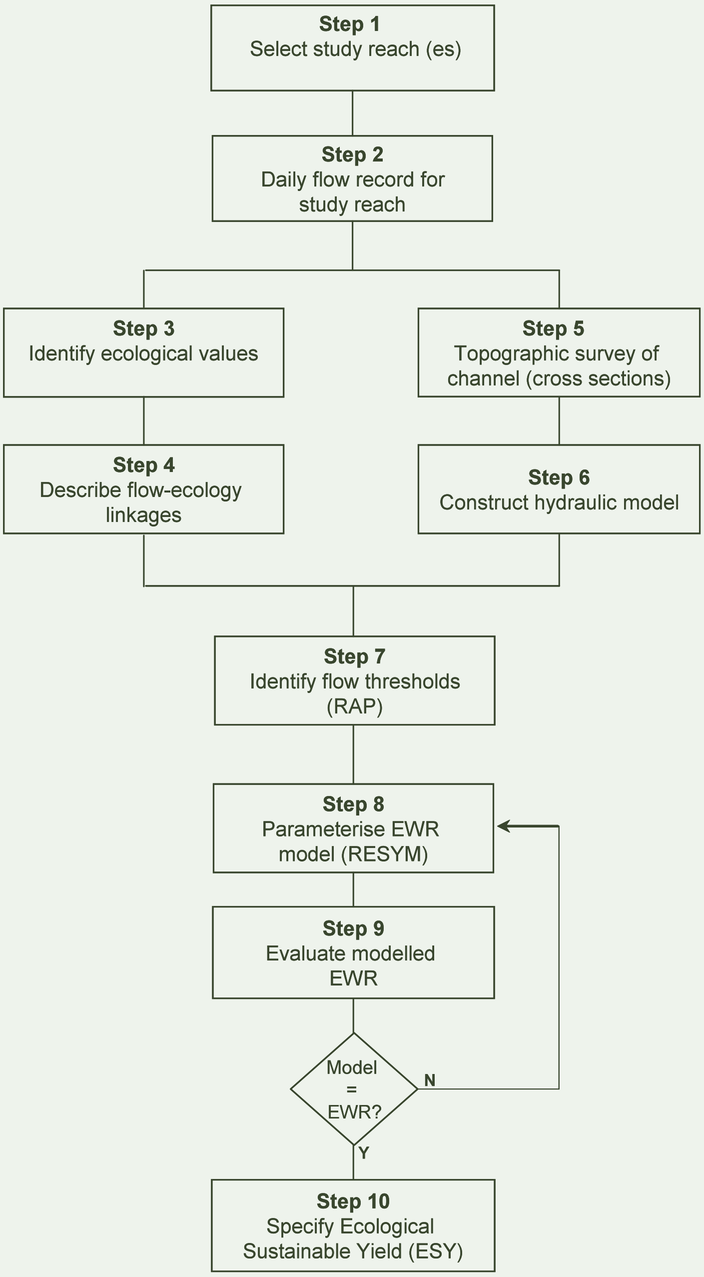


Figure 14

Flow chart showing steps in the proportional abstraction of daily flows method (PADFLOW)

2002) and other approaches used in EWR studies in Western Australia (e.g. Davies & Creagh 2000). Steps 9 to 10 are associated specifically with the PADFLOW approach and the modelling process using RESYM.

In this report, the term 'EWR flow' will be used to describe the RESYM-generated EWR flow regime for Reach 1 and Reach 2 of the Margaret River. The term 'current flow' will be used to refer to the gauged flow record for Reach 1 and modelled flow record for Reach 2 (see Section 3.3).

3.2 Selection of study sites

EWR studies are based on detailed research carried out at particular sites. Study sites are selected to represent the hydraulics and ecology of river reaches. The most important consideration when selecting a study site is the 'naturalness' of the channel morphology, as it is the channel form that largely determines the magnitude of flows needed to inundate important habitats. Highly modified channels, such as those that have been cleared of vegetation, are often deeply incised and simplified in terms of habitat types (CCG 2008; Pen 1999). Consequently, highly modified reaches are not usually selected for EWR studies because it is often difficult to identify critical hydraulic points and habitat types.

The Margaret River EWR study used data collected from two reaches: Reach 1 was selected as being representative of the river's lower section and Reach 2 its middle section (Figure 1 and Figure 15).

Reach 1 is 800 m long and was chosen to represent the current condition of the catchment's lower section. Another factor in choosing the site was its proximity to one of the department's gauging stations (610001), which provided the relevant flow data required to model the reach (see Section 2.2). The reach is located in National Park (jarrah, marri and karri forest) and is in good condition. This stretch of the river has long, deep, wide pools separated by wide rock bars and rapid sections (Figure 16).

Reach 2 was shorter than Reach 1 with a stream length of 470 m. The site was selected as it was immediately downstream of a Water Corporation abstraction pump that sends water to the Ten Mile Brook dam. This section of the Margaret River is therefore representative of flows after abstraction and could be used to determine if sufficient flows are left in the system, post abstraction. The reach is low gradient (Figure 15) and consists of long pools and sandy runs with a lot of in-stream woody debris and trailing vegetation (Figure 17) . It is located in National Park and has good riparian and surrounding vegetation. The stream itself is generally in good condition.

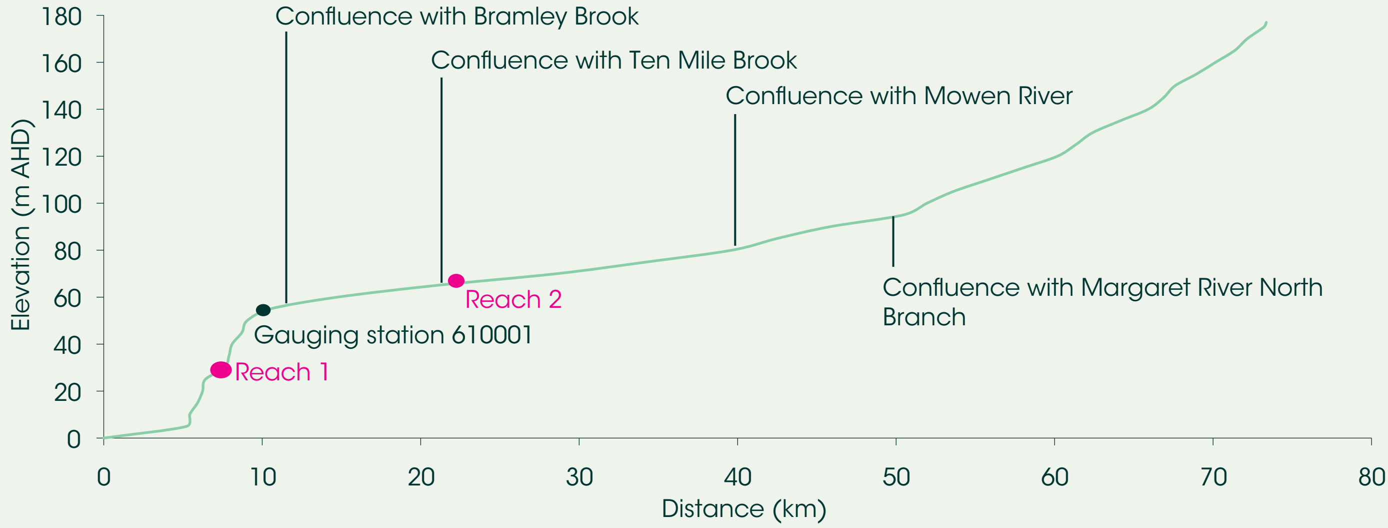


Figure 15
Elevation of the Margaret River from the river mouth, upstream to its origin

Figure 16
Reach 1 of the Margaret River has large pool sections separated by rock bars and good, healthy surrounding riparian vegetation

Figure 17
Reach 2 of the Margaret River is characterised by long pools and sandy runs with a lot of woody debris and trailing vegetation

3.3 Development of the daily flow record

To model an EWR flow, RESYM requires a daily flow time-series covering a period that represents the variation found in the river's flow regime. Reach 1 was located just downstream of Willmott's Farm gauging station (610001) and Reach 2 was located further upstream in the Margaret River's middle reaches (Figure 2 and Figure 15). Flow in both representative river reaches has been described using historical records from this station, covering the period between January 1975 and December 2005. Due to the close proximity of Reach 1 to Willmott's Farm gauging station, the 31 year daily flow record was considered to be an accurate representation of the flow regime in Reach 1 between 1975 and 2005. Reach 2 was located approximately 12 km upstream of the Willmott's Farm gauging station. To derive a daily flow time-series which accurately represented flows in Reach 2 between 1975 and 2005, the flow record from Willmott's Farm gauging station was scaled (as runoff per km^2) to the smaller catchment area of Reach 2.

3.4 Aim of the EWR study

CCG (2003) describes in detail the sort of management actions required to improve the Margaret River's health in different reaches. It lists stock access, loss of fringing vegetation, loss of floodplain habitat, obstruction to native fish and lamprey migration, weeds, stormwater pollution and the unnatural opening of the sand bar across the river mouth as major problems for the river's health. The impact of pumping during summer and autumn on the river's pool ecology is of particular concern.

The aim of this study is to support future planning for the Margaret River's water resources by identifying if and when water may be available for allocation while meeting the river's EWRs. In identifying the river's EWRs, the objectives are to maintain existing values and where possible support restorative activities such as those set out by the CCG (2003).

3.5 Flow-ecology linkages

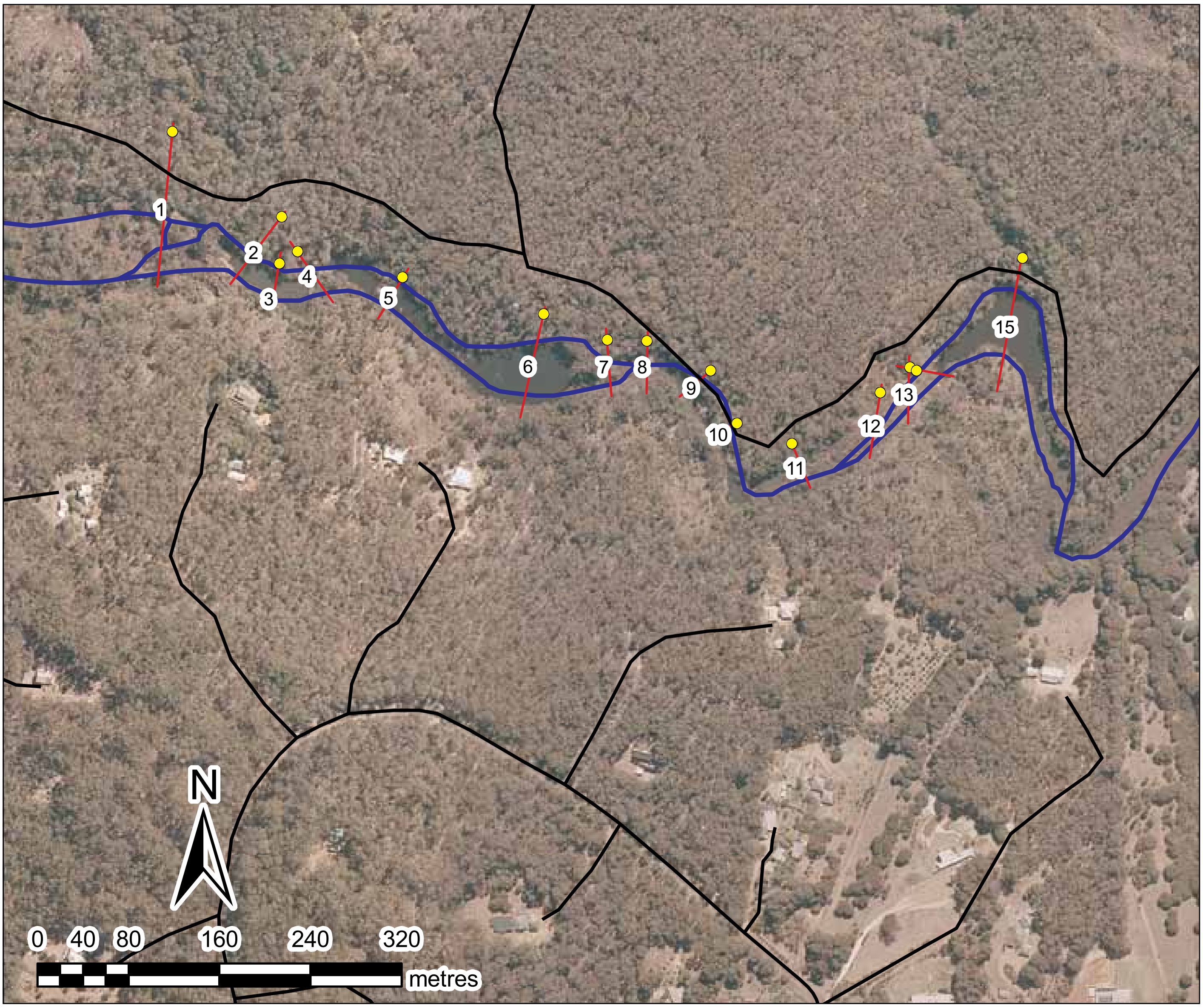
The fifth stage of the PADFLOW method (Figure 14) involves describing the water depths and related flow rates in the Margaret River that maintain in-stream and riparian vegetation, habitat for aquatic invertebrates, native fish, amphibians, reptiles, waterbirds and mammals, ecological processes (carbon sources) and channel morphology (WRM 2005a, 2005b).

The key ecological objectives considered in the determination of EWRs for both reaches of the Margaret River, and the corresponding depth criteria, are listed in Table 3. The objectives are listed in ascending order of the daily rate of flow required to fulfil the depth criteria. Where applicable, different flow criteria have been noted for reaches 1 and 2.

The flow criteria listed in Table 3 were used to develop a set of flow-ecology 'rules' that define the components of the flow regime required to maintain the ecological values of the Margaret River. These rules were used as defining criteria for hydraulic modelling that identified the flow rate needed to achieve the ecological depth criteria in Table 3. This process is described in greater detail in Section 3.8.

Table 3
Ecological objectives and flow criteria for the Margaret River

Ecological objective	Flow criteria	Flow component
1 Provide summer minimum flow to maintain water levels, water quality and dissolved oxygen levels in pools, and maintain upstream/downstream connectivity for carbon transfer	Minimum average velocity of 0.01 m/s in pools	Summer low flows
2 Inundate gravel runs and riffles as summer habitat for aquatic invertebrates	Riffles inundated to a depth of at least 5 cm over 50% of total riffle width	Summer low flows
3 Inundate gravel runs and riffles as winter habitat for aquatic invertebrates	Riffles inundated to a depth of at least 5 cm over 100% of total riffle width	Winter low flows
4 Allow upstream migration of small-bodied fish during spawning season	Water depth of at least 10 cm over obstacles	Winter and spring low flows
5 Inundate aquatic and trailing vegetation as habitat for invertebrates and vertebrates, and as spawning sites for fish and amphibians	Reach 1: Sufficient water levels to fill the depth of the active channel Reach 2: Sufficient water depth to begin inundation of low benches	Autumn, winter and spring low flows
6 Inundate low benches to a.) flush organic matter into the river and provide carbon for foodwebs, and b.) allow access to habitat on the benches	Reach 1: No low benches surveyed Reach 2: Sufficient water depth to begin inundation of low benches	Winter high flows
7 Maintain active channel morphology and scour pools	Sufficient water levels to fill the depth of the active channel	Winter high flows
8 Inundate high benches to flush organic matter into river and inundate riparian vegetation	Sufficient water depth to begin inundation of high benches	Winter high flows
9 Provide overbank flows to inundate floodplain, recharge floodplain wetlands, provide fauna habitat and aid seed dispersal and germination of riparian vegetation	Sufficient water levels to exceed top of bank	Winter high flows (flood event)



Legend

- Reach 1 GPS points
- Reach 1 cross-sections
- Hydrographical features
- Roads

Projection information
Vertical Datum: Australian Height Datum (AHD)
Horizontal Datum: Geodetic Datum of Australia (GDA 94) MGA Zone 50

Requestee: A. Green
Map Author: A. Green
ID: J:/gisprojects/Project/C_series/C2220/0008_Margaret_EWR_XSs/mxd/091203_Margaret_Reach1_AG.mxd
Date: Dec 2009

SOURCES

DoW acknowledges the following datasets and their Custodians in the production of this map:
Road Centrelines – DLI – 08/1999
Busselton_2007_50cm_z50.ecw – Langate
Skyview – 24/03/2007
Hydrography, Linear (Hierarchy) – DoW – 05/11/2007

Government of **Western Australia**
Department of **Water**

This map is a product of the Department of Water, Water Resources Division and was printed December 2009.

Figure 18

Location of 15 surveyed cross-sections in Reach 1 of the Margaret River

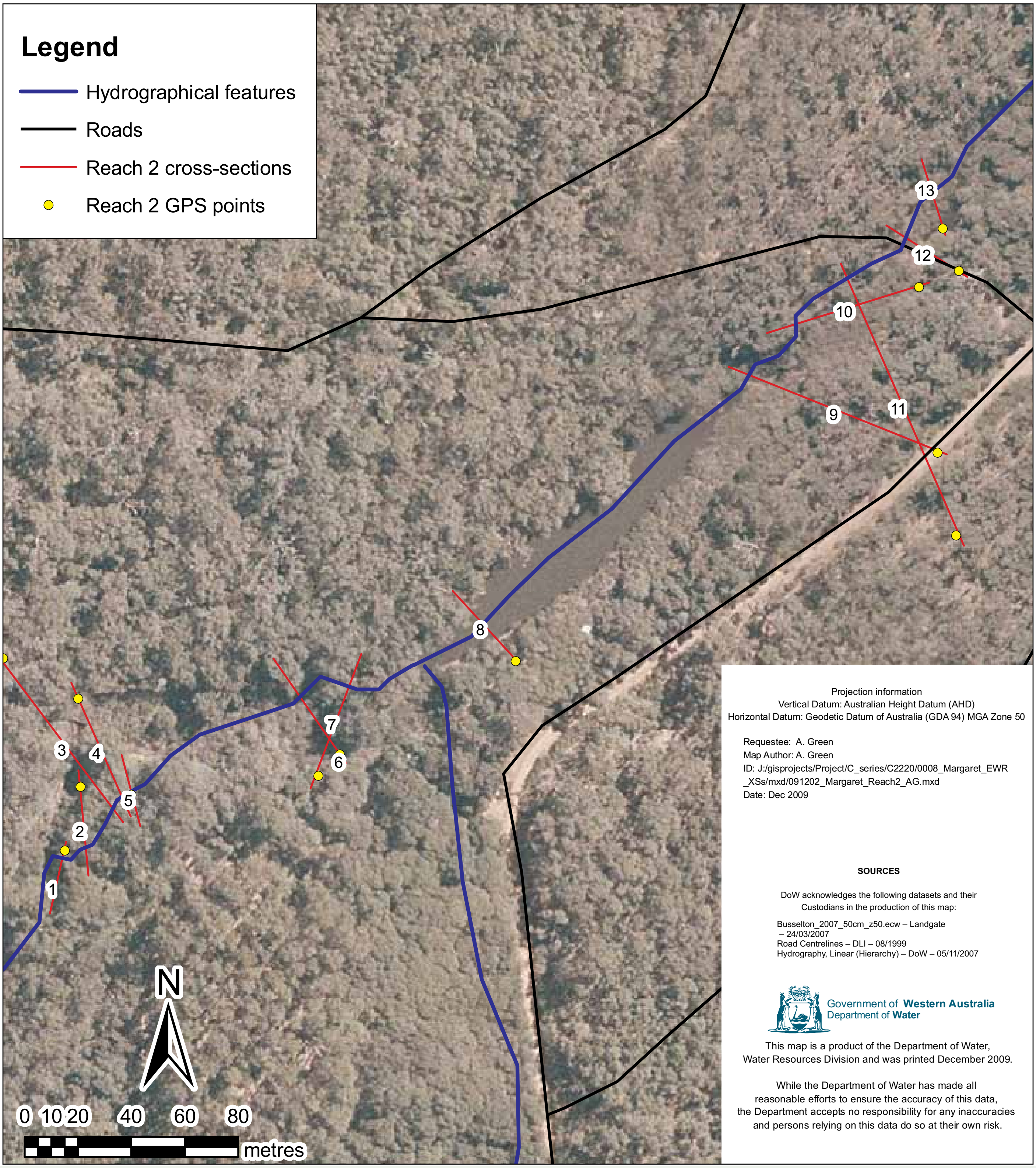
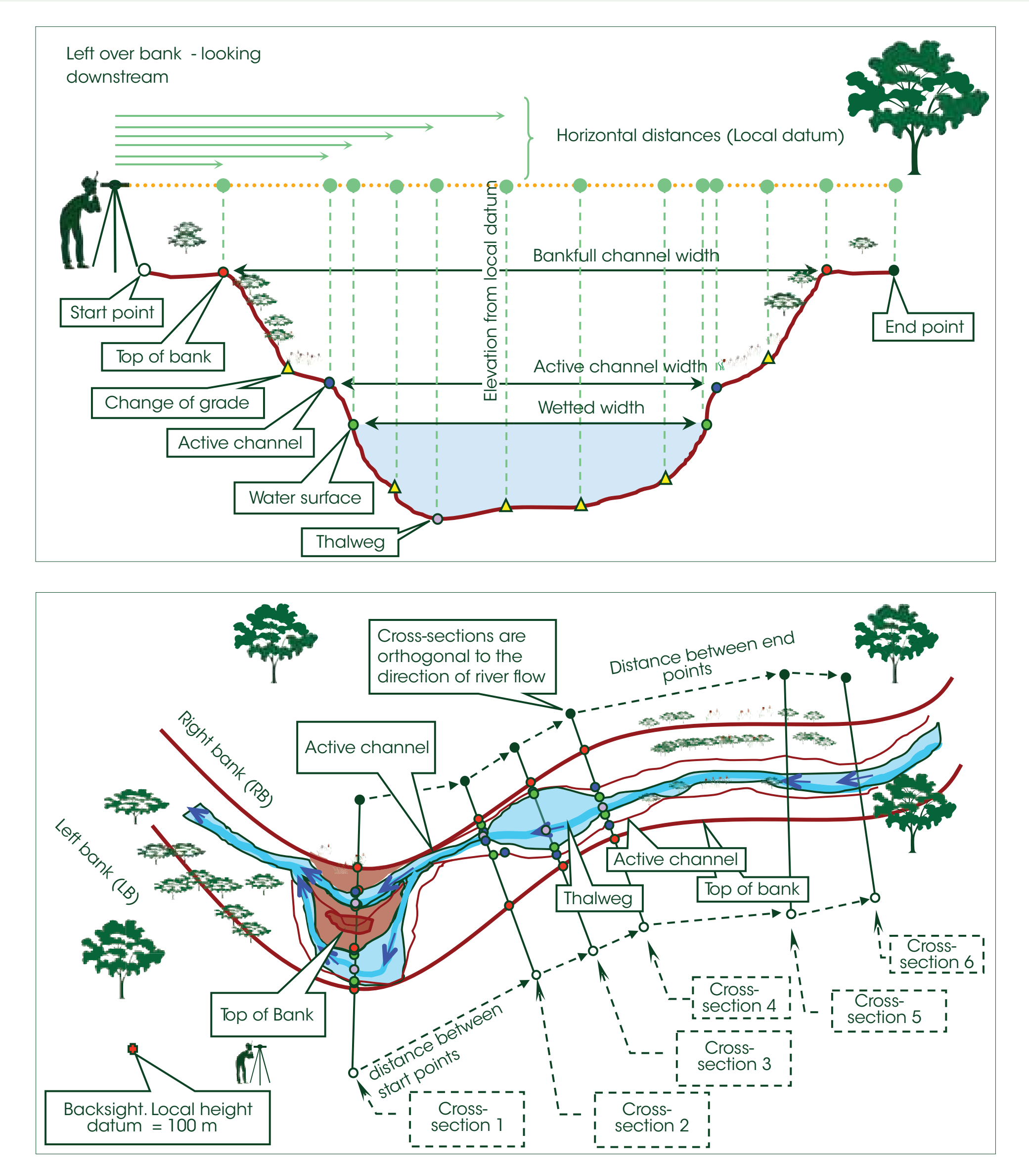


Figure 19

Location of 13 surveyed cross-sections in Reach 2 of the Margaret River

3.6 Cross-section survey of the river channel

To construct a hydraulic model of the Margaret River channel, a topographic survey of each study reach was carried out on 12 and 13 April 2006 (Step 5 in Figure 14). To characterise the shape and variability of the channel profile for both study reaches, a total of 28 cross-sections were surveyed. Fifteen cross-sections were used to capture the 800 m of channel in Reach 1 (Figure 18), while 13 were used for the 470 m of stream length in Reach 2 (Figure 19). The cross-sections were taken at key hydraulic and ecological features such as rock bars, backwaters, pools, riffles, large woody debris and channel constrictions. Figure 20 shows a schematic of how the cross-section locations were selected and point data collected on each cross-section.



To allow for the calibration of the hydraulic model described in Section 3.7 below, discharge measurements were taken before and after the cross-sectional survey and related to measured water depths on the cross-sections. The cross-sectional profiles of the river channel for both study reaches are shown in appendices 3 (Reach 1) and 4 (Reach 2).

Figure 20

Schematic diagram of a river reach

The upper diagram shows the point data surveyed as part of a cross-section. The lower diagram shows the longitudinal layout of cross-sections along a river reach

3.7 Construction of the hydraulic model

The cross-sections from reaches 1 and 2 were used to construct a hydraulic model of the river channel using the US Army Corps of Engineers' Hydrologic Engineering Center's River Analysis System (HEC-RAS). Observed relationships of discharge to stage height were used to calibrate the model. A diagram of the hydraulic model created for Reach 1 of the Margaret River is shown in Figure 21.

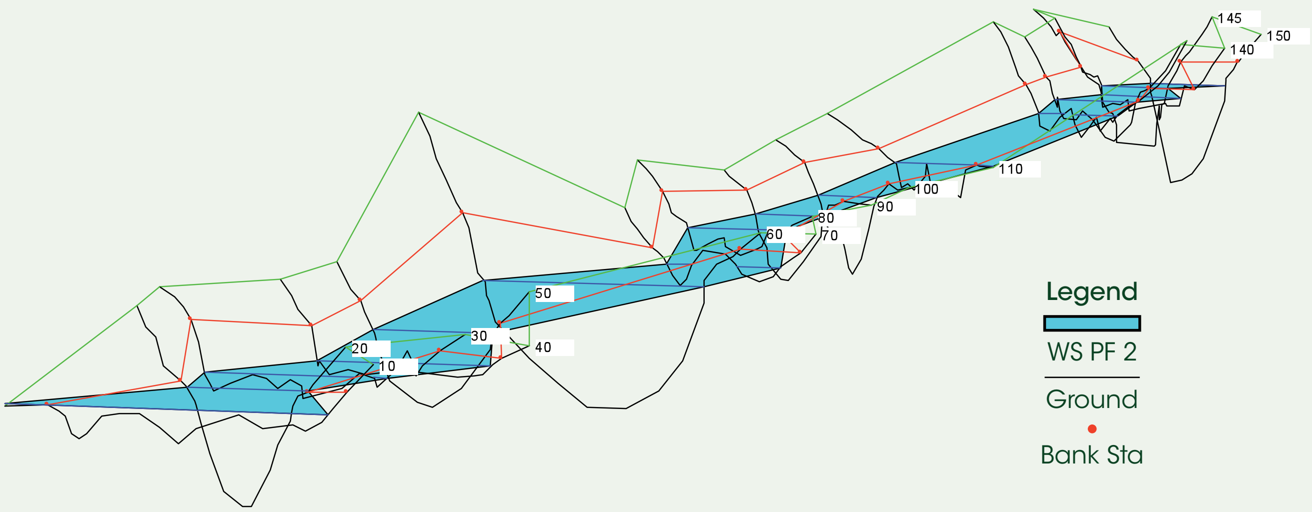


Figure 21
Structure of the HEC-RAS hydraulic model for Reach 1 of the Margaret River
The blue trace shows the water level at the time of the channel surveys

Figure 22 shows the longitudinal profiles for reaches 1 and 2 of the Margaret River. Thalweg depth (measured as the deepest part of the river channel in each cross-section) dropped by approximately 3 m over the length of Reach 1. The slope throughout Reach 2 was low and thalweg depth only dropped by approximately 1 m. In Reach 1, cross-sections 1, 3, 4, 8, 11, 12 and 14 control flow and the remaining cross-sections span pools (Appendix 3). In Reach 2, cross-sections 1, 4, 7, 10, 11 and 12 control flow and the remaining seven cross-sections span pools (Appendix 4). Controlling cross-sections usually contain riffles at low flows where water is turbulent and macroinvertebrate diversity is high. Water velocity in pool cross-sections is slower and less turbulent, and provides refuge habitat for macroinvertebrates such as crayfish and larger vertebrates.

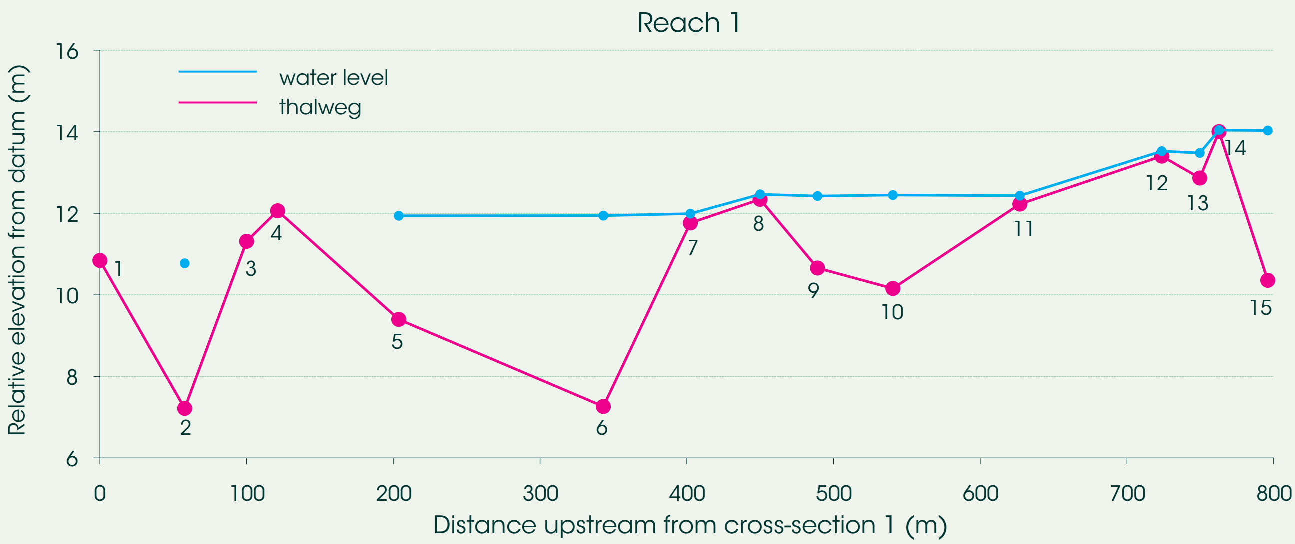


Figure 22

Longitudinal profiles of Reach 1 (upper plot) and Reach 2 (lower plot)

The profiles show a series of deep pools separated by sandy runs and rock bars. The thalweg is the deepest continuous line along a river channel and represents the flow path during very low summer flows. The measured water levels obtained during surveying on 12 and 13 April 2006 (for reaches 2 and 1 respectively) are shown as blue dots on the profiles. Discharge on both days was 0 ML/day.

3.8 Identification of flow thresholds

The River Analysis Package (RAP) was used to identify the critical flow rates required to achieve the ecological objectives set out in Table 3 (Step 7 in Figure 14). Output from the hydraulic model (HEC-RAS) developed in Step 6 of the PADFLOW process (Figure 14) was used in RAP to determine the relationships between channel geometry, flow rate and water depth at various points of the channel in reaches 1 and 2. Depending on the flow-ecology rule applied, such features could include rock bars, benches, pools, riffles or the height of riparian vegetation.

The RAP output includes 'rating curves', which graphically relate changes in discharge to changes in water depth or the wetted width of channel at one or a combination of cross-sections based on user-defined 'queries' of the model (refer to WRM 2007b). Appendices 5 to 8 show the flow rates (as water levels on the cross-sectional profiles) required to inundate various features such as channel benches, the elevation of the top of the bank and riparian vegetation.

The ecologically critical 'threshold' flow rates (in ML/day) for reaches 1 and 2 of the Margaret River that achieve the ecological (depth) objectives listed in Table 3 are summarised in Table 4. The flow rates are thresholds that achieve the particular objectives specified in Table 3. It should be noted, however, that each flow threshold may fulfil multiple ecological objectives including some at flows below the threshold, as well as other ecological outcomes not specifically considered in this study.

The threshold flows described in the following sections are those that satisfy the ecological objectives listed in Table 3.

In one case (inundation of trailing vegetation as breeding habitat), the defining flow criteria were different for the two study reaches. The height of breeding habitat was not surveyed in the field, so the heights of other channel features were used instead.

In Reach 2, the low bench height was used to indicate the approximate height of trailing vegetation, as this is generally the lowest height within a river channel where trailing vegetation can become inundated and provide spawning habitat for aquatic species. No low benches were surveyed in Reach 1, so the active channel depth was used as an approximation of the height of trailing vegetation.

3.8.1 Summer no-flow period

To maintain the natural permanency of the Margaret River, an ecologically critical flow rate of 0 ML/day (0 m^3/sec) was used to classify periods of no-flow.

3.8.2 Macroinvertebrate habitat

Riffle zones provide habitat for a broad range of fauna and tend to support a diversity of macroinvertebrate species. The turbulence of flow over riffles also oxygenates water and improves the quality of downstream habitat such as pools – especially as water levels are falling in the early summer.

To maintain the value of riffles as habitat, RAP was parameterised so that the hydraulic model would determine the flow rate (in ML/day) that would inundate:

- 50 per cent of the width of riffle cross-sections to a depth of 5 cm in summer
- 100 per cent of the width of riffle cross-sections to a depth 5 cm in winter.

These calculations were done using cross-sections 1, 3, 4, 8, 11, 12 and 14 for Reach 1 and cross-sections 1, 4, 7, 10 and 11 for Reach 2, which were all located on riffles (Figure 22). For Reach 1, the mean total width of the riffle habitat (calculated using the riffle cross-sections) was 23.14 m. For Reach 2, the mean width of riffle habitat was 6.08 m. Based on the predictions of the hydraulic model, the instantaneous flow rate required to inundate all riffle habitat to a depth of at least 5 cm was:

Reach 1

- 1.7 ML/day (0.02 m^3/s) to inundate 50 per cent of the riffles in summer
- 6.9 ML/day (0.08 m^3/s) to inundate 100 per cent of the width of the riffles in winter.

Reach 2

- 1.7 ML/day (0.02 m^3/s) to inundate 50 per cent of the riffles in summer
- 6.0 ML/day (0.07 m^3/s) to inundate 100 per cent of the width of the riffles in winter.

Table 4
Ecologically critical flow rates for Reach 1 and Reach 2 of the Margaret River

Flow-ecology rule	Threshold flow		Ecological functions
	Reach 1	Reach 2	
Water depth of 5 cm over 50% of width of riffle runs	0.02 m^3/s 1.7 ML/day	0.02 m^3/s 1.7 ML/day	Provide summer habitat for macroinvertebrates.
Water depth of 5 cm over entire width of riffle runs	0.08 m^3/s 6.9 ML/day	0.07 m^3/s 6.0 ML/day	Provide winter habitat for macroinvertebrates.
Minimum thalweg depth of 10 cm at shallowest cross-section	0.08 m^3/s 6.9 ML/day	0.84 m^3/s 72.6 ML/day	Allow upstream spawning migration of small-bodied native fish.
Minimum flow velocity of 0.01 m/s in pools	0.16 m^3/s 13.8 ML/day	0.11 m^3/s 9.5 ML/day	Maintain water quality and dissolved oxygen levels in pools. Downstream carbon movement maintained by connectivity between pools.
Inundate low benches	N/A – no low benches	0.52 m^3/s 44.9 ML/day	Flush organic matter into river system. Inundate trailing vegetation, providing fish cover and spawning sites.
Inundate active channel	1.30 m^3/s 112.3 ML/day	1.48 m^3/s 127.9 ML/day	Scour and maintain low-flow channel. Inundate trailing vegetation. Prevent incursion of terrestrial vegetation. Flush organic matter into river system.
Inundate high benches	3.15 m^3/s 272.2 ML/day	3.90 m^3/s 337.0 ML/day	Flush organic matter into river system. Inundate riparian vegetation. High-energy flows to scour pools and maintain channel morphology.
Inundate floodplain	11.12 m^3/s 960.8 ML/day	9.00 m^3/s 777.6 ML/day	Inundate and recharge floodplain wetlands. Maintain floodplain wetland nursery areas for fish and tadpoles. Inundate channel and floodplain riparian vegetation. High-energy flows to scour pools and maintain channel morphology.

3.8.3 Upstream migration of native fish

The water-level criterion for upstream migration of small-bodied native fish was set at 10 cm minimum depth over shallow sections and barriers. The 10 cm minimum has been used in other EWR studies (WRM 2007b). This criterion is considered conservative for small species such as pygmy perch, western minnow, nightfish and small cobbler (<100 mm total length or TL). The key period for this flow is leading up to and over the winter breeding period, between approximately mid-May and November.

The minimum water-level depth criterion of 20 cm for upstream migration of large-bodied fish has recently been confirmed for adult freshwater cobbler longer than 180 mm TL in the Blackwood River (Beatty et al. 2008). No large-bodied fish have been reported from the Margaret River, so this criterion was not used (WRM 2007b).

To determine the threshold flow for upstream migration of small fish in both study reaches, RAP was programmed to identify the flow that would:

- maintain a minimum depth of 10 cm over the shallowest cross-section in each reach.

In Reach 1, a rock bar at cross-section 3 was the shallowest feature surveyed and most likely to impede fish migration. A road crossing at cross-section 11 was the shallowest feature surveyed in Reach 2. This road crossing created a wide, shallow profile, and required high flows to be negotiable by fish migrating upstream.

The critical flow rate required to achieve a depth of at least 10 cm throughout the entire reach was:

Reach 1

- 6.9 ML/day (0.08 m^3/s).

Reach 2

- 72.6 ML/day (0.84 m^3/s).

3.8.4 Pool water quality

In order to maintain pool water quality and fish diversity following summer dry periods, a minimum average bulk water velocity of 0.01 m/s in pools is recommended. This is the minimum water velocity required to prevent stratification and maintain dissolved oxygen at more than 4 mg/L (WRM 2007b). Summer flows also maintain permanent pools that act as important summer refuge habitat for native fish and aquatic invertebrates, and are a source of water and food for a variety of riparian vertebrates.

To calculate the flow rates needed to maintain habitat quality in pools in Reach 1 and Reach 2, only those cross-sections across river pools were included in the hydraulic analysis (see Section 3.7).

The flow required to achieve a mid-pool water velocity of 0.01 m/s in each study reach was:

Reach 1

- 13.8 ML/day (0.16 m^3/s).

Reach 2

- 9.5 ML/day (0.11 m^3/s).

3.8.5 Inundation of spawning habitat

As explained in Section 3.8, no field data were available on the elevation of preferred spawning habitat for native fish within each of the reaches. For Reach 1, the flow rate required to inundate the active channel was used as a proxy for spawning habitat. For Reach 2, heights of low benches were used to approximate the height of spawning habitat.

3.8.6 Inundation of riverine benches

A number of ecological objectives are satisfied by inundating benches, including flooding of emergent macrophytes and inundation of aquatic and trailing vegetation (which is good habitat for fauna such as frogs and invertebrates). These flows also wash woody debris and leaf detritus into the river, providing structure for habitat and organic carbon to fuel primary and secondary production and support species diversity and food webs.

There were no low benches surveyed in Reach 1 of the Margaret River. In Reach 2 five low benches were surveyed (cross-sections 1, 2, 3, 4 and 6) (Appendix 5). High benches were surveyed in both Reach 1 (cross-sections 12, 13 and 14) and Reach 2 (cross-sections 7 and 9) (Appendix 6). Different approaches were used in reaches 1 and 2 when determining the flows required for bench inundation.

The flow required to inundate high benches in Reach 1 was determined by identifying the increase in area of channel with a slope of less than 1:100. This defines channel features with a low gradient (i.e. benches) as opposed to steep banks. The rule of slope (of 0.01) identified the flow at which there was a rapid increase in flooded area for a small increase in flow – due to the low-gradient bench being inundated.

This 'change in wetted perimeter' approach did not work for the low and high benches surveyed in Reach 2, possibly due to these benches having a higher lateral gradient. The flow required to inundate these benches was determined using the hydraulic model to calculate a flow rate that would fill the channel to an elevation where the benches became inundated at each cross-section. The threshold flow was calculated as the average flow across the cross-sections with either low- or high-elevation benches.

Benches in the Margaret River channel were inundated using the rules:

- for high benches in Reach 1, the flow where the rate of increase in wetted width was ≥100 times the increase in water level
- for low and high benches in Reach 2, the average flow rates that inundated either low or high benches at the relative cross-sections.

The flows needed to inundate channel benches in Reach 1 and Reach 2 were:

Reach 1

- 272.2 ML/day (3.15 m^3/s) for high benches.

Reach 2

- 44.9 ML/day (0.52 m^3/s) for low benches (Appendix 5)
- 337.0 ML/day (3.90 m^3/s) for high benches (Appendix 6).

3.8.7 Inundation of the active channel

The critical threshold to maintain an open, low-flow channel was defined as the flow required to fill the depth of the active channel. The elevation of the active channel was surveyed as the point on the bank above which vegetation is stable and below which the bank is bare and without extensive vegetation.

Using cross-sections with shallow sandy runs or riffles (depth-controlling features), the average depth from the deepest part of the river bed (thalweg) to the elevation of the active channel was used as the water-level height needed for inundation of the active channel. Seven riffle cross-sections were used in the calculation for Reach 1 (cross-sections 1, 3, 4, 8, 11, 12 and 14), while only four of the riffle cross-sections (1, 4, 7 and 10) were used in the hydraulic analysis for Reach 2 – because two were not considered to be representative (cross-sections 11 and 12). The average thalweg to active channel heights for Reach 1 and Reach 2 were 0.95 m and 1.5 m respectively.

The flow required to inundate the active channel in each study reach was:

Reach 1

- 112.3 ML/day (1.30 m^3/s).
- Inundates the channel to an average depth of 0.95 m.

Reach 2

- 127.9 ML/day (1.48 m^3/s).
- Inundates the channel to an average depth of 1.5 m.

3.8.8 Bankfull and overbank flows

The 'top of bank' heights in both study reaches were noted during the field survey. Only those cross-sections with a well-defined top of bank were used in the hydraulic analysis of bankfull (or overbank) flows (appendices 7 and 8).

Reach 1 had seven cross-sections with a well-defined top of bank, while Reach 2 had eight. The flow required for water levels to reach the height of the top of bank was calculated individually for each cross-section using RAP, and the average flow required to overtop the banks was taken as the ecologically critical flow rate.

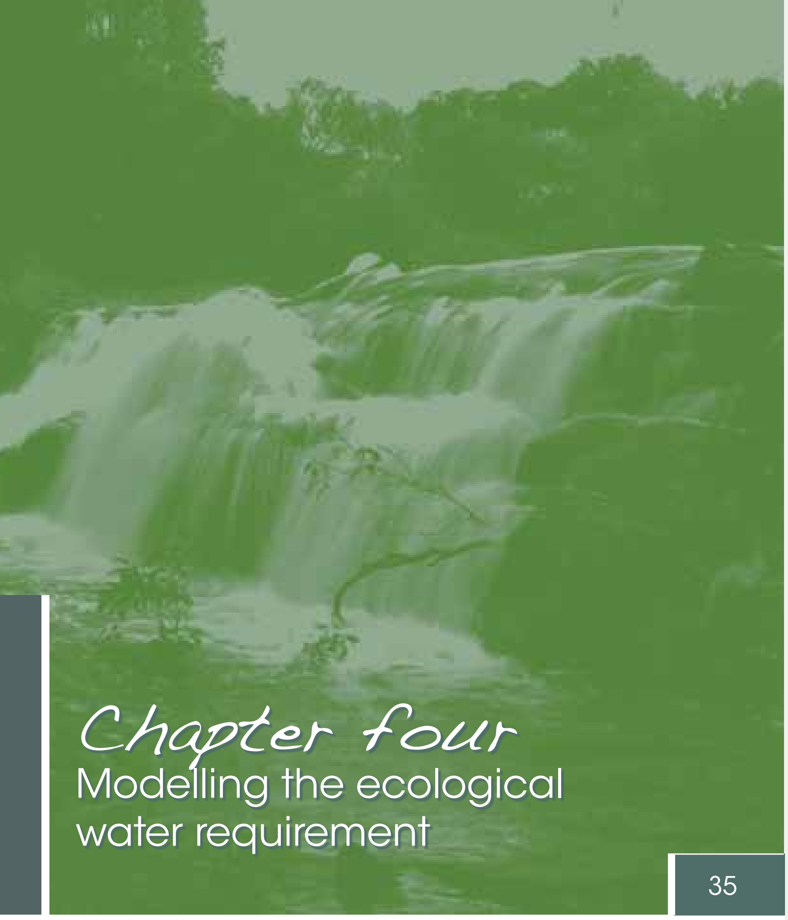
The average discharge required to achieve a bankfull flow in each study reach was calculated as:

Reach 1

- 960.8 ML/day (11.12 m^3/s) (Appendix 7).

Reach 2

- 777.6 ML/day (9.00 m^3/s) (Appendix 8).



Chapter four
Modelling the ecological water requirement

The flow thresholds in Table 4 were used in conjunction with the flow records (1975–2005) for reaches 1 and 2 (see Section 3.3) to guide the modelling team in generating an ecological water requirement (EWR) flow using the River Ecologically Sustainable Yield Model (RESYM). RESYM is a water-balance model designed to be used with the Proportional Abstraction of Daily Flows (PADFLOW) approach in developing a modelled EWR (see Section 3.1). A modelled EWR flow series produced in RESYM by removing a proportion of daily flow from a flow record until the remaining water equals or exceeds each of the identified ecological thresholds (see Section 3.8). An expert panel (see Section 3.1) parameterises and evaluates the resulting EWR flow with respect to the magnitude and timing of flows and their ecological functions.

Bar charts showing the frequency and duration of flows above each specific ecological threshold (Table 4) – for both the 'current' and modelled EWR flow – are part of RESYM's graphic output. Using these bar charts, the expert panel compares the EWR flow with the current flow. If the panel considers that the frequency and duration of flows above each ecological threshold differ significantly between the EWR flow and the current flow, it concludes that the modelled output is not consistent with an EWR at a low level of risk (steps 9 and 10 in Figure 14). When this is the case, the model parameters are adjusted accordingly, the model is re-run, the results are evaluated again, and so on until the model parameters produce an EWR flow consistent with a low level of risk.

While the panel evaluates each threshold individually, it must be emphasised that the final EWR flow reflects the panel's evaluation of the frequency and duration of flows above all the ecological thresholds listed in Table 4. In evaluating the various versions of the modelled EWR, the panel considers the frequency and duration of flow spells greater than the thresholds both within years and across years.

The RESYM parameters used to generate the final EWR for Reach 1 and Reach 2 of the Margaret River are shown in Table 5 and Table 6 respectively. The flow ranges shown were generated using the 'current' flow records (1975–2005) for reaches 1 and 2 (see Section 3.3). All up, six flow ranges were used in each reach (see Table 5 for Reach 1 and Table 6 for Reach 2) to cover the entire range of flows in the flow regime. As a result of the way the final set of model parameters were derived, most of the ecologically critical flow thresholds are encompassed within the three lowest flow ranges for both Reach 1 and Reach 2. The highest flow ranges cover very infrequent events that occur at a frequency of far less than once a year.

In the following sections the term 'current flow' will be used to refer to the daily flow records (1975–2005) for reaches 1 and 2 of the Margaret River. The term 'EWR flow' will refer to the RESYM-generated daily flow records for reaches 1 and 2.

Table 5

Proportion of the 'current' daily flow volume that was retained to meet the ecological water requirements within each flow class in Reach 1 of the Margaret River

Flow range (ML/day)	Ecological water requirements as percentage of daily flow
0 < 2.90	100%
≥2.90 < 16.2	60%
≥16.2 < 838	70%
≥838 < 1792	80%
≥1792 < 4637	90%
≥4637	100%

Table 6

Proportion of the 'current' daily flow volume that was retained to meet the ecological water requirements within each flow class in Reach 2 of the Margaret River

Flow range (ML/day)	Ecological water requirements as percentage of daily flow
0 < 3.50	100%
≥3.50 < 8.65	50%
≥8.65 < 10.0	60%
≥10.0 < 571	70%
≥571 < 3533	80%
≥3533	100%

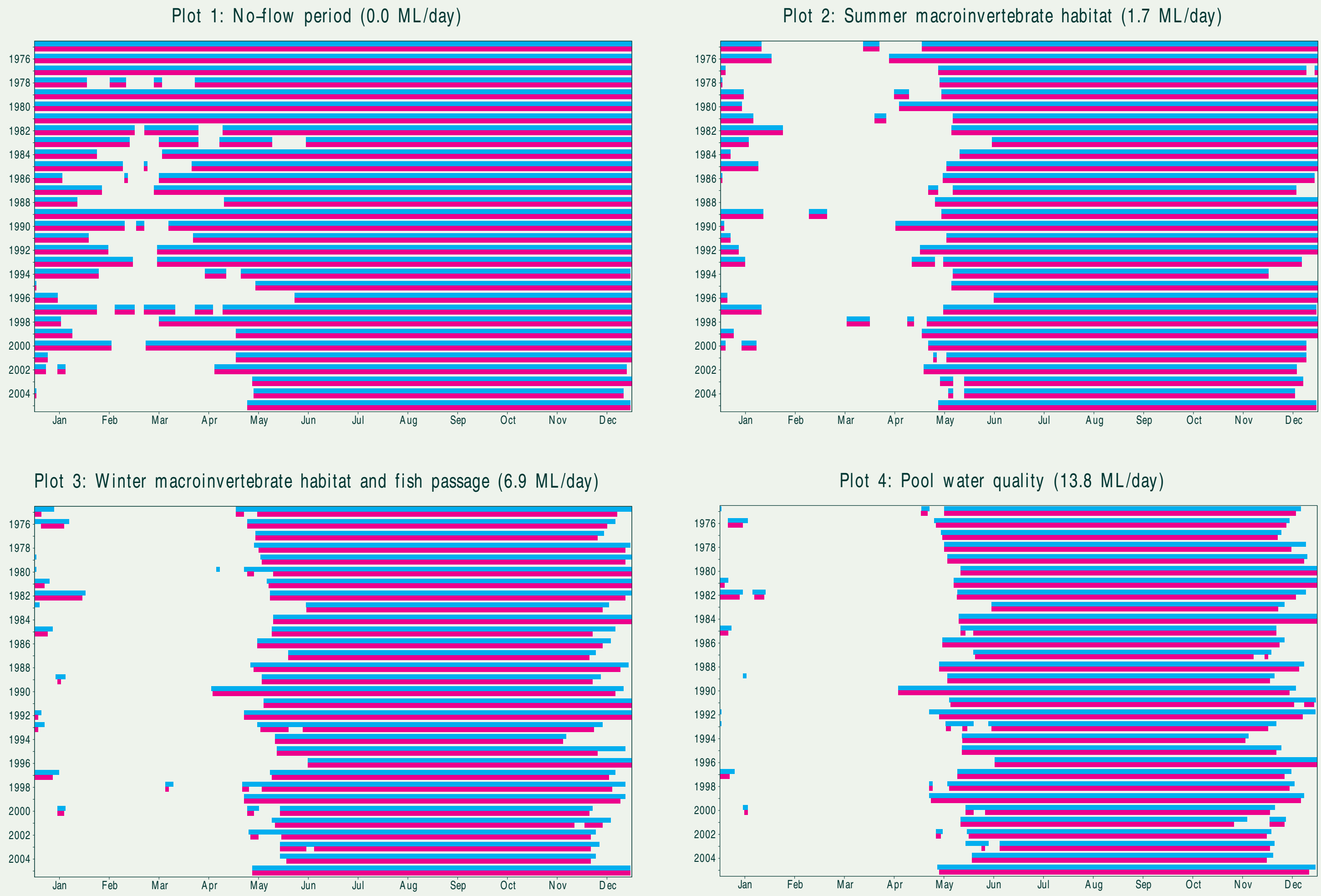
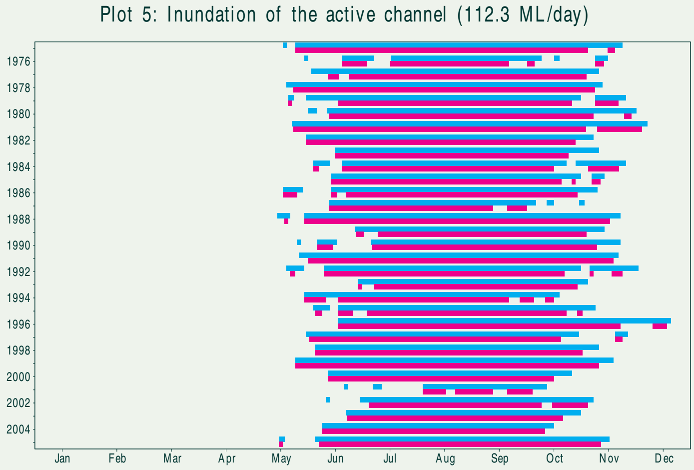
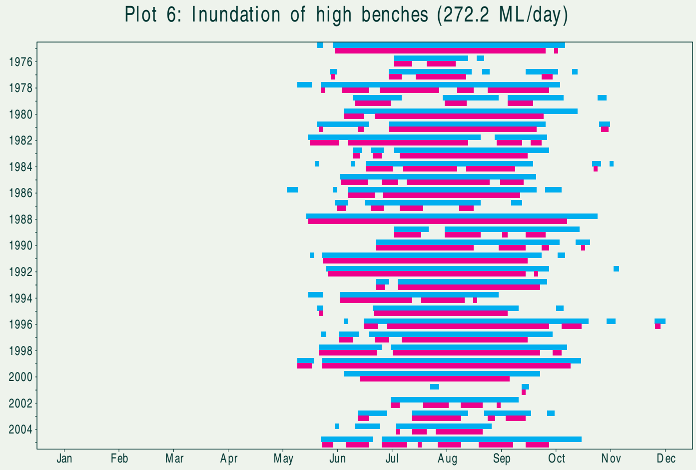


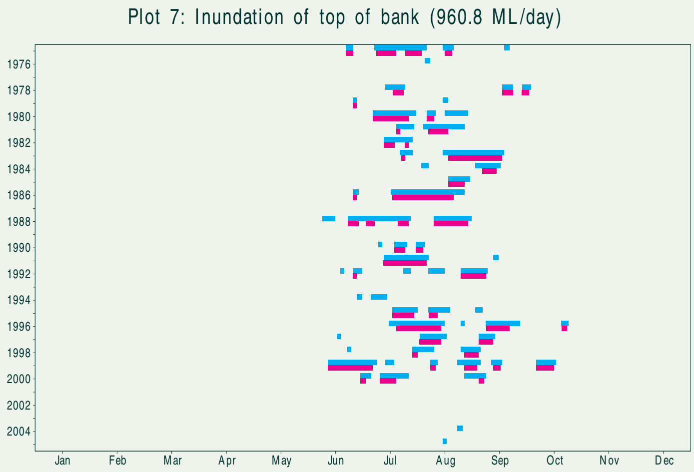
Figure 23

Frequency and duration of flows above the ecological thresholds in the modelled EWR (red bars) compared with that of the current flow (blue bars) for Reach 1 of the Margaret River

The charts show the results of the final model that the expert panel selected using the parameters in Table 5







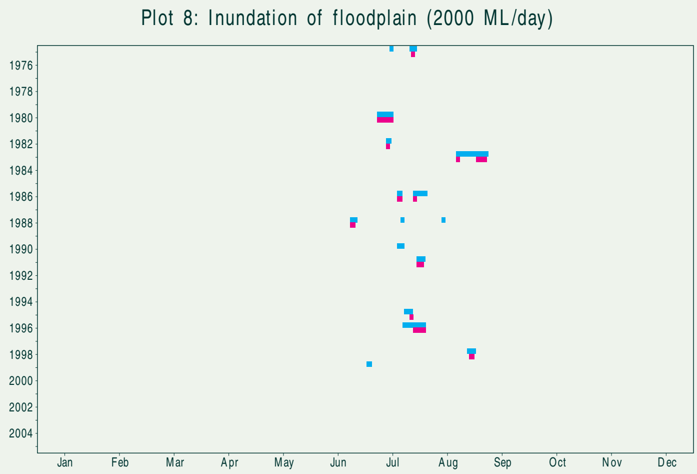


Figure 23 Continued

Frequency and duration of flows above the ecological thresholds in the modelled EWR (red bars) compared with that of the current flow (blue bars) for Reach 1 of the Margaret River

The charts show the results of the final model that the expert panel selected using the parameters in Table 5

4.1 Evaluation of key components of the modelled flow for Reach 1

The final modelled EWR for Reach 1 of the Margaret River was determined as a proportion of the 'current' daily flow within a defined series of flow ranges (Table 5). The EWR flow produced by any set of RESYM parameters was evaluated by the expert panel (Appendix 2) by comparing the frequency and duration of flows above the thresholds in the EWR compared with the current flow record. The bar charts shown in Figure 23 compare the frequency and duration above the ecological thresholds (listed in Table 4) in the final EWR flow that the panel selected for Reach 1 of the Margaret River. Further detail on the flow regimes associated with the threshold flows for Reach 1 is provided in the following sections.

4.1.1 No-flow period

Permanent and ephemeral streams in south-west Western Australia have distinctive faunal assemblages and any EWR flow should aim to maintain this fundamental characteristic.

In modelling an EWR flow, the panel aimed to preserve exactly the 'current' frequency, duration and inter-annual variation of the summer/autumn no-flow period in Reach 1. After the iterative modelling process (Figure 14), the expert panel agreed that retaining 100 per cent of flow in the 0 to 2.9 ML/day range would maintain the current frequency and duration of the no-flow period in the EWR flow regime (Table 5). Section 4.1.2 discusses the origin of this rule.

Plot 1 of Figure 23 compares the current no-flow period in Reach 1 of the Margaret River with that of the EWR flow. The summer low-flow period typically occurs between January and April, with the no-flow period appearing to increase in duration over the period of record (Figure 23). This is particularly noticeable after 2000. The plot shows that the season, frequency and duration of no-flow periods in the EWR flow is identical to that of the current flow regime.

4.1.2 Summer macroinvertebrate habitat

Hydraulic modelling using RAP showed that a flow rate of 1.7 ML/day was needed to inundate half the width of riffles in Reach 1 to a depth of at least 5 cm (Table 4). Any abstraction when flow was below 1.7 ML/day would increase the duration of both the no-flow period and the summer stresses on aquatic fauna compared with the current state. The panel members felt that due to predictions of decreasing rainfall in the region due to climate change, it was important to maintain the summer low-flow regime in the EWR flow, and that the frequency and duration of flows below 1.7 ML/day in the EWR flow should match exactly what was found in the current flow regime.

The panel found that retaining 100 per cent of the current flow in the 0 to 2.9 ML/day range for the EWR flow was needed to maintain summer riffle habitat (Table 5).

Plot 2 of Figure 23 compares the frequency and duration of flows above 1.7 ML/day in the EWR flow with those of the flow record from 1975 to 2005. Flows of this magnitude occurred consistently during late autumn, winter and spring. Flows exceeded the threshold between mid-summer and late autumn in only a small number of years, indicating the ephemeral nature of flow in the Margaret River. When flows over the threshold did occur during this period, they typically lasted for around one week (e.g. 1975 and 1998). As RESYM was set up to retain 100 per cent of daily flow below 2.9 ML/day, flows above 1.7 ML/day in the EWR flow occurred with identical frequency and duration as for the current flow.

Historically, flows above 1.7 ML/day have not occurred during the driest parts of the years in Reach 1. It is therefore unlikely that invertebrates in this part of the river are adapted to the year-round presence of flowing water. Given that the current and EWR discharges were identical, the panel decided that flow frequency and duration in the EWR series (based on the parameters in Table 5) met the summer water requirements of invertebrate fauna in the Margaret River's lower reaches.

4.1.3 Winter macroinvertebrate habitat and upstream migration of small-bodied fish

A flow of 6.9 ML/day is required to inundate the entire width of riffles for winter invertebrate habitat in Reach 1 (Table 4). The same discharge is required to give sufficient water depth over obstacles (10 cm) to allow small-bodied fish to move upstream. To provide for these objectives, RESYM was set up to retain 60 per cent of the current daily flow in the 2.9 to 16.2 ML/day range (Table 5).

Plot 3 of Figure 23 compares the frequency and duration of flows above 6.9 ML/day in the EWR flow with those of the flow record from 1975 to 2005. Continuous flows over the threshold generally occurred between May and December throughout the period of record (1975–2005). The duration of these flows was relatively consistent – generally about seven months. There were very few periods of flow over the threshold from late summer to late autumn.

From June to November, the EWR flows closely replicated the current flows over the threshold. EWR flow spells generally began at the same time and finished several days before the current flows. Some segmentation was present in the EWR flow in May and June while the current flow remained above the threshold. However, when this was the case, the EWR flow generally only fell below the threshold for approximately one week at a time.

Based on the close similarities between the current and EWR flows over 6.9 ML/day, especially between the critical months of May to October, the expert panel concluded that the RESYM parameters in Table 5 met the ecological objectives of maintaining winter macroinvertebrate habitat and providing sufficient water for migration of small-bodied fish in the Margaret River's lower reaches.

4.1.4 Pool water quality

A flow of 13.8 ML/day is required in Reach 1 of the Margaret River to maintain pool water quality, reduce stresses on aquatic fauna and maintain downstream carbon movement by connectivity between pools (Table 4). To provide for this objective, RESYM was set up to retain 60 per cent of daily flow in the 2.9 to 16.2 ML/day range (Table 4).

Plot 4 of Figure 23 compares the frequency and duration of flows above 13.8 ML/day in the EWR flow with those of the flow record from 1975 to 2005. Flows of more than 13.8 ML/day occurred almost continuously from June to November. In late summer and autumn, flows generally fell below the threshold. The duration of flows over the threshold was relatively consistent throughout the period of record, typically between six and seven months. In some years shorter flow spells of a few days to a week were present in late summer and late autumn to early winter.

EWR flow spells closely resembled the current flow spells, particularly from winter to early summer. Flows over the threshold generally began at the same time, with EWR flow spells tapering out a few days to a week earlier than current flow spells. Where current flows extended into the summer period, this was generally closely matched by EWR flows.

Given the absence of flows over the required threshold during the critical period for pool water quality at the end of summer and start of autumn, the expert panel concluded that the flow criteria for reducing stress on aquatic fauna by maintaining pool water quality and pool connectivity was not met currently within the Margaret River system. Consequently, the ecological flow conditions required to provide optimal pool habitat during stressful periods of high ambient temperature are unlikely to occur within the Margaret River.

It should be noted that the critical threshold for pool water quality was unusually high for Reach 1 of the Margaret River when compared with other EWR studies of rivers in the south-west (e.g. Donohue et al. 2009a, 2009b). This is most likely due to the large volume and substantial depth of pools in Reach 1 of the Margaret River and high-energy flows being required for mixing and circulation to occur at depth.

4.1.5 Inundation of the active channel

A discharge of 112.3 ML/day is required to achieve a depth of flow equal to the elevation of the active channel in Reach 1 (Table 4). For the purpose of this study, the active-channel height was defined as the level on the bank above which vegetation is stable and below which the bank is eroding and without extensive riparian vegetation. Active channel flows are responsible for the morphology of the low-flow channel through mobilising sediment, scouring pools and limiting the encroachment of terrestrial vegetation. It is important that this flow occurs at regular intervals, but neither the frequency nor duration of the flow in the EWR need be identical to the flow record.

After the iterative modelling process (Figure 14), the expert panel agreed that retaining 70 per cent of daily flow in the 16.2 to 838 ML/day range for the EWR would provide for the maintenance of the low-flow channel (Table 5).

Plot 5 of Figure 23 compares the frequency and duration of flows above 112.3 ML/day in the EWR flow with those of the flow record from 1975 to 2005. Flows sufficient to inundate the active channel occurred in all years on record. Flows over the threshold were most common between mid-June and early November. Short flow spells of up to one week's duration were sometimes present in May and June before the wet season, and in October and November after the wet season. Periods of flow over the threshold were significantly shorter in 1976, and from 2001 to 2004, with flows in 2001 exceeding the threshold for less than three months.

EWR flow spells generally began at the same time or within a few days of the current flow spells, and ceased around one week earlier. For several of the lower-flow years, EWR flow spells were segmented even though current flow spells were continuous, particularly at the start of the wet season and throughout spring. During these events, the EWR flow typically fell below the threshold for around one week. However, the commonly observed short spells in late autumn and early winter were replicated by the EWR flow spells for most of the years on record, albeit with shorter duration.

It is important that this flow occurs at regular intervals, but neither the frequency nor duration need be identical to the current frequency to maintain the flow's ecological function. The expert panel concluded that there would be relatively little ecological impact from the differences in frequency and duration between the modelled EWR series and the flow record.

4.1.6 Inundation of high benches

A winter flow of 272.2 ML/day is required to inundate high-elevation benches in Reach 1 (Table 4). Flows that inundate high benches in river channels scour pools and maintain channel morphology, flood high riparian vegetation, and provide carbon to river ecosystems through washing accumulated detritus and leaf litter from benches into the channel. The panel emphasised the importance of these flows occurring at regular intervals, but neither the frequency nor duration needed to be identical to the current frequency to maintain the flow's ecological function.

After the iterative modelling process (Figure 14), the expert panel agreed that retaining 70 per cent of flow in the 16.2 to 838 ML/day range for the EWR would maintain the ecological functions of the flow (Table 5).

The frequency and duration of flows above 272.2 ML/day in the EWR flow are compared with those of the flow record (1975–2005) in Plot 6 of Figure 23. Flows over the threshold have occurred in all years on record. Flows of this magnitude varied significantly in duration between 1975 and 2005, and were most prevalent between June and October. There was some inter-annual variation in the total duration of flows over 272.2 ML/day. In some years, these flows occurred continuously for four to five months, while in other years they occurred in intermittent shorter periods above the threshold (usually two to four weeks duration) – interspersed with periods below the threshold. Flow in 2001 was exceptionally low, and only rose above the threshold for a few days in August and September. Short spells of flow over the threshold interspersed with periods of lower flow have occurred regularly in June and July, and in October and November. The longest period of continuous flow above the threshold was in 1988 when flows exceeded 272.2 ML/day for over five months.

In the EWR flow, flows over the threshold also occurred in all years on record, but were slightly less frequent than those of the flow record. Flow occasionally fell below the threshold for short periods in the EWR flow, even though the current flow was over the threshold. Such events typically lasted less than one week. EWR flows of greater than 272.2 ML/day generally began at the same time or within a few days of current flows of the same magnitude, and tapered off a few days to a couple of weeks earlier. The short spells of early and late flows in some years of the flow record were generally not captured in the EWR flow. However, sustained lengthy periods of this flow (around four months' duration) were generally replicated in the EWR flow.

The expert panel decided that the ecological impact of differences in frequency and duration between the modelled EWR flow series and the flow record would probably be small.

4.1.7 Bankfull and overbank flows

A flow of 960.8 ML/day is required to achieve a depth equal to or exceeding bankfull height in Reach 1 (Table 4). High-energy bankfull flows scour pools and maintain channel morphology, provide carbon to river ecosystems by washing accumulated detritus and leaf litter from benches into the channel, and inundate channel and floodplain riparian vegetation.

After the iterative modelling process (Figure 14), the expert panel agreed that retaining 80 per cent of flow in the 838 to 1792 ML/day range, 90 per cent of flow in the 1792 to 4637 ML/day range and 100 per cent of flow greater than 4637 ML/day for the EWR would preserve the regularity of bankfull and overbank flows and subsequent floodplain inundation (Table 5).

Plot 7 of Figure 23 compares the frequency and duration of flows above 960.8 ML/day in the EWR series with those of the flow record from 1975 to 2005. As the plot shows, in Reach 1 flows of this magnitude have occurred in most of the years on record as interspersed spells between June and October. No flows above the threshold occurred between November and May in any of the years on record. Since 2000 flows of this magnitude have only occurred twice. This was only for a few days during August in 2004 and 2005.

Flow spells were generally short and intermittent, with the longest continuous spell occurring in 1986 and lasting for approximately five weeks. Spells of flow above the threshold typically ranged from a few days to one month's duration and were interspersed with similar lengths of time below the threshold.

The EWR flow is relatively similar to the flow record with current flow spells greater than a few days' duration generally captured by the EWR flow. However, in several of the years on record (such as 1976, 1994, 2004 and 2005), the short spells of flow above the threshold in the current flow were not reflected in the EWR flow. In years when current flows remained above the threshold for sustained periods (i.e. greater than one month), the EWR flow generally remained above the threshold for most of the period.

Bankfull and overbank flows are required to inundate and recharge wetlands on the Margaret River's floodplain; they also aid in the seed dispersal and germination of riparian plant species such as *Eucalyptus rudis* and paperbark (*Melaleuca* spp.). These events are irregular and of short duration, so it is important that the modelled EWR mimics the current frequency of these events. Given that the modelled EWR would have provided sufficient flow to overtop banks for approximately three-quarters of current events over the threshold, the expert panel concluded that the RESYM parameters in Table 5 met the objective to provide sufficient water to inundate the floodplain in the Margaret River's lower reaches.

4.1.8 Flood events

The highest ecologically critical flow height measured during the Reach 1 channel survey was top of bank height. As mentioned in the previous section, a flow of 960.8 ML/day was required to reach this height on the channel. During the 31-year period of record, flows in Reach 1 of the Margaret River were as high as 5349 ML/day and were greater than the bankfull threshold for a combined 593 days (equivalent to 5 per cent of the time). High-energy flows such as these scour the floodplain and begin the inundation necessary to maintain wetland areas adjacent to river systems.

Given the large range of flows greater than the highest ecological threshold for Reach 1, a threshold of 2000 ML/day was introduced to provide for irregular, large flood events and to see how the EWR was preserving these 'higher range' flows.

To provide for this objective, the expert panel agreed that retaining 90 per cent of flow in the 1792 to 4637 ML/day range and 100 per cent of flow greater than 4637 ML/day for the EWR would maintain the ecological functions of the flow (Table 5).

The frequency and duration of flows greater than 2000 ML/day in the EWR series is compared with those of the flow record (1975–2005) in Plot 8 of Figure 23. Flows exceeded 2000 ML/day in only 12 of the 31 years on record. These flows always occurred between June and September and ranged in duration from several days to around two weeks. Several short interspersed flow spells of greater than 2000 ML/day occurred in some years such as 1988, while in other years, flows only rose above the threshold for a few days.

EWR flows greater than 2000 ML/day were present for approximately 70 per cent of those observed in the current flow and occurred in 10 of the 31 years of record. When current flows exceeded the threshold for more than a few days, so did the EWR, but typically for shorter periods. Current flows over the threshold of less than a few days' duration were generally not replicated in the EWR flow.

These flood events in Reach 1 of the Margaret River are extremely rare and when they do occur, generally only last for less than a week. The ecological importance of these flows is probably related to seed set and establishment of vegetation in upper/outer floodplain areas, and they most likely influence channel and floodplain morphology. The panel felt that with these events still occurring for around 70 per cent of the time in the EWR flow, the ecological function of these flows would not be compromised.

4.2 Evaluation of key components of the modelled flow for Reach 2

The final modelled EWR for Reach 2 of the Margaret River was determined as a proportion of the 'current' daily flow within a defined series of flow ranges (Table 6). The EWR flow produced by any set of RESYM parameters was evaluated by the expert panel (Appendix 2) by comparing the frequency and duration of flows above the thresholds in the EWR compared with the current flow record (1975–2005). The bar charts shown in Figure 24 compare the frequency and duration above the ecological thresholds (listed in Table 4) in the final EWR flow that the panel selected for Reach 2 of the Margaret River. Further detail on the flow regimes associated with the threshold flows for Reach 2 is provided in the following sections.

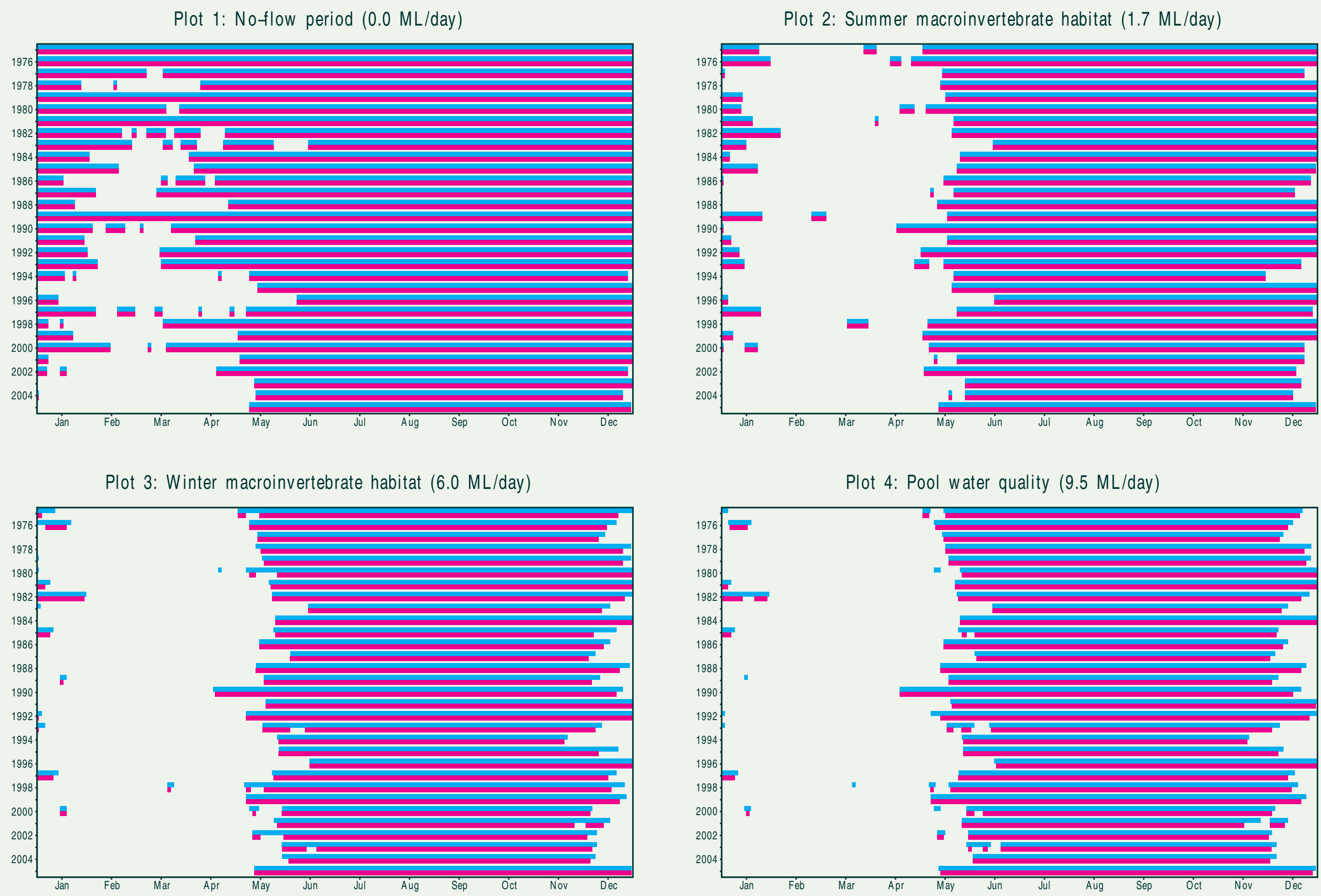
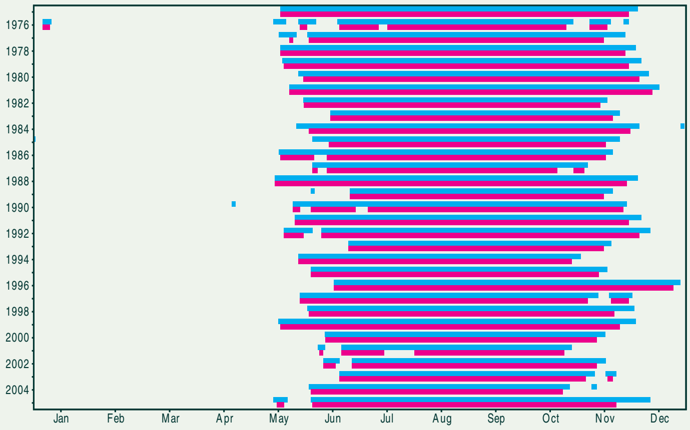


Figure 24

Frequency and duration of flows above the ecological thresholds in the modelled EWR (red bars) compared with that of the current flow (blue bars) for Reach 2 of the Margaret River

The charts show the results of the final model selected by the expert panel using the parameters in Table 6

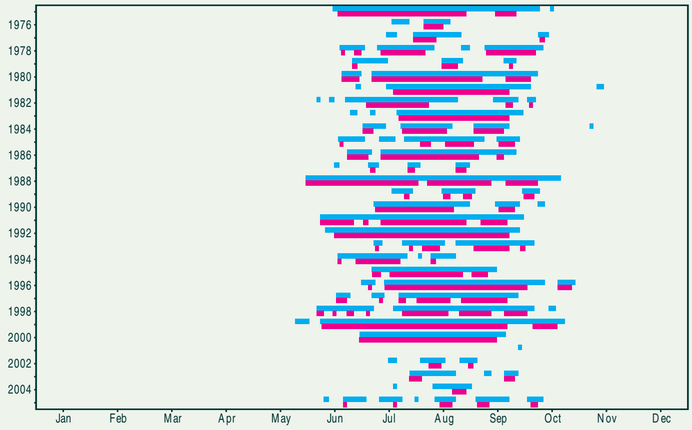
Plot 5: Inundation of low benches (44.9 ML/day)



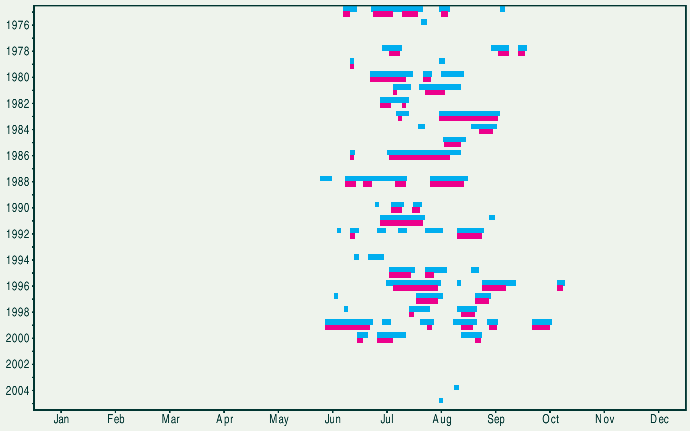
Plot 6: Fish passage (72.6 ML/day)

Plot 7: Inundation of active channel (127.9 ML/day)

Plot 8: Inundation of high benches (337.0 ML/day)



Plot 9: Inundation of top of bank (777.6 ML/day)



Plot 10: Inundation of floodplain (1750.0 ML/day)

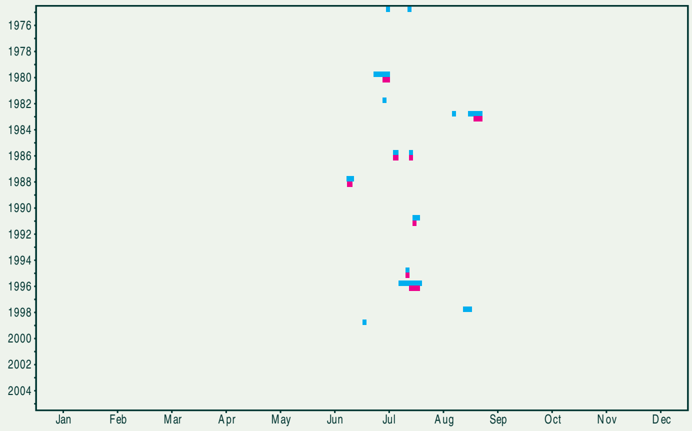


Figure 24 Continued

Frequency and duration of flows above the ecological thresholds in the modelled EWR (red bars) compared with that of the current flow (blue bars) for Reach 2 of the Margaret River

The charts show the results of the final model selected by the expert panel using the parameters in Table 6

4.2.1 No-flow period

Permanent and ephemeral streams in south-west Western Australia have distinctive faunal assemblages and any EWR flow should aim to maintain this fundamental characteristic.

In modelling an EWR flow, the panel aimed to preserve exactly the 'current' frequency, duration and inter-annual variation of the summer/autumn no-flow period in Reach 2. After the iterative modelling process (Figure 14), the expert panel agreed that retaining 100 per cent of flow in the 0 to 3.5 ML/day range would maintain the current frequency and duration of the no-flow period in the EWR flow regime (Table 6). Section 4.1.3 discusses the origin of this rule.

Plot 1 of Figure 24 compares the current no-flow period in Reach 2 of the Margaret River with that of the EWR flow. The summer low-flow period typically occurs between January and April with the no-flow period appearing to increase in duration over the period of record (Figure 24). This is particularly noticeable after 2000. The plot shows that the season, frequency and duration of no-flow periods in the EWR flow are identical to that of the current flow regime.

4.2.2 Summer macroinvertebrate habitat

Hydraulic modelling using RAP showed that a flow rate of 1.7 ML/day was needed to inundate half the width of riffles in Reach 2 to a depth of at least 5 cm (Table 4). Any abstraction when flow was below 1.7 ML/day would increase the duration of both the no-flow period and the summer stresses on aquatic fauna compared with the current state. The panel members felt that due to predictions of decreasing rainfall in the region due to climate change, it was important to maintain the summer low-flow regime in the EWR flow, and that the frequency and duration of flows below 1.7 ML/day in the EWR flow should match exactly what was found in the current flow regime.

The panel found that retaining 100 per cent of the current flow in the 0 to 3.5 ML/day range for the EWR flow was needed to maintain summer riffle habitat (Table 6).

Plot 2 of Figure 24 compares the frequency and duration of flows above 1.7 ML/day in the EWR flow with those of the flow record from 1975 to 2005. Flows of this magnitude occurred consistently during late autumn, winter and spring. Flows exceeded the threshold between mid-summer and late autumn in only a small number of years, indicating the ephemeral nature of flow in the Margaret River. When flows above the threshold did occur during this period, they typically lasted for around one week (e.g. 1975 and 1989). As RESYM was set up to retain 100 per cent of daily flow below 3.5 ML/day, flows above 1.7 ML/day in the EWR flow occurred with identical frequency and duration as for the current flow.

Historically, flows above 1.7 ML/day have not occurred during the driest parts of the year in Reach 2. It is therefore unlikely that invertebrates in this part of the river are adapted to the year-round presence of flowing water. Given that the current and EWR discharges were identical, the panel decided that flow frequency and duration in the EWR series (based on the parameters in Table 6) met the summer water requirements of invertebrate fauna in the Margaret River's middle reaches.

4.2.3 Winter macroinvertebrate habitat

A flow of 6.0 ML/day is required to inundate the entire width of riffles for winter invertebrate habitat in Reach 2 (Table 4). This objective is winter-critical, with the main period of interest being May to October. To provide for this objective, RESYM was set up to retain 50 per cent of the current daily flow in the 3.5 to 8.65 ML/day range (Table 6).

Plot 3 of Figure 24 compares the frequency and duration of flows above 6.0 ML/day in the EWR flow with those of the flow record from 1975 to 2005. Continuous flows over the threshold were consistently observed between mid-May and December throughout the period of record (1975–2005). The duration of these flows was relatively consistent – generally about six to seven months. There were very few periods of flow over the threshold during late summer and early to mid autumn.

From June to November, the EWR flows closely replicated the current flows over the threshold. EWR flow spells of this magnitude generally began at the same time and finished several days to a week before the current flows. Some segmentation was present in the EWR flow in May and June while the current flow remained above the threshold; however, EWR flow generally only fell below the threshold for less than a week at a time. It should be noted that even though flow may fall below the threshold, some sections of the riffle bed would still be inundated by flows of lower magnitude.

Based on the close similarities between the current and EWR flows over 6.0 ML/day, especially between the critical months of May to October, the expert panel concluded that the RESYM parameters in Table 6 met the ecological objectives of maintaining winter macroinvertebrate habitat in the Margaret River's middle reaches.

4.2.4 Pool water quality

A flow of 9.5 ML/day is required in Reach 2 of the Margaret River to maintain pool water quality, reduce stresses on aquatic fauna and maintain downstream carbon movement by connectivity between pools (Table 4). To provide for this objective, RESYM was set up to retain 60 per cent of daily flow in the 8.65 to 10.0 ML/day range (Table 6).

Plot 4 of Figure 24 compares the frequency and duration of flows above 9.5 ML/day in the EWR flow with those of the flow record from 1975 to 2005. Flows of more than 9.5 ML/day occurred almost continuously from late May to early December, with flows in late summer and autumn rarely exceeding the threshold. The duration of these flows was relatively consistent over the period of record, typically around seven months. In some years shorter flow spells of a few days to a week were present in late summer and late autumn to early winter.

EWR flow spells closely resembled the current flow spells, particularly from the start of winter to early summer. Flows above 9.5 ML/day generally began at the same time, with EWR flows typically falling below the threshold a few days to a week before the current flows.

As for Reach 1, current flows over the threshold for pool water quality were absent during the critical period at the end of summer and start of autumn – most likely due to the sheer volume of pools in Reach 2. Therefore this criterion is not met currently in Reach 2 of Margaret River. Due to the close resemblance of current and EWR flows over 9.5 ML/day throughout the period of record, the expert panel concluded that flows of this magnitude would be maintained in the EWR for the Margaret River's middle reaches.

4.2.5 Inundation of low benches

A flow of 44.9 ML/day is required to inundate low-elevation benches in Reach 2 (Table 4). Flows that inundate low benches in river channels flush carbon into the river system, inundate fringing vegetation and provide access to small tributaries for spawning. This objective is winter-critical, with the main period of interest being May to October.

After the iterative modelling process (Figure 14), the expert panel agreed that retaining 70 per cent of flow in the 10.0 to 571 ML/day range for the EWR would maintain the ecological functions of the flow (Table 6).

Plot 5 of Figure 24 compares the frequency and duration of flows above 44.9 ML/day in the EWR flow with those of the flow record from 1975 to 2005. Flows sufficient to inundate low benches were recorded for all years on record. Flows above the threshold occurred continuously in most years from around June to November. Flows of this magnitude were relatively consistent in duration, generally spanning five to six months. Flows tended to taper off by December, with no flows over the threshold between mid-January and mid-April throughout the period of record. Intermittent flows above the threshold of up to one week were observed between May and June, after which the steady winter flow began.

EWR flows over 44.9 ML/day were very similar to the current flows. The EWR flow spells generally began at the same time as the current flow spells, and finished several days to a week earlier. A notable exception to this occurred in 2005, when the EWR flow finished approximately three weeks before the current flow. Between mid-July and early November, the EWR flow spells consistently matched the current flow spells. However in some years, such as 1976, 1987, 1990 and 2001, EWR flows fell below the threshold for a few days to two weeks, while current flows remained above the threshold.

Inundation of low benches fulfils the ecological functions of flooding emergent macrophytes, flushing organic carbon into the river system and providing spawning habitat and cover for fish. As the EWR and current flow spells were generally very similar during the critical months of May to October, the expert panel concluded that the RESYM parameters in Table 6 met the objective of providing sufficient water to inundate low benches in the Margaret River's middle reaches.

4.2.6 Upstream migration of small-bodied fish

An instantaneous flow rate of 72.6 ML/day is required to allow for upstream migration of small-bodied native fish (Table 4). Based on the results of hydraulic modelling, this flow would achieve a depth of 10 cm over the road crossing at cross-section 11, which was the major constriction to upstream fish migration. To provide for this objective, RESYM was set up to retain 70 per cent of the current daily flow in the 10.0 to 571 ML/day range (Table 6).

The frequency and duration of flows above 72.6 ML/day in the EWR flow are compared with those of the flow record (1975–2005) in Plot 6 of Figure 24. Flows over the threshold occurred consistently from early June through to mid-November, with very few periods of flow below the threshold. However, 2001 was a notable exception, with flow falling below the threshold for around three weeks in July. In the drier months from January until late autumn, flows only rose above the threshold twice during the 31 years on record and even then, only for a few days. Segmentation was apparent in some years between late autumn and mid-winter, with flows falling below the threshold for periods of up to two weeks (e.g. 1976, 1986 and 1990).

The critical period for this flow is from around mid-May to August/September, when small-bodied fish migrate upstream to spawn. Most spawning is over by August/September with fish needing less water to move downstream between October and November. Flows above 72.6 ML/day in the modelled EWR occurred with similar frequency and duration to those of the current flow. EWR flow spells generally began at the same time as the current flow spells and fell below the threshold a few days to a week earlier. This could be explained by a rainfall-induced, rapid increase in discharge at the start of winter and a more gradual decline in discharge in late spring and early summer. It is important to note that the modelled EWR and current flows reach the 72.6 ML/day mark at the same time, as fish follow environmental cues at the start of the migration season to begin spawning. From mid-June to the end of October, most of the years on record had EWR flow spells that replicated the current flow spells.

Due to the similarities between the current and EWR discharges, the panel decided that the frequency and duration of flows above 72.6 ML/day in the EWR series (based on the model parameters in Table 6) met the water requirements for migration of small native fish in Reach 2.

4.2.7 Inundation of the active channel

A discharge of 127.9 ML/day is required to achieve a depth of flow equal to the elevation of the active channel in Reach 2. Active channel flows are responsible for the morphology of the low-flow channel through mobilising sediment, scouring pools and limiting the encroachment of terrestrial vegetation. It is important that this flow occurs at regular intervals, but neither the frequency nor duration of the flow in the EWR need be identical to the flow record.

After the iterative modelling process (Figure 14), the expert panel agreed that retaining 70 per cent of flow in the 10.0 to 571 ML/day range for the EWR would provide for the maintenance of the low-flow channel (Table 6).

Plot 7 of Figure 24 compares the frequency and duration of flows above 127.9 ML/day in the EWR flow with those of the flow record from 1975 to 2005. Current lows that inundate the active channel occurred in all years on record. Flows over the threshold generally occurred between June and November. There was little inter-annual variation in the duration of flows over 127.9 ML/day, which generally spanned four to five months each year. An exception to this occurred in 2001, when several shorter periods of flow over the threshold occurred between August and October, interspersed with periods below the threshold.

Flows of greater than 127.9 ML/day were slightly less frequent and always of a shorter duration in the EWR flow than in the current flow. The four to five month current flow spells seen for most years were generally closely matched by the EWR flow spells. EWR flows sometimes fell below the threshold for short periods of less than a week while current flows remained above the threshold (e.g. 1977, 1979 and 2003).

The expert panel concluded that there was no change in the inter-annual frequency of active channel flows in the EWR and that the differences in duration of the flows would not affect their role in maintaining an open low-flow channel.

4.2.8 Inundation of high benches

A winter flow of 337.0 ML/day is required to inundate high-elevation benches in Reach 2 (Table 4). Flows that inundate high benches in river channels scour pools and maintain channel morphology, flood high riparian vegetation, and provide carbon to river ecosystems through washing accumulated detritus and leaf litter from low benches into the channel. The panel emphasised the importance of these flows occurring at regular intervals, but neither the frequency nor duration needed to be identical to the current frequency to maintain the flow's ecological function.

After the iterative modelling process (Figure 14), the expert panel agreed that retaining 70 per cent of flow in the 10.0 to 571 ML/day range for the EWR would maintain the ecological functions of the flow (Table 6).

The frequency and duration of flows above 337.0 ML/day in the EWR flow are compared with those of the flow record (1975–2005) in Plot 8 of Figure 24. Flows above the threshold have occurred in all years on record, typically between mid-June and early October. The flows ranged in duration from several months to a few days. A notable trend is that since 2000, the duration of flows over 337.0 ML/day has become significantly shorter compared with the period before 2000. In 2001, flows in the Margaret River's middle reaches only exceeded the threshold for a few days near the end of September. There was notable inter-annual variation in the total duration of flows over the threshold. In some years, flows over 337.0 ML/day were almost continuous for four to five months, while in other years intermittent short periods of these flows occurred for a few days to around three weeks.

In general, the EWR flows above 337.0 ML/day closely mimicked the current flows. The EWR flow spells were less frequent in some years, particularly post 2000, and generally started several days later and finished a few days to around one week earlier than the current flow spells. EWR flow spells occurred in all years except for 2001. Current flows during this year only exceeded the threshold for approximately three days in September. Shorter intermittent spells of flow above the threshold in early winter and late spring were not always replicated in the EWR flow.

As the main ecological purpose of inundating high benches is to wash organic carbon from the banks into the river, it is important that this flow occurs at regular intervals, but neither the frequency nor duration of these flows need be identical to the current frequency to maintain the flow's ecological function. The expert panel therefore felt that the physical impact of differences in frequency and duration between the modelled EWR series and the flow record would probably be small.

4.2.9 Bankfull and overbank flows

A discharge of 777.6 ML/day is required to achieve a depth equal to or exceeding bankfull height in Reach 2 (Table 4). High-energy bankfull flows scour pools and maintain channel morphology, provide carbon to river ecosystems by washing accumulated detritus and leaf litter from benches into the channel, and inundate channel and floodplain riparian vegetation.

After the iterative modelling process (Figure 14), the expert panel agreed that retaining 80 per cent of flow in the 571 to 3533 ML/day range and 100 per cent of flow greater than 3533 ML/day for the EWR would preserve the regularity of bankfull and overbank flows, and subsequent floodplain inundation (Table 6).

Plot 9 of Figure 24 compares the frequency and duration of flows above 777.6 ML/day in the EWR flow with those of the flow record from 1975 to 2005. Current flows over 777.6 ML/day have occurred at least once in all but seven of the 31 years on record. These flows ranged in duration from a few days to around one month, and generally occurred between June and October. Current flows above the threshold typically occurred as short spells of two days to a month, interspersed by periods of flow below the threshold of one to three weeks. Only three years on record had flow spells extending beyond a month (1983, 1986 and 1988). There appears to be a sharp reduction in the frequency of flow spells for the period 2001 to 2005, compared with the period between 1975 and 2000. Since 2000, flows with sufficient magnitude to overtop banks only occurred for a few days during August in 2004 and 2005.

The EWR flow spells are relatively similar to the current flow spells, starting at a similar time and finishing a couple of days earlier. There were four years (1976, 1994, 2004 and 2005) when there were flows above the flow threshold in the flow record, but there was no corresponding EWR flow.

Bankfull and overbank flows are required to inundate and recharge wetlands on the Margaret River's floodplain; they also aid in the seed dispersal and germination of riparian plant species such as *Eucalyptus rudis* and paperbark (*Melaleuca* spp.). These events are irregular and of short duration, so it is important that the modelled EWR mimics the frequency of current events. Given that the frequency of EWR flows over 777.6 ML/day was relatively similar to that of the current flow, the expert panel concluded that the RESYM parameters in Table 6 met the objective to provide sufficient water to inundate the floodplain in the Margaret River's middle reaches.

4.2.10 Flood events

The greatest ecologically critical flow depth measured during the Reach 2 channel survey was top of bank height (Table 4). As mentioned in the previous section, a flow of 777.6 ML/day was required to reach this height on the channel. During the period of record, current flows in Reach 2 of the Margaret River were as high as 4362 ML/day and were greater than the bankfull threshold for a combined 606 days, equivalent to 5 per cent of the time on record. High-energy flows such as these scour the floodplain and begin the inundation necessary to maintain wetland areas adjacent to river systems.

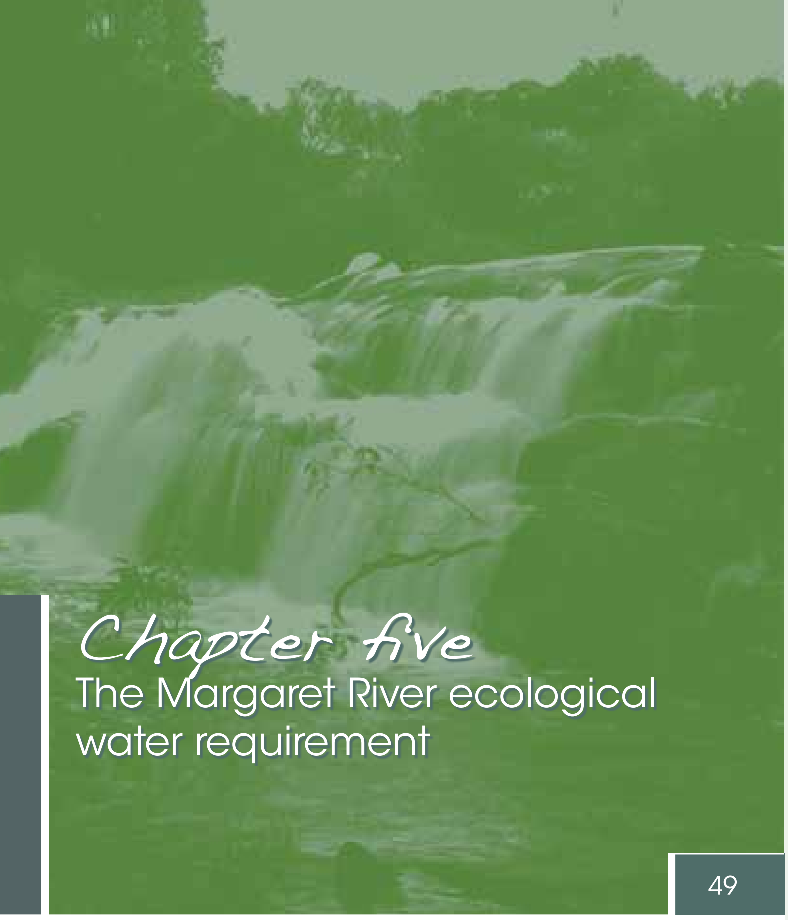
Given the large range of flows greater than the highest ecological threshold for Reach 2, a threshold of 1750 ML/day was introduced to provide for irregular, large flood events and to see how the EWR was preserving these 'higher range' flows.

To provide for this objective, the expert panel agreed that retaining 80 per cent of flow in the 571 to 3533 ML/day range and 100 per cent of flow greater than 3533 ML/day for the EWR would maintain the ecological functions of the flow (Table 6).

The frequency and duration of flows greater than 1750 ML/day in the EWR series is compared with those of the flow record (1975–2005) in Plot 10 of Figure 24. Flows exceeded 1750 ML/day in only 11 of the 31 years on record. These flows always occurred between June and September and were typically less than one week's duration. In some years flows remained above the threshold for sustained periods of one to two weeks (e.g. 1980 and 1996), while in other years flows rose above the threshold a couple of times but generally only for a few days each time (e.g.1975 and 1986).

EWR flows greater than 1750 ML/day were present for approximately 60 per cent of the current flow events and occurred in seven of the 31 years of record. Current flows over the threshold were generally closely matched by the EWR. However, EWR flows occasionally didn't reach the threshold where current flows only exceeded 1750 ML/day for less than a few days.

Flood events of this magnitude in Reach 2 of the Margaret River are extremely rare and when they do occur, generally only last for less than a week. The ecological importance of these flows is probably related to seed set and establishment of vegetation in outer floodplain areas, and they most likely influence channel and floodplain morphology. As the current events were closely replicated by the EWR, the panel believed that the altered flow regime would still perform the flow's ecological function.



Chapter five
The Margaret River ecological water requirement

The annual pattern of summer drought and winter flood is a key feature of the Margaret River and other rivers in south-west Western Australia. This feature was retained in the EWR flow regime for reaches 1 and 2, and can be seen in their respective flow duration curves (Figure 25 and Figure 26). The curves show the proportion of time that flows of different magnitudes were exceeded in both the current and EWR flow regimes between 1975 and 2005. Over the 31 years of record, the EWR flow for both study reaches retains the same permanency as the current flow, with little change to the magnitude and duration of the no-flow period at either site (Figure 25 and Figure 26). The EWR flow also retains infrequent short-duration flood flows. The EWR flow regime therefore has the same period of inundation of habitats as the current flow regime, and the same capacity for channel scouring and maintenance of channel morphology. The plots also show how the ecological thresholds are distributed relatively evenly across the historical flow range, which is typical of naturally shaped river channels.

Figure 27 is a detailed look at the EWR and current flow regimes for Reach 1 of the Margaret River. Plot 1 is a medium flow year (1982), Plot 2 shows the entire period of record (1975–2005) and Plot 3 shows consecutive high, medium and low flow years (1999–2001) (Figure 27). The plots show that the variation and volumes in the EWR flow closely match that of the current flow. For example, the EWR in wet years such as 1999 is larger than in 2001, the driest year in the flow record (Figure 27).

The close relationship between the EWR flow and the current flow is clear in Plot 3 of Figure 27. The plot shows that inter-annual variation in the seasonal pattern of flow in Reach 1 is mimicked by the seasonal variation in the EWR flow, including the duration of the winter flow period and the summer no-flow period. It also shows that the magnitude of individual flow events is smaller in the EWR but the overall frequency of high flow events between years, their timing and seasonal pattern, is a good match with the current flow.

This natural - looking seasonality and timing of flow events in the EWR can also be seen in Plot 1 of Figure 27. The plot shows that the EWR retains exactly the frequency and duration of summer low flows and the no-flow period. Note that the current flow and the EWR are the same while flows are rising at the start of the winter flow season and also as flows recede through November and December (plots 1 and 2, Figure 27).

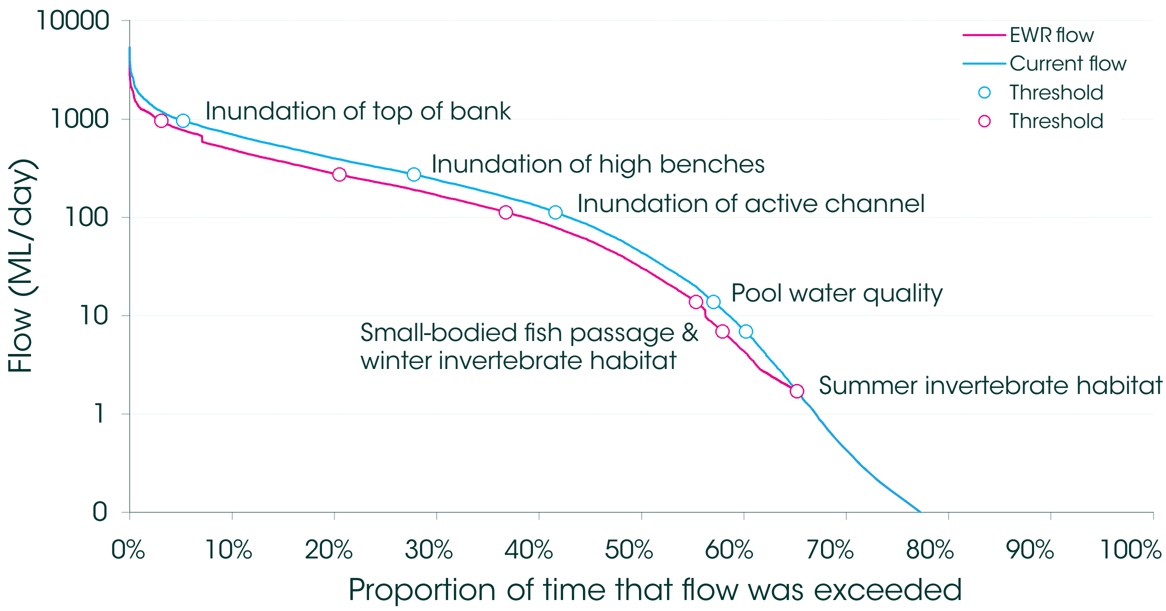


Figure 25

Flow duration curve for Reach 1 of the Margaret River, showing the current flow versus modelled EWR flow

The blue line is the current curve for the period 1975 to 2005 and the red curve is the modelled EWR over the same period (based on the parameters in Table 5)

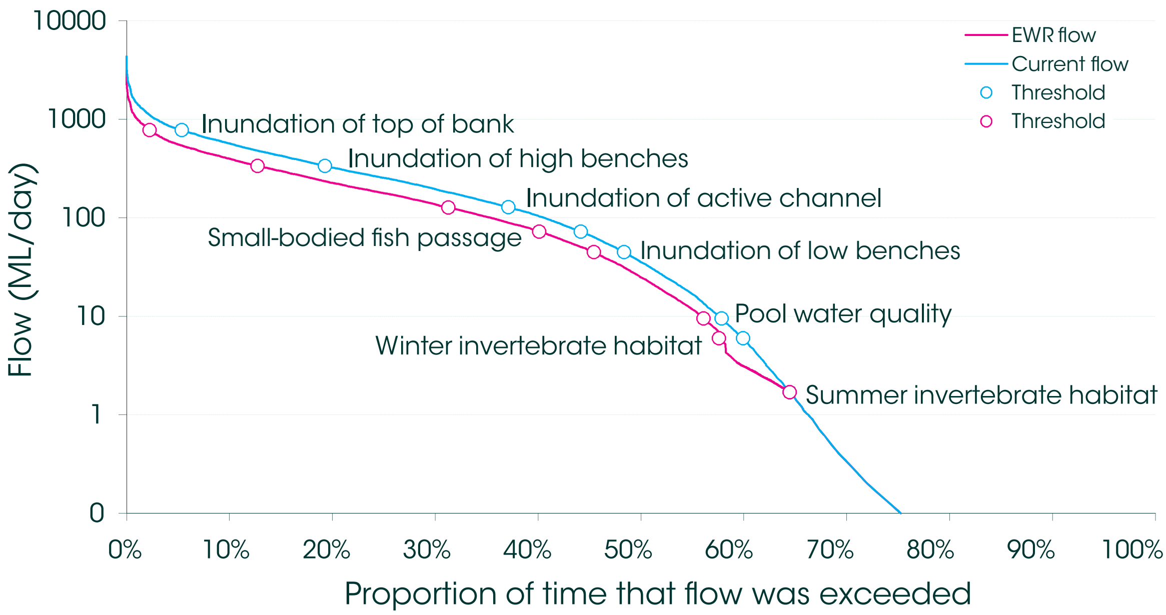


Figure 26

Flow duration curve for Reach 2 of the Margaret River, showing the current flow versus modelled EWR flow

The blue line is the current curve for the period 1975 to 2005 and the red curve is the modelled EWR over the same period (based on the parameters in Table 6)

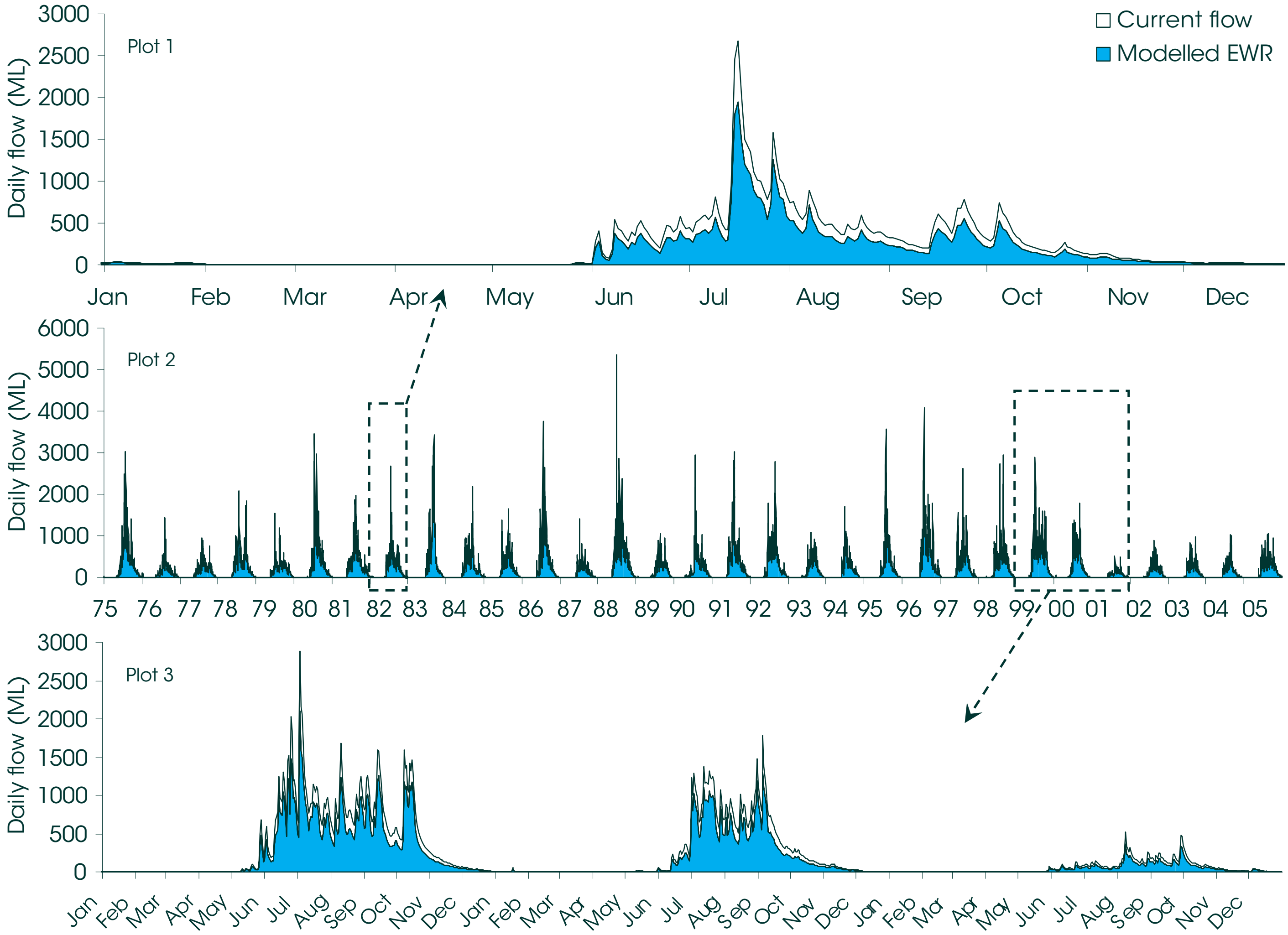


Figure 27

Time-series of the current flow and modelled EWR flow for Reach 1 of the Margaret River. Plot 1 shows the daily record for 1982, whereas Plot 2 is for the period 1975 to 2005 and Plot 3 is for the period 1999 to 2001

Data on the current flow and the modelled EWR for the period 1975 to 2005 for both study reaches are shown in appendices 9 (Reach 1) and 10 (Reach 2). Notice that between February and April of every year, the monthly flow volumes in the current flow tend to be reproduced exactly in the monthly EWR.

Over all the years on record (1975–2005), the annual volume of the EWR for Reach 1 averaged 74 per cent of the annual flow, and varied between 70 and 81 per cent. Reach 2 had an EWR of 70 per cent of annual flow for all the years on record (1975–2005) except in 1988 when the EWR was 71 per cent of annual flow. The average annual EWR for both study reaches is similar to that of other rivers in the south-west of Western Australia where the PADFLOW approach has been used, being around 60 to 70 per cent of total annual flow (e.g. Donohue et al. 2009a, 2009b).

Annual EWR flow volumes between 1975 and 2005 ranged from 15 to 117 GL in Reach 1 (Appendix 9), and 12 to 87 GL in Reach 2 (Appendix 10).

After consideration of the frequency and duration of ecologically functional flows in both the current and EWR flow, the expert panel concluded that the EWR flow regime for reaches 1 and 2 would maintain the ecological values of the Margaret River's middle and lower reaches at a low level of risk.

5.1 Future studies and monitoring

To confirm the accuracy of the modelled flow thresholds it is recommended that monitoring of each reach is conducted to confirm the relationship between flow, water depth and the ecological objectives. Monitoring is needed to test whether the recommended flows achieve the desired water levels predicted by the hydraulic model.

In the context of allocations of the resource, some monitoring would be needed to confirm that the flows remaining after licence allocations are consistent with the EWR in this report. This monitoring should consider the magnitiude, frequency and duration of flows in the recommended EWR (Section 5).

Reseach is required as resources are allocated to confirm that ecosystems and processes are being maintained in line with the objectives outlined in this report (e.g. changes in riparian vegetation or aquatic macroinvertebrate and native fish communities). These data would support an adaptive resource process that may require revision of the EWR or management actions in response to the results of monitoring.

Appendix 1

Macroinvertebrates of the Margaret River

Phylum	Subphylum	Class	Order	Family	Species
Nematoda					
					Nematoda spp.
Mollusca					
		Bivalvia	Unionoida	Hyriidae	*Westralunio carteri*
		Gastropoda	Hygrophila	Planorbidae	*Ferrissia petterdi*
Annelida					
		Oligochaeta			*Oligochaeta* spp.
Arthropoda					
	Crustacea	Malacostraca	Decapoda	Palaemonidae	*Palaemonetes australis*
			Amphipoda	Perthiidae	*Perthia* sp.
		Ostracoda			Ostracoda spp.
		Branchiopoda	Diplostraca		Cladocera spp.
		Maxillopoda	Calanoida		Calanoida spp.
			Cyclopoida		Cyclopoida spp.
	Chelicerata	Arachnida			Hydracarina spp.
	Uniramia	Insecta	Ephemeroptera	Caenidae	*Tasmanocoenis tillyardi*
					Caenidae sp.
				Baetidae	Baetidae spp.
				Leptophlebiidae	*Bibulmena kadjina*
					Leptophlebiidae spp.
			Plecoptera	Gripopterygidae	*Newmanoperla exigua*
			Odonata	Gomphidae	*Zephyrogomphus lateralis*
				Hemicorduliidae	Hemicorduliidae spp.
				Telephlebiidae	*Austroaeschna anacantha*
			Hemiptera	Corixidae	*Micronecta* sp.
			Coleoptera	Dytiscidae	*Allodessus bistrigatus*
					Limbodessus inornatus
					Necterosoma spp.
					Sternopriscus brownii
					Sternopriscus marginatus
					Sternopriscus minimus
					Sternopriscus multimaculatus
					Sternopriscus sp.
					Paracymus pygmaeus
			Diptera	Chironomidae	*Chironomidae* spp.
					Chironomus aff. Alternans
					Cladopelma curtivalva
					Dicrotendipes sp.
					Harrisius sp.
					Paracladopelma sp.
					Polypedilum sp.
					Polypedilum sp.

Appendix 1 continued

Macroinvertebrates of the Margaret River

Phylum	Subphylum	Class	Order	Family	Species
Arthropoda					
	Uniramia	Insecta	Diptera	Chironomidae	Rietha sp.
					Stenochironomus sp.
					Stenochironomus sp.
					Cladotanytarsus sp.
					Rheotanytarsus sp.
					Stempellina sp.
					Tanytarsus sp.
					Botryocladius bibulmun
					Cricotopus annuliventris
					Nanocladius sp.
					Parakiefferiella sp.
					Parakiefferiella sp. *(Nr. Variegatus)*
					Paralimnophyes sp.
					Thienemanniella sp.
					Unknown genus
					Unknown genus
					Ablabesmyia sp.
					Apsectrotanypus maculosus
					Coelopynia pruinosa
					Paramerina levidensis
					Procladius paludicola
				Ceratopogonidae	Ceratopogoninae spp.
					Dasyheleinae spp.
				Culicidae	Culicidae spp.
				Empididae	Empididae spp.
				Simuliidae	*Simulium ornatipes*
					Austrosimulium furiosum
					Austrosimulium bancrofti
					Simulidae spp.
					Simulidae spp.
			Trichoptera		Trichoptera spp.
				Hydroptilidae	*Acritoptila/hellyethira* spp.
				Leptoceridae	*Notalina* sp.
					Triplectides australis
					Leptoceridae spp.
			Lepidoptera	Pyralidae	Nymphulinae spp.

Source: WRM (2008).

Appendix 2

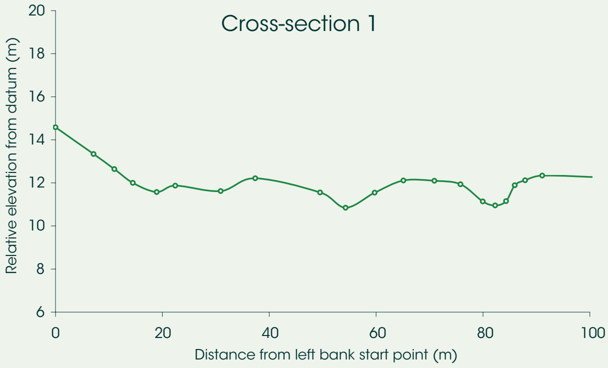
Expert panel members

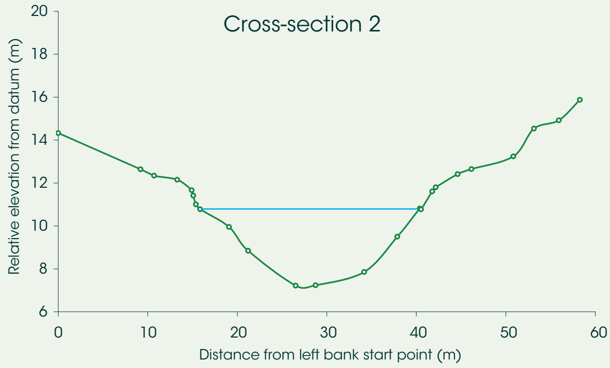
Dr Andrew Storey	Principal Ecologist - Wetland Research and Management
Mr Robert Donohue	Ecologist - Department of Water
Ms Katherine Bennett	Ecologist - Department of Water
Ms Jessica Lynas	Ecologist - Wetland Research and Management

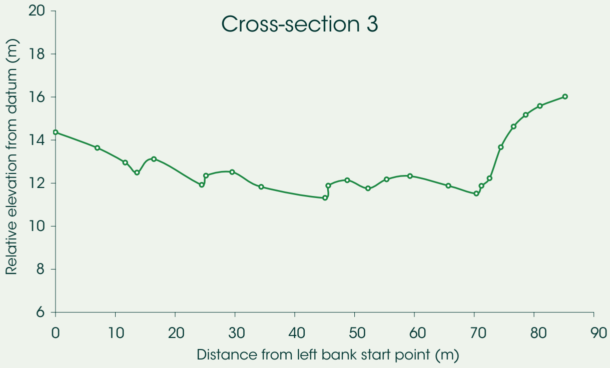
Appendix 3

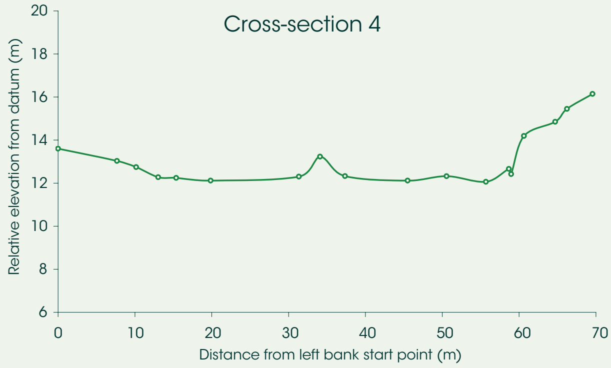
Channel cross-sections from Reach 1 of the Margaret River

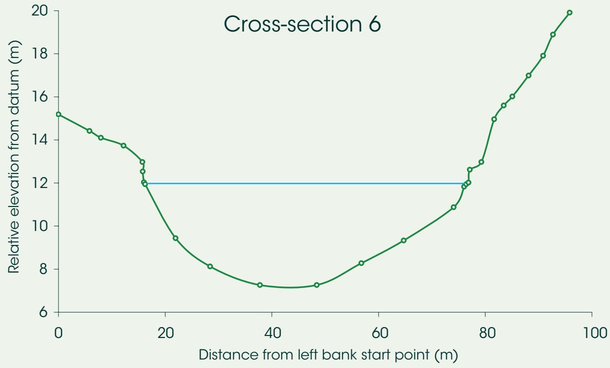
Survey channel profiles for cross-sections 1 to 15. The blue line shows the water level at each cross-section at the time of survey. Note the differences in scale on the horizontal axes.

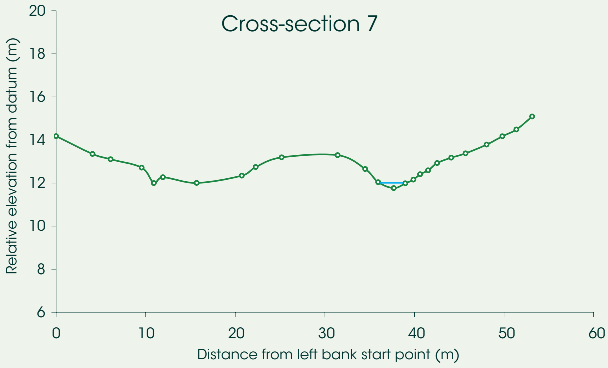


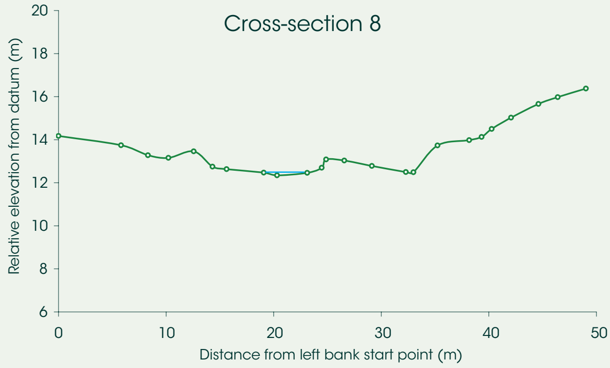








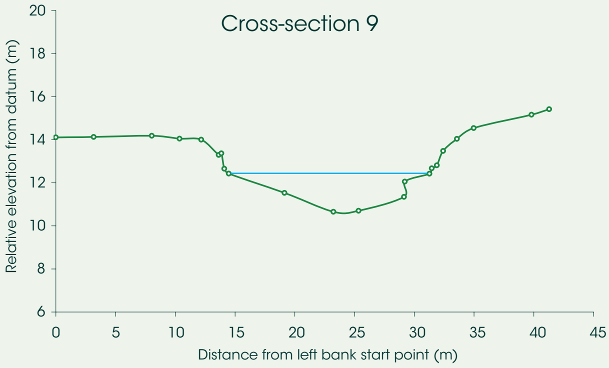


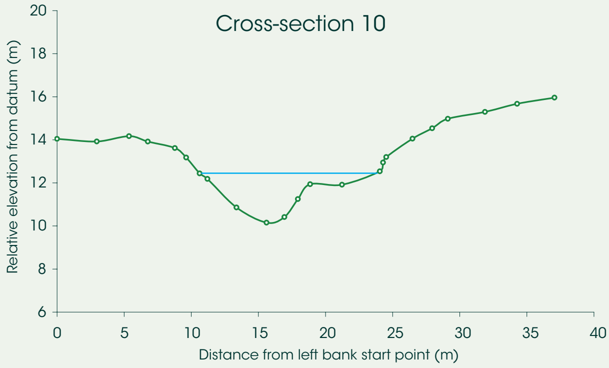


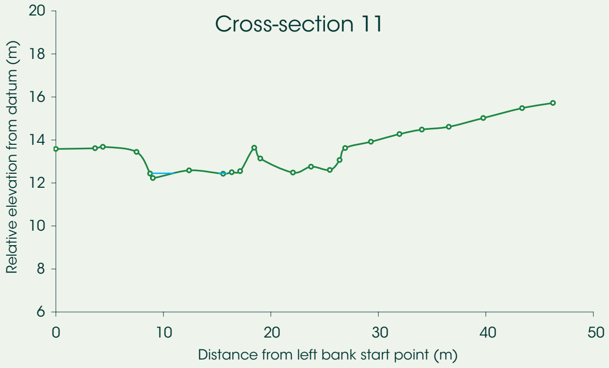
Appendix 3 continued

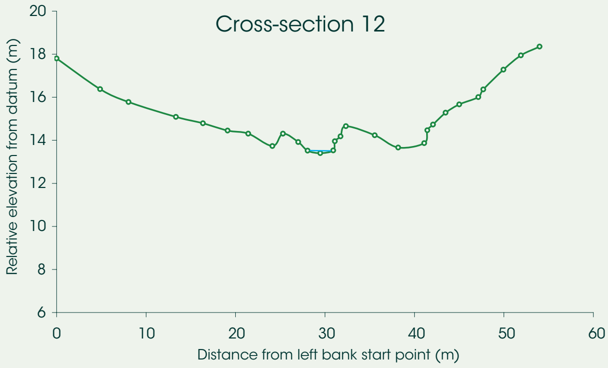
Channel cross-sections from Reach 1 of the Margaret River

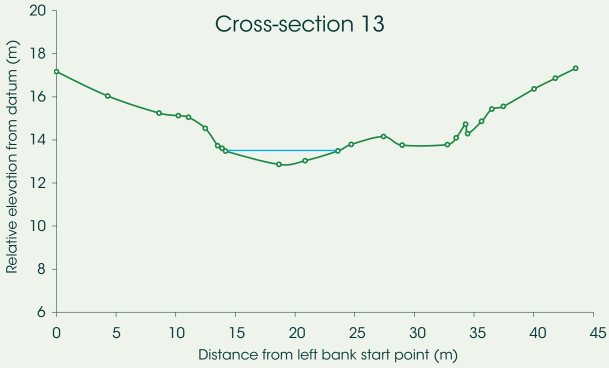
Survey channel profiles for cross-sections 1 to 15. The blue line shows the water level at each cross-section at the time of survey. Note the differences in scale on the horizontal axes.

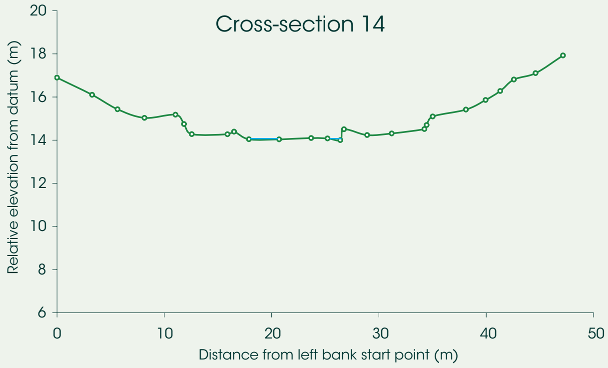


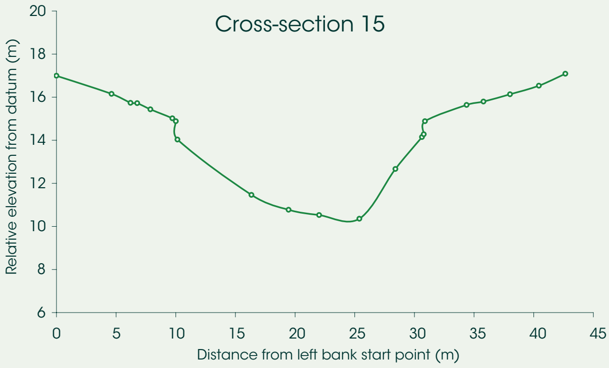








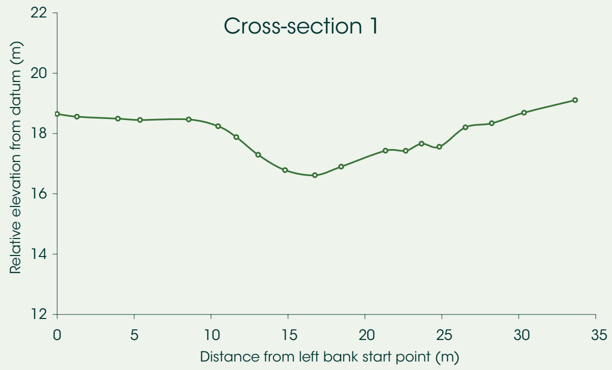


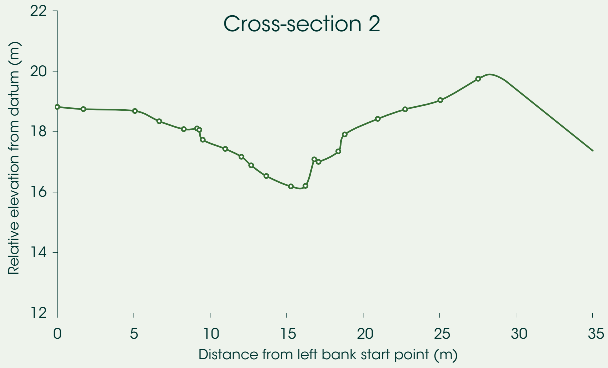


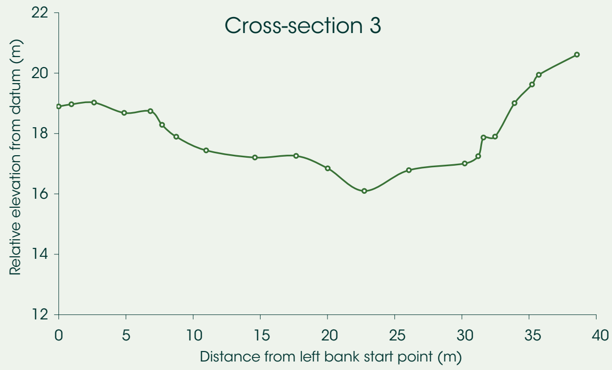
Appendix 4

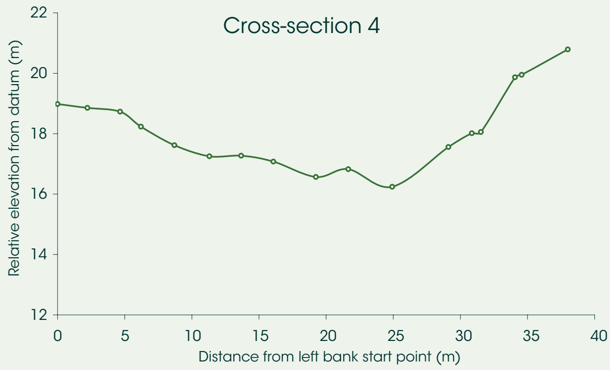
Channel cross-sections from Reach 2 of the Margaret River

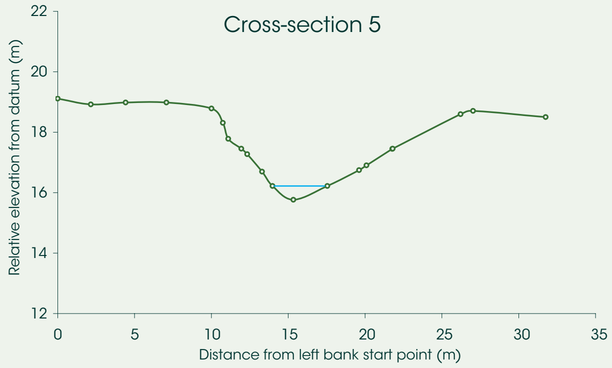
Survey channel profiles for cross-sections 1 to 13. The blue line shows the water level at each cross-section at the time of survey. Note the differences in scale on the horizontal axes.

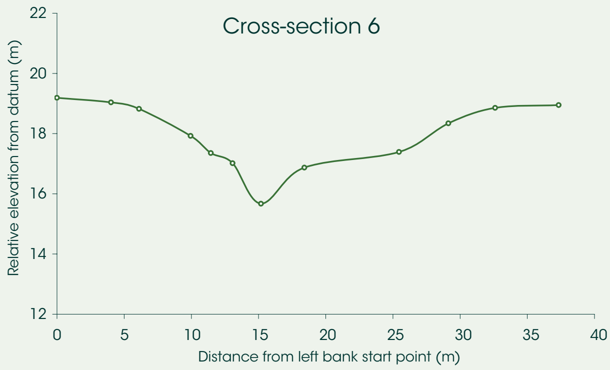


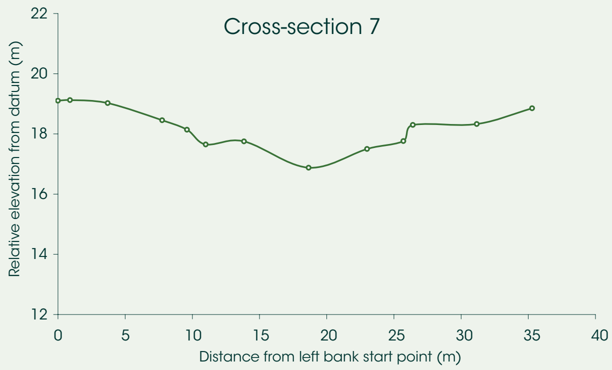


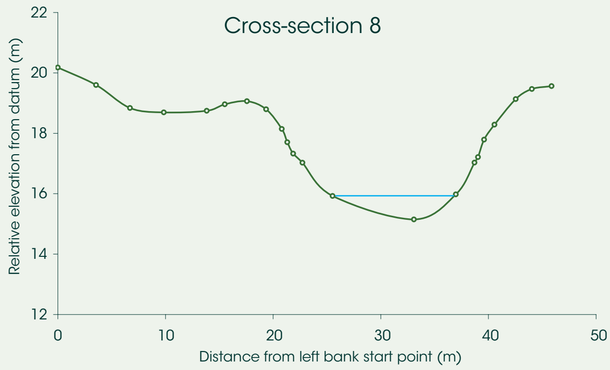








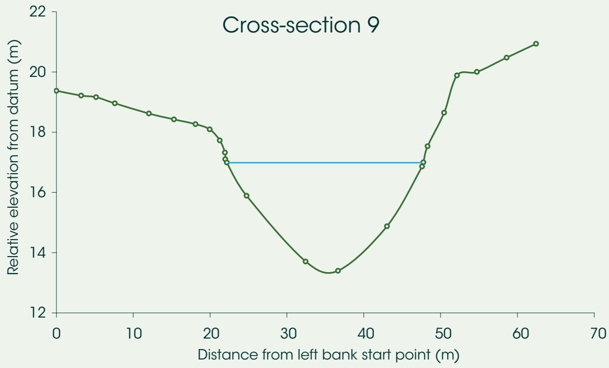


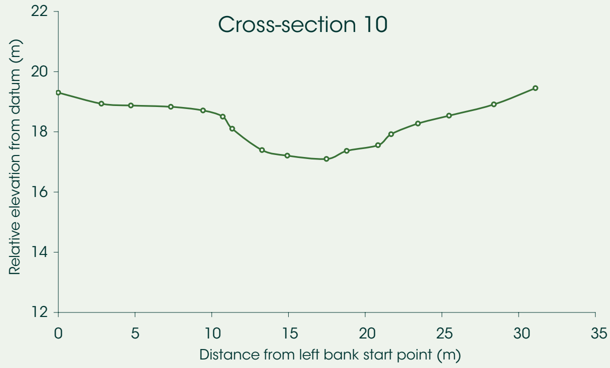


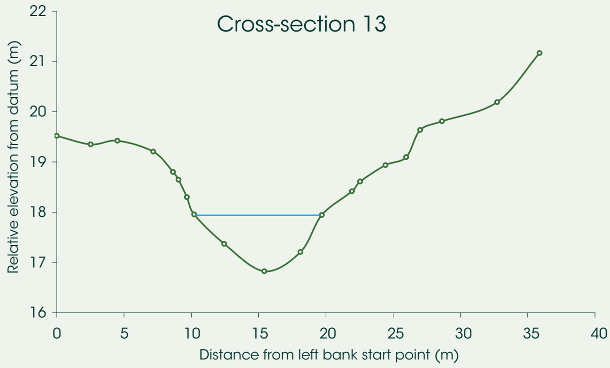
Appendix 4 continued

Channel cross-sections from Reach 2 of the Margaret River

Survey channel profiles for cross-sections 1 to 13. The blue line shows the water level at each cross-section at the time of survey. Note the differences in scale on the horizontal axes.

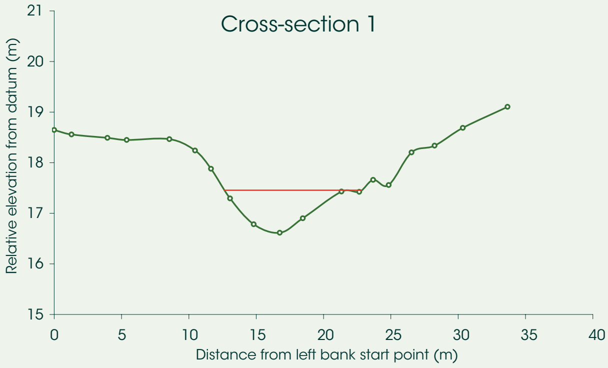


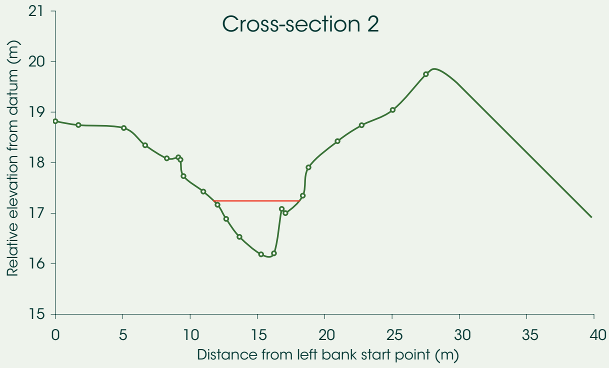


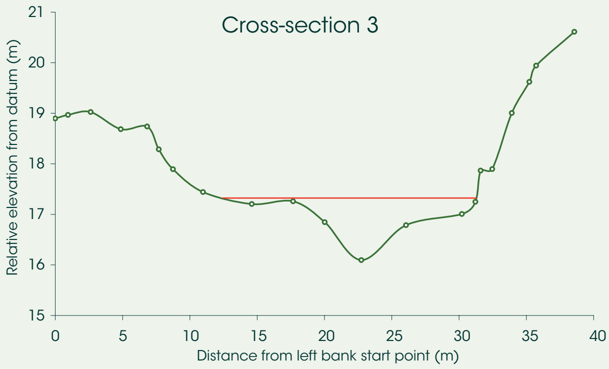


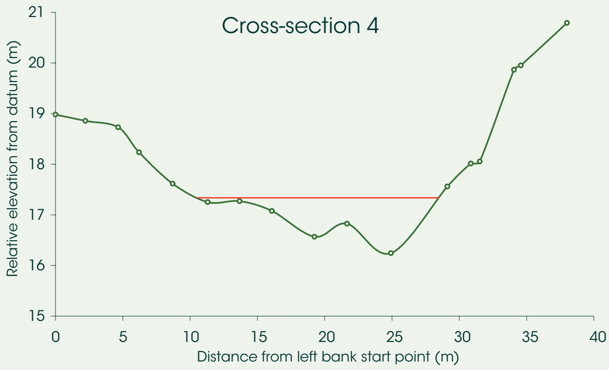
Appendix 5

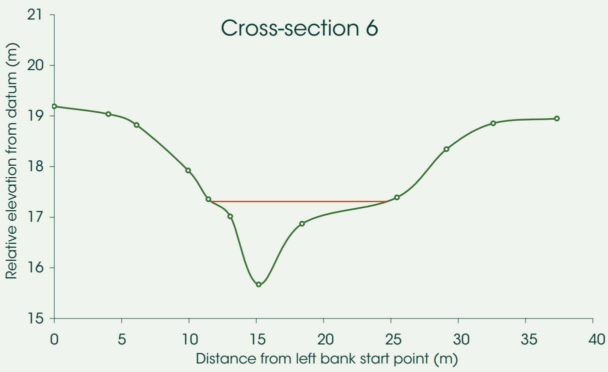
Winter high flows required to inundate low benches in Reach 2 of the Margaret River





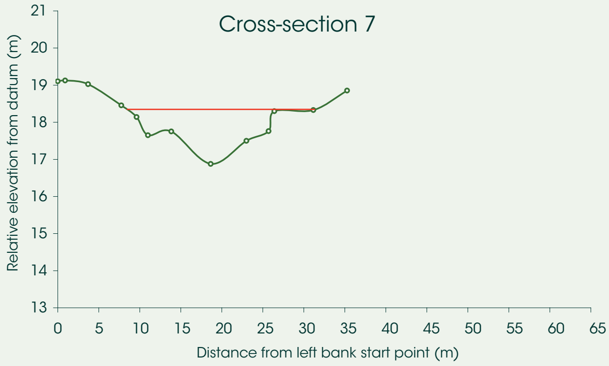


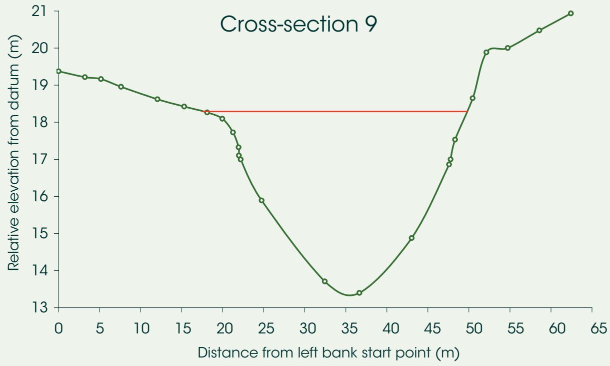




Appendix 6

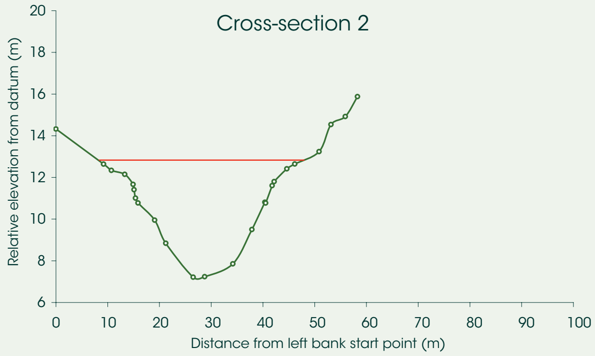
Winter high flows required to inundate high benches in Reach 2 of the Margaret River

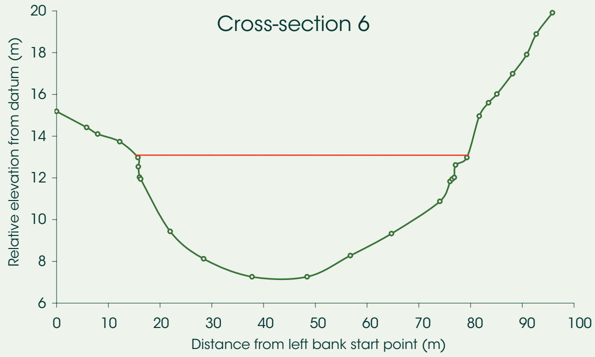


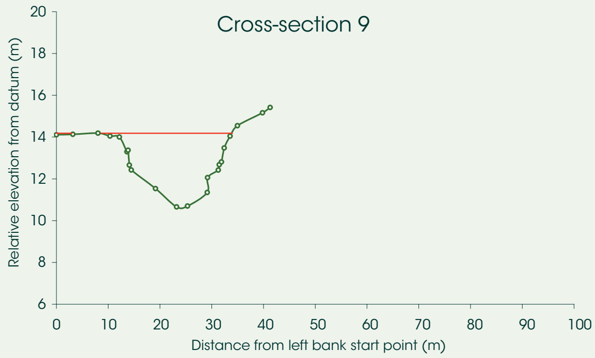


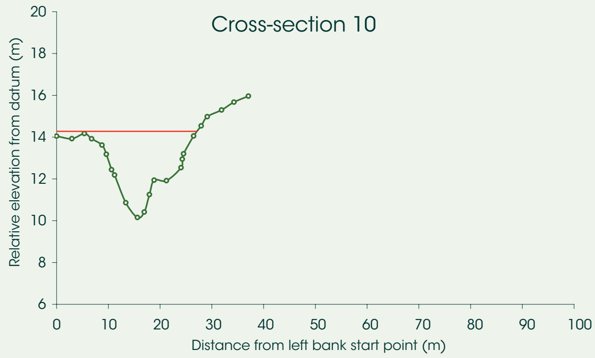
Appendix 7

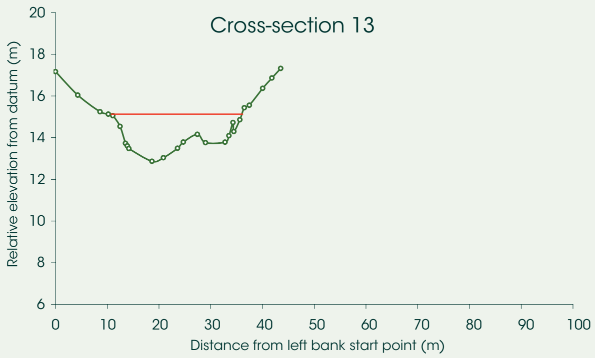
Winter high flows required to achieve a bankfull flow in Reach 1 of the Margaret River

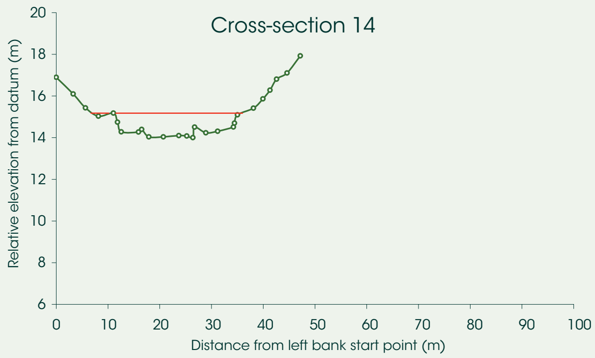


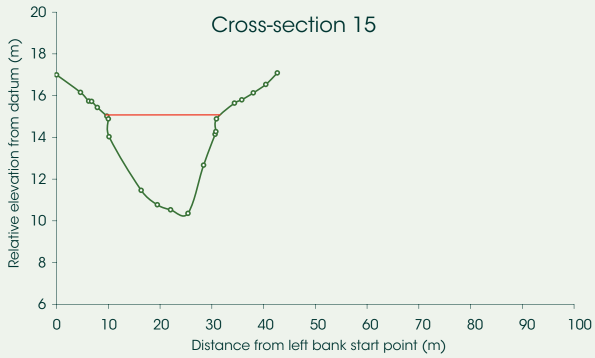












Appendix 8

Winter high flows required to achieve a bankfull flow in Reach 2 of the Margaret River

Appendix 9

Monthly flow and EWR for Reach 1 of the Margaret River (1975–2005)

All data in the table below are given in GL.

Year	Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1975	Flow	0.20	0.01	0.01	0.04	1.81	14.26	42.48	30.62	18.31	10.53	4.16	0.97	123
	EWR	0.12	0.01	0.01	0.04	1.26	10.53	35.17	23.75	13.34	7.37	2.92	0.67	95
1976	Flow	0.74	0.03	0.01	0.06	1.04	2.72	7.49	16.18	6.18	3.73	2.62	0.49	41
	EWR	0.51	0.03	0.01	0.04	0.72	1.91	5.24	11.87	4.33	2.61	1.83	0.33	29
1977	Flow	0.02	0.00	0.00	0.00	0.93	4.96	8.89	16.70	6.63	10.28	2.94	0.38	52
	EWR	0.02	0.00	0.00	0.00	0.65	3.47	6.22	11.97	4.64	7.20	2.06	0.26	37
1978	Flow	0.01	0.00	0.00	0.00	2.15	12.30	24.90	13.64	22.34	15.35	3.92	0.91	96
	EWR	0.01	0.00	0.00	0.00	1.50	8.98	19.23	9.63	16.85	11.57	2.74	0.62	71
1979	Flow	0.07	0.01	0.01	0.03	1.09	7.92	11.68	12.64	10.65	8.62	4.92	1.16	59
	EWR	0.06	0.01	0.01	0.03	0.77	5.85	8.17	9.17	7.46	6.03	3.45	0.81	42
1980	Flow	0.07	0.01	0.00	0.05	0.43	8.51	42.35	32.24	17.29	12.39	4.52	1.61	119
	EWR	0.05	0.01	0.00	0.04	0.28	5.96	35.75	25.41	12.19	8.67	3.16	1.13	93
1981	Flow	0.23	0.00	0.01	0.04	1.48	9.26	17.63	34.04	18.09	8.93	7.05	2.57	99
	EWR	0.16	0.00	0.01	0.04	1.04	6.48	13.35	27.19	12.87	6.25	4.93	1.80	74
1982	Flow	0.68	0.04	0.00	0.00	0.14	10.44	30.69	15.92	12.21	8.83	2.33	0.66	82
	EWR	0.46	0.03	0.00	0.00	0.10	7.31	24.41	11.24	8.54	6.18	1.63	0.45	60
1983	Flow	0.09	0.01	0.00	0.00	0.01	3.59	15.87	36.89	44.61	7.53	2.80	0.39	112
	EWR	0.06	0.01	0.00	0.00	0.01	2.51	11.92	30.42	37.62	5.27	1.96	0.26	90
1984	Flow	0.03	0.00	0.00	0.01	0.30	4.70	14.98	18.65	21.81	5.78	6.33	1.37	74
	EWR	0.02	0.00	0.00	0.01	0.22	3.29	10.76	13.63	16.64	4.04	4.43	0.96	54
1985	Flow	0.35	0.00	0.00	0.01	0.11	7.74	12.58	23.32	15.83	6.39	3.11	0.40	70
	EWR	0.24	0.00	0.00	0.01	0.08	5.55	8.80	17.50	11.17	4.48	2.18	0.26	50
1986	Flow	0.01	0.00	0.00	0.00	2.75	9.83	37.08	39.82	16.40	8.43	2.63	0.41	117
	EWR	0.01	0.00	0.00	0.00	1.93	7.49	30.41	32.17	11.48	5.90	1.84	0.28	92
1987	Flow	0.01	0.00	0.00	0.01	0.07	5.23	13.53	11.88	6.98	3.25	1.32	0.18	42
	EWR	0.01	0.00	0.00	0.01	0.05	3.66	9.70	8.32	4.88	2.27	0.92	0.12	30
1988	Flow	0.01	0.00	0.00	0.00	2.03	35.02	35.83	33.52	21.97	15.28	5.87	1.00	151
	EWR	0.01	0.00	0.00	0.00	1.42	28.99	28.67	26.78	15.94	10.79	4.11	0.69	117
1989	Flow	0.15	0.02	0.03	0.01	0.30	1.32	9.93	13.19	10.25	13.56	2.84	0.26	52
	EWR	0.09	0.02	0.02	0.01	0.20	0.92	7.04	9.34	7.17	9.76	1.99	0.17	37
1990	Flow	0.02	0.00	0.00	0.40	1.32	3.69	25.12	23.57	13.84	9.30	5.16	0.79	83
	EWR	0.02	0.00	0.00	0.28	0.93	2.58	20.15	17.25	9.88	6.51	3.61	0.54	62
1991	Flow	0.04	0.00	0.00	0.00	0.72	16.61	32.78	32.60	20.26	8.36	5.15	1.07	118
	EWR	0.03	0.00	0.00	0.00	0.50	12.00	26.34	26.00	14.99	5.85	3.60	0.75	90
1992	Flow	0.09	0.00	0.00	0.01	1.65	15.63	24.27	31.54	25.72	7.75	4.52	1.57	113
	EWR	0.06	0.00	0.00	0.01	1.14	11.77	18.25	24.98	19.65	5.42	3.16	1.10	86
1993	Flow	0.11	0.00	0.00	0.02	0.29	0.92	10.47	17.80	18.28	9.13	2.25	0.23	60
	EWR	0.07	0.00	0.00	0.02	0.20	0.63	7.33	12.93	12.89	6.39	1.58	0.15	42
1994	Flow	0.00	0.00	0.00	0.00	0.23	9.44	24.43	13.07	7.70	4.46	0.73	0.02	60
	EWR	0.00	0.00	0.00	0.00	0.16	6.70	18.36	9.15	5.39	3.12	0.50	0.02	43
1995	Flow	0.00	0.00	0.00	0.00	0.06	4.85	29.24	27.85	15.70	6.33	2.45	0.42	87
	EWR	0.00	0.00	0.00	0.00	0.05	3.40	24.01	21.43	11.38	4.43	1.72	0.27	67
1996	Flow	0.02	0.00	0.00	0.00	0.00	2.73	33.19	43.59	31.18	19.08	6.48	4.93	141
	EWR	0.02	0.00	0.00	0.00	0.00	1.91	27.15	35.98	24.45	14.18	4.54	3.45	112
1997	Flow	0.39	0.00	0.00	0.00	0.19	11.25	12.53	31.96	24.86	7.70	2.79	0.65	92
	EWR	0.26	0.00	0.00	0.00	0.13	8.22	8.86	25.35	18.73	5.39	1.96	0.45	69
1998	Flow	0.01	0.00	0.08	0.04	0.47	14.22	14.78	30.17	25.61	12.13	3.19	0.75	101
	EWR	0.01	0.00	0.05	0.04	0.32	10.44	10.89	24.08	19.69	8.49	2.23	0.51	77

Appendix 9 continued

Monthly flow and EWR for Reach 1 of the Margaret River (1975–2005)

All data in the table below are given in GL.

Year	Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1999	Flow	0.04	0.00	0.00	0.00	2.82	25.62	33.84	26.68	25.73	23.54	4.24	0.99	143
	EWR	0.03	0.00	0.00	0.00	1.98	20.28	27.14	20.11	19.43	17.91	2.97	0.69	111
2000	Flow	0.16	0.00	0.00	0.01	0.18	4.65	31.01	24.53	20.75	5.91	1.92	0.21	89
	EWR	0.11	0.00	0.00	0.01	0.12	3.24	24.19	18.33	15.57	4.13	1.35	0.14	67
2001	Flow	0.00	0.00	0.00	0.00	0.22	1.74	2.55	5.84	5.78	3.72	0.67	0.41	21
	EWR	0.00	0.00	0.00	0.00	0.15	1.22	1.78	4.09	4.04	2.60	0.45	0.28	15
2002	Flow	0.00	0.00	0.00	0.00	0.24	1.59	7.52	12.07	10.40	5.46	2.54	0.17	40
	EWR	0.00	0.00	0.00	0.00	0.15	1.11	5.26	8.54	7.28	3.82	1.78	0.11	28
2003	Flow	0.00	0.00	0.00	0.00	0.02	2.06	8.83	13.56	12.77	6.69	1.93	0.22	46
	EWR	0.00	0.00	0.00	0.00	0.02	1.43	6.18	9.49	9.13	4.68	1.35	0.15	32
2004	Flow	0.00	0.00	0.00	0.00	0.04	4.59	8.90	16.78	8.08	3.62	1.13	0.17	43
	EWR	0.00	0.00	0.00	0.00	0.03	3.21	6.23	12.23	5.65	2.54	0.79	0.11	31
2005	Flow	0.00	0.00	0.00	0.00	1.14	9.67	12.46	14.50	13.53	12.30	4.49	1.35	69
	EWR	0.00	0.00	0.00	0.00	0.80	6.77	8.81	10.45	9.47	8.70	3.14	0.94	49

Appendix 10

Monthly flow and EWR for Reach 2 of the Margaret River (1975–2005)

All data in the table below are given in GL.

Year	Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1975	Flow	0.16	0.01	0.01	0.03	1.48	11.63	34.64	24.97	14.93	8.58	3.40	0.79	101
	EWR	0.10	0.01	0.01	0.03	1.03	8.14	24.25	17.48	10.45	6.01	2.38	0.54	70
1976	Flow	0.61	0.02	0.00	0.04	0.85	2.22	6.11	13.20	5.04	3.04	2.14	0.40	34
	EWR	0.42	0.02	0.00	0.04	0.60	1.55	4.27	9.24	3.53	2.13	1.50	0.27	24
1977	Flow	0.02	0.00	0.00	0.00	0.76	4.05	7.25	13.62	5.40	8.38	2.40	0.31	42
	EWR	0.02	0.00	0.00	0.00	0.53	2.83	5.07	9.53	3.78	5.87	1.68	0.21	30
1978	Flow	0.01	0.00	0.00	0.00	1.75	10.03	20.30	11.12	18.22	12.52	3.19	0.74	78
	EWR	0.01	0.00	0.00	0.00	1.22	7.02	14.21	7.78	12.75	8.76	2.24	0.51	55
1979	Flow	0.06	0.01	0.01	0.02	0.89	6.46	9.52	10.31	8.69	7.03	4.02	0.95	48
	EWR	0.05	0.01	0.01	0.02	0.63	4.52	6.66	7.22	6.08	4.92	2.81	0.66	34
1980	Flow	0.06	0.01	0.00	0.04	0.35	6.94	34.54	26.29	14.10	10.10	3.69	1.31	97
	EWR	0.04	0.01	0.00	0.03	0.23	4.86	24.18	18.40	9.87	7.07	2.58	0.92	68
1981	Flow	0.19	0.00	0.01	0.03	1.21	7.55	14.38	27.76	14.76	7.28	5.75	2.10	81
	EWR	0.13	0.00	0.01	0.03	0.85	5.29	10.07	19.43	10.33	5.09	4.02	1.47	57
1982	Flow	0.55	0.03	0.00	0.00	0.12	8.51	25.03	12.99	9.95	7.20	1.90	0.54	67
	EWR	0.38	0.02	0.00	0.00	0.08	5.96	17.52	9.09	6.97	5.04	1.33	0.37	47
1983	Flow	0.08	0.01	0.00	0.00	0.01	2.93	12.94	30.08	36.38	6.14	2.29	0.32	91
	EWR	0.05	0.01	0.00	0.00	0.01	2.05	9.06	21.06	25.46	4.30	1.60	0.22	64
1984	Flow	0.03	0.00	0.00	0.00	0.25	3.84	12.21	15.21	17.78	4.71	5.16	1.11	60
	EWR	0.02	0.00	0.00	0.00	0.18	2.68	8.55	10.64	12.45	3.30	3.61	0.78	42
1985	Flow	0.29	0.00	0.00	0.00	0.09	6.31	10.26	19.01	12.91	5.21	2.53	0.32	57
	EWR	0.20	0.00	0.00	0.00	0.07	4.42	7.18	13.31	9.03	3.65	1.77	0.20	40
1986	Flow	0.01	0.00	0.00	0.00	2.24	8.02	30.24	32.47	13.38	6.87	2.15	0.34	96
	EWR	0.01	0.00	0.00	0.00	1.57	5.61	21.17	22.73	9.36	4.81	1.50	0.23	67
1987	Flow	0.01	0.00	0.00	0.00	0.06	4.27	11.03	9.69	5.69	2.65	1.08	0.14	35
	EWR	0.01	0.00	0.00	0.00	0.04	2.99	7.72	6.78	3.98	1.85	0.75	0.10	24
1988	Flow	0.00	0.00	0.00	0.00	1.66	28.56	29.22	27.34	17.91	12.46	4.79	0.82	123
	EWR	0.00	0.00	0.00	0.00	1.16	21.30	20.45	19.14	12.54	8.72	3.35	0.56	87
1989	Flow	0.12	0.02	0.02	0.01	0.24	1.08	8.10	10.76	8.36	11.06	2.32	0.22	42
	EWR	0.09	0.01	0.02	0.01	0.17	0.75	5.67	7.53	5.85	7.74	1.62	0.14	30
1990	Flow	0.01	0.00	0.00	0.33	1.08	3.01	20.49	19.22	11.29	7.58	4.21	0.64	68
	EWR	0.01	0.00	0.00	0.23	0.76	2.10	14.34	13.46	7.90	5.31	2.95	0.44	47
1991	Flow	0.03	0.00	0.00	0.00	0.58	13.54	26.73	26.58	16.52	6.82	4.20	0.88	96
	EWR	0.02	0.00	0.00	0.00	0.41	9.48	18.71	18.61	11.57	4.77	2.94	0.61	67
1992	Flow	0.07	0.00	0.00	0.01	1.34	12.74	19.79	25.72	20.98	6.32	3.69	1.28	92
	EWR	0.05	0.00	0.00	0.01	0.93	8.92	13.86	18.00	14.68	4.42	2.58	0.90	64
1993	Flow	0.09	0.00	0.00	0.01	0.23	0.75	8.54	14.52	14.91	7.45	1.84	0.19	49
	EWR	0.06	0.00	0.00	0.01	0.17	0.51	5.98	10.16	10.43	5.21	1.29	0.12	34
1994	Flow	0.00	0.00	0.00	0.00	0.19	7.70	19.92	10.66	6.28	3.64	0.60	0.02	49
	EWR	0.00	0.00	0.00	0.00	0.13	5.39	13.94	7.46	4.39	2.55	0.41	0.02	34
1995	Flow	0.00	0.00	0.00	0.00	0.05	3.96	23.84	22.71	12.80	5.16	2.00	0.34	71
	EWR	0.00	0.00	0.00	0.00	0.04	2.77	16.69	15.90	8.96	3.61	1.40	0.21	50
1996	Flow	0.02	0.00	0.00	0.00	0.00	2.22	27.07	35.55	25.42	15.56	5.29	4.02	115
	EWR	0.02	0.00	0.00	0.00	0.00	1.56	18.95	24.88	17.80	10.89	3.70	2.81	81
1997	Flow	0.31	0.00	0.00	0.00	0.15	9.17	10.22	26.07	20.28	6.28	2.28	0.53	75
	EWR	0.22	0.00	0.00	0.00	0.11	6.42	7.15	18.25	14.19	4.39	1.59	0.37	53
1998	Flow	0.00	0.00	0.06	0.03	0.38	11.59	12.05	24.60	20.89	9.89	2.60	0.61	83
	EWR	0.00	0.00	0.04	0.03	0.26	8.12	8.44	17.22	14.62	6.92	1.82	0.41	58

Monthly flow and EWR for Reach 2 of the Margaret River (1975–2005)

All data in the table below are given in GL.

Year	Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1999	Flow	0.03	0.00	0.00	0.00	2.30	20.89	27.60	21.75	20.98	19.20	3.46	0.81	117
	EWR	0.03	0.00	0.00	0.00	1.61	14.62	19.32	15.23	14.69	13.44	2.42	0.56	82
2000	Flow	0.13	0.00	0.00	0.01	0.15	3.79	25.29	20.00	16.92	4.82	1.57	0.17	73
	EWR	0.10	0.00	0.00	0.01	0.09	2.65	17.70	14.00	11.84	3.37	1.10	0.12	51
2001	Flow	0.00	0.00	0.00	0.00	0.18	1.42	2.08	4.76	4.71	3.03	0.55	0.33	17
	EWR	0.00	0.00	0.00	0.00	0.13	0.99	1.45	3.33	3.30	2.12	0.37	0.23	12
2002	Flow	0.00	0.00	0.00	0.00	0.19	1.29	6.13	9.84	8.48	4.45	2.07	0.14	33
	EWR	0.00	0.00	0.00	0.00	0.12	0.90	4.29	6.89	5.94	3.12	1.45	0.09	23
2003	Flow	0.00	0.00	0.00	0.00	0.02	1.68	7.20	11.06	10.42	5.45	1.58	0.18	38
	EWR	0.00	0.00	0.00	0.00	0.02	1.16	5.04	7.74	7.29	3.82	1.10	0.12	26
2004	Flow	0.00	0.00	0.00	0.00	0.03	3.75	7.26	13.68	6.59	2.96	0.92	0.14	35
	EWR	0.00	0.00	0.00	0.00	0.02	2.62	5.08	9.58	4.61	2.07	0.64	0.10	25
2005	Flow	0.00	0.00	0.00	0.00	0.93	7.89	10.16	11.83	11.04	10.03	3.66	1.10	57
	EWR	0.00	0.00	0.00	0.00	0.65	5.52	7.12	8.28	7.72	7.02	2.56	0.77	40

Shortened forms

ARL	Aquatic Research Laboratory
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CCG	Cape to Cape Catchments Group
DEC	Department of Environment and Conservation
DoW	Department of Water
EWR	ecological water requirement
HEC-RAS	Hydrological Engineering Center, United States Army Corps of Engineers, River Analysis System
PADFLOW	Proportional Abstraction of Daily Flows (approach)
RAP	River Analysis Package
RESYM	River Ecologically Sustainable Yield Model
WRC	Water and Rivers Commission
WRM	Wetland Research and Management

Glossary

Abstraction	The permanent or temporary withdrawal of water from any source of supply, so that it is no longer part of the resources of the locality.
Aquifer	A geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water. Usually described by whether they consist of sedimentary deposits (sand and gravel) or fractured rock.
Bankfull	Refers to a discharge of a river that completely fills its channel and the elevation of the water surface coincides with the bank margins. Any further rise in water level would cause water to move into the floodplain.
Biodiversity	Biological diversity or the variety of organisms, including species themselves, genetic diversity and the assemblages they form (communities and ecosystems). Sometimes includes the variety of ecological processes within those communities and ecosystems.
Biomass	The total mass of living matter in a given unit area.
Biota	All the plant and animal life of a particular region.
Carbon cycle	The circulation of carbon through the ecosystem.
Catchment	Area of land from which rainfall runoff contributes to a single watercourse, wetland or aquifer.
Climate change	A change of climate attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.
Current flow	Refers to the post-development flow record (1975–2005) for reaches 1 and 2 of the Margaret River.
Diapause	A physiological state of dormancy with very specific triggering and release conditions.
Ecological water requirement	Water regime needed to maintain the ecological values (including assets, functions and processes) of water-dependent ecosystems at a low level of risk.
Ecosystem	A community or assemblage of communities of organisms, interacting with one another, and the specific environment in which they live and with which they also interact, e.g. a lake. Includes all the biological, chemical and physical resources and the interrelationships and dependencies that occur between those resources.
Environment	Living things, their physical, biological and social surroundings, and the interactions between them.
Flow	Streamflow in terms of m^3/yr, m^3/d or ML/yr. Also known as discharge.
Food web	Describes the eating relationships between species within an ecosystem.
Gravid	Bearing eggs or embryos; pregnant.
Groundwater	Water that occupies the pores and crevices of rock or soil beneath the land surface.
Natural flows paradigm	A belief amongst ecologists that the natural regime of flow is responsible for the evolution of the observed ecological state of a river.
Piscivorous	Fish eating.
Riffle	A shallow area of a stream where water flows rapidly over a rocky or gravelly stream bed causing rippling of the water's surface or small waves.
Surface water	Water flowing or held in streams, rivers and other wetlands on the surface of the landscape.
Terrestrial	Lives on the land.
Thalweg	The line joining the lowest points of successive cross-sections of a channel. Usually associated with the path of highest velocity.
Water-dependent ecosystems	Those parts of the environment that are sustained by the permanent or temporary presence of water.
Water regime	A description of the variation of flow rate or water level over time. It may also include a description of water quality.

References

Aquatic Research Laboratory 1989, *Canning Reservoir catchment; lower Canning River catchment; Serpentine/Gooralong Brook catchments; Dirk Brook catchment; North Dandalup Pipehead Dam catchment results and recommendations 1988*, Stream fauna study, Aquatic Research Laboratory, University of Western Australia, report to the Water Authority of Western Australia.

Beard, JS 1990, *Plantlife of Western Australia*, Kangaroo Press Pty Ltd, Kenthurst.

Beatty, SJ, McAleer, FJ & Morgan, DL 2008, *Interannual variation in fish migration patterns and habitats of the Blackwood River and its tributaries: annual progress report*, report prepared for the Department of Water by the Centre for Fish and Fisheries Research, Murdoch University, Perth.

Beatty S, Morgan D, Jury C & Mitchell J 2006, *Fish and freshwater crayfish in streams in the Cape Naturaliste region and Wilyabrup Brook*, unpublished report prepared for the Cape to Cape Catchments Group and GeoCatch.

Bennett, K & Donohue, R 2009, *Methods used to estimate total surface water use and agricultural demand in the Whicher area*, Department of Water, Government of Western Australia, Perth.

Bunn SE, Edward DHD & Loneragan NR 1986, 'Spatial and temporal variation in the macroinvertebrate fauna of streams of the northern jarrah forest, Western Australia: community structure', *Freshwater Biology, 16: 67–91.*

Bunn SE, Davies PM & Edward DHD 1989, 'The association of *Glacidorbis occidentalis* Bunn & Stoddart (Gastropoda: Glacidorbidae) with intermittently-flowing forest streams in south-western Australia', *Journal of the Malacology Society of Australia,* 10: 25–34.

Cape to Cape Catchments Group 2003, *Margaret River action plan*, Water and Rivers Commission, Perth.

— 2008, *Cowaramup creeks action plan*, Perth.

Cogger, HG 2000, *Reptiles and amphibians of Australia.* Reed New Holland, Sydney.

Coppolina, M 2006, *Margaret River hydrology summary*, unpublished report, Water Resource Management division, Department of Water, Perth.

Crossley, K 2007, *Margaret River hydrology summary*, unpublished report, Water Resource Management division, Surface Water Assessment section, Department of Water, Perth.

Commonwealth Scientific and Industrial Research Organisation 2001, *Climate change scenarios for the Australian region*, Climate Impact Group: CSIRO Division of Atmospheric Research.

— 2005, *Augusta-Margaret River regional profile*, unpublished report by Resource Futures Program, CSIRO Sustainable Ecosystems.

Department of Environment and Conservation 2005, *Margaret River catchment area (including Ten Mile Brook catchment) drinking water source protection plan*, unpublished report, Water Resources division, Department of Environment and Conservation, Western Australia. Water resource protection series, report WRP 53.

Department of Water 2009, *Whicher area surface water allocation plan,* Water Allocation Planning branch, Department of Water, Government of Western Australia, Perth.

Donohue, R, Moulden, B, Bennett, K & Green, A 2009a, *Ecological water requirements for Lefroy Brook*, Environmental water report series, Report no. 6, Department of Water, Government of Western Australia.

Donohue, R, Green, A, Bennett, K, Pauli, N, Lynas, J & Storey, A 2009b, *Ecological water requirements of the Brunswick River*, Environmental water report series, Report no. 7, Department of Water, Government of Western Australia.

Humphries, P, Davies, PE & Mulcahy, ME 1996, 'Macroinvertebrate assemblages of littoral habitats in the Macquarie and Mersey rivers, Tasmania: implications for management of regulated rivers', *Regulated Rivers: Research and Management*, 12: 99–122.

Kay, WR, Halse, SA, Scanlon, MD & Smith, MJ 2001, 'Distribution and environmental tolerances of aquatic macroinvertebrate families in the agricultural zone of south-western Australia', *Journal of the North American Benthological Society*, 20: 182–199.

Marnham, JR, Hall, GJ, & Langford, RL 2000, *Regolith-landform resources of the Cowaramup-Mentelle 1:50 000 sheet*, Western Australia Geological Survey, Record 2000/18.

Molony, BW, Wilkinson, IS & Montes, B 2004, *Draft interim recovery plan for Cherax tenuimanus Smith*, unpublished report, Western Australian Department of Conservation and Land Management.

Morgan, DL & Beatty, SJ 2005, *Baseline study on the fish and freshwater crayfish fauna in the Blackwood River and its tributaries receiving discharge from the Yarragadee aquifer*, unpublished report for the Department of Environment by the Centre for Fish and Fisheries Research, Murdoch University, Perth.

— 2004, *Margaret River fishway*, unpublished report to the Margaret River Regional Environment Centre.

— 2003, *Fish fauna of Margaret River Western Australia*, unpublished report to the Margaret River Regional Environment Centre.

Morgan, DL, Gill, HS & Potter, IC 1998, 'Distribution, identification and biology of freshwater fishes in south-western Australia', *Records of the Western Australian Museum Supplement No. 56,* 97 pp.

Pen, L 1999, *Managing our rivers: A guide to the nature and management of the streams of south-west Western Australia*, Water and Rivers Commission, Perth.

Poff, LN, Allan, JD, Bain, MB, Karr, JR, Prestegaard, KL, Richter, BD, Sparks, RE & Stromberg JC 1997, 'The natural flow regime: A paradigm for river conservation and restoration', *BioScience*, 47, pp. 769–784.

Potter, IC 1996, 'Family Geotriidae: pouched lamprey'. In: McDowall, RM (ed), *Freshwater fishes of south-eastern Australia*, Reed Books, Chatswood, NSW.

Pusey, BT, Storey, AW, Davies, PM & Edward, DHD 1989, 'Spatial variation in fish communities in two south-western Australian river systems', *Journal of the Royal Society of Western Australia,* 71: pp. 69–75.

Sinclair Knight Merz 2007, *Impacts of farm dams in seven catchments in Western Australia*, report prepared for the Department of Water, Western Australia.

Storey, AW, Bunn, SE, Davies, PM & Edward, DH 1990, 'Classification of the macroinvertebrate fauna of two river systems in south-western Australia in relation to physical and chemical parameters', *Regulated Rivers: Research and Management,* 5: 217-232.

Tyler, MJ, Smith, LA & Johnstone, RE 2000, *Frogs of Western Australia*, Western Australian Museum, Perth.

Vannote, RL, Minshall, GW, Cummins, KW, Sedell, JR & Cushing, CE 1980, 'The river continuum concept', *Canadian Journal of Fisheries and Aquatic Sciences* 38: pp.130–137.

Water and Rivers Commission 2000, *Environmental water provisions policy for Western Australia, Statewide policy no. 5*, Waters and Rivers Commission, Perth.

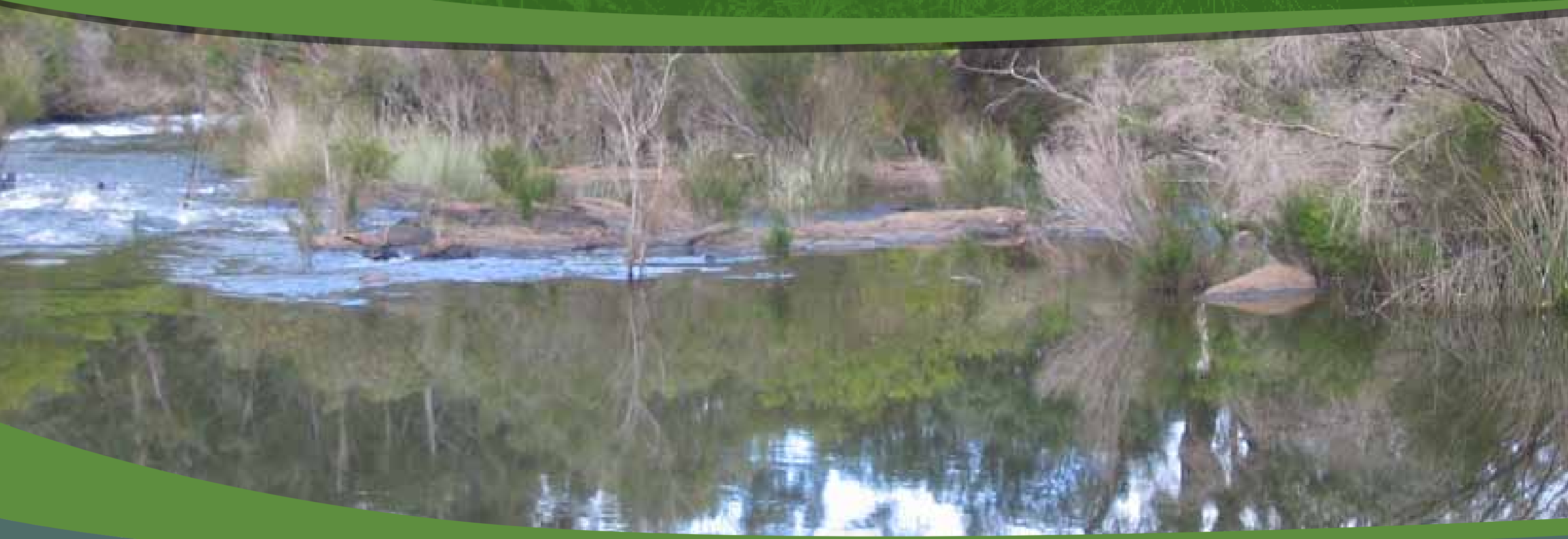
Wetland Research and Management 2005a, *Ecological water requirements of Hill River – intermediary assessment*, report prepared by Wetland Research and Management for Department of Environment and Northern Agricultural Catchment Council.

— 2005b, *Ecological water requirement of Augustus River – intermediary assessment*, report prepared by Wetland Research and Management for Worsley Alumina.

— 2007a, *Ecological values of seven south-west rivers: Desktop review*, report by Wetland Research and Management for the Department of Water, Perth.

— 2007b, *Ecological water requirements for Margaret River (draft)*, unpublished draft report by Wetland Research and Management for the Department of Water, Perth.

— 2008, *Aquatic fauna sampling: Identifying ecological values for the south-west EWRs project*, report prepared by Wetland Research and Management for the Department of Water, Perth.



Department of **Water**
168 St Georges Terrace, Perth, Western Australia
PO Box K822 Perth Western Australia 6842
Phone: 08 6364 7600
Fax: 08 6364 7601
www.water.wa.gov.au

0820–0–0810