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

# Ecological water requirements for the Lower Canning River

***Looking after all our water needs***

Environmental water report series
Report no. 16
August 2010

# Ecological water requirements for the lower Canning River

(below Canning Dam to Kent Street Weir)

*Looking after all our water needs*

Department of Water
Environmental water report series
Report no. 16
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 1833-6582 (print)
ISSN 1833-6590 (online)

ISBN 978-1-921789-16-8 (print)
ISBN 978-1-921789-17-5 (online)

**Disclaimer**



**Acknowledgements**

The Department of Water would like to acknowledge the following for their contribution to this publication: The Canning Environmental Flows Steering Committee, Water Corporation, Swan River Trust, Andrew Storey, Natasha Pauli, Laurence Radin and the project team from the Department of Water's Environmental Water Planning Section.

For more information about this report, contact: Fiona Lynn, Water Resource Use
Phone 08 6364 7600
Email: <Fiona.Lynn@water.wa.gov.au>

The recommended reference for this publication is:

Radin L, Pauli N, La Spina K, Braimbridge M & Malseed B, 2010, *Ecological water requirements for the lower Canning River*, Environmental water report series, Report no. 16, Department of Water, Government of Western Australia.

*This publication is available at our website <www.wa.gov.au> or for those with special needs it can be made available in alternative formats such as audio, large print, or Braille.*

# Contents

## Appendices



## Figures

## Tables

# Summary

The Canning River system has been heavily modified by construction of the Canning Reservoir, Wungong Dam and several other weirs in the catchment. It has been estimated that mean annual flows have been reduced by up to 98 per cent in comparison with pre-dam measurements (Storey et al. 2001). Historically, the lower Canning River was a permanently flowing system. One of the goals of this ecological water requirements (EWR) study is to maintain permanent flow, a flow that is most likely to cease during the dry summer months. During the dry months of November to May, flow in the lower Canning River between Araluen and Kent Street Weir is provided by six ‘environmental release points’ (ERPs). These discharge treated scheme water directly into the river using existing Water Corporation infrastructure. This EWR study improves the delivery of water from the ERPs to better match environmental requirements during the summer months.

The EWR was developed using field observations during a planned low-flow release of water, as well as results from the River Analysis Package (a modelling package that allows the quantification of changes in defined ecological parameters with flow regime). Analyses were completed for 32 flow-ecology linkages previously identified in Radin et al. (2007) – using six representative reaches of the lower Canning River. A total of 60 surveyed river cross-sections were used to develop the revised EWR. Sets of flow recommendations were developed for each reach based on the flow-ecology linkages that were applicable and testable.

The flow recommendations for individual flow-ecology linkages were consolidated and summarised into summer and winter EWRs. The summer minimum water requirements for each reach have typically been presented as minima below which flows should not fall. The summer minimum flow is required to maintain flow connectivity, maintain pool depth as refuge habitat, prevent anoxic conditions in pools and maintain adequate riffle habitat for macroinvertebrates. Summer minimum flows ranged from 1.2 ML/day in Reach 1 (the most upstream reach) to 2.6 ML/day in Reach 5. During the dry months of November to January, additional flow pulses of between 10.7 ML/day and 6.0 ML/day (depending on the reach) are required to inundate obstacles so that upstream reproductive migration of freshwater cobbler *(Tandanus bostocki*) is enabled.

The flow regime required to fulfil the summer EWRs for each reach will be achieved primarily by manipulating the volume of water discharged from the six ERPs along the lower Canning River. In determining the flow regime, very little information was available on losses to the system from abstraction by licensed water users, infiltration to groundwater and evaporation. Based on the results of the summer low-flow trial, a preliminary assumption of 25 per cent loss of discharge from ERP valves to infiltration, abstraction and evaporation has been made. This loss assumption will be reviewed over time and changed if required.

During the higher rainfall and discharge period between April and October, flows of a range of magnitudes and durations are required to meet winter-critical flow-ecology linkages. Between April and October, continuous discharges of up to 10.7 ML/day (depending on the reach) are required to inundate emergent vegetation; provide habitat for macroinvertebrates, fish and waterbirds; and maintain emergent plants. Between June and October, continuous discharges of up to 4.7 ML/day are required to provide sufficient water depth (at least 10 cm) over obstacles, so that upstream passage of small-bodied freshwater fish for spawning and reproduction is enabled.

The remaining winter-critical flow-ecology linkages require sporadic discharges of varying magnitude and frequency. Events with sufficient discharges to inundate mid-bank vegetation, overtop banks and maintain the active channel are likely to occur infrequently, between once a year and once every three to four years, depending on the management reach. Discharges required to inundate in-stream benches of up to 340 ML/day are required depending on the elevation of the benches. The corresponding event frequencies for bench inundation range from continuous throughout winter, to once a year. Shallow backwaters, which are used as refuge and spawning habitat for fish and macroinvertebrates, are found in the lower three management reaches only. Discharges up to 444 ML/day are required for inundation of backwater habitat to begin.

Because of the high level of flow required during the winter, flow from the ERPs are not able to meet the winter-critical EWRs. Time-series analysis of discharge data from 1975 to 2007 showed that winter-critical EWRs have been met naturally by runoff from rainfall events.

A discharge schedule has been developed, based on the discharge from the six ERPs required to fulfil the summer EWRs (i.e. summer minimum flow and freshwater cobbler passage), assuming 25 per cent loss. The proposed discharge schedule will lead to an average daily discharge of 8.5 ML/day from all ERPs compared with approximately 7.8 ML/day released over the 2006–07 summer. The schedule includes simple triggers for turning flow on and off, as well as increasing and decreasing flow, according to variation in mean daily discharge measured at Seaforth gauging station and precipitation measured at the Bureau of Meteorology's Gosnells site. Dates for turning flow from the ERP valves on and off were calculated for hypothetical 'average', 'wet' and 'dry' years, based on historical discharge and precipitation data. In an 'average' year, total annual discharge from the ERP valves would be about 1582 ML. In a 'dry' year, total annual discharge would be approximately 1925 ML; while in a 'wet' year; annual discharge would be about 1201 ML. These figures represent 113 per cent, 138 per cent and 86 per cent of the average annual discharge released between 2004–05 and 2007–08. It is anticipated that the proposed flow regime should be sufficient to account for the licensed water allocation, based on the assumption that in previous years, discharges were sufficient for licensed users and landholders with riparian rights.

Ongoing monitoring occurred throughout the 2008–09 and 2009–10 summers to determine the flow regime's effectiveness. This involved monitoring of mean daily discharge at Seaforth gauging station, as well as occasional gaugings of flow and water levels at the control points in the six management reaches.

A program of additional environmental monitoring has been devised and implemented. The program includes monitoring of water quality parameters (particularly dissolved oxygen, turbidity, conductivity, pH, temperature, total nitrogen and total phosphorus) and triennial monitoring of freshwater fish abundance and movement patterns, particularly during the summer spawning season. The water released through the ERP valves is chlorinated scheme water. Chlorine breaks down rapidly with aeration and exposure to sunlight. Chlorine in the released water dissipates rapidly, so that 500 m downstream of the release points, chlorine concentrations are within acceptable ANZECC/ARMCANZ levels for freshwater systems.

A number of broad recommendations for restoration of the river system, which would complement the revised EWR study, have been made. In particular, the lower Canning River has been substantially affected by sedimentation, as a result of catchment clearance and changing land uses. It is not possible to manage sedimentation using environmental water releases, because the water released from the ERP valves is not of sufficient velocity to mobilise large quantities of sediment. Increased soil erosion, surface runoff and the resulting sedimentation require a whole-of-catchment management approach.

The EWR study for the lower Canning River will be used alongside social, cultural and economic considerations to develop a surface water allocation plan for licensed water use within the Canning catchment.

# 1 Introduction

## 1.1 Purpose of this report

This report presents the results of a study to develop a revised ecological water requirement (EWR) for the lower Canning River between Araluen and Kent Street Weir. The lower Canning River's hydrological regime has been extensively modified by upstream regulation of the river. A preliminary EWR was prepared by Storey et al. (2001), which estimated the minimum monthly flow rate to maintain the ecological values of the lower Canning River. The revised EWR presented here is based on a more detailed set of hydrological and ecological data, and supersedes the preliminary EWR.

Publishing the revised EWR is part of the process to develop a revised surface water allocation plan for the lower Canning River, which will include improved management measures for environmental water releases. A preceding Department of Water publication, *Environmental values, flow-related issues and objectives for the Canning River, Western Australia* (Radin et al. 2007), gives detailed information on the study area's environmental attributes. It also details the relationships between streamflow and ecological processes (referred to as 'flow-ecology linkages'), and the ecological objectives to be met by the EWR (referred to as 'flow objectives'). Where appropriate, information on the ecological and hydrological attributes, flow-ecology linkages and flow objectives have been summarised in this report.

This report outlines the methods used to develop the revised EWR, the results of analyses undertaken to determine the EWR for the different flow-ecology linkages, and the flow recommendations. Information is also provided on how the results will be used to develop a revised environmental water provision (EWP) and water allocation.

## 1.2 What is an ecological water requirement?

In regulated river systems, water is managed to fulfil a range of social, economic and ecological functions. EWRs are estimates of the water required to maintain ecological functions. For the Canning River, the EWR is defined as the water regime needed to maintain and enhance the current ecological values of the water resource at a low level of risk.

A holistic approach to determining the Canning River's EWR has been employed. Holistic approaches to EWR assessments consider the ecosystem as a whole, and are based on the premise that particular flow events perform specific ecological functions. For example, high flows after storm events have the energy to scour the river channel, create diverse riverbed habitats and flood riparian vegetation. Similarly, early winter flows relieve summer stress (such as high water temperatures and low levels of dissolved oxygen), provide cues for breeding migrations of native fish, and provide habitat for an array of organisms such as water birds, micro crustaceans, aquatic insects, in-stream vegetation and larval stages of terrestrial insects.

Accordingly, determining the EWR of a managed river ecosystem is not simply based on calculating a desired minimum water level in the river channel; instead the focus is on maintaining a flow regime to support the full range of ecological interactions in the ecosystem. In this study, the flow events method (Stewardson 2001) is used to determine the lower Canning River's EWR. Further detail is provided in Section 2.

## 1.3 The lower Canning River catchment

### 1.3.1 Hydrology

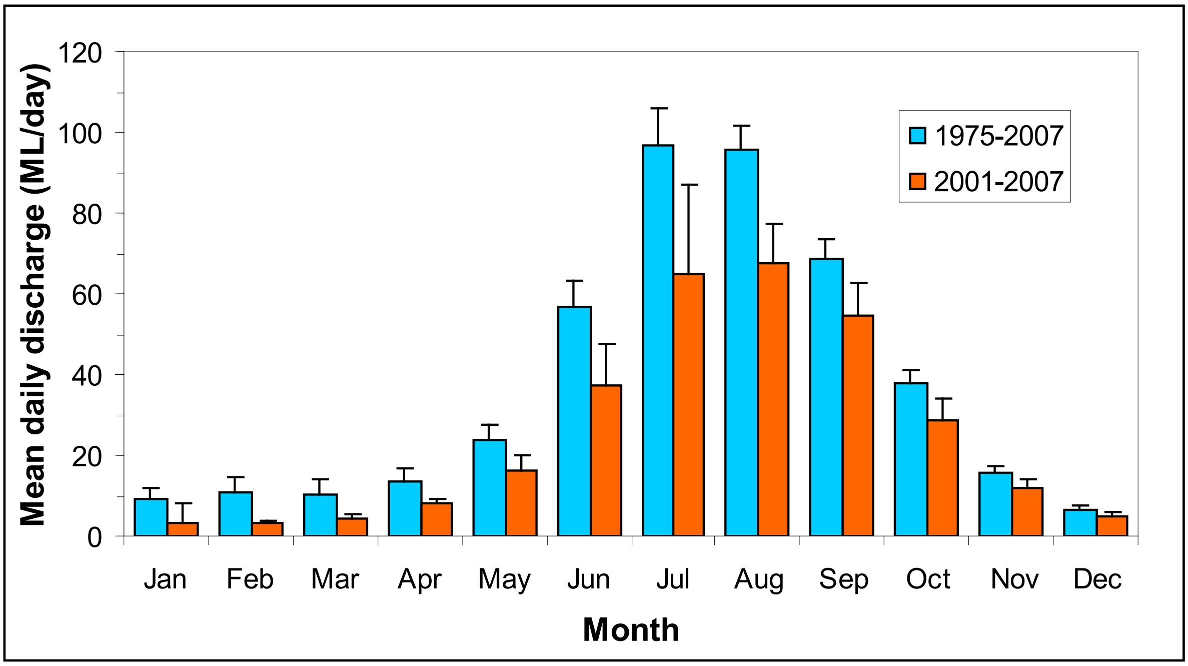
The Canning River and its tributaries historically drained a catchment of around 804 km$^2$ to the south-east of Perth, extending from the ancient lateritic and granitic landscape of the Darling Plateau to the sandy soils of the Swan Coastal Plain. Pre-regulation, streams in the headwaters on the Darling Plateau were typically seasonal and fast-flowing, with substrates of lateritica gravel, granite pebble and bedrock. On the Swan Coastal Plain, flows were generally permanent with low velocity over sand and silt substrates.

The lower Canning River's hydrology has been substantially modified as a result of regulation and land-use changes in the catchment. The upstream impoundment of water in two major water supply reservoirs (Canning Reservoir and Wungong Reservoir), as well as behind numerous smaller weirs, has greatly reduced streamflow in the lower Canning River. Since the construction of Canning Dam began in 1934, it has been estimated that average annual streamflow in the lower Canning River has decreased by 98 per cent (Storey et al. 2001).

Altered land use within the catchment has also significantly altered the system's hydrology. Widespread clearing of vegetation on the Swan Coastal Plain has led to a relative increase in surface runoff, and a decrease in the time taken for runoff to reach watercourses. This has altered the system's hydrology from relatively slow flat-response flows after rainfall, to rapid high-response flows that peak soon after rainfall (Radin et al. 2007).

### 1.3.2 Climate

The Canning River catchment has a Mediterranean climate, typified by hot, dry summers and cool, wet winters. The rainfall distribution pattern is closely linked to streamflow, with over 80 per cent of annual flow in the Canning River occurring between June and October (Figure 1). Since the mid-1970s mean annual rainfall has declined, which has led to a corresponding decrease in mean monthly stream discharge (Storey et al. 2001; Radin et al. 2007). The drying trend has become particularly evident during the past decade, with a resultant decline in stream discharge (Figure 1).




* *Error bars represent standard error (n=33 for 1975–2007, n=7 for 2001–07). The period between 2001 and 2007 was chosen for comparison as these are the years for which data are available on the amount of water released by the Water Corporation into the lower Canning River.*

*Figure 1 Mean daily discharge per month for the Canning River, measured at Seaforth gauging station (S616027), 1975–2007 and 2001–07*

### 1.3.3 Cultural values

The Noongar name for the Canning River is Dyarlgarro, meaning ‘place of abundance’. The Canning River is rich in Noongar culture and history and many significant and sacred sites are embedded within the banks of the river (Perth NRM, 2010).

### 1.3.4 Water resource management and planning

To provide water to licensed users and landholders with riparian rights downstream of the dams, a number of compensatory ‘release points’ were established along the Canning River and southern Wungong River. There are six release points along the Canning River: Araluen Botanic Gardens, Hill 60, Bernard Street, Orlando Street, Manning Avenue and Gosnells Bridge. At each point, treated (i.e. chlorinated) scheme water is released into the river through modified scour valves. The release points operate over the drier months between November and May.

In the 1990s, these release points were redesignated as ‘environmental release points’, with the goal of supplying water to the Canning River to maintain environmental values and ecological processes (Water and Rivers Commission

1996). A preliminary EWR for the lower Canning River was determined based on the information available at the time (Storey et al. 2001). The revised EWR presented in this report refers to a more detailed set of hydrological and ecological data than what was available for the preliminary EWR.

The revised EWR, considered in conjunction with information on social, cultural and economic concerns, will provide the basis for developing a surface water allocation plan for the lower Canning River. The plan will identify the water resources and water regimes to be protected and define the water licensing policies for the river system. The plan will identify an environmental water provision (EWP), which will represent the amount of water to be provided to maintain the lower Canning River's environmental attributes.

## 1.4 Objective of the ecological water requirement study

The study area comprises the stretch of the Canning River between the base of the Canning Dam to Kent Street Weir (Figure 2). As this section of the river is highly modified, the EWR study's principle objective was to determine the flow requirements necessary to maintain (and where possible improve) the composition and structure of the modified 'post-regulation' ecological community – at a low level of risk.

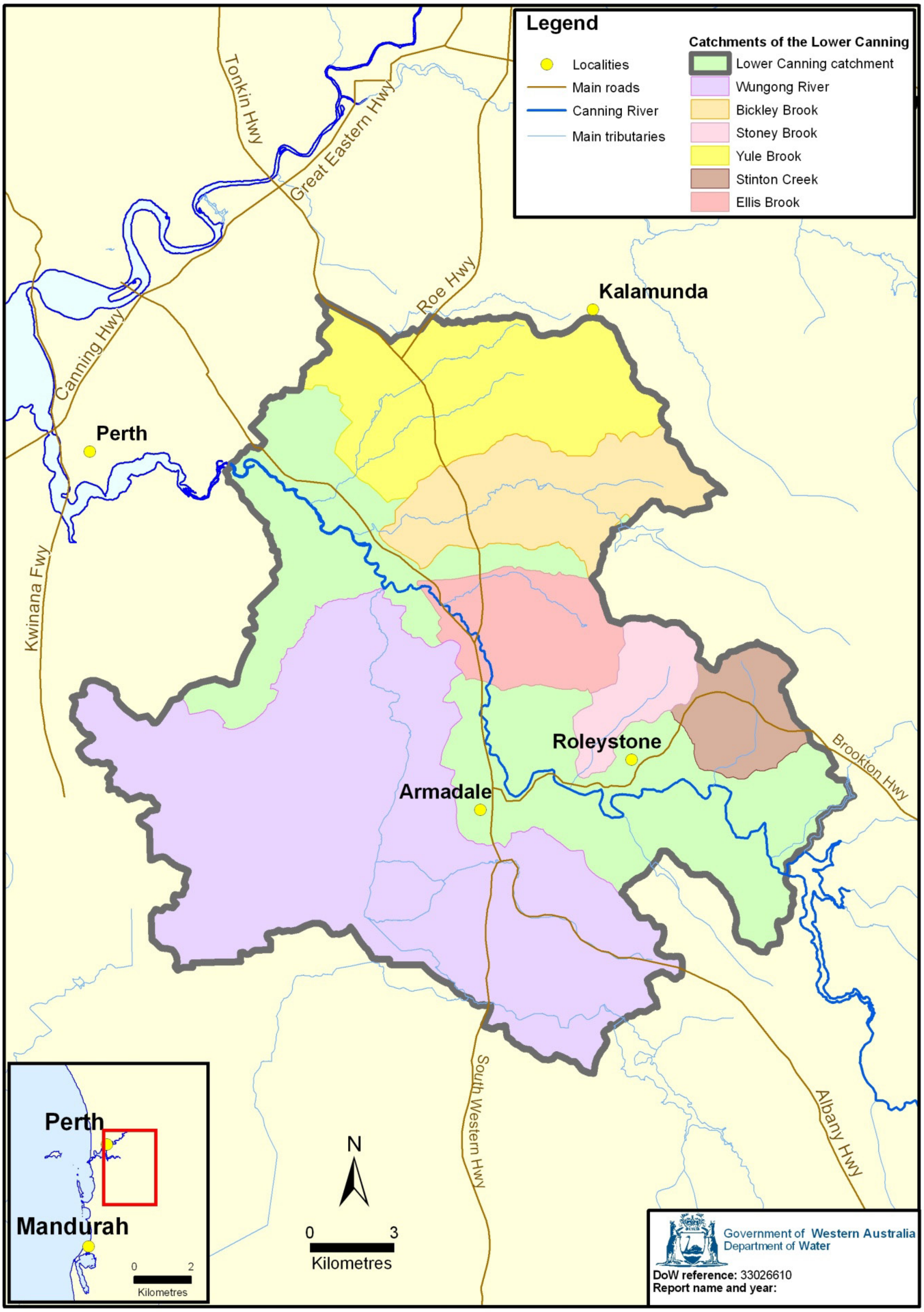



*Figure 2 The lower Canning River catchment and sub catchments*

# 2 Approach

## 2.1 Overview of the flow events method

The flow events method (Stewardson 2001) was used to estimate the ecological water requirements (EWRs) for the lower Canning River. The flow events method is a holistic, habitat-based approach for assessing EWRs. It is based on the premise that different components of the flow regime (such as summer and winter base-flows, bankfull flows and overbank flood flows) have different ecological functions, and that maintaining a range of flows is essential for river ecology (Poff et al. 1997; Richter et al. 1997).

It is important to identify which aspects of the flow regime must be maintained by water released for environmental purposes, so that the ecological integrity of the lower Canning River system may be supported. Flow components can be identified as significant for the river reach or system if they are linked to key ecological features and/or processes. These relationships are known as ‘flow-ecology linkages’, and are an integral component of the flow events method (Stewardson 2004). The method allows for the independent assessment of individual flow components as part of the process to determine a river system’s EWR.

The application of the flow events method to the lower Canning River’s EWR assessment is described in the following sections.

## 2.2 Application of the flow events method to the lower Canning River

Assessment of the lower Canning River’s EWR using the flow events method followed a two-stage process, as represented in Figure 3. The first stage (steps 1 through 5 in Figure 3) involved documenting representative sites and river reaches, field assessments, analysis of existing hydrological and ecological information, and development of an issues paper highlighting environmental assets, threats and flow-related ecological objectives. Much of this information was presented in Radin et al. (2007), and is presented here in summarised form (sections 2.2.1 and 2.2.2).

This report documents the second stage of the process, represented by steps 6 through 10 (Figure 3), and detailed in sections 2.2.3 to 2.2.5. The second stage involved hydraulic surveys, hydraulic modelling, and hydrologic analyses to develop flow recommendations and estimate the EWR for the lower Canning River ecosystem. In addition, a trial program of water releases from the environmental release points (ERPs) was undertaken, so that the modelled EWR could be compared with actual streamflow after the water releases.

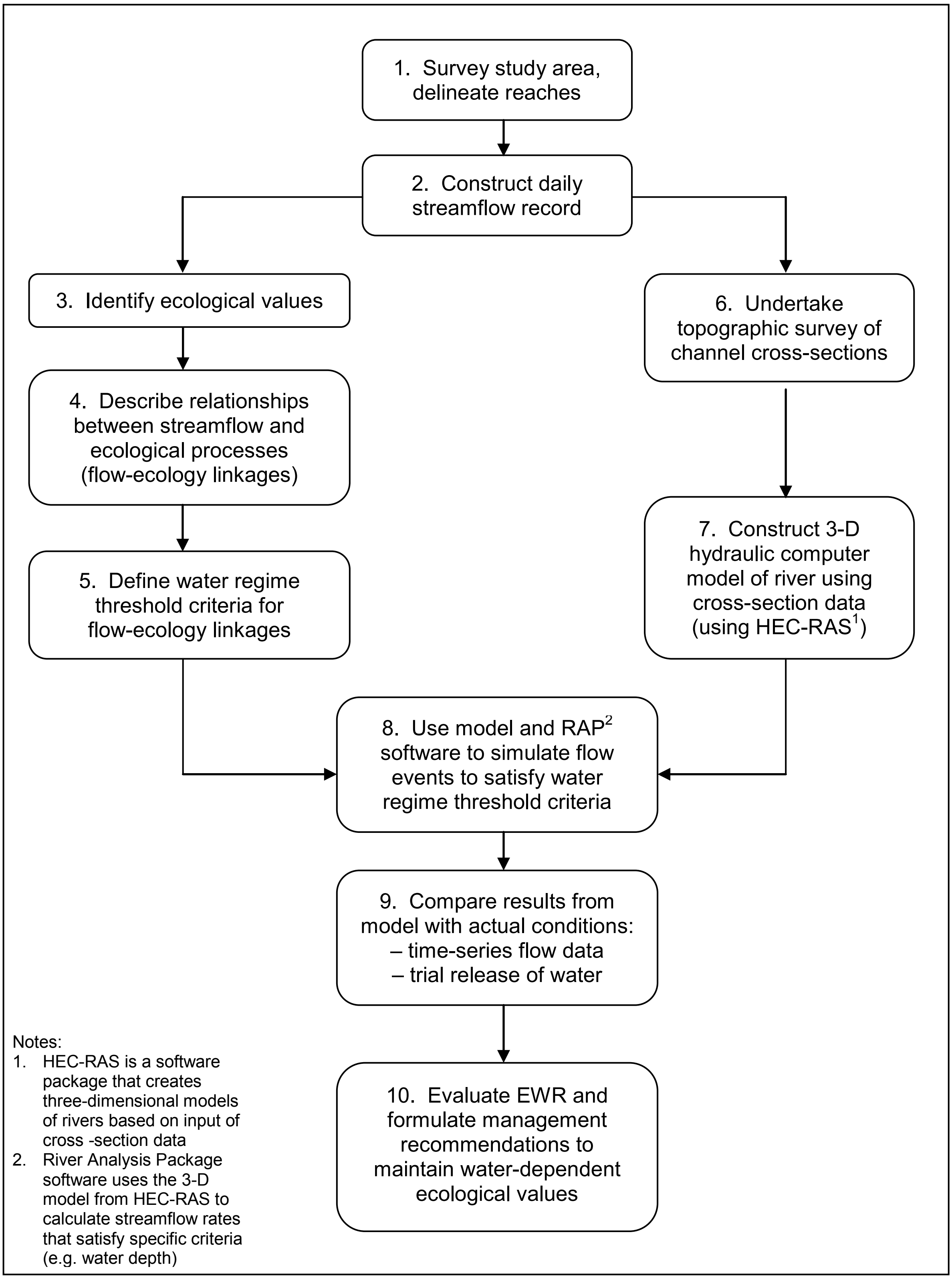



*Figure 3 Diagrammatic representation of the process used to develop the lower Canning River's revised EWR*

### 2.2.1 Definition and characterisation of management reaches

In the current study, six sites (referred to as 'management reaches') were chosen as representing the ecological values and geomorphological conditions of the study area. Two management reaches were located in each of the river's three distinct geomorphological sections (Figure 4). Reach 1 (Soldiers Road) and Reach 2 (Stocker Road) were located within the bedrock-controlled valleys in the upstream section of the study area. Reach 3 (Bernard Street) and Reach 4 (Orlando Street) were situated in the transition zone between the valleys and the Swan Coastal Plain, while Reach 5 (Manning Avenue) and Reach 6 (Pioneer Park) were located on the coastal plain. The locations of the management reaches were designed to coincide with the location of the six ERPs.

Section 4 summarises the EWR for each management reach. A detailed evaluation of the EWR for each reach is presented in Appendix C.

### 2.2.2 Identification of water-dependent ecological values, critical water levels and flow regimes

Environmental attributes and flow-ecology linkages in the lower Canning River were identified in Radin et al. (2007). Seven water-dependent environmental attributes were identified: geomorphological processes; aquatic macroinvertebrates; fish; waterbirds; water quality; riparian vegetation; and ecosystem processes. Flow-ecology linkages were identified for each of the seven key attributes, which gave a total of 32 linkages.

The critical water levels required to maintain each flow-ecology linkage were documented. The critical water levels either identify threshold flows for ecological processes, or describe the strength of the effect that different flows have on the ecological feature or process (Stewardson 2004). For example, the inundation of riffles was identified as an important requirement to support aquatic macroinvertebrate populations. Based on expert advice, a target of continuous inundation of 50 per cent of riffle width to a minimum average depth of 5 cm was identified.

### 2.2.3 Hydraulic assessment and hydrological modelling

To make a hydraulic assessment of the river, 60 channel cross-sections were surveyed along the length of the lower Canning River in 2006. The cross-sections were located within the six management reaches. The cross-sections were selected to represent the channel morphology and ecological characteristics of each reach.

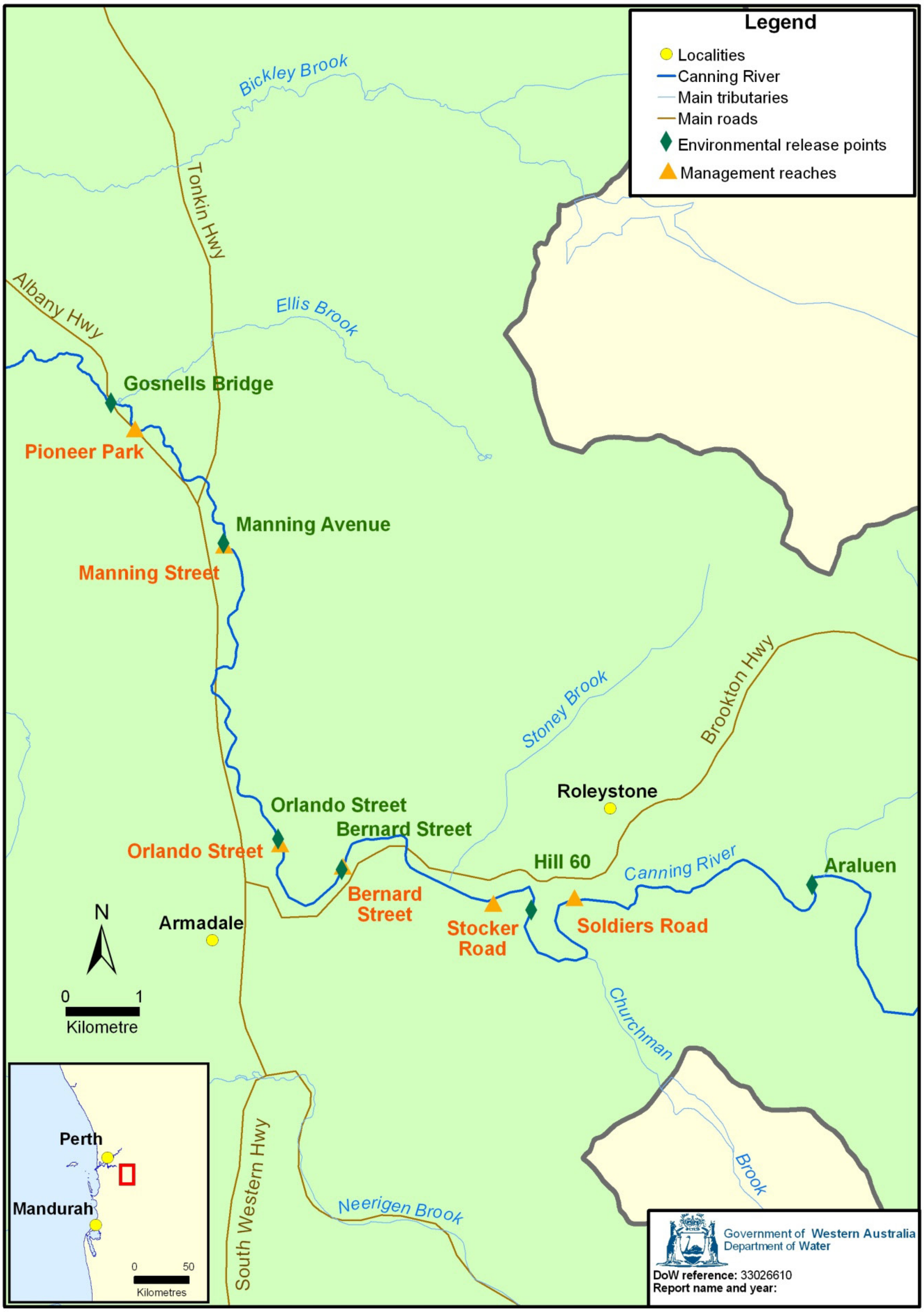



*Figure 4 Location of the six management reaches and ERPs along the lower Canning River*

The cross-sections were used to develop a three-dimensional hydraulic model of the river within each reach using the software HEC-RAS. The model allows assessment of the relationship between the discharge (as $m^3/s$ or ML/day) and water level within the river channel.

The hydraulic model was then used to assess the flow regime necessary to satisfy each of the identified flow-ecology linkages, using the River Analysis Package (RAP). RAP allows the habitat and flow thresholds for modelled flows to be quantified.

The use of RAP is best illustrated with an example. Using the previous example of the riffle inundation for macroinvertebrates, cross-sections within each management reach that contained riffles were selected and ‘rating curves’ were developed in RAP. A rating curve describes the relationship between discharge and the proportion of suitable habitat available (in this case, the proportion of riffle width inundated by more than 5 cm). The example rating curve displayed in Figure 5 shows the total width of riffles inundated to a depth of 5 cm or more within Reach 4 (Orlando Street) over a range of modelled discharges. Four riffle cross-sections were included in the analysis, with a combined width of 4.5 m. The corresponding discharge at which half of this width (i.e. 2.25 m) was inundated was approximately 9 ML/day.

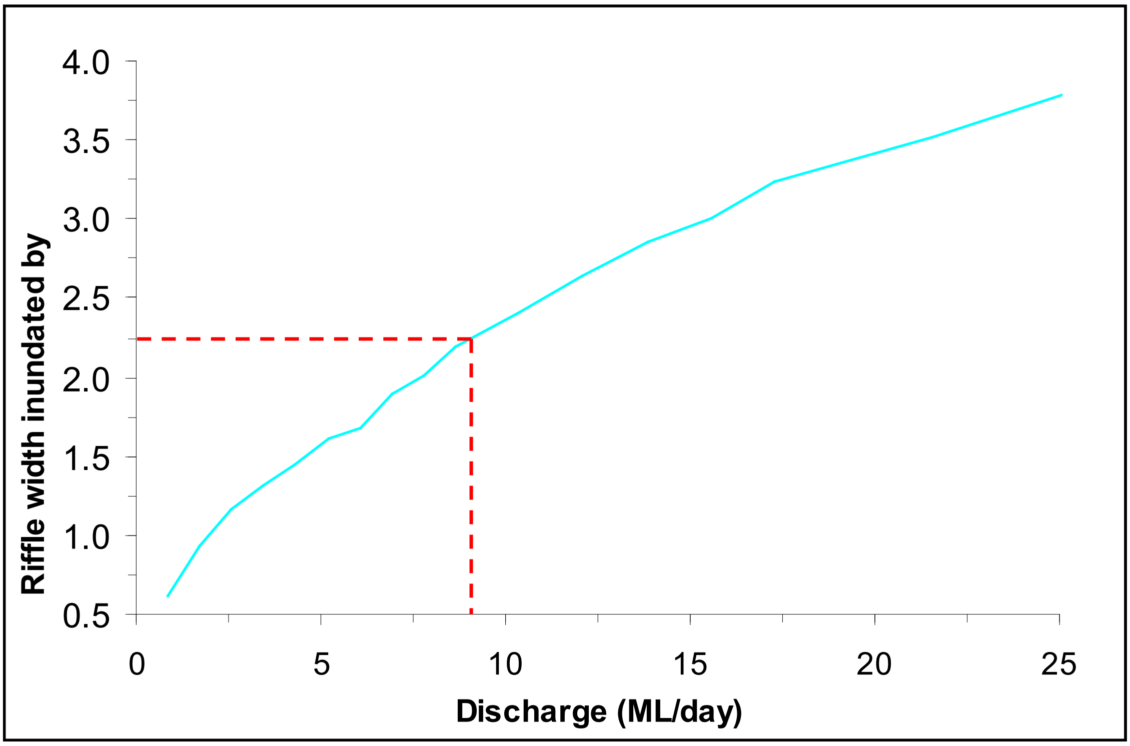



*Figure 5 Example rating curve showing the total width of riffles inundated to 5 cm or more with increasing discharge in Reach 4*

* *The flow objective was to identify the discharge at which 50 per cent of the total width of riffles were inundated to 5 cm or more, as habitat for macroinvertebrates. The total riffle width in Reach 4 was 4.5 m. The corresponding discharge at which half of this width (i.e. 2.25 m) was inundated has been marked on the rating curve in red for reference.*

### 2.2.4 Time-series assessment using historical discharge data

Where appropriate, historical streamflow data records were used to characterise the timing and frequency of critical flows. Comprehensive data were available for the Seaforth gauging station (S616027) on the coastal plain, from 1975 onwards. These data were considered representative of flow at reaches 4, 5 and 6, and were used to conduct a time-series analysis at these three sites to compare the modelled EWR with historical records. Adequate data were not available for the management reaches located in the transition zone and in the bedrock-controlled valley. Hydrological monitoring stations were installed in each management reach in 2004, but these data were not sufficient for use in the time-series analyses.

### 2.2.5 Evaluation of modelled results and field trials

An evaluation was undertaken to determine whether the modelled discharges required to maintain flow-ecology linkages were likely to be met under field conditions. Such an evaluation is normally done with reference to historical data, using a time-series analysis to determine the frequency, duration and seasonality of flow thresholds being met or surpassed in the past. As described above, time-series analyses with historical data could only be undertaken for reaches 4, 5 and 6.

To complement the historical time-series data and provide a means of testing flow thresholds for summer-critical flow-ecology linkages, a trial water-release program was conducted using the six ERPs. The trial was also used to test the existing release points' capacity to meet modelled flow thresholds and to check the hydraulic model's accuracy. The trial was conducted in late summer, between 19 and 23 March 2007.

Releases were staged at incremental volumes over five days at each management reach, starting with base-flow discharge; then going to one-third of total release capacity, two-thirds capacity, and full capacity.

The release program was planned so that ecological observations and flow monitoring could be conducted in the morning, before discharges from the release points increased. A detailed account of the trial program, together with the discharges recorded at the release points and control points within each management reach, is given in Appendix A. Thalweg (the deepest part of the river channel) depth was recorded at each cross-section during the trial, as was water depth across key ecological features such as benches and riffles. The measured water levels were compared with the ecologically critical water levels delineated for each flow-ecology linkage.

Hydraulic modelling results for each flow-ecology linkage were compared with observed results measured during the summer trial release. Where there was a substantial difference between modelled and measured thalweg depths, the modelled results were excluded from further analysis.

### 2.2.6 Development of water regime management recommendations

The results of the hydraulic modelling, time-series analysis and trial water release were used to formulate discharge recommendations for each of the 32 flow-ecology linkages. A detailed explanation of the methods used to assess each linkage is given in Appendix B. The results are detailed in Appendix C. Section 4 summarises the EWRs for each reach.

The discharges required to meet the EWRs of summer-critical flow-ecology linkages have been used as the basis for a preliminary managed flow regime. The recommended flow regime is detailed in Section 5. The preliminary regime was implemented and evaluated over the summers of 2008–09 and 2009–10, and modifications made as necessary to ensure that enough water was available to meet the EWRs and abstraction by licensed water users.

# 3 Streamflow requirements for key environmental attributes

## 3.1 Flow-ecology linkages and flow objectives

Seven key water-dependent environmental attributes of the lower Canning River have been identified: geomorphological processes, macroinvertebrates, fish, waterbirds, water quality, riparian vegetation and ecosystem processes (Radin et al. 2007). For each attribute, flow-ecology linkages were developed to reflect important relationships between each attribute and the flow regime.

A total of 32 flow-ecology linkages to be maintained in the lower Canning River were identified, as shown in Table 1.

There is considerable overlap between the flow requirements for several of the flow-ecology linkages. For example, aquatic macroinvertebrates and fish have many of the same habitat and flow requirements. Additionally, some individual flow-ecology linkages are equivalent to a suite of other linkages. For example, waterbirds require healthy riparian vegetation, which in itself depends on the maintenance of a number of individual flow-ecology linkages related to emergent vegetation, mid-bank vegetation and floodplain vegetation.

Where linkages are directly comparable, the determination of EWRs has been undertaken once and the results applied to all linkages. For brevity, comparable linkages are not explicitly referred to in the detailed results (Appendix C); note that this does *not* imply that these linkages are of less importance than those that have been explicitly described. Table 2 summarises the 15 flow-ecology linkages for which the EWRs have been explicitly described (left-hand column), and the comparable flow-ecology linkages that are subsumed within each described linkage.

*Table 1 Flow-ecology linkages and flow considerations for ecological processes in the Canning River*

| Flow objectives | Flow-ecology linkages | Reach | Flow considerations | | | |
|---|---|---|---|---|---|---|
| | | | **Flow components** | **Season/ timing** | **Flow objectives** | **Comparable linkages** |
| **Geomorphology** | | | | | | |
| Maintain an active channel | 1a) Sufficient flow to scour pools and remove accumulated sediments and organic material | All reaches | Active channel flows; bankfull or overbank flows | Winter (June to August) | Sufficient stream power to mobilise sediments <300 μm diameter | 3i |
| | 1b) Sufficient flow to maintain the shape of the active channel | All reaches | Active channel flows | Winter (June to August) | Maintain frequency of bankfull flow for the active channel | Part of 7b |
| **Macroinvertebrates** | | | | | | |
| Maintain species richness and composition of macroinvertebrate communities | 2a) Maintain water depth of 5-10 cm over gravel runs and riffles as biodiversity 'hotspots' for macroinvertebrates | All reaches | Low flows | All year (summer critical) | Water depth of at least 5 cm over 50% of riffle width | None |
| | 2b) Maintain submerged macrophyte beds as habitat for macroinvertebrates | 3[†] | Low flows | All year (summer critical) | Water depth of at least 20 cm in pools containing macrophyte beds | 3f, 6d |
| | 2c) Sufficient water depth to ensure marginal reeds and rushes provide habitat for macroinvertebrates | All reaches | Low flows | All year (summer critical) | Inundate root base of emergent vegetation to 10 cm | 3f, 6d |
| | 2d) Maintain overbank flows to inundate the floodplain and provide shallow floodplain and backwater areas for habitat and avoidance of high flow | All reaches | High flow | Winter (June to August) | Sufficient discharge to overtop riverbanks | Floodplain: 3j, 6a, 7a; Backwaters: 3h |
| | 2e) Maintain connectivity of pools year-round | All reaches | Low flows | All year (summer critical) | Minimum flow over barriers to maintain permanent flow | 3e, 5a |
| | 2f) Sufficient flow to prevent anoxia in pools | All reaches* | Low flows | All year (summer critical) | Maintain dissolved oxygen content of at least 2 mg/L[‡] | 3c, 5b |

| Flow objectives | Flow-ecology linkages | Reach | Flow considerations | | | |
|---|---|---|---|---|---|---|
| | | | Flow components | Season/ timing | Flow objectives | Comparable linkages |
| | 2g) Maintain typical flow regime to maintain the macroinvertebrate community structure typical of reach location | All reaches | Seasonal and predictable flows | All year | Maintain characteristic flow regime, including permanent flow year-round | 5a, Part of 7b |
| **Fish** | | | | | | |
| Maintain species richness and composition of fish communities | 3a) Sufficient water depth to provide passage of small-bodied fish for reproductive migration | All reaches | High flow | June to October | Water depth of at least 10 cm over obstacles | None |
| | 3b) Sufficient water depth to provide passage of large-bodied fish for reproductive migration | All reaches | High flow | November to January | Water depth of at least 20 cm over obstacles | None |
| | 3c) Sufficient flow to prevent anoxia in pools to avoid fish kills | All reaches* | Low flow | All year (summer critical) | Maintain dissolved oxygen content of at least 2 mg/L‡ | 2f, 5b |
| | 3d) Inundation of emergent sedges and rushes to provide fish habitat and spawning and recruitment | All reaches | High flow | April to October | Inundation of emergent vegetation to a depth of at least 10 cm | 2c, 6b |
| | 3e) Sufficient flow to maintain connectivity of pools year-round | All reaches | Low flow | All year (summer critical) | Minimum flow over barriers to maintain permanent flow | 2e, 5a |
| | 3f) Maintain submerged macrophyte riverbed habitat for fish | 3† | Low flow | All year (summer critical) | Water depth of at least 20 cm in pools containing macrophyte beds | 2b, 6d |
| | 3g) Maintain pool depth for cobbler nests and as refuge habitat for other fish species | 1, 2, 4, 5, 6† | Low flow | All year (summer critical) | Water depth of at least 80 cm in pools | 4aΩ |
| | 3h) Inundate shallow backwaters as nurseries for juvenile fish and provide habitat for smaller-bodied fish during high flows | 4, 5, 6† | High flow | April to October | Begin inundation of backwaters | Part of 2d |
| | 3i) Sufficient flow to prevent sediment aggradation and maintain habitat and functionality of pools for fish | All reaches | High flow | Winter (June to August) | Sufficient stream power to mobilise sediments <300 µm diameter | 1a |

| Flow objectives | Flow-ecology linkages | Reach | Flow considerations | | | |
|---|---|---|---|---|---|---|
| | | | Flow components | Season/ timing | Flow objectives | Comparable linkages |
| | 3j) Overbank flows to inundate and connect floodplain wetlands and shallow-flooded off-river areas for foraging and spawning habitat for native fish | All reaches | High flow | April to October | Sufficient discharge to overtop riverbanks | 6a, 7a, part of 2d |
| | 3k) Undercutting of riverbanks to provide habitat for fish | All reaches | Low flow to high flow | All year | Inundate top of undercut riverbanks | None |
| | 3l) Sufficient flow to inundate in-stream benches to provide foraging areas and spawning habitat for fish | All reaches | High flow | April to October | Water depth of at least 10 cm above in-stream benches | 7c |
| **Waterbirds** | | | | | | |
| Maintain habitat to support waterbird communities | 4a) Maintain permanent pools as a summer and drought refuge for waterbirds | 1, 2, 4, 5, 6[†] | Low flow | All year (summer critical) | Water depth of at least 50 cm in pools | 3g[Ω] |
| | 4b) Maintain flows to protect riparian vegetation, particularly seasonally inundated vegetation that may provide breeding habitat | All reaches | High flow | Winter | As outlined for riparian vegetation flow-ecology linkages | Combination of 6a, 6b and 6c |
| **Water quality** | | | | | | |
| Prevent de-oxygenation of the water column | 5a) Sufficient flow to maintain connectivity of pools year-round | All reaches | Low flow | All year (summer critical) | Minimum flow over barriers to maintain permanent flow | 2e, 3e, part of 7b |
| | 5b) Prevent anoxia and significant stratification in pools | All reaches* | Low flow | All year (summer critical) | Maintain dissolved oxygen content of at least 2 mg/L[‡] | 2f, 3c |
| **Riparian vegetation** | | | | | | |
| Maintain the diversity of the riparian zone and bank stability | 6a) Sufficient flow to maintain and/or allow restoration in winter-wet floodplain regions and off-channel wetlands. | All reaches | High flow | Winter (June to August) | Sufficient discharge to overtop riverbanks | 3j, 7a, part of 2d, part of 7b |
| | 6b) Seasonal inundation of emergent vegetation for survival, germination and recruitment | All reaches | High flow | Winter (June to August) | Inundate root base of emergent vegetation | 3d, 2c |

| Flow objectives | Flow-ecology linkages | Reach | Flow considerations | | | |
|---|---|---|---|---|---|---|
| | | | Flow components | Season/ timing | Flow objectives | Comparable linkages |
| | 6c) Seasonal inundation of mid-bank vegetation for survival, germination and recruitment | 3, 4, 5, 6♣ | High flow | Winter (June to August) | Inundate root base of mid-bank vegetation | Part of 7b |
| | 6d) Sufficient flows to maintain populations of submerged macrophytes | 3† | Low flow | All year (summer critical) | Water depth of at least 50 cm in pools | 2b, 3f |
| **Ecosystem processes** | | | | | | |
| Maintain transfer of energy to downstream systems | 7a) Seasonal inundation of riparian zones for allochthonous litter transfer | All reaches | High flow | Winter (June to August) | Sufficient discharge to overtop riverbanks | 3j, 6a, part of 2d |
| | 7b) Maintenance of flow connectivity between upstream and downstream reaches for energy transfer | All reaches | High flow | Winter (June to August) | Minimum flow over barriers to maintain permanent flow | Combination of 1b, 5a, 6a, 6c |
| | 7c) Seasonal inundation of lower benches for algal production | All reaches | High flow | Winter (June to August) | Water depth of at least 10 cm over in-stream benches | 3l |

*Notes:*

* *Although these flow-ecology linkages were important in all reaches, they could only be tested in reaches 4, 5 and 6, due to the importance of having a comprehensive hydrological dataset to determine threshold criteria. Such a dataset was only available for Seaforth gauging station, and was applicable only to the lower management reaches.*

† *Habitat not found at other reaches during detailed site surveys, but may occur along other unsurveyed sections of the lower Canning River outside of the six management reaches.*

‡ *Minimum stream velocity to maintain levels of dissolved oxygen above the threshold of 2 mg/L will differ at each site.*

Ω *Flow-ecology linkage 4a (pools for waterbirds) requires a shallower water depth (50 cm) than linkage 3g (pools for freshwater cobbler) at 80 cm water depth. Both linkages have been tested with the upper criterion of 80 cm pool depth, as the timing for both linkages is the same (summer).*

♣ *No mid-bank vegetation was surveyed at reach 1 or 2 during detailed site surveys; there may be other examples of mid-bank vegetation in the vicinity.*

*Table 2 Flow-ecology linkages explicitly described in the text, and comparable linkages that are implicitly described*

| Flow-ecology linkages and 'rule' numbers | Comparable linkages |
|---|---|
| 1a) Scour pools | 3i |
| 1b) Maintain active channel | Part of 7b |
| 2a) Submerge riffles | Unique |
| 3a) Small fish passage | Unique |
| 3b) Large fish passage | Unique |
| 3d) Submerge emergent vegetation | 2c, 6b, part of 4b |
| 3g) Maintain pools | 4a |
| 3h) Inundate shallow backwaters | Part of 2d |
| 3k) Undercut habitat | Unique |
| 3l) Inundate in-stream benches | 7c |
| 5a) Maintain pool connectivity | 2e, 3e, 2g, part of 7b |
| 5b) Prevent anoxia | 2f, 3c |
| 6a) Overbank flows | 3j, 7a; parts of 2d, 7b and 4b |
| 6c) Inundate mid-bank vegetation | Parts of 4b and 7b |
| 6d) Submerged macrophytes | 2b, 3f |

*If the criteria for the 15 flow-ecology linkages in the left-hand column are met, then all 32 flow-ecology linkages will be satisfied.*

# 4 Ecological water requirements for six representative river reaches

This section briefly describes the six management reaches assessed in this study, and outlines the EWRs for each reach. For a more detailed account of the assessment of EWRs for each flow-ecology linkage, refer to Appendix B (which describes the methods used) and Appendix C (which details the results).

## 4.1 Reach 1: Soldiers Road

Soldiers Road management reach (Reach 1) is at Roleystone, on the Darling Plateau's western margin. Summer flows in this reach are maintained largely by the Araluen release point, situated approximately 6 km upstream. Figure 6 shows the 'control point' within this reach (i.e. the point at which discharge was measured during the trial water-release program).

The river upstream of Soldiers Road consists of long, slow-flowing pools segregated by a number of private weirs. This section of the Canning River is bedrock-controlled. Eleven cross-sections were surveyed within the reach (Figure 7).

*Figure 6 Reach 1 (Soldiers Road) control point*

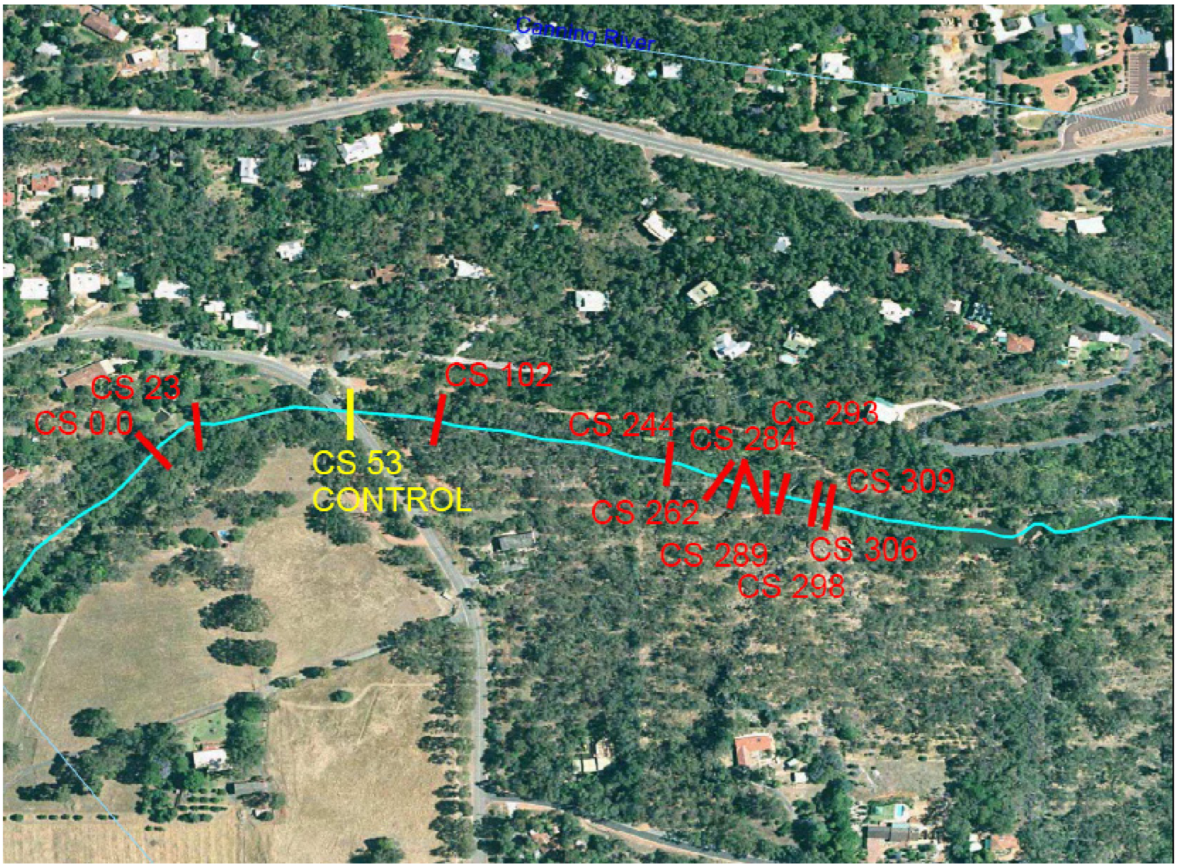



*Figure 7 Aerial view of Soldiers Road management reach showing the cross-sections and control point*

### 4.1.1 Ecological water requirements

The estimated threshold flows and recommended flow regimes to fulfil the EWR for Reach 1 are summarised in Table 3. As for all the management reaches, the estimated flow thresholds apply to discharges measured *at the control point* within the reach, rather than at the ERP valves. For more detail on the calculation of flow thresholds, see Appendix C.

Flow from the ERP valves is required to maintain summer-critical flow-ecology linkages. In Reach 1, a summer minimum flow of approximately 1.2 ML/day is required to submerge sufficient riffle habitat, maintain pool depth, maintain pool connectivity and prevent anoxic conditions in pools. Further detail on the recommended discharge regime from the ERPs is provided in Section 5.2.2.

The other summer-critical linkage is to provide sufficient flow for upstream reproductive migration of freshwater cobbler during November, December and January. There were insufficient data to determine historical discharges within the reach, so it is not possible to determine whether past flows have been sufficient for cobbler passage. An approximate flow regime has been provided based on what was derived for the downstream reaches, where historical flow data were available. The estimated flow threshold of 10.4 ML/day exceeds the capacity of the nearest upstream ERP. If this estimate is accurate and no other sources of water (such as releases from Canning Reservoir) are available during the dry months of November, December and January, it appears that water levels will be insufficient for cobbler migration in this reach.

There are two groups of winter/spring flow-ecology linkages for which relatively small discharges are required. Small fish require an estimated 2.1 ML/day for upstream migration between June and October. The same estimated discharge is needed between April and October to submerge emergent vegetation as habitat for macroinvertebrates, fish and waterbirds. It is likely that these relatively small discharges will be attained naturally from rainfall runoff throughout the target months.

Larger, sporadic winter flows are required to inundate in-stream benches and overtop riverbanks. Inundated in-stream benches provide habitat for fish while overbank flows are important for macroinvertebrates, fish, waterbirds, riparian vegetation and ecosystem processes. The required discharges are estimated at 30 ML/day for in-stream benches, and 37.2 ML/day for overbank flows.

There were several flow-ecology linkages for which a recommended flow regime has not been provided for Reach 1, including linkages related to sedimentation (1a and 3i), maintenance of the active channel (1b and part of 7b), and provision of undercut habitat for fish (3k). The relatively small volumes of water that could be discharged from the ERPs would not be enough to manage sedimentation in the river. Increased soil erosion, surface runoff and the resulting sedimentation require a whole-of-catchment management approach. Flows to maintain the active channel could not be determined for Reach 1 owing to a lack of historical discharge data. Undercut habitat for fish occurs over a wide range of flows; the height of riverbank undercuts varies from year to year in accordance with the inherent interannual variation in water levels. Additionally, several environmental attributes were not identified in this reach, including mid-bank vegetation (linkages 6c and parts of 4b and 7b), shallow backwaters (3h and part of 2d) and macrophyte beds (linkages 6d, 2b and 3f).

*Table 3 Recommended flow regime to fulfil EWRs for Reach 1*

| Flow-ecology linkages | Timing | Estimated threshold (ML/day) | Recommended flow frequency | Flow required from ERP valves? |
|---|---|---|---|---|
| Submerge riffles<br>2a | All year | 1.2 | Continuous | Yes |
| Maintain pool depth<br>3g, 4a | All year | 1.2 | Continuous | Yes |
| Maintain pool connectivity<br>5a, 2e, 3e, 2g; and part of 7b | All year | 1.2 | Continuous | Yes |
| Prevent anoxia<br>5b, 2f, 3c | All year | 1.2 | Continuous | Yes |

| Flow-ecology linkages | Timing | Estimated threshold (ML/day) | Recommended flow frequency | Flow required from ERP valves? |
|---|---|---|---|---|
| Small fish passage<br>3a | June to October | 2.1 | Continuous | Possibly* |
| Submerge emergent vegetation<br>3d, 2c, 6b; part of 4b | April to October | 2.1 | Continuous | Possibly* |
| Large fish passage<br>3b | November to January | 10.4 | Continuous throughout November<br>At least three spells of five days each, December to January | Yes† |
| Inundate in-stream benches<br>3l, 7c | April to October | 30.0 | Sporadic<br>(at least once a year during winter) | Unlikely |
| Overbank flows<br>6a, 3j, 7a; and parts of 2d, 7b and 4b | June to August | 37.2 | Sporadic<br>(at least once a year during winter) | Unlikely |

*Notes:*

* *Although the threshold flows for these linkages are relatively low at 2.1 ML/day, there are insufficient data to determine whether such flows are regularly achieved, or whether additional releases from ERP valves would be required.*

† *This threshold may not be achievable with the existing ERP infrastructure.*

## 4.2 Reach 2: Stocker Road

Stocker Road management reach (Reach 2) is at Roleystone, on the Darling Plateau's western margin and 3.3 km downstream of Soldiers Road management reach (Figure 8 and Figure 9). Summer flows in this section of the river are maintained by a combination of flows from the Araluen ERP, the Hill 60 ERP (located approximately 800 m upstream of Stocker Road), and from Churchman's Brook. The Churchman's Brook and Canning River confluence is 2.2 km upstream of the reach. Ten cross-sections were surveyed in this reach (Figure 10).

*Figure 8 Upstream view of Reach 2 (Stocker Road)*

*Figure 9 Example of riffle run (at left) and fringing vegetation at Reach 2*


*Figure 10 Aerial view of Stocker Road management reach showing the cross-sections and control point*

### 4.2.1 Ecological water requirements

The estimated threshold flows and recommended flow regimes to fulfil the EWR for Reach 2 are summarised in Table 4. The estimated flow thresholds in Table 4 apply to discharges measured at the control point within the reach, rather than at the ERP valves. For more detail on the calculation of flow thresholds, see Appendix C. The recommended discharge regime from the ERPs to attain the EWR is detailed in Section 5.

A summer minimum flow of approximately 2.2 ML/day (as measured at the control point) is required to submerge riffle habitat by at least 5 cm, maintain pool connectivity and prevent anoxic conditions in pools. Flow should be maintained at or above this level throughout the year.

For the months of November to January, freshwater cobbler require 'pulses' of approximately 6.1 ML/day to submerge riffles to at least 20 cm to allow upstream reproductive migration. Insufficient historical data on discharges within the reach prevented determination of whether past flows had been sufficient for cobbler passage. An approximate flow regime has been provided based on what was derived for the downstream reaches, where historical flow data were available.

Relatively small discharges of between 2.2 and 3.0 ML/day are required for small fish passage, submerging emergent vegetation and inundation of in-stream benches. Given that both groups of linkages require small volumes of water throughout the winter/spring period (when precipitation is highest); it is likely the flow thresholds will be attained naturally from rainfall runoff – without the need for supplementation from ERPs.

Hydraulic modelling indicates that a discharge of around 446 ML/day would be required to overtop riverbanks in Reach 2. Due to insufficient historical discharge data, it is not possible to determine the typical frequency of such events. However, based on discharge data from Seaforth gauging station, a reasonable estimate for a discharge of this magnitude would be once every three years or so during exceptionally high winter-rainfall events.

Flow recommendations have not been provided for several flow-ecology linkages in Reach 2. These include linkages related to sedimentation (1a and 3i), maintaining the active channel (1b and part of 7b), and provision of undercut habitat for fish (3k), for the same reasons as explained in Section 4.1.1. Additionally, several environmental attributes were not identified in this reach, including mid-bank vegetation (linkages 6c and parts of 4b and 7b), shallow backwaters (3h and part of 2d), pools deep enough to act as refuges during summer (3g and 4a) and macrophyte beds (6d, 2b and 3f).

*Table 4 Recommended flow regime to fulfil EWRs for Reach 2*

| **Flow-ecology linkages** | **Timing** | **Estimated threshold (ML/day)** | **Recommended flow frequency** | **Flow required from ERP valves?** |
|---|---|---|---|---|
| Submerge riffles<br>2a | All year | 2.2 | Continuous | Yes |
| Submerge emergent vegetation<br>3d, 2c, 6b; part of 4b | April to October | 2.2 | Continuous | Possibly* |
| Small fish passage<br>3a | June to October | 2.2 | Continuous | Possibly* |
| Maintain pool connectivity<br>5a, 2e, 3e, 2g; and part of 7b | All year | 2.2 | Continuous | Yes |
| Prevent anoxia<br>5b, 2f, 3c | All year | 2.2 | Continuous | Yes |

| Flow-ecology linkages | Timing | Estimated threshold (ML/day) | Recommended flow frequency | Flow required from ERP valves? |
|---|---|---|---|---|
| Inundate in-stream benches 3l, 7c | April to October | 3.0 | Sporadic (likely to be continuous during winter) | Unlikely |
| Large fish passage 3b | November to January | 6.1 | Continuous throughout November At least three high spells of five days each for the period December to January | Yes |
| Overbank flows 6a, 3j, 7a; and parts of 2d, 7b and 4b | June to August | 446.1 | Sporadic (approximately once every three years during winter)† | Unlikely |

*Notes:*

* *Although the threshold flows for these linkages are relatively low at 2.2 ML/day, there are insufficient data to determine whether such flows are regularly achieved, or whether additional releases from ERP valves would be required.*

† *Insufficient historical discharge data are available to accurately determine a flow regime for discharges of this magnitude.*

## 4.3 Reach 3: Bernard Street

Bernard Street management reach (Reach 3) is at Kelmscott, in the transition zone between the granitic Darling Plateau and the sands of the Swan Coastal Plain. Reach 3 consists of a large, slow-flowing pool that is highly aggradated (i.e. affected by sedimentation); it also has a number of riffle runs (Figure 11 and Figure 12 show typical views). See Figure 13 for an aerial view of the reach showing the location of the cross-sections and control point. The Bernard Street ERP is approximately 15 m downstream of the control point. Two of the nine surveyed cross-sections within the reach are downstream of the ERP. Flows at the seven cross-sections upstream of the ERP are provided by water released from the Araluen ERP and the Hill 60 ERP.

Figure 11 View of Reach 3 (Bernard Street) near the control point

Figure 12 Pool containing macrophyte bed in Reach 3 (Bernard Street)

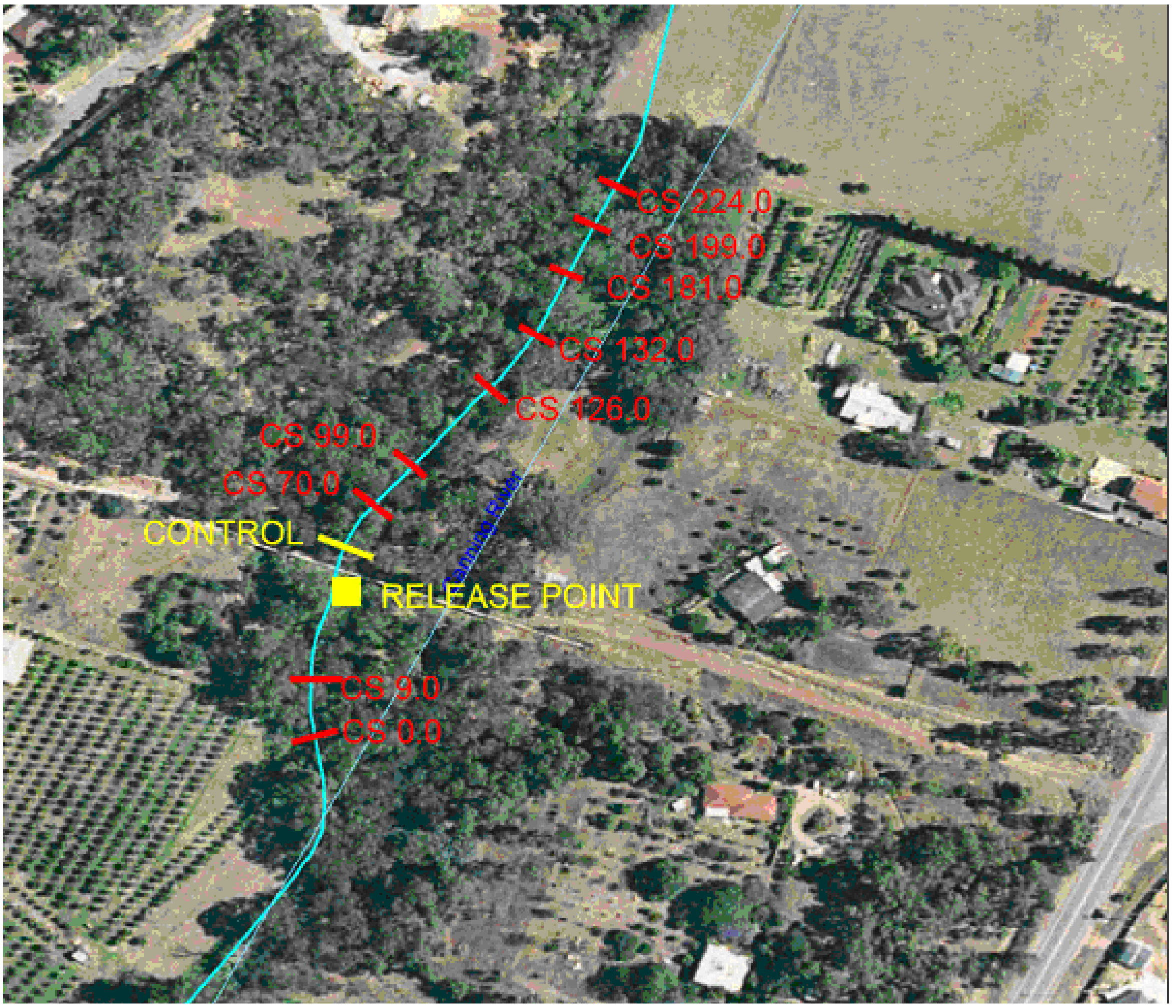



*Figure 13 Aerial view of Bernard Street management reach showing the cross-sections, control point and release point*

### 4.3.1 Ecological water requirements

The estimated threshold flows and recommended flow regimes to fulfil the EWR for Reach 3 are summarised in Table 5. For more detail on the calculation of flow thresholds, see Appendix C. The recommended flow regime from the six ERPs to meet the EWR is explained in Section 5.

In Reach 3, a summer-minimum flow of approximately 2.4 ML/day (as measured at the control point) is required to submerge sufficient riffle habitat to a depth of 5 cm, maintain pool connectivity and prevent anoxic conditions in pools. During the dry part of the year, much of this flow would be provided by water released from the ERP valves.

To enable upstream migration of freshwater cobbler, flow pulses of approximately 6.0 ML/day are required throughout their spawning season of November to January. Insufficient historical data were available to determine the past frequency of flows of this magnitude during the target months. An approximate flow regime of three high spells of five days' duration has been provided based on what was derived for the downstream reaches, where historical flow data were available. It is possible the estimated threshold flow of 6.0 ML/day could be attained with the existing release infrastructure.

A discharge of 4.7 ML/day is required to fulfil several winter/spring flow-ecology objectives, including providing sufficient water for small fish passage (at least 10 cm over obstacles), submerging emergent vegetation and inundating in-stream benches. Given the relatively small volume of water required during the wettest part of the year, it is likely these thresholds will be met by rainfall runoff during the target months – without the need for additional discharge from the ERP valves.

Relatively large flows are required sporadically in winter to inundate mid-bank vegetation and overtop riverbanks. Hydraulic modelling gave estimated discharges of 325.7 ML/day to inundate mid-bank vegetation and 580 ML/day to overtop riverbanks. Insufficient data were available to determine the historical frequency of such events. However, based on data from Seaforth gauging station, it is reasonable to assume these discharges would occur approximately once every two and three years respectively. No additional discharge from the ERP valves would be required.

Recommended flow regimes have not been provided for linkages related to sedimentation (1a and 3i), maintaining the active channel (1b and part of 7b), and provision of undercut habitat for fish (3k), for the same reasons explained in Section 4.1.1. Further, several environmental attributes were not identified in this reach, including shallow backwaters (3h and part of 2d) and pools deep enough to act as refuges during summer (3g and 4a).

*Table 5 Recommended flow regime to fulfil EWRs for Reach 3*

| Flow-ecology linkages | Timing | Estimated threshold (ML/day) | Recommended flow frequency | Flow required from ERP valves? |
|---|---|---|---|---|
| Submerge riffles<br>2a | All year | 2.4 | Continuous | Yes |
| Maintain pool connectivity<br>5a, 2e, 3e, 2g; and part of 7b | All year | 2.4 | Continuous | Yes |
| Prevent anoxia<br>5b, 2f, 3c | All year | 2.4 | Continuous | Yes |
| Submerge emergent vegetation<br>3d, 2c, 6b; part of 4b | April to October | 4.7 | Continuous | Possibly* |
| Small fish passage<br>3a | June to October | 4.7 | Continuous | Possibly* |
| Inundate in-stream benches<br>3l, 7c | April to October | 4.7 | Sporadic<br>(will occur continuously during winter) | Unlikely |

| Flow-ecology linkages | Timing | Estimated threshold (ML/day) | Recommended flow frequency | Flow required from ERP valves? |
|---|---|---|---|---|
| Large fish passage<br>3b | November to January | 6.0 | Continuous throughout November<br>At least three high spells of five days each for the period December to January | Yes |
| Inundate mid-bank vegetation<br>6c, parts of 4b and 7b | June to August | 325.7 | Sporadic (approximately once every two years during winter)† | Unlikely |
| Overbank flows<br>6a, 3j, 7a; and parts of 2d, 7b and 4b | June to August | 580.0 | Sporadic (approximately once every three years during winter)† | Unlikely |

*Notes:*

* *Although the threshold flows for these linkages are relatively low at 4.7 ML/day, there are insufficient data to determine whether such flows are regularly achieved, or whether additional releases from ERP valves would be required.*

† *No historical discharge data are available to accurately determine a flow regime for discharges of these magnitudes.*

## 4.4 Reach 4: Orlando Street

Orlando Street management reach (Reach 4) is at Kelmscott, within the transition zone between the Darling Plateau and the Swan Coastal Plain. The upstream section of Reach 4 has a large, slow-flowing pool affected by sedimentation. The middle and lower part of the reach has a narrower channel with a sequence of smaller pools and riffles (Figure 14). The Orlando Street ERP is located within the reach, beneath the Orlando Street bridge (Figure 15). Ten cross-sections were surveyed within Reach 4 (Figure 16).

*Figure 14 View of Reach 4 (Orlando Street) showing riparian vegetation*

*Figure 15 Canning River at Reach 4 release point (Orlando Street bridge)*


*Figure 16 Aerial view of Orlando Street management reach showing the cross-sections, control point and release point*

### 4.4.1 Ecological water requirements

The estimated threshold flows and recommended flow regimes to fulfil the EWR for Reach 4 are summarised in Table 6. As for all management reaches, the estimated flow thresholds apply to discharges measured *at the control point* within the reach, rather than at the ERP valves. For more detail on the calculation of flow thresholds, see Appendix C. The recommended flow regime from the ERP valves to achieve summer-critical EWRs is outlined in Section 5.

In Reach 4, a summer minimum flow of approximately 1.8 ML/day (as measured at the control point) is required to submerge sufficient riffle habitat to 5 cm, maintain pool depth to 50 cm, maintain pool connectivity and prevent anoxic conditions in pools.

Freshwater cobbler require flow pulses of around 9.3 ML/day at intervals throughout November, December and January to submerge obstacles to 20 cm (so the species can migrate upstream for spawning). Based on historical data from 1975 to 2007, flows have generally been sufficient throughout much of November. However, more flow than has normally been provided is likely to be needed during December and January. Wherever possible, water levels should be maintained at 20 cm over obstacles during these two months. However, recognising that water availability may be limited in dry years, a minimum recommendation of three high spells over the threshold of 9.3 ML/day for five days each has been made.

A discharge of approximately 1.8 ML/day is required continuously from April through to October to submerge emergent vegetation and provide sufficient water for upstream migration of small fish. At this discharge, obstacles such as riffles would be submerged by at least 10 cm. Time-series analysis of historical discharge data indicates that flow has very rarely fallen below the threshold in the target months over the past 33 years (see Appendix C). It is unlikely that additional flow from the ERP valves would be required to satisfy these linkages.

Large-volume sporadic flows during winter are required to satisfy the remainder of the flow-ecology linkages in Table 6. A discharge of around 219 ML/day will inundate in-stream benches, while discharges of 351 and 358 ML/day will inundate mid-bank vegetation and shallow backwaters respectively. Time-series analysis indicates that discharges of 219 ML/day occur at least once a year in winter in most years, while discharges of 358 ML/day occur in two out of every three years on average. Flows to maintain the active channel are estimated at 306 ML/year, a discharge that would occur once a year in 80 per cent of years. Insufficient data were available for estimating the discharge required to overtop banks. However, it is expected that flows of such magnitude would occur on average once every three years during winter.

Flow regimes have not been recommended for linkages related to sedimentation (1a and 3i) and provision of undercut habitat for fish (3k), for the same reasons outlined in Section 4.1.1. Additionally, there were no macrophyte beds in this reach (linkages 6d, 2b and 3f).

*Table 6 Recommended flow regime to fulfil EWRs for Reach 4*

| **Flow-ecology linkages** | **Timing** | **Estimated threshold (ML/day)** | **Recommended flow regime** | **Flow required from ERP valves?** |
|---|---|---|---|---|
| Submerge riffles<br>2a | All year | 1.8 | Continuous | Yes |
| Maintain pool depth<br>3g, 4a | All year | 1.8 | Continuous | Yes |
| Maintain pool connectivity<br>5a, 2e, 3e, 2g; and part of 7b | All year | 1.8 | Continuous | Yes |
| Prevent anoxia<br>5b, 2f, 3c | All year | 1.8 | Continuous | Yes |

| Flow-ecology linkages | Timing | Estimated threshold (ML/day) | Recommended flow regime | Flow required from ERP valves? |
|---|---|---|---|---|
| Submerge emergent vegetation<br>3d, 2c, 6b; part of 4b | April to October | 1.8 | Continuous | Unlikely |
| Small fish passage<br>3a | June to October | 1.8 | Continuous | Unlikely |
| Large fish passage<br>3b | November to January | 9.3 | Continuous throughout November<br>At least three high spells of five days for December to January | Yes |
| Inundate in-stream benches<br>3l, 7c | April to October | 219.5 | Sporadic<br>(at least once a year during winter) | Unlikely |
| Maintain active channel<br>1b; and part of 7b | June to August | 306.0 | Sporadic<br>(at least once a year in 80% of years) | Unlikely |
| Inundate mid-bank vegetation<br>6c, parts of 4b and 7b | June to August | 351.0 | Sporadic<br>(at least once in two of every three years) | Unlikely |
| Inundate shallow backwaters<br>3h; and part of 2d | April to October | 358.0 | Sporadic<br>(at least once in two of every three years) | Unlikely |
| Overbank flows<br>6a, 3j, 7a; and parts of 2d, 7b and 4b | June to August | Insufficient data to estimate discharge | Sporadic<br>(approximately once every three to four years during winter) | Unlikely |

## 4.5 Reach 5: Manning Avenue

Manning Avenue management reach (Reach 5) is located at Gosnells, on the Swan Coastal Plain (Figure 17 and Figure 18). Reach 5 has heavily aggradated slow-flowing pools within a heavily incised channel. The Manning Avenue ERP, located within the reach, is operated during summer to ensure water is available to licensed users. Ten cross-sections were surveyed within Reach 5 (Figure 19).

Figure 17 Canning River near Reach 5 release point (Manning Avenue)

Figure 18 Measuring thalweg depth in a pool in Reach 5 (Manning Avenue)

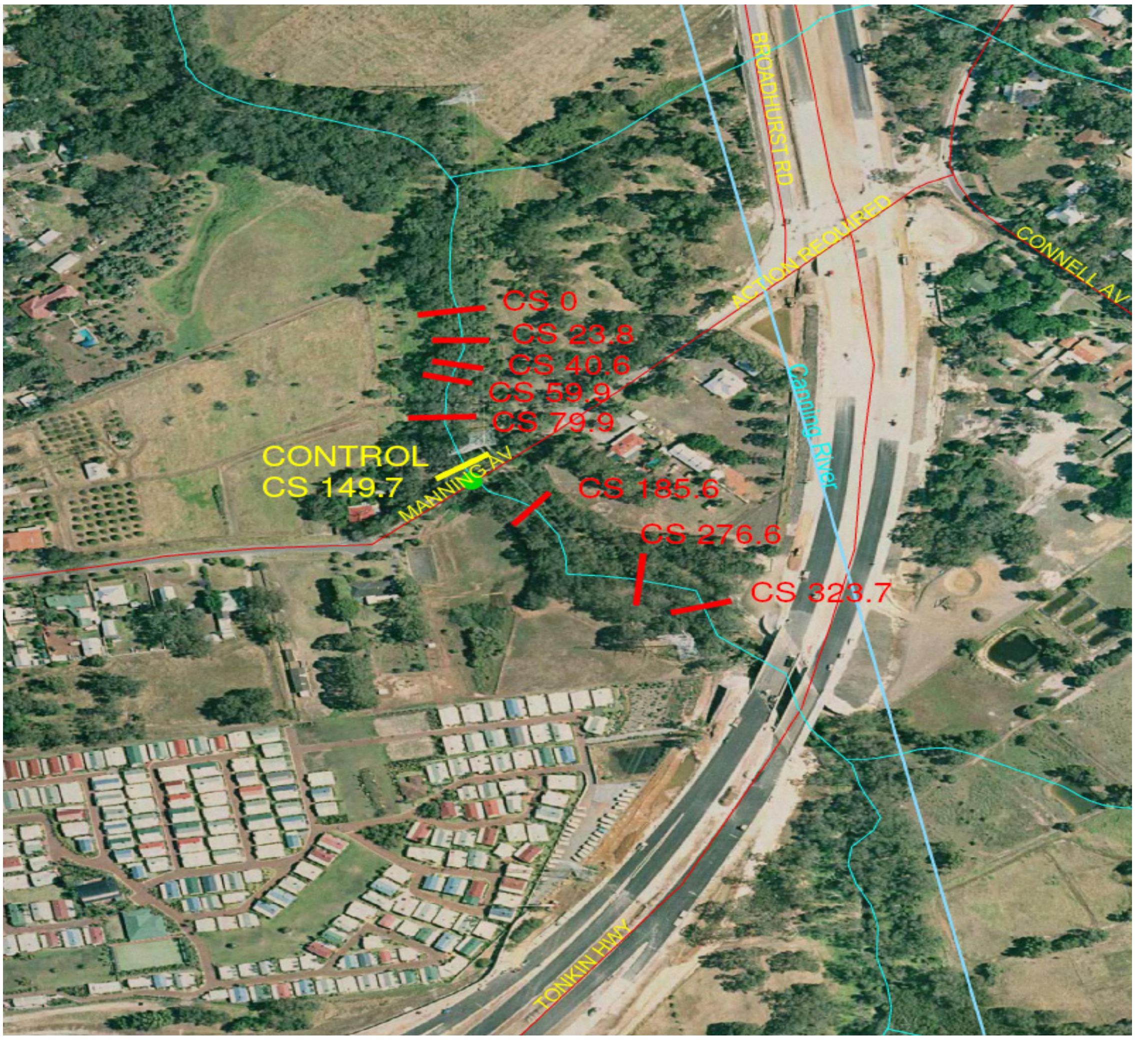



*Figure 19 Aerial view of Manning Avenue management reach showing the cross-sections, control point and release point*

### 4.5.1 Ecological water requirements

The estimated threshold flows and recommended flow regimes to fulfil the EWR for Reach 5 are summarised in Table 7. The estimated flow thresholds in Table 7 apply to discharges measured at the control point within the reach. For more detail on the calculation of flow thresholds, see Appendix C.

A summer minimum flow of approximately 2.6 ML/day is required to submerge sufficient riffle habitat to 5 cm, maintain pool depth to 80 cm, maintain pool connectivity and prevent anoxic conditions in pools[1]. Time-series analysis indicates that flow falls below the summer minimum flow for 21.5 days a year on average. Low spells have lasted for an average of just under five days. In the future, flows should be managed so that discharge remains above the threshold at all times, as far as practicable.

1 Not all of these linkages require a discharge of 2.6 ML/day (see Table 7). The highest discharge required continuously throughout summer has been used as the summer minimum.

Freshwater cobbler require a discharge of around 6.1 ML/day at intervals during November, December and January (so the species can migrate upstream). Based on historical data from 1975 to 2007, flows have generally been sufficient during November but have typically been below the threshold for much of December and January. Wherever possible, water levels should be maintained at 20 cm over obstacles during these two months. However, recognising that water availability may be limited in dry years, a minimum recommendation of three high spells over the threshold of 6.1 ML/day for five days each has been made. This flow regime corresponds to the average pattern of high spells over the threshold during the past 33 years.

A discharge of 4.6 ML/day between April and October is required to submerge emergent vegetation as habitat for fish, macroinvertebrates and waterbirds, and to provide sufficient flow (at least 10 cm over riffles) for upstream migration of small-bodied fish. Time-series analysis indicates that flows have almost always been above this threshold between June and October, and have occasionally fallen below the threshold in April and May. This discharge is likely to be attained naturally, without additional discharge from the ERP valves.

Larger, episodic winter flows are required to satisfy the remainder of the linkages in Table 7. A discharge of around 340 ML/day will inundate in-stream benches, an event that would occur in two out of every three years on average. Flows of around 416.5 and 444 ML/day should be enough to inundate mid-bank vegetation and shallow backwaters. Such events occur once every two years on average. Flows to maintain the active channel are estimated at 306 ML/year, which would occur at least once a year in 80 per cent of years based on past records. Insufficient data were available for estimating the discharge required to overtop banks. However, it is assumed that flows of such magnitude would occur once every three years.

No flow recommendations have been made for flow-ecology linkages related to sedimentation (1a and 3i) and provision of undercut habitat for fish (3k) (see Section 4.1.1. for an explanation). Additionally, there were no macrophyte beds (linkages 6d, 2b and 3f) in Reach 5.

*Table 7 Recommended flow regime to fulfil EWRs for Reach 5*

| Flow-ecology linkages | Timing | Estimated threshold (ML/day) | Recommended flow regime | Flow required from ERP valves? |
|---|---|---|---|---|
| Prevent anoxia<br>5b, 2f, 3c | All year | 0.6 | Continuous | Yes |
| Submerge riffles<br>2a | All year | 1.6 | Continuous | Yes |
| Maintain pool connectivity<br>5a, 2e, 3e, 2g; and part of 7b | All year | 1.9 | Continuous | Yes |

| Flow-ecology linkages | Timing | Estimated threshold (ML/day) | Recommended flow regime | Flow required from ERP valves? |
|---|---|---|---|---|
| Maintain pool depth<br>3g, 4a | All year | 2.6 | Continuous | Yes |
| Submerge emergent vegetation<br>3d, 2c, 6b; part of 4b | April to October | 4.6 | Continuous | Unlikely |
| Small fish passage<br>3a | June to October | 4.6 | Continuous | Unlikely |
| Large fish passage<br>3b | November to January | 6.1 | Continuous throughout November<br>At least three high spells of five days each, December to January | Yes |
| Maintain active channel<br>1b; and part of 7b | June to August | 306.0 | Sporadic<br>(at least once a year in 80% of years in winter) | Unlikely |
| Inundate in-stream benches<br>3l, 7c | April to October | 340.0 | Sporadic<br>(at least once in two of every three years) | Unlikely |
| Inundate mid-bank vegetation<br>6c, parts of 4b and 7b | June to August | 416.5 | Sporadic<br>(approximately once every two years) | Unlikely |
| Inundate shallow backwaters<br>3h; and part of 2d | April to October | 444.0 | Sporadic<br>(approximately once every two years) | Unlikely |
| Overbank flows<br>6a, 3j, 7a; and parts of 2d, 7b and 4b | June to August | Insufficient data to estimate discharge | Sporadic<br>(approximately once every three to four years during winter) | Unlikely |

## 4.6 Reach 6: Pioneer Park

Pioneer Park management reach (Reach 6) is located at Kelmscott, on the Swan Coastal Plain (Figure 20 and Figure 21). Reach 6 consists largely of partially aggradated, slow-flowing pools within heavily incised channels. Extensive river restoration activities to reduce riverbank and streambed erosion were completed in 2005. Works included installation of bank toe protection, establishment of timber riffles and bank revegetation. The Gosnells Bridge ERP is located downstream of Reach 6; the nearest upstream ERP is within Reach 5. Ten cross-sections were surveyed within Reach 6 (Figure 22).

*Figure 20 Canning River with suspended sediment, Reach 6 (Pioneer Park)*

*Figure 21 Canning River during trial release, Reach 6 (Pioneer Park)*


*Figure 22 Aerial view of Pioneer Park management reach showing the cross-sections, control point and release point*

### 4.6.1 Ecological water requirements

The estimated threshold flows and recommended flow regimes to fulfil the EWR for Reach 6 are summarised in Table 8. The estimated flow thresholds in Table 8 apply to discharges measured at the control point within the reach. For more detail on the calculation of flow thresholds, see Appendix C.

In Reach 6, a summer-minimum flow of approximately 2.0 ML/day is required to submerge riffle habitat to at least 5 cm, maintain pool depth to at least 50 cm, maintain pool connectivity and prevent anoxia in pools[2].

A discharge of 10.7 ML/day is required to provide sufficient water depth (20 cm over obstacles) for upstream reproductive migration of freshwater cobbler during November, December and January. Based on historical data from 1975 to 2007,

[2] Not all of these linkages require a discharge of 2.0 ML/day (see Table 8). The highest discharge required continuously throughout summer has been used as the summer minimum.

flows have generally been sufficient during November, but insufficient for most of December and January. Wherever possible, water levels should be maintained at 20 cm over obstacles for these two months. Recognising that availability may be limited in dry years, a minimum recommendation of three high spells over the threshold of 10.7 ML/day for five days each has been made.

A discharge of 10.7 ML/day is required from April to October to submerge emergent vegetation as habitat for fish, macroinvertebrates and waterbirds, and to inundate in-stream benches. Time-series analysis of historical discharge data from 1975 to 2007 (Appendix C) indicates that flows have generally been sufficient throughout the target months, with occasional low spells below the threshold. Additional flow from ERP valves is unlikely to be required to satisfy these flow-ecology linkages.

High-volume, sporadic winter flows are required to satisfy the other flow-ecology linkages in Table 8. A modelled discharge of around 90 ML/day will be enough to inundate shallow backwaters, an event which is likely to occur several times a year in spells of at least four days. Flows to maintain the active channel are estimated at 306 ML/year, an event which would occur at least once a year in 80 per cent of years. Insufficient data were available for estimating the discharges required to inundate mid-bank vegetation or overtop banks. However, it is expected that flows of such magnitude would occur on average once every two, three or four years during winter.

There were several flow-ecology linkages for which a recommended flow regime has not been provided, including linkages related to sedimentation (1a and 3i) and provision of undercut habitat for fish (3k) (see Section 4.1.1 for further explanation). In this reach, there were no macrophyte beds (linkages 6d, 2b and 3f).

*Table 8 Recommended flow regime to fulfil EWRs for Reach 6*

| **Flow-ecology linkages** | **Timing** | **Estimated threshold (ML/day)** | **Recommended flow regime** | **Flow required from ERP valves?** |
|---|---|---|---|---|
| Prevent anoxia<br>5b, 2f, 3c | All year | 0.6 | Continuous | Yes |
| Submerge riffles<br>2a | All year | 2.0 | Continuous | Yes |
| Maintain pool connectivity<br>5a, 2e, 3e, 2g; and part of 7b | All year | 2.0 | Continuous | Yes |
| Maintain pool depth<br>3g, 4a | All year | 2.0 | Continuous | Yes |
| Small fish passage<br>3a | June to October | 2.0 | Continuous | Unlikely |

| Flow-ecology linkages | Timing | Estimated threshold (ML/day) | Recommended flow regime | Flow required from ERP valves? |
|---|---|---|---|---|
| Large fish passage<br>3b | November to January | 10.7 | Continuous throughout November<br>At least three high spells of five days each for the period December to January | Yes |
| Submerge emergent vegetation<br>3d, 2c, 6b; part of 4b | April to October | 10.7 | Continuous | Unlikely |
| Inundate in-stream benches<br>3l, 7c | April to October | 10.7 | Sporadic<br>(based on past discharges, will occur almost continuously) | Unlikely |
| Inundate shallow backwaters<br>3h; and part of 2d | April to October | 90.0 | Sporadic<br>(several high spells lasting around four days each in winter) | Unlikely |
| Maintain active channel<br>1b; and part of 7b | June to August | 306.0 | Sporadic<br>(at least once a year in 80% of years in winter) | Unlikely |
| Inundate mid-bank vegetation<br>6c, parts of 4b and 7b | June to August | Insufficient data to estimate discharge | Sporadic<br>(approximately once every two years in winter) | Unlikely |
| Overbank flows<br>6a, 3j, 7a; and parts of 2d, 7b and 4b | June to August | Insufficient data to estimate discharge | Sporadic<br>(approximately once every three to four years during winter) | Unlikely |

# 5 Discussion

This section discusses how this study was implemented and described the release schedule implemented over the summers of 2008–09 and 2009–10. It evaluates some of the limitations of the methods used, recommends further monitoring and other work. It outlines the next steps in the water allocation planning process.

## 5.1 Implementation of the EWR study

The implementation of the flow regime described in this report is achieved primarily by manipulating the volume of water discharged from the six ERPs along the lower Canning River during the relatively dry months of November to May. Currently the Water Corporation coordinates the release of water from these points. Section 5.2 examines the data on water provision since the summer of 2002–03 and presents preliminary guidelines used for the release of water from ERP valves over the summers of 2008–09 and 2009–10.

A more ‘fine scale’ management of water releases than what has occurred previously was required for implementation of the flow regime described here. The flow regime from the ERP valves required ongoing monitoring and the capacity to manipulate releases at short notice. Bearing in mind the practical side of implementation, the preliminary guidelines in Section 5.2 have been based on the use of simple, easily measured ‘triggers’ for turning ERP valves on and off, and increasing and decreasing discharges from ERPs when required. A key component of the plan will be to install better meters on the ERPs to enable accurate calculation of the volume of water released.

The ERP valves will not be required to meet flows for winter-critical flow-ecology linkages. However, monitoring should be undertaken over the winter months to determine the frequency, duration and magnitude of flows required to fulfil winter EWRs.

The logistics of implementing the flow regime, the responsibilities to be assigned and the development of a reporting and management system will be discussed between stakeholders. The key stakeholders are the Department of Water and the Water Corporation. The monitoring and reporting program will be detailed in the surface water allocation plan for the lower Canning River (see Section 5.6).

## 5.2 Provision of water from environmental release points

This section examines past provision of water from the ERPs, and provides guidelines on how to improve the delivery of water from them (based on the results of this study).

### 5.2.1 Historical provision of water from environmental release points

The flow regimes from the six ERP valves from the summers of 2004–05 to 2007–08 are given in Table 9. The average volume of water released for the five seasons was 1399 ML, ranging between 1046 ML in 2004–05 to 1789 ML in 2006–07. For reference, as of February 2007, the total annual licensed water allocation along the whole length of the Canning River below Canning Reservoir was approximately 760 ML.

*Table 9 Annual discharges for the six environmental release points (ERPs), 2004–05 to 2007–08*

| Environmental release point | Total amount released a year (ML) | | | |
|---|---|---|---|---|
| | **2004–05** | **2005–06** | **2006–07** | **2007–08** |
| Araluen | 508.0 | 605.3 | 577.0 | 545.0 |
| Hill 60 | 74.0 | 133.8 | 254.3 | 59.5 |
| Bernard Street | 2.0 | 0.0 | 0.0 | 0.0 |
| Orlando Street | 317.3 | 361.1 | 532.3 | 420.1 |
| Manning Avenue | 0.0 | 0.0 | 16.5 | 124.0 |
| Gosnells Bridge | 145.1 | 306.9 | 409.0 | 205.8 |
| **Annual total** | **1046.4** | **1407.1** | **1789.1** | **1354.4** |
| **Average release** | **1399.2 ML/year** | | | |

For the years 2002–03 to 2006–07, the dates the valves were first turned on ranged from 30 October to 25 November. The Araluen ERP was typically turned on first, to its full capacity of approximately 2.8 ML/day. The date the last ERP valve was turned off in each year ranged from 16 May to 6 August (see Figure 23 for diagrammatic representation).

Discharge at Seaforth gauging station is compared with the summer EWRs[3] in Figure 23. The time period shown in Figure 23 includes those years when data were available on water released by the Water Corporation at the ERP valves, and when mean daily discharge data were available from Seaforth station. For three of the five seasons with data, discharge at Seaforth station either did not drop below the summer-minimum discharge, or dropped below for only a short period. However, in 2002–03 and 2006–07, discharge at Seaforth station dropped well below the summer minimum on several occasions. In 2002–03, discharge was below the minimum for a large part of the summer. In all years, there have been relatively few periods with discharges high enough to allow for upstream migration of freshwater cobbler in November, December and January.

For all years, it seems likely that ERP valves could have been shut off at least four weeks earlier without compromising the year-round minimum EWR (Figure 23). In

[3] The summer EWRs shown in Figure 23 are those of Reach 4, which is the nearest upstream control point to Seaforth gauging station.

two of the years on record, flow could have been turned off three months earlier without having a significant effect on the minimum EWR.

### 5.2.2 Preliminary guidelines for water provision from the ERP valves

A regime for water provision from the ERPs has been developed to guide the delivery of water over the summer months (Table 10). For the summers of 2008–09 and 2009–10, monitoring was undertaken to determine whether the guidelines were adequate or needed modification. The guidelines were based on maintaining the minimum summer water level in the six management reaches (see Section 4) year-round, and providing pulses of water for upstream migration of freshwater cobbler during December and January. At no time was flow to be reduced to zero along any section of the lower Canning River.

The regime is based on the best available information. However, substantial gaps in knowledge of the system exist. When more information becomes available, improvement of the environmental water provision scheme can occur. In particular, very little data on losses of water from the system are available. Based on the summer trial results, a loss of 25 per cent of the volume of water between discharge points and downstream control points (to abstraction, evaporation and infiltration) is assumed. The basis for the '25 per cent loss rule' is the finding that after three days of discharge from the Araluen ERP (at full capacity), the nearest downstream control point was registering a discharge of approximately 75 per cent of what was released at the ERP.

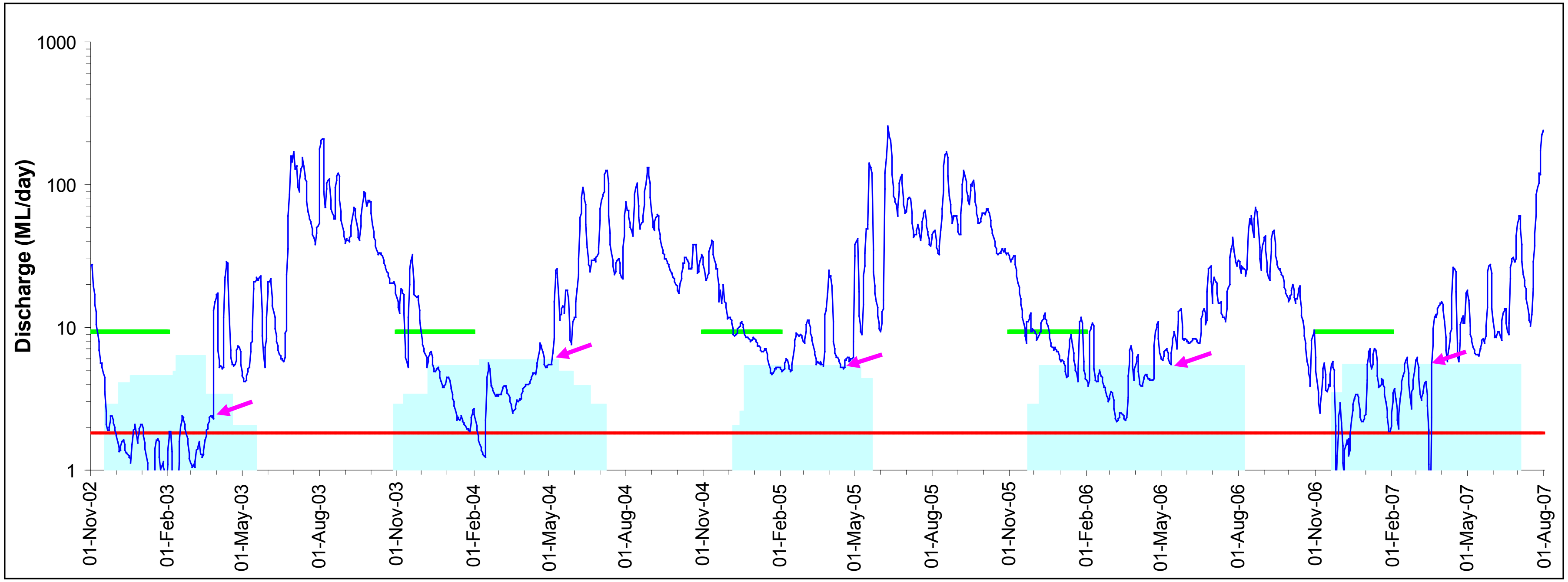



*Figure 23 Comparison of discharge at Seaforth with discharge from the ERPs and minimum summer water requirements*

*Table 10 Regime for water provision from the ERPs over the summer months*

Note that no additional discharge for sporadic, winter or interannual flows is likely to be required from the ERP valves.

| Flow component | Task/activity | Trigger for action | Information source | Daily volumes of water to be released from the ERPs | Timeframe |
|---|---|---|---|---|---|
| **Summer minimum flow** (includes discharges required to maintain flow connectivity, maintain pool depth as refuge habitat, maintain minimum flow over riffles for macroinvertebrates and prevent anoxic conditions in pools) | Turn on ERPs in late spring to maintain summer flow. | When discharge at Seaforth gauging station falls below 9.3 ML/day (0.108 $m^3$/sec) for three consecutive days in late spring.<br>ERP valves to be turned on to standard summer-flow schedule within 48 hours of this event. | Daily telemetry data on discharge and stage height for Seaforth gauging station on Department of Water website. | The volumes listed below are referred to as the **'standard summer-flow schedule'**.<br>Araluen ERP: 2.8 ML/day<br>Hill 60 ERP: 2.2 ML/day<br>Bernard St ERP: 0.7 ML/day<br>Orlando St ERP: 1.6 ML/day<br>Manning Ave ERP: 0.2 ML/day<br>Gosnells Bridge ERP: 1.0 ML/day<br>These volumes are to be maintained until the end of the low-flow period, which will coincide with the onset of substantial late autumn/early winter rains. | Revision of mean daily discharge at Seaforth gauging station to start on 15 October. Revision to continue until mean daily discharge drops below 9.3 ML/day and flows have commenced. |
| **Summer minimum flow** | Inform the Department of Water if mean daily discharge at Seaforth gauging station falls below the recommended summer minimum flow. | If mean daily discharge at Seaforth gauging station falls below 1.8 ML/day (0.021 $m^3$/sec) following the start of summer flow. | Daily telemetry data on discharge and stage height for Seaforth gauging station on Department of Water website. | To be negotiated between the Department of Water and Water Corporation in the event that summer flow consistently falls below 1.8 ML/day at Seaforth gauging station. | Once ERP valves have been turned on, regular revision of mean daily discharge at Seaforth gauging station to ensure sustained minimum flow of at least 1.8 ML/day at Seaforth gauging station. |

| Flow component | Task/activity | Trigger for action | Information source | Daily volumes of water to be released from the ERPs | Timeframe |
|---|---|---|---|---|---|
| **Summer minimum flow** | Turn off valves in late autumn or early winter following the onset of winter rains. | Once cumulative rainfall received after 1 April reaches 40 mm.<br>Note that this trigger may occur in May, or even early June in an exceptionally dry year. | Daily rainfall data for Gosnells weather station on Bureau of Meteorology (BOM) website. | Not applicable.<br>Note that ERP valves should be turned off gradually, starting from the furthest downstream and ending with the furthest upstream. The recommended schedule is to turn off ERPs two at a time, at one week intervals. | Revision of rainfall data from 1 April from Gosnells BOM station.<br>Revision to continue until trigger has been reached. |
| **Summer minimum flow** | Inform the Department of Water if flow falls below the minimum level of 1.8 ML/day after ERP valves have been turned off. | If heavy rainfall in April or May is followed by an extended (i.e. three weeks or more) period of no or very low rainfall. | Daily telemetry data on discharge and stage height for Seaforth gauging station on Department of Water website. | To be negotiated between the Department of Water and Water Corporation in the event that flow consistently falls below 1.8 ML/day at Seaforth gauging station after ERP valves have been turned off. | Occasional revision of discharge data as required. |
| **Freshwater cobbler passage flows** (includes up to three higher volume 'pulse' flows to aid upstream fish migration between November and January) | Provide flow pulse(s) of five days' duration for upstream passage of freshwater cobbler. | Once mean daily discharge at Seaforth gauging station falls below 9.3 ML/day (0.108 $m^3$/sec) for 15 consecutive days at any point between the start of November and the end of January. | Daily telemetry data on discharge and stage height for Seaforth gauging station on Department of Water website. | Note that the volumes below are to be released for FIVE DAYS only. After five days, ERP flow volumes must be returned to the standard summer-flow schedule.<br>Araluen ERP: 2.8 ML/day<br>Hill 60 ERP: 3.1 ML/day<br>Bernard St ERP: 4.5 ML/day<br>Orlando St ERP: 2.5 ML/day<br>Manning Ave ERP: 5.4 ML/day<br>Gosnells Bridge ERP: 2.5 ML/day | Revision of mean daily discharge figures for Seaforth gauging station from 1 November to determine whether flow has fallen below 9.3 ML/day for 15 consecutive days.<br>Revision to continue until end of January.<br>Note that more than one flow pulse may be required. |

Following the 25 per cent loss rule, for each management reach it has been assumed the discharge at the control point will be approximately 75 per cent of the volume of water passing through the nearest upstream control point, plus 75 per cent of the volume of water discharged from any ERPs in between the two control points. While this assumption is a good starting point for environmental water provision, further monitoring is required to test its robustness – particularly at different flow rates and during periods of low and high water demand by licensed users. The corresponding minimum discharges from the ERPs that would deliver the required summer discharges at the control points are outlined in Figure 24.

The recommended date for ERP valves to be turned on is when mean daily flow at Seaforth gauging station falls below 9.3 ML/day for the first time in spring. This is the discharge that corresponds to the water requirement for upstream migration of freshwater cobbler at Reach 4 (the nearest upstream control point to Seaforth station). The logic behind using this discharge as the 'trigger' value is to maintain water levels suitable for cobbler passage for as long as possible. Evaluation of the historical discharge data at Seaforth station for 1975 to 2007 shows the median date for flow falling below 9.3 ML/day for the first time is 14 November. In the driest 20 per cent of years, flow fell below 9.3 ML/day on 1 November or earlier. In the wettest 20 per cent of years, flow fell below the threshold for the first time on 2 December or later. These three dates have been used to calculate *indicative* volumes of water discharged in a hypothetical 'average', 'dry' and 'wet' summer (Table 11). It is thought that these volumes will be enough to satisfy the EWR *taking into account* abstraction from licensed users.

The recommended date for ERP valves to be turned off corresponds with the onset of substantial autumn/winter rains. This has been defined as the first date that cumulative rainfall *after* 1 April reaches 40 mm, as recorded at the Bureau of Meteorology weather station in Gosnells. For example, if cumulative rainfall for the year has reached 15 mm by 1 April, ERP valves should be gradually turned off starting on the first date that cumulative rainfall for the year reaches 55 mm (e.g. by turning off two valves at one-week intervals). The cut-off date of 1 April has been chosen to avoid confounding rains from summer thunderstorms (or decaying tropical cyclones) with the onset of winter rains.

Examination of rainfall records from 1975 to 2007 showed the median date for cumulative rainfall reaching 40 mm or more after 1 April was 7 May. In the driest 20 per cent of years, sufficient rainfall was recorded by 19 May or later. In the wettest 20 per cent of years, adequate rainfall was measured by 18 April or earlier. These three dates have been used to calculate *indicative* volumes of water to be discharged in a hypothetical 'average', 'dry' and 'wet' year (Table 11).

Pulses of water will also be required for upstream cobbler migration at intervals during December and January. Analysis of historical discharge data showed that the average regime of the lowest discharge suitable for cobbler migration (i.e. 6.1 ML/day in Reach 5) was three high spells of around five days each in December and January. It is recommended that the 'average' regime be maintained, and that monitoring be carried out to determine whether cobbler are able to take advantage of pulses of water and move upstream.

Up to three higher-volume flow pulses over five days should be provided throughout December and January for cobbler migration. The recommended 'trigger' for turning on such flows occurs when discharge at Seaforth gauging station has fallen below 9.3 ML/day (the minimum discharge for cobbler passage in Reach 4) for 15 consecutive days. The monitoring period should start in November. After 15 days of flow below the threshold, all ERP valves should be switched to approximately two-thirds of their total capacity for a period of five days, and then changed back down to the normal flow regime. Monitoring of mean daily discharge at Seaforth station should begin immediately after the flow pulse is stopped. If discharge at Seaforth station again falls below 9.3 ML/day for another 15 consecutive days, this would trigger another flow pulse of two-thirds capacity for five days. The cycle of monitoring and release of flow pulses should continue until the end of January. In a 'wet' year, it is unlikely that additional flow pulses for cobbler passage would be needed. Conversely, in an exceptionally dry year, all three flow pulses may be needed from the ERP valves. In most years, one or two flow pulses from the ERP valves would be triggered by environmental conditions. The indicative values shown in Table 11 reflect this interannual variability.

Monitoring of discharge at Seaforth gauging station and occasional flow gaugings at the control points will be required to ensure that discharge does not drop below the minimum EWR. If discharge does fall below this threshold, small incremental increases in the volume of water discharged by the ERPs should be made until minimum water levels and discharges are restored. In years when heavy rainfall in April or May is followed by an extended dry period (as occurred in 2002, for example), occasional monitoring of discharge at Seaforth station will be required to ensure that discharge does not fall below the minimum level after ERP valves have been turned off. A suitable monitoring and reporting schedule for flow gaugings at the control points will need to be determined.

A reduction in the minimum recommended discharges may be considered if the discharge data from Seaforth gauging station and the control points within the management reaches suggest that flows are continuously well above (i.e. at least 50 per cent above) the summer minimum EWR. A thorough review of the available data and consultation between the Water Corporation and Department of Water would be required in such an event.

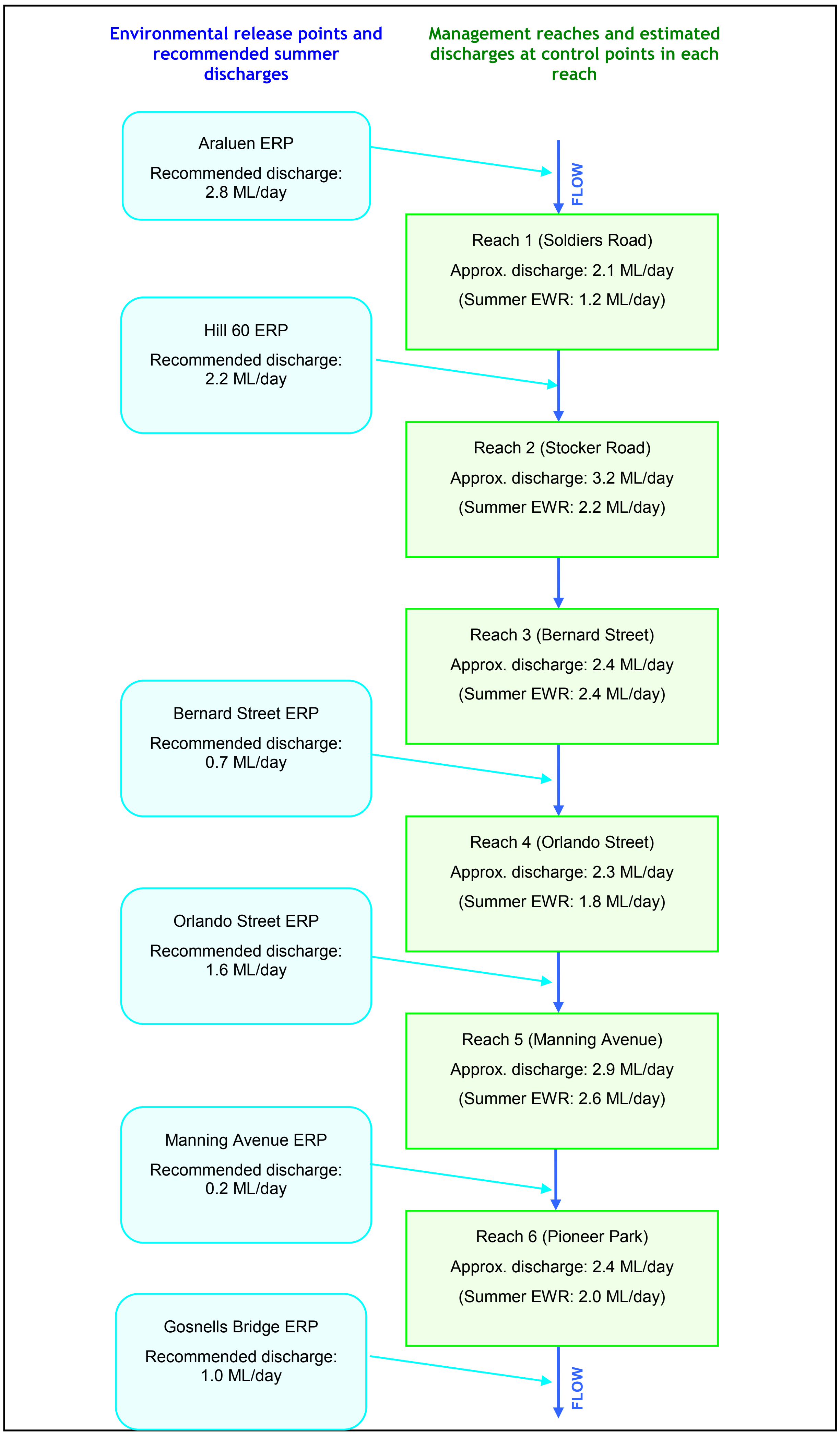



*Figure 24 Diagrammatic representation of summer minimum ERP discharges for the lower Canning River*[iv]

[iv] The boxes on the left side of the diagram represent the proposed volumes of water to be released from the six ERPs that would satisfy the summer-minimum EWRs in the six management reaches along the lower Canning River. The six reaches are represented by the green boxes on the right of the diagram. The approximate discharge (at the control point) given for each reach was calculated as 75 per cent of the discharge from upstream sources. Upstream sources are denoted as blue arrows in the diagram, and represent water flowing along the Canning River through upstream management reaches (dark blue) and additional water provided from ERPs (lighter blue).

*Table 11 Approximate volumes of water that would be released in hypothetical 'average', 'dry' and 'wet' years, using dates for 2008–09*

* *The total discharges given below should only be used as a guide to the approximate volume of water that would be released, based on the guidelines in Table 10. They should not be used in a prescriptive or absolute sense. Actual total discharge from the ERPs will vary annually based on weather patterns, abstraction demands and other variables. See text for details on the calculation of indicative dates.*

| **Environmental release points** | Indicative date ERP turned on | Indicative date ERP turned off | Days of baseflow | Baseflow (ML/day) | Total baseflow (ML) | Cobbler passage days | Cobbler flow (ML/day)* | Total cobbler flow (ML) | Total discharge (ML) |
|---|---|---|---|---|---|---|---|---|---|
| ***Hypothetical 'average' year*** | | | | | | | | | |
| Araluen | 14/11/08 | 07/05/09 | 174 | 2.8 | 487.2 | NA† | NA† | NA† | 487.2 |
| Hill 60 | 14/11/08 | 07/05/09 | 174 | 2.2 | 382.8 | 5 | 0.9 | 4.7 | 387.5 |
| Bernard Street | 14/11/08 | 14/05/09 | 181 | 0.1 | 18.1 | 5 | 3.0 | 15.2 | 33.3 |
| Orlando Street | 14/11/08 | 14/05/09 | 181 | 1.6 | 289.6 | 5 | 3.1 | 15.3 | 304.9 |
| Manning Avenue | 14/11/08 | 21/05/09 | 188 | 0.2 | 37.6 | 5 | 5.2 | 26.0 | 63.6 |
| Gosnells Bridge | 14/11/08 | 21/05/09 | 188 | 1.6 | 300.8 | 5 | 0.9 | 4.3 | 305.1 |
| *Estimated total volume of water discharged from ERPs in 'average' year:* **1581.6 ML** | | | | | | | | | |
| ***Hypothetical 'dry' year*** | | | | | | | | | |
| Araluen | 01/11/08 | 19/05/09 | 199 | 2.8 | 557.2 | NA† | NA† | NA† | 557.2 |
| Hill 60 | 01/11/08 | 19/05/09 | 199 | 2.2 | 437.8 | 15 | 0.9 | 14.0 | 451.8 |
| Bernard Street | 01/11/08 | 26/05/09 | 206 | 0.1 | 20.6 | 15 | 3.0 | 45.5 | 66.1 |
| Orlando Street | 01/11/08 | 26/05/09 | 206 | 1.6 | 329.6 | 15 | 3.1 | 46.0 | 375.6 |
| Manning Avenue | 01/11/08 | 02/06/09 | 213 | 0.2 | 42.6 | 15 | 5.2 | 78.0 | 120.6 |
| Gosnells Bridge | 01/11/08 | 02/06/09 | 213 | 1.6 | 340.8 | 15 | 0.9 | 13.0 | 353.8 |
| *Estimated total volume of water discharged from ERPs in 'dry' year:* **1925.1 ML** | | | | | | | | | |
| ***Hypothetical 'wet' year*** | | | | | | | | | |
| Araluen | 02/12/08 | 18/04/09 | 137 | 2.8 | 383.6 | NA† | NA† | NA† | 383.6 |
| Hill 60 | 02/12/08 | 18/04/09 | 137 | 2.2 | 301.4 | 0 | 0.9 | 0.0 | 301.4 |
| Bernard Street | 02/12/08 | 25/04/09 | 144 | 0.1 | 14.4 | 0 | 3.0 | 0.0 | 14.4 |
| Orlando Street | 02/12/08 | 25/04/09 | 144 | 1.6 | 230.4 | 0 | 3.1 | 0.0 | 230.4 |
| Manning Avenue | 02/12/08 | 02/05/09 | 151 | 0.2 | 30.2 | 0 | 5.2 | 0.0 | 30.2 |
| Gosnells Bridge | 02/12/08 | 02/05/09 | 151 | 1.6 | 241.6 | 0 | 0.9 | 0.0 | 241.6 |
| *Estimated total volume of water discharged from ERPs in 'wet' year:* **1201.6 ML** | | | | | | | | | |

## 5.3 Quality of water released from valves

At present the water released at the ERP valves is chlorinated scheme water. In January and February 2005, a study was undertaken to determine the levels of chlorine in the river system downstream of the six ERP valves (Chandler & Reid, 2005; Radin et al. 2007). Chlorine breaks down rapidly with adequate aeration and exposure to sunlight. The results indicated that chlorine levels dissipated with increasing distance from the release points, so that chlorine concentrations 500 m downstream of all six release points were within acceptable ANZECC/ARMCANZ levels of 6 μg/L or less (ANZECC/ARMCANZ 2000).

Chlorinated water is the river's main source of water during the summer months. Improved aeration of the released water would further lower chlorine levels (Radin et al. 2007).

## 5.4 Evaluation and limitations of the methods used to evaluate the EWR

Evaluation of the EWRs for particular species, groups of organisms and ecological processes is an imprecise science based on available (and usually incomplete) information on water requirements (as reviewed in the companion document by Radin et al. 2007), computer modelling of discharge and revision of historical data.

Field manipulation of flows is usually impossible in EWR studies, limiting control over the water levels used to calibrate the hydraulic model of the riverbed. This may mean that no 'calibration' curves are available to adjust the model for very high or very low flows, leading to inaccuracies in the modelled discharges. In the lower Canning River, it was possible to manipulate low flows with a trial water release. Observations during the trial were used to compare water levels associated with actual discharges with those derived from modelled discharges. The results gained using these two methods were often different. The limitations of the two techniques must be considered, because together they were used to determine the EWRs for each reach.

### 5.4.1 Limitations of hydraulic modelling

In many cases, there were substantial differences between the hydraulic modelling results and the field observations of water levels at different discharges. Often the hydraulic model overestimated the discharge required to attain a particular water level, especially for summer-critical criteria that required relatively small volumes of water. This may have been because the model was not calibrated with sufficient measurements of low flows. In all cases, field measurements of discharge were preferred over modelled flows and used as the threshold criteria. Most of the low-flow objectives have been specified with reference to actual discharges measured in the field.

Conversely, the hydraulic model was calibrated with only a small number of discharge measurements over 430 ML/day (equivalent to 5 $m^3$/sec). A discharge of this magnitude corresponds roughly to the maximum daily flow that would be recorded once a year in 80 per cent of years. Modelled discharges greater than this magnitude should be considered as estimates only.

### 5.4.2 Evaluation and limitations of the summer trial water release

The results of the summer trial water release from the ERP valves during March 2007 were useful in defining the threshold discharges necessary to reach target water levels. In particular, the trial results enabled an accurate determination of discharges for meeting summer low-water-level criteria. However, the trial release had two main limitations.

Firstly, some of the threshold discharges listed in this report are likely to overestimate the minimum discharge required to meet target water levels. During the trial, discharge was measured at 24-hour intervals, rather than continuously or at the exact moment that critical water levels were reached. Future monitoring may show that the threshold discharges can be revised downwards.

Secondly, the trial results cannot be used to directly correlate discharges from the ERP valves with downstream discharges measured at the control points within each reach. The pre-trial low-flow period led to a pronounced drop in water levels at several management reaches. There were long delays (up to three days) before resumption of downstream flow in locations where large pools became disconnected and then slowly refilled. Discharges from the ERP valves increased sharply over a short period of time, and it seems unlikely that sufficient time elapsed before flows at downstream control points were a true reflection of the upstream discharge from the ERP valves. For example, at the three uppermost management reaches, discharge at the control point continued to increase after upstream ERP valves were set to a constant discharge for two or more days (see Appendix A). The ‘25 per cent loss rule’ that has guided water provision from the ERP valves (as described in Section 5.2.2) is an approximation only, and may be revised as more comprehensive data become available.

### 5.4.3 Modifications to improve results of any future trial release

If the summer low-flow trial were to be repeated, several modifications could be made to improve the utility of the results. First, periods of very low to zero flow should be avoided so that flow does not become disconnected. Second, more accurate measurements of discharge are required from the ERP valves. This could be accomplished by calibrating the existing flow meters on each of the discharge points, and replacing faulty meters.

Third, the trial and associated flow monitoring should be extended over a longer period, including ‘stepping up’ and ‘stepping down’ flows. In particular, longer periods should elapse at each measured discharge before increasing or decreasing the flow from the ERP valves, so that flows are allowed to equilibrate. For example, after increasing flows at the valves, discharge at the control point should not change substantially for two days in a row before the next increase or decrease in flow is implemented. Fourth, smaller increments in the volume of water released should be considered to enable fine-tuning of the upstream discharges required to meet summer-critical water levels. It may not be necessary to increase flows to full capacity in any future trial, considering that the larger flows are required only for passage of freshwater cobbler during the months of November to January.

Fifth, in any future trial, there should be more direct communication between staff of the Water Corporation and Department of Water. This would avoid a repeat of some of the 2007 trial’s implementation problems, such as difficulties synchronising the field activities of the two groups. Finally, more information is required on rates of abstraction by licensed users. Any future trial could include collection of accurate information on how much water was abstracted by individual users during the trial. This is likely to require negotiation and communication with individual licensed users.

## 5.5 Recommendations for environmental monitoring and restoration

### 5.5.1 Environmental monitoring and data collection

Environmental monitoring and additional data collection are required to refine the recommended flow regimes, to ensure the EWRs and flow thresholds can be met. Information that could be collected is briefly outlined below. A suitable monitoring and reporting program should be devised and implemented to complement the EWR study.

Monitoring of water quality parameters should be considered, especially during the summer months. Measurement of dissolved oxygen (DO) levels in pools should be conducted in late summer or early autumn, when environmental stressors are typically at their peak. DO monitoring is most important in the upper and middle reaches of the lower Canning River, because a DO trial has not been conducted in those reaches. Inclusion of additional water quality parameters (such as turbidity, conductivity, pH, temperature, total nitrogen and total phosphorus) in future water quality monitoring along the lower Canning River should also be considered.

Monitoring of freshwater fish for one season is required to assess whether they can migrate upstream and spawn successfully. This will be particularly important for freshwater cobbler, which need at least 20 cm of water over obstacles during the months of November, December and January. The required water depth will only be obtained sporadically throughout these months by manipulation of flows from the

ERP valves. Monitoring sites for freshwater cobbler should be set up and observations made – before, during and after summer flow pulses – over one migration season. It is recommended that such monitoring takes place three or four years after the summer-flow schedule described in this report has been implemented.

A monitoring and reporting program was employed during implementation of the guidelines for water provision (Table 10) over the summers of 2008–09 and 2009–10 (approximately November to May). This included monitoring of mean daily discharge at Seaforth gauging station, and also included occasional flow gaugings at the control points within each reach. More accurate information will be required on the volumes of water abstracted by licensed users, and on the volume of water discharged at each of the ERPs. This is likely to require the cooperation of licensed users, and the installation of meters at the ERPs. The information gathered will be used to refine the guidelines for water provision.

Finally, monitoring will be needed to assess whether winter-critical flow-ecology linkages are being fulfilled by the current water regime. This is likely to require a program of flow gaugings at the control points and observations within the management reaches to assess water levels, together with monitoring of mean daily discharge at Seaforth gauging station. This monitoring does not need to be ongoing; it could be conducted over one to three years, as considered appropriate.

### 5.5.2 Restoration recommendations

The Canning River is a highly modified system. This study's goal was to determine the flow requirements to maintain, and where possible improve, the composition and structure of the modified ecological community. This section provides brief restoration recommendations that, together with the flow recommendations, could help improve the lower Canning River's ecological values.

Revegetation works have occurred at several locations along the lower Canning River. Revegetation provides habitat for native flora and fauna, improves bank stability and increases carbon input to the river system. These revegetation and restoration works need to continue. Simple strategies such as fencing-off areas of bushland in frequently trafficked areas can reduce degradation due to trampling and removal of plants, as can be seen near the Orlando Street bridge.

Catchment clearance and changing land uses have led to the lower Canning River being substantially affected by sedimentation. Several pools within the management reaches were partially filled with sediment, reducing their utility as habitat. However, it is not possible to manage sedimentation using environmental water releases. This is because the water released from the ERPs is not of sufficient velocity to mobilise large quantities of sediment. Increased soil erosion, surface runoff and the resultant sedimentation require a whole-of-catchment management approach. Further investigations are required to determine the best course of action for managing sediment load in the Canning River.

Several freshwater fish species inhabit stretches of the lower Canning River. During field surveys, a number of private weirs along the river were noted. It appears that some landholders have constructed artificial weirs using rocks and other materials to form deep pools upstream of the weirs, to be used as sources of water during the dry months. The steep gradients of these weirs may hinder upstream passage of freshwater fish during the migration and spawning season (from June to January, depending on the species). Further investigations to determine whether these structures impede upstream fish passage are needed. The Seaforth gauging station weir has been investigated as a possible impediment to upstream fish passage during spring (Morgan et al. 2007). While Morgan et al. (2007) found that cobbler passage was not impeded by the weir in spring, the study did not encompass the drier summer months when water levels are lower, and when freshwater cobbler are still likely to be moving upstream (i.e. in December and January).

## 5.6 Next steps: development of a surface water allocation plan

This EWR study for the Canning River will be used alongside social, cultural and economic considerations to produce a surface water allocation plan for the lower Canning River. The goals of the plan will be to allocate water to licensed users while maintaining the ecological integrity of the river and its catchment and the quality of water for public supply. When this plan is being formulated, the Department of Water will consider input received from stakeholders such as the Water Corporation, licensed water users, SERCUL and the Perth Region NRM, as well as community representatives.

# Appendices

# Appendix A — Trial water-release program

## A.1 Purpose of the trial

A staged trial water-release program for the lower Canning River was undertaken in March 2007 using the six existing environmental release points (ERPs), as described in the main part of this report. The trial's results were used to measure dissolved oxygen levels (Appendix D) and assess whether flow objectives for summer-critical flow-ecology linkages could be met using environmental releases of water in each of the six management reaches (see the main report for further detail on the six reaches). The trial was deliberately staged in mid-March, when stresses on aquatic flora and fauna were likely to be highest due to high temperatures and low water levels, and when flow was maintained almost solely by water released from the ERPs by the Water Corporation.

## A.2 Methods

### A.2.1 Implementation of trial water-release program

A pre-trial low-flow period ran between Thursday 15 March and the morning of Monday 19 March 2007. The trial proper began on Monday 19 March (referred to as Day 1 of the trial) and finished on Friday 23 March (Day 5). Ecological observations and control point discharges were measured within each reach on every day of the trial[5].

Originally, the intention was to start the trial with close-to-zero flows, and then incrementally increase the discharge to one-third of total release point capacity, two-thirds of total capacity, and full capacity over a period of three days. Due to ongoing abstraction and irrigation demands, the ERP valves were not turned off completely during the low-flow period; rather, discharge was reduced to a 'baseflow component', which was the estimated discharge at which demand was the same as flow.

The intended baseflow discharge to be released at the ERP valves was calculated using estimated mean daily abstraction rates for licensed water users, with the addition of an extra 0.43 ML/day to compensate for possible discrepancies in release point discharge and variations in mean daily abstraction rates. Estimated mean daily abstraction rates were 0.73 ML/day for reaches 1 and 2, 1.03 ML/day for reaches 3 and 4, and 0.67 ML/day for reaches 5 and 6. Baseflow discharge was not measured in the field.

[5] Note that measurements were made on days 1 to 5 for the three upstream management reaches, and on days 1 to 4 for the three downstream reaches.

**Flow recommendation**

- Flows of 37.2 ML/day are required annually to inundate the off-channel restoration wetland.

### C.1.7 Ecosystem processes

The three flow-ecology linkages for ecosystem processes have been addressed with reference to other, comparable linkages that fall under the headings of geomorphology, macroinvertebrates, fish, water quality and riparian vegetation. See Appendix B for further details.

## C.2 Reach 2: Stocker Road

### C.2.1 Geomorphology

Table C6 summarises the flow requirements for geomorphological processes in Reach 2 (Stocker Road).

*Table C6 Flow requirements for geomorphology, Stocker Road*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 1a) Sufficient flow to scour pools and remove sediments | June to August | • No significant sediment deposits were observed within the reach. |
| 1b) Sufficient flow to maintain the shape of the active channel | June to August | • Not assessed for this reach due to limited hydrological information. |

### C.2.2 Macroinvertebrates

Six of the seven flow-ecology linkages for macroinvertebrates were either not assessed for Reach 2, or were addressed by other flow-ecology linkages. Here, detailed results are presented only for flow-ecology linkage 2a (Table C7).

*Table C7 Flow requirements for macroinvertebrates, Stocker Road*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 2a) Maintain water depth of 5 cm over gravel runs and riffles | All year | • Maintain minimum discharge of 2.2 ML/day within the reach throughout the year. |

#### *2a) Water depth of at least 5 cm over riffles*

Riffle habitat was recorded at seven cross-sections within Reach 2. Hydraulic analysis results overestimated the actual discharge required to inundate riffles. On the third day of the trial release, all riffle sections were inundated to at least 5 cm over at least 50 per cent of their width, at a discharge of 2.2 ML/day.

ERP discharge was reduced to baseflow on the afternoon of 15 March, and remained at this level until the afternoon of 19 March, when all release valves were increased to approximately one-third of total capacity. The original plan was to increase discharge to approximately two-thirds of total capacity at all sites on the afternoon of 20 March, then to full capacity on the afternoon of 21 March, returning to 'normal' flow conditions on the afternoon of the 22 March (which was originally the final day of the trial).

However, during the three days of low-flow conditions before 19 March, deep pools above some reaches became disconnected and had to be refilled before substantial downstream flow could resume. For this reason, ERP discharge was increased directly to full capacity on 20 March at Araluen ERP (above Reach 1) and Orlando Road ERP (upstream of the Reach 5 control point). Further, Araluen ERP and Hill 60 ERP (above Reach 2) were maintained at full release capacity for an additional day (22 March). As a result, the final set of ecological observations and control point discharges were measured at reaches 1, 2 and 3 on Day 5 of the trial (23 March); for the downstream reaches (4, 5 and 6), the final set of observations were conducted on Day 4 of the trial (22 March).

The release program was planned so that ecological observations and flow monitoring could be conducted in the morning, before increases in discharge from the release points in the afternoon. Therefore, each set of ecological observations was undertaken between 18 and 24 hours *after* the corresponding increase in discharge from the ERP valves. It was thought that leaving a lag time of between 18 and 24 hours would give a more accurate estimate of the downstream discharge associated with an increase in flow upstream. In several cases, flow from the ERPs was inadvertently increased *before* the corresponding set of downstream measurements were complete. In all cases, downstream observations were completed within three hours of the increase in discharge from the nearest upstream ERP.

### A.2.2 Relative locations of ERPs and control points

The locations of the management reaches were selected with reference to the six ERPs. Of those, the furthest downstream (Gosnells Bridge ERP) was below Reach 6 and therefore did not affect discharges measured within the management reaches. However, discharges from Gosnells Bridge ERP did affect one of the monitoring sites used in the dissolved oxygen trial (Appendix D). Table A1 explains the locations of each ERP in relation to the six management reaches, together with the release schedule followed at each site.

*Table A1 Locations of ERPs relative to control points and water-release schedule during the trial*

| Environmental release point (ERP) | Location relative to management reaches | Corresponding downstream control points* and reaches | Release schedule during summer trial release program (March 2007) |
|---|---|---|---|
| Araluen ERP | ~ 6 km upstream of Reach 1 | Reach 1 (Soldiers Road) | Low flow: 15–19 March<br>⅓ capacity: 19 March<br>Full capacity: 20–22 March |
| Hill 60 ERP | ~ 800 m upstream of Reach 2 | Reach 2 (Stocker Road) and Reach 3 (Bernard Street) | Low flow: 15–19 March<br>⅓ capacity: 19 March<br>⅔ capacity: 20 March<br>Full capacity: 21–22 March |
| Bernard Street ERP | Within Reach 3 (just downstream of control point) | Reach 4 (Orlando Street) | Low flow: 15–19 March<br>⅓ capacity: 19 March<br>⅔ capacity: 20 March<br>Full capacity: 21–22 March |
| Orlando Street ERP | Within Reach 4 (just downstream of control point) | Reach 5 (Manning Avenue) | Low flow: 15–19 March<br>⅓ capacity: 19 March<br>Full capacity: 20–21 March |
| Manning Avenue ERP | Within Reach 5 (just downstream of control point) | Reach 6 (Pioneer Park) | Low flow: 15–19 March<br>⅓ capacity: 19 March<br>⅔ capacity: 20 March<br>Full capacity: 21 March |
| Gosnells Bridge ERP | ~ 500 m downstream of Reach 6 | Dissolved oxygen trial monitoring | Low flow: 15–19 March<br>⅓ capacity: 19 March<br>⅔ capacity: 20 March<br>Full capacity: 21 March |

*Note:*

* *Denotes control points that are in between the ERP mentioned and the closest downstream ERP. Note that there was no ERP in between Reach 2 and the control point at Reach 3; hence, the discharge measured at the control point in Reach 3 is related to the (upstream) Stocker Road ERP and not to the (downstream) Bernard Street ERP.*

### A.2.3 Flow monitoring and ecological observations

A pre-trial assessment of water levels and summer-critical flow-ecology linkages was undertaken on Friday 16 March, approximately 20 hours after flows from the ERP valves were reduced to ‘baseflow’ level. Discharge was not gauged on 16 March.

Estimates of the discharge from the six ERPs on each day of the trial, together with the time of observation, were provided by the Water Corporation. Flow gaugings at each of the control points within each reach were undertaken by Department of Water staff. Flow was measured at the control points once a day during the trial.

Summer-critical flow-ecology linkages (aside from dissolved-oxygen-related linkages) were assessed as ‘met’ or ‘not met’ at cross-sections within the management reaches for each day of the trial (i.e. Monday 19 March to Thursday 22 March or Friday 23 March). Summer-critical linkages were: 2a, 2b, 2c, 2d, 3a, 3b, 3e, 3f, 3g, 3k, 4a, 5a and 6d (refer to Table 1 in the main report). At each of the surveyed cross-sections, thalweg depth (i.e. the deepest part of the river channel) was recorded, as was water depth across key ecological features such as benches and riffles.

## A.3 Results

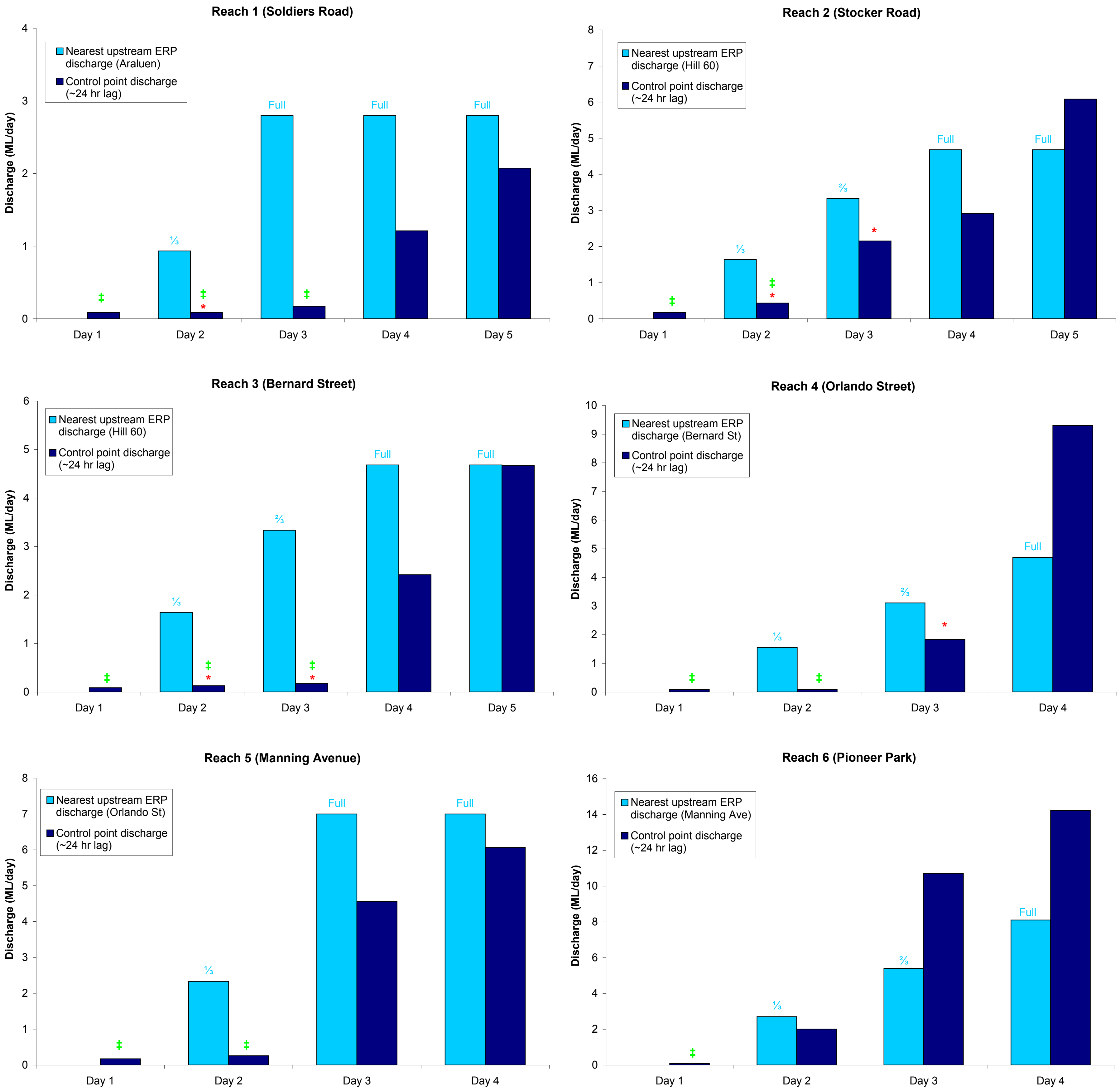
The discharges measured at the control points during the trial are displayed in Table A2. The control point discharges are compared with discharges from the corresponding upstream ERPs in Figure A1.

Measured discharges at the control points were lower than expected during the trial's early stages. This was largely because the baseflow component released for the three days before the trial began was not enough to maintain connectivity between pools. Therefore, minimal discharge was recorded at a number of control points until disconnected pools upstream had filled up, resulting in an extended lag time (one to three days) before increases in releases from ERPs were registered as increases in discharge at downstream control points.

Figure A1 illustrates the variation in thalweg depth at each cross-section over the course of the trial. In nearly all cases, a drop in water level was recorded between the start and end of the low-flow period (compare thalweg depth on 16 March with 19 March in Figure A1). For Reach 1, the thalweg depth recorded on 16 March was the deepest recorded throughout the whole trial. For all other reaches, the highest water level was (generally) that recorded on the last day of the trial.

*Table A2 Discharges measured at control points during the trial release*

| Reach | Discharge (ML/day) | | | | |
|---|---|---|---|---|---|
| | **Day 1** 19/03/07 | **Day 2** 20/03/07 | **Day 3** 21/03/07 | **Day 4** 22/03/07 | **Day 5** 23/03/07 |
| **Reach 1** (Soldiers Road) | 0.09 | 0.09 | 0.17 | 1.21 | 2.07 |
| **Reach 2** (Stocker Road) | 0.17 | 0.43 | 2.15 | 2.92 | 6.08 |
| **Reach 3** (Bernard Street) | 0.09 | 0.17 | 0.17 | 2.42 | 4.67 |
| **Reach 4** (Orlando Street) | 0.09 | 0.09 | 1.84 | 9.31 | *Not measured* |
| **Reach 5** (Manning Avenue) | 0.17 | 0.26 | 4.56 | 6.07 | *Not measured* |
| **Reach 6** (Pioneer Park) | 0.09 | 2.01 | 10.70 | 14.22 | *Not measured* |




**KEY**

‡ Indicates that water levels were too low to accurately gauge discharge

* Denotes control point discharges that were inadvertently measured *after* flow at the nearest upstream ERP was increased (see text for details)

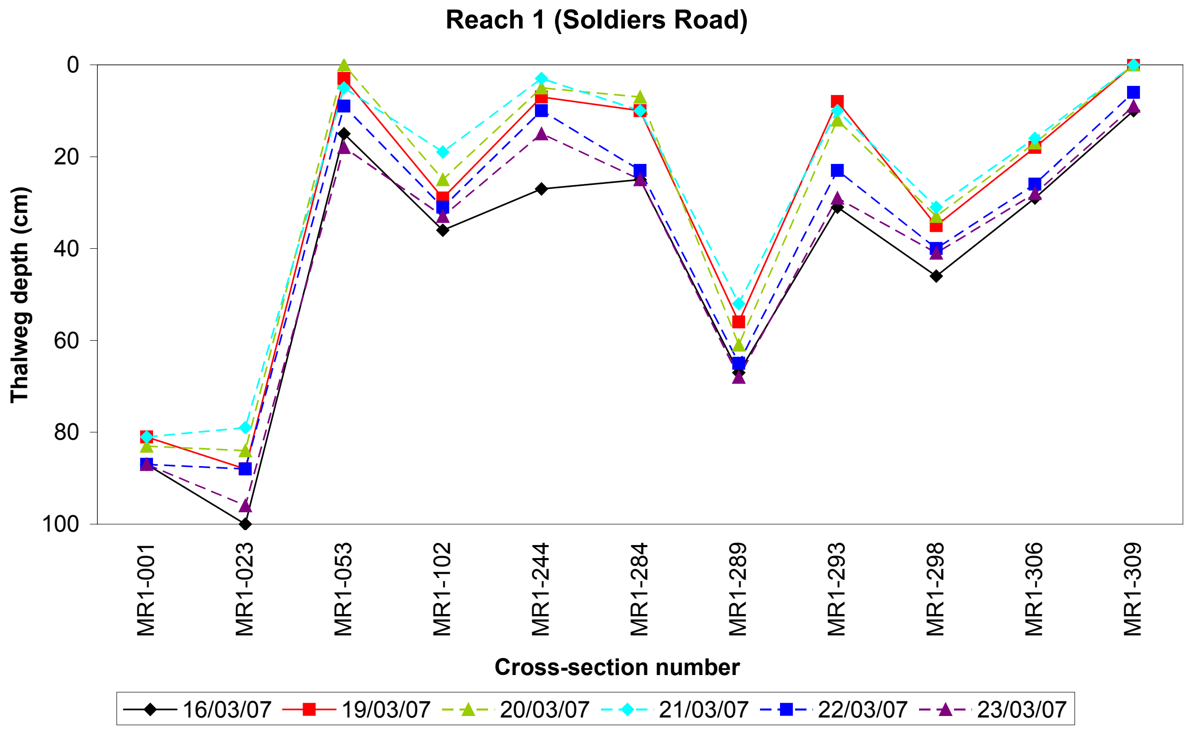
⅓ ERP discharge set at approximately one-third of total capacity

⅔ ERP discharge set at approximately two-thirds of total capacity

Full ERP discharge set to full capacity

*Figure A1 Discharges measured at the environmental release points and control points during the trial water release program*

The discharges at the control points are those that were measured on days 1 to 5 of the trial. Note that the corresponding upstream ERP discharges were measured approximately 24 hours *before* the control point discharge measurements were made. Day 1 measurements correspond to baseflow conditions. Baseflow was *not* measured at the ERPs; as such there is no corresponding ERP discharge for Day 1



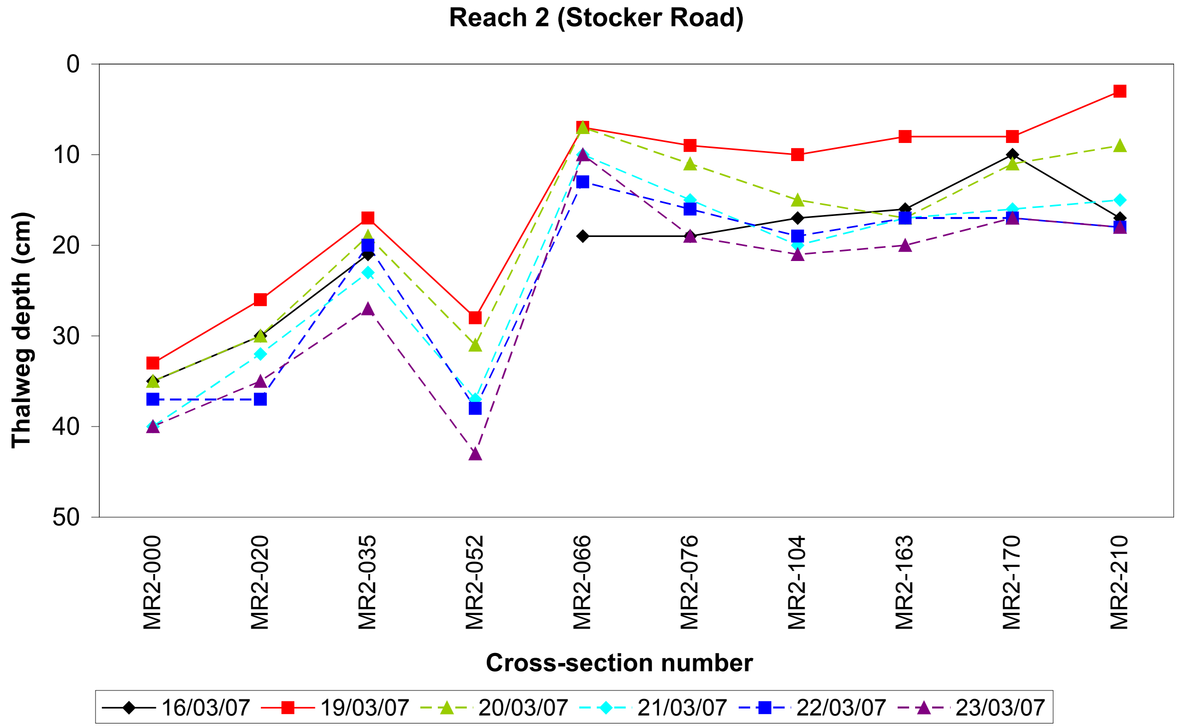
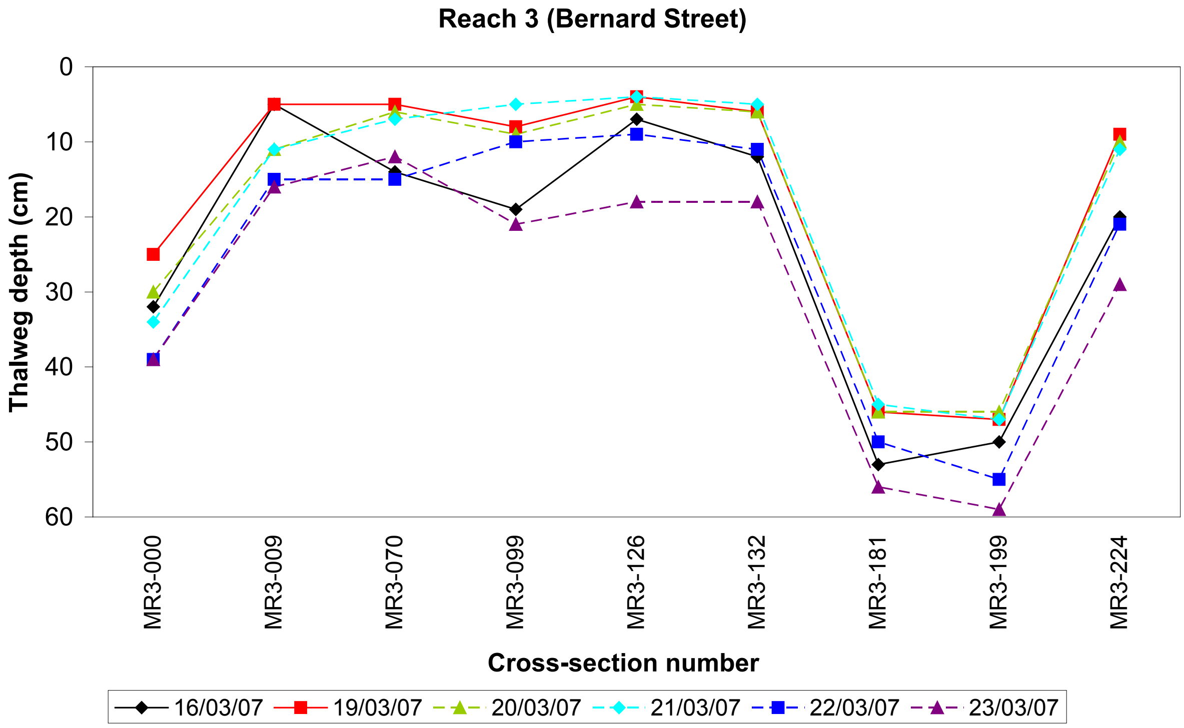




*Figure A2 Change in thalweg depth for all cross-sections during the summer trial release program*



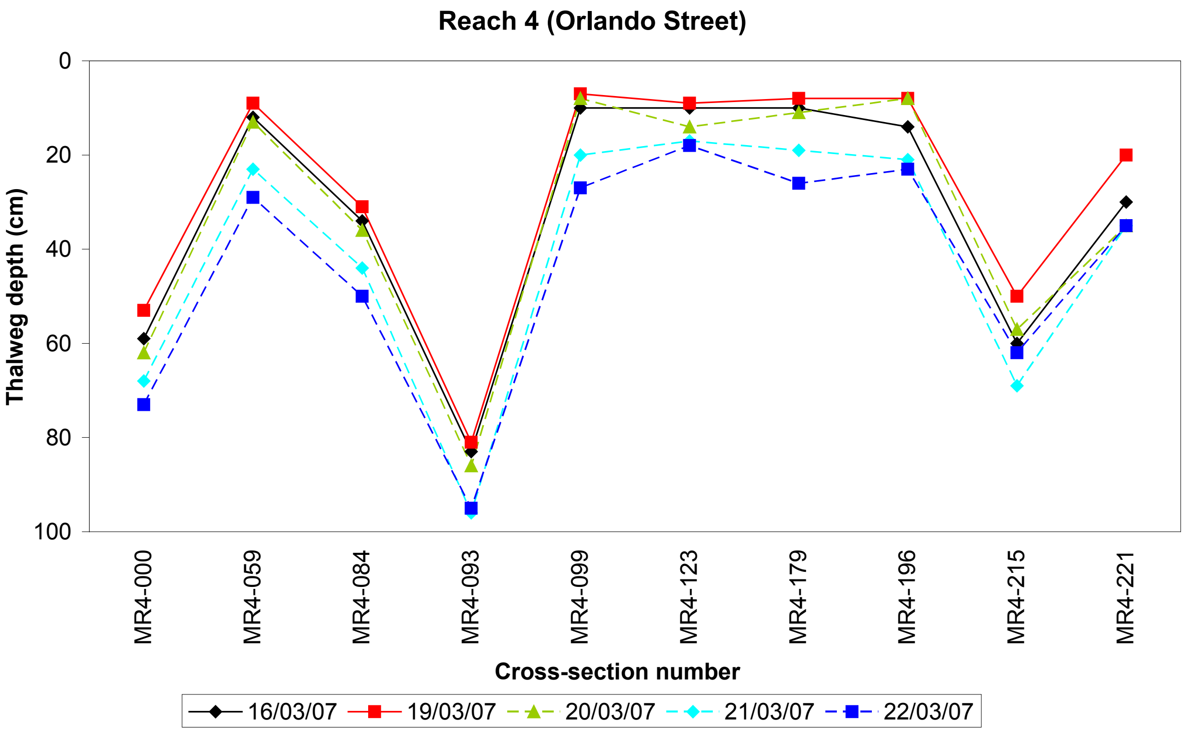
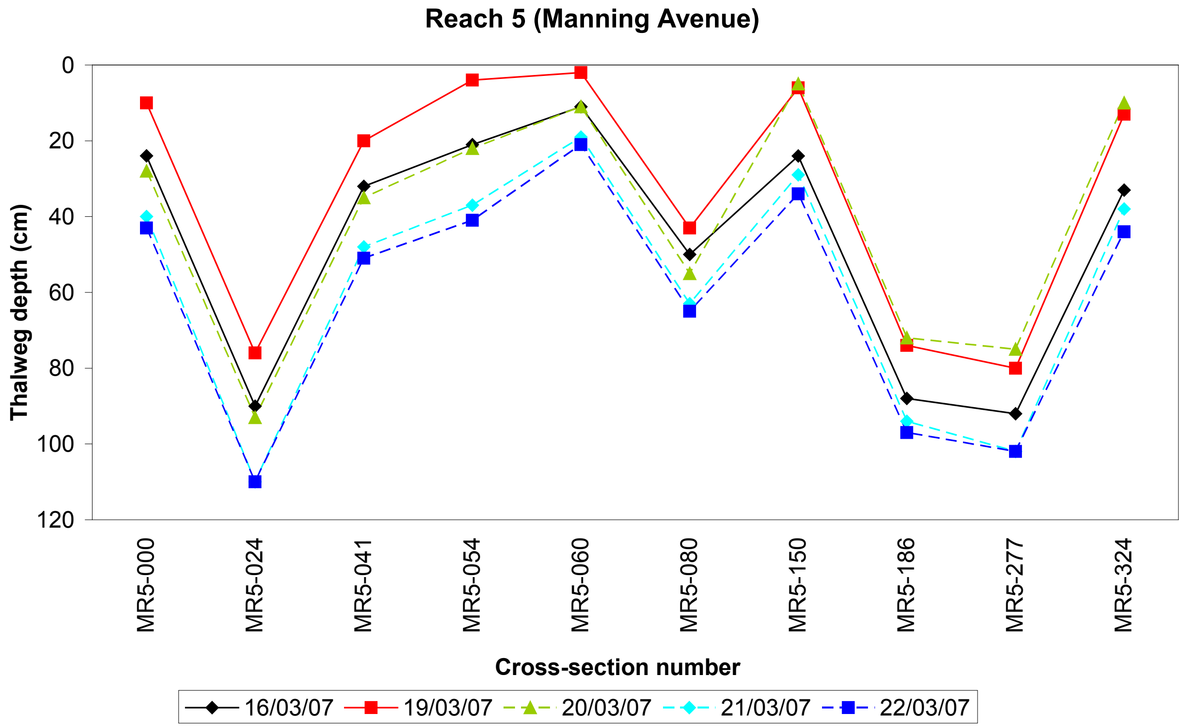




*Figure A2 Change in thalweg depth for all cross-sections during the summer trial release program (continued)*



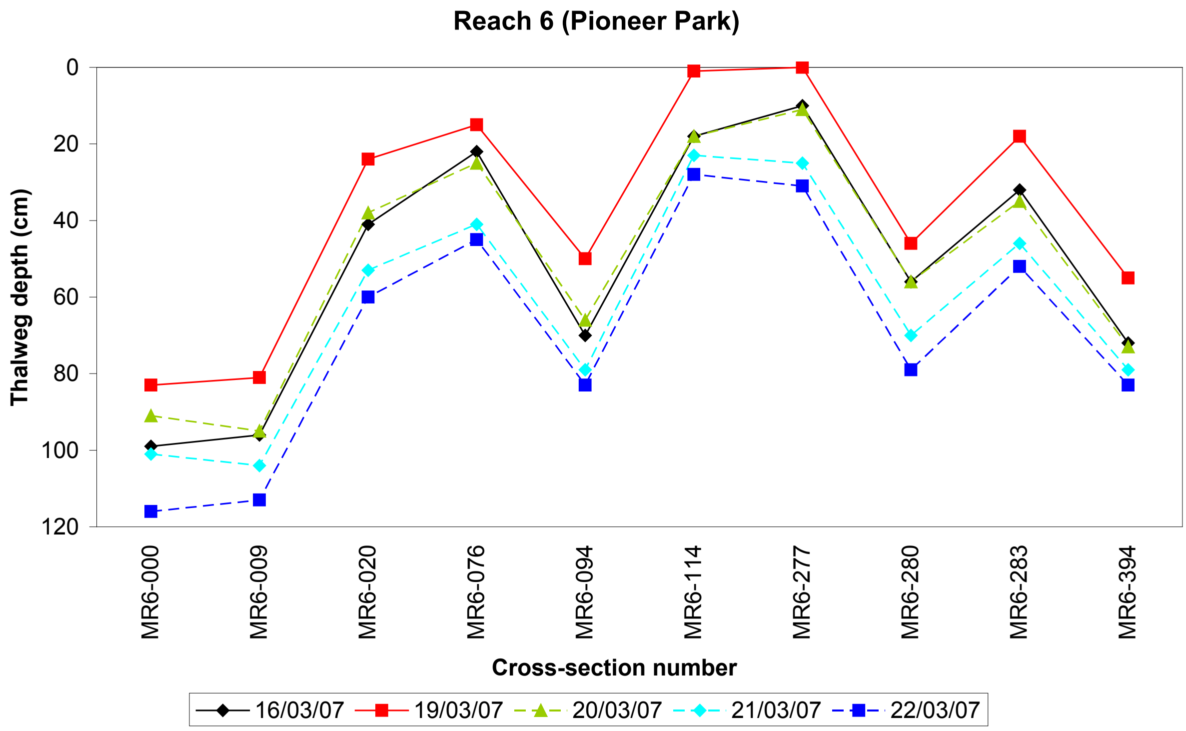




*Figure A2 Change in thalweg depth for all cross-sections during the summer trial release program (continued)*

## A.4 Limitations of the trial water-release program

The trial water-release program enabled in situ testing and measurement of the discharges required to meet flow requirements for summer-critical flow-ecology linkages. Clearly, the field observations better reflect the actual discharges required to reach particular water levels, compared with the hydraulic modelling results. Due to the difficulty of controlling flow rates in river systems, for most EWR studies it is not possible to undertake such a trial. However, the trial release had limitations that need to be considered.

As noted previously, the baseflow component released at the start of the trial was not enough to maintain connectivity along the length of the lower Canning River, which had flow-on effects for the trial's implementation. The lag time between increases in ERP discharge and increases in discharge measured at downstream control points was substantially longer than expected, due to the refilling of large, disconnected pools.

The long lag time had three important effects on the trial's outcome. First, water levels were so low in the trial's early stages that accurate discharges could not be measured on Day 1 for all reaches, on Day 2 from Soldiers Road to Manning Avenue (i.e. reaches 1 to 5), and on Day 3 for Soldiers Road and Bernard Street management reaches. Second, for some management reaches there was a substantial jump in discharge registered during the trial. This effect was particularly notable for downstream reaches, which were likely to have been affected by the cumulative impact of the delayed resumption of flow at upstream sites. For example, there was a marked increase in discharge between Day 2 and Day 3 of the trial at Manning Avenue and Pioneer Park, and between Day 3 and Day 4 at Orlando Street.

The combined impact of these two effects means that although some of the flow requirements would have been met at discharges lower than those measured during the later stages of the trial, the lowest discharges measured cannot be used as flow recommendations due to low gauging accuracy. It would have been useful to measure discharge within the reaches after ERP valves were turned off (or returned to normal flow schedule), to enable low flows at control points to be more precisely measured as discharge decreased.

Finally, the long lag time led to difficulties in correlating discharge from ERP valves to downstream discharges within management reaches. Discharges measured at control points in reaches 1, 2, 3 and 5 continued to increase after the nearest upstream release points had been kept at a constant discharge for more than 24 hours. This made it difficult to delineate a particular discharge regime from the ERP valves that would satisfy downstream ecological flow requirements. As such, ongoing monitoring is required to ensure the recommended discharge regime will meet the flow requirements; modifications may be required if discharge is insufficient.

# Appendix B — Determination of flow requirements for individual flow-ecology linkages

The approach to and results of analyses completed for individual flow-ecology linkages are presented in the following sections. Linkages have been grouped under the broad headings of geomorphology, macroinvertebrates, fish, waterbirds, water quality, riparian vegetation and ecosystem processes. The ecological importance of each of the 32 flow-ecology linkages is briefly described, together with the methods used to develop their flow recommendations.

For many of the flow-ecology linkages, two complementary methods were used to determine the threshold discharges. First, queries and cross-section data were input into the hydraulic model developed for each reach from the surveyed cross-sections, using the software RAP. The output of the hydraulic model is a simulated relationship between the relevant factors, such as stage height and discharge, within the study reach. Second, where possible (generally for summer-critical linkages), the modelled results were assessed against field observations and actual discharges measured during the trial water-release program (Appendix A).

In some cases, the two sets of results were very similar and the flow recommendations were based on both the hydraulic model and the field results. In other cases, there were large differences between the modelled results and the observations. In such cases, the field observations were given greater credence than the modelled results, and flow recommendations were based solely on field observations.

## B.1 Geomorphology

Two flow-ecology linkages were identified for geomorphology in the lower Canning River. An account of the process used to determine the flow requirements for each linkage is given below.

### *1a) Sufficient flows to scour pools*

Sedimentation in pools is a major management issue for the Canning River. Within the study area, the middle and lower management reaches (reaches 3 to 6) are substantially affected by sedimentation. The flushing flows after heavy rainfall events that once maintained channel morphology and pool depth now occur at a reduced frequency and magnitude, largely due to river regulation. In addition, land use change and vegetation clearing within the Canning catchment are associated with increased surface runoff and soil erosion.

To be effective, flows need to be of sufficient magnitude and duration to exceed the thresholds required to shift and transport sediments. Flows with velocities of at least

30 cm/s are required to mobilise sediments of 300 μm diameter (fine sand) and smaller (Storey et al. 2001).

### Approach

Using the hydraulic model and RAP, an attempt was made to determine the threshold discharge required to mobilise fine sand sediments in pools. For each pool cross-section, a bulk velocity rule was applied to the rating curve to estimate the discharge required to generate a threshold velocity of 30 cm/s at mid-pool depth.

However, the hydraulic modelling results cannot be used to estimate the required discharges to scour pools and prevent sedimentation. The modelled discharges were extremely unlikely to mobilise sediments, as they were substantially lower than recently recorded discharges during high-flow and flood events (e.g. 16.5 $m^3$/s and 11.6 $m^3$/s during bankfull events in autumn and winter 2003, as reported in Radin et al. 2007) that failed to scour pools. This is likely due to the growth of vegetation within the sediment beds, which would slow water velocity at the substrate surface and protect sediments from mobilisation. The hydraulic model does not take vegetation into account, meaning that the modelled results underestimate the actual required discharge.

No recommendations have been made as to how environmental releases of water can be used to manage sedimentation. Even recent bankfull winter flows have not been sufficient to shift the sediment currently entering the Canning River system, so it cannot be expected that the relatively small volumes of water able to be released using the current infrastructure (i.e. the six release points) would significantly improve the situation. Increased soil erosion, surface runoff and resultant sedimentation require a whole-of-catchment management approach.

*1b) Sufficient flows to maintain the shape of the active channel*

Active channel flows are important to maintain pool depths and the shape of the channel. Modification of the Canning River's flow regime has meant that the 'historic' bankfull profile of the river channel reflects the pre-impoundment hydrologic regime, and not the current, greatly reduced flow regime. Bankfull flows for the historic channel no longer occur once or twice a year (as is typically the case with rivers in the south-west of Western Australia). The active, current channel has become incised in many sections of the river, resulting in a modified bankfull profile that reflects actual flow conditions. To be consistent with the desired future state for the Canning River, the objective is to provide adequate frequency of bankfull flows for the current channel, rather than the historic channel (Radin et al. 2007).

### Approach

The frequency of bankfull flows for the active channel was determined by examining the recent (i.e. post-1975) flow regime using discharge data from the Seaforth gauging station. The discharge data were only applicable to Reach 4 (Orlando Street), Reach 5 (Manning Avenue) and Reach 6 (Pioneer Park); as such, this flow-ecology linkage could not be assessed for reaches 1 to 3.

To determine the typical maximum discharges recorded for the active channel, the time-series of recorded flows at Seaforth gauging station was examined to find the maximum daily discharge in 80 per cent of years (P80). The P80 criterion was used instead of the mean discharge, so that the influence of uncharacteristically large events was limited. Further, the P80 criterion excludes those years where flow was relatively low.

Flow recommendations with a minimum discharge, frequency and duration were determined, based on the historical data, for both the maintenance of bankfull flows and the maintenance of typical active channel flows.

## B.1 Macroinvertebrates

Seven flow-ecology linkages were identified for macroinvertebrates in the lower Canning River. An account of the process used to determine the flow requirements for each linkage is given below.

### *2a) Submerged gravel runs and riffles*

Riffle habitat is highly productive for macroinvertebrates and important in maintaining biodiversity (Storey et al. 2001). Riffle habitat supports a relatively diverse macroinvertebrate assemblage that depends on permanent flow for food and oxygen (Wetland Research Management 2005). A water depth of 5 cm over 50 per cent of the total width of riffle zones is regarded as the minimum necessary to support benthic invertebrate communities through summer (Storey et al. 2001).

**Approach**

For each reach, cross-sections representative of riffle habitat were used to quantify riffle availability (as surface area of channel with depth ≥5 cm) versus discharge using RAP. The rating curve was used to determine the mean discharge required to inundate 50 per cent of riffle widths across all cross-sections within the reach.

Flow-ecology linkage 2a was also assessed during the trial water-release program. At each surveyed cross-section that contained riffles, the total riffle width was measured and the proportion inundated by at least 5 cm was recorded for each measured discharge.

Where applicable (reaches 4, 5 and 6 only), time-series data were analysed to determine the frequency and duration of modelled and observed flows providing sufficient riffle habitat. This determined whether the flow objective had been met by past patterns of water release.

### *2b) Submerged macrophyte habitat*

Submerged macrophytes provide important habitat for the maintenance of macroinvertebrate communities (Radin et al. 2007). Macrophytes often support a distinct macroinvertebrate assemblage compared with other substrate types.

#### Approach

Flow-ecology linkage 2b is directly comparable with linkages 3f (fish: submerged macrophyte habitat) and 6d (riparian vegetation: maintain submerged macrophytes). The approach used to determine the threshold flow criteria was identical to that described for linkage 6d.

### *2c) Inundation of emergent vegetation*

Emergent vegetation provides important macroinvertebrate habitat throughout the year. Inundation to a depth of 5 cm is considered enough to make emergent vegetation habitat available to macroinvertebrates.

#### Approach

This flow-ecology linkage is comparable with linkage 3c (fish: inundate emergent vegetation). The approach used to determine the threshold flow criteria for linkage 2c was identical to that used for linkage 3c.

### *2d) Shallow floodplain and backwater habitat*

Secondary channels, shallow floodplain areas and backwaters provide foraging areas for macroinvertebrates, as well as refuge habitat from spates of high flow in winter (Radin et al. 2007). Modification to the river bank and riparian zone, and the significant reduction of flows reaching the Canning River, has resulted in the isolation of many potential shallow-water habitats, even during high winter flows.

#### Approach

Flow-ecology linkage 2d is comparable with a combination of linkages 3h (fish: inundate shallow backwaters) and 6a (riparian vegetation: maintain winter-wet floodplain vegetation). The methods used to determine the critical flows for linkage 2d are described in detail for linkages 3h and 6a.

### *2e) Permanent flows to connect pools*

Predictability and seasonality of flows is an important determinant of macroinvertebrate population structure and composition. Flow permanency is a defining hydrologic characteristic of the lower Canning River (Storey et al. 2001). Maintaining the permanent flow is vital to sustain the existing macroinvertebrate community structure and composition.

**Approach**

Flow-ecology linkage 3e is equivalent to linkages 3e (fish: maintain pool connectivity) and 5a (water quality: maintain pool connectivity). The approach used to determine the threshold flow criteria for linkage 2e was identical to that described for linkage 5a.

*2f) Sufficient flow to oxygenate pools*

Sufficient flow to minimise the risk of anoxia in pools during summer is crucial to maintain macroinvertebrate community composition and structure. Levels of dissolved oxygen below 2 mg/L are likely to result in reduced health and possible death of aquatic fauna (Wetland Research Management 2005).

**Approach**

The approach for determining an appropriate flow regime to prevent anoxia was identical to that described for flow-ecology linkage 5b (water quality: avoid stratification and maintain dissolved oxygen levels). This linkage is also directly comparable with linkage 3c (fish: maintain dissolved oxygen levels).

*2g) Maintain macroinvertebrate community structure*

Macroinvertebrate community structure is closely tied to the predictability and seasonality of flows. The lifecycle stages of many macroinvertebrate species are intrinsically linked to the predictable low summer flows and high winter flows typical of river systems in the south-west of Western Australia. Continuation of a flow regime with these features is essential to maintaining macroinvertebrate community structure. As the Canning River was historically a permanent watercourse (rather than seasonal or ephemeral), the objective for this linkage is to maintain year-round flow.

**Approach**

Flow-ecology linkage 2g is comparable with linkage 5a (water quality: maintain pool connectivity). The approach used to determine the threshold flow criteria for linkage 2g was identical to that described for linkage 5a.

## B.3 Fish

Twelve flow-ecology linkages were identified for fish in the lower Canning River. An account of the process used to determine the flow requirements for each linkage is given below.

*3a) Fish passage for small-bodied fish*

There are three relatively small-bodied freshwater fish species found within the lower Canning River: the western minnow (*Galaxias occidentalis*), western pygmy perch

(*Edelia vittata*) and the nightfish (*Bostockia porosa*). All three species migrate upstream to spawn in winter and spring. Peak spawning season for the western minnow is between June and late September, while for the western pygmy perch the peak migration and spawning period is between September and mid-October. The nightfish migration occurs in late August to late September (Storey et al. 2001; Morgan et al. 2007; Radin et al. 2007).

A minimum water depth of 10 cm over obstacles is required for passage of the three small-bodied freshwater fish species (Storey et al. 2001; Morgan et al. 2007). Flows need to be delivered in pulses during the migration season to maximise the opportunity for fish to traverse obstacles. Barriers such as private weirs will remain impassable for upstream movement of fish unless some form of fish passage structure or modification is undertaken (Storey et al. 2001; Morgan et al. 2007).

**Approach**

Obstructions such as riffles, fallen logs, weirs and other obstacles were considered the major barrier to upstream migration of small-bodied fish species. Using the hydraulic model, binary rating curves were developed for individual cross-sections containing riffles to determine the threshold discharge for submerging all obstructions within each management reach to a minimum thalweg depth of 10 cm.

Water depth over obstructions and riffles was monitored during the trial water-release program, and compared with discharges measured in the field, as well as modelled discharges. Flow recommendations were developed based on a combination of hydraulic modelling and field trial results.

'Passage flows' for fish migration should be delivered in pulses lasting for several hours to allow fish to traverse through the pool and riffle sequences (Wetland Research Management 2005). Time-series analysis was conducted for Orlando Street, Manning Avenue and Pioneer Park reaches to determine the recent (i.e. post-1975) occurrence and duration of passage flows of the required discharge between June to October.

*3b) Fish passage for large-bodied fish*

The freshwater cobbler (*Tandanus bostocki*) is the largest endemic freshwater fish species in the south-west of Western Australia. It has become an iconic native freshwater fish for the Swan Coastal Plain and south-west region, because it is the only endemic species sought for recreational fishing. Habitat alteration may pose threats to some populations of this species (Morgan et al. 1996). The freshwater cobbler is not threatened on a regional basis, but it was rarely recorded or absent in recent studies on the Canning and Southern Wungong rivers (Storey 1998; Wetland Research Management 2000).

Freshwater cobbler migrate upstream to spawn in late spring to late summer (November to January), when water temperatures are 20°C to 24°C. An estimated minimum water depth of at least 20 cm over obstacles is required for cobbler migration during these months (Radin et al. 2007). Similarly for small-bodied fish, some barriers, such as private weirs, will remain impassable for upstream movement of cobbler unless some form of modification is undertaken (Storey et al. 2001; Morgan et al. 2007).

**Approach**

The approach to determine threshold criteria for discharges to provide passage for cobbler was almost identical to that described for small-bodied fish under flow-ecology linkage 3a. The two differences were: firstly, a minimum thalweg depth of 20 cm over obstructions was used in place of 10 cm; and secondly, the frequency recommendations were developed for the peak period of cobbler migration (November to January) rather than for June to October.

*3c) Oxygen levels*

Dissolved oxygen levels below 2 mg/L are likely to result in reduced health and possible death of aquatic fauna (Storey et al. 2001). Summer refuge pools are important to maintaining fish populations and must remain oxygenated during low-flow periods.

**Approach**

The approach used to determine an appropriate flow regime to prevent anoxia was identical to that described for flow-ecology linkage 5b (water quality: maintain dissolved oxygen levels). This flow-ecology linkage is also directly comparable with flow-ecology linkage 2f (macroinvertebrates: maintain dissolved oxygen levels).

*3d) Inundation of sedges and rushes*

Emergent vegetation, such as sedges and rushes, provides habitat for fish spawning and recruitment (Radin et al. 2007). Inundation of emergent vegetation to a depth of 10 cm is considered the minimum necessary water depth to provide suitable fish habitat (Storey et al. 2001). Ten days of continuous inundation is considered the ideal duration to meet the spawning requirements for small-bodied native fish and prevent desiccation of fish eggs (Storey et al. 2001; Morgan et al. 2007).

**Approach**

The height of emergent vegetation was recorded for all cross-sections. The discharge required to achieve the required stage height of vegetation elevation plus 10 cm was determined for individual cross-sections in all management reaches. A flow requirement for each reach was determined by calculating the mean discharge required to inundate vegetation from the individual cross-sections (within the summer and winter active channel areas).

Where applicable, time-series flow data from Seaforth gauging station were analysed to determine the frequency and duration of required flows during winter and spring to determine how often thresholds had been met in the past. Recommendations were made based on the timing and duration of critical flows based on fish species' ecological requirements, and using analyses of the time-series flow data.

*3e) Connectivity of pools*

Adequate permanent water is integral to the survival of fish populations over summer, as none of the fish species in the Canning system are adapted to withstand desiccation (Storey et al. 2001). Pools throughout the lower Canning River should remain connected by a continuous flow of water year-round to ensure survival of fish species in the system.

**Approach**

Flow-ecology linkage 3e is equivalent to linkages 2e (macroinvertebrates: maintain pool connectivity) and 5a (water quality: maintain pool connectivity). The approach used to determine the threshold flow criteria for linkage 3e was identical to that described for linkage 5a.

*3f) Submerged macrophyte habitat*

Submerged macrophyte beds have been identified as an important habitat for juvenile fish (Storey et al. 2001). Flows during spring and summer – to maintain populations of macrophytes for juvenile fish refuge, habitat and food – are crucial to sustaining freshwater fish species (Radin et al. 2007).

**Approach**

Flow-ecology linkage 3f is directly comparable with linkages 2b (macroinvertebrates: submerged macrophyte habitat) and 6d (riparian vegetation: maintain submerged macrophytes). The approach used to determine the threshold flow criteria was identical to that described for linkage 6d.

*3g) Pool habitat for freshwater cobbler*

Maintenance of sufficient flow to fill refuge pools for freshwater cobbler (*Tandanus bostocki*) recruitment, spawning and nesting during summer is critical to the survival of the species in the Canning River system (Morgan et al. 2007). Summer refuge pools also sustain populations of other fish species during low-flow periods. A thalweg depth of 80 cm is considered the ideal minimum pool depth.

**Approach**

For each reach, a binary rating curve was developed for cross-sections with pools to determine the discharge required to maintain a minimum thalweg depth of 80 cm.

The mean discharge across all pool cross-sections was used as the modelled threshold discharge for each management reach.

Pool depth was assessed during the trial water-release program, to review the accuracy of modelled estimates of discharge required to maintain a mean thalweg depth of at least 80 cm. Flow recommendations were based on the combined results of hydraulic modelling and field observations.

Using the time-series data from Seaforth gauging station, a low-spells analysis was conducted to examine the frequency and duration of flows below the threshold discharge. The results of the time-series analysis were only applicable to the lower reaches (Reach 4 – Orlando Street, Reach 5 – Manning Avenue and Reach 6 – Pioneer Park).

*3h) Shallow backwater habitat*

Along the lower Canning River's length, the connection between the main channel and off-channel wetland habitats and seasonal tributaries has been significantly reduced. This is a result of reduced flow due to the presence of weirs and other man-made obstructions. Shallow backwater areas connected to the main channel during winter flows are important for predator avoidance and for the provision of nursery areas and habitat for small-bodied fish.

**Approach**

The entry points to backwater habitats were recorded during cross-section surveys. Hydraulic analysis was used to examine the stage height/discharge relationship and determine the discharge required to begin inundation of backwaters.

Flow frequency and duration recommendations were formulated using a high-spells analysis based on time-series data from Seaforth gauging station. This determined and replicated the historic frequency and duration of events of the modelled threshold discharge. Results of the time-series analysis were directly applicable only to the lower reaches (Reach 4 – Orlando Street, Reach 5 – Manning Avenue and Reach 6 – Pioneer Park).

*3i) Prevent sedimentation of pools*

Sedimentation has reduced overall pool depths in the Canning River. This has made these sites less suitable as summer refuges for fish. This is particularly evident within the lower management reaches from Reach 3 (Bernard Street) to Reach 6 (Pioneer Park). For existing pools to provide habitat and refuge for fish, sufficient flushing flows are required during wet periods to scour accumulated sediments and maintain pool functionality.

**Approach**

This linkage is comparable with flow-ecology linkage 1a (geomorphology: scour pools and remove sediment). The approach to attempt to determine flow thresholds is identical to that described for 1a. As noted in Appendix B.1, sedimentation is a catchment-level issue: management of sedimentation within the river cannot be achieved by way of environmental water releases only.

*3j) Inundation of floodplain*

Floodplain wetlands, seasonal tributaries and drains provide off-channel habitat for native fish to forage and spawn. Connection between the main channel and floodplain wetlands has been significantly reduced post-impoundment. Maintenance of connectivity with remaining off-channel habitats in late autumn to early spring is therefore of great importance in providing spawning and foraging opportunities for native fish.

**Approach**

This flow-ecology linkage is comparable with linkage 6a (riparian vegetation: maintain winter-wet floodplains and off-channel wetlands). It is assumed that inundation of floodplain wetland areas, as identified in linkage 6a, would provide access to off-channel habitats for foraging and spawning enough to satisfy this flow-ecology linkage. The approach to determining critical flows is described under linkage 6a.

*3k) Undercutting of riverbanks*

Riverbank undercuts provide habitat and areas for predator avoidance for fish, particularly the western pygmy perch and nightfish (Storey et al. 2001).

**Approach**

Field surveys during periods of varying discharge showed that undercut habitat occurred at a range of spot heights within each management reach. Thus the availability of undercut habitat varies throughout the year depending on water levels. Some of the bank undercuts surveyed in the original cross-sections were no longer apparent during the summer trial. Conversely, additional bank undercuts were noted during the summer field trial and were opportunistically included in field observations.

Most undercut sites were located within eroded bank areas and the summer active channel. This suggests that these features result from bank erosion, exacerbated by clearing of riparian vegetation. Substantial modification of the flow regime (either larger or smaller flows) may result in the establishment of new undercuts within exposed bank areas, possibly increasing bank instability.

During the trial water release, at least some bank undercuts were inundated at all cross-sections across a range of flows. Because undercut habitat is available during a wide range of flows throughout the year, no specific flow recommendations to provide undercut habitat for fish have been provided, although it is recognised that such habitat is important. Maintaining the threshold flows for submerging emergent vegetation (flow-ecology linkage 3d) will also provide fish habitat at undercut sites.

*3l) Inundated in-stream bench habitat*

Sufficient flows should be maintained to seasonally inundate in-stream benches to a minimum depth of 10 cm to provide foraging and spawning habitat for fish.

**Approach**

Elevations of in-stream benches were identified during cross-section surveys. Only benches that would be inundated during low-flow events were included in the analysis. The stage height/discharge relationship was examined for individual cross-sections to determine the mean threshold per reach for inundating in-stream benches to a depth of 10 cm.

During the trial water-release program, the depth of inundation of summer in-stream benches was recorded for different measured discharges. Flow recommendations were developed based on modelled results in combination with field observations.

To define the flow-frequency recommendations, time-series analysis was conducted to determine the historic frequency and duration of flow events exceeding the mean threshold discharge to inundate benches. The results of the time-series analysis are directly applicable only to the lower reaches (i.e. reaches 4, 5 and 6).

## B.4 Waterbirds

Two flow-ecology linkages were identified for waterbirds in the lower Canning River. An account of the process used to determine the flow requirements for each linkage is given below.

*4a) Permanent pool habitat*

The permanent freshwater reaches upstream from Kent Street Weir to the Canning Dam may act as important refuges for waterbirds during periods of low rainfall (Radin et al. 2007).

**Approach**

Flow-ecology linkage 4a is comparable with linkage 3g (fish: maintain pool depth), which requires sufficient flow to fill summer refuge pools to a minimum depth of 80 cm for freshwater fish species. The approach used to determine flow criteria for linkage 4a was identical to that pursued for linkage 3g.

### *4b) Sufficient flow to protect riparian vegetation*

Areas of winter-wet riparian vegetation are important breeding habitat for waterbirds.

**Approach**

This flow-ecology linkage is comparable with a combination of three of the linkages listed for riparian vegetation: 6a (maintain winter-wet floodplain vegetation), 6b (inundate emergent vegetation) and 6c (inundate mid-bank vegetation). Further detail on the methods for assessing the EWR for riparian vegetation is given in Appendix B.6.

## B.5 Water quality

Two flow-ecology linkages were identified for water quality in the lower Canning River. An account of the process used to determine the flow requirements for each linkage is given below.

### *5a) Pool connectivity in summer*

Maintenance of pool connectivity throughout the year ensures the distribution of nutrients throughout the system. Connectivity also reduces the risk of anoxia by reducing the residence time of water in pools. Interactions between surface water and groundwater, abstraction and evaporation make it difficult to accurately estimate the flows required to maintain connectivity.

**Approach**

The minimum flow to maintain connectivity within each management reach could not be estimated using the hydraulic model. Because the hydraulic model does not incorporate any potential losses to the system, connectivity is indicated at extremely low discharges (in this case, the minimum discharge that could be input into the model). To gain a more realistic estimate of the flows required to maintain connectivity, observations were made during the trial water-release program. The trial releases were staged at incremental volumes over five days at each management reach, starting with a baseflow component, and then going to one-third, two-thirds and full-release capacity. Details of the methods used during the trial are provided in Appendix A.

Based on the trial results, it was not possible to accurately determine a minimum threshold discharge to maintain flow connectivity between pools within each reach. More detailed information on losses of water from the system is required to prepare a more comprehensive estimate of flows to maintain connectivity year-round. For each reach, a rough estimate of discharge required to maintain connectivity has been given, based on flows measured and estimated in the field during periods of full flow connectivity.

### *5b) Sufficient flow to oxygenate pools and avoid stratification*

An adequate concentration of dissolved oxygen (DO) in the water column at all times is essential to the survival of aquatic species (Storey et al. 2001). The concentration of DO depends on both biological and physical processes, and varies in predictable ways throughout the day and between summer and winter. During the day, photosynthesis results in a net gain of DO in the water column. At night, respiration by aquatic plants, animals and microorganisms results in a net loss of DO concentration, with the minimum reached just before dawn. DO levels are lowest in summer and autumn, when higher water temperatures result in decreased solubility of oxygen, flow rates are reduced leading to reduced physical re-aeration of the water, and respiration rates are elevated (see Appendix D).

In the lower Canning River, pools are susceptible to anoxia (particularly at night and in summer) because of their relatively small volume – induced by river regulation, sedimentation and an abundance of organic material. It is likely that pool volumes are no longer sufficient to ‘buffer’ the increased oxygen demand associated with the organic material that has accumulated in many pools (Appendix D).

#### Approach

As no information was available on the flow velocity required to adequately oxygenate water within pools, a DO study was conducted at a representative pool in Reach 6 (Pioneer Park) immediately before and during the summer trial water release. The study’s objective was to determine the velocity and discharge thresholds at which DO levels were sufficiently high to avoid anoxia.

In mid-channel at the downstream end of the representative pool, automatic data loggers were used to take frequent measurements (i.e. every 15 minutes) of DO and water temperature over two periods of 72 hours. The first 72-hour period was during a period of minimum baseflow. The second 72-hour period occurred while release valves were gradually opened, and discharge increased. Probes were suspended approximately 10 cm below the water surface, and approximately 10 cm above the bottom sediments. Discharge was measured roughly every 24 hours during the trial.

DO readings throughout the 72-hour period were compared with discharge measurements. This was to determine a threshold discharge for DO being maintained at sufficient levels throughout the entire diel (day-night) cycle. Because discharge was not measured as frequently as DO and temperature, and due to inaccuracies associated with measuring discharge at very low flows, the interpolated threshold at which discharge exceeds the minimum required to maintain physical re-aeration of the water column must be seen as approximate, and not as an absolute trigger value throughout the lower Canning River.

The full report on DO levels, including further details on the methods employed during the study, can be found in Appendix D.

## B.6 Riparian vegetation

Four flow-ecology linkages were identified for riparian vegetation in the lower Canning River. An account of the process used to determine the flow requirements for each linkage is given below.

### *6a) Maintenance of vegetation in winter-wet floodplains and off-channel wetlands*

Inundation or water logging of winter-wet pastured sites, floodplain regions and backwaters is important for the establishment and survival of riparian and fringing vegetation.

**Approach**

Elevations of likely entry points to off-channel areas were recorded during cross-section surveys. The minimum discharge required to achieve a stage height equal to the elevation of entry points, and thereby inundate off-channel areas and winter-wet floodplains, was determined using the hydraulic model.

Using historic data from Seaforth gauging station, a high-spells analysis was conducted to determine the frequency and duration of events of sufficient magnitude to inundate off-channel features. The results of the high-spells analysis were directly applicable only to the lower reaches (i.e. reaches 4, 5 and 6).

### *6b) Seasonal inundation of emergent vegetation*

Inundation of emergent vegetation is an important cue for germination of propagules and the growth of existing vegetation.

**Approach**

The location and elevation of emergent vegetation was recorded during cross-section surveys. The minimum discharge required to achieve stage heights equivalent to the root base of emergent vegetation was determined by examining the stage height/discharge relationship output by the hydraulic model for individual cross-sections. The mean discharge required to inundate emergent vegetation was calculated for each reach.

During the trial water-release program, observations were made at each cross-section as to whether the root base of emergent vegetation was inundated during flow events of measured discharge. Flow recommendations were developed based on the hydraulic model and field observations.

For Reach 4 (Orlando Street), Reach 5 (Manning Avenue) and Reach 6 (Pioneer Park), the time-series was examined to determine the frequency and duration of flows capable of inundating emergent vegetation. A flow recommendation was formulated for each reach based on modelled and trial results where applicable.

*6c) Seasonal inundation of mid-bank vegetation*

Maintenance of a sufficient natural flow regime is important to ensure germination, recruitment and colonisation of mid-bank native vegetation. Failure to provide flows to promote recruitment and survival of intact riparian vegetation communities may result in thinning or a reduction in health of the riparian zone. Resultant degradation of the riparian zone can increase erosion and further degrade the stream bank, increase sedimentation downstream, and reduce shade and in-stream habitat.

In Australian wetlands, periods of water-logged soils during autumn represent the peak germination period for native plant species, with fewest species germinating in the summer months (Britton & Brock 1994; Storey et al. 2001).

**Approach**

The location and elevation of mid-bank vegetation was recorded during cross-section surveys. Using the hydraulic model, a minimum discharge required to achieve stage heights equivalent to the elevation of mid-bank vegetation was determined by examining the stage height/discharge relationship for individual cross-sections. A mean discharge was determined for each reach.

For management reaches 4, 5 and 6 (Orlando Street, Manning Avenue and Pioneer Park), historic data from Seaforth gauging station were examined to determine the frequency and duration of events of the required discharge to inundate mid-bank vegetation.

*6d) Sufficient flow for submerged macrophytes*

In the Canning River system, submerged aquatic macrophytes provide habitat for macroinvertebrates and fish, and provide a substrate for epiphytic algae. Macrophyte biomass peaks over summer in relatively shallow (less than 2 m depth) and open parts of the channel, and is reduced during winter. Macrophytes require permanent water for survival and recolonisation following periods of low flow.

**Approach**

Macrophyte beds were identified in only one management reach: this flow-ecology linkage and the comparable linkages 2b (macroinvertebrates: submerged macrophyte habitat) and 3f (fish: submerged macrophyte habitat) were therefore not assessed in other management reaches. During the trial water-release program, observations were made to determine whether the macrophyte beds within the reach were inundated to a depth of 20 cm or more at the different discharges recorded. Flow recommendations were developed based on the trial observations.

## B.7 Ecosystem processes

Three flow-ecology linkages were identified for ecosystem processes in the lower Canning River. A detailed account of the process used to determine the flow requirements for each linkage is given below.

*7a) Seasonal inundation of the riparian zone*

Regulation and altered land use have changed the frequency and magnitude of peak-flow events that inundate the riparian zone in the lower Canning River. Inundation of riparian zones maintains the input of terrestrial carbon into the system, which sustains food webs and nutrient cycling.

**Approach**

This flow-ecology linkage is directly comparable with linkage 6a (riparian vegetation: maintain winter-wet floodplains and off-channel wetlands). The approach used to determine the ecologically critical discharge for linkage 7a was identical to that described for linkage 6a.

*7b) Flow connectivity*

Flows are required to mobilise accumulated nutrients in the river, as well as to flush leaf litter from riparian wetland areas. This allows the transfer of energy from upstream reaches to the lower Canning River and into the Swan-Canning estuary. Flow connectivity can be achieved by a combination of over-bank flows, active channel flows and mean winter baseflow.

**Approach**

Components of this flow-ecology linkage were addressed in linkages 1b (geomorphology: maintain active channel), 5a (water quality: pool connectivity), 6a (riparian vegetation: maintain winter-wet floodplains and off-channel wetlands) and 6c (riparian vegetation: inundate mid-bank vegetation). Flow-ecology linkage 7b will be satisfied if the flow objectives for the five component linkages are also met.

*7c) Seasonal inundation of lower benches*

Algal production is an important ecosystem driver. Low-flow in-stream benches are sites for algal growth during dry periods. Baseflows should be sufficient to inundate low-flow benches year-round for algal production.

**Approach**

This flow-ecology linkage is comparable with linkage 3l (fish: inundate in-stream benches). The approach used to determine threshold criteria for linkage 7c was identical to that described for linkage 3l.

# Appendix C — Detailed results used to determine ecological water requirements

## C.1 Reach 1: Soldiers Road

### C.1.1 Geomorphology

Table C1 summarises the flow requirements for geomorphological processes in Reach 1 (Soldiers Road).

*Table C1 Flow requirements for Reach 1 (Soldiers Road)*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 1a) Sufficient flow to scour pools and remove sediments | June to August | • Sedimentation cannot be managed in the lower Canning River with environmental releases of water. |
| 1b) Sufficient flow to maintain the shape of active channel | June to August | • Not assessed for this reach due to limited hydrological information. |

*1a) Sufficient flow to scour pools and remove sediments*

There was one pool within the reach that was affected by sedimentation, due largely to the presence of a private weir downstream. As explained in Appendix B.1, no flow recommendations have been formulated for this flow-ecology objective. Sedimentation cannot be managed in the lower Canning River with only the relatively small volumes of water that could be discharged from the environmental release points (ERPs). Increased soil erosion, surface runoff and the resultant sedimentation require a whole-of-catchment management approach.

### C.3.2 Macroinvertebrates

Table C2 summarises the flow requirements for macroinvertebrates in Reach 1 (Soldiers Road). Six of the seven flow-ecology linkages were either not assessed for Reach 1, or were addressed by other flow-ecology linkages. Here, detailed results are presented only for flow-ecology linkage 2a.

*Table C2 Flow requirements for macroinvertebrates, Soldiers Road*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 2a) Maintain water depth of 5 cm over gravel runs and riffles | All year | • Maintain minimum discharge of 1.2 ML/day within the reach throughout the year. |

### 2a) Water depth of at least 5 cm over riffles

Riffle habitat was recorded at six of the 11 surveyed cross-sections. Hydraulic analysis indicated that a mean discharge of 1.7 ML/day was required to provide sufficient riffle habitat (i.e. inundation of 50 per cent of riffle width to a depth of 5 cm averaged across all surveyed riffle sections).

During the field trial, observations of riffle inundation were made at discharges of 1.2 ML/day (Day 4) and 2.1 ML/day (Day 5). The threshold criterion was met at just two out of the six surveyed riffle cross-sections at both of these discharges. However, for two of the four cross-sections where riffles were not sufficiently inundated, there was alternative riffle habitat located either upstream or downstream of the cross-section.

There was no substantial increase in available riffle habitat at the highest measured discharge. The lower discharge of 1.2 ML/day has been adopted as the minimum flow recommendation, recognising that for this reach, not all riffles will be inundated to the recommended depth, but that sufficient habitat would be available.

**Flow recommendation**

- Maintain minimum discharge of 1.2 ML/day throughout the year.

## C.1.3 Fish

Table C3 summarises the flow requirements for fish in Reach 1 (Soldiers Road).

*Table C3 Flow requirements for fish, Soldiers Road*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 3a) Sufficient water depth (10 cm) for small-bodied fish for reproductive migration | June to October | • Maintain minimum discharge of 2.1 ML/day within the reach between June and October.<br>• Modifications may be required to some riffle structures to allow passage of small-bodied fish. |
| 3b) Sufficient water depth (20 cm) for large-bodied fish (cobbler) for reproductive migration | November to January | • Provide discharge of approximately 10.4 ML/day within the reach between November and January. Wherever possible, passage flows should be delivered in pulses lasting several days.<br>• Modifications may be required to some riffle structures to allow passage of large-bodied fish (such as cobbler).<br>• Further monitoring is required to confirm that the recommended discharge will submerge all obstacles to 20 cm. |
| 3d) Inundation of emergent sedges and rushes to provide fish habitat | April to October | • Flows of 2.1 ML/day are required to inundate emergent vegetation within the summer active channel. |

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 3g) Maintain pool depth for cobbler nests and as refuge habitat for other fish species | All year | • A discharge of 1.2 ML/day is sufficient to maintain refuge pools to a depth of at least 65 cm. |
| 3h) Inundate shallow backwaters as nurseries and as habitat for small fish during high flows | April to October | • Not assessed for this reach due to access difficulties (potential shallow backwater habitat smothered in overgrowth of blackberry). |
| 3k) Undercutting of riverbanks to provide habitat | All year | • No specific flow recommendations to provide undercut habitat have been made, as this habitat occurs at a range of flows year-round. Maintaining flows to submerge emergent vegetation (linkage 3d) will provide fish habitat at undercut sites. See Appendix B.3 for further information. |
| 3l) Sufficient flow to inundate in-stream benches to provide foraging and spawning habitat | April to October | • A discharge of approximately 30 ML/day is required to inundate mid-flow benches at intervals during winter and spring. |

### *3a) Sufficient water depth for reproductive migration of small fish*

Six of the 11 cross-sections were identified as possible obstructions to fish passage. Hydraulic analysis results indicated that a discharge of 10.4 ML/day would submerge all surveyed obstacles to at least 10 cm. Field observations showed that the modelled discharges generally overestimated the flow required to achieve particular water levels by around 50 per cent.

During the field trial, five of the six cross-sections were submerged to at least 10 cm at the maximum recorded discharge of 2.1 ML/day. The sixth cross-section, which was submerged to a depth of 9 cm, was an 80-cm-high waterfall that represented a significant obstacle to fish passage. Removal of some of the obstacles may be required to allow passage of small-bodied fish.

#### Flow recommendations

- Maintain minimum discharge of 2.1 ML/day within the reach between June and October.
- Modifications may be required to some riffle structures to allow passage of small-bodied fish.

### *3b) Sufficient water depth for reproductive migration of large fish*

Six cross-sections were identified as possible obstructions to fish passage. Hydraulic analysis results showed that a discharge of 28.5 ML/day would submerge all surveyed obstacles to at least 20 cm. Field observations showed that the modelled discharges generally overestimated the flow required to achieve particular water levels by around 50 per cent.

During the summer trial, three of the six cross-sections were submerged to at least 20 cm at 2.1 ML/day. At the measured discharge, the other three cross-sections – one of which was a small (80 cm) waterfall – would represent significant obstructions to upstream cobbler migration during summer. Modifications to some of the riffle structures may be required.

As the measured discharges were insufficient to submerge all obstacles to 20 cm, the modelled result for linkage 3a has been used as the flow recommendation. It is recognised that at the time of year cobbler passage flows are required (November to January), ERP capacity may not be sufficient to deliver the recommended flow. ‘Passage flows’ for cobbler should be delivered in pulses. This may require opening ERP valves to full capacity for periods during the cobbler reproductive migration.

**Flow recommendations**

- Provide discharge of approximately 10.4 ML/day within the reach between November and January. Such ‘passage flows’ should be delivered in pulses lasting several days.
- Modifications may be required to some riffle structures to allow passage of large-bodied fish (such as cobbler).
- Further monitoring is required to confirm that the recommended discharge is appropriate to submerge all obstacles to 20 cm.

*3d) Inundation of emergent sedges and rushes for habitat*

Emergent vegetation was recorded at six cross-sections within the reach. Hydraulic analysis results generally overestimated the discharge required to inundate emergent vegetation at each cross-section. During the summer trial, the water level was sufficient to inundate emergent vegetation at four out of six sites, at a measured discharge of 2.1 ML/day.

**Flow recommendation**

- Flows of 2.1 ML/day are required to inundate emergent vegetation within the summer active channel.

*3g) Maintain pool depth for cobbler and other fish species*

There are two pools within Reach 1 that were considered as possible summer refuge sites (Figure C1). The hydraulic analysis results have not been used for this flow-ecology linkage within this reach. The modelled results gave a much lower thalweg depth for a given discharge than what was measured in the field for the same discharge.

*Figure C1 Cross-section MR1-000 (A) and cross-section MR1-289 (B) showing summer refuge pools for cobbler and other fish species*

Summer trial observations found that the downstream pool's thalweg depth (cross-section MR1-000) was maintained at greater than 80 cm throughout the trial. At the other pool cross-section (MR1-289), thalweg depth reached a maximum of 68 cm at a discharge (measured at the control point) of 2.1 ML/day. At a discharge of 1.2 ML/day, the pool was 65 cm deep. While the recommended depth was not reached, the pool at MR1-289 was considered to be an excellent fish habitat site incorporating undercutting, trailing vegetation, stream shading and a cobbler riverbed habitat. Maintaining a depth of 65 cm may still be enough to support cobbler nesting over summer, and provide refuge for smaller fish species.

**Flow recommendation**

- A discharge of 1.2 ML/day is sufficient to maintain refuge pools to a depth of at least 65 cm.

*3h) Inundate shallow backwaters as fish habitat*

A secondary channel exists within Reach 1, but it could not be surveyed as it was smothered in dense blackberry (*Rubus fruticosus*). Inundation of the secondary channel was observed during a period of peak flow, suggesting it might provide a backwater area for fish to avoid high flows in the main channel. Removal of blackberry and revegetation with native plants would improve the habitat value of this backwater for fish and other aquatic fauna. No other backwaters were present within the reach.

*3l) Sufficient flow to inundate in-stream benches*

Three mid-flow in-stream benches were identified within Reach 1. Hydraulic analysis indicated that the mean discharge required to inundate the bench features to 10 cm was 30.0 ML/day. Such discharges were not measured during the summer trial.

### Flow recommendation

- A discharge of approximately 30 ML/day is required to inundate mid-flow benches at intervals during winter and spring, as foraging and spawning habitat for fish.

## C.1.4 Waterbirds

The two flow-ecology linkages for waterbirds have been addressed with reference to other, comparable linkages that fall under the headings of fish and riparian vegetation. See Appendix B for further details.

## C.1.5 Water quality

Two flow-ecology linkages were identified for water quality in Reach 1 (Soldiers Road) (Table C4).

*Table C4 Flow requirements for water quality, Soldiers Road*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 5a) Sufficient flow to maintain connectivity of pools in summer | All year | • A discharge of 1.2 ML/day is sufficient to maintain connectivity within the reach and within large slow-flowing pools upstream. |
| 5b) Prevent anoxia and significant stratification in pools during summer | All year | • An investigation should be undertaken to define a threshold discharge to avoid anoxia in slow-flowing weir pools of the upper Canning River; the interim recommendation is to maintain flow connectivity as per linkage 5a above. |

### *5a) Sufficient flow to maintain connectivity of pools in summer*

During the summer trial release, flow connectivity occurred within the reach at all times, including during the baseflow period (estimated discharge of less than 0.9 ML/day). However, the baseflow component was not enough to ensure that pools upstream of Reach 1 remained connected during the trial's low-flow phase. As a result, Araluen ERP was increased to full capacity on the second day of the trial to ensure that the slow-flowing pools were filled rapidly. When discharge was measured at the control point on the fourth day of the trial at 1.2 ML/day, upstream connectivity had been restored.

A minimum flow threshold cannot be determined from the trial results, because the discharge was measured once a day and not at the precise moment that upstream connectivity was restored. Further, no information was available on losses from the system due to abstraction, infiltration or evaporation. The best discharge estimate able to be provided from the field data is that 1.2 ML/day is sufficient to ensure connectivity within the management reach and between upstream pools during summer.

**Flow recommendation**

- A discharge of 1.2 ML/day is sufficient to maintain connectivity during summer within Reach 1 and upstream pools.

*5b) Prevent anoxia and stratification in pools during summer*

The results of the dissolved oxygen (DO) study (Appendix D) were directly applicable to the lower management reaches only. An investigation should be undertaken to define a threshold discharge to avoid anoxia in slow-flowing weir pools of the upper Canning River. The interim recommendation is to maintain flow connectivity as per linkage 5a above, because even relatively low discharges may be sufficient to oxygenate pools (see Appendix D).

**Flow recommendations**

- An investigation should be undertaken to define a threshold discharge to avoid anoxia in slow-flowing weir pools of the upper Canning River.
- Maintain flow connectivity as per linkage 5a (maintain pool connectivity).

### C.1.6 Riparian vegetation

Table C5 summarises the flow requirements for vegetation in Reach 1 (Soldiers Road).

*Table C5 Flow requirements for riparian vegetation, Soldiers Road*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 6a) Sufficient flow to maintain winter-wet floodplain regions and off-channel wetlands. | June to August | • Flows of 37.2 ML/day are required annually to inundate the off-channel restoration wetland. |
| 6c) Seasonal inundation of mid-bank vegetation for survival, germination and recruitment | June to August | • No mid-bank vegetation was recorded within Reach 1. |
| 6d) Sufficient flow to maintain populations of submerged macrophytes | All year | • No macrophyte beds were identified within Reach 1. |

*6a) Maintain winter-wet floodplain and off-channel wetlands*

The entry point to an off-channel restoration wetland was identified at one cross-section within this reach. Hydraulic analysis results indicated that a discharge of 37.2 ML/day would be required to begin inundation of this site. Flows are required annually in winter or spring for germination, seedling establishment and maintenance of riparian plant communities.

### Flow recommendation

- Maintain minimum discharge of 2.2 ML/day within the reach throughout the year.

### C.2.3 Fish

Table C8 summarises the flow requirements for fish in Reach 2 (Stocker Road).

*Table C8 Flow requirements for fish, Stocker Road*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 3a) Sufficient water depth (10 cm) for small-bodied fish for reproductive migration | June to October | • Maintain minimum discharge of 2.2 L/day within the reach between June and October.<br>• Modifications may be required to a private weir structures. |
| 3b) Sufficient water depth (20 cm) for large-bodied fish (cobbler) for reproductive migration | November to January | • Maintain minimum discharge of 6.1 ML/day within the reach between November and January.<br>• Flows of greater discharge should be provided in pulses at intervals throughout the peak cobbler migration period (November to January).<br>• Modifications may be required to a private weir structure. |
| 3d) Inundation of emergent sedges and rushes to provide fish habitat | April to October | • Flows of at least 2.2 ML/day are required to inundate emergent vegetation within the summer active channel. |
| 3g) Maintain pool depth for cobbler nests and as refuge habitat for other fish species | All year | • Pool depth cannot be maintained over summer to the required depth (80 cm) with the existing release point infrastructure. This reach should be assessed for future fish passage and refuge requirements. |
| 3h) Inundate shallow backwaters as nurseries and as habitat for small fish during high flows | April to October | • Backwater habitat not identified within Reach 2; refer to flow-ecology linkage 6a for details of discharge required to inundate off-channel wetlands. |
| 3k) Undercutting of riverbanks to provide habitat | All year | • No specific flow recommendations to provide undercut habitat have been made, because this habitat occurs at a range of flows year-round. Maintaining flows to submerge emergent vegetation (linkage 3d) will provide fish habitat at undercut sites. See Appendix B.3 for further information. |
| 3l) Sufficient flow to inundate in-stream benches to provide foraging and spawning habitat | April to October | • A discharge of approximately 2 to 3 ML/day is required to inundate mid-flow benches at intervals during winter and spring, as foraging and spawning habitat for fish. |

*3a) Sufficient water depth for reproductive migration of small fish*

Seven cross-sections within Reach 2 were identified as possible obstructions to fish passage. Hydraulic analysis results indicated that a discharge of 7.8 ML/day would submerge all surveyed obstacles to a depth of at least 10 cm. Field observations showed that this result overestimated the actual flow required.

During the summer trial, all surveyed cross-sections were submerged to at least 10 cm at a discharge of 2.2 ML/day. However, the privately constructed small weir above cross-section MR2-282 poses a major obstruction to upstream movement of fish. This structure may need to be modified to permit fish passage.

**Flow recommendations**

- Maintain minimum discharge of 2.2 ML/day within the reach between June and October.
- Modifications may be required to a private weir structure to allow passage of small-bodied fish.

*3b) Sufficient water depth for reproductive migration of large fish*

Seven cross-sections within the reach were identified as possible obstructions to fish passage. Hydraulic analysis results indicated that a discharge of 28.5 ML/day would submerge all surveyed obstacles to at least 20 cm. As for linkage 3a, the modelled results overestimated the flow required to achieve particular water levels.

During the summer trial, all except three of the surveyed cross-sections were submerged to at least 20 cm at a discharge of 6.1 ML/day. The three remaining cross-sections were submerged to 10 cm, 17 cm and 19 cm. However, the water level at the shallowest of the three cross-sections was 19 cm at the start of the low-flow trial, when discharge was estimated at less than 4.3 ML/day. The highest discharge measured in the field trial has been adopted as the flow recommendation (because the modelled result appears to overestimate the required flow), although it is noted that higher discharges are required in pulses throughout the cobbler migration period.

**Flow recommendations**

- Maintain minimum discharge of 6.1 ML/day within the reach between November and January.
- Flows of greater discharge should be provided in pulses of at least several hours at intervals throughout the peak cobbler migration period.
- Modifications may be required to private weir structures to allow passage of large-bodied fish.

### *3d) Inundation of emergent sedges and rushes for habitat*

Modelled results and field observations show that inundation of emergent vegetation occurs at relatively low flows. Hydraulic modelling indicated that all four cross-sections with emergent vegetation would be inundated at a discharge of 2.6 ML/day. During the summer trial, all four cross-sections were inundated at a discharge of 2.2 ML/day. The results suggest that emergent vegetation has adapted to the prevailing summer water levels.

**Flow recommendation**

- Flows of at least 2.2 ML/day are required to inundate emergent vegetation within the summer active channel.

### *3g) Maintain pool depth for cobbler and other fish species*

Freshwater cobbler have been observed in this management reach. The pool at cross-section MR2-052 is considered the only likely summer refuge habitat within the reach. Hydraulic modelling estimated that a discharge of more than 200 ML/day would maintain the pool to a depth of 80 cm; such a discharge (if accurate) is well beyond the maximum capacity of the Araluen and Hill 60 ERPs. Observations during the field trial showed that the maximum depth of the pool at MR2-052 was 43 cm, at a discharge of 6.1 ML/day. With the current water-release infrastructure, this flow objective cannot be achieved for Reach 2 (Stocker Road).

**Flow recommendation**

- Pool depth cannot be maintained over summer to the required depth (80 cm) with the existing infrastructure. This reach should be assessed for future fish passage and refuge requirements.

### *3l) Sufficient flow to inundate in-stream benches*

Two low-flow in-stream benches were surveyed within Reach 2. Hydraulic modelling indicated that a discharge of 58.8 ML/day would be required to inundate low-flow benches to 10 cm; this is likely to be a substantial overestimate of the actual discharge required, as both benches were inundated by 5 cm at a measured discharge of 2.1 ML/day. Neither bench was inundated by the requisite 10 cm during the field trial.

**Flow recommendation**

- A discharge of approximately 2 to 3 ML/day is required to inundate mid-flow benches at intervals during winter and spring, as foraging and spawning habitat for fish.

### C.2.4 Waterbirds

The two flow-ecology linkages for waterbirds have been addressed with reference to other, comparable linkages that fall under the headings of fish and riparian vegetation. See Appendix B for further details.

### C.2.5 Water quality

Two flow-ecology linkages were identified for water quality in Reach 2 (Stocker Road) (Table C9). More detail on individual linkages is supplied below.

*Table C9 Flow requirements for water quality, Stocker Road*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 5a) Sufficient flow to maintain connectivity of pools in summer | All year | • A discharge of 2.2 ML/day is sufficient to maintain connectivity within the reach and within large slow-flowing pools upstream. |
| 5b) Prevent anoxia and significant stratification in pools during summer | All year | • An investigation should be undertaken to define a threshold discharge to avoid anoxia in slow-flowing weir pools of the upper Canning River; the interim recommendation is to maintain flow connectivity as per linkage 5a above. |

*5a) Sufficient flow to maintain connectivity of pools in summer*

Field observations indicated that flow connectivity was maintained at all times within the reach during the trial, even during baseflow conditions of approximately 0.9 ML/day. However, baseflow was not enough to maintain connectivity throughout the lower Canning River. A slow-flowing weir pool upstream of Reach 2 became disconnected during the baseflow period for approximately three days. There was consistent flow over riffles and other barriers on Day 3 of the trial, at which time the discharge measured at the downstream control point in Reach 2 was 2.2 ML/day, and both upstream ERPs were operating at full capacity.

Similarly to Reach 1, a minimum critical discharge could not be determined using the trial results (see Appendix C.1.5). Discharge measurements at the control point were made once a day and not at the precise moment that upstream connectivity was restored. Further, no information was available on losses from the system due to abstraction, infiltration or evaporation. The flow recommendation may overestimate the actual discharge required to maintain flow. The best discharge estimate able to be provided from the field data is that 2.2 ML/day (measured at the control point) is sufficient to ensure connectivity within the management reach and between upstream pools during summer.

**Flow recommendation**

- A discharge of 2.2 ML/day is sufficient to maintain connectivity during summer within Reach 2 and upstream pools.

### *5b) Prevent anoxia and stratification in pools during summer*

The results of the DO study (Appendix D) were directly applicable to the lower management reaches only. An investigation should be undertaken to define a threshold discharge to avoid anoxia in slow-flowing weir pools of the upper Canning River. The interim recommendation is to maintain flow connectivity as per linkage 5a above, because even relatively low discharges may be sufficient to oxygenate pools (see Appendix D).

**Flow recommendations**

- An investigation should be undertaken to define a threshold discharge to avoid anoxia in slow-flowing weir pools of the upper Canning River.
- Maintain flow connectivity as per linkage 5a (maintain pool connectivity).

## C.2.6 Riparian vegetation

Table C10 summarises the flow requirements for riparian vegetation in Reach 2. Two flow-ecology linkages (6c and 6d) were not assessed because no mid-bank vegetation or macrophyte beds existed within the reach.

*Table C10 Flow requirements for riparian vegetation, Stocker Road*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 6a) Sufficient flow to maintain winter-wet floodplain regions and off-channel wetlands. | June to August | • Flows of 446.1 ML/day are required to inundate the off-channel restoration wetland. |
| 6c) Seasonal inundation of mid-bank vegetation for survival, germination and recruitment | June to August | • No mid-bank vegetation was recorded within Reach 2. |
| 6d) Sufficient flow to maintain populations of submerged macrophytes | All year | • No macrophyte beds were identified within Reach 2. |

### *6a) Maintain winter-wet floodplain and off-channel wetlands*

Three cross-sections contained entry points to off-channel wetlands or restoration areas. Hydraulic modelling indicated that a mean discharge of 446.1 ML/day would be required to begin inundation of off-channel wetlands. Ideally, flows should occur annually in winter or spring for germination, seedling establishment and maintenance of riparian plant communities. No comprehensive hydrological information is available for Reach 2, so the average historical frequency of events of this magnitude cannot be determined.

**Flow recommendation**

- Flows of 446.1 ML/day are required to inundate the off-channel restoration wetland.

### C.2.7 Ecosystem processes

The three flow-ecology linkages for ecosystem processes have been addressed with reference to other, comparable linkages that fall under the headings of geomorphology, macroinvertebrates, fish, water quality and riparian vegetation. See Appendix B for further details.

## C.3 Reach 3: Bernard Street

### C.3.1 Geomorphology

Table C11 summarises the flow requirements for geomorphological processes in Reach 3 (Bernard Street).

*Table C11 Flow requirements for geomorphology, Bernard Street*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 1a) Sufficient flow to scour pools and remove sediments | June to August | • Sedimentation cannot be managed in the lower Canning River with environmental releases of water. |
| 1b) Sufficient flow to maintain the shape of the active channel | June to August | • Not assessed for this reach due to limited hydrological information. |

#### *1a) Sufficient flow to scour pools and remove sediments*

The long pools within Bernard Street management reach are substantially affected by sedimentation. As explained in Appendix B.1, no flow recommendations have been formulated for this flow-ecology objective. Sedimentation cannot be managed in the lower Canning River with the relatively small volumes of water that could be discharged from the ERPs.

### C.3.2 Macroinvertebrates

Six of the seven flow-ecology linkages for macroinvertebrates were addressed by other flow-ecology linkages. Here, detailed results are presented only for flow-ecology linkage 2a (Table C12).

*Table C12 Flow requirements for macroinvertebrates, Bernard Street*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 2a) Maintain water depth of 5 cm over gravel runs and riffles | All year | • Maintain minimum discharge of 2.4 ML/day within the reach throughout the year. |

### *2a) Water depth of at least 5 cm over riffles*

Riffle habitat was assessed at three cross-sections within Reach 3. The hydraulic analysis results indicated that a discharge of 9.5 ML/day was required to inundate 50 per cent of the total width of riffles surveyed to a depth of at least 5 cm.

During the field trial, water levels were sufficiently high to allow for discharge measurements on Day 4 (2.4 ML/day) and Day 5 (4.7 ML/day). Field observations showed that all riffle sections surveyed were sufficiently inundated on the fourth day of the trial. The corresponding discharge has been used as the flow recommendation.

**Flow recommendation**

- Maintain minimum discharge of 2.4 ML/day within the reach throughout the year.

## C.3.3 Fish

Table C13 summarises the flow requirements for fish in Reach 3 (Bernard Street).

*Table C13 Flow requirements for fish, Bernard Street*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 3a) Sufficient water depth (10 cm) for small-bodied fish for reproductive migration | June to October | • Maintain minimum discharge of 4.7 ML/day within the reach between June and October. |
| 3b) Sufficient water depth (20 cm) for large-bodied fish (cobbler) for reproductive migration | November to January | • Maintain minimum discharge of approximately 6 ML/day within the reach between November and January.<br>• Flows of greater discharge should be provided in pulses at intervals throughout the peak cobbler migration period (November to January).<br>• Modifications may be required to rock weirs to allow passage of large-bodied fish. |
| 3d) Inundation of emergent sedges and rushes to provide fish habitat | April to October | • Flows of 4.7 ML/day are required to inundate emergent vegetation to a depth of at least 10 cm. |

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 3g) Maintain pool depth for cobbler nests and as refuge habitat for other fish species | All year | • Due to sedimentation, there are no pools appropriate for summer refuge within Reach 3. |
| 3h) Inundate shallow backwaters as nurseries and as habitat for small fish during high flows | April to October | • Shallow backwater areas were not identified within Reach 3. |
| 3k) Undercutting of riverbanks to provide habitat | All year | • No specific flow recommendations to provide undercut habitat have been made, as this habitat occurs at a range of flows year-round. Maintaining flows to submerge emergent vegetation (linkage 3d) will provide fish habitat at undercut sites. See Appendix B.3. |
| 3l) Sufficient flow to inundate in-stream benches to provide foraging and spawning habitat | April to October | • A discharge of 4.7 ML/day is sufficient to inundate the low-flow bench in Reach 3. |

*3a) Sufficient water depth for reproductive migration of small fish*

Hydraulic analysis results indicated that a modelled discharge of 24.2 ML/day would submerge all surveyed obstacles within the reach to at least 10 cm. Field observations showed that the modelled discharge substantially overestimated the actual discharge required to reach a water level of at least 10 cm throughout the reach. During the summer trial, all cross-sections were submerged to at least 10 cm at a discharge of 4.7 ML/day.

**Flow recommendation**

- Maintain minimum discharge of 4.7 ML/day within the reach between June and October.

*3b) Sufficient water depth for reproductive migration of large fish*

Hydraulic analysis results indicated that a modelled discharge of 78.6 ML/day would submerge all surveyed obstacles within the reach to at least 20 cm. Based on field observations during the summer trial, this is likely to be a substantial overestimate of the actual discharge required.

During the summer trial, water depth did not reach 20 cm at four of the nine surveyed cross-sections. For these four cross-sections, water depths at the maximum recorded discharge of 4.7 ML/day ranged between 12 and 18 cm. Rock weirs are present at two of these cross-sections, which may need to be modified to allow reproductive migration of freshwater cobbler. Together with the weir modifications, an increase in discharge may be enough to allow cobbler passage.

A provisional estimate of around 6.0 ML/day (similar to the flow recommended for Reach 2) is the flow recommendation for the reach. Further monitoring should be undertaken to determine whether this provisional estimate is sufficient to submerge all obstacles to at least 20 cm.

**Flow recommendation**

- Maintain a minimum discharge of approximately 6 ML/day within the reach between November and January.
- Flows of greater discharge should be provided in pulses at intervals throughout the peak cobbler migration period.
- Modifications may be required to private rock weirs to allow the passage of large-bodied fish.

*3d) Inundation of emergent sedges and rushes for habitat*

The hydraulic analysis results greatly overestimated the actual discharge required to inundate emergent vegetation. During the summer field trial, the four cross-sections that contained emergent vegetation were submerged to a depth of at least 10 cm at a measured discharge of 4.7 ML/day.

**Flow recommendation**

- Flows of 4.7 ML/day are required to inundate emergent vegetation to a depth of at least 10 cm within the summer active channel.

*3l) Sufficient flow to inundate in-stream benches*

Within Reach 3, one cross-section contained an in-stream low-flow bench. During the field trial, the low-flow bench was inundated to 10 cm at a discharge of 4.7 ML/day.

**Flow recommendation**

- A discharge of 4.7 ML/day is sufficient to inundate the low-flow bench in Reach 3.

### C.3.4 Waterbirds

The two flow-ecology linkages for waterbirds have been addressed with reference to other, comparable linkages that fall under the headings of fish and riparian vegetation. See Appendix B for further details.

### C.3.5 Water quality

Two flow-ecology linkages were identified for water quality in Reach 3 (Bernard Street) (Table C14).

*Table C14 Flow requirements for water quality, Bernard Street*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 5a) Sufficient flow to maintain connectivity of pools in summer | All year | • A discharge of 2.4 ML/day is sufficient to maintain connectivity within the reach and within large slow-flowing pools upstream. |
| 5b) Prevent anoxia and significant stratification in pools during summer | All year | • An investigation should be undertaken to define a threshold discharge to avoid anoxia in slow-flowing weir pools of the upper Canning River; the interim recommendation is to maintain flow connectivity as per linkage 5a above. |

### *5a) Sufficient flow to maintain connectivity of pools in summer*

During the trial water-release program, flow conditions in Reach 3 were very similar to those reported for the two upstream management reaches. Field observations indicated that flow connectivity was maintained within the reach at all times during the trial, even during baseflow conditions of less than 0.9 ML/day. However, baseflow was not sufficient to maintain connectivity throughout the lower Canning River. A slow-flowing weir pool upstream of Reach 3 became disconnected during the baseflow period for approximately three days. The pool was not fully refilled until the fourth day of the trial, at which time the discharge measured at the downstream control point in Reach 3 was 2.4 ML/day, and both upstream ERPs were operating at full capacity.

For the same reasons described for Reach 2 (see Appendix C.2.5), a minimum critical discharge could not be determined using the trial results. The best discharge estimate able be provided from the field data is that 2.4 ML/day (measured at the control point) is sufficient to ensure connectivity within the management reach and between upstream pools during summer.

**Flow recommendation**

- A discharge of 2.4 ML/day is sufficient to maintain connectivity during summer within Reach 3 and upstream pools.

### *5b) Prevent anoxia and stratification in pools during summer*

The results of the DO study (Appendix D) were directly applicable to the lower management reaches only. An investigation should be undertaken to define a threshold discharge to avoid anoxia in slow-flowing weir pools of the upper Canning River. The interim recommendation is to maintain flow connectivity as per linkage 5a above, because even relatively low discharges may be sufficient to oxygenate pools (see Appendix D).

### Flow recommendations

- An investigation should be undertaken to define a threshold discharge to avoid anoxia in slow-flowing weir pools of the upper Canning River.
- Maintain flow connectivity as per linkage 5a (maintain pool connectivity).

## C.3.6 Riparian vegetation

Three flow-ecology linkages were identified for riparian vegetation in Reach 3 (Table C15).

*Table C15* Flow requirements for riparian vegetation, Bernard Street

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 6a) Sufficient flow to maintain winter-wet floodplain regions and off-channel wetlands. | June to August | • Flows of approximately 580 ML/day are required to inundate the low-lying off-channel wetland. |
| 6c) Seasonal inundation of mid-bank vegetation for survival, germination and recruitment | June to August | • Discharges of 31.1 ML/day and 325.7 ML/day are required at intervals during winter and spring to allow survival, germination and recruitment of native vegetation and restoration plantings. |
| 6d) Sufficient flow to maintain populations of submerged macrophytes | All year | • Maintain minimum discharge of 2.4 ML/day during the summer months. |

### *6a) Maintain winter-wet floodplain and off-channel wetlands*

An entry point to a low-lying off-channel wetland was identified at one cross-section. Hydraulic modelling estimated that a discharge of 579.8 ML/day would be required to initiate inundation of the off-channel area. No comprehensive hydrological information is available for Reach 3, so the average historical frequency of events of this magnitude cannot be determined. However, floodplain inundation at least once every three years would help seed set and establishment of *Melaleuca preissiana* and *Eucalyptus rudis* seedlings on the floodplain.

### Flow recommendation

- Flows of 446.1 ML/day are required to inundate the low-lying off-channel wetland.

### *6c) Seasonal inundation of mid-bank vegetation*

Mid-bank vegetation within Reach 3 was characterised by restoration planting of emergent rushes across two mid-flow benches within the reach (as described in linkage 3l). The modelled discharges required to inundate the two mid-flow benches were 31.1 ML/day and 325.7 ML/day. Approximate frequencies for these events could not be determined due to a lack of detailed hydrological data. However, based on the results of time-series analysis for the lower reaches, it is likely the lower discharge would be achieved regularly during winter, while the upper discharge would occur once a year.

**Flow recommendation**

- Discharges of between 31.1 ML/day and 325.7 ML/day are required at intervals during winter and spring to allow survival, germination and recruitment of native vegetation and restoration plantings.

*6d) Maintain submerged macrophyte beds*

Submerged macrophytes are important in providing habitat to aquatic fauna within Reach 3. Field observations from the summer trial showed that a discharge of 2.4 ML/day provided a depth of 20 cm or greater across 90 per cent of the macrophyte bed present within the reach.

**Flow recommendation**

- Maintain minimum discharge of 2.4 ML/day during the summer months.

### C.3.7 Ecosystem processes

The three flow-ecology linkages for ecosystem processes have been addressed with reference to other, comparable linkages that fall under the headings of geomorphology, macroinvertebrates, fish, water quality and riparian vegetation. See Appendix B for further details.

## C.4 Reach 4: Orlando Street

### C.4.1 Geomorphology

Table C16 summarises the flow requirements for geomorphological processes in Reach 4 (Orlando Street).

*Table C16* Flow requirements for geomorphology, Orlando Street

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 1a) Sufficient flow to scour pools and remove sediments | June to August | • Sedimentation cannot be managed in the lower Canning River with environmental releases of water. |
| 1b) Sufficient flow to maintain the shape of the active channel | June to August | • Maintain one or more spells over 306 ML/day in 80% of years. |

*1a) Sufficient flow to scour pools and remove sediments*

Two pools within Orlando Street management reach are substantially affected by sedimentation, with sediment beds more than 30 cm deep. As explained in

Appendix B.1, no flow recommendations have been formulated for this flow-ecology objective. Sedimentation cannot be managed in the lower Canning River with the relatively small volumes of water that could be discharged from the ERPs. Increased soil erosion, surface runoff and resultant sedimentation require a whole-of-catchment management approach.

*1b) Sufficient flow to maintain the shape of the active channel*

Analysis of the times-series data from Seaforth gauging station indicated that for 80 per cent of the years analysed (between 1975 and 2007), a maximum mean daily discharge of at least 306 ML/day was recorded (see Appendix B for further detail on methods). For those 80 per cent of years, the median number of days a year when a discharge of 306 ML/day or more was recorded was two days (range, one to 11 days; mean 3.1 days).

**Flow recommendation**

- Maintain annual maximum daily discharge of at least 306 ML/day in 80 per cent of years. Total annual duration of flows of at least one day should be maintained.

### C.4.2 Macroinvertebrates

Six of the seven flow-ecology linkages for macroinvertebrates were either not assessed for Reach 4, or were addressed by other flow-ecology linkages. Here, detailed results are presented only for flow-ecology linkage 2a (maintain inundated riffle sections) (Table C17). See Table 1 and Appendix B for further details on comparable linkages.

*Table C17 Flow requirements for macroinvertebrates, Orlando Street*

| Flow-ecology linkages | Timing | Flow recommendation |
| --- | --- | --- |
| 2a) Maintain water depth of 5 cm over gravel runs and riffles | All year | • Maintain minimum discharge of 1.8 ML/day within the reach throughout the year. |

*2a) Water depth of at least 5 cm over riffles*

Four cross-sections containing riffles were surveyed within Reach 4. Hydraulic analysis indicated that a discharge of 9.0 ML/day was required to inundate 50 per cent of the total width of riffles surveyed to a depth of at least 5 cm.

Water levels were sufficiently high to make accurate discharge measurements on the third and fourth days of the summer trial. On the third day of the trial release, all riffle sections were inundated to at least 5 cm depth over at least 50 per cent of their width, at a measured discharge of 1.8 ML/day at the control point.

Analysis of the time-series data from Seaforth gauging station indicated that flow fell below the threshold of 1.8 ML/day in 29 of the 33 years on record. For years when flow fell below the threshold value, an average of 4.5 low spells (i.e. consecutive days with flow below the threshold) occurred each year, with a mean duration of 4.7 days. The mean number of days a year with flow below the threshold value was 21.5 days. The longest low spell recorded lasted for 41 days in 2002, while the median longest low spell was eight days.

The results suggest that in general, flows have historically been higher than the threshold value throughout the year, which is likely to have maintained riffles as habitat for macroinvertebrates. Additional water releases may be required during the driest months to avoid extended periods of flow below the threshold.

**Flow recommendation**

- Maintain minimum discharge of 1.8 ML/day within the reach throughout the year.

### C.4.3 Fish

Table C18 summarises the flow requirements for fish in Reach 4 (Orlando Street).

*Table C18 Flow requirements for fish, Orlando Street*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 3a) Sufficient water depth (10 cm) for small-bodied fish for reproductive migration | June to October | • Maintain minimum discharge of 1.8 ML/day within the reach between June and October. |
| 3b) Sufficient water depth (20 cm) for large-bodied fish (cobbler) for reproductive migration | November to January | • Maintain minimum discharge of approximately 9.3 ML/day within the reach in November.<br>• In December and January, flows should provide a minimum of three high spells over 9.3 ML/day for a minimum duration of five days each. Additional flows over 9.3 ML/day should be provided whenever possible to maintain water levels 20 cm in December and January. |
| 3d) Inundation of emergent sedges and rushes to provide fish habitat | April to October | • Flows of 1.8 ML/day are required to inundate emergent vegetation to a depth of at least 10 cm within Reach 4. |
| 3h) Inundate shallow backwaters as nurseries and as habitat for small fish during high flows | April to October | • Winter and spring flows should be sufficient to provide at least one spell over 358 ML/day in two out of every three years (on average). |

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 3k) Undercutting of riverbanks to provide habitat | All year | • No specific flow recommendations to provide undercut habitat have been made, as this habitat occurs at a range of flows. Maintaining flows to submerge emergent vegetation (3d) will provide fish habitat at undercut sites. See Appendix B.3. |
| 3l) Sufficient flow to inundate in-stream benches to provide foraging and spawning habitat | April to October | • A discharge of around 219.5 ML/day is required to inundate mid-flow benches at intervals during winter and spring, as foraging and spawning habitat for fish. |

### *3a) Sufficient water depth for reproductive migration of small fish*

Six of the surveyed cross-sections in Reach 4 were potential obstacles to upstream fish migration. Hydraulic analysis results indicated that a discharge of 1.7 ML/day would submerge all riffles and obstacles to at least 10 cm. During the field trial, all cross-sections were inundated to at least 10 cm on the third day of the trial, at a discharge of 1.8 ML/day.

Analysis of time-series data from Seaforth gauging station indicated that mean daily flows between the start of June and the end of October had not fallen below 1.8 ML/day for the measured period (1975–2007).

**Flow recommendation**

- Maintain minimum discharge of 1.8 ML/day within the reach between June and October.

### *3b) Sufficient water depth for reproductive migration of large fish*

Six of the surveyed cross-sections in Reach 4 were potential obstacles to upstream fish migration. During the field trial, all cross-sections except one were inundated to at least 20 cm on the fourth day of the trial, at a discharge of 9.3 ML/day. The one remaining cross-section failed to meet the threshold thalweg depth by 2 cm. The field observation has been given as the flow recommendation, recognising that additional discharge may be needed for thalweg depth to reach 20 cm throughout the reach.

Analysis of time-series data from Seaforth gauging station showed that flow fell below the threshold of 9.3 ML/day between the start of November and the end of January (cobbler migration season) in all but one of the 33 years on record (1975–2007). For all years combined, an average of 3.4 spells below 9.3 ML/day occurred during cobbler migration season, with a mean duration of 24 days. The average duration of the intervening high spells (consecutive days with flow over 9.3 ML/day) was 4.1 days.

Historically, flows have decreased from the start to the end of cobbler migration season. The average number of days with flows less than 9.3 ML/day was 9.9 days for November, 25.1 days for December and 26.1 days for January.

As there were relatively few days in December and January when discharge was above the required threshold, a separate high-spells analysis was undertaken for these two months for the period 1975 to 2007. The duration of high spells above the threshold of 9.3 ML/day ranged from zero to 62 days in December and January. There were nine years when flow did not reach the threshold at any time in December and January, and one year when daily flow exceeded the threshold for the entire period. An average of 2.7 high spells over the threshold occurred, for a mean duration of 4.2 days each (excluding the years when flow was above or below the threshold for all of January and December).

Flows have generally been adequate for cobbler passage for most of November. However, for the months of December and January, historical flows have only been enough to support upstream cobbler migration in pulses. Indeed, for three of the years that data on ERP discharge were available (i.e. 2001–02 to 2006–07), cobbler migration was possible for less than 10 days of the entire three-month breeding season (Table C19). Similar extended low-flow periods should be avoided in the future to give the freshwater cobbler the best chance of successful migration and spawning. Anecdotal evidence suggests that freshwater cobbler populations have declined in the lower Canning River; if so, this may be partly attributed to a lack of water over summer to allow upstream migration and spawning.

*Table C19 Number of days above and below threshold flow for freshwater cobbler in Reach 4 during the summers of 2001–02 to 2006–07*

| **Season** | **Number of days when mean daily flow fell *below* the threshold (6.1 ML/day)** | | | | **Total number of days above threshold flow** |
|---|---|---|---|---|---|
| | **November** | **December** | **January** | **Total** | |
| 2001–02 | 27 | 31 | 31 | 89 | **3** |
| 2002–03 | 21 | 31 | 31 | 83 | **9** |
| 2003–04 | 8 | 31 | 31 | 70 | 22 |
| 2004–05 | 2 | 17 | 31 | 50 | 42 |
| 2005–06 | 7 | 21 | 27 | 55 | 37 |
| 2006–07 | 29 | 31 | 29 | 89 | **3** |

The flow regime derived for Reach 5 has been used as a benchmark for all management reaches. Reach 5 has the lowest recommended discharge for cobbler passage, and this discharge has occurred more frequently throughout the period of available data (1975–2007) than the other reaches. Pulses of water from the ERP valves to support cobbler migration should be coordinated so that they occur simultaneously throughout the lower Canning River.

**Flow recommendations**

- Maintain minimum discharge of 9.3 ML/day within the reach in November.
- In December and January, flows should provide a minimum of three high spells over 9.3 ML/day for a minimum duration of five days each. Additional flows over 9.3 ML/day should be provided whenever possible to maintain water levels of 20 cm in December and January.

*3d) Inundation of emergent sedges and rushes for habitat*

Emergent vegetation was present at all 10 cross-sections surveyed within Reach 4. The hydraulic analysis results overestimated the actual discharge required to inundate emergent vegetation. During the field trial, most sites with emergent vegetation were inundated by at least 10 cm of water at the lowest accurately measured discharge of 1.8 ML/day.

Analysis of the historical data from Seaforth gauging station indicated that between April and October, flows fell below the threshold of 1.8 ML/day in only six of the 33 years on record. The average duration of low spells in those three years was just under three days. This suggests that historical flows have been adequate to inundate emergent vegetation for fish habitat.

**Flow recommendation**

- Flows of 1.8 ML/day are required to inundate emergent vegetation to a depth of at least 10 cm within the summer active channel.

*3g) Maintain pool depth for cobbler and other fish species*

Two pools were found to be appropriate as summer refuge pools for fish within Reach 4 (MR4-093 and MR4-215). Hydraulic modelling indicated that a discharge of 32.0 ML/day would inundate the pool at MR4-093 to a depth of 80 cm, while a discharge of 8.6 ML/day would be required at the MR4-215 pool. The lowest measurable discharge during the summer trial was 1.8 ML/day, at which point the pool at MR4-215 was 57 cm deep, and the pool at MR4-093 was 86 cm deep. The deepest level of the pool at MR4-215 was 69 cm, at a measured discharge of 9.3 ML/day at the control point. The lowest measurable discharge has been adopted as the flow recommendation, because it is unlikely that a depth of 80 cm or more can be attained throughout summer at MR4-215.

Analysis of the historical discharge data from Seaforth gauging station showed that flows fell below the threshold value of 1.8 ML/day in 29 of the 33 years on record. For years when flows fell below the threshold, the mean number of low spells (i.e. consecutive days with flow below the threshold) was 4.5 spells a year, with a mean duration of 4.7 days. The results suggest that in general, historical flows have been sufficient to maintain pools to a depth of at least 50 cm throughout the year.

**Flow recommendation**

- A discharge of 1.8 ML/day is sufficient to maintain refuge pools within Reach 4 to a depth of at least 50 cm.

*3h) Inundate shallow backwaters as fish habitat*

One potential backwater habitat area was identified within the reach. Hydraulic analysis results determined that a discharge of just over 358 ML/day would be required to begin inundation of the backwater.

Analysis of the time-series data from the downstream Seaforth gauging station for the period 1975 to 2007 showed a discharge of 358 ML/day occurred at least once in two-thirds of years. In years when high spells of this magnitude occurred, the average duration was 1.5 days.

**Flow recommendation**

- Winter and spring flows should be sufficient to provide at least one spell over 358 ML/day in two out of every three years.

*3l) Sufficient flow to inundate in-stream benches*

Mid-flow benches were surveyed at four cross-sections in Reach 4. The modelled mean discharge required to inundate all four was 219.5 ML/day.

Analysis of the time-series data from Seaforth station indicated that spells of 219.5 ML/day or more occurred in all but two years between 1975 and 2007. In years when high spells over 219.5 ML/day occurred, there were an average of just under four high spells, lasting for an average duration of 6.4 days.

**Flow recommendation**

- A discharge of 219.5 ML/day is required to inundate mid-flow benches during winter and spring as foraging and spawning habitat for fish.

### C.4.4 Waterbirds

The two flow-ecology linkages for waterbirds have been addressed with reference to other, comparable linkages that fall under the headings of fish and riparian vegetation. See Appendix B for further details.

### C.4.5 Water quality

Two flow-ecology linkages were identified for water quality in Reach 4 (Orlando Street) (Table C20).

*Table C20 Flow requirements for water quality, Orlando Street*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 5a) Sufficient flow to maintain connectivity of pools in summer | All year | • A discharge of 1.8 ML/day is sufficient to maintain connectivity within the reach and within large slow-flowing pools upstream. |
| 5b) Prevent anoxia and significant stratification in pools during summer | All year | • An investigation should be undertaken to define a threshold discharge to avoid anoxia in slow-flowing weir pools of the upper Canning River; the interim recommendation is to maintain flow connectivity as per linkage 5a above. |

### *5a) Sufficient flow to maintain connectivity of pools in summer*

During the summer trial, field observations indicated that flow connectivity was maintained within the reach at all times during the trial, even during baseflow conditions of less than 0.9 ML/day. The lowest, accurately measured[6] discharge at which flow throughout the reach and between upstream pools occurred was 1.8 ML/day, as measured at the control point within Reach 4.

For the same reasons described for Reach 2 (see Appendix C.2.5), a minimum critical discharge could not be determined using the trial results. The best discharge estimate able to be provided from the field data is that 1.8 ML/day (measured at the control point) is sufficient to ensure connectivity within the management reach and between upstream pools during summer.

Analysis of the historical discharge data from Seaforth gauging station showed that flows fell below the threshold value of 1.8 ML/day in 29 of the 33 years on record. For years when flows fell below the threshold, the mean number of low spells (i.e. consecutive days with flow below the threshold) was 4.5 spells a year, with a mean duration of 4.7 days. The longest low spell recorded lasted for 41 days in 2002, while the median longest low spell for all years was eight days.

The results suggest that in general, historical flows have been sufficient to maintain connectivity throughout the year. Additional water releases may be required during the driest months to avoid extended periods of flow below the threshold.

### Flow recommendation

- A discharge of 1.8 ML/day is sufficient to maintain connectivity during summer within Reach 4 and upstream pools.

[6] Due to low stage heights, measured discharges of less than 0.9 ML/day (equivalent to 0.01 $m^3/s$) were not considered accurate.

### *5b) Prevent anoxia and stratification in pools during summer*

The results of the DO study (Appendix D) were directly applicable to the lower management reaches only. An investigation should be undertaken to define a threshold discharge to avoid anoxia in slow-flowing weir pools of the upper Canning River. The interim recommendation is to maintain flow connectivity as per linkage 5a above, because even relatively low discharges may be sufficient to oxygenate pools (see Appendix D).

**Flow recommendations**

- An investigation should be undertaken to define a threshold discharge to avoid anoxia in slow-flowing weir pools of the upper Canning River.
- Maintain flow connectivity as per linkage 5a (maintain pool connectivity).

## C.4.6 Riparian vegetation

Table C21 summarises the flow requirements for riparian vegetation in Reach 2. One linkage (6d) was not assessed because no macrophyte beds were found within the reach.

*Table C21 Flow requirements for riparian vegetation, Orlando Street*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 6a) Sufficient flow to maintain winter-wet floodplain regions and off-channel wetlands. | June to August | • No recommendation formulated due to insufficient data. |
| 6c) Seasonal inundation of mid-bank vegetation for survival, germination and recruitment | June to August | • Maintain one or more high spells exceeding 351 ML/day in two out of three years (on average). |
| 6d) Sufficient flow to maintain populations of submerged macrophytes | All year | • No macrophyte beds were identified within Reach 4. |

### *6a) Maintain winter-wet floodplain and off-channel wetlands*

One entry point to an off-channel wetland was identified during site surveys. Hydraulic analysis results estimated that the discharge required to begin inundation of this wetland was 1121 ML/day.

The estimate for this flow-ecology linkage is probably an overestimate, given that analysis of historical data from Seaforth gauging station showed that mean daily discharges of this magnitude have occurred just three times in 33 years. Without further data, it is not possible to accurately estimate the flow required to overtop banks in Reach 4. No flow recommendation has been made for this linkage.

*6c) Seasonal inundation of mid-bank vegetation*

Mid-bank vegetation was recorded at four cross-sections. These sites are typified by revegetation planting and occasional recruitment. The hydraulic modelling estimated that a mean discharge of 351 ML/day was required to inundate mid-bank vegetation for the four cross-sections.

Analysis of the time-series data from Seaforth gauging station indicated that at least one spell of 351 ML/day or more had occurred in 23 of the 33 years on record. For those 23 years, the mean number of days a year with a discharge of 351 ML/day or more was 2.7 days.

**Flow recommendation**

- A discharge of at least 351 ML/day is required in two out of three years to inundate mid-bank vegetation.

### C.4.7 Ecosystem processes

The three flow-ecology linkages for ecosystem processes have been addressed with reference to other, comparable linkages that fall under the headings of geomorphology, macroinvertebrates, fish, water quality and riparian vegetation. See Appendix B for further details.

## C.5 Reach 5: Manning Avenue

### C.5.1 Geomorphology

Table C22 summarises the flow requirements for geomorphological processes in Reach 5 (Manning Avenue).

*Table C22 Flow requirements for geomorphology, Manning Avenue*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 1a) Sufficient flow to scour pools and remove sediments | June to August | • Sedimentation cannot be managed in the lower Canning River with environmental releases of water. |
| 1b) Sufficient flow to maintain the shape of the active channel | June to August | • Maintain one or more spells over 306 ML/day in 80% of years. Total annual duration of flows of at least one day should be maintained. |

*1a) Sufficient flow to scour pools and remove sediments*

Manning Avenue reach is substantially affected by sedimentation, with sediments of up to 60 cm depth identified within existing pools. However, as explained in Appendix B.1, no flow recommendations have been formulated for this flow-ecology objective. Sedimentation cannot be managed in the lower Canning River with the relatively small volumes of water that could be discharged from the ERPs. Increased soil erosion, surface runoff and resultant sedimentation require a whole-of-catchment management approach.

*1b) Sufficient flow to maintain the shape of the active channel*

Analysis of the times-series data from Seaforth gauging station indicated that for 80 per cent of the years analysed (between 1975 and 2007), a maximum mean daily discharge of at least 306 ML/day was recorded (see Appendix B for further detail on methods). For those 80 per cent of years, the median number of days a year when a discharge of 306 ML/day or more was recorded was two days (range, one to 11 days; mean 3.1 days).

**Flow recommendation**

- Maintain annual maximum daily discharge of at least 306 ML/day in 80 per cent of years. Total annual duration of flows of at least one day should be maintained.

### C.5.2 Macroinvertebrates

Six of the seven flow-ecology linkages for macroinvertebrates were either not assessed for Reach 5, or were addressed by other flow-ecology linkages. Here, detailed results are presented only for flow-ecology linkage 2a (maintain inundated riffle sections) (Table C23). See Table 1 and Appendix B for further details on comparable linkages.

*Table C23 Flow requirements for macroinvertebrates, Manning Avenue*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 2a) Maintain water depth of 5 cm over gravel runs and riffles | All year | • Maintain minimum discharge of approximately 1.6 ML/day within the reach throughout the year. |

*2a) Water depth of at least 5 cm over riffles*

Three of the surveyed cross-sections within Reach 5 contained riffles. Hydraulic analysis results indicated that the mean discharge required to inundate 50 per cent of the total riffle width at each cross-section was 11.5 ML/day. The hydraulic model overestimated the actual discharge required to inundate riffles.

During the field trial, water levels at the control point were sufficiently high to allow for discharge measurements on Day 3 and Day 4. Field observations showed that all four riffle sections surveyed were sufficiently inundated on the third day of the trial at 4.6 ML/day. However, this discharge is likely to substantially overestimate the minimum flow requirement, given there was a relatively large jump in measured discharge between the baseflow of ~0.3 ML/day on Day 2 of the trial (when riffles were not sufficiently inundated) and 4.6 ML/day on Day 3. For this reason, the recommended discharge has been set at 1.6 ML/day, which is the average of the figures calculated for the nearest upstream reach (Orlando Street) and the nearest downstream reach (Pioneer Park). Monitoring should be undertaken to ensure that this discharge is adequate to ensure the inundation of 50 per cent of total riffle width for the reach.

Analysis of the time-series data from Seaforth gauging station indicated that flow fell below the threshold of 1.6 ML/day in 29 of the 33 years on record. For years when flow fell below the threshold value, an average of 4.1 low spells (i.e. consecutive days with flow below the threshold) occurred each year, with a mean duration of just over four days. The mean number of days a year with flow below the threshold value was 19.9 days.

The results suggest that in general, flows have historically been higher than the threshold value throughout the year, which is likely to have maintained riffles as habitat for macroinvertebrates. Additional water releases may be required during the driest months to avoid extended periods of flow below the threshold.

**Flow recommendation**

- Maintain minimum discharge of approximately 1.6 ML/day within the reach throughout the year.

### C.5.3 Fish

Table C24 summarises the flow requirements for fish in Reach 5 (Manning Avenue). More detail on individual linkages is supplied below.

*Table C24 Flow requirements for fish, Manning Avenue*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 3a) Sufficient water depth (10 cm) for small-bodied fish for migration | June to October | • Maintain minimum discharge of 4.6 ML/day within the reach between June and October. |
| 3b) Sufficient water depth (20 cm) for large-bodied fish (cobbler) for reproductive migration | November to January | • Maintain minimum discharge of 6.1 ML/day within the reach in November.<br>• In December and January, flows should provide a minimum of three high spells over 6.1 ML/day for a minimum duration of five days each. Additional flows over 6.1 ML/day should be provided whenever possible to maintain water levels of 20 cm in December and January. |
| 3d) Inundation of emergent sedges and rushes to provide fish habitat | April to October | • Flows of 4.6 ML/day are required to inundate emergent vegetation to a depth of at least 10 cm. |
| 3g) Maintain pool depth for cobbler nests and as refuge habitat for other fish species | All year | • A discharge of approximately 2.6 ML/day is sufficient to maintain refuge pools within Reach 5 to a depth of at least 80 cm. |

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 3h) Inundate shallow backwaters as nurseries and as habitat for small fish during high flows | April to October | • Winter and spring flows should be sufficient to provide at least one spell over 444 ML/day approximately once every two years. |
| 3k) Undercutting of riverbanks to provide habitat | All year | • No specific flow recommendations to provide undercut habitat have been made, as this habitat occurs at a range of flows. Maintaining flows to submerge emergent vegetation (3d) will provide habitat at undercut sites. See Appendix B.3. |
| 3l) Sufficient flow to inundate in-stream benches to provide foraging and spawning habitat | April to October | • A discharge of at least 340 ML/day is required to inundate mid- to high-flow benches in approximately two out of every three years. |

### *3a) Sufficient water depth for reproductive migration of small fish*

The hydraulic analysis results indicated that a discharge of 4.3 ML/day would inundate all cross-sections by at least 10 cm. During the field trial, all cross-sections were inundated to a depth of at least 10 cm on Day 3 of the trial, at a discharge of 4.6 ML/day.

Analysis of time-series data from Seaforth gauging station indicated that daily flow between the start of June and the end of October fell below 4.6 ML/day for three of the years within the measured period (1975–2007). The longest low spell was four days. This suggests that historical flows have been sufficient to allow for fish passage during migration and spawning season.

**Flow recommendation**

- Maintain minimum discharge of 4.6 ML/day within the reach between June and October.

### *3b) Sufficient water depth for reproductive migration of large fish*

The hydraulic analysis results indicated that a discharge of 13.0 ML/day would inundate all cross-sections by at least 20 cm. During the field trial, all cross-sections were inundated to a depth of at least 20 cm on Day 4 of the trial, at a discharge of 6.1 ML/day (measured at the control point).

Analysis of time-series data from Seaforth gauging station showed that flow fell below the threshold of 6.1 ML/day between the start of November and the end of January (cobbler migration season) in all but two of the 33 years on record (1975–2007). An average of 3.4 spells below 6.1 ML/day occurred between November and January, with an average duration of 18.8 days. Flows tend to decrease from the start to the end of cobbler migration season. The average number of days with flows less than 6.1 ML/day was 5.1 days in November, 19.8 days in December and 21.2 days in January.

As there were relatively few days in December and January when discharge was above the required threshold, a separate high-spells analysis was undertaken for these two months for 1975 to 2007. The duration of high spells above 6.1 ML/day ranged from one to 62 days. There were two years when daily flow exceeded the threshold for the entire period, and five years when the threshold was not reached at any time in December of January. An average of 2.7 high spells over the threshold occurred, for a median duration of five days (excluding the years when flow was either above or below the threshold all season).

Flows have generally been adequate for cobbler passage throughout November. However, for December and January, historical flows have only been enough to support upstream cobbler migration in pulses. Indeed, for three of the years that data on ERP discharge were available (i.e. 2001–02 to 2006–07), cobbler migration was possible for less than two weeks of the entire three-month breeding season (Table C25). Similar extended low-flow periods should be avoided in the future to give the freshwater cobbler the best possible chance of successful migration and spawning.

*Table C25 Number of days above and below threshold flow for freshwater cobbler in Reach 5 during the summers of 2001–02 to 2006–07*

| Season | Number of days where mean daily flow fell *below* the threshold (9.3 ML/day) | | | | Total number of days above threshold flow |
|---|---|---|---|---|---|
| | November | December | January | Total | |
| 2001–02 | 17 | 31 | 31 | 79 | 13 |
| 2002–03 | 17 | 31 | 31 | 79 | 13 |
| 2003–04 | 5 | 24 | 31 | 60 | 32 |
| 2004–05 | 1 | 0 | 16 | 17 | 75 |
| 2005–06 | 1 | 1 | 20 | 22 | 70 |
| 2006–07 | 27 | 30 | 25 | 82 | 10 |

It is recommended that maintenance of the average flow regime of the past 30 years (i.e. at least three high spells in December and January for a minimum duration of five days each) should be used as the minimum acceptable level for discharges. This flow regime has been used for all other reaches. Pulses of water from ERP valves to support cobbler migration should be coordinated so that they occur simultaneously throughout the lower Canning River.

### Flow recommendation

- Maintain minimum discharge of 6.1 ML/day within the reach in November.
- In December and January, flows should provide a minimum of three high spells over 6.1 ML/day for a minimum duration of five days each. Additional flows over 6.1 ML/day should be provided whenever possible to maintain water levels of 20 cm in December and January.

### *3d) Inundation of emergent sedges and rushes for habitat*

Emergent vegetation was present at six cross-sections within the reach. During the summer trial, five of the six sites were inundated to the required depth at a discharge of 4.6 ML/day, as measured at the control point.

Analysis of the historical discharge data from Seaforth gauging station indicated that from the start of April to the end of October, flows fell below the threshold value of 4.6 ML/day in 22 of the 33 years on record. In those 22 years, an average of 2.4 low spells between April and October occurred, lasting for a mean duration of 6.3 days. This suggests that historical flows have generally been adequate to sufficiently inundate emergent vegetation for fish habitat.

**Flow recommendation**

- Flows of 4.6 ML/day are required to inundate emergent vegetation to a depth of at least 10 cm.

### *3g) Maintain pool depth for cobbler and other fish species*

Within Reach 5, two pools were suitable as summer refuge habitat for fish, defined by cross-sections MR5-024 (Figure C2) and MR5-186. Hydraulic modelling indicated that discharges of 1.7 ML/day (MR5-024) and 2.6 ML/day (MR5-186) would maintain the pools to 80 cm depth.

*Figure C2 Pool at MR5-024 during the pre-trial low-flow period*

At the start of the low-flow period during the summer trial (16 March 2007), both pools were deeper than 80 cm. At the lowest accurately measured discharge of 4.6 ML/day on Day 3 of the trial, both pools were inundated to a depth of at least 70 cm, and one pool was inundated to a depth of more than 90 cm. The measured discharge on Day 2 of the trial is likely to be an overestimate of the required discharge to fill pools to a depth of 80 cm, due to an extended period of low-flow conditions during the trial, and a rapid increase in discharge between Day 2 and Day 3 of the trial. Therefore, the results of hydraulic modelling have been adopted as the flow recommendation.

Analysis of the historical discharge data from Seaforth gauging station showed that flows fell below the threshold value of 2.6 ML/day in all but three of the 33 years on record. For years when flows fell below the threshold, the mean number of low spells (i.e. consecutive days with flow below the threshold) was 6.3 spells a year, with a mean duration of 6.6 days. The longest low spells recorded lasted for 73 days in 2001 and 69 days in 2002, while the average longest low spell for all years was 17.8 days.

The results suggest that in general, historical flows have been sufficient to maintain pools to a depth of at least 80 cm throughout the year. Additional flows may be required during the driest months to avoid extended (i.e. more than one week) low-flow conditions.

**Flow recommendation**

- A discharge of approximately 2.6 ML/day is sufficient to maintain refuge pools within Reach 5 to a depth of at least 80 cm.

*3h) Inundate shallow backwaters as fish habitat*

Five cross-sections were included in the analysis for this flow-ecology linkage. A mean discharge of just over 444 ML/day was required to begin inundation of off-channel wetlands (as potential backwater habitat).

Analysis of the time-series data from the Seaforth gauging station for the period 1975 to 2007 indicated that a discharge of 444 ML/day occurs at least once in about 50 per cent of years. The average duration of high spells above 444 ML/day was 1.2 days.

**Flow recommendation**

- Winter and spring flows should be sufficient to provide at least one spell over 444 ML/day approximately once every two years.

*3l) Sufficient flow to inundate in-stream benches*

Vegetated in-stream benches were identified at five cross-sections in Reach 5. None were inundated during the summer trial and are therefore considered to be mid- to high-flow benches. Hydraulic analysis results suggested that a mean discharge of just less than 340 ML/day would be required to inundate all bench features to 10 cm.

Analysis of the time-series data from Seaforth gauging station indicated that at least one spell exceeded 340 ML/day in approximately two-thirds of years, with an average of 1.8 spells over the threshold a year. The mean duration of high spells was 1.5 days.

**Flow recommendation**

- A discharge of at least 340 ML/day is required to inundate mid- to high-flow benches in approximately two out of every three years.

### C.5.4 Waterbirds

The two flow-ecology linkages for waterbirds have been addressed with reference to other, comparable linkages that fall under the headings of fish and riparian vegetation. See Appendix B for further details.

### C.5.5 Water quality

Two flow-ecology linkages were identified for water quality in Reach 5 (Manning Avenue) (Table C26).

*Table C26 Flow requirements for water quality, Manning Avenue*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 5a) Sufficient flow to maintain connectivity of pools in summer | All year | • A discharge of 1.9 ML/day is sufficient to maintain connectivity during summer within Reach 5 and upstream pools. |
| 5b) Prevent anoxia and significant stratification in pools during summer | All year | • Maintain permanent flow year-round. A discharge of approximately 0.6 ML/day should be sufficient to avoid anoxic conditions in shallow pools of the lower Canning River.<br>• Further monitoring should be undertaken to ensure that pools remain oxygenated during extreme low flow and high ambient temperature events. |

#### *5a) Sufficient flow to maintain connectivity of pools in summer*

Field observations indicated that flow connectivity was maintained within the reach at all times during the trial, even during baseflow conditions of less than 0.9 ML/day. The lowest, accurately measured discharge at which flow throughout the reach and between upstream pools occurred was at 4.6 ML/day. This is likely to be an overestimate of the actual discharge required to maintain connectivity upstream of the reach.

For the same reasons described for Reach 2 (see Appendix C.2.5), a minimum critical discharge could not be determined using the trial results. Because the lowest accurate discharge is likely to be a substantial overestimate of the actual discharge required to maintain connectivity, an estimated discharge of 1.9 ML/day has been given as the flow criteria (using the average of the flow recommendations for the neighbouring reaches 4 and 6).

Analysis of time-series data from Seaforth gauging station indicated that low spells of less than 1.9 ML/day occurred in all but three years throughout the period of recorded data (1975–2007). In years when flow fell below the threshold, an average of 4.9 low spells occurred each year, with an average duration of 4.4 days. The longest low spell on record was 41 days in 2002, while the median longest low spell for all years was eight days. During the longer low spells on record, it is possible that flow connectivity was lost. This situation should be avoided in the future.

**Flow recommendation**

- A discharge of 1.9 ML/day is sufficient to maintain connectivity during summer within Reach 5 and upstream pools.

*5b) Prevent anoxia and stratification in pools during summer*

The results of the DO trial using pools downstream of Pioneer Park (Appendix D) showed that a discharge of approximately 0.6 ML/day would be enough to avoid anoxia within shallower pools (i.e. thalweg depth of 40 cm or less) within the lower reaches of the Canning River, while a discharge of up to approximately 5.6 ML/day may be required to avoid anoxia in larger pools over 80 cm in depth.

The authors of the DO investigation (Appendix D) emphasised that these values should not be used as a ‘trigger’ values because they are interpolated values, and further, low water levels introduce uncertainty into the discharge measurements used to calculate this figure. However, the authors observed that maintenance of permanent flow along the river is likely to be enough to avoid anoxic conditions.

Analysis of the time series from Seaforth gauging station indicated that flows fell below 0.6 ML/day for just 73 days throughout the recorded period (1975–2007). Low spells below 0.6 ML/day have occurred in one third of years (11 years of the total 33), with an average duration of 3.6 days. The longest periods of low flow on record were eight days in 1999, and seven days in 2003. Flow below the threshold for more than two days should be avoided wherever possible, as field trials showed that DO levels dropped rapidly when flows dropped to nearly zero (Appendix D).

In general, historical flows have been sufficient to avoid anoxic conditions in pools of the lower Canning River. Additional water may need to be released during periods of extreme low water levels and/or extreme high temperatures.

**Flow recommendations**

- Maintain permanent flow year-round. A discharge of approximately 0.6 ML/day should be sufficient to avoid anoxic conditions in shallow pools of the lower Canning River.
- Further monitoring should be undertaken to ensure that pools remain oxygenated during extreme low-flow and high-ambient-temperature events.

### C.5.6 Riparian vegetation

Table C27 summarises the flow requirements for riparian vegetation in Reach 2. One linkage (6d) was not assessed because no macrophyte beds were found within the reach.

*Table C27 Flow requirements for riparian vegetation, Manning Avenue*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 6a) Sufficient flow to maintain winter-wet floodplain regions and off-channel wetlands. | June to August | • No recommendation formulated due to insufficient data. |
| 6c) Seasonal inundation of mid-bank vegetation for survival, germination and recruitment | June to August | • Maintain one or more spells over 416.5 ML/day in 50% of years. |
| 6d) Sufficient flow to maintain populations of submerged macrophytes | All year | • No macrophyte beds were identified within Reach 5. |

#### *6a) Maintain winter-wet floodplain and off-channel wetlands*

Four cross-sections contained off-channel wetland vegetation within Reach 5. Hydraulic analysis results suggested the average discharge required to begin inundation of these four sites was 1258 ML/day.

Analysis of the time-series data from Seaforth gauging station found that such events occurred infrequently; with the result that the modelled discharge was likely to be a substantial overestimate of the actual discharge required to inundate off-channel wetland vegetation. A discharge of 1258 ML/day or more was recorded in just two of the 33 years on record. No flow recommendations have been formulated for this objective.

#### *6c) Seasonal inundation of mid-bank vegetation*

Mid-bank vegetation was recorded at six cross-sections within Reach 5. Hydraulic analysis results indicated that a mean discharge of 416.5 ML/day was required to inundate mid-bank vegetation.

Analysis of the time-series data from Seaforth gauging station showed that for 19 of the years between 1975 and 2007, at least one high spell occurred with a discharge of more than 416.5 ML/day. The average duration of these high spells was 1.3 days.

**Flow recommendation**

- Maintain one or more spells over 416.5 ML/day in 50 per cent of years. The current flow regime of a mean high-spell duration of at least one day should be maintained.

### C.5.7 Ecosystem processed

The three flow-ecology linkages for ecosystem processes have been addressed with reference to other, comparable linkages that fall under the headings of geomorphology, macroinvertebrates, fish, water quality and riparian vegetation. See Appendix B for further details.

## C.6 Reach 6: Pioneer Park

### C.6.1 Geomorphology

Table C28 summarises the flow requirements for geomorphological processes in Reach 6 (Pioneer Park). More detail on individual linkages is supplied below.

*Table C28 Flow requirements for geomorphology, Pioneer Park*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 1a) Sufficient flow to scour pools and remove sediments | June to August | • Sedimentation cannot be managed in the lower Canning River with environmental releases of water. |
| 1b) Sufficient flow to maintain the shape of the active channel | June to August | • Maintain one or more spells over 306 ML/day in 80% of years. Total annual duration of flows of at least one day should be maintained. |

#### *1a) Sufficient flow to scour pools and remove sediments*

Four of the 10 cross-sections surveyed in Reach 6 contained pools that were substantially affected by sedimentation. As explained in Appendix B.1, no flow recommendations have been formulated for this flow-ecology objective. Sedimentation cannot be managed in the lower Canning River with the relatively small volumes of water that could be discharged from the ERPs.

#### *1b) Sufficient flow to maintain the shape of the active channel*

Analysis of the times-series data from Seaforth gauging station indicated that for 80 per cent of the years analysed (between 1975 and 2007), a maximum mean daily discharge of at least 306 ML/day was recorded (see Appendix B for further detail on methods). For those 80 per cent of years, the median number of days a year when a discharge of 306 ML/day or more was recorded was two days (range, one to 11 days; mean 3.1 days).

**Flow recommendation**

- Maintain annual maximum daily discharge of at least 306 ML/day in 80 per cent of years. Total annual duration of flows of at least one day should be maintained.

### C.6.2 Macroinvertebrates

Six of the seven flow-ecology linkages listed in Table 1 were either not assessed for Reach 6, or were addressed by other flow-ecology linkages. Here, detailed results are presented only for flow-ecology linkage 2a (Table C29).

*Table C29 Flow requirements for macroinvertebrates, Pioneer Park*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 2a) Maintain water depth of 5 cm over gravel runs and riffles | All year | • Maintain minimum discharge of 2.0 ML/day within the reach throughout the year. |

*2a) Water depth of at least 5 cm over riffles*

Three riffle cross-sections were assessed within Reach 6. Hydraulic analysis results indicated that a mean discharge of 6.9 ML/day would be required to inundate 50 per cent of the total riffle width within the cross-sections.

Field observations showed that on Day 2 of the trial, the three riffle sections were inundated to at least 5 cm depth over at least 50 per cent of their width, at a measured discharge of 2.0 ML/day.

Analysis of the time-series data from Seaforth gauging station indicated that flow fell below the threshold of 2.0 ML/day in 19 of the 33 years on record. For years when flow fell below the threshold value, an average of five low spells a year occurred, with a mean duration of just over five days. Flow fell below the threshold for an average of 26.8 days a year.

The results suggest that in general, flows have historically been higher than the threshold value throughout the year. However, there have been extended periods (i.e. more than seven days) of low flow that should be avoided in the future. The longest periods of flow below the threshold occurred in 2001 and again in 2002, when there were 43 consecutive days below the threshold.

**Flow recommendation**

- Maintain minimum discharge of 2.0 ML/day within the reach throughout the year.

### C.6.3 Fish

Table C30 summarises the flow requirements for fish in Reach 6.

*Table C30 Flow requirements for fish, Pioneer Park*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 3a) Sufficient water depth (10 cm) for small fish for reproductive migration | June to October | • Maintain minimum discharge of 2.0 ML/day within the reach between June and October. |
| 3b) Sufficient water depth (20 cm) for large-bodied fish (cobbler) for reproductive migration | November to January | • Maintain minimum discharge of 10.7 ML/day within the reach in November.<br>• In December and January, flows should provide a minimum of three high spells over 10.7 ML/day for a duration of five days each. Additional flows over 10.7 ML/day should be provided whenever possible to maintain water levels of 20 cm in December and January. |
| 3d) Inundation of emergent sedges and rushes to provide fish habitat | April to October | • A discharge of 10.7 ML/day is sufficient inundate emergent vegetation to a depth of at least 10 cm. |
| 3g) Maintain pool depth for cobbler nests and as refuge for other species | All year | • A discharge of 2.0 ML/day is sufficient to maintain refuge pools within Reach 6 to a depth of at least 50 cm. |
| 3h) Inundate shallow backwaters as nurseries and as habitat for small fish during high flows | April to October | • Winter and spring flows should be sufficient to provide several high spells over 90 ML/day. Mean duration of high spells of approximately four days should be maintained. |
| 3k) Undercutting of riverbanks to provide habitat | All year | • No specific flow recommendations for undercut habitat have been made, as this habitat occurs at a range of flows. Maintaining flows to submerge emergent vegetation (3d) will provide fish habitat at undercut sites. (See Appendix B.3.) |
| 3l) Sufficient flow to inundate in-stream benches | April to October | • A discharge of at least 10.7 ML/day is required to inundate mid-flow benches at intervals during winter and spring. |

#### *3a) Sufficient water depth for reproductive migration of small fish*

Hydraulic modelling results indicated that within Reach 6, a discharge of 6.0 ML/day would submerge all surveyed obstacles by at least 10 cm. During the summer trial, all cross-sections were submerged by more than 10 cm at a discharge of 2.0 ML/day.

Analysis of time-series data from Seaforth gauging station indicated that daily flow between the start of June and the end of October had not fallen below 2 ML/day for the measured period (1975–2007).

**Flow recommendation**

- Maintain minimum discharge of 2 ML/day within the reach between June and October.

*3b) Sufficient water depth for reproductive migration of large fish*

Hydraulic modelling results indicated that within Reach 6, a discharge of 22.5 ML/day would submerge all surveyed obstacles by at least 20 cm. During the field trial, all cross-sections were submerged by at least 20 cm at a discharge of 10.7 ML/day.

Analysis of time-series data from Seaforth gauging station showed that flow fell below the threshold of 10.7 ML/day between the start of November and the end of January (cobbler migration season) in all but one of the 33 years on record (1975–2007). For all years combined, an average of 2.8 spells below 10.7 ML/day occurred during cobbler migration season, with an average duration of 29.5 days. The average duration of the intervening high spells was 4.8 days.

Flows decreased from the start to the end of cobbler migration season. The average number of days with flows less than 10.7 ML/day was 11.8 days in November, 26.2 days in December and 27.4 days in January.

As there were relatively few days in December and January when discharge was above the required threshold, a separate high-spells analysis was undertaken for these two months. The duration of high spells above 10.7 ML/day ranged from zero to 62 days. There were 13 years when flow did not reach the threshold at any time in December or January, and one year when daily flow exceeded the threshold for the entire period. An average of 2.2 spells over the threshold occurred, for a median duration of three days (excluding the years when flow was above or below the threshold all season).

Flows have generally been adequate for cobbler passage for at least half of November. However, for December and January, historical flows have only been enough to support upstream cobbler migration in pulses. Indeed, for three of the years that data on ERP discharge were available (i.e. 2001–02 to 2006–07), cobbler migration was possible for one week or less out of the entire three-month breeding season (Table C31). Similar extended low-flow periods should be avoided in the future to give the freshwater cobbler the best chance of successful migration and spawning.

*Table C31 Number of days above and below threshold flow for freshwater cobbler in Reach 6 during the summers of 2001–02 to 2006–07*

| Season | Number of days where mean daily flow fell *below* the threshold (10.7 ML/day) | | | | Total number of days above threshold flow |
|---|---|---|---|---|---|
| | November | December | January | Total | |
| 2001–02 | 29 | 31 | 31 | 91 | **1** |
| 2002–03 | 23 | 31 | 31 | 85 | **7** |
| 2003–04 | 10 | 31 | 31 | 72 | 20 |
| 2004–05 | 3 | 25 | 28 | 56 | 36 |
| 2005–06 | 12 | 24 | 28 | 64 | 28 |
| 2006–07 | 30 | 31 | 30 | 91 | **1** |

The flow regime derived for Reach 5 has been used as a benchmark for all management reaches. Reach 5 has the lowest recommended discharge for cobbler passage, and this discharge has occurred more frequently throughout the period of available data (1975 to 2007) than that recorded at other reaches. Pulses of water from ERP valves to support cobbler migration should be coordinated so that they occur simultaneously throughout the lower Canning River.

**Flow recommendations**

- Maintain minimum discharge of 10.7 ML/day within the reach in November.
- In December and January, flows should provide a minimum of three high spells over 10.7 ML/day for a minimum duration of five days each. Additional flows over 10.7 ML/day should be provided whenever possible to maintain water levels of 20 cm in December and January.

*3d) Inundation of emergent sedges and rushes for habitat*

Emergent vegetation was recorded at eight cross-sections. Hydraulic analysis results overestimated the actual discharge required to inundate emergent vegetation to a depth of 10 cm. During the field trial, all eight cross-sections were inundated to at least 10 cm at a measured discharge of 10.7 ML/day. Given that half of the sites were inundated at a measured discharge of 2.0 ML/day, the figure of 10.7 ML/day is likely to be an overestimate of the minimum discharge required to inundate emergent vegetation.

Analysis of the historical discharge data from Seaforth gauging station indicated that from the start of April to the end of October, flows fell below the threshold value of 10.7 ML/day in all 33 years on record. From 1975 to 2007, an average of 4.4 spells below the threshold of 10.7 ML/day occurred between April and October, lasting for a mean duration of 10.5 days. The results suggest that historical flows have generally been adequate to inundate emergent vegetation for fish habitat.

**Flow recommendation**

- A discharge of 10.7 ML/day is sufficient inundate emergent vegetation to a depth of at least 10 cm.

*3g) Maintain pool depth for cobbler and other fish species*

Five cross-sections containing pools were surveyed in Reach 6, one of which is shown in Figure C3. During the low-flow period at the start of the field trial, thalweg depth at two of the five cross-sections was greater than 95 cm; for the other three cross-sections, thalweg depth ranged between 56 and 72 cm. At the lowest measurable discharge of 2.0 ML/day, two cross-sections were inundated to more than 90 cm, while the other three were inundated to between 56 and 73 cm. The lowest measurable discharge has been set as the flow recommendation, because at this discharge at least one pool was available as a summer refuge, and the other three pools were at least 55 cm deep. The next highest measured discharge was substantially higher at 10.7 ML/day.

*Figure C3 Fish refuge pool at MR6-094 at a discharge of ~2 ML/day*

Analysis of time-series data from Seaforth gauging station indicated that low spells of less than 2.0 ML/day occurred in all but three years throughout the period of recorded data (1975-2007). In years when flow dropped below the threshold, an average of five low spells occurred, lasting for a mean duration of just over five days. It is possible that during the longer low spells on record (the longest recorded was 43 days in both 2001 and 2002), pool depth was substantially affected. This situation should be avoided in future.

**Flow recommendation**

- A discharge of 2 ML/day is sufficient to maintain refuge pools within Reach 6 to a depth of at least 50 cm.

*3h) Inundate shallow backwaters as fish habitat*

One entry point to a secondary channel and backwater was noted during the cross-section survey (Figure C4). Hydraulic modelling results estimated that inundation of this feature would begin at a discharge of 58.8 ML/day. Field observations in July 2007 indicated that inundation of the backwater occurs at a discharge of between approximately 60 and 90 ML/day, as measured at Seaforth gauging station. The upper measured discharge of 90 ML/day has been used as the flow recommendation for this linkage.

Analysis of the time-series data from the Seaforth gauging station for the period 1975 to 2007 indicated that all years had high spells with a discharge of 90 ML/day or greater. An average of 8.9 high spells a year occurred, lasting for a mean duration of 3.7 days.


*Figure C4 Inundation of a backwater in Pioneer Park at a discharge of between 60 to 90 ML/day*

**Flow recommendation**

- Winter and spring flows should be sufficient to provide several high spells over 90 ML/day. Mean duration of high spells of between four and five days should be maintained.

*3l) Sufficient flow to inundate in-stream benches*

Five cross-sections containing low-flow in-stream benches were recorded in Reach 6. Hydraulic analysis results greatly overestimated the discharge required to inundate benches to 10 cm. During the field trial, at a measured discharge of 10.7 ML/day, three out of the five in-stream benches were inundated by at least 10 cm.

Analysis of the historical discharge data from Seaforth gauging station indicated that from the start of April to the end of October, flows fell below the threshold value of 10.7 ML/day in all 33 years on record. From 1975 to 2007, an average of 4.4 spells below the threshold of 10.7 ML/day occurred between April and October, lasting for a mean duration of 10.5 days. The results suggest that historical flows have generally been adequate to inundate emergent vegetation for fish habitat.

**Flow recommendation**

- A discharge of at least 10.7 ML/day is required to inundate mid-flow benches at intervals during winter and spring, as foraging and spawning habitat for fish.

### C.6.4 Waterbirds

The two flow-ecology linkages for waterbirds have been addressed with reference to other, comparable linkages that fall under the headings of fish and riparian vegetation. See Appendix B for further details.

### C.6.5 Water quality

Two flow-ecology linkages were identified for water quality in Reach 6 (Pioneer Park) (Table C32).

*Table C32 Flow requirements for water quality, Pioneer Park*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 5a) Sufficient flow to maintain connectivity of pools in summer | All year | • A discharge of 2.0 ML/day is sufficient to maintain connectivity during summer within Reach 6 and upstream pools. |
| 5b) Prevent anoxia and significant stratification in pools during summer | All year | • Maintain permanent flow year-round. A discharge of approximately 0.6 ML/day should be sufficient to avoid anoxia in shallow pools of the Canning River.<br>• Further monitoring to be undertaken to ensure that pools remain oxygenated during extreme low-flow and high-ambient-temperature events. |

#### *5a) Sufficient flow to maintain connectivity of pools in summer*

During the field trial, the lowest, accurately measured discharge at which flow occurred throughout the reach and between upstream pools was at 2.0 ML/day, as measured at the control point within Reach 6.

For the same reasons described for Reach 2 (see Appendix C.2.5), a minimum critical discharge could not be determined using the trial results. The best discharge estimate able to be provided from the field data is that a discharge (measured at the control point) of 2.0 ML/day is sufficient to ensure connectivity within the management reach and between upstream pools during summer.

Analysis of the time-series data from Seaforth gauging station indicated that flow fell below the threshold of 2.0 ML/day in 19 of the 33 years on record. For years when flow fell below the threshold value, an average of five low spells a year occurred, with a mean duration of just over five days. Flow fell below the threshold for an average of 26.8 days a year.

The results suggest that in general, flows have historically been higher than the threshold value throughout the year. However, it is possible that during the longer low spells on record (the longest recorded was 43 days in both 2001 and 2002), flow connectivity was lost. This situation should be avoided in future. Additional flows may be required during conditions of extreme low water levels and/or high ambient temperatures to prevent flow from dropping below the threshold for more than two or three days in a row.

**Flow recommendation**

- A discharge of 2.0 ML/day is sufficient to maintain connectivity during summer within Reach 6 and upstream pools.

*5b) Prevent anoxia and stratification in pools during summer*

The results of the DO trial using pools downstream of Pioneer Park (Appendix D) showed that a discharge of approximately 0.6 ML/day would be enough to avoid anoxia within smaller pools (i.e. depth of 40 cm or less) within the lower reaches of the Canning River, while a discharge of up to approximately 5.6 ML/day would be required to avoid anoxia in deeper pools (i.e. depth of 80 cm or more).

The authors of the DO investigation (Appendix D) emphasised that these values should not be used as a ‘trigger’ values because they are interpolated values, and further, low water levels introduce uncertainty into the discharge measurements used to calculate this figure. However, the authors observed that maintenance of permanent flow along the river is likely to be enough to avoid anoxic conditions.

Analysis of the time-series data from Seaforth gauging station indicated that flows fell below 0.6 ML/day for just 73 days throughout the recorded period (1975–2007). Low spells below 0.6 ML/day have occurred in one third of years (11 years of the total 33), with an average duration of 3.6 days. The longest periods of low flow on record were eight days in 1999, and seven days in 2003. Flow below the threshold for more than two days should be avoided wherever possible, as field trials showed that dissolved oxygen DO levels dropped rapidly when flows dropped to nearly zero (Appendix D).

In general, historical flows have been sufficient to avoid anoxic conditions in pools of the lower Canning River. Additional water may need to be released during periods of extreme low water levels and/or extreme high temperatures.

**Flow recommendations**

- Maintain permanent flow year-round. A discharge of approximately 0.6 ML/day should be sufficient to avoid anoxic conditions in shallow pools of the lower Canning River.
- Further monitoring should be undertaken to ensure that pools remain oxygenated during extreme low-flow and high-ambient-temperature events.

### C.6.6 Riparian vegetation

Table C33 summarises the flow requirements for riparian vegetation in Reach 2. One linkage (6d) was not assessed because no macrophyte beds were found within the reach.

*Table C33 Flow requirements for riparian vegetation, Pioneer Park*

| Flow-ecology linkages | Timing | Flow recommendation |
|---|---|---|
| 6a) Sufficient flow to maintain winter-wet floodplain regions and off-channel wetlands. | June to August | • No flow recommendation formulated due to insufficient data. |
| 6c) Seasonal inundation of mid-bank vegetation for survival, germination and recruitment | June to August | • No flow recommendation formulated due to insufficient data. |
| 6d) Sufficient flow to maintain populations of submerged macrophytes | All year | • No macrophyte beds were identified within Reach 6. |

#### *6a) Maintain winter-wet floodplain and off-channel wetlands*

Three cross-sections were identified within Reach 6 that contained entry points to off-channel wetlands or winter-wet areas. Hydraulic analysis results indicated that a mean discharge of 1100 ML/day would be required to begin inundation of the off-channel wetlands and winter-wet areas.

Analysis of the time-series data from Seaforth gauging station found that such events occurred infrequently, with the result that the modelled discharge was likely to be a substantial overestimate of the actual discharge required to inundate off-channel wetland vegetation. A discharge of 1100 ML/day or more was recorded in only four of the 33 years on record. No flow recommendations have been formulated for this objective.

#### *6c) Seasonal inundation of mid-bank vegetation*

Mid-bank vegetation was recorded at cross-sections typified by revegetation planting and recruitment between four cross-sections. Revegetation works have been established from the low water mark to the floodplain zone. Upstream of the new plantings, the vegetation is dominated by established flooded gum *(Eucalyptus rudis*), peppermint (*Agonis flexuosa*) and paperbark (*Melaleuca* species).

Hydraulic analysis results indicated that a mean discharge of 868.3 ML/day would be required to inundate the mid-bank and revegetation zone. Analysis of the time-series data suggests the modelled discharge is probably an overestimate of the actual discharge required. Inundation of mid-bank vegetation would normally occur seasonally, perhaps annually or once every two or three years. A mean daily discharge of 868 ML/day has occurred six times in 33 years (1975–2007). No flow recommendation has been formulated for this flow-ecology linkage due to insufficient data.

### C.6.7 Ecosystem processes

The three flow-ecology linkages for ecosystem processes have been addressed with reference to other, comparable linkages that fall under the headings of geomorphology, macroinvertebrates, fish, water quality and riparian vegetation. See Appendix B for further details.

# Appendix D — Report on dissolved oxygen levels during the trial water-release program

Monitoring Effect of Trial Releases on Dissolved Oxygen Levels in the Canning River

March 2007

## Field Methods and Results

**Final Report May 2007**

**prepared for**

Department of Water

**by**

*Wetland Research & Management*

## BACKGROUND

The Department of Water (DoW) commissioned *Wetland Research & Management* to undertake monitoring of dissolved oxygen levels in relation to a trial release of environmental flows in the Canning River. This work is required as part of on-going monitoring of EWPs and river restoration activities under the Caring for the Canning programme.

Recommendations from preliminary assessments of Environmental Water Requirements (EWRs) for the Canning (Storey *et al.* 2001) included environmental releases to ameliorate poor water quality in pools in downstream reaches in summer. Other studies at that time (Storey 1998, WRM 2000) noted substantial in-filling of pools with organic material in the upper Canning catchment and inorganic material in the lower catchment. With in-filling, there was a loss of important aquatic habitat. Functionally, there is now likely to be insufficient pool volumes to 'buffer' the increased oxygen consumption associated with organic material, particularly in summer-autumn when water temperatures and respiration rates are elevated and flows are reduced With elevated respiration, the pools may go hypoxic at night with the associated loss of intolerant species, *e.g.* most fish. As well as provision of water for the environment, DoW is committed to implementing appropriate monitoring programmes to ensure provisions are adequate to meet environmental water needs and protect water dependent ecological values at a low level of risk.

Final DO concentration in any water body is the net result of biological processes and physical re-aeration. Biological processes include metabolic rates, *i.e.* photosynthesis and respiration by aquatic biota, and physical re-aeration is the exchange of oxygen between the surface of the river and the atmosphere, at the water-air interface. Oxygen concentrations in aquatic systems naturally undergo a diel cycle. Large diel (day-night) fluctuations in DO are a characteristic of water bodies with high primary productivity (abundant algal or plant growth) or with large organic sediment loads where high microbial activity increases biological oxygen demand (BOD). Typically, there is a mid to late afternoon maximum, as a result of peaking photosynthetic production of oxygen by algal and macrophytes exceeding consumption by respiring aquatic fauna and microbes (refer Figure 1). There is then a night-time minimum DO as a direct consequence of respiration by plants and animals. Levels are often at their lowest in the early hours of the morning. Eutrophication, increased turbidity and sedimentation can all deleteriously affect oxygen levels in flowing waters.

Dissolved oxygen is typically expressed in terms of concentration (ppm = mg/L) or percent saturation (%). Percent saturation is independent of temperature and salinity, making it a useful measure if comparing between greatly varying waterbodies. Generally, DO values less than 4 ppm represent increasing levels of stress to aquatic fauna and ecological processes. For freshwaters with a temperature range of around 20 - 25°C, as in the current study, this represents ca. 45 - 50 % DO saturation. In order to protect aquatic biota, previous ANZECC guidelines recommended day-night DO levels should not be permitted to fall below 60% saturation. Current more conservative trigger values[7] are given for day-time only, with a range of 80 - 120% (ANZECC/ARMCANZ 2000).

Rates of physiological processes vary as a function of DO concentration (and temperature) and at saturation less than 50% these rates are increasingly limited by DO availability, thereby reducing ecological vigour. Continued low levels ultimately will lead to death of fauna and may also result in water quality problems as nutrients and some heavy metals are released from sediments during

[7] ANZECC/ARMCANZ (2000) trigger values are an interim guideline to be used in the absence of site-specific guidelines. Site specific guidelines for seasonal maxima and minima should be developed from the 20th and 80th percentiles of data collected over a minimum 2 year period. This should also incorporate day-night (24 hour) variation in DO levels.

anoxia (zero DO). In well-aerated waters, many metals adsorb (bond) readily to suspended matter (*e.g.* clay or organic particles suspended in the water column) and to river bed substrates, thereby reducing their bioavailability. Under conditions of low or zero DO, heavy metals and nutrients are released from the sediments into the water column in bioavailable forms (it should be noted that not all metals liberated from the benthos are bioavailable; only a proportion). Aquatic fauna, especially macroinvertebrates exhibit a range of tolerances to DO concentrations with the least tolerant species being lost from a system first, and species with special adaptations (*e.g.* chironomid midge larvae with haemoglobin in their blood) persisting under very low DO concentrations. Periodic reductions in DO concentrations often may be survived by all fauna, with loss of species only occurring under continued low DO conditions.

## OBJECTIVE

Concurrent trial releases from environmental release valves on the Canning River were conducted in collaboration with the Water Corporation during March 2007. Trials were conducted during early autumn, when conditions most adverse to aquatic biota were expected to prevail, *i.e.* low water levels, limited flow, high day-time water temperatures, likely low overnight dissolved oxygen concentrations and generally poor water quality.

The aims of the current study project were to:

1. Monitor diel changes in dissolved oxygen (DO) concentrations in a control and an exposed pool over three days under reduced flows;
2. Monitor diel changes in dissolved oxygen (DO) concentrations in a control and an exposed pool over three days under trial releases to assess effects of progressive increases in flows on pool DO;
3. Provide summary plots of DO data for surface and bottom probes in control and exposed pools for before (low flow) and after (trial releases);
4. Document methods and findings in a summary document for DoW to incorporate in an overall Trial Release report.

## METHODS

### Environmental Release Points

The environmental release points on the Canning River were (in order from most upstream to most down-stream):

- Soldiers Road (Araluen)
- Stockers Road (Hill 60),
- Bernard Road,
- Orlando Road,
- Manning Avenue and
- Gosnells (under Albany Highway traffic bridge).

The release valves at these sites were originally designed in the 1940s to protect riparian (irrigation) rights following construction of the Canning Dam (~1934). These release points are located where the Water Corporation's scheme water supply pipes (trunk mains) cross the Canning River. Till recently, water has primarily been released in response to irrigation demands over the summer-autumn dry period (typically December-March). However, in the late 1990s the release points were designated Environmental Release Points, with water released to satisfy environmental flows. The use of these valves to deliver environmental flows was a compromise in the absence of adequate infrastructure at Canning Dam to release water at the dam. The water released into the river from the release valves is chlorinated scheme water.

The trial was conducted over a one week period between 15th and 22nd March 2007. Initially, the Water Corporation were requested to close the release points to reduce flows to almost zero to assess the effects of zero flows on pool DO. Because there are ongoing irrigation demands on river flows at this time, valves were not shut-off, but reduced to a point where demand equalled flow and so downstream flows were anticipated to be close to zero. After establishing low flows, the release points were then progressively opened over three days to progressively increase flows. Measurements of discharge were then made on a daily basis by DoW staff at appropriate locations above each of the selected pools to record discharge and allow an assessment of the point at which flow was sufficient to ameliorate any DO stress observed. Flows during the low flow period were not gauged, but were assumed to be low. Trial releases to ameliorate DO commenced on the 19th April:

| | | |
|---|---|---|
| 13:00h Thu 15th March | Flows reduced | DO monitoring |
| 00:00h Fri 16th – 13:00h Mon 19th March | Low flow | DO monitoring |
| 13:00h Mon 19th – 15:45h Thu 22nd March | Trial release | DO monitoring |
| 15:45h Thu 22nd March | Return to normal flow schedule | --- |

**Dissolved Oxygen Monitoring**

As noted above, manipulating releases whilst balancing irrigation demands made it difficult to achieve zero flow conditions in the upper/middle reaches of the Canning. However, flows in the river around Gosnells were more easily managed as this location was downstream of the main irrigation demand. Therefore, pools above and below the environmental release point at Albany Highway were selected for monitoring. Changes in dissolved oxygen were monitored in two river pools, immediately below the most downstream release point at Gosnells and in an upstream pool:

- Pool in Pioneer Park (ca. 500 m upstream of release valve),
- Pool downstream of the Albany Highway traffic bridge (ca. 50 m downstream of the release valve).

The pool upstream of the Albany Hwy release point was selected as a 'control' to assess the effects of increased flows from the release point on the downstream pool. Ideally, flows upstream of the release point would have remained low throughout the trial, whilst flows downstream would increase in response to the Albany Hwy valve being opened. However, due to logistical constraints (i.e. balancing irrigation demands), and other objectives of the trial release project on upstream reaches, flows in the 'control' reach also increased during the trial due to releases from valves further upstream (i.e. Manning Avenue, Orlando Road, Bernard Road). As a result the control site was also influenced by releases/increased flows.

*In situ* automatic data loggers were used to take frequent (*i.e.* every 15 minutes) measurements of dissolved oxygen and temperature over three consecutive 24 hour periods (*i.e.* three days), both immediately prior to (low flow control) and during the trial release.

Diel (24 hour) variations in water temperature and concentration of dissolved oxygen (DO mg/L) were determined using YSI 5739 Oxygen/Temperature field probes attached to TPS WP-82Y dissolved oxygen-temperature meters/loggers. YSI stirrers connected to D-cell battery packs on the river bank were used to maintain constant water flow across the polarographic membranes of the probes. Two probes were deployed at each monitoring location. The probes were positioned in the centre of the channel and at the downstream end of the selected pools to ensure maximum depletion/re-oxygenation levels were captured. At each location, one probe was secured ca. 10 cm below the water surface and one ca. 10 cm above the bottom sediments.

At the end of each 24-hr period, all loggers were downloaded to a laptop computer and then re-set. DO probes were calibrated prior to deployment and at each re-deployment. As a further check on calibration and drift, a WTW field meter was used to take a single measurement of dissolved oxygen and temperature at the start and end of each 24-hr period.

At the end of the low flow monitoring and prior to commencement of trial releases, loggers were removed in the early evening, recharged overnight and re-set the following morning. Loggers are powered by 6V NiCad batteries which require a minimum 8 hours to fully re-charge. Fully recharged loggers have a maximum running time of 75 hours and maximum data storage capacity of 150 records.

Field notes on weather condition (*e.g.* cloud cover, wind, rain), water depth and qualitative changes in flow conditions were made to help interpret diel variations in temperature and dissolved oxygen data. The Bureau of Meteorology website was checked for ambient air temperatures and overnight weather conditions as a further aid to interpretation of data.

Logged data was plotted as a diel curve (refer Figure 1). Changes in DO concentrations were also compared against DoW discharge data recorded during the trial.

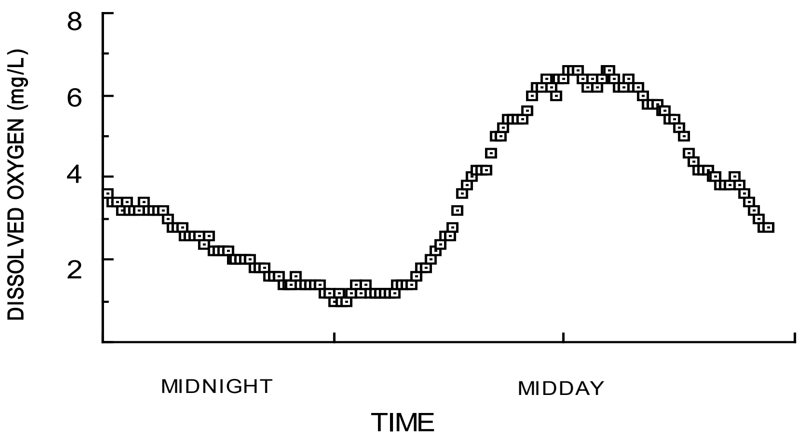



***Figure 1.*** Idealised 24 hour curve of dissolved oxygen showing daytime peak and night time minimum.

## RESULTS & DISCUSSION

### General observations

Weather conditions during the trial were mostly fine though often overcast and humid. Daytime temperatures ranged from maxima of 27.6 - 36°C to overnight minima of 18.1 - 19.3°C. Mid-way through the trial period, on Saturday 17th March, there was a daytime thunderstorm and heavy rainfall in hills catchment areas associated with cyclonic activity in the north of the State. Although no rain fell in the study area, run-off from hills catchments appears to have briefly affected stream flows (and DO levels).

River pools at both monitoring locations showed excessive aggradation (in-filling). There were extensive deposits of fine organic sediment up to 40 cm deep with anoxic bottom substrates. Waters were tannin-stained and turbid. The monitored pool at Pioneer Park had a maximum water depth of ca. 80 cm, whereas the downstream pool was more shallow and uniform in depth, ca 40 cm. Field observations recorded no native fish or crayfish, though introduced mosquitofish (*Gambusia holbrooki*) were abundant at the downstream site.

**Diel changes in DO**

Plots of diel DO and temperature curves are shown in Figure 2A-B and comparisons with discharge data shown in Figure 3A-B and gauged discharge at Seaforth in Figure 4. Under low flow conditions there was a steady and progressive decline in DO levels from around 4 - 5 ppm (~45 - 60%) from when flows were shut-off, down to 2 - 3 ppm (~20 - 30%) at the downstream site and down to 0.5 - 2 ppm (<10%) at the deeper upstream site.

Two anomalies were evident in the low flow data prior to trial flows starting. From around mid-night on Friday 16th there was a gradual rise in DO at the downstream site (surface and bottom logger), but this change was not evident at the upstream site, suggesting it reflected an event originating in the Pioneer Park area between the sites. The rise lasted for 6 - 8 hours, before levels again declined. It was thought this could have reflected a flushing/release event from ponds in the Gosnells City council grounds, being the only obvious infrastructure in the area, but enquiries with the council environmental staff failed to reveal any process that gave rise to this anomaly.

The second anomaly was a very pronounced spike in low flow DO concentration evident at the upstream site, but not detectable at the downstream site. This occurred early afternoon on Saturday 17th March, and lasted 2 - 4 hrs. Reason for this spike is not known, but may be associated with thunderstorm activity in the hills with localised rainfall that may have affected flows. This small increase in flow was not sufficient to elevate day-time concentrations above 4.5 ppm, and levels continued to decline once this event has passed.

Apart from these anomalies, the data for the low flow period showed a very consistent trend of progressively declining DO levels. After 85[8] hours of low flow conditions, day-night ranges were only 0.5 - 1.8 ppm at Pioneer Park and 1.8 - 3.8 ppm downstream of the Gosnells release valve (Tables 1 & 2). These concentrations are well below levels at which aquatic fauna and ecological processes experience severe stress, particularly the night-time minima.

DO concentrations showed significant and very rapid response following commencement of trial releases. Response was most rapid immediately downstream of the Gosnells release point (Figure 3B). This was not unexpected given the proximity of the monitoring pool to the release valve (approx 50 m downstream). Based on field observations on the afternoon of Tuesday 20th, stage height at this downstream site appeared to have initially risen around 20 cm and then fallen back by 10 cm (as evidenced by the high-water mark on tree trunks and banks). Initial flows resulted in DO levels rapidly increasing from < 2 - 3 ppm to >6 ppm and a dampening of diel DO oscillations (probably reflecting the proximity and nature of the release water – constant temperature and aeration). Concentrations appeared to stabilise after a period of 18 hours with a trend toward mid-afternoon maxima of 6.5 ppm (75%) and early morning minima of 5.7 ppm (60%) (Table 1). Using bi-plots of changes in DO and discharge against time, it was possible to estimate discharge for specific DO concentrations (Figures 3A & 3B). Plots indicated flows in the order of 0.0064 cumecs were sufficient to raise DO to their maximum at the downstream site. Further increases in discharge over the following two days did not result in any further increase in DO concentration (Figure 3B & Table 1).

At the deeper upstream pool, response times were slower, likely reflecting the greater distance of this pool downstream from the nearest release point (Manning Avenue). From bi-plots it was

[8] Assuming low flow conditions were achieved by midnight Thurs 15th March and maintained till at least 1:00 pm Monday 19th March.

estimated that a discharge of 0.0133 cumecs raised DO levels by 2 - 3 ppm (Figure 3A, Table 1). As flow increased to around 0.06 cumecs, DO levels increased further to a maximum 5.6 ppm in bottom waters and 6.1 ppm in surface waters (Figure 3A, Table 1). Levels rapidly stabilised with mid-afternoon maxima of 5.7 ppm (65%) and early morning minima of 4.9 ppm (30%) (Table 1). Flows in excess of 0.06 cumecs did not result in any further improvement in DO concentration at the upstream site (Figure 3A).

It should be noted that the discharge data provided for this exercise had a low level of accuracy/confidence, due to difficulties associated with accurately gauging discharge under low flows at the selected locations. Therefore, any extrapolations also have a low level of accuracy/confidence. Estimates of flow thresholds are therefore approximate/indicative and should NOT be used as specific trigger values/critical thresholds. However, the study did show that DO in pools very quickly declines to critical levels under low flow conditions, but relatively small flows are required to ameliorate water DO concentrations.

The discharge responses derived from the current study will be specific to the pools monitored, and will likely vary with pool size and condition. For example, deeper/wider pools or pools with a higher BOD will likely require a higher discharge to achieve the same result. Similarly, a higher discharge will likely to required in the current pools under more extreme weather conditions (i.e. > 40°C temperatures). To surmount the problem with using discharge as the key hydraulic metric, water velocity in pools may be a better indicator of critical flows. Water velocity was measured at the time of gauging flows, but at locations not directly transferable to the pools. Cottingham, Stewardson, Crook, Hillman, Roberts and Rutherford (2003) consider that a minimum average velocity of 0.01 m/sec in pools is required to avoid stratification, maintain mixing and thereby maintain dissolved oxygen levels > 2mg/L. Water velocity in pools may be modelled using discharge and pool dimensions where a reasonable accurate hydraulic model exists for the target reach. Otherwise, pool water velocity should be measured in any repeat study to assess whether the rule provided by Cottingham *et al.* (2003) applies to pools in the Canning.

Water temperatures were relatively high at both sites throughout the day and night (20 - 25°C). The surface probes indicated an increase in temperatures during the latter part of the afternoon, while bottom probes indicated a smaller diel range (Figure 2A-B). Trial releases appeared to have little effect on diel fluctuations in temperature.

***Table 1.*** Average range in pool DO concentration (ppm & %) with varying discharge (cumecs) at release points. Note: discharge rates are estimates only and have been interpolated from available discharge data as shown in Figure 3A-B and Table 2.

| | **Low flow** | | **Trial release discharge** | | | |
|---|---|---|---|---|---|---|
| | | | **0.0133 cumecs** | | **0.0600 cumecs** | |
| **Pioneer Park** | ppm | % | DO ppm | DO % | DO ppm | DO % |
| night-time minimum | 0.5 | 6 | 2.3 | 25 | 4.9 | 30 |
| daytime maximum | 1.8 | 20 | 3.7 | 45 | 5.7 | 65 |

| | **Low flow** | | **Trial release discharge** | | | |
|---|---|---|---|---|---|---|
| | | | **0.0064 cumecs** | | **0.0128 cumecs** | |
| **d/s Gosnells Release valve** | DO ppm | DO % | DO ppm | DO % | DO ppm | DO % |
| night-time minimum | 1.8 | 20 | 5.7 | 60 | 5.7 | 60 |
| daytime maximum | 3.8 | 45 | 6.5 | 75 | 6.5 | 75 |

## CONCLUSIONS

- The pre-release low flow period showed that DO levels in pools rapidly declined to levels which would be considered stressful to biota and ecological processes. This occurred within 48 - 72 hrs of flows ceasing, under conditions not considered extreme (*i.e.* not excessively high air temperatures).
- The trial water releases successfully raised DO concentrations in pools of the Canning River;
- Pool DO concentration showed a very rapid response to increased flows, with a significant improvement in DO levels above those considered stressful to biota in a very short time (several hrs);
- Rough estimates of flow suggest 0.0064 cumecs is sufficient to prevent hypoxia (low DO) in shallower pools (≤ 40cm) pools;
- Rough estimates of flow suggest up to 0.06 cumecs may be required to prevent hypoxia in deeper pools (≥ 80cm) pools;
- This was a once-off assessment of effects of low flows on pool DO, and should be repeated to demonstrate consistency and repeatability in DO response with flows.
- Discharge measurements were not considered accurate because of difficulties associated with accurately gauging low flows on the selected locations, therefore estimates of flow thresholds are very approximate and should NOT be used as trigger values/critical thresholds.
- Discharge was not measured during the low flow period prior to the trial. Discharge during this period should be monitored in any future trial.
- The trial was conducted under reasonably benign conditions. DO responses may vary under more extreme weather conditions often experienced in mid-summer (*i.e.* higher

ambient temperatures). Therefore, DO response and flow relationships may change under more extreme conditions. The trial should be repeated in mid summer under more extreme conditions (i.e. higher air temperatures).

- Discharge thresholds derived from the current data are specific to the pools monitored, and will likely vary with pool size (depth/width), BOD and location on the river. Water velocity in pools may be a better indicator of critical flows in pools rather than discharge. Water velocity was measured at the time of gauging flows, but at locations not directly transferable to the pools (*i.e.* often in shallow areas with laminar flows). Pool water velocity should be measured in any repeat study.

## REFERENCES

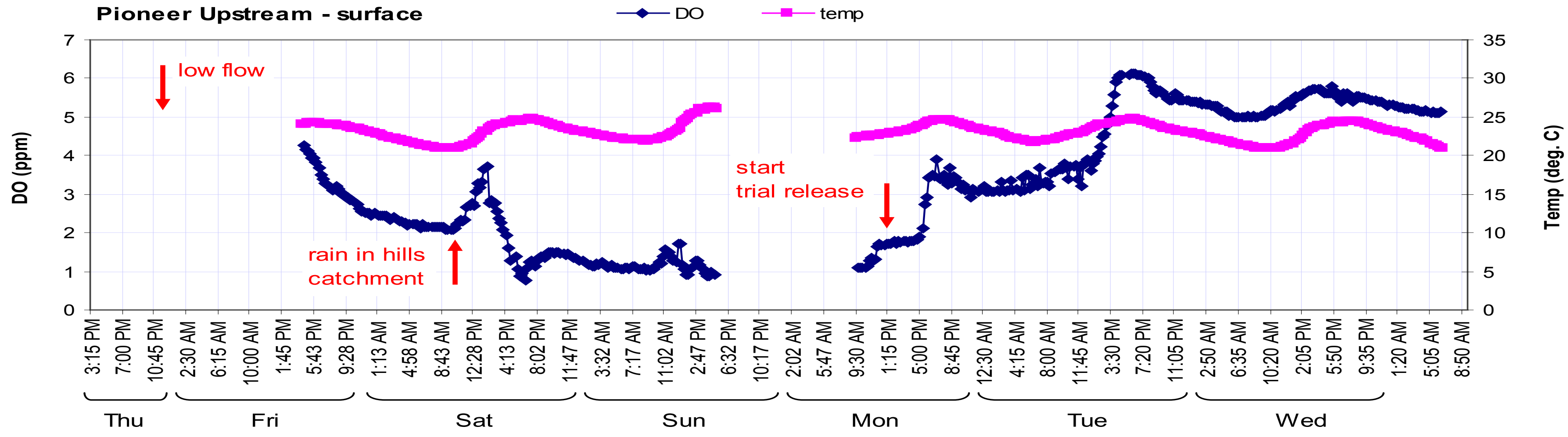
ANZECC/ARMCANZ (2000) Australian and New Zealand guidelines for fresh and marine water quality. www.ea.gov.au/water/nwqms/index.html

Cottingham P, Stewardson M., Crook D., Hillman T., Roberts J. & Rutherford I. (2003). Environmental Flow Recommendations for the Goulburn River below Lake Eildon. Cooperative Research Centre for Freshwater Ecology in association with CRC for Catchment Hydrology. Technical Report 01/2003. Canberra. November 2003.

Storey, A.W., Davies, P.M. & Creagh, S. (2001) Preliminary Environmental Water requirements for the Caning River system. Unpublished report to the Water & Rivers Commission, pp 57

Storey, A.W. (1998). Fish and fish habitat survey of the Canning River and its tributaries. Unpublished report to the Upper Canning / Southern-Wungong Catchment Management Team, pp 43.

WRM (2000) Ecological monitoring of the Canning and Southern- Wungong Rivers: baseline data for assessing effectiveness of EWRs Unpublished report by Wetland Research & Management to the Water & Rivers Commission.



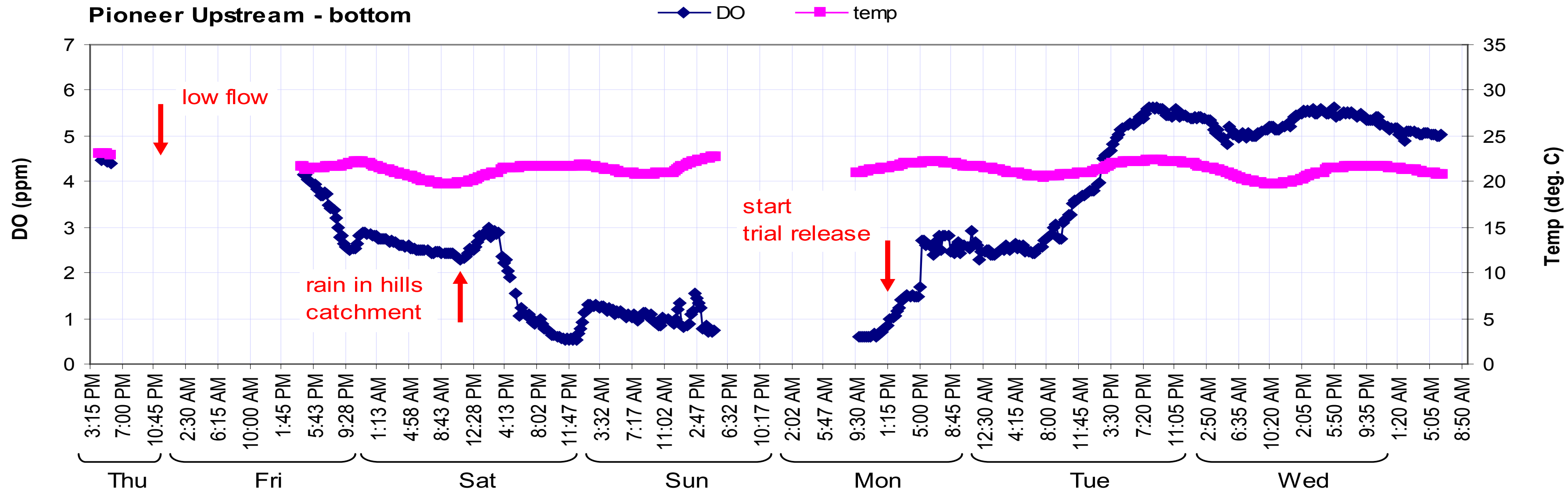
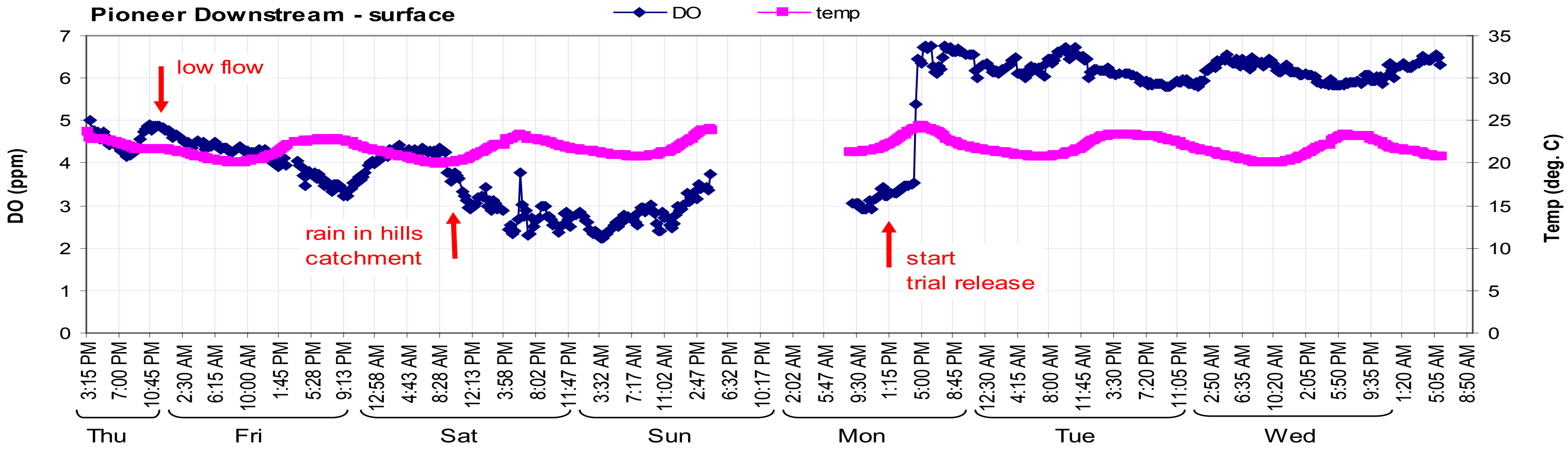




***Figure 2A.*** Diel plots of DO (ppm) and temperature (°C) in Canning River pools at Pioneer Park, Gosnells, monitored from 15th to 22nd March 2007. Plots indicate surface and bottom waters.



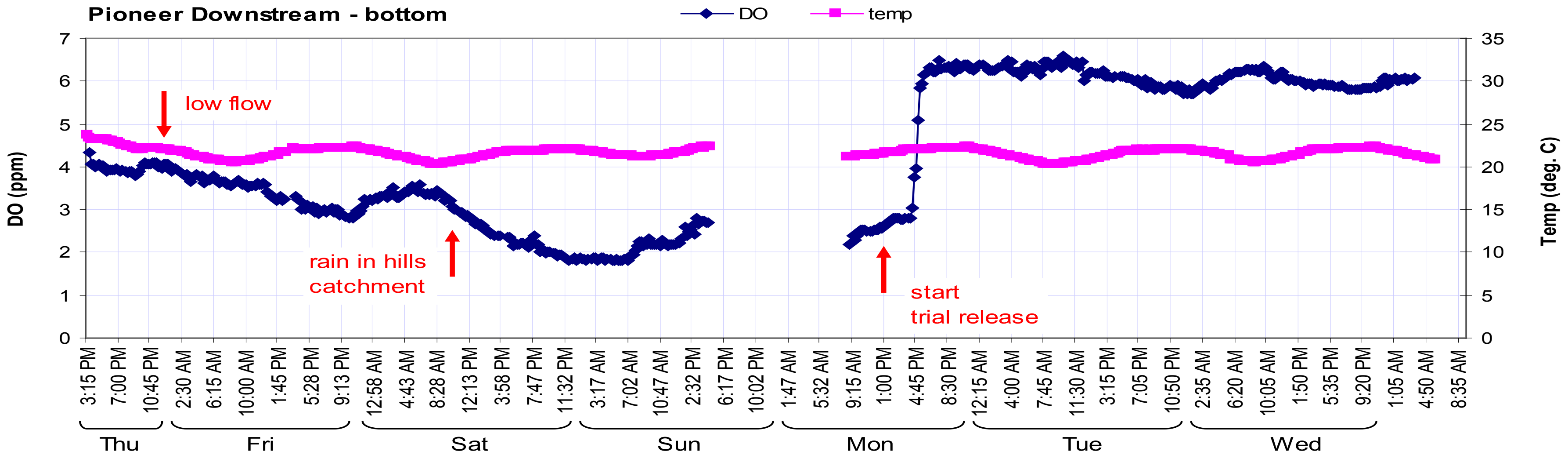




***Figure 2B.*** Diel plots of DO (ppm) and temperature (°C) in Canning River pools downstream of Gosnells release valve, monitored from 15th to 22nd March 2007. Plots indicate surface and bottom waters.

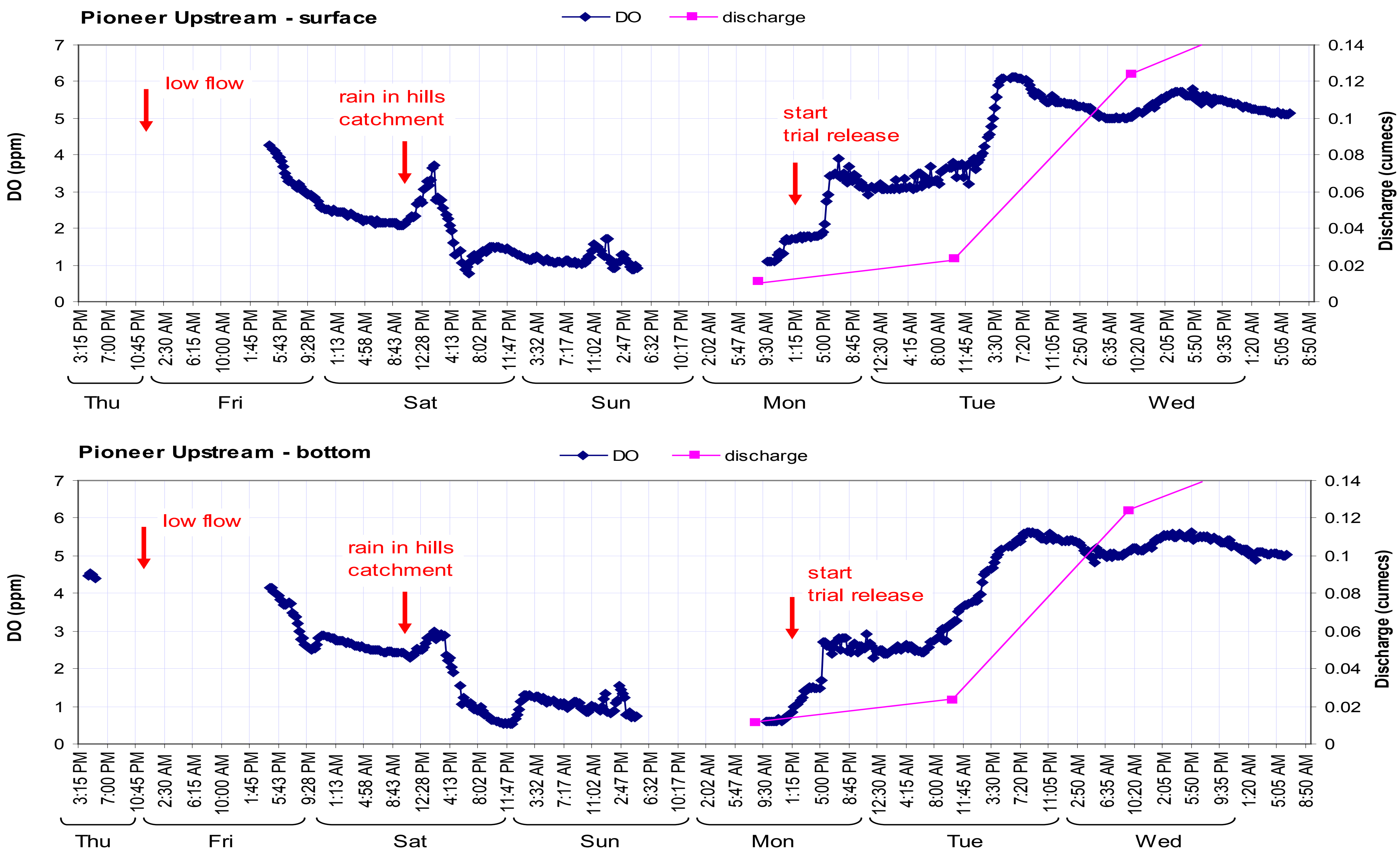
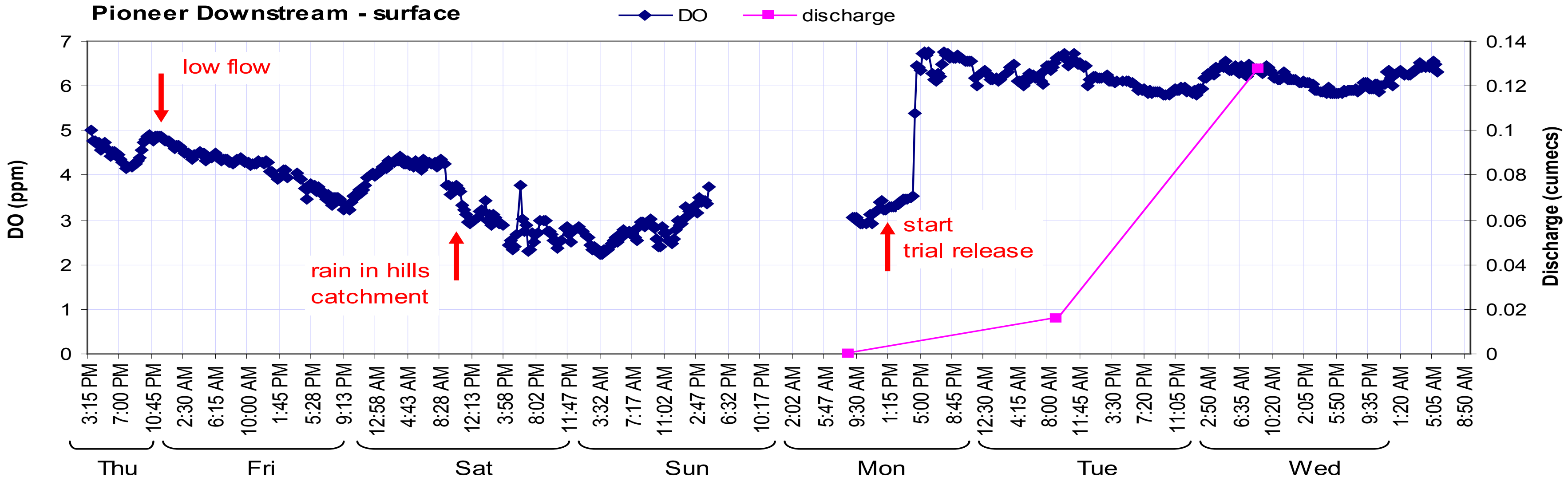



***Figure 3A.*** Diel plots of DO (ppm) compared against DoW discharge data (cumecs) in Canning River upstream pool at Pioneer Park, Gosnells, monitored from 15th to 22nd March 2007. DO data indicates surface and bottom waters.



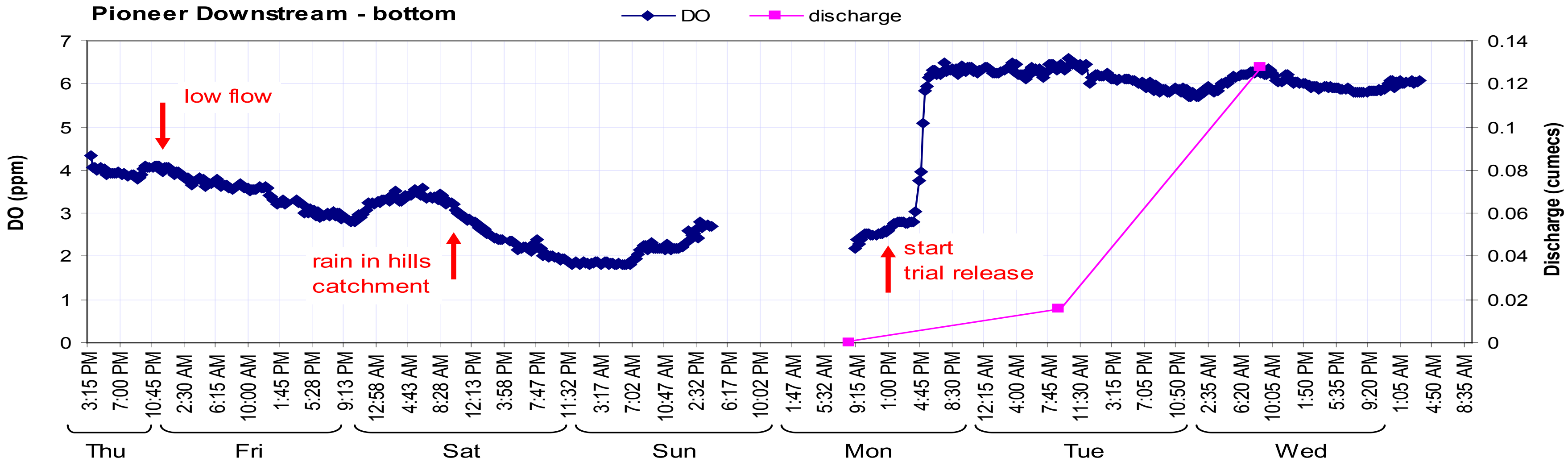




***Figure 3A.*** Diel plots of DO (ppm) compared against DoW discharge data (cumecs) in Canning River pools downstream of the Gosnells release valve, monitored from 15th to 22nd March 2007. DO data indicates surface and bottom waters.

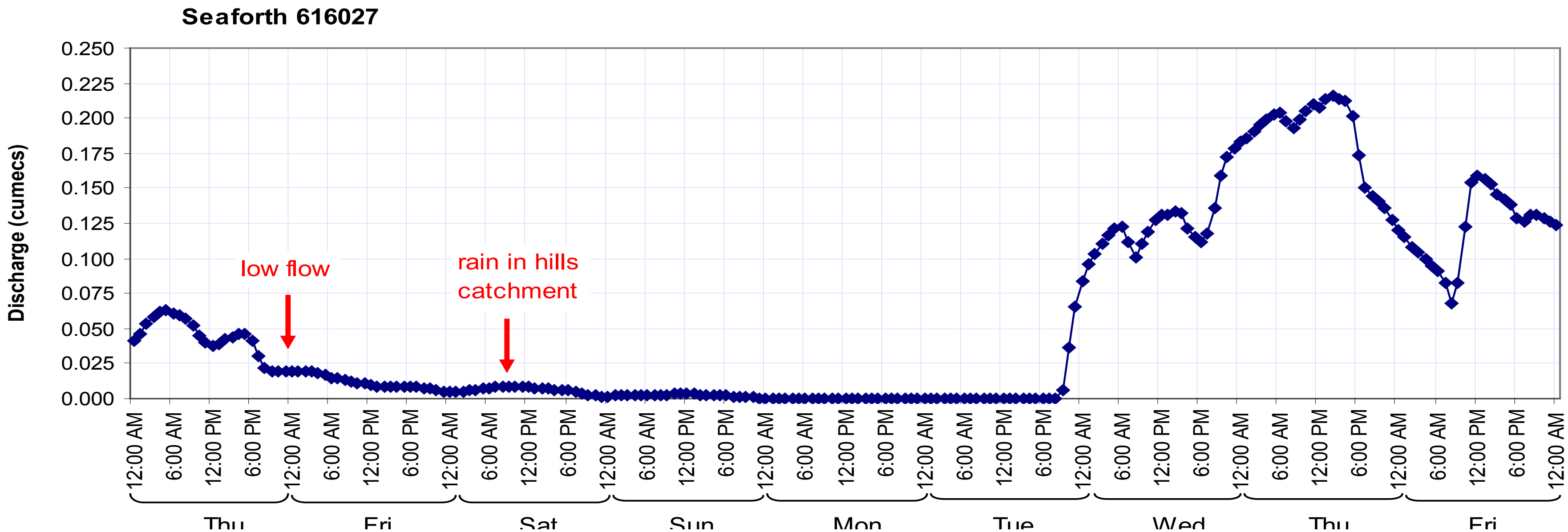



Figure 4. ***Discharge at Seaforth gauging station from 15th to 23rd March 2007.***

Table 2. ***DoW gaugings of flow (litres/minute) at release valves and river discharge (cumecs) over the trial release period.***

| Site | Mon 19/3/07 | | | | Tue 20/3/07 | | | | Wed 21/3/07 | | | | Thur 22/3/07 | | | | Fri 23/3/07 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Time** | **Stage** | **Flow** L/min | **Discharge** cumecs | **Time** | **Stage** | **Flow** L/min | **Discharge** cumecs | **Time** | **Stage** | **Flow** L/min | **Discharge** cumecs | **Time** | **Stage** | **Flow** L/min | **Discharge** cumecs | **Time** | **Stage** | **Flow** L/min | **Discharge** cumecs |
| **Soldiers** | 13:30 | >10 | | 0.0010 | 10:20 | | 1944 | | 9:30 | | 1944 | | 12:20 | | 1944 | | 10:20 | 10.11 | N/A | 0.0240 |
| | 13:50 | | 648 | | 13:00 | >10 | | 0.0010 | 14:45 | >10 | | 0.0020 | 15:00 | 10.10 | | 0.0139 | | | | |
| **Stockers** | 11:30 | >10 | | 0.0020 | 11:00 | | 2316 | | 10:30 | | 3250 | | 13:20 | | 3250 | | 12:00 | 10.20 | N/A | 0.07042 |
| | 14:05 | | 1158 | | 12.06 | >10 | | 0.0050 | 14:10 | 10.18 | | 0.02814 | 14:20 | 10.18 | | 0.0338 | | | | |
| **Bernard** | 10:30 | >10 | | 0.0010 | 11:20 | | 2178 | | 11:35 | | 3264 | | 11:30 | 10.20 | | 0.0280 | 13:30 | 10.23 | N/A | 0.05414 |
| | 14:20 | | 1086 | | 11:30 | >10 | | 0.0015 | 13:40 | >10 | | 0.0015 | 14:20 | | off | | | | | |
| **Orlando** | 9:35 | >10 | | 0.0010 | 10:45 | >10 | | 0.0010 | 11:40 | | 4866 | | 12:00 | 10.30 | | 0.1077 | | N/A | | N/A |
| | 14:40 | | 1620 | | 11:45 | | 4866 | | 13:06 | 10.22 | | 0.0213 | 15:10 | | off | | | | | |
| **Manning** | 9:00 | >10 | | 0.0020 | 10.3 | >10 | | 0.0030 | 10:00 | 10.29 | | 0.0528 | 10:30 | 10.32 | | 0.0702 | | N/A | | N/A |
| | 15:20 | | 1878 | | 12:10 | | 3750 | | 11:50 | | 5628 | | 15:30 | | off | | | | | |
| **Pioneer US** | 8:40 | >10 | | 0.0010 | 10:06 | 10.16 | | 0.0233 | 09:00 | 10.28 | | 0.1239 | 08:50 | 10.30 | | 0.1646 | | N/A | | N/A |
| **Pioneer DS** | 8:30 | >10 | | 0 | 8:35 | 10.16 | | 0.0160 | 08:20 | 10.28 | | 0.1277 | 08:00 | 10.30 | | 0.1868 | | N/A | | N/A |
| | 15:20 | | 1111 | | 12:40 | | 2569 | | 12:20 | | 2569 | | 15:45 | | off | | | | | |

Estimated velocities apply to stage levels below 10 and should be noted, quality is poor.

# 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. |
| **Allocation** | Permanent or temporary withdrawal of water from any source of supply, so that it is no longer part of the resources of the locality. |
| **Allocation limit** | Annual volume of water set aside for use from a water resource. |
| **Baseflow** | The component of streamflow supplied by groundwater discharge. |
| **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. |
| **Catchment** | The area of land from which rainfall runoff contributes to a single watercourse, wetland or aquifer. |
| **Confluence** | Running together, flowing together, e.g. where a tributary joins a river. |
| **Dam** | An embankment constructed to store or regulate surface water flow. A dam can be constructed in or outside a watercourse. |
| **Discharge** | The water that moves from the groundwater to the ground surface or above, such as a spring. This includes water that seeps onto the ground surface, evaporation from unsaturated soil, and water extracted from groundwater by plants (evapotranspiration) or engineering works (groundwater pumping) |
| **Discharge rate** | Volumetric outflow rate of water, typically measured in cubic metres per second. |
| **Dissolved oxygen** | The concentration of oxygen dissolved in water normally measured in milligrams per litre (mg/L). |
| **Ecological values** | The natural ecological processes occurring within water-dependent ecosystems and the biodiversity of these systems. |
| **Ecological water requirement** | The 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, to include 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 interactions between all of these. |
| **Environmental water provision** | The water regimes that are provided as a result of the water allocation decision-making process, taking into account ecological, social, cultural and economic impacts. They may meet in part or in full the ecological water requirements. |
| **Evaporation** | Loss of water from the water surface or from the soil surface by vaporisation due to solar radiation. |
| **Evapotranspiration** | The combined loss of water by evaporation and transpiration. It includes water evaporated from the soil surface and water transpired by plants. |
| **Flow** | Streamflow – may be measured as $m^3$/yr, $m^3$/d or ML/yr. May also be referred to as discharge. |
| **Inflows** | Surface water runoff; deep drainage to groundwater (groundwater recharge); and transfers into the water system (both surface and groundwater), for a defined area |
| **Licence** | A formal authorisation which entitles the licence holder to ‘take’ water from a watercourse, wetland or underground source for a specified quantity and period of time. |
| **Riparian right** | Right of a riparian landowner to take water from a watercourse, which flows through or is contiguous to their property, unlicensed and free of charge for the purpose of non-intensive stock and ordinary domestic use, without sensibly diminishing the flow of water downstream. |
| **Scheme water** | Water diverted from a source (or sources) by a water services authority or private company and supplied via a distribution network to customers for urban, industrial or irrigation use. |
| **Surface water** | Water flowing or held in streams, rivers and other wetlands on the surface of the landscape. |
| **Surface water allocation area** | An area defined by the Department of Water, used for water allocation planning and management, that is generally a hydrologic basin or part of a basin. |
| **Surface water allocation subarea** | An area within a surface water management area defined by the Department of Water, used for water allocation planning and management, that is generally a hydrologic catchment. |

| | |
|---|---|
| **Surface water resource** | Defined area for allocation and licensing decisions for a particular plan area. For this plan, surface water resource boundaries are the same as surface water allocation subareas. |
| **Watercourse** | A watercourse means:<br>a. any river, creek, stream or brook in which water flows<br>b. any collection of water (including a reservoir) into, through or out of which any thing coming within paragraph (a) flows<br>c. any place where water flows that is prescribed by local by-laws to be a watercourse<br>and includes the bed and banks of any thing referred to in paragraph a, b or c.<br>(Definition from the *Rights in Water and Irrigation Act 1914*) |
| **Water-dependent ecosystems** | Those parts of the environment which are sustained by the permanent or temporary presence of water. |
| **Water entitlement** | The quantity of water that a person is entitled to take on an annual basis in accordance with the *Rights in Water and Irrigation Act 1914* and a licence. |
| **Water regime** | A description of the variation of flow rate or water level over time. It may also include a description of water quality. |
| **Waterways** | All streams, creeks, stormwater drains, rivers, estuaries, coastal lagoons, inlets and harbours. |

## Volumes of water

| | | | |
|---|---|---|---|
| One litre | 1 litre | 1 litre | (L) |
| One thousand litres | 1000 litres | 1 kilolitre | (kL) |
| One million litres | 1 000 000 litres | 1 Megalitre | (ML) |
| One thousand million litres | 1 000 000 000 litres | 1 Gigalitre | (GL) |

# Shortened forms

| | |
|---|---|
| ANZECC | Australian and New Zealand Environment Conservation Council |
| ARMCANZ | Agriculture and Resource Management Council of Australia and New Zealand |
| BOM | Bureau of Meteorology |
| DoW | Department of Water |
| ERP | Environmental release point |
| EWR | Environmental water requirement |
| EWP | Environmental water provision |
| RAP | River Analysis Package |

# Map disclaimer

*Figure 2*

*Datum and projection information*

Vertical datum: Australian Height Datum (AHD)

Horizontal datum: Geocentric Datum of Australia 94

Projection: MGA 94 Zone 50

Spheroid: Australian National Spheroid

*Project information*

Client: R. Rowling

Map Author: B. Huntley, D. Abbott

Filepath: J:\gisproject\project\C2204\330\26610\mxd\

Filename: 100726_Canningv2.mxd

Compilation date: July 2010

*Disclaimer*

This map is a product of the Department of Water, Water Resource Use Division and was printed as shown.

This map was produced with the intent that it be used for information purposes at the scale as shown when printing.

While the Department of Water has made all reasonable efforts to ensure the accuracy of this data, the department accepts no responsibility for any inaccuracies and persons relying on this data do so at their own risk.

*Sources*

The Department of Water acknowledges the following datasets and their custodians in the production of this map:

WA Coastline, WRC (Poly) – DoW – 20/07/2006

Hydrography, Linear (Hierarchy) – DoW – 05/11/2007

State Roads – DOLA – 06/01/1999

Population Centres – GA – 13/11/1998

*Figure 4*

*Datum and projection information*

Vertical datum: Australian Height Datum (AHD)

Horizontal datum: Geocentric Datum of Australia 94

Projection: MGA 94 Zone 50

Spheroid: Australian National Spheroid

*Project information*

Client: R. Rowling

Map Author: B. Huntley, D. Abbott

Filepath: J:\gisproject\project\C2204\330\26610\mxd\

Filename: 100726_Canningv2.mxd

Compilation date: July 2010

*Disclaimer*

This map is a product of the Department of Water, Water Resource Use Division and was printed as shown.

This map was produced with the intent that it be used for information purposes at the scale as shown when printing.

While the Department of Water has made all reasonable efforts to ensure the accuracy of this data, the department accepts no responsibility for any inaccuracies and persons relying on this data do so at their own risk.

*Sources*

The Department of Water acknowledges the following datasets and their custodians in the production of this map:

WA Coastline, WRC (Poly) – DoW – 20/07/2006

Hydrography, Linear (Hierarchy) – DoW – 05/11/2007

State Roads – DOLA – 06/01/1999

Population Centres – GA – 13/11/1998

# References

Australian and New Zealand Environment Conservation Council (ANZECC) & Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) 2000, *Australian and New Zealand guidelines for fresh and marine water quality,* Volume 1, Australia.

Britton DL & Brock MA 1994, 'Seasonal germination from wetland seedbanks', *Australian Journal of Marine and Freshwater Research* 45: 1445-1457.

Chandler F & Reid N 2005, Investigation in the impacts of chlorine on macroinvertebrate fauna in the Canning and Wungong rivers, unpublished draft report for the Department of Water.

Morgan DL, Beatty SJ & McAleer FJ 2007, Canning River – freshwater fishes and barriers to migrations, Center for Fish and Fisheries Research, Murdoch University, unpublished report for Department of Water and South East Regional Centre for Urban Landcare.

Morgan D Gill H & Potter I 1996, *The distribution of freshwater fish in the South-Western Corner of Australia*, Report no. WRT4 1996, Water and Rivers Commission.

Perth Region NRM 2010, *Noongar values of the Canning River*, internal document, Perth Region NRM, Perth.

Poff NL, 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 (11) 769-784.

Radin L, La Spina K, Braimbridge M & Malseed B 2007, *Environmental values, flow related issues and objectives for the Canning River, Western Australia*, Environmental water report series, Report no. 5, Department of Water, Perth.

Richter B, Baumgartner J, Wigington R & Braun D 1997, 'How much water does a river need?' *Freshwater Biology* 37 (1) 231-249.

Stewardson M 2004, *Workshop notes: using the River Analysis Package (RAP) environmental flow analysis report*, Cooperative Research Centre for Catchment Hydrology, University of Melbourne.

Stewardson M 2001, 'The flow events method for developing environmental flow regimes', in Rutherford I, Sheldon F, Brierley G & Kenyon C (eds), *The value of healthy rivers, proceedings of the 3rd Australian Stream Management Conference*, *27-29 August 2001*, Cooperative Research Centre for Catchment Hydrology, Brisbane, pp. 577-582.

Storey A, Davies PM & Creagh S 2001. *Preliminary environmental water requirements for the Canning River system*, Aquatic Research Laboratory, University of Western Australia, report for the Water and Rivers Commission, Western Australia.

Storey A 1998, Fish and fish habitat survey of the Canning River and its tributaries, unpublished report for the Upper Canning/Southern Wungong Catchment Management Team.

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

Wetland Research Management 2005. Ecological water requirements of the Hill River – intermediary assessment, unpublished report by Wetland Research and Management for the Water and Rivers Commission, Perth.

Wetland Research Management 2000, Ecological monitoring of the Canning and Southern-Wungong rivers: baseline data for assessing effectiveness of EWRs, unpublished report by Wetland Research and Management for the Water and Rivers Commission, 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

0820–0–0110