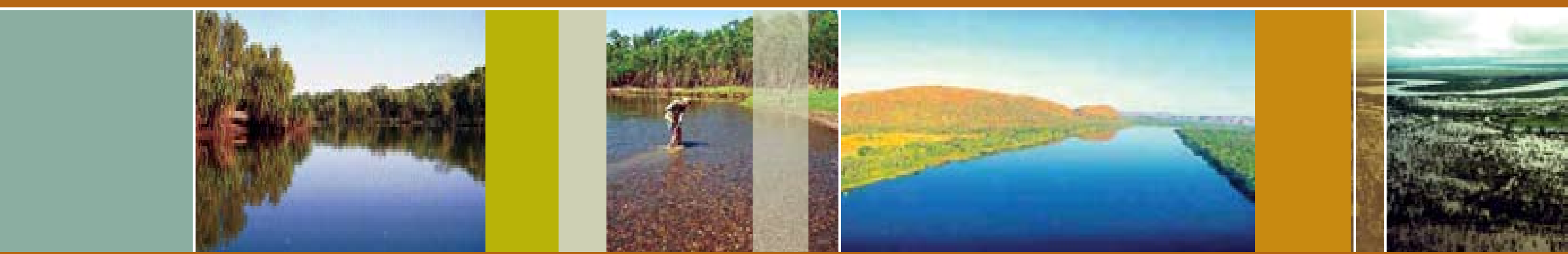
Department of Water
Government of Western Australia

Ecological Water Requirements
for the lower Ord River

MAY 2007



Environmental Water Report Series
Report no. EWR 4

Department of Water
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Ecological Water Requirements for the lower Ord River

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Water Resource Use
Department of Water

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Cover photographs:

Lower Ord River pool (courtesy of A. Storey), macroinvertebrate sampling (courtesy of A. Storey), lower Ord River, and Parry Lagoon in flood.

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Summary

A revised ecological water requirement for the lower Ord River has been developed using the Flow Events Methodology. This approach represents a higher degree of resolution in determining flow requirements than previously employed in developing the ecological water requirement[1] (EWR) and subsequently developing the environmental water provision[2] (EWP) and water allocation limit detailed in the *Ord River Water Management Plan* (DoW, 2006).

The analyses undertaken in developing the revised EWR were completed using the River Analysis Package (RAP), a modelling package that allows the quantification of changes in ecological parameters with flow regime spatially and temporally. Analyses were completed for 22 flow ecology linkages previously identified in Trayler *et al*. (2006), using three representative reaches of the lower Ord. Where appropriate, individual flow recommendations were developed for each reach for each flow ecology linkage.

The flow recommendations for individual flow ecology linkages were consolidated and summarised into a dry season and wet season EWR. Dry season flow recommendations are typically presented as minima below which flows should not fall. Three flow-ecology linkages are exceptions to this general rule with limits set on the reduction in dry season flows from one year to the next rather than having an absolute minimum flow.

By ranking the flow recommendations for the remaining dry season flow-ecology linkages, a dry season minimum of 42 m^3/s, which will satisfy all of the minimum flow recommendations, was established. That is, if dry season flows are maintained at 42 m^3/s or higher then the remaining dry season flow-ecology linkages will be satisfied.

Wet season flow recommendations require a number of events of varying magnitude, duration and frequency. The resulting flow regime is summarised by four EWR scenarios that should occur annually, once every two years, once every four years and once every 27-35 years.

The total discharge for the comprehensive annual EWR is 1,619 GL. In comparison, the interim EWP of 45 m^3/s has an annual discharge of 1,419 GL. The median stream flow since regulation is 2,830 GL (Trayler *et al*., 2006).

The revised EWR will be one component in the development of a revised Environmental Water Provision (EWP) and water allocation limit. In developing an EWP, the Department will consider the water demands of the environment, social and cultural needs and economic development. It is anticipated that a revised water allocation for the lower Ord River will be released within the next three years.

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1 Ecological water requirement (EWR) as defined in the State-wide Policy No. 5 (WRC 2000) is the water regime needed to maintain ecological values of water dependent ecosystems at a low level of risk.

2 Environmental water provision (EWP) as defined in the State-wide Policy No. 5 (WRC 2000) is the water regime provided as a result of the water allocation decision-making process taking into account ecological, social and economic impacts. They may meet in part or in full the ecological water requirements.

1 Introduction

1.1 Purpose of this document

This document presents the findings of work undertaken to develop a revised ecological water requirement (EWR) for the lower Ord River. The revised EWR builds a higher resolution flow recommendation than that used in developing the current *Ord River Water Management Plan* (see also section 1.3)(DoW, 2006).

The publication of the EWR for the lower Ord is the next step in developing a revised water allocation. It follows the publication of *Environmental values, flow related issues and objectives for the lower Ord River* (Trayler *et al*., 2006). A revised water allocation for the lower Ord will be developed in consideration of the competing water requirements of the environment, social and cultural needs, the potential full development of the Stage II irrigation area, and power generation. This could include an allocation to the Stage II development beyond the 400 GL/yr provided by the current water management plan (DoW, 2006).

Trayler *et al*. (2006) provides a detailed description of the current project study area and the results of ecological and hydrological investigations completed between 1999 and 2005. The information provided by these investigations have facilitated a more detailed approach to developing an EWR. Trayler *et al*. (2006) also details the flow objectives and flow ecology linkages that have been used to frame the development of the revised EWR. Where appropriate, information on the ecological and hydrological investigations, flow objectives and flow ecology linkages has been provided in the current document in a summarised form.

This document provides details on:

- the methodology used in developing a revised EWR;
- the results of analyses undertaken;
- a description of how these results compare with the previous EWR; and
- how the results will be used in developing a revised environmental water provision (EWP) and water allocation.

1.2 Study Area

1.2.1 Catchment characteristics

The Ord River is situated in the east Kimberley region of Western Australia (Figure 1) and has a catchment (at the site of the Ord River Dam) of approximately 45,300 km^2, which extends into the Northern Territory. The 650 km-long Ord River is one of Western Australia's major river systems. It drains into the Cambridge Gulf near Wyndham and had a mean annual streamflow pre-dam (at the river mouth) of approximately 4,500 GL. The largest recorded instantaneous flow was approximately 30,800 m^3/s (1956).

The catchment has a semi-arid to arid monsoonal climate with two distinct seasons: a warm, dry season (May-Oct) and a hot wet season (Nov-April). Most of the annual rainfall is the result of the monsoonal depressions and tropical cyclones. Rainfall can be infrequent for the remainder of the year and consecutive dry months are common.

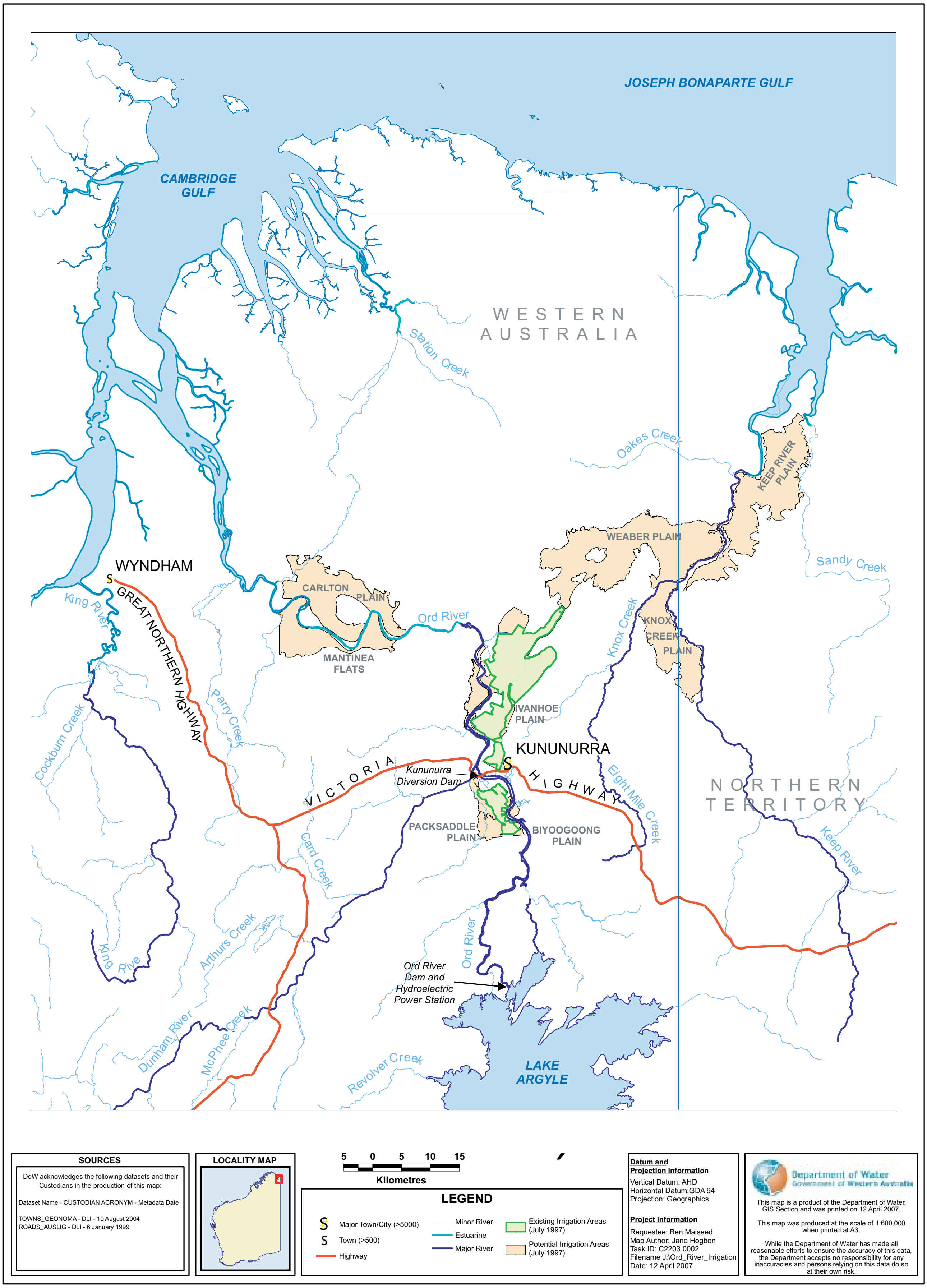

Figure 1: Ord River study area and irrigation development areas

1.2.2 Irrigation development

The Ord River Irrigation Project began in 1963 with the commissioning of the Kununurra Diversion Dam (KDD) and 12,000 ha of serviced farmland. With the completion of construction of the Ord River Dam and associated irrigation infrastructure in 1972, Stage I of the development was available for irrigation.

In the mid-1990s, the spillway on Lake Argyle was raised to allow for the construction and operation of a hydro-electric power station at the Ord River Dam. During the same period, the Department of Resource Development (DRD) sponsored a series of investigative studies and conceptual designs (DRD, 1995, 1997a, 1997b) to update earlier development plans for Stage II of the irrigation development.

The Government of Western Australia is progressing with the staged development of Stage II of the Ord Irrigation area, which potentially will create an additional 16,000 ha of farmland in Western Australia. Sufficient water has currently been allocated to enable a further 7,000 ha to be developed downstream of the KDD in the Martinea Flats and Carlton Plains areas and 2,500 ha for expansion of the existing Stage I irrigation area.

Future development of the project in the Northern Territory has the potential to include a further 14,000 ha of farmland.

1.3 Allocation process to date

A water allocation for the environment, for the existing Stage I and potential Stage II irrigation areas, was proposed initially in 1999 and outlined in the *Draft Interim Water Allocation Plan for the lower Ord River* (WRC, 1999). This plan allocated 600 GL/yr to meet the EWP (WRC, 1999). The approach taken for determining the EWP was to use the 20th percentile of the natural flows. At that time, there was limited ecological data available to justify a more sophisticated approach.

Public comments on the 1999 draft water allocation plan considered that the then Water and Rivers Commission had not adequately protected the environmental values that had developed in the 30 years since regulation of river flow.

On advice from the Environmental Protection Authority, the Commission established a scientific panel to provide input towards establishing an EWR, focusing on maintaining the riverine environmental values that have established since the construction of the Ord River Dam in 1972. This was a major challenge as there was limited ecological data on the river and little published work on determining the EWR for large subtropical river systems, particularly those with regulated flow. In the absence of sound quantitative ecological data, an interim estimate of the EWR was determined using changes in wetted perimeter as a surrogate for habitat availability. Minimum flow rates of 45 m^3/s from the Kununurra Diversion Dam (KDD) to the downstream 57.5 km point and 40 m^3/s below that point were identified as an acceptable interim estimate of the EWR. The recently published *Ord River Water Management Plan* (DoW, 2006) provides details on this EWR, the subsequent EWP and allocation of water for irrigation and hydropower generation. The plan allocates an additional[3] 400 GL/yr for the initial phases of the Stage II irrigation development, resulting in a total allocation for irrigation of 750 GL/yr.

Substantial additional ecological and hydrological investigations have since been completed. The results of these investigations facilitated the determination of a more comprehensive, higher resolution EWR as outlined in this document. It is important to note that the objective of the interim EWR to maintain riverine environmental values that have established since the construction of the Ord River Dam has been retained for the revised EWR. That is, the objective in conducting the analyses detailed in subsequent sections was to determine EWR to preserve ecological values that have developed since the construction of the Ord River Dam.

The revised EWR together with social, cultural and economic considerations will be used in developing a revised EWP and allocation of water for consumptive use for the lower Ord River. A brief description of the proposed process to be used in developing a revised EWP and water allocation is provided in section 6.

3 The existing allocation for the Stage I irrigation area is 350 GL/yr.

2 Approach

2.1 Flow Events Methodology

2.1.1 Background

The Flow Events Methodology (FEM) as developed by Stewardson (2001), has been used to determine an EWR for the lower Ord River. Central to the flow events methodology is the natural flow paradigm, which states that the integrity of river systems is related to the intra and inter-annual variation of hydrological regimes (Poff *et al*., 1996; Richter *et al*., 1997). It follows that there is a requirement to identify which aspects of the flow variability need to be maintained by environmental flows. That is, it is recognised that different components or parts of the flow regime have different ecological functions.

The FEM allows each of these flow components to be assessed independently. Flow components are identified as significant for the reach or system following consideration of their implications to key ecological features and/or processes. This consideration of how different parts of the flow regime (ie flow components) influence or relate to the ecology results in the identification of a set of specific flow-ecology linkages for the system. This is a key feature of the flow events method (Stewardson, 2004). That is, there is no *a priori* set of events as there is in other methods such as FLOWS (SKM, 2002).

The flow events method provides a standardised and systematic procedure for determining flow requirements for rivers. It builds greater transparency into the process than other methods, such as the Building Block Approach, that have previously been used in determining EWR for streams and rivers in Western Australia (eg Davies *et al*., 1998; WEC and Streamtec, 2000; Storey *et al*., 2001; Storey and Davies, 2002; Streamtec, 2002). The method still allows for the input of expert opinion. The approach is adaptive, recognising that different EWR studies are likely to have differing constraints (Stewardson, 2004). The flow events method has been applied successfully to rivers in south eastern Australia (Cottingham *et al*., 2003) and Western Australian (WRM, 2005).

2.1.2 Stages of the Flow Events Method

The development of an EWR or flow recommendations using the FEM typically follows two stages (Cottingham *et al*., 2003):

Stage 1

- Documentation of the representative sites and reaches;
- Field assessment by expert panel members; and
- Development of an issues paper that highlights environmental assets, threats and flow-related ecological objectives that form the basis for flow recommendations.

Stage 2

- Hydraulic survey and modelling using HecRAS;
- Hydrological analyses, utilising the River Analysis Package (RAP)[4] to develop flow recommendations (ie ecological water requirements) that address the flow related objectives; and
- Development of a report is in consultation with key stakeholders/an expert panel.

2.2 Applying the Flow Events Method to the lower Ord River

Much of the work undertaken towards the development of an EWR for the lower Ord River was completed prior to the development of the flow events method. Therefore, the process (Figure 2) differed to that typically used by the FEM and was as follows:

- An hydraulic model was created for the lower Ord River as part of the development of the *Interim Water Allocation Plan* (WRC, 1999b).
- A scientific panel was established and undertook a field visit in order to develop recommendations for the Interim Water Allocation Plan (WRC, 1999b).
- Following a review of available biophysical information, additional scientific investigations were scoped and conducted. Trayler *et al*. (2006) summarises the findings of these investigations.
- Flow-ecology linkages (see section 3) were defined (also presented in Trayler *et al*., 2006). These provide the basis for the development of a comprehensive EWR.
- The hydraulic model for the lower Ord River was updated to conform to the requirements of the River Analysis Package; and a daily flows hydrological model was developed so that modelled historic, current and potential future flow information could be analysed (see section 2.3).
- Flow event analyses were undertaken using the river analysis package and developed into an EWR in consultation with the scientific panel (Table 1).

Further details of the flow event analyses, development of the hydrologic model and time series and involvement of the scientific panel has been provided in subsequent sections.

2.2.1 Flow event analyses

This section outlines the general approach taken to flow event analyses using the River Analysis Package for the lower Ord River. Based on the nature of each flow-ecology linkage, the analyses varied slightly to that presented below. Specific details of the analysis and results for each flow-ecology linkage are presented in subsequent sections.

2.2.1.1 Define environmental flow considerations

For each flow-ecology linkage, relevant flow considerations were defined to allow assessment of the impacts of flow modifications. The flow considerations either identify threshold flows at which flow ecology linkages are triggered or describe the strength of the effect that different flows have on the flow ecology linkage (Stewardson, 2004). For

4 The River Analysis Package is a computer software package developed by the CRC for Catchment Hydrology that allows reach based analysis of flow statistics and hydraulic conditions for stream habitat studies (CRC 2005). Further details of analyses undertaken are provided below.

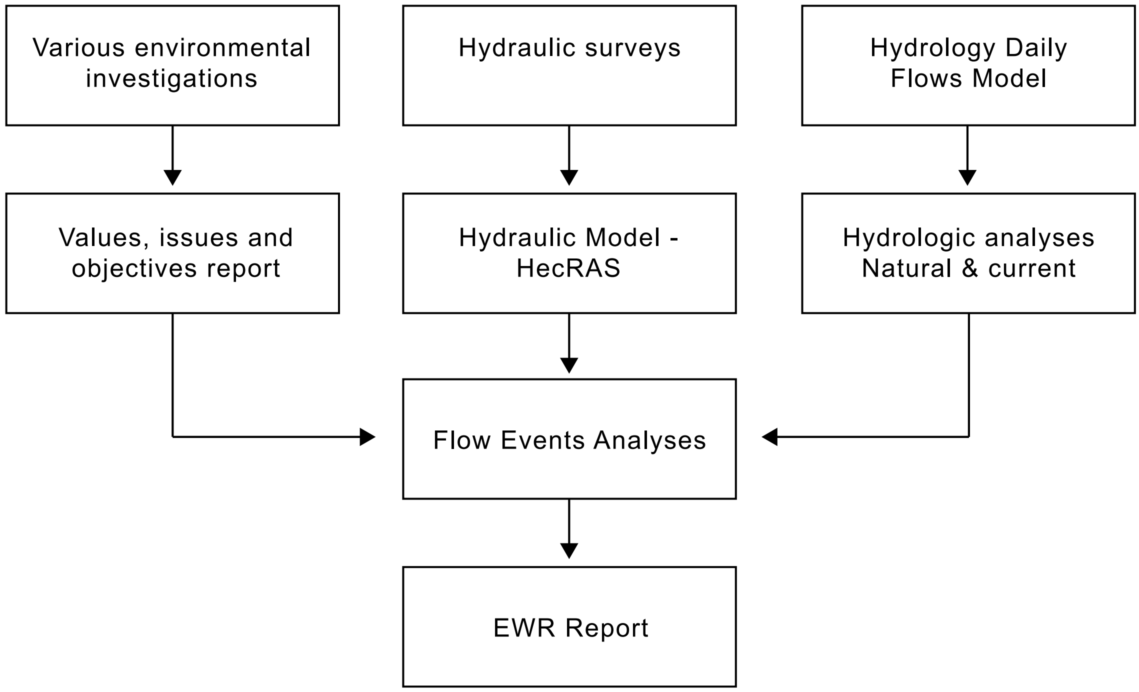

Figure 2: Process for the determination of a revised EWR for the lower Ord River

example, for riverine benches to be available as habitat for fish (feeding and spawning), wet season inundation of benches to a minimum depth of one metre is required. Therefore a specific criteria or rule for depth greater than one metre on lateral benches was developed.

2.2.1.2 Model hydraulic or habitat ratings

A rating curve for each flow-ecology linkage was developed using the defined environmental flow statistic or rule and the output of the hydraulic model. Rating curves describe the relationship between environmental flow statistics (and therefore the flow ecology linkage) and discharge. This is typically expressed in terms of the amount or proportion of habitat available at different discharges. Continuing the fish spawning example, using a rule of depth ≥ 1m, a rating curve showing the relationship between width of channel satisfying the rule (ie with depth ≥ 1m) and discharge was produced (Figure 3).

By examining the rating curve, it was possible to identify the threshold at which the flow ecology linkage is triggered. In this example, it can be seen that there is an inflection in the curve at approximately 125 m^3/s. This indicates that there is a rapid increase in the width of channel with a depth ≥ 1m when discharge exceeds 125 m^3/s. That is, water depth on flat wide benches outside the main channel is exceeding one metre. This was confirmed by examining the stage height to flow relationship for individual cross sections. Figure 4 shows the stage height at a discharge of 125 m^3/s for a representative cross section. At this discharge (125 m^3/s), benches are starting to inundate to sufficient depth to meet the criteria and therefore the width of channel >1m increases rapidly.

2.2.1.3 Evaluate historic changes in flow regime

Time-series of discharge were analysed to characterise the frequency, duration and seasonal variation with which flow-ecology linkages are triggered. This involved either (i)

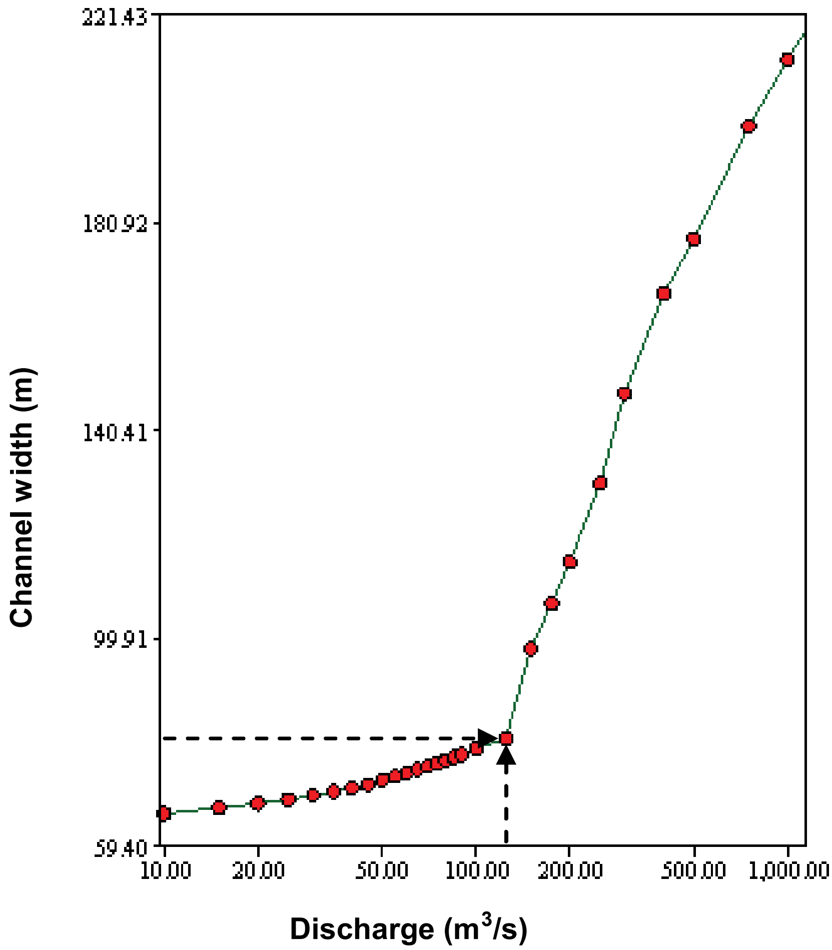

Figure 3: Flow rating curve of area of channel with depth >1m with discharge. Arrows indicate flow and channel width at 125 m³/s

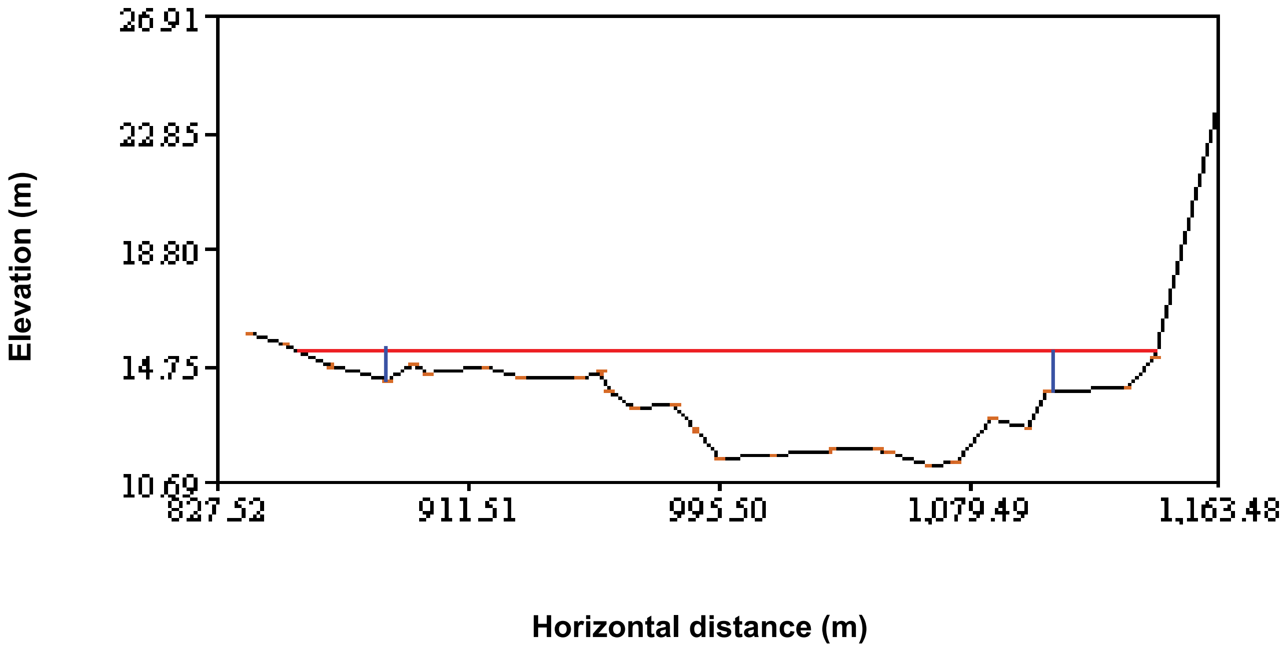

Figure 4: Example cross section showing inundation of benches at discharge of 125 m³/s

transformation of the discharge time series to a time series of the hydraulic metric using the relevant rating curve or (ii) analysis of the existing time series using threshold discharge values identified from the relevant rating curve. For the bench inundation example, the time series of observed flow was analysed to determine how often and for how long benches have been inundated under the current flow regime. That is, how often and for how long had flows in excess of 125 m^3/s been recorded.

Where necessary, cumulative probability distribution curves were developed and threshold frequencies determined. These were then translated, with input from the expert panel, into flow requirements for each flow-ecology linkage that maintain the existing ecological values at a low level of risk. For inundation of riparian benches, flows in excess of 125 m^3/s had been exceeded at least four times in 80 per cent of years. A flow recommendation for this example was developed based on these results and advice from the expert panel and is provided in full in section 4.1.1.

2.3 Daily release estimates for the lower Ord River Ecological Water Requirements analyses

The development of an EWR using the flow events method required compiling a mean daily time series of flow for the lower Ord River. However, there was insufficient gauged records on the lower Ord River for this purpose and therefore a longer time series of daily flows was developed based on the main inputs to the lower Ord. The main inputs to the lower Ord River are the releases from the Kununurra Diversion Dam and the flow from the Dunham River, the largest tributary that flows into the Ord approximately two kilometres downstream from the Kununurra Diversion Dam.

The time series adopted to analyse the various metrics is 1974 to 2005. The first two years following the construction of the Ord River Dam have been excluded from the time series as they are not representative of the post-regulation flows – as the dam was simply filling up. The degree to which the flow in the Ord River has been regulated has varied from 1974 to 2005, most markedly through the establishment of a hydropower scheme at the Ord River Dam in 1996. To characterise the differing degrees of regulation, the following time series covering this period were developed:

- the best estimates of the observed flows in the lower Ord River (including an estimate of observed Dunham River flows); and
- the best estimates of the natural (pre-regulation) streamflow.

Details of the inputs and methodology used to develop the flow time series are provided in Appendix 1.

2.4 Timing of wet and dry seasons

The Ord catchment is subject to two distinct seasons: a warm, dry season (May-Oct) and a hot wet season (Nov-Apr). As a result of regulation, wet season flows in the lower Ord have reduced and dry season flows have increased. However, the timing of wet season flows in the lower Ord has also shifted. Much of the runoff from early wet season rains is now captured in Lake Argyle by the Ord River Dam (ORD), delaying any increased flows in the lower Ord River. Conversely, wet season flows continue later as a result of the extended overflows from the ORD spillway in years when Lake Argyle is full (Figure 5).

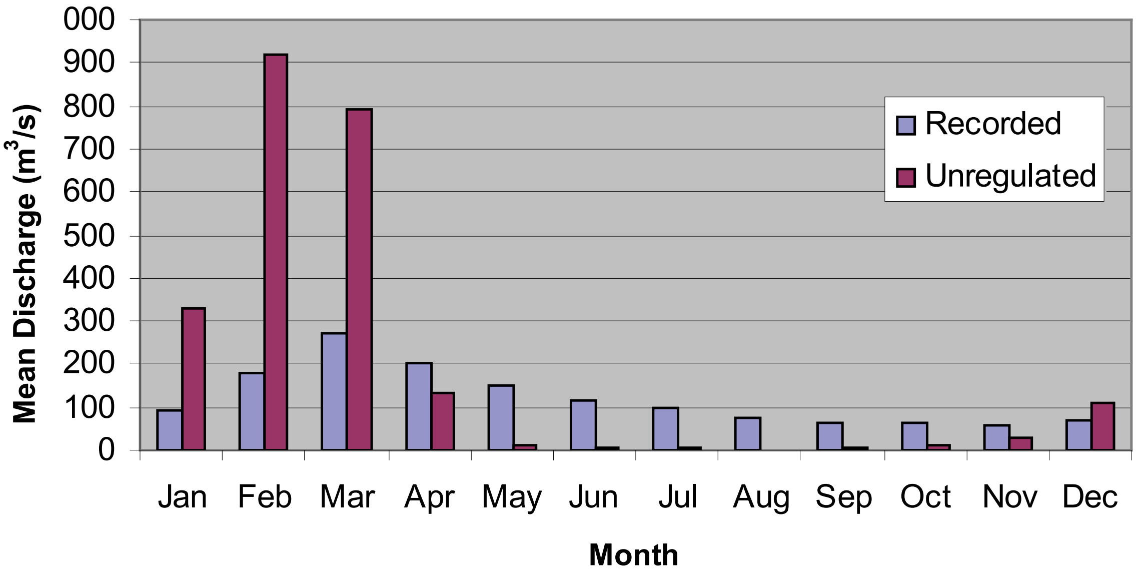

Figure 5: Monthly mean daily flows for modelled unregulated and actual recorded flows (1974-2005)

In response to the potential ecological impact of this shift, the wettest months of January-June have been adopted as the wet season along with a dry season of July-December for analyses undertaken in determining an EWR based on post-regulation flows in the lower Ord River.

2.5 River channel surveys and reaches

To develop the hydraulic model discussed previously, 51 channel cross sections were surveyed below the KDD during 2000. Although these cross-sections were surveyed without any specific regard to ecological features in mind, it was assumed the quantity and detail of the surveys were adequate to meet the requirements of the River Analysis Package[5]. The cross sections were located within the three distinct geomorphological reaches: below KDD to Tarrara Bar (Reach 1); from Tarrara Bar to the start of the tidal dominance (73 km below the KDD) (Reach 2); and the tidal-dominant reach (below 73 km) (Reach 3) (Figure 6). The tidal dominant reach was defined as the section of the river within which there is upstream flow of water during the tidal cycle. The impact of the tide on river levels is evident for an additional 10 kilometres upstream of the limit of upstream flow (approximately Carlton Crossing).

In the following sections, flow ecology linkages and flow recommendations are presented for specific reaches. Ideally, additional cross section surveys would have been undertaken to specifically target features linked to ecological objectives such as benches, backwaters and rapids. In the current study, additional detail for some of the key low-flow features was

5 Surveyed cross-sections for environmental flow studies should provide a representative sample of hydraulic and ecological characteristics of each reach (Stewardson, 2004). For the current study, cross-sections did not always include the detail required to identify small scale ecological features (ie backwaters and in-stream benches). Where necessary, additional relevant information was used to supplement analyses.

obtained via additional surveys and incorporated into the existing cross sections (rather than cross sections being surveyed with the initial intention of targeting these features). As detailed in subsequent sections applicable, additional information on ecological features such as backwaters and vegetation zones has also been incorporated from relevant studies and linked to the hydraulic model or incorporated into analyses.

2.6 Scientific Panel Involvement

The scientific panel was consulted throughout the process to determine an ecological water requirement for the lower Ord River. Members of the panel (see Table 1) were involved in a number of the ecological investigations undertaken on the lower Ord since 1999 and members subsequently provided input into the development of flow-ecology linkages for the system. Panel members also provided comment on the *Environmental values, flow related issues and objectives for the lower Ord River* (Trayler *et al*., 2006) report prior to its publication. Throughout the development of flow recommendations, advice from panel members was sought on an ongoing basis. The approach to and results of analyses were then presented to and discussed with panel members at a workshop before preparation of this report. Additional involvement with panel members followed the workshop to further refine some of the analyses and recommendations. A draft version of this report was circulated to the panel prior to its completion and publication.

Panel Member	Member position/title
Professor Peter Davies	Professor & Director Centre of Excellence in Natural Resource Management University of Western Australia
Dr Andrew Storey	Adjunct Senior Lecturer School of Animal Biology The University of Western Australia
Dr Ray Froend	Senior Lecturer School of Natural Sciences and Centre for Ecosystem Management Edith Cowan University
Dr Tony Start	Principal Research Scientist Department of Environment and Conservation
Dr Karl-Heinz Wyrwoll[6]	Senior Lecturer School of Earth and Geographical Sciences The University of Western Australia
Dr Clare Taylor	Australian Government NRM Facilitator - Rivercare/Water Department of Environment and Heritage

6 Dr Wyrwoll was not available to be involved during the development of the flow recommendations therefore Dr Taylor was invited to join the Scientific Panel for this phase of the project.

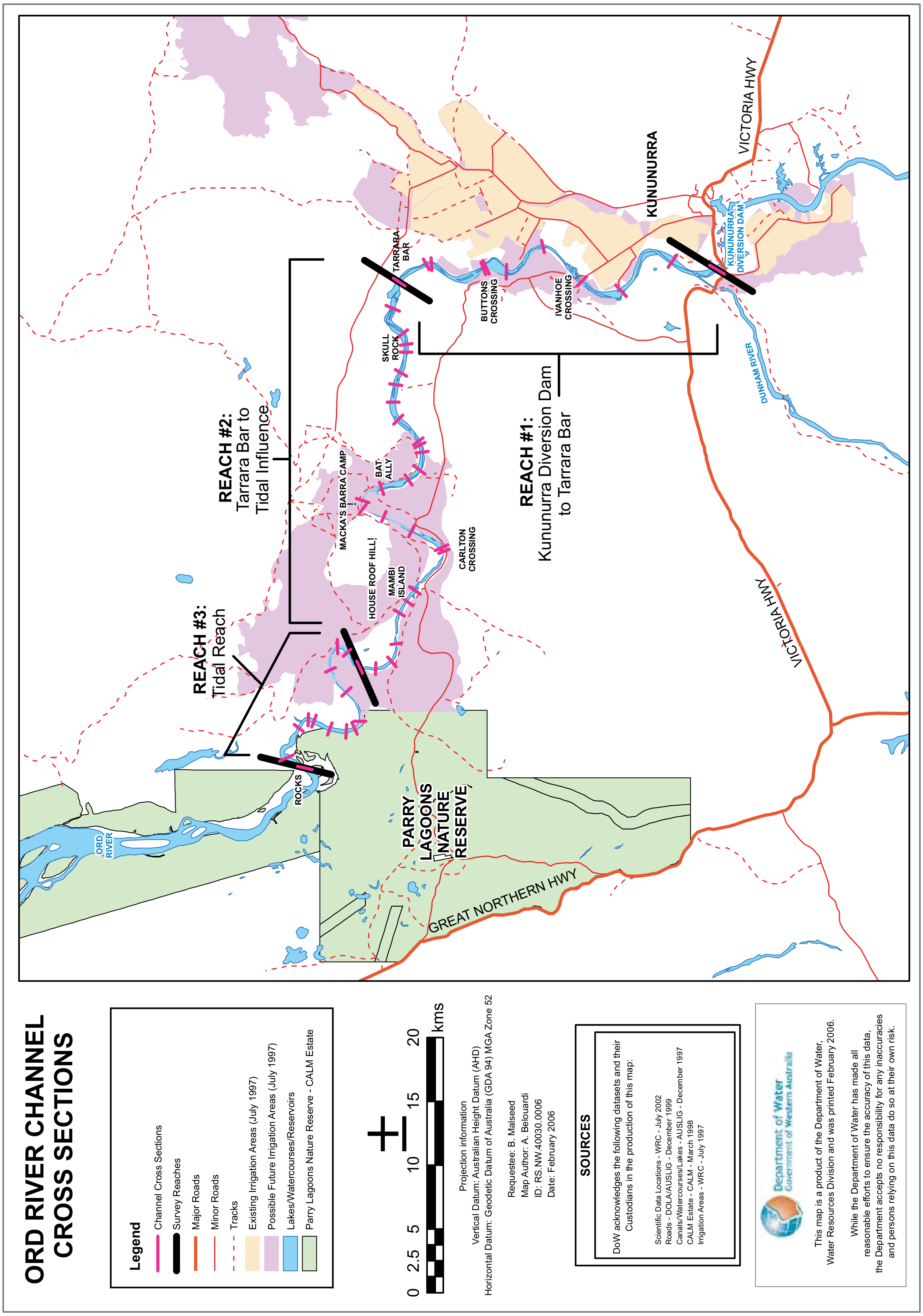

Figure 6: Lower Ord River cross section and study reach locations

3 Flow objectives and flow-ecology linkages

Information detailing and supporting the development of flow related issues and objectives for the lower Ord River has been published previously by the Department of Water in Trayler *et al*. (2006). For the purposes of this document the 22 specific flow ecology linkages that were developed in consultation with the expert panel have been presented in Table 2, grouped under the broad headings of fish, macroinvertebrates, ecosystem processes and connectivity, geomorphology, water quality and riparian vegetation. For each flow ecology linkage (or simply linkage) the relevant reach and flow considerations necessary for further analysis in the River Analysis Package are presented (Table 2).

The study did not aim to determine an EWR for the estuarine environment. For this reason there is a bias towards Reach 1 and 2 over Reach 3. As a tidally influenced reach, Reach 3 is subjected to different processes and contains different ecological communities. However, where communities and ecological objectives are similar, Reach 3 has been included in analyses.

Consistent with the aim of maintaining existing ecological values the maintenance of fish and macroinvertebrate community composition has been associated with habitat availability. It is acknowledged that local loss of species may not occur as a result of changes in habitat availability. However, the association between habitat availability and community composition is based on studies that have shown habitat preferences for fish and macroinvertebrate species and differences between the ecology of the lower Ord in comparison to neighbouring unregulated systems (Trayler *et al*., 2006). The development of flow-ecology linkages and subsequent analyses have used the best available information with the aim of maintaining the post regulation community composition and structure of the lower Ord at a low level of risk.

Table 2: Environmental objectives and flow considerations for the lower Ord River.

Objectives	No.	Flow-ecology linkage	Reach	Flow Considerations			
				Flow component	**Season /Timing**	**Hydraulic Factors / Constraints**	**Time series**
Fish							
Maintain the species richness and composition of fish communities	1a	Shallow backwater habitat inundated and available for small bodied fish and juveniles of large bodied fish	1,2	Low flows	Dry season	Area of channel with zero velocity and depth 20-85 cm (average 45 cm)	Event frequency (minimum magnitude)
	1b	Shallow macrophyte habitat inundated and available for small bodied fish and juveniles of large bodied fish	1,2	Low flows	Dry season	Area of channel with depth 0.45-2 m	Event frequency (minimum magnitude)
	1c	Deep pool habitat available for large bodied fish	1,2	Low flows	Dry season	Area of channel depth 3-4 m	Event frequency (minimum magnitude)
	1d	Deep backwater habitat inundated and available large bodied fish as habitat and possible spawning site	1,2	High flow	Wet season	Area of channel with velocity <20 cm/sec and depth <2 m	Event frequency (minimum magnitude)
	1e	Riparian bench flooded and available large bodied fish as habitat and possible spawning site	1,2,3	High flow	Wet season	Area of inundated channel with gradient <0.1 and depth <1 m	High flow spells
	1f	Passage over in-stream obstacles by migratory species	1,2,3	High flow	Wet season – extending through April	Depth over shallowest point 0.5-1 m	Low flow spells
	1g	Flow sufficient to oxygenate pools and avoid fish kills	1,2	Low flows	Dry season	Pool velocity > 0.08 $m.sec^{-1}$	Low flow spells
Macroinvertebrates							

Objectives	No.	Flow-ecology linkage	Reach	Flow Considerations			
				Flow component	Season /Timing	Hydraulic Factors / Constraints	Time series
Maintain the species richness and composition of macroinvertebrate communities	2a	Submerged macrophyte habitat inundated and available for a range of macroinvertebrate species	1,2	Low flows	Dry season	Area of channel with velocity <0.3 cm/sec and depth 45-90 cm	Event frequency (minimum magnitude)
	2b	Gravel runs and rapids inundated and available for a range of macroinvertebrate species	1,2	Low flows	Dry season	Area of channel with depth > 16 cm. NB minimum width to ensure lateral coverage also important.	Event frequency (minimum magnitude)
	2c	Emergent macrophytes inundated and available for a range of macroinvertebrate species	1,2	Low flows	Dry season	Area of channel with depth 0.3-2.5 m (average 1.3 m)	Event frequency (minimum magnitude)
	2d	Permanent flows so that pools do not become isolated	1,2,3	Low flows	Dry season	Pool velocity > 0.08 $m.sec^{-1}$	Low flow spells
Ecosystem processes and connectivity							
Maintain connectivity and in-stream algal production	3a	Permanent flows maintaining shallow areas for algal production	1,2,3	Low flows	Dry season	Area of inundated channel with depth <50 cm	Flow duration
	3b	Lower riparian bench (damp zone) inundated to maintain algal production	1,2	High flow	Wet season	Area of inundated channel with depth <50 cm	Flow duration
	3c	Wet season base flow	1,2,3	Low flows	Wet Season	Area of inundated channel	Flow Magnitude duration
Maintain riparian inputs to river	4a	Seasonal inundation of mid-bank	1,2,3	Freshers	Wet season	Flood higher terrace to 0.25 m for short duration (~2-3 days)	Flow Magnitude duration
Maintain connectivity with Parry Lagoon Floodplain	5a	Wetland inundation	2,3	Overbank flows	Wet season	Area of floodplain inundated	Event frequency (peak magnitude and duration)
Geomorphology							

Objectives	No.	Flow-ecology linkage	Reach	Flow Considerations			
				Flow component	Season /Timing	Hydraulic Factors / Constraints	Time series
Discourage excessive build up of fine sediments, organics and associated in-channel vegetation	6a	Flows to provide sufficient power to scour sediment and vegetation build-up	1,2,3	Active channel flows	~ 3-yearly	Stream power sufficient to mobilise finer sediments (< 500 µm diameter)	Magnitude, duration
Water Quality							
Prevent deoxygenation of pools	7a	Sufficient water exchange in pools to ensure dissolved oxygen levels do not reduce to anoxia	1,2	Low flows	Dry season	Pool velocity > 0.08 m.sec-1	Percent time exceeded
Riparian Vegetation							
Maintain diversity of the damp zone and aquatic vegetation by reducing terrestrialisation, weed invasion and simplification of the vegetation structure	8a	Seasonal inundation of lower riparian terrace	1,2,3	High flow	Wet season	Area of inundated channel with gradient <0.1 and depth <1 m	Flow duration, magnitude
	8b	Manage dominance of emergent species through the provision of flows with sufficient power to scour vegetation	1,2,3	Active channel flows	~ 3-yearly	Stream power sufficient to scour vegetation	Flow duration, magnitude
Retain dryer elements of ‘old’ riparian zone	8c	Encourage Eucalyptus and other dryland species to persist on the mid-banks behind the damp zone. Seasonal pulses of higher flows may encourage this	1,2,3	Freshers	Wet season (Feb-April)	Flood higher terrace to 0.25 m for short duration (~2-3 days)	Flow Magnitude duration
	8d	Irregular high magnitude flood flows, equivalent to those observed in the 2000 wet season.	1,2,3	Bankfull	Every 20 years	Stage height at least equivalent to the 2000 wet season flood	Magnitude, frequency

4 Flow requirements

4.1 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 values headings of fish, macroinvertebrates, ecosystem processes and connectivity, geomorphology, water quality and riparian vegetation with flow recommendations for applicable flow-ecology linkages summarised in a table. Detailed descriptions of the linkage, the approach to the analyses, analysis results and the resultant flow recommendation for each linkage are also presented.

4.1.1 Fish

Seven flow-ecology linkages were identified for fish in the lower Ord River. The flow requirements of each linkage have been summarised in Table 3. A detailed account of the process used to determine the flow requirements of each linkage is given below.

Table 3: Summary of flow requirements for fish.

Flow-ecology linkages	Season	Reach	Flow Requirements
1a). Shallow Backwater Habitat	Dry	1,2	• Minimum of 42 m^3/s in Reach 1 and 2
1b). Shallow Macrophyte Habitat	Dry	1,2	• Limited rate of change from one dry season to the next (effective when mean discharge for the previous Oct/Nov was above 70 m^3/s)
1c). Deep Pool Habitat	Dry	1,2	• Minimum of 37 m^3/s in Reach 1 and 2
1d). Deep Backwater Habitat	Wet	1,2	• Four spells above 125 m^3/s with a total duration of at least 10 days in Reach 1 • Two spells above 200 m^3/s with a total duration of at least five days in Reach 2
1e). Flooded Riparian Benches	Wet	1,2,3	• Four spells above 125 m^3/s with a total duration of at least 10 days in Reach 1 • Two spells above 200 m^3/s with a total duration of at least five days in Reach 2 • One spell above 300 m^3/s with a minimum duration of two days in Reach 3
1f). Fish Passage	Wet	1,2,3	• One spell above 425 m^3/s with a minimum duration of two days in Reach 1 [7] • Minimum of 20 m^3/s in Reach 2 • Minimum of 10 m^3/s in Reach 3
1g). Sufficient flow to oxygenate pools and avoid fish kills	Dry	1,2	• Trigger level of 35 m^3/s in Reach 1 and 2 (commence monitoring in selected pools if flows fall below 35 m^3/s)

7 See below for further discussion regarding fish passage over Ivanhoe Crossing. Modification of the crossing to facilitate fish passage at lower flows should be considered and would be a necessary part of any project to restore fish passage within the lower Ord River including Lake Kununurra.

1a). Shallow backwater habitat

The shallow backwater habitats have been shown to be important and preferred habitats in the lower Ord River for a diverse array of small bodied fish (both juveniles and adult) and for juveniles of large bodied fish (Storey, 2003). To maintain current fish populations it is important that the current area of shallow backwater be maintained in the dry season. Shallow backwaters are characterised as areas of negligible flow velocity, often associated with meanders and point bar formations, with a recorded depth range of between 20 and 85 cm (average 45 cm; Storey, 2003). Shallow backwaters need to be greater than 20 cm deep to provide functional fish habitat (WRM, 2002).

Applicable to:

Reach 1 and 2.

Approach:

Using aerial photographs, notes made during surveys and knowledge from surveyors and others, cross sections containing shallow backwater habitats were identified. Rating curves reporting the area of channel with a depth <0.85 (depth at which shallow backwaters become too deep) at modelled discharges and with a depth >20 cm (depth at which shallow backwaters start functioning) at modelled discharges were developed. Neither rating curve provided an indication of threshold discharges required to inundate backwaters within the specified depth range. It is likely that this is a result of the relatively small area of the channel these habitats represent in the surveyed cross sections, and the random position of cross-sections performed under high baseflows. That is, few backwaters appear on cross-sections, and where they do, the influence of shallow backwaters on area of habitat available is too small to be evident in rating curves.

As an alternative approach, a discharge stage height (water level) relationship was developed for cross sections of shallow backwaters surveyed by WRM (2002) during low flow trials. These trials indicated that as water levels declined, shallow backwaters dried, but were not replaced by backwaters at lower stage heights. Therefore, maintenance of existing backwaters was seen as critical. Backwaters surveyed in the low flow trials in combination with existing ‘whole river’ cross sections, which included backwaters, were examined on an individual basis (cross section by cross section) and discharges required for a range of stage heights/water depths within backwaters (20 cm to 80 cm) were recorded.

Results:

Reach 1 - KDD to Tarrara Bar (33 km below KDD)

Although backwaters are known to exist in Reach 1, none were surveyed in any of the existing ‘whole river’ cross sections and Reach 1 was not included in the low flow trials (WRM, 2002). This has meant that development of a flow recommendation to meet this linkage specifically for Reach 1 was not possible. It has therefore been assumed that requirements of Reach 1 will be met by those developed for Reach 2 (see below).

Reach 2 - Tarrara Bar to the start of the tidal influence (76 km below the KDD)

Four existing cross sections were identified as including shallow backwaters (42422, 47847, 55214, 68234) and these were examined in combination with specific backwater cross sections surveyed during the low flow trial (WRM, 2002).

Each backwater was examined individually and the discharge at 10 cm intervals for maximum depths of 20 cm to 80 cm calculated (Figure 7). A mean discharge for each depth was then calculated (Table 4).

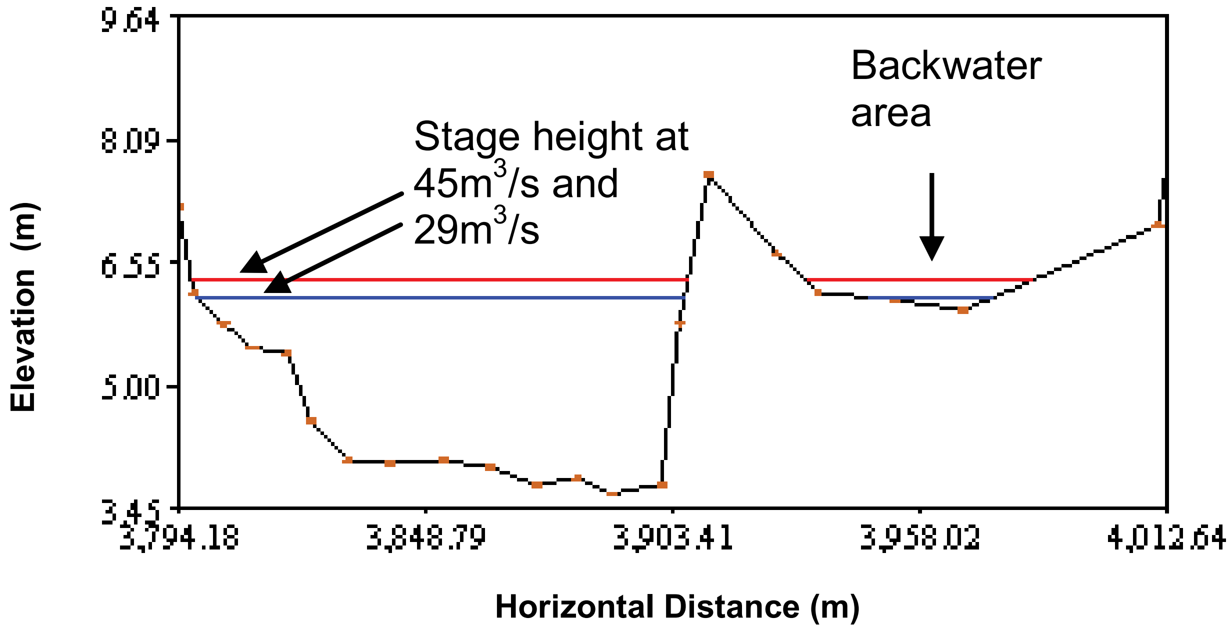

Figure 7: Shallow backwater in cross section 47,847 at 29 m^3/s (20 cm max depth) and 45 m^3/s (40 cm max depth)

Table 4: Discharge stage height relationship for shallow backwaters.

Maximum depth (cm)	Mean discharge required (m^3/s)	Percentage of functional habitat available (proportion of cross sectional area available)
20	23	0
30	29	16
40	37	37
50	43	53
60	52	76
70	61	100
80	70	NA

Analysis of the recorded time series indicated that the annual dry season minimum discharge was less than 61 m^3/s in 90 per cent of years (Figure 8). With input from the expert panel it was decided that 61 m^3/s (70 cm maximum depth) would provide the upper limit of achievable dry season functional backwater habitat (ie 100% available) as minimum flows have rarely been greater than this. The relative availability of habitat at different discharges was then calculated as a proportion of that available at 61 m^3/s (Table 4).

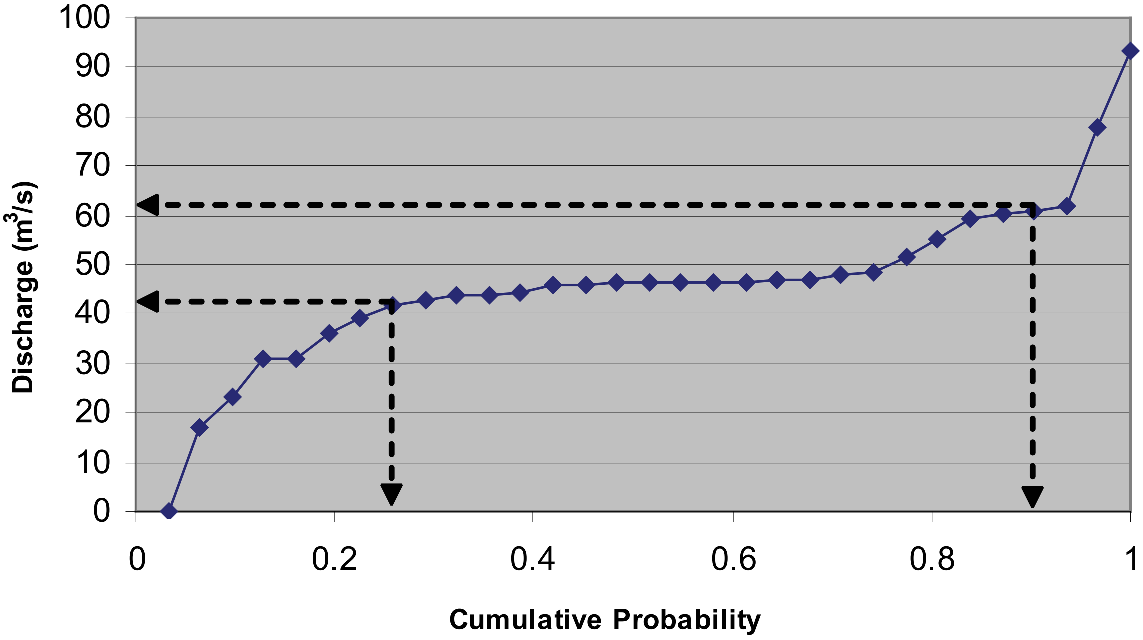

Figure 8: Annual dry season minimum flows

Discussion

Examination of discharge depth relationship for the cross sections, indicates that shallow backwater habitat will be available when minimum dry season discharge is maintained between 23 m^3/s and 61 m^3/s. After discussion with the expert panel, it was determined that to maintain this habitat at a low level of risk the minimum dry season discharge should be set at 42 m^3/s. This provides a mean maximum depth of 50 cm and around 50 per cent of the of the potential functional shallow backwater habitat. Historically, minimum dry season flows have remained greater than 42 m^3/s in 75 per cent of years (Figure 8).

In the absence of specific data on shallow backwaters for Reach 1, it has been assumed that the requirement for flows greater than 42 m^3/s for Reach 2 will meet requirements for Reach 1.

While the expert panel were of the opinion that the importance of shallow backwaters would be elevated in years following very high flow wet seasons in which submerged macrophyte beds were lost (AW Storey pers. obs), this has not been incorporated into the flow recommendation for this flow-ecology linkage. The position of shallow backwaters in the channel are probably influenced by hydrology, and it is possible that backwaters will reform at a lower stage height than present under a modified flow regime. However, since this is not known conclusively, it is assumed that the current position is critical.

Recommendations:

- Minimum dry season flows should not be permitted to fall below 42 m^3/s in Reaches 1 and 2.

1b). Shallow macrophyte habitat

Submerged macrophyte habitat has been shown to be important and preferred habitat in the lower Ord River for a diverse array of small bodied fish (both juveniles and adult) and for juveniles of large bodied fish (Storey, 2003). To maintain fish populations it is important that the current area of submerged macrophyte be maintained in the dry season. In the dry season, submerged macrophyte beds typically have been recorded in water 90 cm deep (minimum 47 cm) and low flow velocities (average three cm.sec-1; Storey, 2003). However, submerged macrophytes can occur in much deeper water (~2m Storey, pers comm.) depending on light availability, substrata composition, and time since last scouring flood.

Applicable to:

Reach 1 and 2.

Approach:

The critical factor in maintaining the current area of submerged macrophyte was considered to be the rate of change in dry season water levels from one year to the next. Macrophyte beds tend to establish from the water edge into the channel, up to several metres depth of water. If there was a marked decline in water levels from the late dry season of one year (ie upper edge of beds), to the dry season of the following year, macrophyte beds would become exposed, reducing the amount of shallow macrophyte habitat available to fish in the lower Ord River.

A rating curve of average thalweg depth with discharge was developed for each reach and used to transform the time series to provide a time series of average thalweg depth. The transformed time series was then used to determine the range of historical change by comparing the mean thalweg depth of the late dry season (October/November) to the minimum thalweg depth (using the 95th percentile flows to exclude shutdowns where flows periodically drop lower) of the following dry season (May-September). A cumulative probability was then developed for each time series and a threshold (acceptable change in thalweg depth) chosen.

Results:

Reach 1 - KDD to Tarrara Bar (33 km below KDD)

From the cumulative probability plot of recorded change in discharge since regulation, 80 per cent of years had a reduction of no more than 26 cm from the late dry season of one year to the dry season of the successive year (Figure 9). Using 26 cm as the threshold for allowable change, the following discharge relationship was developed (Figure 10; Table 5).

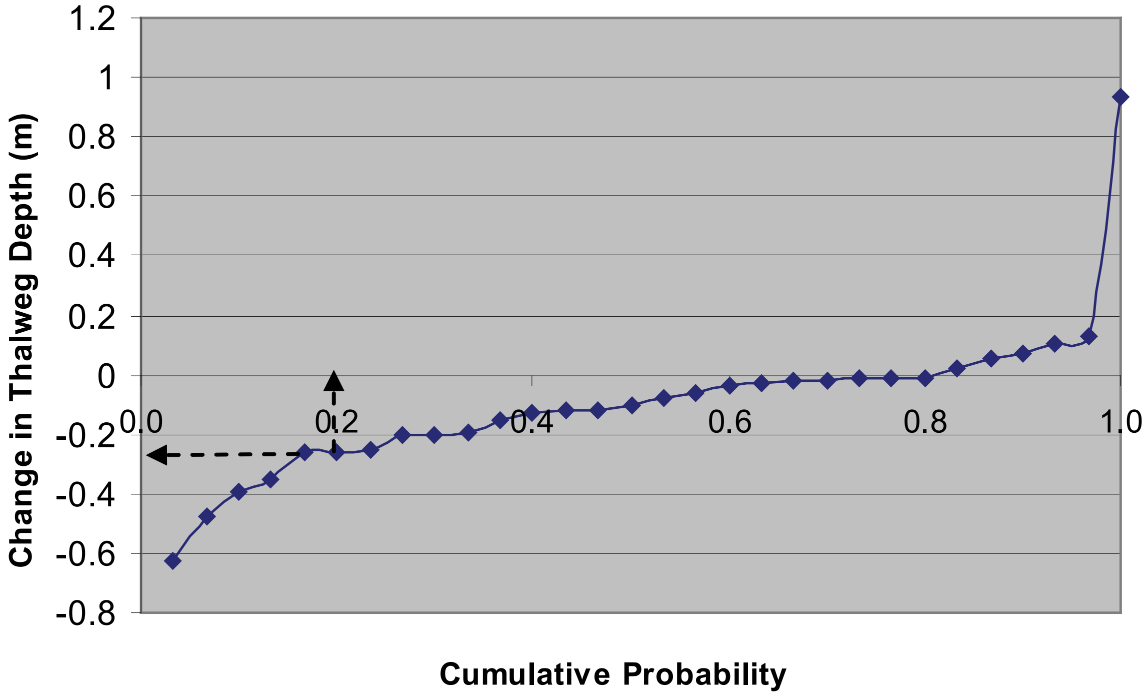

Figure 9: Annual difference between late dry season mean thalweg depth and minimum thalweg depth of the following dry season

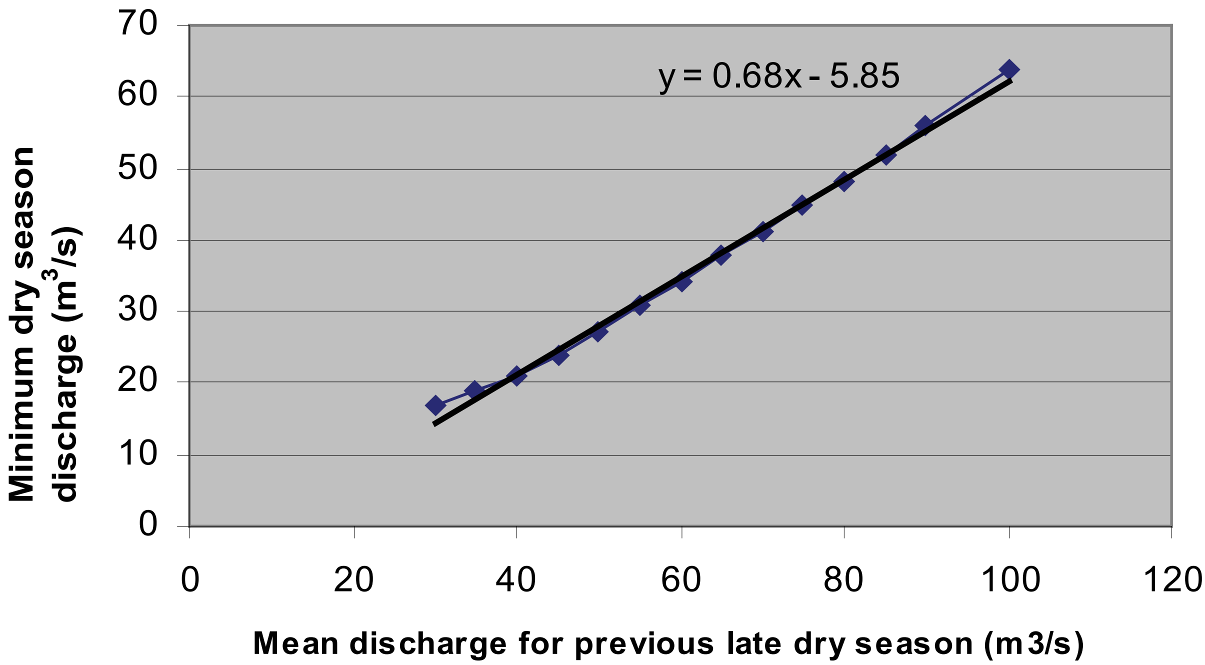

Figure 10: Maximum reduction in discharge from one year to the next

Table 5: Reach 1 Dry Season Discharge Rules.

Mean discharge (m^3/s) for late dry season (Oct-Nov)	Minimum allowable discharge (m^3/s) for following dry season (June-November)
30	17
35	19
40	21
45	24
50	27
55	31
60	34
65	38
70	41
75	45
80	48
85	52
90	56
100	64

This relationship can be represented by the following equation:

$D = 0.68PLD - 5.85$

Where:
D = Minimum Dry Season Discharge (m^3/s)
PLD = Mean discharge (m^3/s) for **P**revious **L**ate **D**ry season (Oct-Nov)

Reach 2 - Tarrara Bar to the start of the tidal influence (76 km below the KDD)

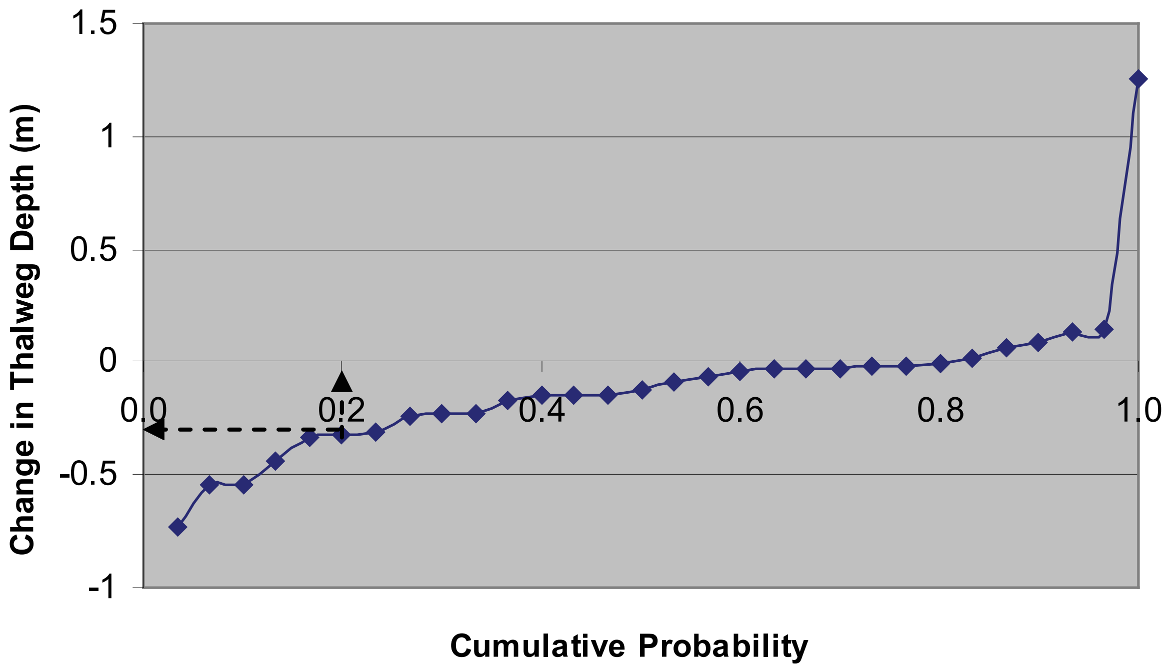

Figure 11: Annual difference between late dry season mean thalweg depth and minimum thalweg depth of the following dry season

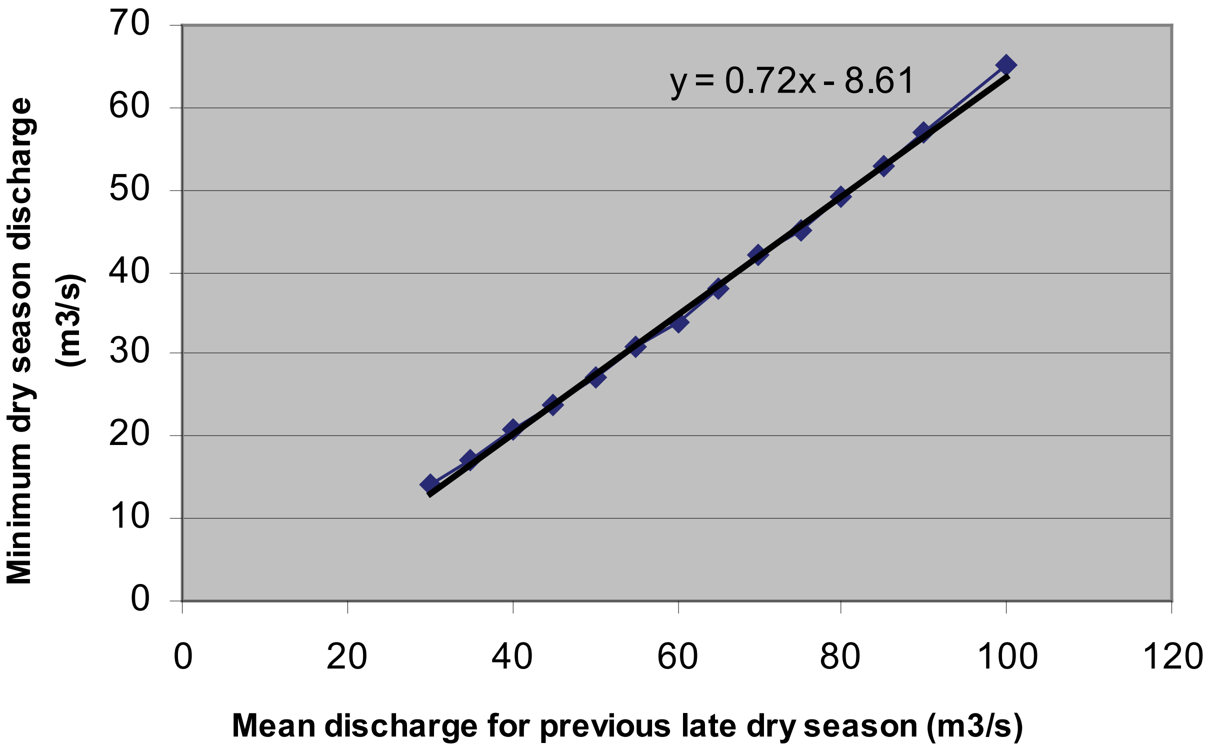

Figure 12: Maximum reduction in discharge from one year to the next

From the cumulative probability plot of recorded discharge since regulation, 80 per cent of years had a reduction of no more than 32 cm from the late dry season of one year to the dry season of the successive year (Figure 11). Using 32 cm as the threshold for allowable change, the following discharge relationship was developed (Figure 12; Table 6).

Table 6: Reach 2 Dry Season Discharge Rules.

Mean discharge (m^3/s) for late dry season (Oct-Nov)	Minimum allowable discharge (m^3/s) for following dry season (June-November)
30	14
35	17
40	21
45	24
50	27
55	31
60	34
65	38
70	42
75	45
80	49
85	53
90	57
100	65

Again this can be represented by the following equation:

$D = 0.72PLD - 8.61$

Where:
D = Minimum Dry Season Discharge (m^3/s)
PLD = Mean discharge (m^3/s) for **P**revious **L**ate **D**ry season (Oct-Nov)

Recommendation:

- Minimum flows for subsequent dry season to be determined by calculating mean discharge for late dry season (Oct/Nov) and using the relationships provided. For example, if the average late dry season flows are 75 m^3/s, flows for the following dry season should not drop below 45 m^3/s for both Reach 1 and 2.

1c). Deep pool habitat

During the dry season, larger bodied fish tended to be found in deep pools (3-4 m). During the wet season when alternative habitats such as flooded riparian vegetation and deep backwaters became available, they supported a lower biomass and fewer species than in the late dry (Storey, 2003). Deep pools must be maintained as refuge for large bodied fish during low flow periods.

Applicable to:

Reach 1 and 2.

Approach:

A rating curve was developed for a minimum thalweg depth of three metres (taken as the minimum depth of 'deep' pools). This was then used to transform the recorded flows time series to determine the area of deep pools available in the lower Ord River since regulation (ie developing a time series of deep pool habitat availability). The minimum (95th percentile to exclude shutdowns) amount of deep pool area (habitat) provided in 80 per cent of years was taken as the threshold. The habitat available was then converted to a discharge using the rating curve relationship.

Results:

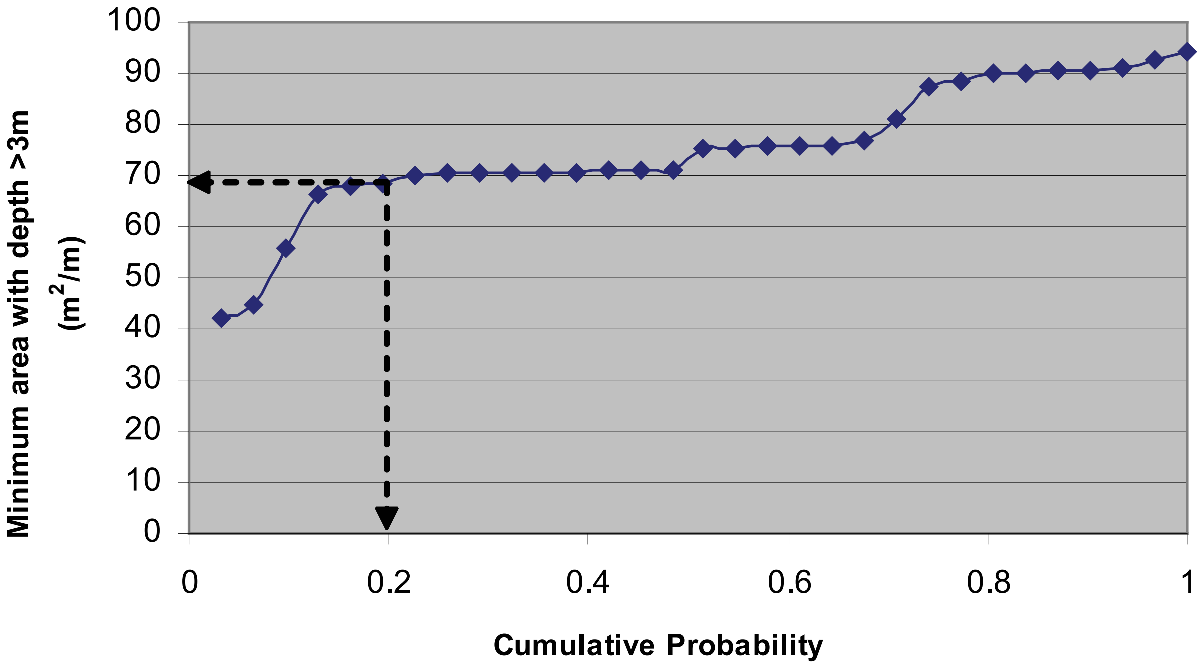

Figure 13: Annual minimum area of deep pool habitat (>3m)

Reach 1 - KDD to Tarrara Bar (33 km below KDD)

From the cumulative probability plot of annual minimum area of deep pools since regulation, 80 per cent of years had a minimum area of deep pool habitat equal to or greater than 68 m^2/m (Figure 13). Using the rating curve this can be converted to a discharge of 37 m^3/s (Figure 14).

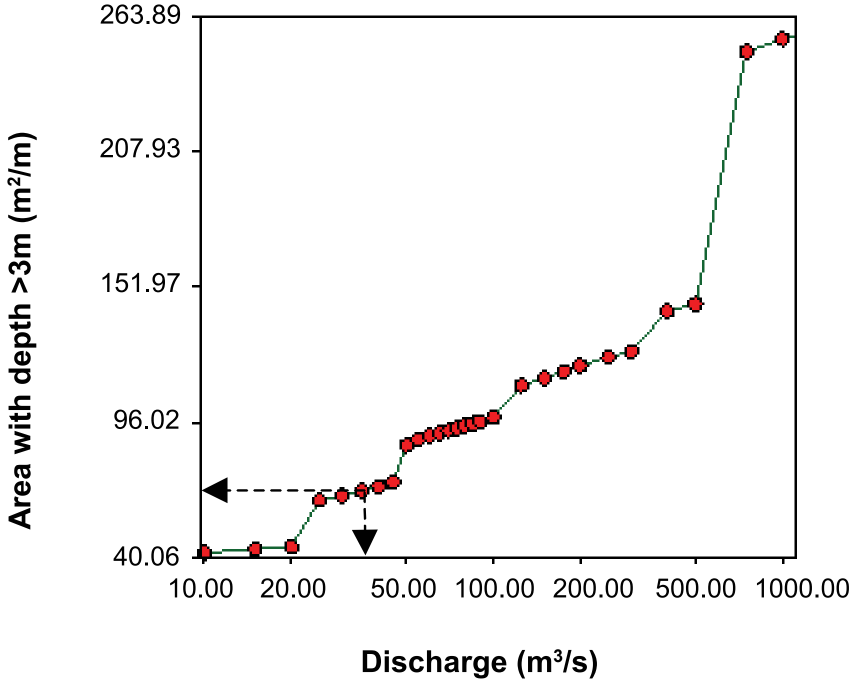

Figure 14: Deep pool habitat Reach 1

Reach 2 - Tarrara Bar to the start of the tidal influence (76 km below the KDD)

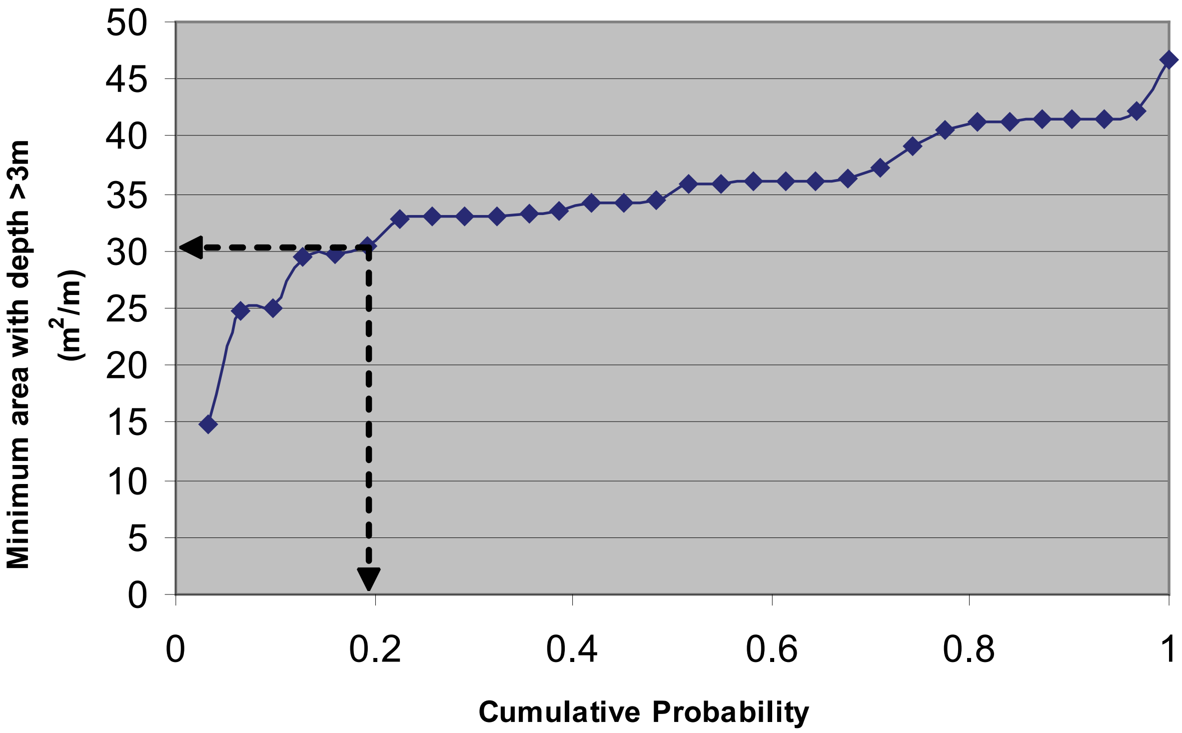

Figure 15: Annual minimum area of deep pool habitat (>3m)

From the cumulative probability plot of annual minimum area of deep pools since regulation, 80 per cent of years had a minimum area of 30 m^2/m or greater (Figure 15). Using the rating curve this also converts to a discharge of 37 m^3/s (Figure 16).

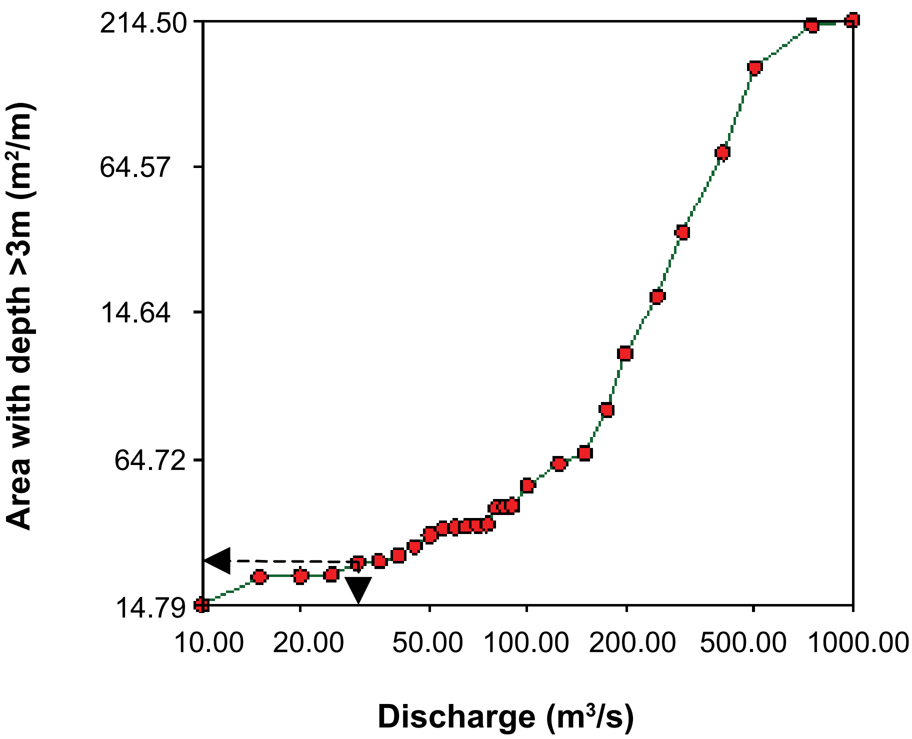

Figure 16: Annual minimum area of deep pool habitat (>3m)

Recommendation:

- Minimum dry season flows for Reach 1 and 2 should not be permitted to fall below 37 m^3/s.

1d). Deep backwater habitat

During the wet season larger bodied fish showed a strong preference towards deep backwaters (average two metres), which do not exist in the dry season. This is presumably a flow avoidance strategy with pools having flows at least four to eight times faster than the flooded riparian vegetation and backwaters respectively (Storey, 2003). Flooding of deep backwaters (to ~2m) in the wet season will help to maintain these areas for large bodied fish habitat and as possible spawning sites. The frequency and duration of flooding will need to be evaluated.

Applicable to:

Reach 1 and 2.

Approach:

None of the existing cross sections included backwaters in Reach 1. Therefore, an alternative approach was used that assumed that deep backwaters would become available when riparian benches were inundated to a depth greater than one metre. This assumption was based on field observations and confirmed by examining water level discharge relationships in the River Analysis Package. A high spells analysis was conducted to examine the frequency and duration of events greater than the minimum threshold value.

For Reach 2, the water level discharge relationships were examined for individual cross sections identified as containing backwaters. The mean discharge required to achieve a maximum backwater depth of two metres was calculated.

Results:

Reach 1 – KDD to Tarrara Bar (33 km below KDD)

Although backwaters are known to exist in Reach 1, none were surveyed in any of the cross sections. It was assumed, therefore, that deep backwaters would form at a similar stage height to the inundation of riparian benches (as is the case in Reach 2).

In Reach 1, riparian benches were inundated at 125 m^3/s (see flow-ecology linkage 1e) and it is therefore assumed that 125 m^3/s will also be sufficient to flood deep backwaters.

Analysis of the recorded time series indicated:

- There are four or more high spells exceeding 125 m^3/s in 80 per cent of years (median seven and maximum 19).
- High spells exceeding 125 m^3/s have ranged from one to 252 days with a mean duration of 11 days and median two days.
- The annual total duration above 125 m^3/s in 80 per cent of years is 10 days or more (median 51 days and mean 81).

If the Dunham River flows were excluded the frequency of spells greater than 125 m^3/s would be greatly reduced (Figure 17). The median number of spells per year would be reduced from seven to four and the median annual total duration reduced from 51 to 20 days.

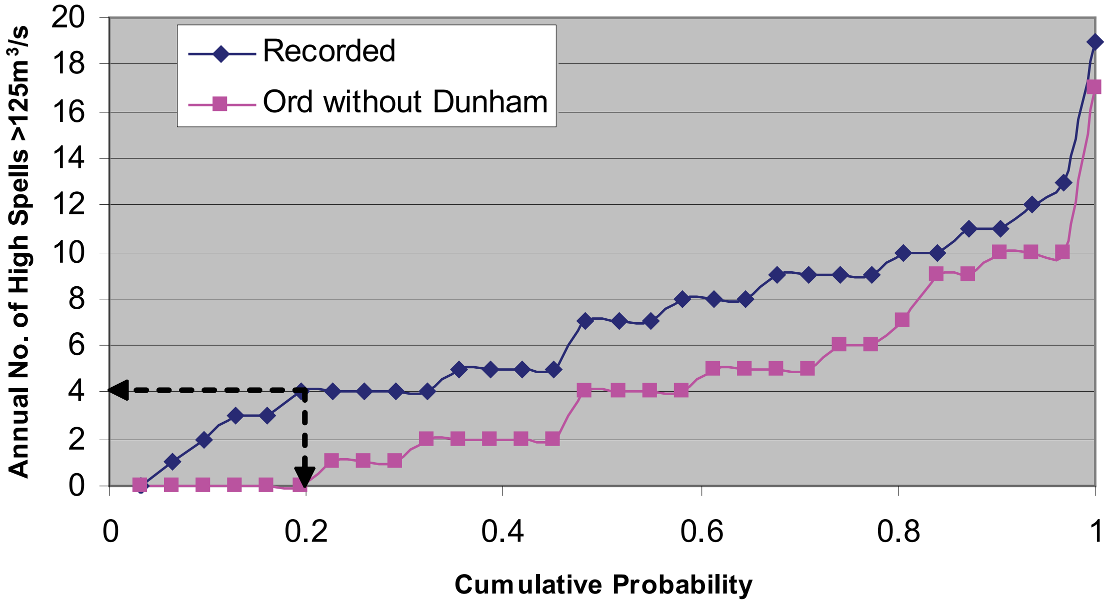

Figure 17: Annual occurrence of spells >125 m³/s with and without Dunham River flows

Reach 2 – Tarrara Bar to the start of the tidal influence (76 km below the KDD)

Backwaters were identified in the following cross sections:

42422, 47847, 48511, 51364, 55214 and 68234.

While backwaters were evident in the cross sections, it was not possible to develop a rule that would identify deep backwaters in a rating curve.

Therefore, each of the backwater cross sections were looked at individually. A discharge of 200 m³/s was identified as the average discharge where a maximum backwater depth of two metres was achieved (Figure 18). This is consistent with the flooding of riparian benches, which is known to occur at a similar discharge (see 1e).

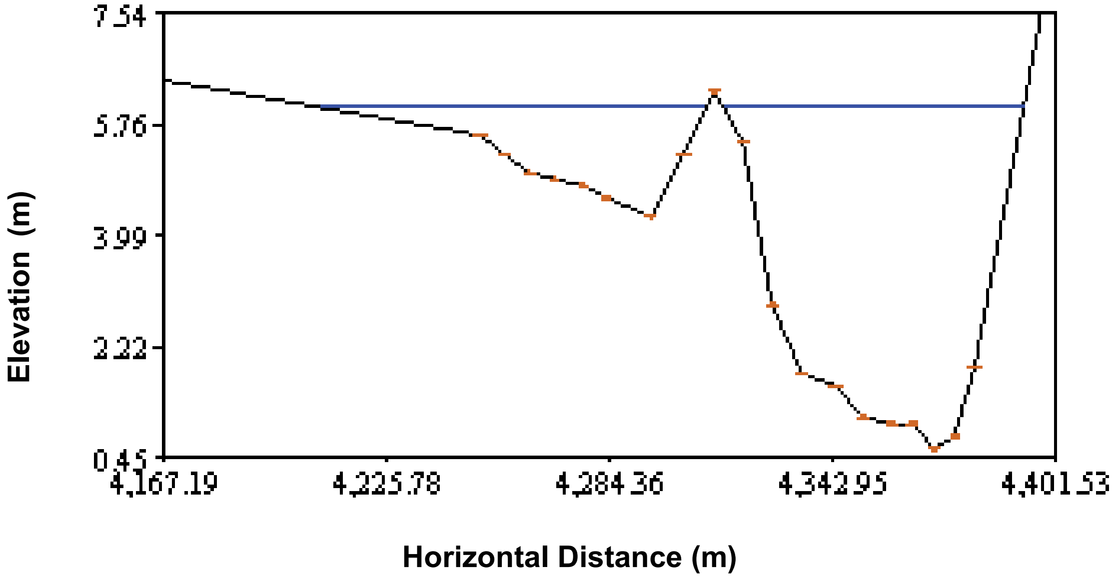

Figure 18:Deep backwater in cross section 55214 at 200 m³/s

Analysis of the recorded time series indicated:

- There are at least two high spells exceeding 200 m³/s in 80 per cent of years (median five and maximum 12).
- High spells exceeding 200 m³/s have ranged from one to 204 days with a mean duration of eight days and median two days.
- The annual total duration above 200 m³/s in 80 per cent of years is five days or more (median 17 days and mean 46).

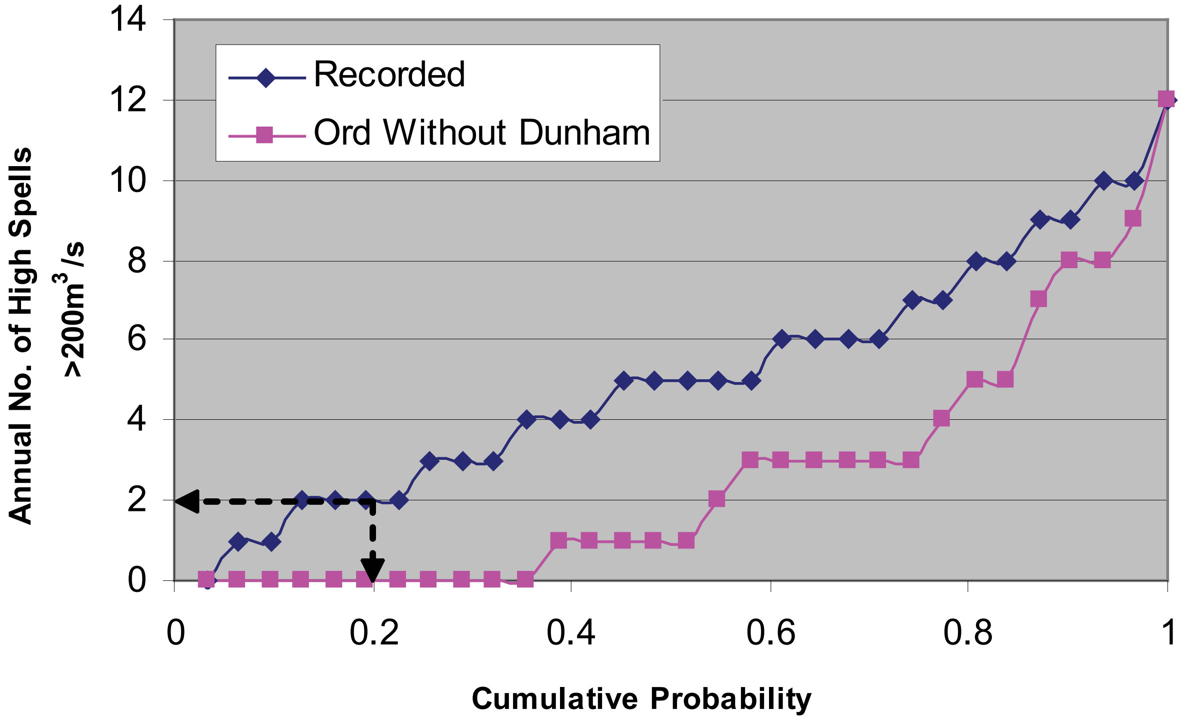

Figure 19: Probability of spells >200 m³/s with and without Dunham River flows

If the Dunham River flows were excluded the frequency of spells greater than 200 m^3/s would be greatly reduced (Figure 19), again demonstrating the importance of Dunham River flows. The median number of spells per year would be reduced from five to one and the median annual total duration reduced from 17 to four days.

Discussion:

Literature suggests that at least one spell of 14 days or more may allow sufficient time for egg development for up to 12 species of fish that could potentially spawn in deep backwater habitat (Pusey *et al*., 2004; Bishop *et al*., 2001; Storey pers. comm, 2006). However, the time series shows that this has only occurred occasionally (in 35% and 61% of years for 200 and 125 m^3/s respectively) and on occasions has not occurred for extended periods (13 years for 200 m^3/s from 1985-97 and six years for 125 m^3/s from 1988-93). Without information on changes in fish populations in response to these events, or lack of events, it is difficult to draw definite conclusions on the implications to fish populations. However, it seems reasonable to assume that in intervening years these fish species must also be spawning in alternative habitats and therefore the recommendation provided below is considered adequate.

It is acknowledged that, for spells greater than 200 m^3/s in particular, management of high spells is difficult and that the majority of flow in high spell events is provided by the Dunham River. Further regulation of the Dunham River could reduce the frequency of high flow events and mean that flow-ecology linkages including 1d are not met.

Recommendation:

- Wet season flows must provide four or more spells over 125 m^3/s in Reach 1 and two or more spells over 200 m^3/s in Reach 2. Total annual durations of at least 10 days and five days for 125 m^3/s and 200 m^3/s spells respectively should be maintained.
- No further regulation of the Dunham River should be permitted.

1e). Flooded riparian benches

During the wet season larger bodied fish showed a strong preference towards flooded riparian vegetation (average 1m depth)(Storey, 2003). This habitat does not exist in the dry season. This is presumably a flow avoidance strategy with pools having flows at least four to eight times faster than the flooded riparian vegetation and backwaters respectively (Storey, 2003). The flooded riparian vegetation likely offers foraging habitat for a range of species, and also offers possible spawning areas for adults and nursery sites for juveniles. Flooding of riparian vegetation (to ~1m) in the wet season will help to maintain these areas for large bodied fish habitat and as possible spawning sites. The frequency and duration of flooding of riparian benches must be evaluated.

Applicable to:

All reaches.

Approach:

A rating curve of the relationship between channel surface width with discharge was developed for local depth >1m. Cross sections known to have riparian benches were targeted and a change in slope indicating the minimum threshold discharge required to inundate benches to a depth of one metre were identified. The threshold values were confirmed by examining the stage height/discharge relationship for individual cross sections in the River Analysis Package. The recorded flow time series was then analysed using a high spells analysis to determine the frequency and duration of events over the threshold discharge. A cumulative probability distribution was developed for the number of events in exceedence of the threshold value.

Results:

Reach 1 - KDD to Tarrara Bar (33 km below KDD)

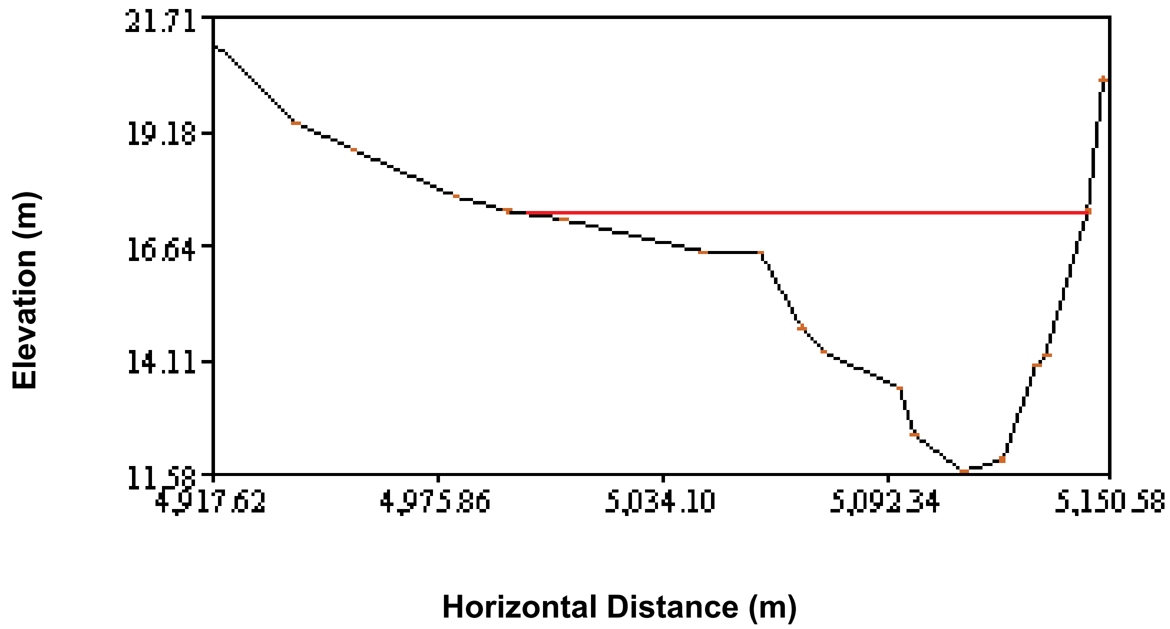

Figure 20: Inundation of riparian bench in cross section 19166 at 125 m³/s

In Reach 1 the only cross section with a riparian bench was 19166 (Figure 20). A discharge of 125 m³/s is required to inundate riparian benches to a depth of one metre (Figure 21).

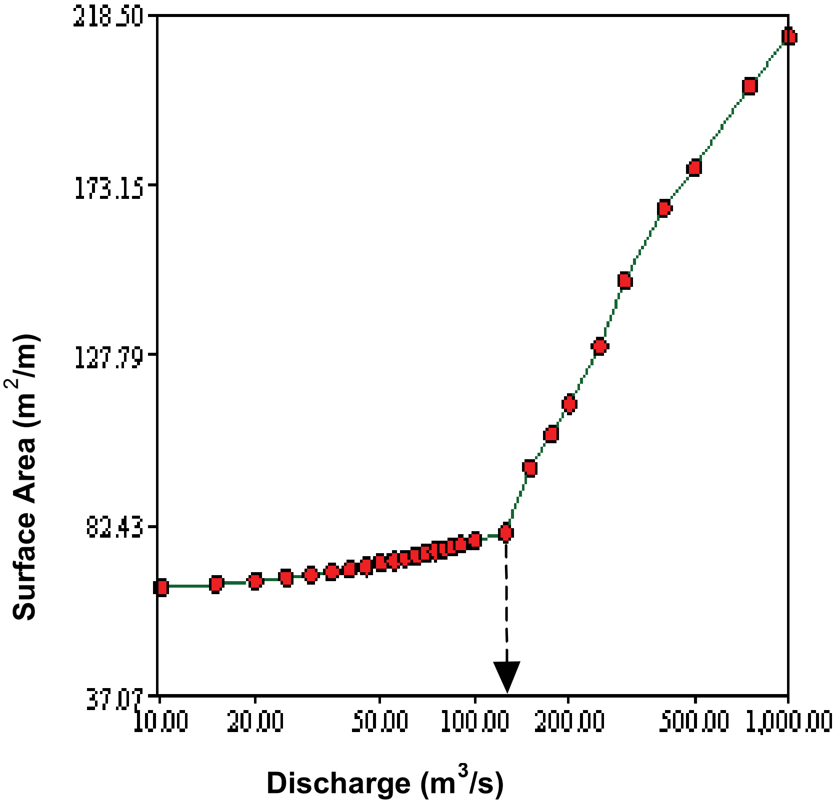

Figure 21: Relationship between area of channel with depth >1m and discharge

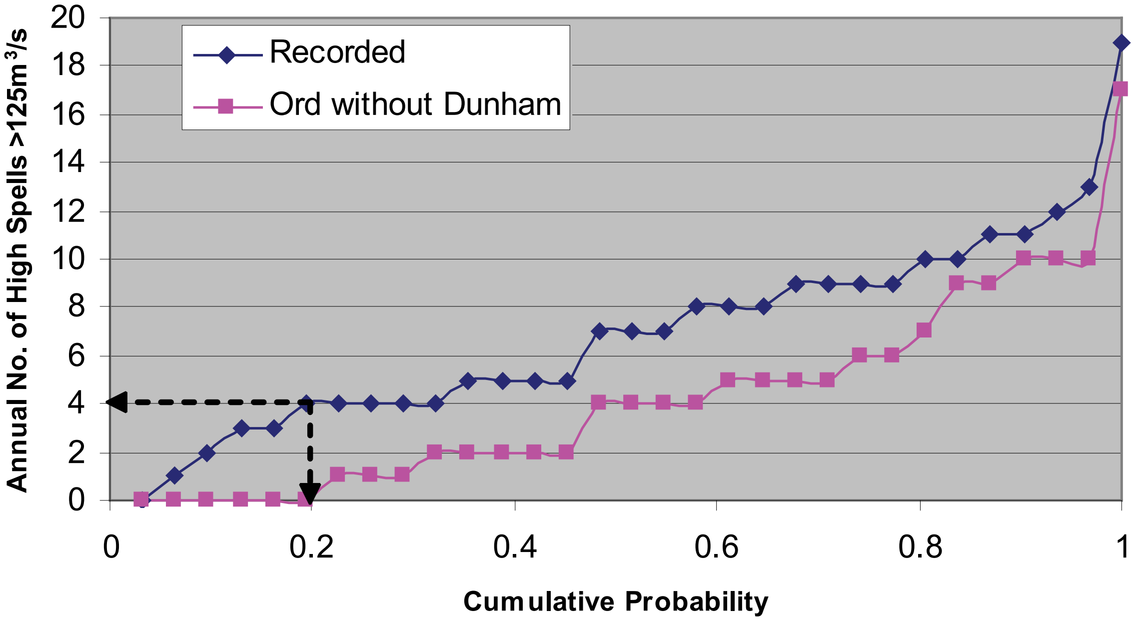

Figure 22: Annual riparian bench inundation

Analysis of the recorded time series indicated:

- There are four or more high spells exceeding 125 m^3/s in 80 per cent of years (Figure 22) (median seven and maximum 19).
- High spells exceeding 125 m^3/s have ranged from one to 252 days with a mean duration of 11 days and median two days.
- The annual total duration above 125 m^3/s in 80 per cent of years is 10 days or more (median 51 days and mean 81).

Reach 2 - Tarrara Bar to the start of the tidal influence (76 km below the KDD)

Riparian benches were identified in the following cross sections:
35514, 38123, 41452, 41992, 43788, 50077, 55214, 69282, 71487, 73153, 75948

From these cross sections a threshold of 200 m^3/s was identified before riparian benches are inundated to a depth of one metre (Figure 23).

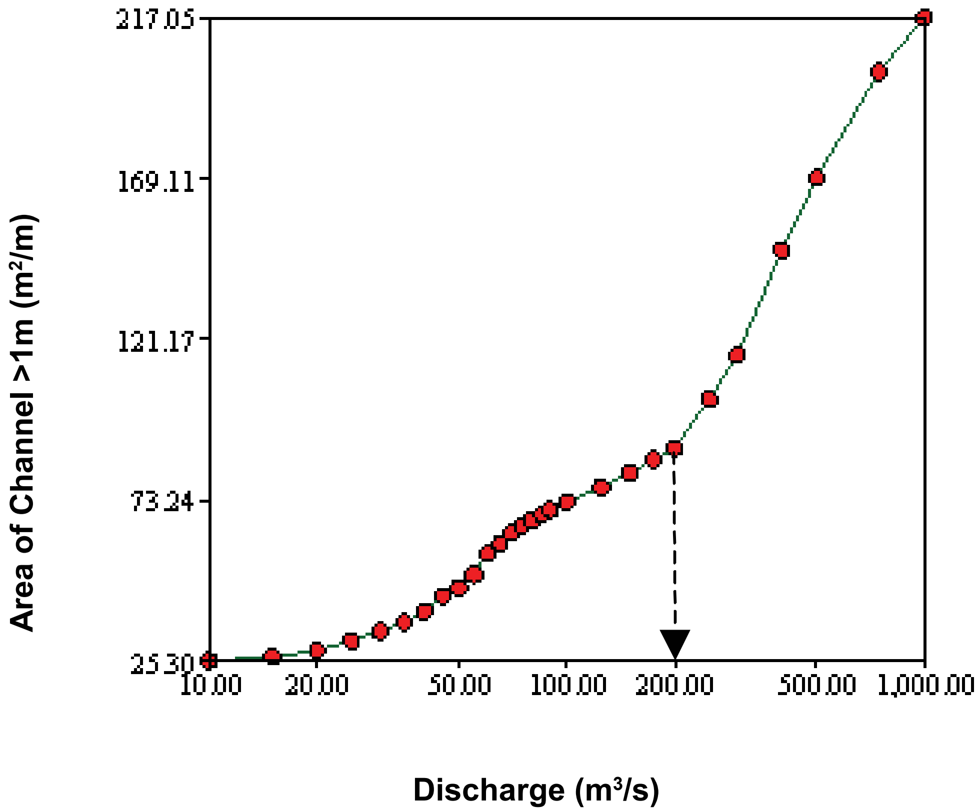

Figure 23:Reach 2 area of channel>1m

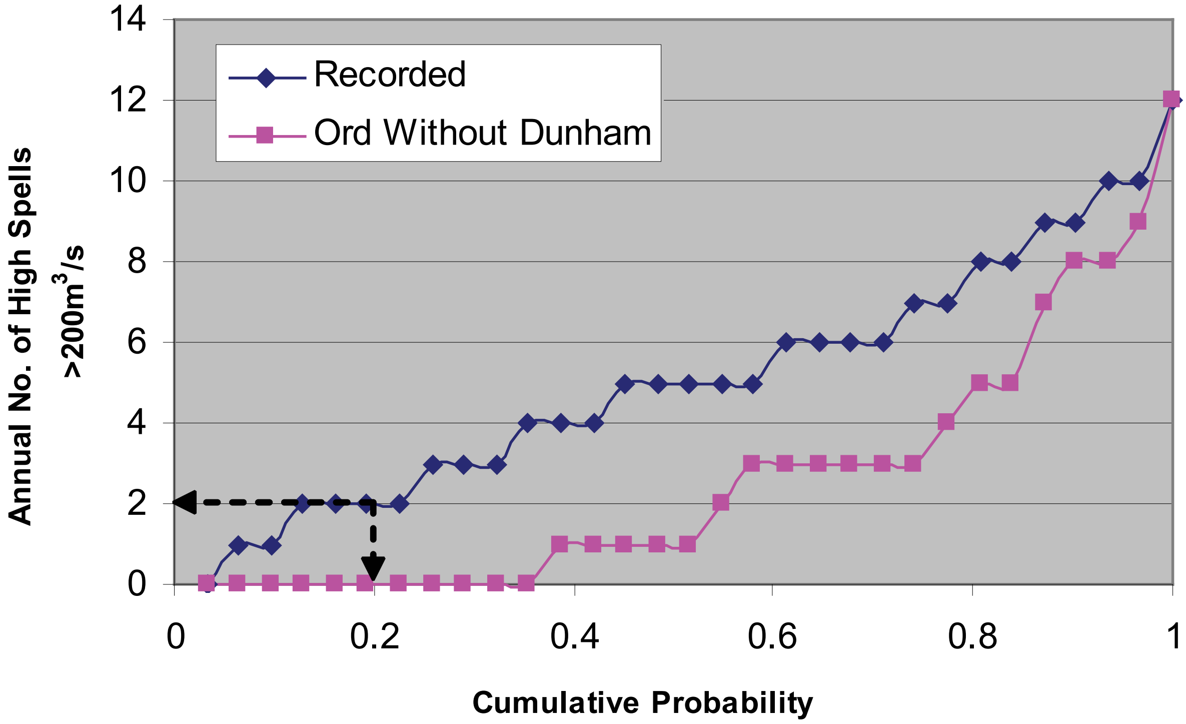

Figure 24: Annual riparian bench inundation

Analysis of the recorded time series indicated:

- There are at least 2 high spells exceeding 200 m^3/s in 80 per cent of years (Figure 24)(median five and max 12).
- High spells exceeding 200 m^3/s have ranged from one to 204 days with a mean duration of eight days and median two days.
- The annual total duration above 200 m^3/s in 80 per cent of years is five days or more (median 17 days and mean 46).

Reach 3 - the tidal-influenced reach (below 76 km)

Riparian benches were identified in the following cross sections:
75948, 77606, 82138, 85806, 86565, 89284.

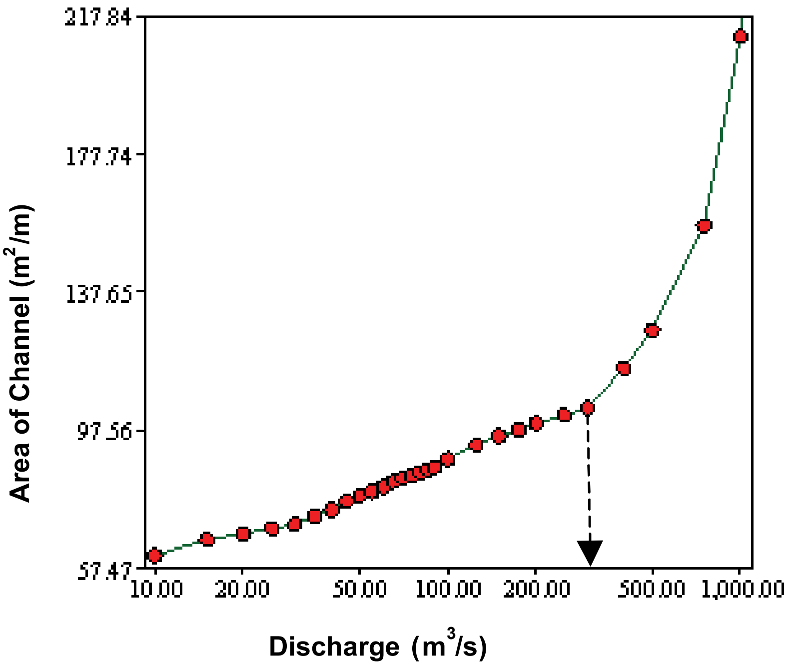

Figure 25: Area of channel >1m

From these cross sections a threshold of 300 m³/s was identified before riparian benches are inundated to a depth of one metre (Figure 25). It is acknowledged that the flow / water level relationship in the tidal dominant reach is affected by the tide. The average level over a spring/neap tidal sequence has been adopted. Lower flows will inundate the riparian benches at high tides.

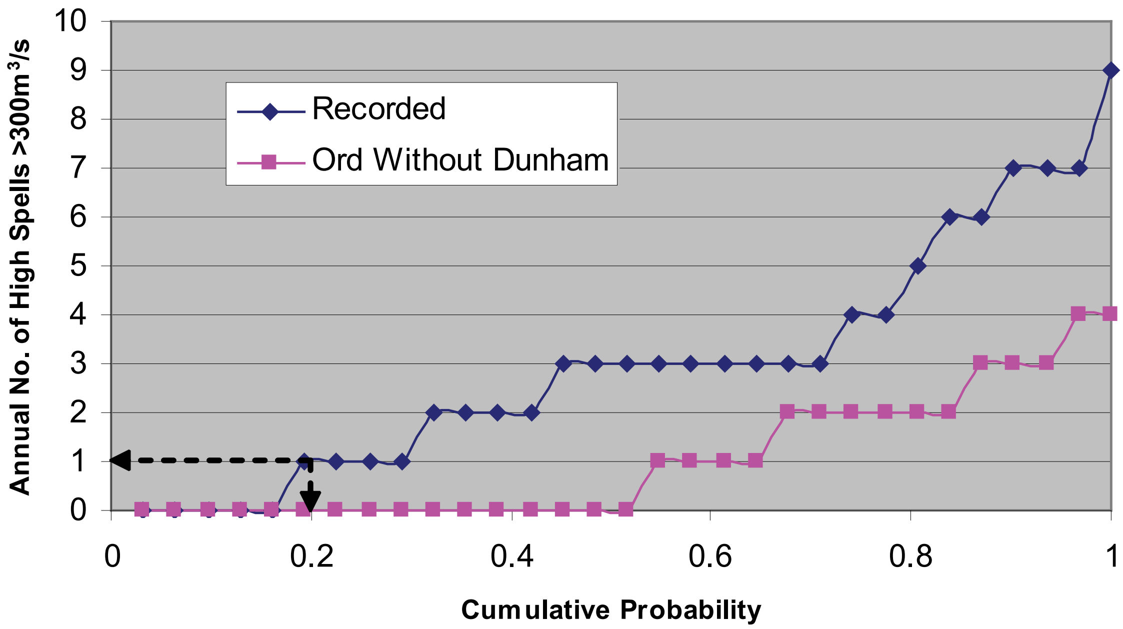

Figure 26: Annual riparian bench inundation

Analysis of the recorded time series indicated:

- There is at least one high spell exceeding 300 m^3/s in 80 per cent of years (Figure 26) (mean and median three).
- High spells exceeding 300 m^3/s have ranged from one to 165 days with a mean duration of nine days and median of two.
- The annual total duration above 300 m^3/s in 80 per cent of years is 2 days or more (median nine days and mean 33).

Discussion:

Literature suggests that at least one spell of 14 days or more may allow sufficient time for egg development for up to 12 species of fish, which could potentially spawn on flooded riparian benches (Pusey *et al*., 2004; Bishop *et al*., 2001; Storey pers. comm., 2006). However, the time series shows that this has only occurred occasionally (in 35% and 61% of years for 200 and 125 m^3/s respectively) and at times has not occurred for extended periods (13 years for 200 m^3/s from 1985-97 and six years for 125 m^3/s from 1988-93). Without information on changes in fish populations in response to these events or lack of events, it is difficult to draw definite conclusions on the implications to fish populations. However, it seems reasonable to assume that in intervening years, these fish species must also be spawning in alternative habitats and the flow recommendation provided below is considered adequate to protect fish populations.

If the Dunham River flows were excluded, the frequency of spells required for each reach (ie frequency of spells > 125 m^3/s, 200 m^3/s and 300 m^3/s respectively) would be greatly reduced (Figure 21, 23 and 25). For Reach 1 the median number of spells per year would be reduced from seven to four and the median annual total duration reduced from 51 to 20 days; for Reach 2 reduced from five to one and the median annual total duration from 17 to four days; and for Reach 3 from three to zero and the median annual total duration from nine to zero days.

It is acknowledged that management of high spells is difficult and that much of the flow in high spell events is provided by the Dunham River. Further regulation of the Dunham River could reduce the frequency of high flow events and mean that flow-ecology linkages (including 1e) are not met.

Recommendation:

- Wet season flows should be sufficient to provide four or more spells over 125 m^3/s, two or more spells over 200 m^3/s and at least one over 300 m^3/s. Total annual durations of at least 10, five and one day(s) for 125 m^3/s, 200 m^3/s and 300 m^3/s spells respectively should be maintained.
- No further regulation of the Dunham River should be permitted.

1f). Fish passage

It is recognised that barriers such as the Kununurra Diversion and Ord River Dams will remain impassable for upstream movement of fishes unless some form of fish ladder is installed (currently under consideration; Berghuis & Storey, 2006). However, there are also an array of smaller, manmade or modified (eg Ivanhoe Crossing) and naturally occurring obstacles and shallow areas in the system (including Carlton Crossing, Bat Alley, Sandy Beach, Mambi Island and rapids above and below Buttons and Ivanhoe Crossings). If these were to become impassable, then there may be some loss of migratory species in parts of the system. The critical period for fish movement is during the wet season with a second peak in the late wet (around April) for returning species (upstream migration). A depth of around 0.6m over these obstacles during those times is considered ample to ensure passage for the recreationally important barramundi (Lates calcarifer), with this depth also allowing passage of a range of other migratory species. Frequency and duration of flow events to provide adequate depth over potential obstacles must be evaluated.

Applicable to:

All reaches.

Approach:

Rating curves of minimum thalweg depth for modelled discharges were developed for each reach. Threshold discharge levels to maintain a minimum thalweg depth equal to or greater than 60 cm were determined. A low spell analysis was undertaken for the time series flow data to determine the frequency and duration of events below the threshold value since regulation.

Results:

Reach 1 – KDD to Tarrara Bar (33 km below KDD)

The shallowest cross sections were identified as 23255 (Bullocks Crossing) and 14800 (Ivanhoe Crossing). At these points, a minimum flow of 25 m^3/s is required to maintain a thalweg depth of 0.6m. However, the cross section at Ivanhoe Crossing was not surveyed at the road crossing itself and the flow required to maintain passage over the actual crossing is much greater than 25 m^3/s.

Interpretation of photographs for a rising stage height, cross-referenced against flows at Tarrara Bar gauging station, indicated that to enable upstream fish passage over Ivanhoe Crossing a minimum discharge of approximately 425 m^3/s would be required (Plates 1 and 2).

Plate 1 – Ivanhoe crossing at approximately 425 m^3/s

Plate 2 – Ivanhoe crossing at approximately 350 m^3/s

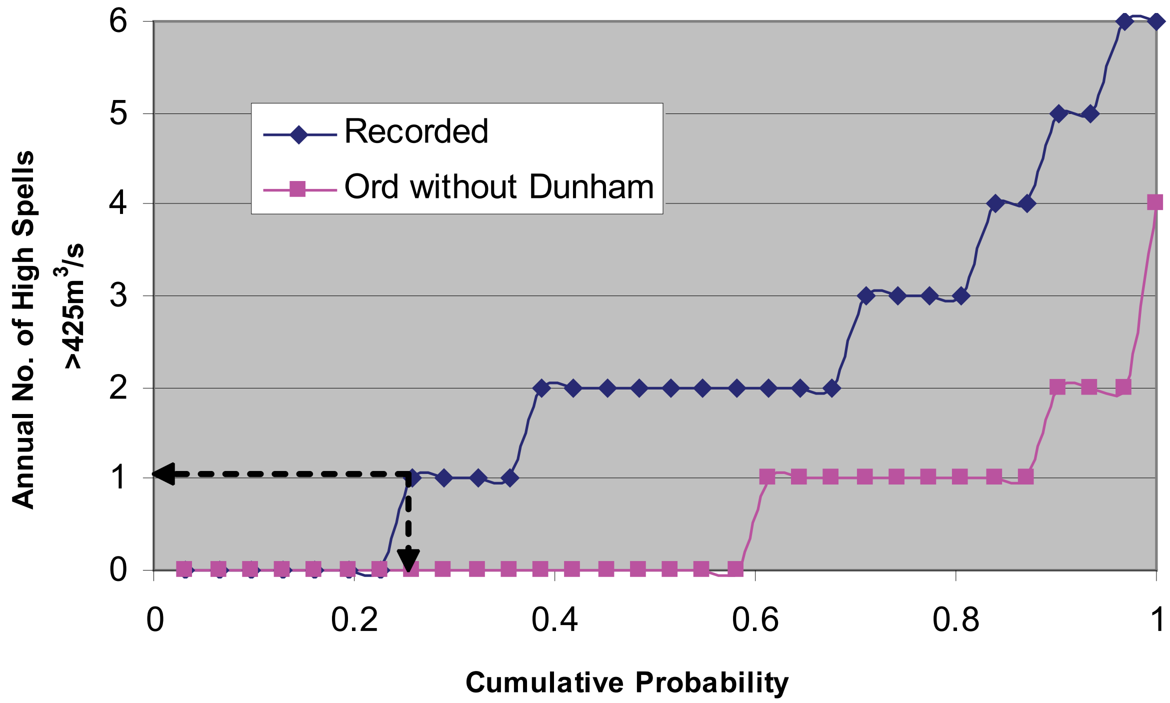

Figure 27: Annual occurrence of high spells >425 m³/s

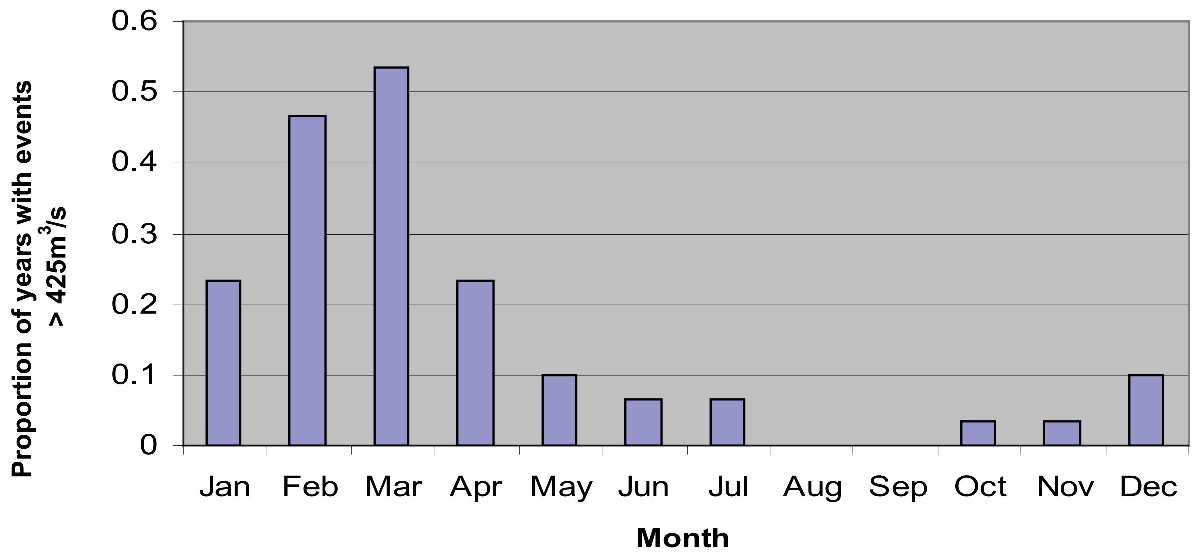

Figure 28: Monthly occurrence of high spells >425 m³/s

Time series analysis indicates:

- There is at least one high spell exceeding 425 m³/s in 75 per cent of years (Figure 27) (mean and median 2).
- High spells exceeding 425 m³/s have ranged from one to 147 days with a mean duration of nine days and median two days.
- In 80 per cent of the years when high spells above 425 m³/s have occurred, the total duration has been two days or more (mean nine and median four).
- High spells greater than 425 m³/s occur most commonly in February (at least one event in 47 per cent of years) and March (53% of years) (Figure 28).

If the Dunham River flows were excluded, the frequency of spells greater than 425 m³/s would be greatly reduced (Figure 27). The median number of spells per year would be reduced from two to zero and the median annual total duration reduced from four to zero days.

Reach 2 – Tarrara Bar to the start of the tidal influence (76 km below the KDD)

The shallowest cross section was 63144 (Carlton Crossing). At this point, a minimum flow of 20 m³/s is required to maintain a thalweg depth of 0.6m (Figure 29).

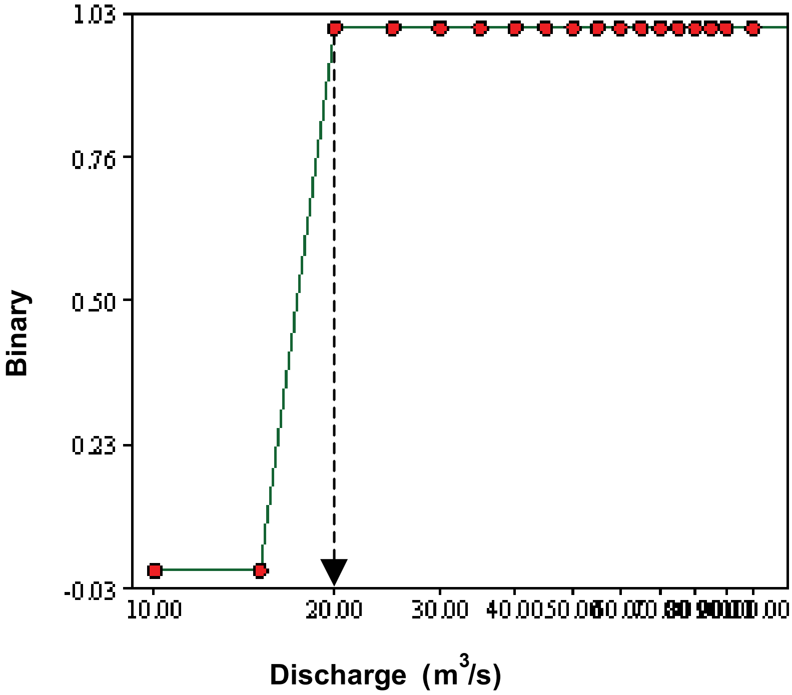

Figure 29: Fish passage in Reach 2 (Thalweg >0.6)

Time series analysis shows that flows have rarely dropped below 20 m³/s and fish passage is therefore available year round. In 80 per cent of years, fish passage was possible 361 days or more per year.

Reach 3 - the tidal-influenced reach (below 76 km)

Fish passage is maintained at even the lowest modelled flows in the tidal reach with a minimum thalweg depth of 1.24m at 10 m³/s (Figure 30).

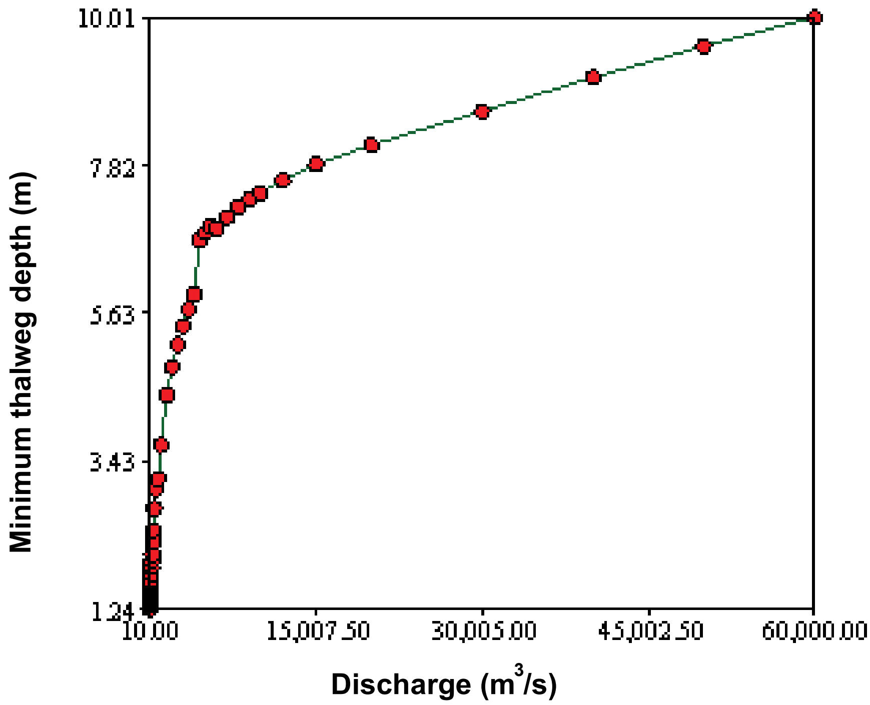

Figure 30: Fish passage in Reach 3

Discussion:

Downstream fish passage will generally be available throughout the wet season but upstream passage in Reach 1 will require at least 425 m^3/s. Since regulation, events of this magnitude have occurred most frequently in February and March and the expert panel agrees that this would provide upstream passage for most fish species at the ideal time. However, due to the short duration and infrequent nature of events greater than 425 m^3/s, it appears that upstream fish passage is quite limited. For example, there were only two days with flows above 425 m^3/s during the six-year period from 1988 to 1993. Recent studies have confirmed that Ivanhoe Crossing forms a barrier to fish passage for much of the year (Berghuis and Storey, 2006).

Fish that fail to get above Ivanhoe Crossing are restricted from the Dunham River as well as the last 15 km of the 94 km lower Ord River before the impassable Kununurra Diversion Dam. If the proposed fish ladder on the Kununurra Diversion Dam is constructed, flows greater than 425 m^3/s at Ivanhoe to provide for passage over the crossing will be essential to ensure the fish ladder at KDD is viable. The obvious alternative as recommended by Berghuis and Storey (2006) is to construct an additional structure at, or the modification of, Ivanhoe Crossing to facilitate fish passage over the crossing at lower flows.

Recommendations:

- Limited fish passage past Ivanhoe Crossing will be maintained if flows greater than 425 m^3/s occur in Reach 1 at least once a year (preferably in February or March) with a minimum duration of two days.
- Flow in Reaches 2 and 3 should not drop below 20 m^3/s for more than four days a year.

1g). Sufficient flow to oxygenate pools and avoid fish kills

Reduced flow velocity in the dry season, coupled with poor water quality could promote anoxia in pools, particularly when extremes in weather (high temperature, low wind) occur. It is important that oxygen levels are maintained above two mg/L to avoid the possibility of fish kills. Pools should not become isolated in the dry season and flow velocities in pools should not decrease below 0.08 m/s.

Applicable to:

Reaches 1 and 2.

Approach:

Previous modelling suggested that if flows were allowed to fall below 35 m^3/s, velocities below 0.08 m/s were likely and the risk of anoxia occurring in pools increased (WRC 2003). A low flow spells analysis was conducted to determine the frequency and duration of spells below 35 m^3/s since regulation. A cumulative probability distribution of the number of events below 35 m^3/s was developed. Analyses for Reach 1 and 2 for this objective have been combined.

Results:

Reach 1 – KDD to Tarrara Bar (33 km below KDD)

During the low flow trial, a minimum average flow velocity of 0.08 m^3/s was calculated in Reach 1 at a discharge[8] of 35 m^3/s.

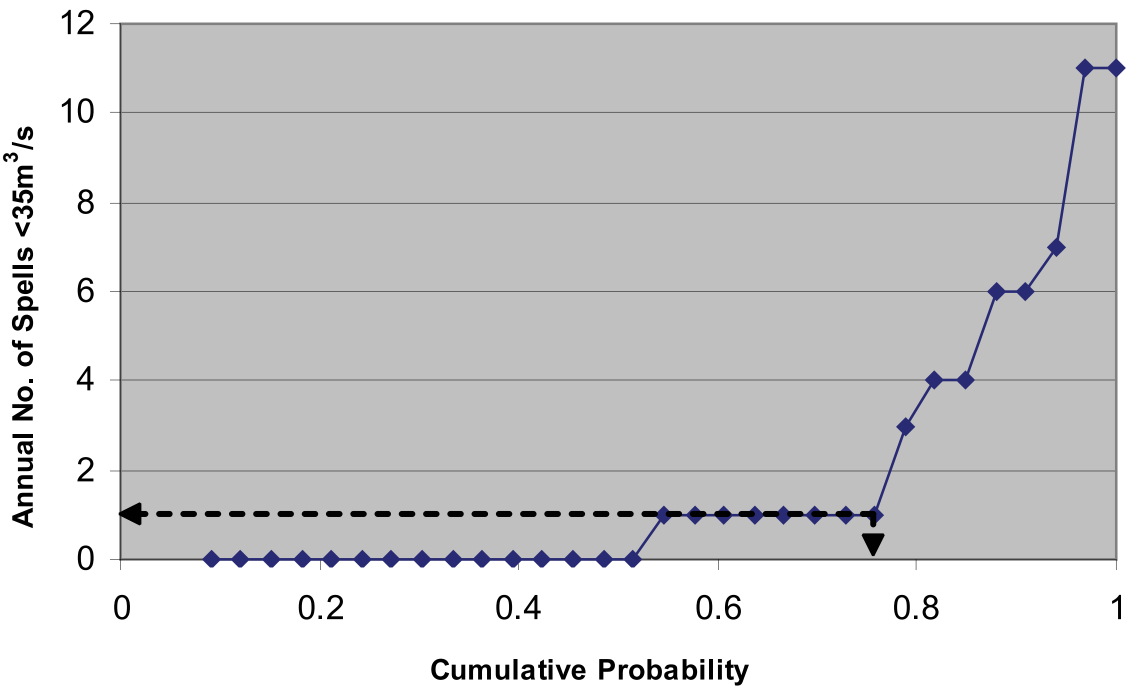

Figure 31: Annual occurrence of Low Spells <35 m^3/s

8 35m^3/s was used in preference to higher discharges calculated using hydraulic analysis in RAP.

When compared to the recorded time series of flow data, low spells below 35 m^3/s:

- Occur in 75 per cent of years no more than once per year (Figure 31) with a mean of two and a median of one.
- Have a mean duration of four days.
- Have a mean annual total duration of seven days and median two days.

Reach 2 – Tarrara Bar to the start of the tidal influence (76 km below the KDD)

During the low flow trial, a minimum average flow velocity of 0.08 m/s was calculated in Reach 2 at a discharge of 35 m^3/s. See Reach 1 for frequency and duration of such events in the recorded time series.

Discussion:

Modelling of turnover rates in pools and dissolved oxygen (DO) levels did not extend below flows less than 35 m^3/s. It was determined that there was a risk of anoxia occurring within two metres of the bottom in Carlton Crossing Pool if the biological oxygen demand (BOD) of inflow was doubled, DO saturation level lowered and fish density doubled from that recorded during 18-24 October 2002. It would appear that a large number of variables influence the likelihood of anoxia occurring. Therefore, the degree of certainty surrounding a definitive flow recommendation is diminished. It is therefore proposed that a minimum flow level be used as a trigger to start monitoring of DO levels, particularly at Carlton Crossing pool, and a trigger value for DO saturation is set at which flows must be increased.

Recommendations:

- Minimum discharge should not fall below 35 m^3/s more than once per year and the duration of low spells should not exceed four days. If flows fall below 35 m^3/s monitoring of oxygen levels in pools, particularly Carlton Crossing pool, should commence. If monitoring indicates that dissolved oxygen concentrations are equal to or lower than two mg/L, discharge should be increased to 35 m^3/s or greater, and monitoring of DO continue until levels are again in excess of two mg/L.

4.1.2 Macroinvertebrates

Four flow flow-ecology linkages were identified for macroinvertebrates in the lower Ord River. The flow requirements of each objective have been summarised in Table 7 (see Table 2 for full details of objectives). A detailed account of the process used to determine the flow requirements of each objective is given below.

Table 7. Flow requirements for macroinvertebrates

Flow-ecology linkages	Season	Reach	Flow Requirements
2a) Submerged Macrophyte Habitat	Dry	1,2	• Limited rate of change from one dry season to the next (effective when mean discharge for the previous Oct/Nov was above 70 m^3/s)
2b) Gravel Runs and Rapids	Dry	1,2	• Minimum of 25 m^3/s in Reach 1 and 2
2c) Inundation of Emergent Macrophyte Habitat	Dry	1,2	• Limited rate of change from one dry season to the next (effective when mean discharge for the previous Oct/Nov was above 70 m^3/s)
2d) Permanent Flows (connection of pools)	Dry	1,2,3	• Trigger level of 35 m^3/s in Reach 1, 2 and 3 (commence monitoring if flows fall below 35 m^3/s) • Minimum of 10 m3/s in Reach 1, 2 and 3

2a) Submerged macrophyte habitat

Submerged macrophyte habitats have been shown to be important and preferred habitats for some species of Macrobrachium prawns and other macroinvertebrates in the lower Ord River (Storey, 2002). It is important that the current area of submerged macrophyte be maintained in the dry season. In the dry season, submerged macrophyte beds typically occur in water 90 cm deep (minimum 47 cm) and low flow velocities (average three cm/s; Storey, 2003). However, submerged macrophytes can occur in much deeper water (>2m; Marshall and Storey, 2005) depending on light availability, substrata composition, and time since last scouring flood.

Applicable to:

Reaches 1 and 2. Comparable to flow-ecology linkage 1b.

Approach:

It was considered that this flow objective would be met if flow-ecology linkage 1b was satisfied. For objective 1b, it was considered that the difference in water level between consecutive dry seasons was the critical factor in ensuring sufficient submerged macrophyte habitat was available. The details of the analysis undertaken are provided in full for linkage 1b and therefore have not been repeated here.

Results:

Refer to flow-ecology linkage 1b.

Recommendation:

- Minimum flows for subsequent dry season to be determined by calculating mean discharge for late dry season (Oct/Nov) and using the relationship provided for linkage 1b.

2b) Gravel runs and rapids

Gravel runs and rapids are important habitats for macroinvertebrates and susceptible to change under reduced dry season flows (Storey, 2002). It is important that a minimum stage height be maintained in these habitats during the dry season. Typically, average depth over these habitats observed in the dry season are ~24 cm (Storey, 2002).

Applicable to:

Reaches 1 and 2.

Approach:

The minimum depth of functional gravel runs and rapid habitat was assumed to be 16 cm (minimum recorded depth; Storey 2002). Using cross sections with known gravel runs and rapids a rating curve of surface area with discharge was developed for local depth >16 cm. Thresholds for provision of gravel run and rapid habitat were identified from the rating curves. The time series were then analysed to determine the frequency of flows below the identified thresholds.

Results:

Reach 1 – KDD to Tarrara Bar (33 km below KDD)

In Reach 1 gravel runs and/or rapids were identified in the following cross sections: 14800, 23255 and 30856

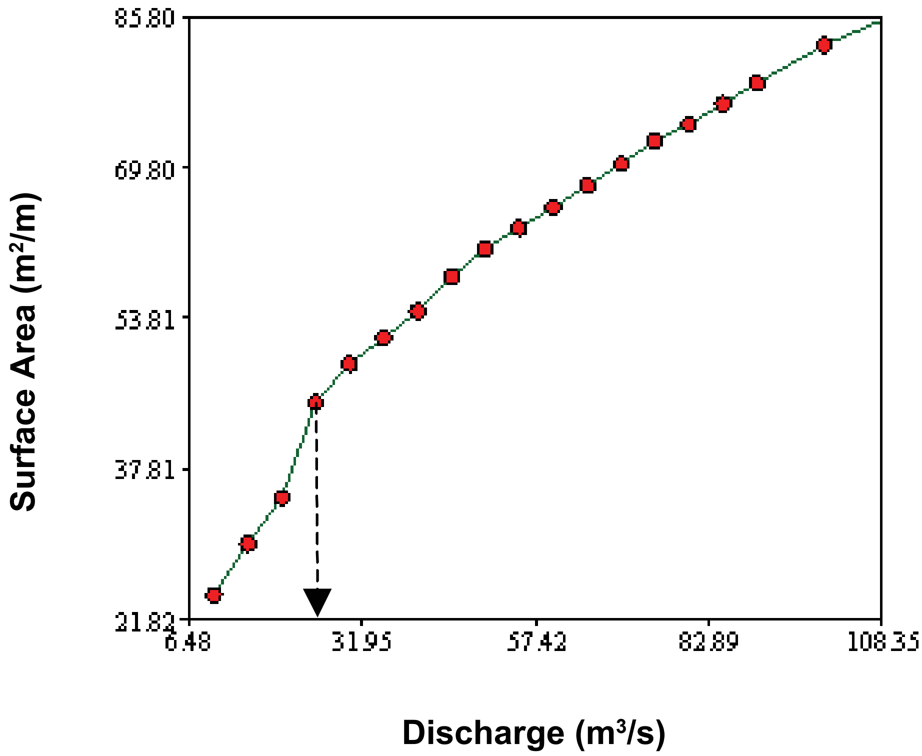

Figure 32: Gravel runs and rapids >16 cm deep (Reach 1)

From the rating curve, a discharge of 25 m³/s was identified as the lower threshold for gravel run and rapid habitat as the available habitat area begins to diminish rapidly below this point (Figure 32).

Reach 2 – Tarrara Bar to the start of the tidal influence (76 km below the KDD)

In Reach 2, gravel runs and rapids were identified in the following cross sections: 49407, 53271, 55737, 56040, 63144.

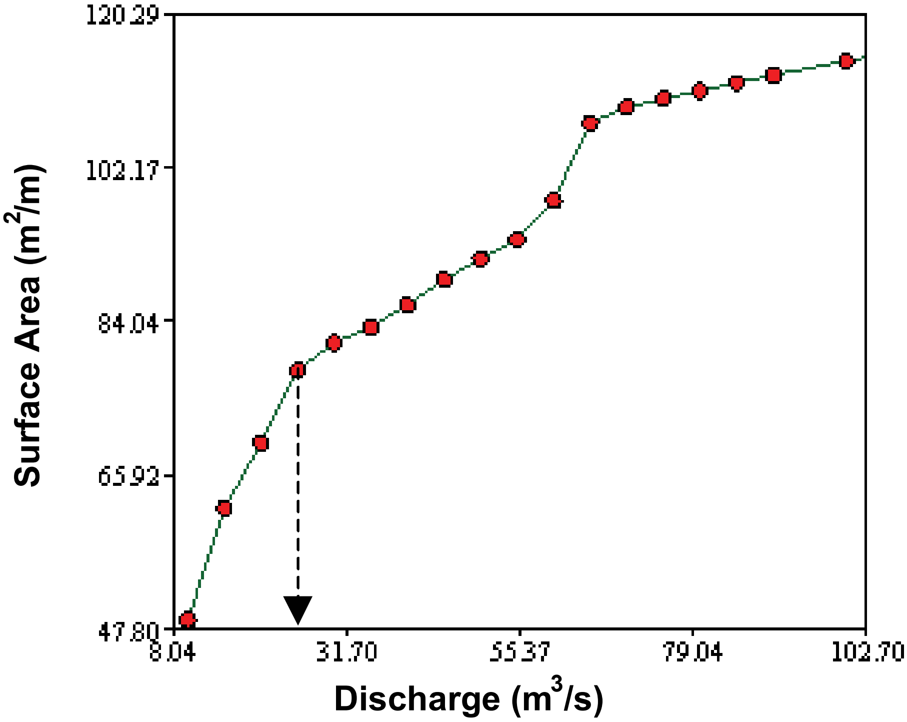

Figure 33: Gravel runs and rapids >16 cm deep (Reach 2)

As for Reach 1, a discharge of 25 m³/s was identified as the lower threshold for gravel run and rapid habitat below which the available habitat area begins to diminish rapidly (Figure 33).

Analysis of the recorded time series indicates that spells below 25 m³/s have occurred since regulation. However, the frequency of these spells is low with 55 per cent of years not experiencing spells below the threshold value and 77 per cent of years recording one or less spells below 25 m³/s (Figure 34). The median number of spells and median total duration (for all years) below 25 m³/s are both zero. In years where spells below the threshold have occurred, the median total duration is four days with a mean duration of 2.7 days.

Discussion:

It should be noted that the occurrence of flows below 25 m³/s since 1977 has decreased; with only one year, 1979, recording more than three spells below the threshold (Figure 35). In the years immediately following the construction of the Ord River Dam (in 1974), spells below 25 m³/s occurred with a greater frequency, most likely as a combined result of relatively low inflows into the dam and initially low water levels in the dam itself and minimal (if any) overflow.

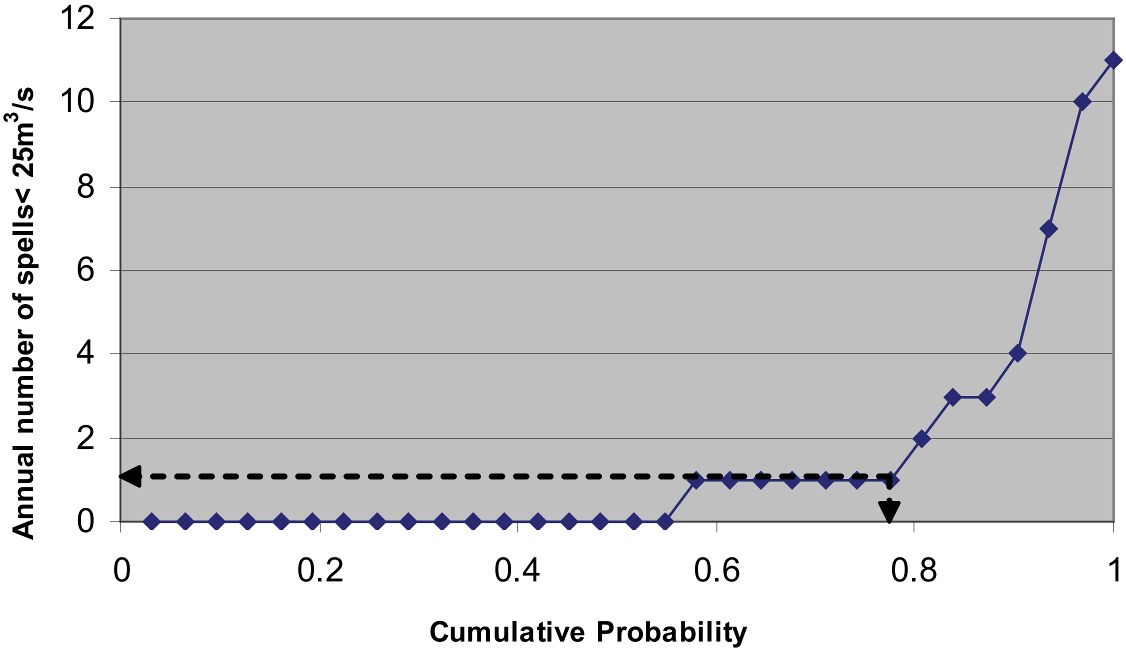

Figure 34: Occurrence of spells < 25 m³/s

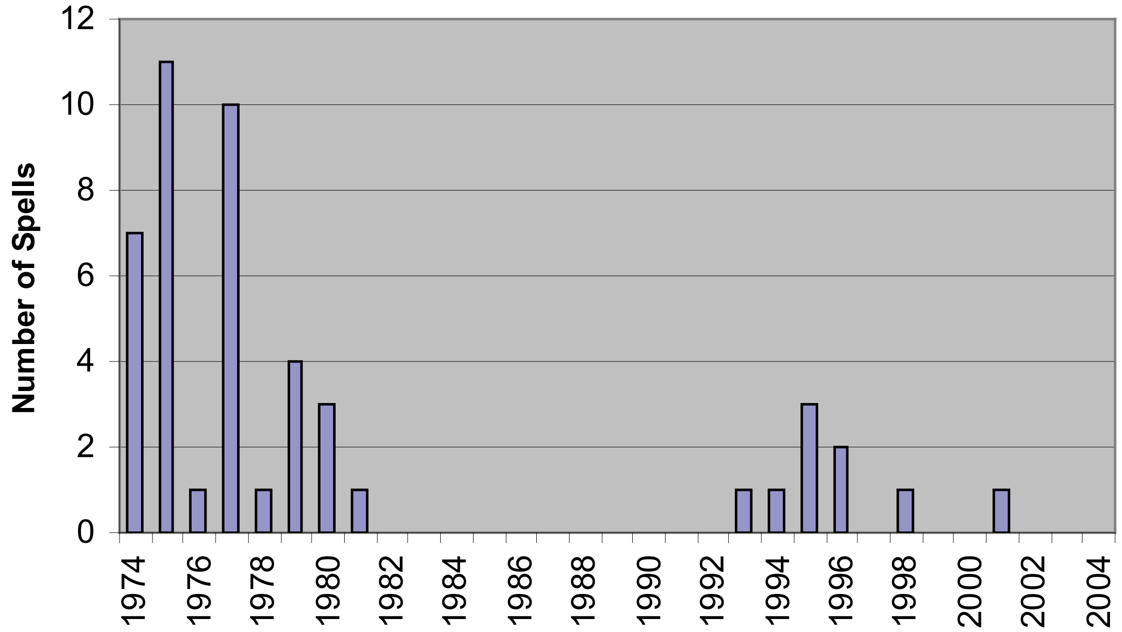

Figure 35: Annual number of spells below 25 m³/s

Recommendations:

- A minimum discharge of 25 m^3/s in the dry season is required to maintain adequate gravel runs and rapid habitat.

2c) Inundation of emergent macrophyte habitat

Emergent macrophytes in the lower Ord River support the highest number of macroinvertebrate taxa and is the most preferred habitat, being particularly important to Trichoptera (caddisfly larvae), Odonata (dragonfly and damselfly larvae) and Coleoptera (beetles). The average depth of this habitat during the dry season is 1.3 m and a minimum of 0.3 m should not be exceeded.

Applicable to:

Reaches 1 and 2. Comparable to 1b and 2a.

Approach:

It was assumed that this flow-ecology linkage would be satisfied if linkage 1b was met. That is, emergent macrophytes would be most affected by the rates of change in water level from one year to the next and maintenance of emergent macrophyte communities would be achieved (by ensuring rates of change were within those recorded historically) in turn maintaining macroinvertebrate populations. It is acknowledged that the assumption that meeting flow-ecology linkage 1b will also maintain emergent macrophytes could be correct without also necessarily maintaining conditions required for macroinvertebrates. However, in lieu of additional detailed information on the location of emergent macrophyte populations within the channel it was not possible to identify an alternative approach. Details of the analysis and results for linkage 1b have been provided previously.

Results:

Refer to flow-ecology linkage 1b.

Recommendations:

- Minimum flows for subsequent dry season to be determined by calculating mean discharge for late dry season (Oct/Nov) and using the relationship provided for linkage 1b.

2d) Permanent flows (connection of pools)

Reduced flow velocity in the dry season may result in a more typical macroinvertebrate community, but species that are now adapted to permanent flows may be lost. However, if flows are to be reduced, it is important that pools do not become isolated in the dry season and flow velocities in pools should not decrease below 0.08 m/s. Requires flow-duration analyses.

Applicable to:

All reaches. Comparable to flow-ecology linkage 1g.

Approach:

There are two aspects to this flow-ecology linkage: the maintenance of connectivity and the maintenance of sufficient dissolved oxygen levels in pools to sustain macroinvertebrate populations. The latter will be satisfied if linkage 1g is met (assuming that macroinvertebrates have a similar dissolved oxygen demand to fish). For flow linkage 1g, it was assumed that a minimum discharge of 35 m^3/s was required to achieve a minimum velocity of 0.08 m/s, which ensured turnover rates in deep pools were adequate to minimise the risk of anoxia.

For the maintenance of connectivity, rating curves of minimum thalweg depth were constructed for each reach to determine if connectivity was lost in the range of modelled discharges. Where thresholds were determined, a low spells analysis was conducted to determine the frequency and duration of spells below the threshold value.

Results:

As stated for flow-ecology linkage 1g, when compared to the recorded time series of flow data, low spells below 35 m^3/s:

- Occur in 75 per cent of years no more than once per year (mean two and median one).
- Have a mean duration of four days.
- Have a mean annual total duration of 14 days and median nine days.

The rating curves of minimum thalweg depth (Figures 36, 37 and 38 for Reach 1, 2 and 3 respectively) indicate that at the lowest flows modelled (10 m^3/s), connectivity is maintained throughout all three reaches. The respective minimum thalweg depths for Reaches 1, 2 and 3 were calculated as 46 cm, 42 cm and 124 cm.

This can also be demonstrated by examining the long section profiles of the three reaches (Figure 39 – long section profile for Reach 2).

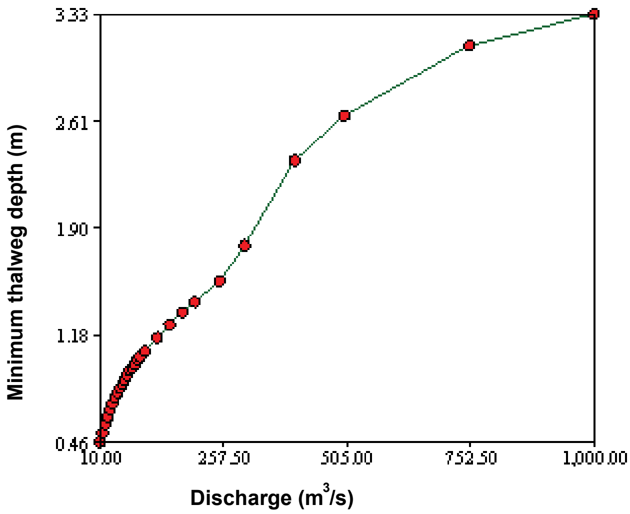

Figure 36: Minimum thalweg depth Reach 1

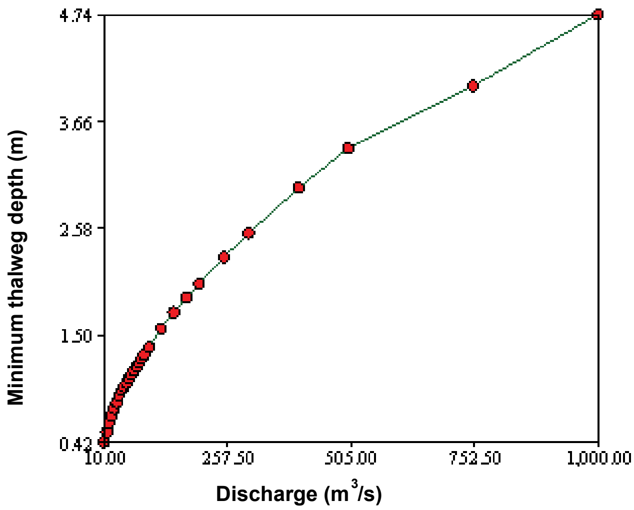

Figure 37:Minimum thalweg depth Reach 2

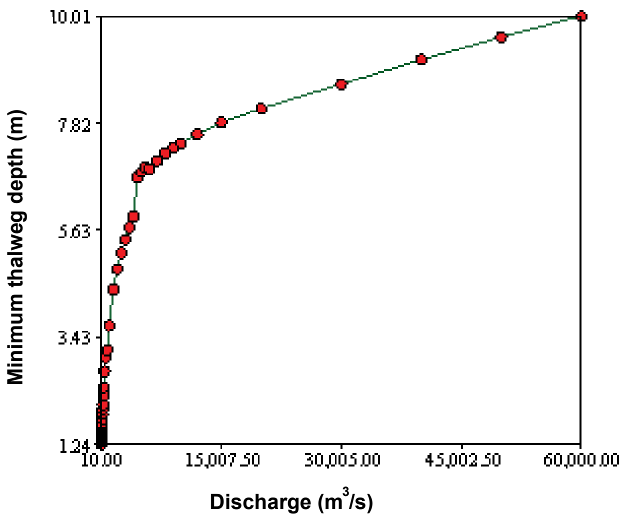

Figure 38: Minimum thalweg depth Reach 3

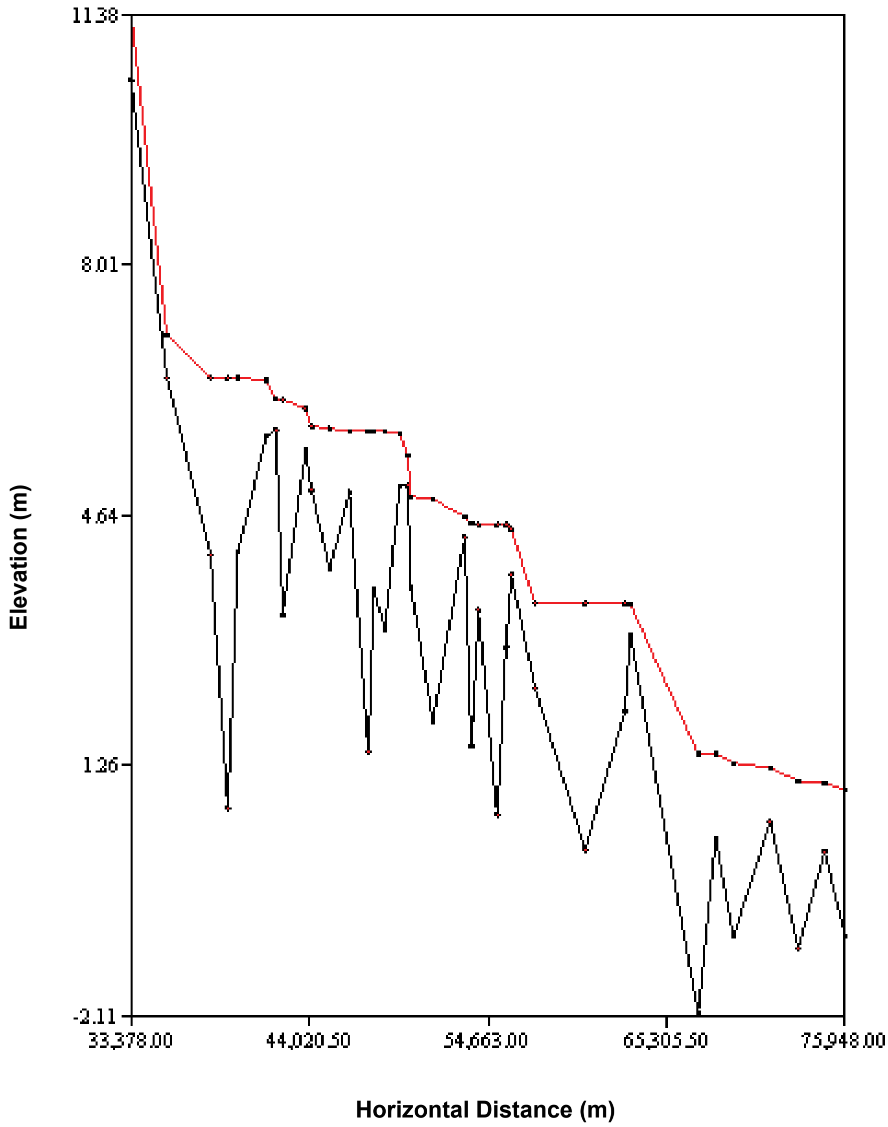

Figure 39: Long section thalweg profile for Reach 2 at 10 m^3/s

When compared to the recorded time series of flow data, spells below 10 m^3/s do not occur in 75 per cent of years (Figure 40; mean number of events one and median number of events zero). It should also be noted that since 1981 no year has recorded more than one spell below 10 m^3/s; that is, the years where multiple occurrences of spells below 10 m^3/s were recorded were predominantly those years during and immediately following the construction of the Ord River Dam from 1974 to 1977. The mean duration for spells below 10 m^3/s was two days.

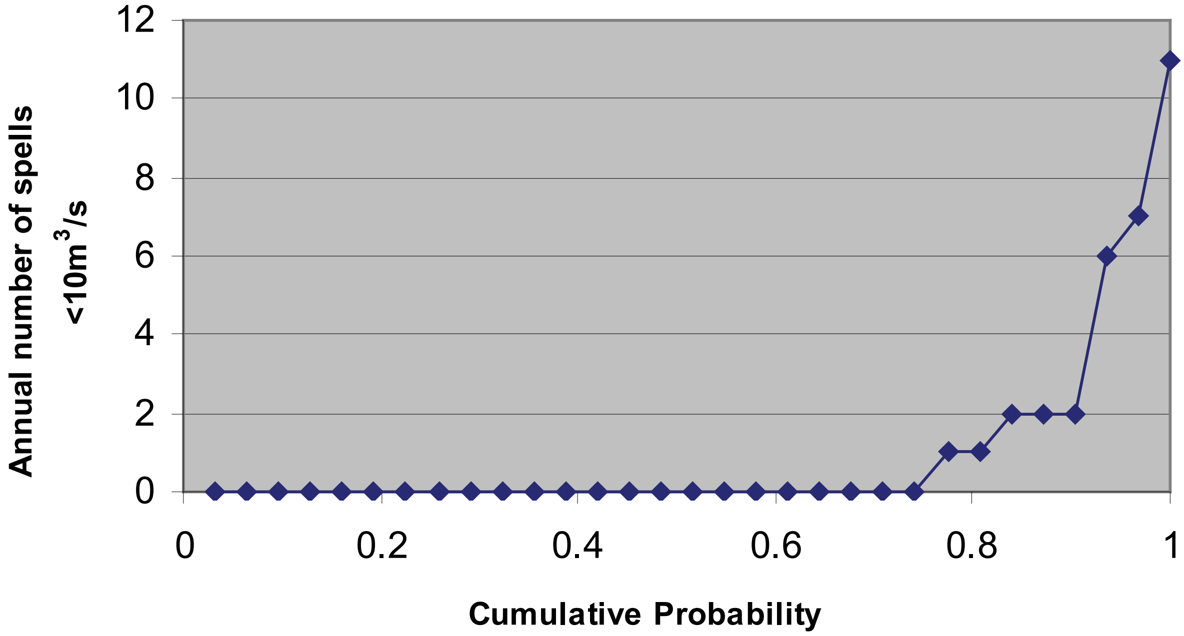

Figure 40: Annual frequency of spells <10 m^3/s

Recommendations:

- Minimum discharge should not fall below 35 m^3/s more than once per year and the duration of low spells should not exceed four days. If flows fall below 35 m^3/s monitoring of oxygen levels in pools should start, particularly Carlton Crossing pool. If monitoring indicates that dissolved oxygen concentrations are equal to or lower than two mg/L, discharge should be increased to 35 m^3/s or greater and monitoring of DO continue until levels are again in excess of two mg/L.
- Perennial flow in the lower Ord River greater than 10 m^3/s should be maintained.

4.1.3 Ecosystem Processes and connectivity

Five flow flow-ecology linkages were identified to maintain ecosystem processes and connectivity in the lower Ord River. The flow requirements of each linkage have been summarised in Table 8 (Flow-ecology linkages are provided in full in Table 2). A detailed account of the process used to determine the flow requirements of each linkage is given below.

Table 8. Flow requirements for ecosystem processes and connectivity

Flow-ecology linkages	Season	Reach	Flow Requirements
3a) Permanent flows for algal production	Dry	1,2,3	• Minimum of 10 m^3/s in Reach 1, 2 and 3
3b) Inundation of Riparian Bench for Algal Production	Wet	1,2	• Flows greater than 100 m^3/s for a minimum 18 days per year in Reach 2
3c) Wet season base-flow	Wet	1,2,3	• Minimum of 50 m^3/s in January • Minimum of 57 m^3/s in February and March • Minimum of 53 m^3/s in April • Minimum of 48 m^3/s from 1st to 15th May
4a) Seasonal Inundation of Mid-bank	Wet	1,2,3	• High flow event of at least 750 m^3/s every two years in Reach 1 • High flow event of at least 1,400 m^3/s every four years in Reach 2
5a) Wetland Inundation	Wet	2,3	• Flood event with peak mean daily flow of 3,700-4,000 m^3/s every 27-35 years in Reach 2 and 3

3a) Permanent flows for algal production

Flow permanence is important in the regulated environment in order to maintain connectivity and provide sufficient shallow areas inundated for algal production. The system should not be permitted to dry out in the dry season.

Applicable to:

All reaches. Comparable to flow-ecology linkage 2d.

Approach:

Flow permanence and connectivity has been addressed previously for flow-ecology linkage 2d and therefore has not been repeated here. Examination of minimum thalweg rating curves developed in the River Analysis Package indicate that connectivity is maintained in the minimum flows modelled by the package (10 m^3/s) and that flows less than this have not occurred in 75 per cent of years since regulation.

Results:

Refer to flow-ecology linkage 2d.

Discussion:

The expert panel recommended that the objective of this flow ecology linkage should be to maintain current level of algal production. That is, the current food webs are maintained by current levels of algal production, which are a reflection of current habitat available for algal production. Recognising that algal production is likely to be fairly dynamic and respond relatively quickly to changes in water levels, minimum stage heights/water level are not considered of high importance.

Recommendation:

- A minimum flow requirement of 10 m^3/s is required to maintain connectivity.

3b) Inundation of riparian bench for algal production

Localised algal production is an important ecosystem driver during the wet season. Throughout the wet season, base flows should be sufficient to inundate lower level terraces (damp zone) to a maximum depth of 50 cm (photic zone).

Applicable to:

Reaches 1 and 2.

Approach:

Rating curves of surface area and discharge were developed for both reaches and thresholds for bench inundation were determined by examining the slope of the rating curves. These were cross-checked in the River Analysis Package by examining water level/stage height for the threshold discharge. High flow spells analyses were conducted for the threshold values to determine the frequency and duration of spells exceeding the threshold and a cumulative probability distribution created for the number of events exceeding the threshold.

Results:

Reach 1 – KDD to Tarrara Bar (33 km below KDD)

In Reach 1, the only cross section containing a riparian bench was 19166. As indicated by the change in slope of the rating curve of surface width versus discharge, a threshold of 50 m^3/s is required to begin bench inundation and provide habitat for algal production (Figure 41).

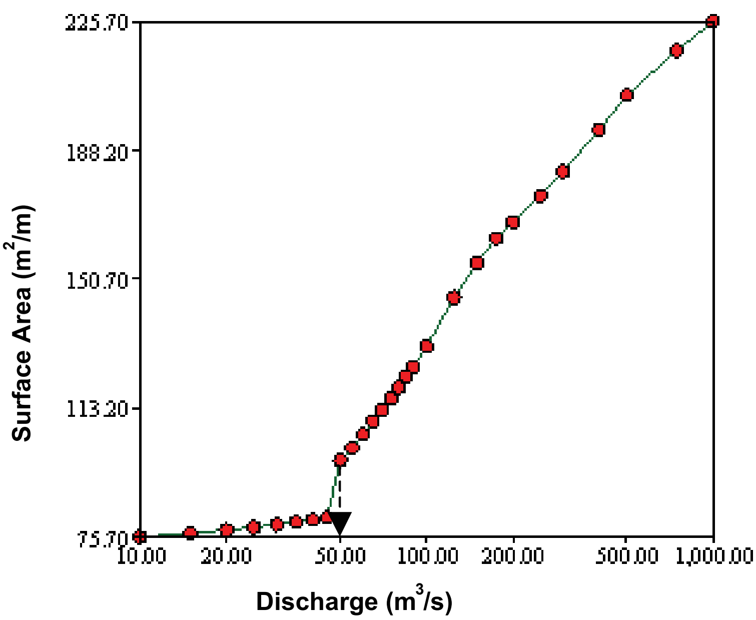

Figure 41: Inundation of riparian bench for algal production

Given that the threshold for Reach 1 of 50 m^3/s is below both the overall mean (74 m^3/s) and median (57 m^3/s) dry season values for the recorded time series, this threshold appears not to be representative of the discharge at which current riparian benches are inundated.

Therefore, this cross section and threshold has been excluded and it has been assumed that the threshold for Reach 2 will also be sufficient to inundate benches in Reach 1.

Reach 2 – Tarrara Bar to the start of the tidal influence (76 km below the KDD)

Riparian benches were identified in the following cross sections:
35514, 38123, 41452, 41992, 43788, 50077, 55214, 69282, 71487, 73153, 75948

From these cross sections, a threshold of 100 m^3/s was identified for riparian benches to begin to inundate and provide habitat for algal production (Figure 42).

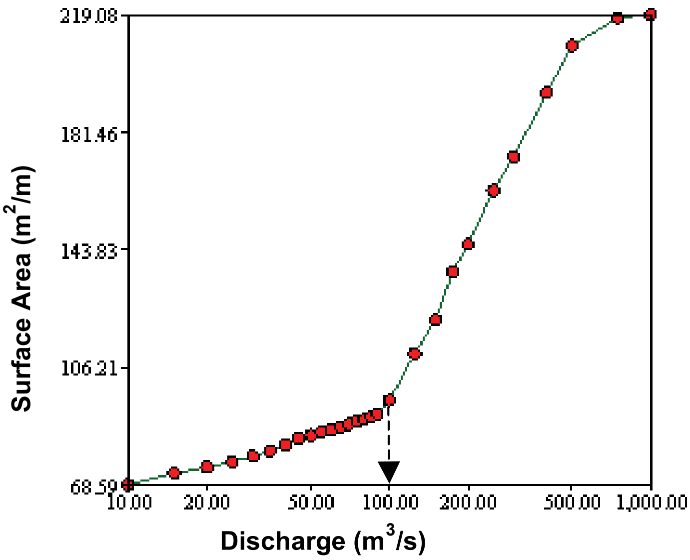

Figure 42: Inundation of riparian bench for algal production

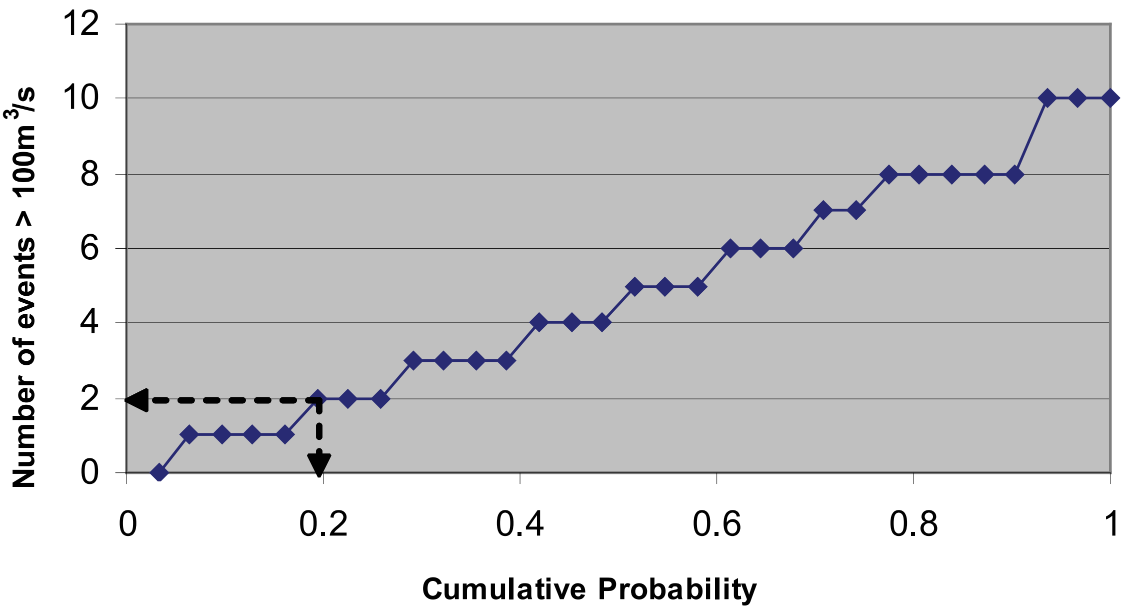

Figure 43: Frequency of wet season events greater than 100 m^3/s

Analysis of the time series indicates that during wet seasons, flows greater than 100 m^3/s:

- Occur at least twice in 80 per cent of years (Figure 43), with a median occurrence of five events per year and
- Have a median total duration of 74 days per year, with a minimum total duration of 18 days exceeded in 80 per cent of years.

Discussion:

As for flow-ecology linkage 3a, the expert panel advised that the objective is maintaining the current levels of algal production in the system and subsequently the existing food webs. It was considered that the total annual duration of flows adequate to inundate benches and therefore allow algal production on the benches was the key to achieving this objective (ie it is not the number of events that are important as algal production will occur for as long as flows are over the required threshold).

Recommendations:

- A minimum total duration for flows greater than 100 m^3/s of 18 days per year is required.

3c) Wet Season Base-flow

Wet season base-flow determines lateral extent of habitat and hydrologic connectivity. This has become critical to the ecology of the lower Ord River due to the reduced duration and magnitude of high flow events post regulation. Various wet season ecological processes now occur within the channel margins, which remain inundated as a result of the elevated wet season base-flow provided since regulation.

Applicable to:

All reaches.

Approach:

To approximate a wet season base flow, the P80 for each month of the wet season was calculated using the 1974-2005 time series. P80 was considered appropriate as it excludes the extreme low flows and gives a discharge for which 80% per cent of wet season flows have exceeded. Calculating the base-flow monthly adds variability, which better mimics the natural flow regime within the wet season (Jan-Jun).

Results:

The P80 (wet season base flow) was calculated for each month (Jan-Jun) using all data from 1974-2005 (Table 9).

Table 9: Wet season base-flow

Month	P80 (m^3/s)
Jan	50
Feb	57
Mar	57
Apr	53
May	49
Jun	47

Discussion:

The extended nature of the wet season base flow into May and June is a result of overflow from the Ord River Dam in years when Lake Argyle is full. It is unlikely that ecological processes require such an extended increase in flows although a gradual decline in discharge may be essential. The expert panel agreed that the wet season base flow is required during the wettest months of Jan-Apr. Flows should then gradually decline to the dry season minimum flow.

Recommendations:

- A wet season base-flow of at least 50 m^3/s in January, 57 m^3/s in February and March and 53 m^3/s in April should be maintained. Flows can then step down to a minimum of 48 m^3/s until 15 May before returning to the dry season minimum flow.

4a) Seasonal inundation of mid-bank

Riparian areas provide important habitat and contribute sources of carbon that support food web processes in the lower Ord River. Therefore, seasonal inundation of mid-bank should be ensured through periodic flood pulses. Flooding of riparian vegetation (to 0.25 m) may be sufficient. The frequency and duration of flooding will need to be evaluated.

Applicable to:

All reaches. Comparable to flow-ecology linkage 8c.

Approach:

Mid-bank benches were difficult to identify from a rating curve or examination of discharge water levels for cross sections in the River Analysis Package. The mid-bank zone was identified using vegetation transect information for flow-ecology linkage 8c. The same flow recommendations have been adopted to satisfy this linkage.

Results:

Refer to flow-ecology linkage 8c.

Discussion:

To ensure the input of terrestrial carbon from the riparian zone, short pulse flows are likely to be sufficient. That is, the duration of flows is not likely to be of high importance. However, where inundation of the mid-bank vegetation for the purpose of stimulating recruitment and maintaining riparian species behind the damp zone is the flow objective (8c), the timing and duration of flows will be more critical. This is discussed further for flow-ecology linkage 8c.

It is again recognised that management for flows of this magnitude through manipulation of infrastructure is unlikely to be practicable and that much of the flow in high spell events is provided by the Dunham River. However, where possible, peak flows should be maximised and further regulation of the Dunham River should not be permitted.

Recommendations:

- Flows in Reach 1 should exceed 750 m^3/s for at least one day once every two years.
- Flows in Reach 2 should exceed 1,400 m^3/s for at least one day once every four years.

5a) Wetland inundation

High magnitude wet season floods arising from the Ord River that are sufficient to inundate the Parry Lagoon floodplain have become rare events since regulation. Given the importance of the Parry Lagoon area, no further reduction in the frequency, duration and magnitude of these events should occur.

Applicable to:

Reach 2 and 3.

Approach:

Cross sections in the vicinity of Parry Lagoon floodplain (67181 to 85806) were assessed individually and the discharge required to overflow the left bank and provide connection with the Parry Lagoon floodplain was determined (Table 10).

Results:

Table 10: Discharge required to flood Parry Lagoon.

Reach	Cross section	Discharge (m^3/s)
2	67181	3300
2	68234	3800
2	69282	4200
2	71487	3100
2	73153	3500
2	74720	3750
2/3	75948	4200
3	77606	3900
3	78424	3900
3	80069	3700
3	82138	5500
3	84801	2800
3	85806	4600
	Mean	**3865**

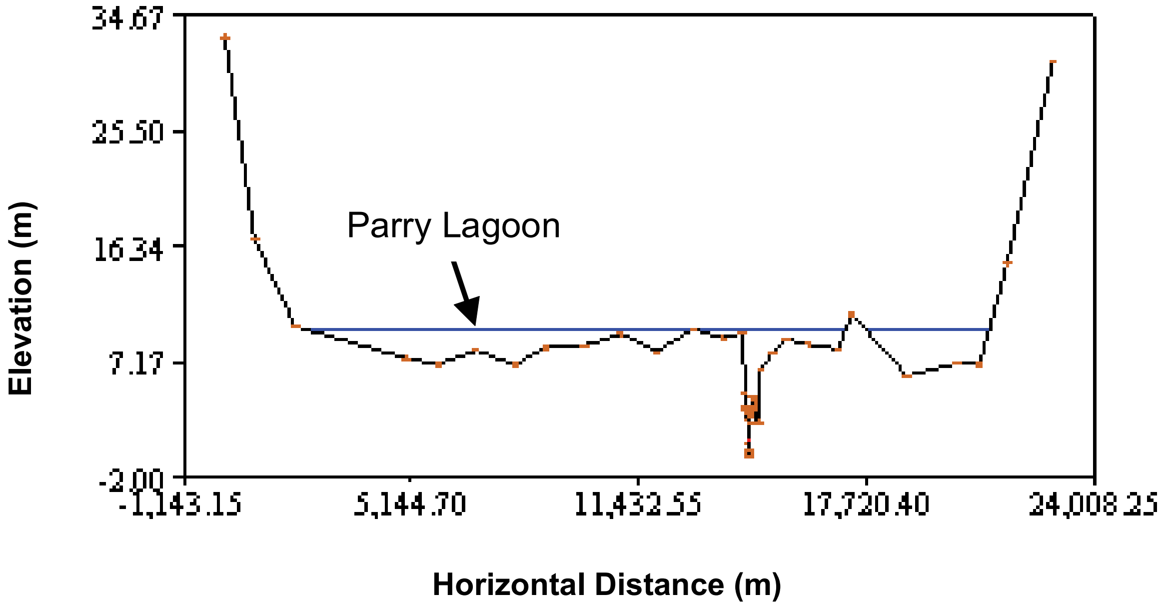

Figure 44: Cross section 77606 at 3,900 m³/s showing the Parry Lagoon floodplain relative to the lower Ord River channel

The mean discharge required to overflow the left (western) bank and potentially flood Parry Lagoon is 3,865 m³/s (Figure 44).

Analysis of the recorded time series indicated that mean daily flows during the flood events of 2000 and 2002 were in this vicinity and reached between 3,700 to 4,000 m³/s. Parry Lagoon was flooded during these events.

For a target mean daily discharge of 3,700 m³/s, the ARI is 27 years (Figure 45). For a target of 4,000 m³/s, the ARI is 35 years.

Discussion:

The results of the analyses, that is, a flow requirement of between 3,700 and 4,000 m³/s which occurred in 2000 and 2002, is corroborated by observations of flood events for the lower Ord. In both 2000 and 2002, the Parry Creek Lagoon was inundated during large flow events on the lower Ord. However, inundation of Parry Creek Lagoon is also influenced by tidal levels in the lower Ord/Ord Estuary and rainfall/runoff in the local Parry Creek Lagoon catchment. The relative contribution of Ord flows to inundation of the lagoon will differ depending on both of these factors.

It should also be noted that the time series analysis undertaken for this flow ecology linkage (as for others) has used a mean daily time series of flows. The ARI for an instantaneous flow of 4,000 m³/s was calculated at 15 years. This is a considerably shorter interval than that calculated using mean daily flows. Further information is required to clarify the duration of flows of the identified magnitude (3,700 to 4,000 m³/s) required to inundate the lagoon and how inundation is influenced by the other factors identified above. This information was not available for input into this study.

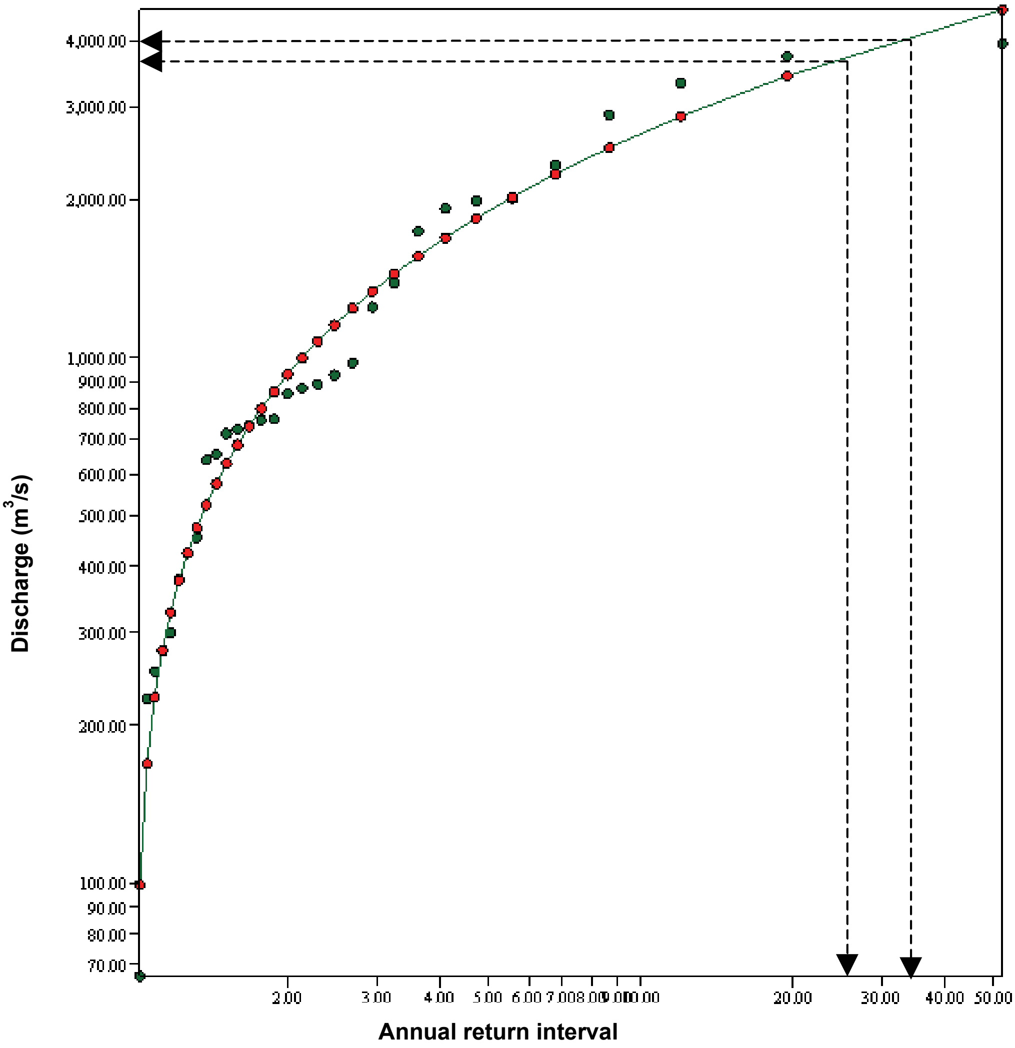

Figure 45: Annual series flood frequency curve for lower Ord River

The relative contribution of the Dunham River to peak/large flood events in the lower Ord River is of elevated importance post-regulation. For example, the Dunham River contributed around 80 per cent of the peak flow in 2002 and greater than 50 per cent in 2000. It is recognised that for high flow recommendations such as that made below for objective 5a, maintaining the current contributions of the Dunham River will be the main mechanism by which these flow flow-ecology linkages continue to be met.

Recommendations:

- Target ARI for peak events in the vicinity of 3,700 to 4,000 m^3/s every 27-35 years should be maintained.
- No further regulation of the Dunham River should be permitted.

4.1.4 Geomorphology

One flow-ecology linkage was identified for geomorphology in the lower Ord River. The flow requirements of this linkage have been summarised in Table 11. A detailed account of the process used to determine the flow requirements for this linkage is given below.

Table 11. Geomorphological flow requirements

Objective	Season	Reach	Flow Requirements
6a) Flows to Scour Sediment and Vegetation Build-up	Wet	1,2,3	• Flood event with peak mean daily flow of 3,700-4,000 m^3/s every 27-35 years in Reach 1, 2 and 3

6a) Flows to scour sediment and vegetation build-up

Discourage excessive build up of fine sediments, organics and associated in-channel vegetation by providing active channel flows where opportunities arise to supplement high Dunham River flow. A key issue here would be providing sufficient stream power to scour fine cohesive sediment (<500µm). This is complicated by the cohesive effect of vegetation and its modification of the velocity profile. These events could be about three-yearly, but if flows are sufficiently regular, then sequential events may contribute to reduced channel encroachment.

Applicable to:

All reaches.

Approach:

Based on observations of recent flood events, a threshold value equivalent to the peak discharges recorded in the 2000 and 2002 events was thought to be required to scour sediment and associated submerged and emergent vegetation. An annual series flood frequency curve was constructed (using time series of mean daily flows from 1974-2005) to examine the frequency of the events.

Results:

Based on the time series used for the analysis, the flood events of 2000 and 2002 had mean daily flow peaks within an estimated range of 3,700 to 4,000 m^3/s.

Based on the time series used for the current analyses, the ARI of events with mean daily flow peaks of 3,700 m^3/s and 4,000 m^3/s are 27 and 35 years respectively (Figure 45).

The median duration and single longest duration of spells in excess of 3,700 m^3/s is one day.

Discussion:

As discussed previously for objective 5a, the relative contribution of the Dunham River to large flood events in the lower Ord has increased since regulation of the Ord. Maintenance of the current contribution of the Dunham to flood flows in the lower Ord is of high importance to satisfying this linkage.

Recommendations:

- Target ARI for peak events in the vicinity of 3,700 to 4,000 m^3/s should be maintained.
- No further regulation of the Dunham River should be permitted.

4.1.5 Water Quality

One flow-ecology linkage was identified for the maintenance of water quality in the lower Ord River. The flow requirements of this linkage have been summarised in Table 12. A detailed account of the process used to determine the flow requirements for this linkage is given below.

Table 12. Water quality flow requirements

Objective	Season	Reach	Flow Requirements
7a) Permanent flows (oxygenation of pools)	Dry	1,2	• Trigger level of 35 m^3/s in Reach 1 and 2 (commence monitoring if flows fall below 35 m^3/s)

7a) Permanent flows (oxygenation of pools)

Maintain sufficient flow velocity in the dry season in order to minimise the risks associated with nutrient enrichment and anoxia. Pools should not become isolated in the dry season and hydraulic residence times should be kept short. Flow velocities in pools should not decrease below 0.08 m/s. Requires flow-duration analyses.

Applicable to:

Reaches 1 and 2. Comparable to 1g and 2d.

Approach:

This flow-ecology linkage will be satisfied if flow linkage 1g is met. For linkage 1g it was assumed, based on previous modelling, that a minimum discharge of 35 m^3/s was required to achieve a minimum velocity of 0.08 m/s necessary to ensure that turnover rates in deep pools are sufficient to minimise the risk of anoxia in pools. As stated for linkage 1g, when compared to the recorded time series of flow data, spells below 35 m^3/s:

- Occur in 75 per cent of years no more than once per year (mean two and median one).
- Have a mean duration of four days.
- Have a mean annual total duration of 14 days and median nine days.

Results:

Refer to flow-ecology linkages 1g and 2d.

Recommendations:

- Minimum discharge should not fall below 35 m^3/s more than once per year and the duration of low spells should not exceed four days. If flows fall below 35 m^3/s, monitoring of oxygen levels in pools, particularly pool below Carlton Crossing, should start. If monitoring indicates that dissolved oxygen concentrations are equal to or lower than two mg/L, discharge should be increased to 35 m^3/s or greater and monitoring of DO should continue until levels are again in excess of two mg/L.

4.1.6 Riparian vegetation

Four flow-ecology linkages were identified for the maintenance of riparian vegetation in the lower Ord River. The flow requirements of each linkage have been summarised in Table 13 (linkages are provided in full in Table 2). A detailed account of the process used to determine the flow requirements for each linkage is provided below.

Table 13. Flow requirements for riparian vegetation

Flow-ecology linkages	Season	Reach	Flow Requirements
8a) Seasonal inundation of lower riparian terrace	Wet	1,2,3	• Four spells above 125 m^3/s with a total duration of at least 10 days in Reach 1 • Two spells above 200 m^3/s with a total duration of at least five days in Reach 2 • One spell above 300 m^3/s with a minimum duration of two days in Reach 3
8b) Flows to scour emergent vegetation	Wet	1,2,3	• Flood event with peak mean daily flow of 3,700-4,000 m^3/s every 27-35 years in Reach 1, 2 and 3
8c) Seasonal inundation of mid-bank	Wet	1,2,3	• High flow event of at least 750 m^3/s every two years in Reach 1 • High flow event of at least 1,400 m^3/s every four years in Reach 2
8d) Bankfull flood flows	Wet	1,2,3	• Flood event with peak mean daily flow of 3,700-4,000 m^3/s every 27-35 years in Reach 1, 2 and 3

8a) Seasonal inundation of lower riparian terrace

The diversity of vegetation within the damp zones should be maintained and enhanced where possible. Regular wet season inundation of the lower riparian terraces may serve to diminish weed invasion and prevent terrestrialisation.

Applicable to:

All reaches. Comparable to linkage 1e.

Approach:

Flow-ecology linkage 1e requires the inundation of lower riparian benches to a depth of one metre for fish habitat. It has been assumed that satisfaction of linkage 1e (flooded riparian benches for fish habitat) will also satisfy 8a.

Results:

Refer to flow-ecology linkage 1e.

Recommendation:

- Wet season flows should be sufficient to provide four or more spells over 125 m^3/s, two or more spells over 200 m^3/s and at least one over 300 m^3/s. Total annual durations of at least 10, five and one day(s) for 125 m^3/s, 200 m^3/s and 300 m^3/s spells respectively, should be maintained.
- No further regulation of the Dunham River should be permitted.

8b) Flows to scour emergent vegetation

The submerged and emergent vegetation of the lower Ord River is likely to be retained, provided that the dry season flows do not entirely diminish. Dominance by emergent Typha and other 'weed' species may be managed through the provision of high power flood flows, although the minimum magnitude and duration required is unknown. These events need not be annual. An event every three years may be sufficient to minimise Typha and other weedy species encroachment on the channel.

Applicable to:

All reaches. Comparable to 5a and 6a.

Approach:

Will be satisfied when 5a and 6a satisfied.

Results:

Refer to flow-ecology linkage 5a.

Discussion:

As discussed previously for objective 5a, the relative contribution of the Dunham River to large flood events in the lower Ord has increased since regulation of the Ord. Maintenance of the current contribution of the Dunham to flood flows in the lower Ord is of high importance to meeting this linkage.

Recommendations:

- Target ARI for peak events in the vicinity of 3,700 to 4,000 m^3/s should be maintained every 27-35 years.
- No further regulation of the Dunham River should be permitted.

8c) Seasonal inundation of mid-bank

The proliferation of tree species such as Eucalyptus spp. behind the damp zone should be encouraged. Higher magnitude wet season pulses of short duration that extend to the mid-slope may serve this purpose. Short duration shallow flows (~2-3 days, 25 cm) may be all that is required. Timing: Feb-April.

Applicable to:

All reaches.

Approach:

During 2001, the Department of Environment and Conservation (formerly CALM) in conjunction with the University of Western Australia established six vegetation transects along the lower Ord (Start *et al*., 2002). Information collected during the survey of these transects documented the location of riparian vegetation species relative to the distance from the main active channel. Results indicated a bimodal distribution of species with typically a clear distinction between the distribution of damp zone species (typifying the new post-regulation riparian zone) and mid-slope dry zone species (typifying the old riparian zone dominated by *Eucalyptus* spp.). Elevations for the transects were also available allowing the estimation of the lower margin of the *Eucalyptus* spp. zone for four of the six transects (two of the established transects did not exhibit the zonation discussed above and were excluded from the analysis) which was taken as a minimum target water level to satisfy the flow-ecology linkage.

Vegetation transects were matched to the closest existing river cross sections and the discharge required to achieve the target water level (at the desired elevation) for each transect was estimated in the River Analysis Package using discharge water level relationships. A mean discharge to achieve the target water level for each reach (where possible) was calculated.

The frequency and duration of spells in excess of the discharges calculated above were analysed in the River Analysis Package to determine a target flow recommendation.

Discussion:

The small seed size of many of our northern *Eucalyptus* spp. suggests that these species do not survive long in the soil and are therefore unlikely to be a major component of the soil seedbank. Timing of seed set to coincide with periods of high soil moisture sufficient to trigger germination and then sustain seedlings is critical to the reproductive success of these riparian species (Pettit and Froend, 2000). *E. camaldulensis* and other northern Australian *Eucalyptus* spp. are reported to release the majority of their seed over a relatively short period late in the wet season (Pettit and Froend, 2000).

The duration of flows required to achieve ideal soil moisture levels is difficult to estimate. Soil moisture levels post-saturation by flood flows will be influenced primarily by ambient climatic conditions and not necessarily be flow-related. Typically, durations of flows of the desired magnitude have been short (see below) and it is likely that maintenance of the existing frequency and 'typical' duration is the limit of what can be achieved.

Results:

Reach 1 – KDD to Tarrara Bar (33km below KDD)

There was one vegetation transect (WRC2) located in Reach 1. The transect was closest to cross section 23255 and a discharge of 750 m^3/s was required to achieve the target water level.

Spells analysis indicated that:

- There are one or more high spells exceeding 750 m^3/s in 55 per cent of years, or no high spells of 750 m^3/s in 45 per cent of years.
- The longest total annual duration of flows in excess of 750 m^3/s was 96 days in 2001 and in years where spells occurred, the median duration was one day.

Analysis of the occurrence of spells on a monthly basis was also completed (Figure 46). Spells greater than 750 m^3/s typically occur during the late wet season months of February and March. This appears to coincide with the reported seedfall period for northern eucalypt species (Pettit and Froend, 2000).

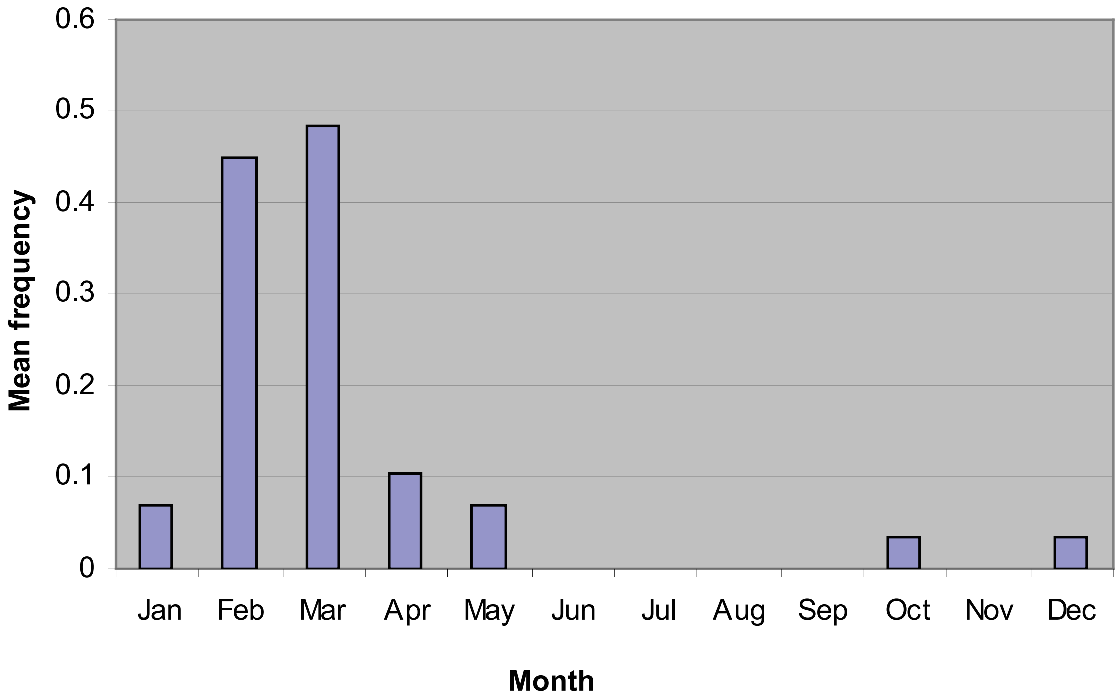

Figure 46: Mean monthly number of spells >750 m^3/s

Reach 2 – Tarrara Bar to the start of the tidal influence (76km below the KDD)

Three transects were located within Reach 2. The required discharges to achieve the minimum target water level for each transect are shown in Table 14.

Table 14: Required discharge for Reach 2 transects.

Vegetation transect	Cross section	Target minimum water level (mAHD)	Discharge (m^3/s)
WRC3	42422	12.5	1500
WRC4	53664	9.5	1100
WRC6	41452	13.0	1600

The mean required target discharge for Reach 2 is 1,400 m^3/s.

Analysis of the recorded time series indicates that spells equal to or greater than 1,400 m^3/s:

- Occur one or more times in 25 per cent of years (Figure 47);
- Have a median total annual duration of one day (in years in which spells occur); and
- The longest total annual duration for flows in excess of 1,400 m^3/s was 20 days in 2001.

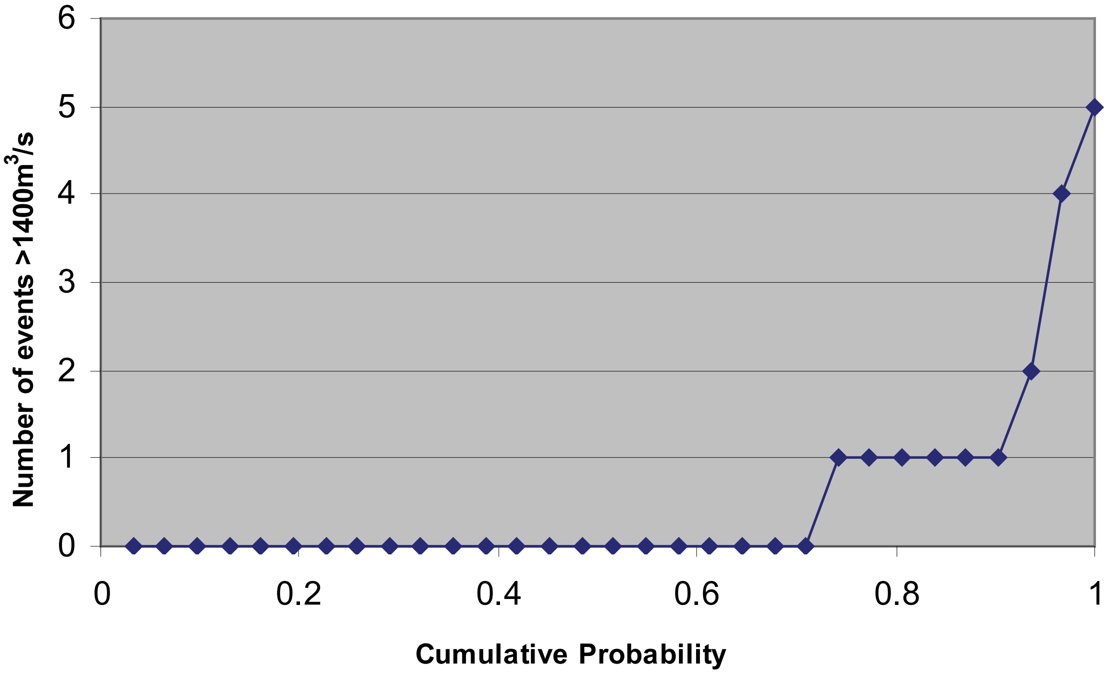

Figure 47: Annual frequency of flows greater than 1,400 m^3/s

Spells of this magnitude occur almost invariably in the late wet season months of February, March or April (Figure 48).

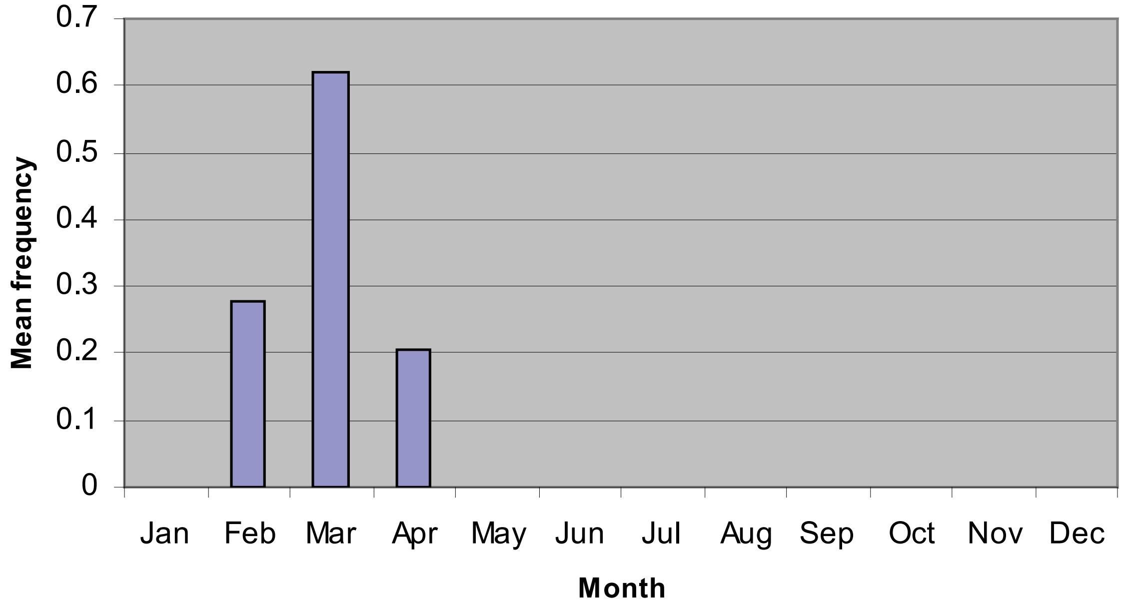

Figure 48: Frequency by month of flows in excess of 1,400 m^3/s

Recommendation:

- Flows in Reach 1 equal to or greater than 750 m^3/s are required for at least one day between February and April every second year.
- Flows in Reach 2 equal to or greater than 1,400 m^3/s are required for at least one day between February and April once every four years.

8d) Bankfull flood flows

The high bank vegetation of the 'old' riparian zone is degenerating; however some elements of this vegetative community may be maintained by irregular high magnitude flood flows equivalent to those observed in the 2000 wet season. An event of this magnitude might occur only once in every 20 years. This flow-ecology linkage should not be viewed as a priority.

Applicable to:

All reaches. Comparable to flow-ecology linkages 5a, 6a and 8b.

Approach:

Over-bank flood flows occurred during 2000 and 2002. The peak mean daily flows during these events were in the vicinity of 3,700 to 4,000 m^3/s. The occurrence of events in this range has been characterised previously for flow-ecology linkage 6a. Meeting flow-ecology linkage 6a will also satisfy linkage 8d.

Anecdotal evidence confirms that the 2000 and 2002 events stimulated some regeneration (including establishment of seedlings) in the 'old' riparian zone, indicating that flows of similar magnitude will satisfy this objective.

Recommendation:

- Target ARI of 27 – 35 years for peak events in the vicinity of 3,700 to 4,000 m^3/s should be maintained.
- No further regulation of the Dunham River should be permitted.

4.2 Summary of flow requirements

The flow recommendations presented in the previous sections have been consolidated and summarised into dry season and wet season ecological water requirements. Dry season flow recommendations have typically been presented as minima below which flows should not fall. The exception being flow-ecology linkages 1b, 2a and 2c, which limit the reduction in dry season flows from one year to the next rather than having an absolute minimum flow.

By ranking the flow recommendations for the remaining dry season flow-ecology linkages it can be seen that a dry season minimum of 42 m^3/s will satisfy all of the minimum flow recommendations (Table 15). That is, if dry season flows are maintained at 42 m^3/s or higher, then the majority of dry season flow-ecology linkages will be satisfied.

Table 15 Ranking dry season ecological water requirements

Flow Requirements	Season	Reach	Flow-ecology linkages Satisfied
• Minimum of 42 m^3/s in Reach 1 and 2	Dry	1,2	1a
• Minimum of 37 m^3/s in Reach 1 and 2	Dry	1,2	1c
• Trigger level of 35 m^3/s in Reach 1 and 2 (commence monitoring if flows fall below 35 m^3/s)	Dry	1,2	1g, 2d, 7a
• Minimum of 25 m^3/s in Reach 1 and 2	Dry	1,2	2b
• Minimum of 10 m^3/s in Reach 1, 2 and 3	Dry	1,2,3	2d, 3a
• Limited rate of change from one dry season to the next (effective when mean discharge for the previous Oct/Nov was above 70 m^3/s)	Dry	1,2	1b, 2a, 2c

Wet season flow requirements require a number of events of varying magnitude, duration and frequency. The wet season flow recommendations are summarised and ranked in Table 16 from lowest to highest target peaks.

Table 16 Ranking wet season ecological water requirements.

Flow requirements	Season	Reach	Flow-ecology linkages satisfied
• Minimum of 50 m^3/s in January • Minimum of 57 m^3/s in February and March • Minimum of 53 m^3/s in April • Minimum of 48 m^3/s from 1st to 15th May	Wet	1,2,3	3c
• Flows greater than 100 m^3/s for a minimum 18 days per year in Reach 2	Wet	1,2	3b
• Four spells above 125 m^3/s with a total duration of at least 10 days in Reach 1 • Two spells above 200 m^3/s with a total duration of at least five days in Reach 2 • One spell above 300 m^3/s with a minimum duration of two days in Reach 3	Wet	1,2,3	1d, 1e, 8a
• One spell above 425 m^3/s with a minimum duration of two days in Reach 1 • Minimum of 20 m^3/s in Reach 2 • Minimum of 10 m^3/s in Reach 3	Wet	1,2,3	1f
• High flow event of at least 750 m^3/s every two years in Reach 1 • High flow event of at least 1,400 m^3/s every four years in Reach 2	Wet	1,2,3	4a ,8c
• Flood event with peak mean daily flow of 3,700-4,000 m^3/s every 27-35 years in Reach 1, 2 and 3	Wet	1,2,3	5a, 6a, 8b, 8d

The result of wet season flow requirements that incorporate events of varying frequency is four scenarios that should occur annually, once in two years, once in four years and once in 27-35 years.

The comprehensive annual ecological water requirements are more easily interpreted when summarised and presented as an annual hydrograph (Figure 49).

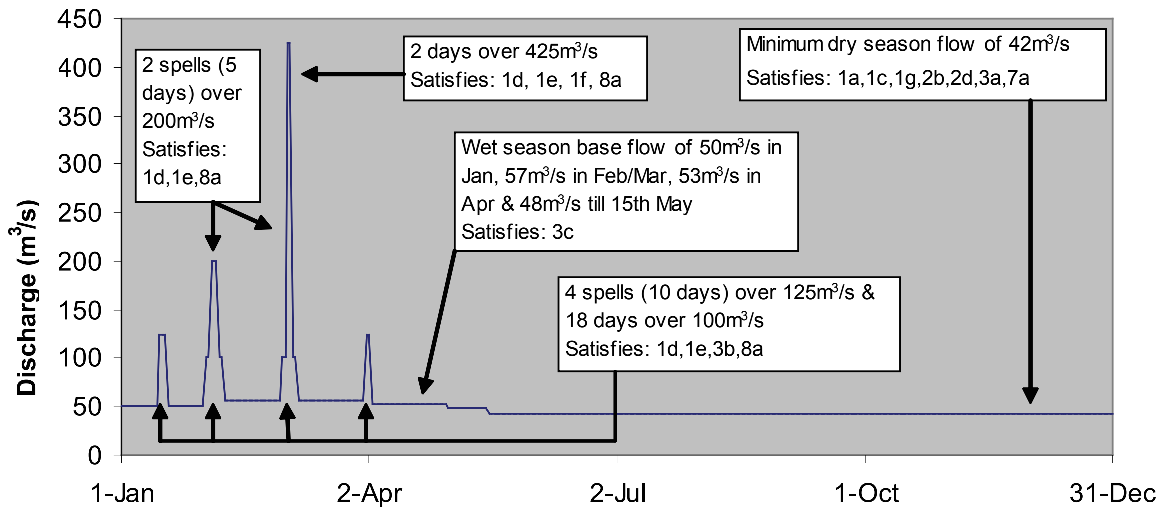

Figure 49: Annual lower Ord River comprehensive EWR hydrograph

The above scenario satisfies each of the identified flow requirements (as marked) and gives an indication of the possible timing of such events.

The comprehensive wet season ecological water requirement scenarios that occur less frequently are also summarised and compared against the comprehensive annual ecological water requirement hydrograph in Figure 50. The only difference being the magnitude of the peak flood event.

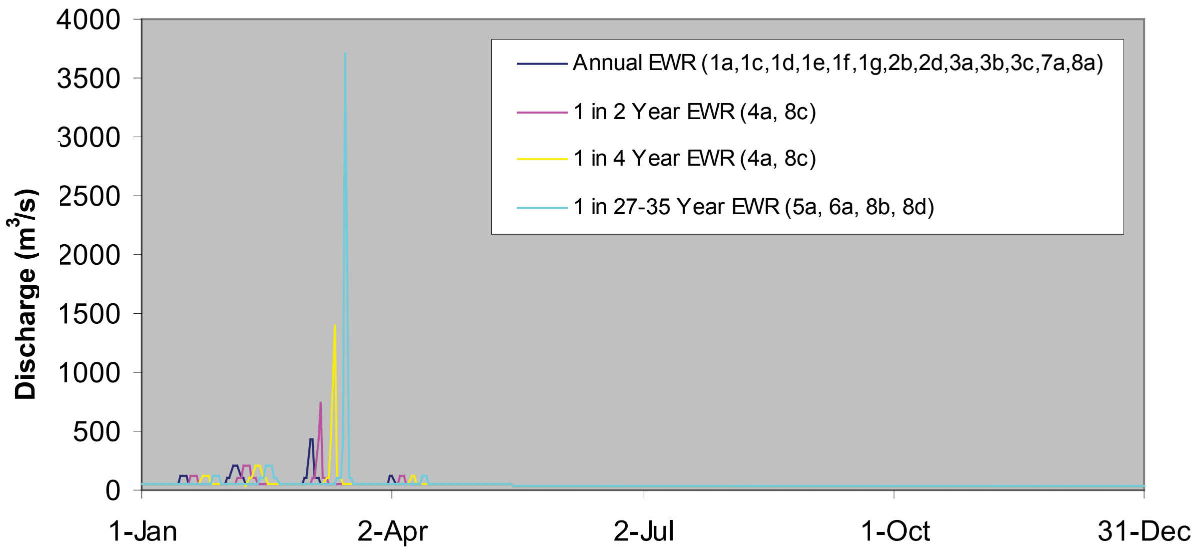

Figure 50: Lower Ord River comprehensive EWR hydrographs

An indicative monthly breakdown and annual total discharge required to meet each of the comprehensive EWR scenarios are given in Table 17.

Table 17: Total monthly comprehensive EWR discharge

	ANNUAL EWR (GL)	1 in 2 year EWR (GL)	1 in 4 year EWR (GL)	1 in 27-35 year EWR (GL)
Jan	153	153	153	153
Feb	190	190	190	190
Mar	231	259	315	514
Apr	150	150	150	150
May	120	120	120	120
Jun	109	109	109	109
Jul	112	112	112	112
Aug	112	112	112	112
Sep	109	109	109	109
Oct	112	112	112	112
Nov	109	109	109	109
Dec	112	112	112	112
Total	1619	1647	1703	1902

To put the comprehensive ecological water requirement scenarios in perspective, comparisons have been made with recent flows for the lower Ord River (dry, wet and average years) from the 1974-2005 historical flow hydrograph. The drought year of 1985 was the driest year since 1974, the 2000 floods gave the highest flows in the past 30 years, while 2003 was an average year with annual discharge close to the median for the period 1974 to 2005 (Figure 51).

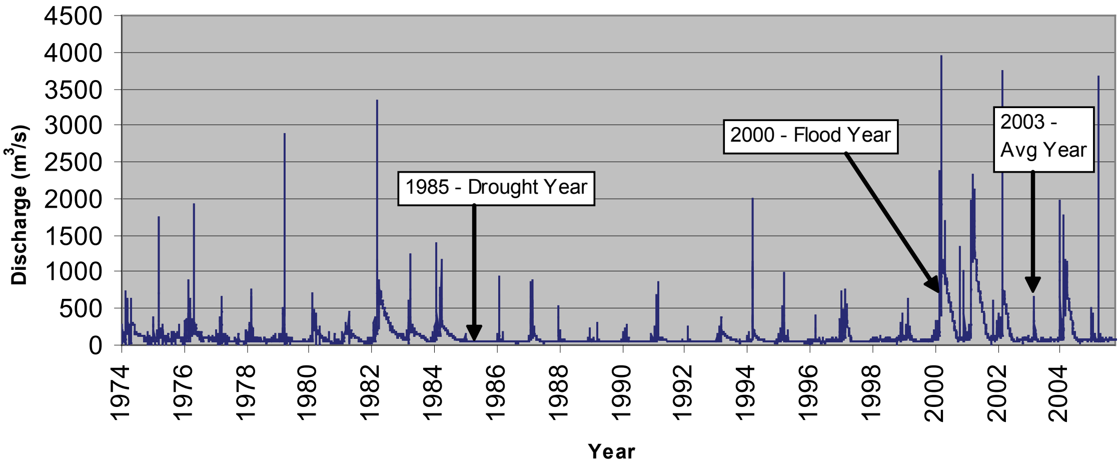

Figure 51: Mean daily discharge for representative years from the historical flows on the lower Ord River: 1974-2005

The total discharge for the annual EWR of 1,619 GL (table 17) is similar to the 1985 drought year discharge of 1,538 GL. However, when the hydrographs are compared, the actual flow regimes are found to be quite different. In 1985, there were no flood pulses during the wet season and the dry season base-flow remained greater than 42 m^3/s. The annual EWR contains a similar wet season base-flow but has four minor flood pulses and a dry season discharge of 42 m^3/s (Figure 52).

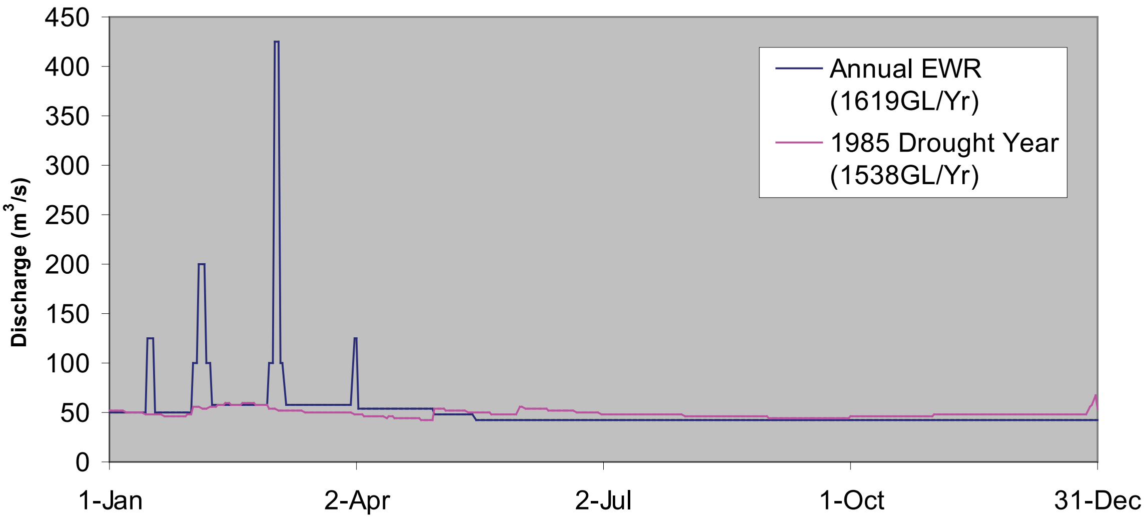

Figure 52: Comparison of mean daily discharge for comprehensive annual EWR against 1985 'drought year'

The total discharge for the annual EWR of 1,619 GL is considerably less than the median stream flow since regulation of 2,830 GL (Trayler *et al*., 2006). When compared with an 'average year', such as 2003 which had an annual flow of 2,638 GL, the wet season variability and magnitude of events is somewhat similar but the dry season flows (due to hydroelectric power generation)[9] are much greater than the comprehensive EWR of 42 m^3/s. Wet season base-flows in 2003 are also considerably higher than those of the annual EWR (Figure 53).

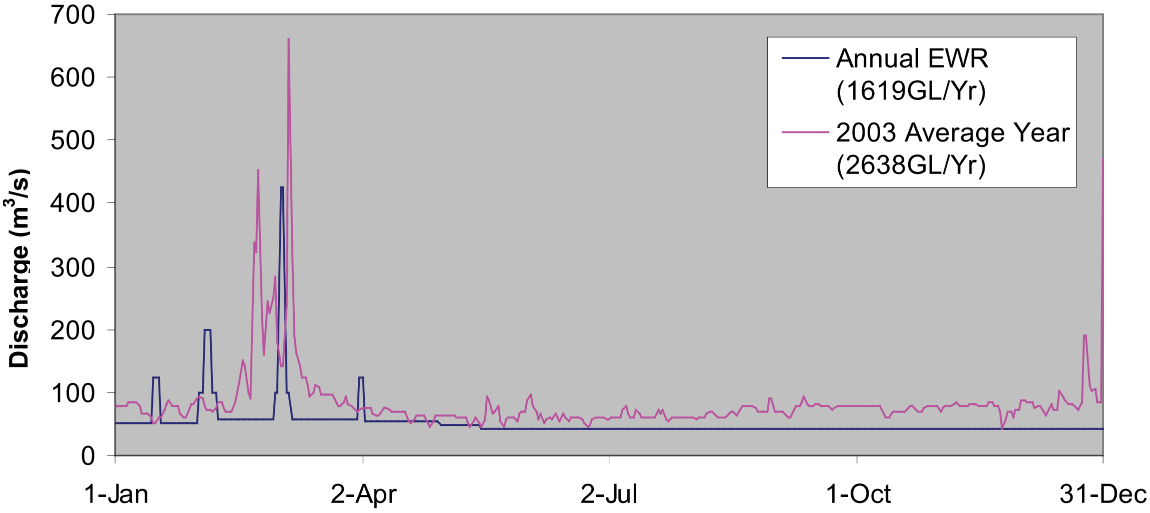

Figure 53: Comparison of mean daily discharge for comprehensive annual EWR against 2003 'average year'

The comprehensive 27 to 35-year flood EWR reaches a similar peak as the 2000 floods, but the short duration means that the annual discharge of 1,902 GL is much less than the 14,129,GL discharge of 2000, the wettest year since regulation (Figure 54).

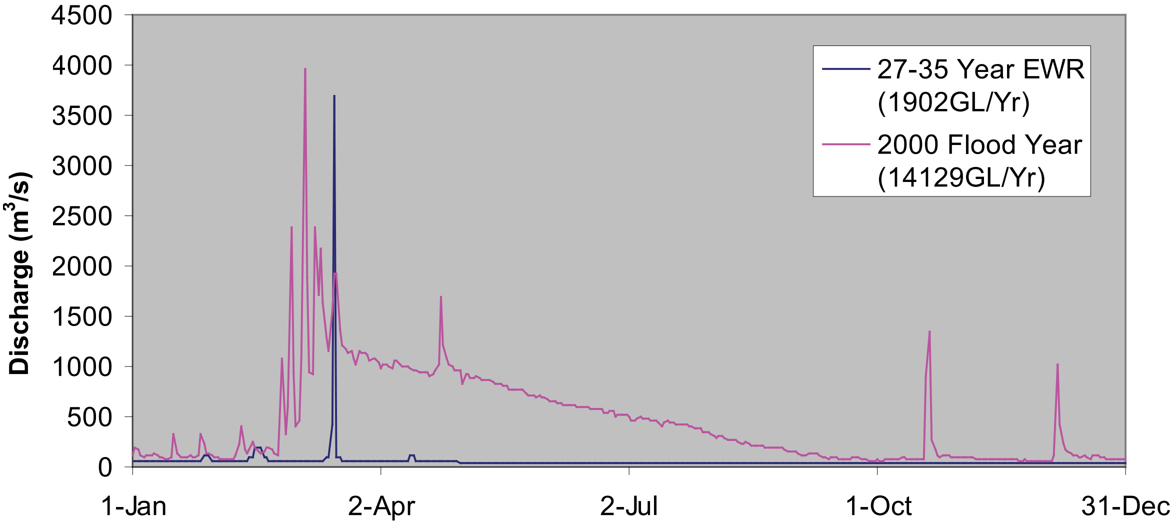

Figure 54: Comparison of mean daily discharge for comprehensive 27 to 35-year flood EWR against 2000 'flood year'

9 The hydropower station has operated since 1996, covering approximately 30 per cent of the period since the construction of the Ord River Dam. The high dry, and to some degree wet season, baseflows for 2003 (as an indicative 'average' year) compared to the comprehensive EWR are a function of the releases for hydropower generation.

In the event of a flood of this magnitude occurring again, the flood hydrograph may still resemble that of 2000, particularly if the majority of runoff comes from the upper Ord catchment. In this scenario, much of the flood volume is trapped and stored in Lake Argyle with large overflow releases continuing over following months (Figure 54). However, if the majority of flow comes from the Dunham catchment, as occurred in 2005, then the flood hydrograph will be much closer to the comprehensive EWR and recede rapidly (Figure 55).

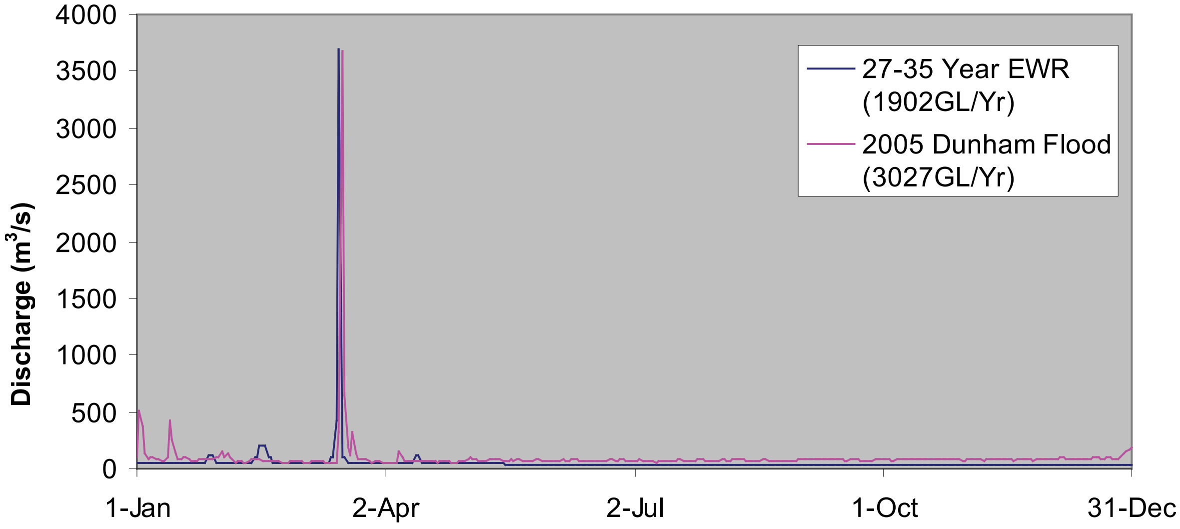

Figure 55: Comparison of comprehensive 27 to 35-year flood EWR against 2005 'Dunham flood'

5 Comparison to Interim Environmental Water Provisions

5.1 Interim EWR

During 2001, in consultation with the expert panel, the Department determined an interim EWR for the lower Ord River. In the absence of quantitative data directly linking water levels and ecological responses for the lower Ord River, it was not possible to use the preferred Holistic Approach. Rather, changes in wetted perimeter relative to different discharge levels were used to estimate in-river ecological change against a dry season base-flow of 50 m^3/s. From this process, the interim EWR was determined as a minimum flow rate of 45 m^3/s from the KDD to the 57.5 km point and 40 m^3/s below that point (Department of Water, 2006). The interim EWR was seen to limit the change to the dry season flows and hence to reduce the risk of triggering the adverse dry season ecological impacts identified by the expert panel – thereby maintaining the biodiversity and essential ecosystem processes of the riverine environment established since regulation at a low level of risk.

5.2 Interim Environmental Water Provision

The objective of the interim EWP was to establish a sustainable limit for water released from Lake Argyle that enables further irrigation development but ensures that the health of the lower Ord River is sustained and its modified riverine and aquatic habitats are protected. After considering social and cultural values, potential irrigation demands, economic impacts and ecological concerns of the Scientific Panel, the EWPs outlined in Table 18 were proposed. The EWPs essentially satisfy the interim EWR other than in drought years when a further reduction in flows is proposed if levels in Lake Argyle drop below 76 m AHD.

Table 18: Proposed interim EWP for the lower Ord River

Hydrologic Conditions	Lake Argyle Level m AHD	Minimum monthly flows* for the lower Ord River between	
		the Dunham River confluence to House Roof Hill (57.5 km)	House Roof Hill to the tidal reach
Non-drought	>76 m	45 m^3/sec	40 m^3/sec
Drought	<76 m	35 m^3/sec	30 m^3/sec

** Maintained from waters released from Kununurra Diversion Dam or contributed by the Dunham River*

5.3 Comparison of comprehensive EWR with Interim EWP

The interim EWP of 45 m^3/s was essentially a dry season flow requirement and is quite similar to the comprehensive EWR dry season flow of 42 m^3/s. When summed to give an annual discharge, the interim EWP gives an annual discharge of 1,419 GL, almost 200 GL less than the comprehensive annual EWR of 1,619 GL. The main difference being that the interim EWR made no attempt to include high flow events during the wet season. It did, however, acknowledge the importance of high flows provided by the unregulated Dunham River in maintaining the wet season ecological functions of the lower Ord River. To maintain these values the exclusion of new dam developments within the catchment of the lower Ord River was identified as an integral part of the Interim EWP.

During drought periods (when Lake Argyle Dam levels fall below 76m AHD) the interim EWP of 35 m^3/s is around 500 GL lower than the comprehensive EWR with an annual discharge of 1,104 GL. It should be noted that while drought period releases have not been specifically addressed as part of the comprehensive EWR, they will be considered carefully as part of the upcoming licence assessments and EWP process.

The interim drought period EWP of 35 m^3/s is more than 400 GL less than the 1985 drought year discharge of 1,538 GL (the driest year since regulation, Figure 52). However, in 1985 the drought period EWP would not have been triggered as Lake Argyle Dam levels remained above 76m, due in part to the absence of hydro-power releases and an above average wet season the previous year.

6 Implementation

The implementation of the flow regime described in this document will be achieved primarily through manipulating releases from the Ord River Dam and through the Kununurra Diversion Dam. These releases will need to be balanced with water demand for irrigation and power generation and take into consideration flows from the Dunham River. The Dunham River flows are generally restricted to the wet season and as discussed previously, it is anticipated that Dunham River flows will continue to be important in achieving targets for wet season flow objectives. This is particularly the case with the larger inter-annual target peaks, acknowledging the constraints that the Ord River Dam imposes on providing flows of these magnitudes to the lower Ord River. Therefore, in the absence of additional understanding of the flow-ecology linkages in the lower Ord River, it is recommended that no further regulation of the Dunham River is permitted.

In situations where Dunham River flows are marginally short of target peaks (particularly the lower to moderately sized wet season target flows) it may be possible to top up flows down the lower Ord with releases from the dams. Management of flows in this way would require close monitoring of flows in the lower Ord and Dunham and the capability to manipulate releases from the dams at short notice. Adequate monitoring and response systems would need to be developed to support this level of flow management.

Monitoring and response systems will also be required to manage dry season flows. Flow recommendations such as 1b will require the calculation of allowable rates of change from late dry season one year to the start of the following dry season. Similar rules on the allowable rates of change could also be incorporated into any revised or new operating strategies for the dams to manage shutdowns. In developing dry season minimum flows, shutdowns were excluded from analyses. However, it is acknowledged that shutdowns may be necessary in the future to maintain infrastructure.

It is anticipated that the design of management and monitoring systems to enable this refined level of flows management will be incorporated into the development of new or revised operating strategies resulting from expansion of the irrigation areas, and/or an increase in power demand from the hydro-electric plant at the Ord River Dam.

The planned process for the development and revision of operating strategies and ultimately the revision of the Water Management Plan for the lower Ord River incorporating the comprehensive EWR and subsequent EWP, is discussed below.

6.1 Where to from here

The recently released *Ord River Water Management Plan* (DoW, 2006) allocates sufficient water for irrigation developments to proceed in the Western Australian portion of the M2 Supply Area and in areas that will take water from downstream of House Roof Hill. However, further work is required to incorporate the revised EWR presented in this document and recent improvements in knowledge of the hydrology of the lower Ord River and resolve the competition between hydro-power generation and further allocations to irrigation. Specifically, the conditions under which additional water can be made available for use in the Northern Territory portion of the M2 Supply Area need to be determined.

This EWR and updated hydrology for the lower Ord River will be used, in conjunction with the sustainable diversion limits of the current plan, to assess the licence application for the first phase of M2 Supply Area development. Under the provisions of the *RIWI Act* applicants are required to advertise their licence application. The environmental effect of granting the licence is expected to be assessed by the EPA under the provisions of the Western Australian *EP Act* and the Commonwealth Department of Environment and Heritage under the provisions of the *EPBC Act*. Reservoir simulations will be repeated, using updated information, to establish compatible water release rules for the Ord River Dam Hydro-power Station with the new licence. As part of the assessment, the Department will address input received from key stakeholders and the community on the application and the current plan, and release a report on the proposed licence conditions and power station water release rules. The report will inform the EPA and the Commonwealth Department of Environment and Heritage (DEH) on the water management aspects of the M2 Supply Area development and will be used to assist in their environmental impact assessment of the development.

Resolution of the competition between additional water for irrigation (above the initial 400 GL/yr of the current plan) and hydro-power generation is required before the NT portion of the M2 Supply Area can proceed. This will require input from the key stakeholders and the community, and further reservoir simulations of allocation options, to fine tune the environmental water provisions and establish new sustainable diversion limits of this plan.

6.2 Monitoring

The Department of Water currently conducts water quality monitoring programs for the lower Ord from Kununurra to House Roof Hill to monitor the potential impact of irrigation return flows on the lower Ord, and within Cambridge Gulf to monitor water quality in the Ord Estuary. In 2003, the Department also commissioned a trial remote sensing project to map functional habitats in the lower Ord River. In 2006, this trial was extended to a monitoring program for a further three years. It is intended that the habitat mapping project and water quality monitoring programs will form part of a comprehensive monitoring program for the lower Ord. This program will aim to:

- further our understanding of the natural dynamics of river and riparian ecosystems in the lower Ord;
- provide a baseline for future monitoring to assess the adequacy of environmental water provisions once implemented;
- facilitate review and refinement of environmental water provisions if and when necessary; and
- ensure adequate management and protection of existing ecological (and other) values of the system.

It is intended that the design and implementation of this monitoring program will be commenced in 2007. The potential for this monitoring program to complement existing and additional required monitoring for Department of Water and other agencies' objectives will be investigated and where possible programs aligned.

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Appendices

Appendix 1 — Development of time series of mean daily flow for the lower Ord River.

The development of an EWR using the flow events method required the compiling a mean daily time series of flow for the lower Ord River. However, there was insufficient gauged record on the lower Ord River for this purpose and therefore a longer time series of daily flows was developed based on the main inputs to the lower Ord. The main inputs to the lower Ord River are the releases from the Kununurra Diversion Dam and the flow from the Dunham River, the largest tributary that flows into the Ord, approximately two kilometres downstream from the Kununurra Diversion Dam.

The time series adopted to analyse the various metrics is 1974-2005. The first two years following the construction of the Ord River Dam have been excluded from the time series as they are not representative of the post-regulation flows (as the dam was simply filling up). The degree to which the flow in the Ord River has been regulated has varied over the period 1974-2005, most markedly through the establishment of a hydropower scheme at the Ord River Dam in 1996. To characterise the differing degrees of regulation the following time series covering this period were developed:

- the best estimates of the observed flows in the lower Ord River (including an estimate of observed Dunham River flows); and
- the best estimates of the natural (pre-regulation) streamflow.

Recorded data

The most complete recorded daily streamflow data available for the lower Ord River is from the Tarrara Bar gauging station, operated by the Department of Water from October 2001 to 2005. The quality of the flow estimates at this station is relatively poor due to a limited number of discharge measurements. Continuous water level information is available at six other sites on the lower Ord River upstream of the tidal influence for short periods (Table 1).

Water Corporation, which is currently vested with the operation of the gates at the KDD, has records of releases through the structure. Unfortunately, the data is incomplete and the data quality is uncertain. Hard copy records of the daily flow past the KDD and the daily diversions into the irrigation area for 1974 to 1983 are available. Electronic files of the estimated releases from the KDD since 1998 are also available. However, the records for the daily releases from the KDD for 1983 to 1998 are not currently available.

In 2002, the Department of Water (then the Department of Environment) installed a river level recording station on the lower reaches of the Dunham River, ~12 kilometres from the Ord River confluence, which encompasses the flow from 90 per cent of the entire Dunham River catchment. An additional river level gauging station has been in operation in the upper reaches of the Dunham River since the late 1960s and covers the flow from approximately 40 per cent of the entire Dunham River catchment.

Continuous water level and spillway flow estimates are available for the Ord River Dam since its completion in 1972. Daily valve release information for the Ord River Dam is available for certain periods; however, there are lengthy periods where no information is available.

Table 19. Summary of the available river level information on the lower Ord River

Gauging Station No.	Name	Period of Operation
809324	Kununurra Diversion Dam	1/1/74 – 1/1/83 1/1/98 – pres
809339	Ord River @ Tarrara Bar	5/10/98 – pres
809340	Dunham River @ Flying Fox Hole	22/11/02 – pres
8091048	Ord River @ Carlton Crossing	26/10/94 – 20/12/94 25/10/95 – 22/1/96
8091130	Dunham River @Victoria Hwy ds 200 m	1/10/98 – 30/11/98
8091151	Ord River ~ Div Dam 50 m ds RB	28/9/93 – 5/10/93 1/10/98 – 9/2/99
8091152	Ord River @ River Farm Rd Block 205	28/9/93 – 4/10/93 25/9/98 – 21/10/98
8091153	Ord River @ Ivanhoe Crossing 200 m us LB	29/9/93 – 4/10/93 1/10/98 – 8/10/98
8091154	Ord River @ Buttons Gap	28/9/93 – 4/10/93 25/9/98 – 21/10/98

Methodology

The estimated flow in the lower Ord River is the sum of the flow on the Ord River through the Kununurra Diversion Dam and the streamflow from the Dunham River. The contribution of other tributaries and the return flows from the existing irrigation area has been assumed to be a constant flow rate along the lower Ord River equivalent to the estimated flow just downstream of the Dunham River confluence.

Best estimate of the observed flows in the lower Ord River

During periods for which recorded estimates of the releases from the KDD are available (1974-83; 1998-2005) estimates of the Dunham River flow only are required to determine the flow passing down the lower Ord River. Dunham River inflows to the lower Ord River were estimated by scaling the recorded flows for the upstream gauge, which monitors flows from 40 per cent of the entire Dunham River catchment. The formula used to scale the flows was:

$$q_{DR} = q_{DG}\left(\frac{4100}{1600}\right)^{0.75} \qquad \text{equation 1}$$

where q_{DR} = Dunham River discharge to lower Ord River
q_{DG} = Gauged flow at the Dunham River@ Dunham Gorge

During periods for which the release information from KDD is not available (1984-97), an estimate of both the KDD release and the contribution from the Dunham River is required. The estimated release from KDD was calculated by subtracting a net evaporation and irrigation demand, based on a mixture of horticultural crops, from the release information from Lake Argyle (Ord River Dam). Recorded daily release information for the Ord River Dam is available for the majority of the period since April 1996. Historic monthly releases from the Ord River Dam are available for the period January 1984 to May 1991. The daily releases during this period have been assumed to be constant across the month. For the remaining periods between June 1991 and March 1996 inclusive, a constant release of 55 m^3/s from the Ord River Dam has been assumed, with no allowance for any variability. This flow rate was thought to provide sufficient depth over in-stream obstacles to allow for tour boats to navigate between the two dams.

The runoff generated between the dams has also been addressed in order to estimate the flow through KDD and down the lower Ord. This catchment area has been combined with the ungauged portion of the Dunham River and scaled using the Dunham River at Dunham Gorge recorded flows (equation 2):

$$q_{DR} = q_{DG}\left(\frac{5100}{1600}\right)^{0.75} \qquad \text{equation 2}$$

where q_{DR} = Dunham River and KDD catchment discharge to lower Ord River
q_{DG} = Gauged flow at the Dunham River@ Dunham Gorge

For short periods in 1993, 1994 and 1995 gauged data is available at locations on the lower Ord River (Table 1). This available data was collected as part of trial release studies, during which the releases from the KDD was varied over relatively short time periods. The data was adopted as the best estimate of flows in the lower Ord during these periods, despite discrepancies with the estimates provided by alternative measures.

Best estimate of the expected natural (pre-regulation) flow in the lower Ord River

The flow in the lower Ord River that would have been expected under a pre-regulation scenario with both dams on the Ord River not present has been estimated using a rainfall runoff model. A LUCICAT model of the entire Ord River catchment, including the Dunham River catchment, was developed and incorporated some 96 sub-catchments. The daily rainfall information (1900 – June 2005) for all Bureau of Meteorology and Department of Water monitoring sites was input and the various parameters within the model were calibrated for 1973-2003 using the gauged data for the main gauged catchments (Station numbers 809310, 809316, 809315, 809322, 809321, and 809320; Table 1). The flow at the confluence of the Dunham and Ord Rivers for the required period (1974-2005) was output from the model. This flow has been adopted as the best estimate of the natural (pre-regulation) flow in the lower Ord River for the 1974 to 2004 period. The modelled data was extended to May 2005 using the available gauged flow record and an estimation of the flow generated in the ungauged catchment. The flow generated in the ungauged catchment was estimated by areally scaling the gauged flow data for the Dunham River at Dunham Gorge.

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.
Aboriginal heritage	Includes both the physical and cultural aspects and relates to the significance of places and objects to Aboriginal people in terms of traditions, observations, customs and beliefs.
Allocation limit (AL)	The quantity of water available for consumptive use, after Environmental Water Provisions and domestic requirements have been set. Domestic Allocation: refers to the volume of water required for household purposes and the irrigation of a small domestic garden.
Aquifer	A geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water. Usually described by whether they consist of sedimentary deposits (sand and gravel) or fractured rock. Aquifer types include unconfined, confined and artesian.
Biodiversity	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. Biodiversity has two key aspects: its intrinsic value at the genetic, individual species, and species assemblages levels; and •its functional value at the ecosystem level. Two different species assemblages may have different intrinsic values but may still have the same functional value in terms of the part they play in maintaining ecosystem processes.
Conservation	The management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations, while maintaining its potential to meet the needs and aspirations of future generations. Thus conservation is the positive, embracing, preservation, maintenance, sustainable utilisation, restoration and enhancement of the natural environment.
Dissolved oxygen (DO)	The concentration of oxygen dissolved in water or effluent, normally measured in milligrams per litre (mg/L).
Ecological values	The natural ecological processes occurring within water-dependent ecosystems and the biodiversity of those systems.

Ecological water requirements (EWR)	The water regime needed to maintain ecological values 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, eg 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 provisions (EWP)	The water regimes that are provided as a result of the water allocation decision-making process taking into account ecological, social and economic values. 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.
	The combined loss of water by evaporation and transpiration. It includes water evaporated from the soil surface and water transpired by plants.
Flow-ecology linkage	Describe the link between components of the ecology or ecologically important features of the channel and components of the flow regime. These are used to frame or guide the determination of ecological water requirements.
Gigalitre (GL)	A commonly used term to measure large volumes of water, equal to one billion litres, one million cubic metres or one million kilolitres (kL).
Groundwater	Water found under the land surface which occupies the pores and crevices of soil or rock.
Groundwater area	An area proclaimed under the Rights in Water and Irrigation Act 1914 in which private groundwater abstraction is licensed.
Groundwater availability	The annual amount of groundwater available for abstraction, equal to the allocation limit minus any licensed entitlements.
GWhrs/yr	Gigawatt hours per year; the amount of (electrical) energy (generated or supplied) over a 12-month period.

Hectare (ha)	Hectare = 10,000 square metres or 2.47 acres.
Kilolitre (kL)	1 Kilolitre = 1,000 litres, one cubic metre or 220 gallons.
Levee	An artificial embankment or wall built to exclude flood waters, or a natural formation adjacent to a waterway built by the deposition of silt from floodwaters.
Licence	An authority to carry out an activity, usually issued under the powers of a particular Act of a parliament. Carrying out the activity without a licence where one is required is illegal and an offence against the Act.
m AHD	Australian Height Datum – height in metres above Mean Sea Level + 0.026 m at Fremantle.
m^3/sec	Cubic metres per second.
Megalitre (ML)	Unit of (water) volume; one million litres, a thousand kilolitres or a thousand cubic metres.
Mt/yr	Million tonnes per year.
MW	Megawatts; a measure of power or rate of (electrical) energy production
Policy	A definite course of action adopted as expedient or from other considerations.
ppt	Parts per thousands, same equivalent as grams/litres.
Precautionary principle	Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason to postpone measures to prevent environmental degradation. In the application of the precautionary principle, public and private decisions should be guided by: careful evaluation to avoid, wherever practicable, serious or irreversible damage to the environment; and an assessment of the risk-weighted consequences of various options. This provides an approach for considering the environmental impacts of a proposal on biodiversity values where there is a lack of knowledge and lack of scientific certainty. A useful methodology for applying the precautionary principle is that of Deville and Harding (1997).

Recharge area	An area through which water from a groundwater catchment percolates to replenish (recharge) an aquifer. An unconfined aquifer is recharged by rainfall throughout its distribution. Confined aquifers are recharged in specific areas where water leaks from overlying aquifers, or where the aquifer rises to meet the surface. Recharge of confined or artesian aquifers is often at some distance 'up flow' from points of extraction and discharge.
Salinity	The measure of total soluble (or dissolved) salt, ie mineral constituents in water. Water resources are classified on the basis of salinity in terms of Total Soluble Salts (TSS) or Total Dissolved Salts (TDS). TSS and TDS are measured by different processes, but for most purposes they can be read as the same thing. Measurements are usually in milligrams per litre (mg/L) or parts per thousand (ppt). Measurements in ppt can be converted to mg/L by multiplying by 1,000, eg seawater is approximately 35 ppt or 35,000 mg/L TSS. Salinity is also often expressed as electrical conductivity, measured by an electronic probe (conductivity meter). Water resources are classified as fresh, marginal, brackish or saline on the basis of salinity.
Social water requirements	Elements of the water regime that are identified to meet social (including cultural) values.
Stage 1 areas	The irrigation farmland areas serviced by the Stage 1 infrastructure of the Ord River Irrigation Project. Includes the areas supplied by the OIC (the M1 Channel Supply Area, the Packsaddle Pump Station Supply Area and the proposed Green Location development) and self supply areas (around Lake Kununurra), and land adjacent to the Ord River for the first 15 km downstream of the Diversion Dam.
Stage 1 (infrastructure)	All water related infrastructure that stores, diverts or transports water from the Ord River or drains water from farmland in the Ord Irrigation District, existing at September 2004. See also footnote on page 1.
Surface water	Water flowing or held in streams, rivers and other wetlands on the surface of the landscape.
Sustainability	Measure at the extent to which the needs of current and future generations are met through integration of environmental protection, social advancement and economic prosperity.

Sustainable yield	The limit on potentially divertible water available from a source is determined after taking account of "in-stream" values and making provision for environmental water needs, so that water extraction does not cause lowering of the watertable, intrusion of more saline water or environmental damage. The level of extraction measured over a specified planning timeframe that should not be exceeded to protect the higher value social, environmental and economic uses associated with the aquifer.
Water conservation	The management of water use to achieve and maintain an appropriate level of water use efficiency.
Water-dependent ecosystems	Those parts of the environment, the species composition and natural ecological processes of which are determined by the permanent or temporary presence of water resources, including flowing or standing water and water within groundwater aquifers.
Water efficiency	The minimisation of water use through adoption of best management practices.
Water entitlement	The quantity of water that a person is entitled to take on an annual basis as specified on a licence held by that person, and issued under the licensing powers of the *Rights in Water and Irrigation Act 1914*.
Water services provider licence	A licence issued under the provisions of the *Water Services Licensing Act 1995*, by the Economic Regulation Authority.
Water licence	A licence issued under the licensing provisions of the *Rights in Water and Irrigation Act 1914*.
Water resources	Water in the landscape (above and below ground) with current or potential value to ecosystems and the community.
Water regime	A description of the variation of flow rate in surface water or water level over time; it may also include a description of water quality.
Watercourse	A river, stream or creek in which water flows in a natural channel, whether permanently or intermittently.

Wetland	Wetlands are areas that are permanently, seasonally or intermittently waterlogged or inundated with water that may be fresh, saline, flowing or static, including areas of marine water the depth of which at low tide does not exceed six metres. In WA, the term 'wetland' is commonly used to describe that subgroup of non-marine wetlands that are in basin or flat form (such as lakes, sumplands, damplands and palusplain), with the term 'waterways' more commonly used to describe those occurring in channel form (such as rivers and streams).

Most definitions have been taken from the Department of Water's glossary located at http://portal.water.wa.gov.au/portal/page/portal/dow. The remainder were defined specifically for the purpose of this plan.

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