Environmental values, flow related issues and objectives for the lower Ord River, Western Australia.

Prepared by

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Foreword

This document has been developed as a summary of scientific investigations undertaken to date on the hydrology and ecology of the lower Ord River. This information, predominantly gathered since 1999, has been used to help identify flow related issues and objectives for the lower Ord River. The objectives will be used to guide the determination of ecological water requirements (EWRs) for the system. Details of the process for determining EWRs and progressing towards environmental water provisions (EWPs) and ultimately a revised Water Allocation Plan are also provided.

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1 Introduction

1.1 Ord River Study Area

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 46,100km^2, which extends into the Northern Territory. The 650km long Ord 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 4 500GL. The largest recorded flow was approximately 30 800m^3.sec^{-1} (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.

1.2 Ord River Development

The Ord River Irrigation Project, originally conceived in the 1940s, was commenced in 1963 with the commissioning of the Kununurra Diversion Dam and 12 000ha of serviced farmland on the fertile black floodplain soils of the Ord River valley. This was the first of four stages, with subsequent stages being the construction of the Ord River Dam and further expansion of the irrigated farmland. The Ord River Dam and associated irrigation works were completed in time for the 1973 irrigation season. However, further expansion of the distribution areas has not yet occurred for reasons including the marginal commercial viability of irrigated agriculture during the 1970s and 80s. The location of the dams, current irrigation area and potential future irrigation areas are shown in Figure 1.

The failure of cotton as the primary cash crop was a major early setback. Costs of controlling the *Heliothis* moth by intensive pesticide spraying had reached 50% of a growers total costs by 1974 (Le Page, 1986), making the crop uneconomic and causing significant environmental and health concerns. The remoteness of potential markets and consequent high costs of transport and supplies made finding alternative commercial crops difficult in subsequent years.

By the mid 1980s, however, with improved roads and better protection of produce during transport, horticultural crops became commercially attractive. Cucurbit crops such as melons and pumpkins, grown out of season from traditional areas in southern Australia, were introduced and bananas and mango plantations established. With confidence in the economic future of the district increasing, sugar production commenced in late 1995. The area irrigated has continued to grow, with over 11 000ha already utilised and approaching full development.

In the mid-1990's 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.

At about the same period, the Department of Resource Development (DRD), the agency responsible for coordinating development projects in Western Australia, sponsored a series of investigative studies and conceptual designs (DRD, 1995, 1997a, 1997b) to update earlier development plans. These provided a base for the Governments of Western Australia and the Northern Territory to call for expressions of interest from the private sector to consider financing the expansion of the irrigated areas.

In 1998, a joint venture of Wesfarmers Co. and the Marubeni Corporation were awarded preferred developer status to investigate the financial and environmental feasibility of a project based on the processing and export of raw sugar produced in the Ord Irrigation District. Known as the M2 Sugar Project it involves growing sugarcane on 32 000ha of farmland to the east of currently developed areas on the Weaber, Knox and Keep River Plains (Figure 1). In 1999, Henry Walker Elton Limited was selected as preferred tender to investigate the feasibility of developing approximately 4000 ha of serviced irrigation blocks on Mantinea Flats, about 50 to 70km downriver from the Kununurra Diversion Dam.

In December 2001, Wesfarmers and the Marubeni Corporation withdrew their proposal for the M2 Sugar Project citing low world sugar prices as a major issue affecting their withdrawal. The Western Australian Government is, however, committed to the expansion of the Ord Irrigation Area, with the Department of Industry and Resource Development (DoIR) currently acting as the proponent (November 2005), undertaking additional studies and seeking necessary approvals.

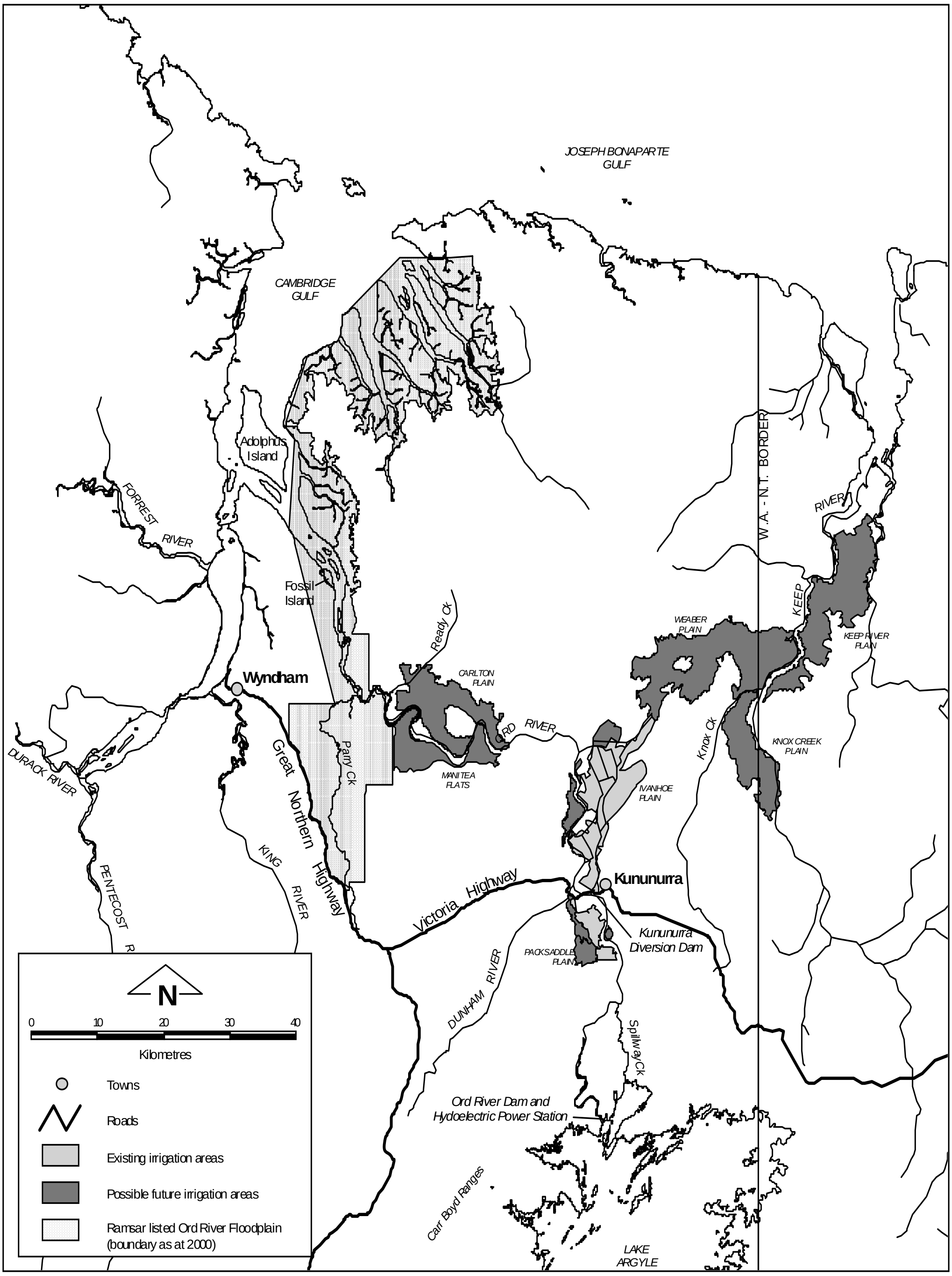

Figure 1: Location map showing area downstream of the Ord River Dam.

1.3 Allocation Planning

1.3.1 Responsibilities of the Department of Water

The Department of Water (formerly the Water and Rivers Commission) has overall responsibility for management of water resources of Western Australia and is the lead agency for their assessment, protection, and allocation to serve the competing needs for water within the Western Australian community. The Department's water resource allocation responsibilities are governed by the recently amended *Rights in Water and Irrigation Act* (1914).

In keeping with agreements made under the 1994 COAG Water Reform Framework Agreement the Western Australian Government ensures that explicit water provisions are made for the environment as part of it's allocation planning process. These are known as the Environmental Water Provisions (EWP). The Department of Water seeks to balance the ecological needs and social expectations for water in the natural environment with society's need to use water for economic benefit. The Department prepares allocation plans that propose how the resource should be shared between these conflicting pressures, seeks public input on the plans and refers them to the EPA for review if proposed diversions could have a significant environmental impact, as required under the *Environmental Protection Act* (1986). A sustainable diversion limit is set for particular resources to ensure that sufficient water is available for the protection of water-dependent ecosystems and to meet specific social needs.

The Department generally implements its allocation decisions through a water-licensing regime in areas proclaimed under the *Rights in Water and Irrigation Act* (1914)[1]. Licences grant a right to divert a specified quantity or share of a resource under specified conditions. The legislation sets out factors the Department (Note: legislation at completion of report refers to the Water and Rivers Commission) can consider when granting a licence. These include whether the applicant can legally hold a licence, whether the proposed use is consistent with an allocation plan, local by-laws or policy, whether it represents efficient water use, and whether it could impact other users or the environment. The Department has powers to set conditions on licence holders to ensure that the use is sustainable in the long term and environmental impacts are minimised.

1.3.2 1999 Interim Water Allocation Plan for the Lower Ord River

The Water and Rivers Commission (WRC) released an Interim Water Allocation Plan for the lower Ord River in 1999 (WRC, 1999). In that plan, the approach taken to determining the environmental water provision (EWP) was a rule of thumb 20th percentile of the natural flows. Little ecological data were available to justify a more sophisticated approach. A volume of $600GL.yr^{-1}$ was to be released to meet the environmental water provision. In keeping with the precautionary principle,

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[1] Under the amended Act local by-laws can be written to manage use in a local area by means other than licensing.

approximately 265GL remained unallocated. That is, 1235 $GL.yr^{-1}$ of an estimated possible 1500 $GL.yr^{-1}$ was allocated to allow some flexibility in the allocation process as the planning and development of the Stage 2 area progressed and additional information on the ecological water requirements (EWRs)[2] of the system became available. Priority for this (unallocated 265GL) water was to meet revised environmental provisions when adequate data on riverine ecology became available and an additional dry season flow provision was foreshadowed to mitigate irrigation return (WRC, 1999). Despite this, public comments on the 1999 draft water allocation plan considered that the Commission had not adequately protected the environmental values that had arisen in the 30 years since regulation altered the hydrology. Strategic advice from the Environmental Protection Authority (EPA) recommended that the Commission review the proposed environmental water provisions and that maintenance of the riverine environmental values established since the construction of the Ord River Dam be the basis of that review. The EPA also recommended that the Commission seek advice from a panel with expert knowledge of tropical river ecosystems and undertake further community consultation. The Commission subsequently established a Community Reference Group and Scientific Panel to provide input towards establishing socio-cultural and ecological water requirements, respectively.

1.3.3 Towards a Revised Allocation Plan

The Scientific Panel (see Appendix 1) was established to assist the Water and Rivers Commission in determining interim estimates of the water regimes needed to maintain the ecological values of water dependent ecosystems, in the lower Ord River, at a low level of risk – the interim ecological water requirements (EWRs).

The Scientific Panel identified important physical and biological attributes of the Ord River system and the water regime dependency of those attributes (Table 1). Each attribute was described in terms of the pre and post-regulation hydrology and an assessment made of the potential risk (to each attribute) associated with reductions in the current flow regime.

The Panel emphasised the limitations imposed by the minimal ecological data. Within that constraint, they identified the maintenance of an adequate dry season flow as a key consideration in determining the ecological water requirements. They made a number of recommendations (WRC, 2000b), including:

- Dry season water levels and flows should be maintained at current or possibly slightly lower levels. The level to which flows could be lowered would be dependent on assessment of impacts on habitat and water quality.
- Flows could be allowed to gradually decline towards the end of the dry season, but not to the extent where the river would recede to isolated pools.

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[2] Defined here as the water regime required to maintain the post-regulation environment in the Lower Ord River at a low level of risk.

- To maintain present ecological processes, waterbird and aquatic invertebrate values of the lower Ord River floodplain, there should be no significant diminution in the existing frequency and size of flood events. Flood flows down the Dunham River were seen as critical, and as such, the Dunham should not be impounded.

The Scientific Panel also identified a number of ecological components that were important to maintaining the health of the modified environment and required maintenance of an adequate dry season flow rate. In brief, these include:

- limiting the encroachment of macrophytes and terrestrial vegetation;
- maintaining in-stream habitat for invertebrates and fish;
- maintaining water quality within and between river pools, including the avoidance of diurnal anoxia;
- maintaining adequate connections between pools and river reaches; and
- maintaining carbon and nutrient transport along the river.

At that time there were no quantitative data available directly linking water levels and ecological responses for the lower Ord River. Therefore the approach undertaken by the Commission in determining ecological water requirements was to determine changes in the dry season wetted perimeter relative to different discharge levels. Wetted perimeter was interpreted to provide some measure of change in the channel area available for fish and invertebrates and to examine proportional changes of deep (>1m) and shallow (<1m) “habitat” with decreased flow volume. The selection of these zones was not based on knowledge of species habitat requirements, but rather an assumption that shallow, slow flowing areas would support different species and age-class assemblages than deeper, faster flowing areas.

A total of 51 channel cross sections were surveyed below the KDD in June 2000. These were located within the three distinct geomorphological reaches: below KDD to Tarrara Bar (Reach 1); from Tarrara Bar to the start of the tidal influence (73 km below the KDD) (Reach 2); and the tidal-influenced reach (below 73 km) (Reach 3) (Figure 2). Wetted perimeter was measured as the width of the channel underwater at each transect location. The potential for risk to the riverine environment was estimated by determining wetted perimeter and comparing a range of potential future flow regimes against a representative ‘minimum’ dry season flow rate for the historic period (1971-2000). A flow of $50 m^3.sec^{-1}$ downstream of the KDD was adopted as the basis for comparison. This was determined from the median flow over the driest 5 months of the year during the historic period. Changes in wetted perimeter of more than 10% were considered significant and changes of more than 20% were viewed to be of considerable concern. Predicted changes in wetted perimeter (>20%) along three separate sections of the river under a range of flow scenarios were summarized. As would be expected, the greater the reduction in minimum flow rates, the greater the change to wetted perimeters. The greatest risk to the modified river and habitat are on channel sections between Tarrara Bar and the start of the tidal influence.

However, once flows drop below 40m^3.sec^{-1}, there is a marked increase in the number of sections that change “significantly” above Tarrara Bar. There was very little difference in wetted perimeter outcomes between the maintenance of 45m^3.sec^{-1} for all of the lower Ord River, or for 45m^3.sec^{-1} from the KDD to the 57.5 km point and 40m^3.sec^{-1} below that point. This is due to the channel being generally a flattened “U” shape downstream of the 57.5km point. It also becomes predominantly tidal from the 73km mark and flow rates there will have less impact on wetted perimeter.

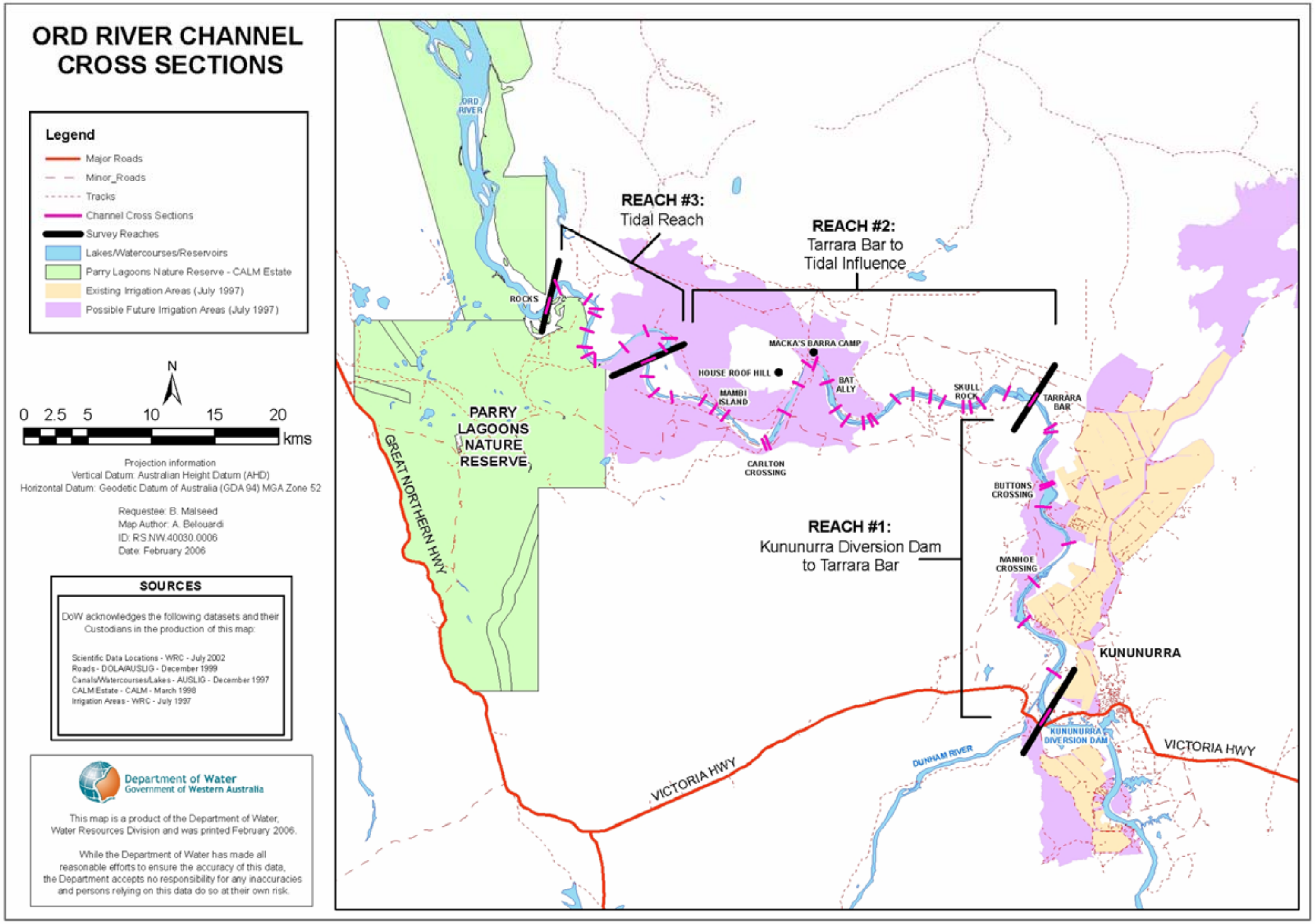
The Commission concluded that the decrease in depth and wetted perimeter associated with the maintenance of a minimum flow rate of 45m^3.sec^{-1} from the KDD to the 57.5km point and 40m^3.sec^{-1} below that point was an acceptable estimate of the ecological water requirement. This was viewed as limiting the change to the dry season flows and hence to the risk of triggering the adverse dry season ecological impacts described by the Scientific Panel. This estimate of the ecological water requirement, was however, viewed as an interim measure. The absence of sound quantitative data (other than hydrological information) on which to base the development of ecological water requirements and the assumptions made in interpreting the wetted perimeter results meant that the estimates of ecological risk could only be regarded as preliminary.

Table 1: Summary of potential impacts of future changes to the water regime (after the Scientific Panel Report-WRC, 2000b).

Attribute	Likely impact of potential flow modifications (compared with the current scenario)	Key considerations
Channel dynamics and sedimentation	Probably insignificant compared to impact of dams but may exacerbate channel narrowing and pool infilling	Assumptions based on limited investigations. Impacts of 1999/2000 wet season floods need assessment and determination of potential for active channel management. Relationship between deposition and encroachment of vegetation needs further clarification. Catchment and floodplain management should be considered.
Aquatic and riparian vegetation	Probably benign if dry season flows do not become 'no flow', but a shift in communities is likely. Potential for further encroachment of emergent macrophytes into shallower parts of channel will increase the rate of channel infill	Relationship between sedimentation and vegetation establishment needs to be confirmed. Increased nutrient concentrations in lower flows could also increase macrophyte growth.
Mangroves	Impacts likely to be benign.	
Invertebrates	Low dry season flows could increase species diversity, but loss of wetted area and shallow instream habitat could reduce abundance.	Relationship between discharge levels and wetted area/shallow instream habitat areas needs to be confirmed to allow assessment of significance of lower dry season flows.
Fish	Potentially significant. Less wetted area will mean reduced habitat for fish. Proportion of channel covered by macrophytes/ epiphytes may increase – high respiration may result in anoxia and fish kills if there are no flow periods. Dry season no flow periods with isolated pools would be potentially catastrophic for fish.	Relationship between discharge levels and wetted area/shallow instream habitat areas needs to be confirmed to allow assessment of significance of lower dry season flows.
Waterbirds	Potentially benign if flood frequency and area of inundation remains unchanged. Rates of change of water levels in Lakes Argyle and Lake Kununurra need to be maintained near current.	Management of water levels in Lake Kununurra should be reviewed to meet downstream management requirements but protect Jacana nesting requirements.
Crocodiles	Likely to be benign.	Impact on nesting site availability may need review.
River processes	Depends on impact of reduced dry season flows on habitat and energy inputs. Sufficient flows are required to maintain pool levels that can "buffer" the effects of high oxygen consumption by plants and animals.	Relationship between dry season water level and habitat needs better definition. Relative importance of shallow margins and of deeper water needs to be determined.
Water quality	Potentially highly significant. Lower flows could increase concentrations if nutrient and pesticide inputs remain unchanged. High sediment levels create a sink for nutrients that may be released as sediments are exposed by low water. Isolated pools with no flow periods potentially catastrophic.	The level of low flows which may be acceptable - while maintaining water quality - needs to be determined. The potential for mitigation through catchment management needs to be addressed.

The wetted perimeter estimates of ecological risk, together with hydrological analyses, water quality data and information on socio-cultural and economic values provide the basis for determination of the environmental water provision as part of the Revised Water Allocation Plan for the lower Ord River. This plan is in the late stages of development. The Department of Water is expected to release the Revised Plan in 2006. An interim and precautionary environmental provision, equal to the estimated ecological water requirement in 95% of years has been proposed. That is, the minimum flow rate from the KDD to 57.5km downstream should be set at 45m^3.sec^{-1}, but could be reduced to 40m^3.sec^{-1} below that mark. This flow rate would be sufficient for minimising the impact on the riverine environment and ensure that the environmental, recreational and tourism values of the post-regulation lower Ord River are maintained. Reduced environmental provisions during extended drought periods (eg. 35/30m^3.sec^{-1} baseflow in 5% of years) are also prescribed.

An interim environmental water provision that is based on a minimum dry season flow rate does not mean that the Department of Water advocates an unvarying baseflow throughout all dry seasons as the best ecological outcome. Through a series of ecological studies and improved hydrologic models, it is likely that any minimum flow provision will be refined to better define the magnitude and pattern of variability within seasons or between years. In addition, the focus on the minimum dry season flow does not imply that wet season flows are of no significance. Rather, it reflects an acceptance that there have been functional changes to the Ord River during the 30 years of permanent flows. In addition, it reflects the imposition of infrastructure design that has placed irreversible constraints on the delivery of the medium-high range of flows. Annual instantaneous peak flows are expected to remain similar to that which currently occurs. This reflects the importance of the largely unregulated Dunham River catchment to the post-regulation flood peaks and the importance of ensuring that the Dunham River flow regime is not further altered.



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Horizontal Datum: Geodetic Datum of Australia (GDA 94) MGA Zone 52

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Scientific Data Locations - WRC - July 2002
Roads - DOLA/AUSLIG - December 1999
Canals/Watercourses/Lakes - AUSLIG - December 1997
CALM Estate - CALM - March 1998
Irrigation Areas - WRC - July 1997

This map is a product of the Department of Water, Water Resources Division and was printed February 2006.

While the Department of Water has made all reasonable efforts to ensure the accuracy of this data, the Department accepts no responsibility for any inaccuracies and persons relying on this data do so at their own risk.

Figure 2: Lower Ord River cross sections and survey reaches.

1.3.4 Beyond the Revised Water Allocation Plan

The Revised Water Allocation Plan for the lower Ord River is intended to protect the riverine ecological and social values associated with the modified post-regulation flow regime and to provide conservative estimates of the amount of water available for consumptive demand. It was always intended that the Revised Plan would be replaced with a ‘final’ plan within 5 years, based on new information available. A series of ecological, social and hydrological studies intended to underpin the development of the ‘final’ plan have been completed in the intervening period. A list of the types of projects completed and related documentation are shown in Table 2. Further work to develop a hydrological model for the lower Ord River based on daily flows has recently been completed and ongoing work to develop better understanding of the ecology of the downstream estuarine environment is underway.

1.4 Purpose of this document

This document is intended to lay the foundation for the development of ecological water requirements for the lower Ord River. The report brings together the findings of a large number of scientific investigations (undertaken between 2000 and 2002, see Table 2) in order to summarize the key values and flow related issues for the lower Ord River.

The document focuses on the key environmental attributes that were considered by the Scientific Panel as most likely to be affected by future changes in flow downstream of the Kununurra Diversion Dam (WRC, 2000b). These included:

- channel dynamics and sedimentation;
- aquatic and riparian vegetation;
- fish assemblages;
- macroinvertebrates;
- waterbirds (see River-Floodplain: Communities and Process);
- ecological processes (see River-Floodplain: Communities and Process); and
- water quality.

As discussed previously, the focus for the document is limited to the three reaches covered by previous surveying, (KDD to Tarrara Bar, Tarrara Bar to start of tidal influence and tidal influence reach). It should be noted that no attempt has been made to address estuarine values and issues in this document.

The information is presented in a way that assists the development of recommendations for ecological water requirements by summarising what is known about environmental attributes and the effect of water management and regulation on these. Flow related ecological objectives and considerations developed in association with key members of an expert group (who were part of the original Scientific Panel) are outlined for three reaches of the system in following sections.

In summarising and interpreting the information arising from the investigations detailed in Table 2, the authors have borne in mind that these studies were undertaken during flows atypical for the post regulation lower Ord River. The wet seasons of 2000, 2001 and 2002 were three of the wettest recorded since the Ord River was regulated in the early 1970's. These wet years, together with increased dry season flows from the hydro-electric power station which begun operating at the Ord River Dam in the mid 1990's, have increased post regulation mean daily base flows from around $40m^3.sec^{-1}$ (1974-1996) to almost $70m^3.sec^{-1}$ (1996-2005). The hydrology of the lower Ord River pre and post-regulation is discussed in greater detail in the following section.

Table 2: Investigations completed since the Scientific Panel Report was compiled (WRC, 2000b).

Study area	**Key Information**	**Involvement**	**Documentation / Outputs**
Ecological	Fish & invertebrate habitat surveys	Contracted investigation (WRC)	Storey, A.W. (2002). Lower Ord River: Invertebrate Habitat Survey. Report to the Water and Rivers Commission. Storey, A.W. (2003). Lower Ord River: Fish Habitat Survey. Report to the Water and Rivers Commission. Wetlands Research and Management (2000). Review of Impacts of Changed River Flows on Fish Habitat Availability and Utilisation. Report to the Water and Rivers Commission.
	Productivity and Water Flow Regulation	Research project (WRC, UWA, ECU, GU, EA)	Water and Rivers Commission (2003a). Productivity and Water Flow Regulation in the Ord River of North Western Australia: Final Report on Sampling. Water and Rivers Commission, unpublished report.
	Water quality & aquatic biota responses to low flow rates	Monitoring effects of trial flow rates (WRC)	Wetlands Research and Management (2002). Lower Ord River: Fish Response to Lowered Ord River Flow. Report to the Water and Rivers Commission. Water and Rivers Commission (2003b). Water Quality and Ecological Response to Reduced Flow in the Lower Ord River. Water and Rivers Commission, unpublished report.
	Riparian Eco-geomorphology	Research Project (CRCMTS, UWA, WRC)	Historic records & field work
	River – estuary project	Applied research (CSIRO – OBP)	Parslow J., Margvelashvili N., Palmer D, Revill A., Robson B., Sakov P., Volkman J., Watson R. and Webster I. (2003). The Response of the Lower Ord River and Estuary to Management of Catchment Flows and Sediment and Nutrient Loads. OBP Project 3.4/4.1/4.2. Final Science Report. CSIRO
Hydrological	Supporting river hydraulics and hydrology for ecological studies	Hydrologic investigation (WRC)	HEC-RAS hydraulic model; daily flows model
Socio-cultural	Cultural values of the Ord River held by the traditional owners	Contract Investigation (WRC)	Barber, K. and Rumley, H. (2003) Gunanurang: (Kununurra) Big River Aboriginal Cultural Values of the Ord River. Unpublished Report to the Water and Rivers Commission.

2 Hydrological impacts of regulation

2.1 Ord River before flow regulation

2.1.1 Annual streamflow

Pre-regulation annual flows at the Ord River Dam site averaged 3980GL (Ruprecht and Rodgers, 1999). Over 85% of the total inflow to the tidal dominated section of the river was generated from the catchment upstream of the Ord River Dam (Table 3). The Dunham River, which enters less than a kilometre downstream of the Kununurra Diversion, contributed the majority of the additional input. Flows from the catchment between the dams and from the local creeks downstream of the Dunham River contribute about half of the Dunham River input. Average streamflow per unit area (or “runoff”) varied from 65mm in the drier parts of the upper catchment (Negri River sub-catchment) to about 110mm in the higher rainfall local tributaries downstream of the Dunham River tributary.

Table 3: Pre-regulation flows in the Ord River – Mean and median values for the water years 1906-7 to 1991-2[1]

Ord River location	Catchment Area (km^2)	Mean Flow (GL/yr)	Median Flow (GL/yr)
At the Ord River Dam site (ORD)	46 100	3 980	3 030
At the Kununurra Division Dam (KDD)	47 100	4 070	3 100
Just below Dunham River Confluence	51 300	4 420	3 390
At Tarrara Bar	51 790	4 480	3 410
At Carlton Crossing	52 020	4 500	3 430
At the Rocks below Reedy Creek	52 800	4 560	3 480
At Cambridge Gulf Mouth	53 800	4 630	3 530

[1] Water year – November to October

2.1.2 Annual and seasonal variability

Prior to the construction of the dams, Ord River flows were highly seasonal and very variable (Table 4). The widespread and intense monsoonal rainfall events of the wet season exceeded the high evaporation rates and generated the large wet season flows. However, if no major monsoonal depressions developed during a wet season and rainfall was limited to local thunderstorm activity, the resultant streamflows were limited.

The seasonal variation was also very high. In typical years, over 80% of the annual streamflow occurred between January and March (Figure 3). Streamflow volumes reduced rapidly towards the end of the wet season as evaporation again exceeded rainfall. Although, some streamflow was possible in the early months of the "dry" when late rains occurred, typically little or no flow occurred between May to October.

Table 4: Annual and season flows in Ord River just below the Dunham River –Pre-regulation (1906-7 to 1991-2)

Statistic	**Water Year Nov-Oct GL**	**Wet Season Nov -Mar GL**	**Dry Season* Apr-Oct GL**	**Dry 5 months Jun to Oct m^3/sec**
Mean	4420	4170	250	1.8
Historic maximum	14560	12660	2030	17.7
90th percentile	8850	8470	610	5.9
75th percentile	6250	6120	270	1.6
50th percentile	3390	3210	140	0.6
25th percentile	1970	1800	50	0.2
10th percentile	1020	830	20	0.0
5th percentile	680	460	10	0.0
Historic minimum	225	220	5	0.0

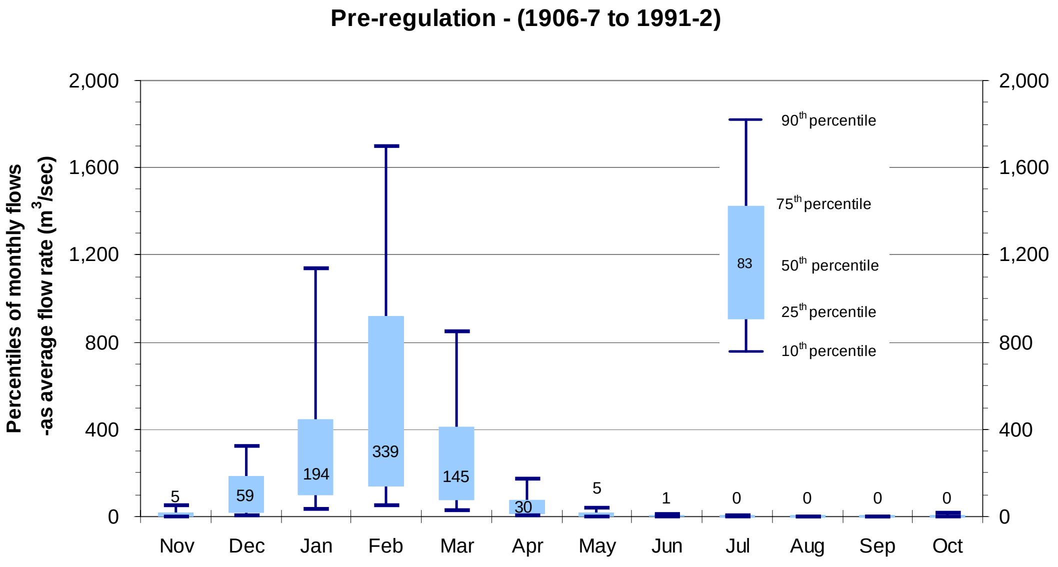

Figure 3: Distribution of monthly pre-regulation flows of the lower Ord River below the confluence with the Dunham River.

2.1.3 Flood responses

The small creeks and tributaries of the Ord respond quickly to rainfall events during the wet season. Local flash flooding is common and is a result of local rainfall of high intensity, coupled with the shallow soils and steep terrain (in parts of the catchment). When the areal extent of intense rainfall is large the main river also responds quickly and generates large flood flows that peak within 48 hours of the rainfall event. The Ord River, prior to its regulation, recorded a peak flow rate of 30 800$m^3.sec^{-1}$ in 1956, comparible with the largest recorded flow rates of any world river of equivalent catchment area (Rodgers and Ruprecht, 2000).

2.1.4 Low flows

In the dry season, the river dried to a series of isolated pools in the deeper parts of the channel, such as on the outside of the meander bends. With little or no dry season flow, the large tidal range within Cambridge Gulf (7 metres at spring tide) pushed salt water well up the river channel. Hydraulic modelling indicates that salt water would have reached beyond Carlton Crossing when river flows reduced to around 2$m^3.sec^{-1}$ at spring tides.

2.2 The Ord River since construction of the dams

Changes to the regulation of the Ord River began with the construction of the Kununurra Diversion Dam (KDD) in 1963. However, the most significant change occurred with the completion of construction of the Ord River Dam in 1971/72 and after Lake Argyle first filled towards the end of the 1973/74 wet season. In 1995, the height of the Ord River Dam spillway was raised by six metres to provide additional head for power generation. The dam can now store 10 700 GL in Lake Argyle at the full supply level of 92.2m AHD. This storage is more than 2.5 times the average inflow. Significantly, however, the Dam's maximum flood storage, above the base of the spillway, exceeds 30 000 GL. This is over 2.2 times the maximum annual inflow volume estimated to have occurred since rainfall data were first recorded in the catchment (1906). The construction and operation of the Kununurra Diversion Dam, and Ord River Dam and power station, have substantially altered the flow regime of the lower Ord River as described below.

2.2.1 Annual and seasonal changes in flow volumes

River regulation and irrigation diversion have reduced annual flows in the lower Ord River. Prior to the construction of the power-station and raising of the spillway, average annual flows downstream of the Dunham River has been estimated to decline by 35%, from the estimated unregulated flows over the period 1974-5 to 2004-5 (Table 5). The reduction is a combination of the high net evaporation loss from Lake Argyle and the water diverted from Lake Kununurra. Net evaporation is the dominant component, being estimated to be more than 85% of the total reduction. [In the early years of regulation, net evaporation contributed over 90% of the loss, as diversions for irrigation were less than 100 GL/year and net evaporation averaged around 1100 GL per annum (Water and Rivers Commission, 1999). Since the early 1990s, while the water diverted has increased to over 300 GL/year, net evaporation rates have also increased in response to much higher inflows and consequent higher water levels in Lake Argyle.]

Construction of the Ord River Dam has also caused large change in the seasonal pattern of flow in the lower Ord River (Table 5). Over the 31 years from 1974-5, average wet season flows reduced by 67% respectively and average dry season flows increased by 439%. Similar changes are apparent in median wet and dry season flows in the lower Ord River.

The lower Ord has become a perennial system since regulation. In ecological terms, the dry season changes have effectively transformed the lower Ord River into a ‘wet tropics’ river from a ‘dry tropics’ river. Under typical dry season conditions, as reflected by the pre- and post-regulation median, dry season flows have increased by over 1000 GL.

The effect of regulation on the monthly flows in the lower Ord River is shown in Figure 4. The figure compares estimates of the percentiles of monthly flows in the lower Ord River below the Dunham River confluence under unregulated and post regulation conditions over the same hydrologic period (1974-5 to 2004-5). Also included are percentiles of monthly flows likely to have occurred in the lower Ord River if the spillway had not been raised and the Hydro-electric power station not established in 1995/6. That is, flows in the lower Ord River were estimated for each condition based on dam operational records and estimates of unregulated flows at the Ord River Dam, the Diversion Dam and Dunham River for the 1974-5 to 2004-5 period.

Table 5: Estimates of annual and seasonal flows in the lower Ord River below the Dunham confluence.

Statistic	**Mean streamflow**			**Median streamflow**		
Lower Ord River flows - From 1974-5 to 2004-5	Pre-regulation (GL)	Post–regulation (GL)	% Change from Pre-regulation	Pre-regulation (GL)	Post–regulation (GL)	% Change from Pre-regulation
Water Year (Nov to Oct)	6,070	3,940	-35%	4,740	2,830	-40%
Wet Season (Nov to Mar)	5,690	1,890	-67%	4,700	1,380	-73%
Dry Season (Apr to Oct)	380	2050	439%	230	1,240	365%

The reduction and seasonal change in flows following the construction of the Ord River Dam is apparent by comparing Figures 4(a) with Figures 4(b) and (c). Decreases in the 50th to 90th percentile flows between December and March reflect the storage of wet seasons inflows to the Ord River Dam in Lake Argyle. The increases in the 50th to 90th percentiles between April and June are a consequence of delayed spillage from Lake Argyle following wet seasons with above average rainfall. The increases in 10th and 25th percentiles between April and November reflect releases from the Ord River Dam that exceed the quantities diverted for irrigation from Lake Kununurra[3].

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[3] Diversions from Lake Kununurra to supply Stage 1 irrigation areas typically have ranged between 5 and 15$m^3.sec^{-1}$.

Changes between Figures 4(b) and 4(c) are minor compared with changes from Figure 4(a), indicating that the effect of raising the base of the spillway by 6 metres and operations while generating hydro-electric power on flows in the lower Ord River are secondary to the changes caused by the initial regulation[4]. Nevertheless, flows between June and October are between 5 to 10m^3.sec^{-1} higher under power station operations, reflecting an increase in base flows in recent years.

Regulation has reduced the variability of monthly flow rates in the lower Ord River (Table 6).

Table 6: Coefficients of variation for monthly flows in the lower Ord River under three cases of regulation

Regulation cases[1]	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
No-regulation	132%	90%	79%	85%	152%	174%	212%	344%	363%	496%	340%	317%
Post Dam -Pre Hydro	30%	42%	55%	91%	128%	129%	129%	124%	115%	87%	55%	54%
Post Dam and Hydro	34%	39%	50%	85%	122%	134%	131%	124%	105%	68%	44%	41%

[1] Cases are same as used in Figure 4

Seasonal changes reflect both the nature of the spillway configuration (see peak flow changes below) and operational practice since the construction of the Ord River Dam. In the early years of operation, when irrigation diversion rates were commonly less than 5m^3.sec^{-1}, releases of 40 to 50m^3.sec^{-1} were maintained for ease of operation of the Kununurra Diversion Dam and the M1 channel. As dry season water based tourism developed on Lake Kununurra through the 1980s, additional releases to enable tour boat operators to navigate through Carlton Gorge to the base of the Ord River Dam became normal practice. Releases of 50-60m^3.sec^{-1} were common. With the construction of the hydro-power station in 1995 releases have averaged 60m^3.sec^{-1} and exceeded 70m^3.sec^{-1} at times of high power demand and low lake level.

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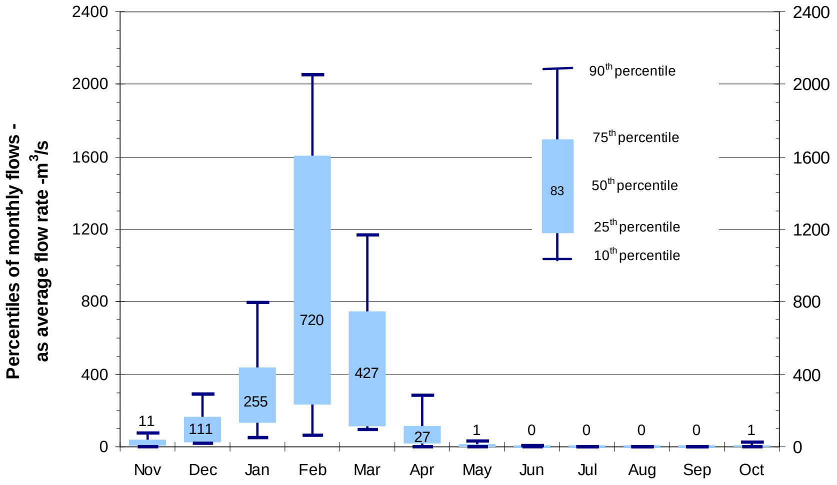
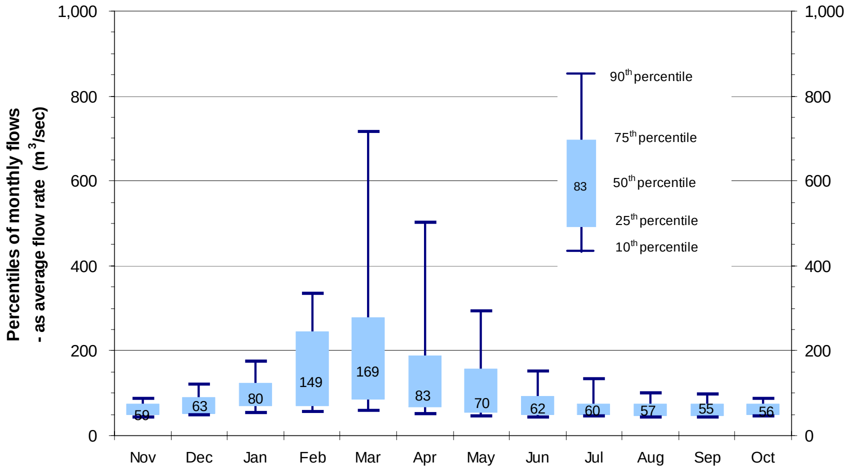
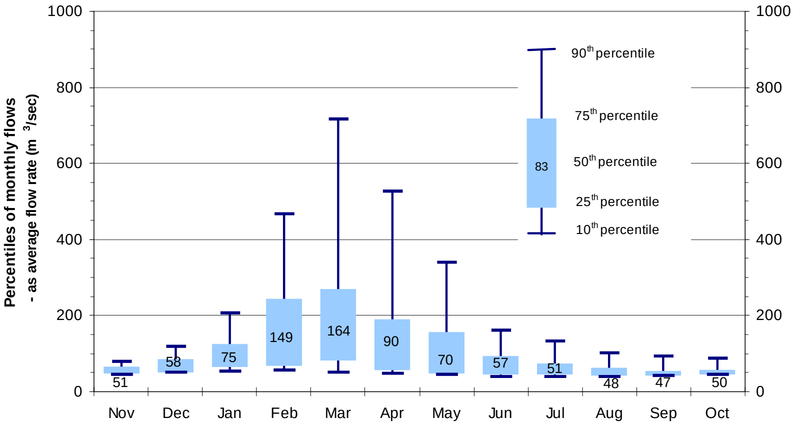
[4] Note that differences between Figures 3(b) and (c) do not fully reflect the changes to lower Ord River flows following the operation of the power station, as Figure 3 (c) includes data from the period before the power station was constructed (1995-6).



(a) Unregulated flows – No Ord River Dam (1974-5 to 2004-5)



(b) Post Dam- Pre Hydro conditions –No increase in the height of the spillway or operation of the Ord Dam power-station from 1995/6



(c) Historic -Post regulation conditions (1974-5 to 2004-5)

Figure 4: Monthly flow percentiles in the lower Ord River flows under (a) Unregulated, (b) Post dam- Pre-hydro, and (c) Historic post regulation conditions.

2.2.2 Peak or flood flow changes

Pre regulation, large variations in Ord River flow rates occurred within hours of heavy rainfall and caused regular major flooding of the lower floodplain areas. The Ord River Dam was designed to provide extremely large flood storage in Lake Argyle, to save the costs of a conventional spillway and minimise the flood risk to the new town of Kununurra and the new irrigation areas. A relatively small capacity spillway, cut into a saddle approximately seven kilometres from the Ord River Dam, discharges floodwaters from Lake Argyle down Spillway Creek and back into the Ord River about 30 km upstream of the Diversion Dam. The large flood flows from the catchment are therefore temporarily stored in Lake Argyle and discharged slowly over a period of many months, reducing the flood storage to zero over the dry season. The major high energy, channel-forming peak flows of the Ord River no longer occur below the Ord River Dam. As a result of the high rainfall events of the 1999/2000 wet season, the combined flow downstream of the Ord River Dam and Spillway Creek was approximately 1050m^3.sec^{-1}. Approximately 900m^3.sec^{-1} flowed over the spillway and 150m^3.sec^{-1} through the valves at the dam wall. This is an order of magnitude less than the estimated peak inflow to Lake Argyle of approximately 13 000m^3.sec^{-1}.

The estimated flood frequency distributions of the lower Ord River at its Dunham River confluence for pre- and post-regulation conditions are compared in Figure 5. A reduction from approximately 17 000m^3.sec^{-1} to just over 3000m^3.sec^{-1} after regulation in the annual peak flow expected to be exceeded in 10% of years has occurred (Annual Exceedence Probability of 0.1). The 1 in 100 year flood (annual probability of exceedence of 1%) is estimated to have reduced from over 52 000m^3.sec^{-1} to approximately 10 000m^3.sec^{-1} under the current level of regulation.

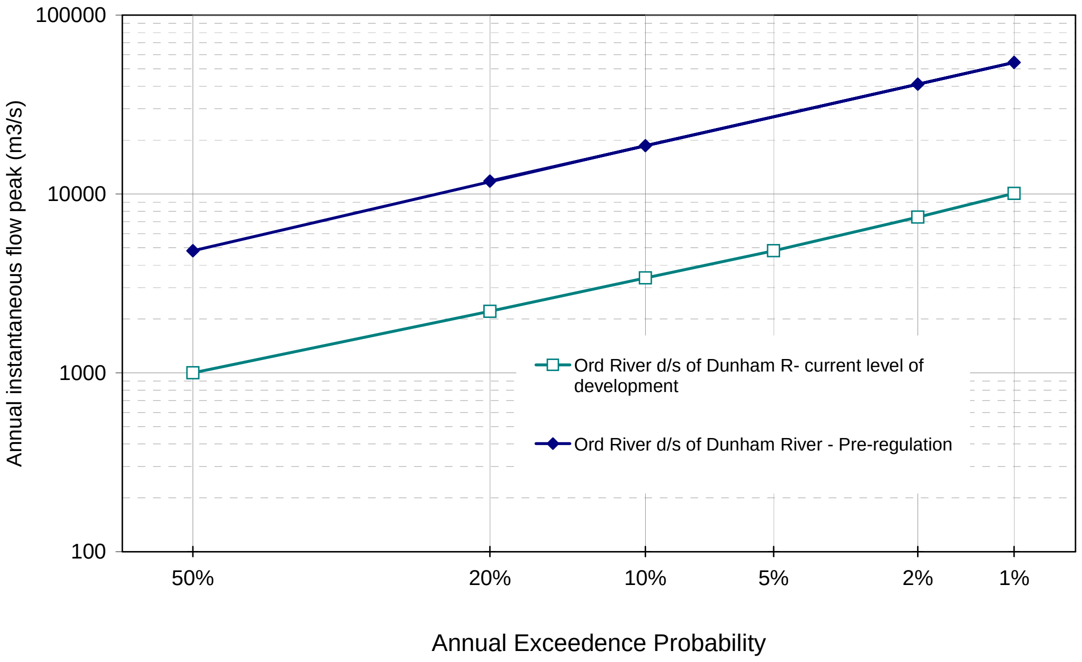
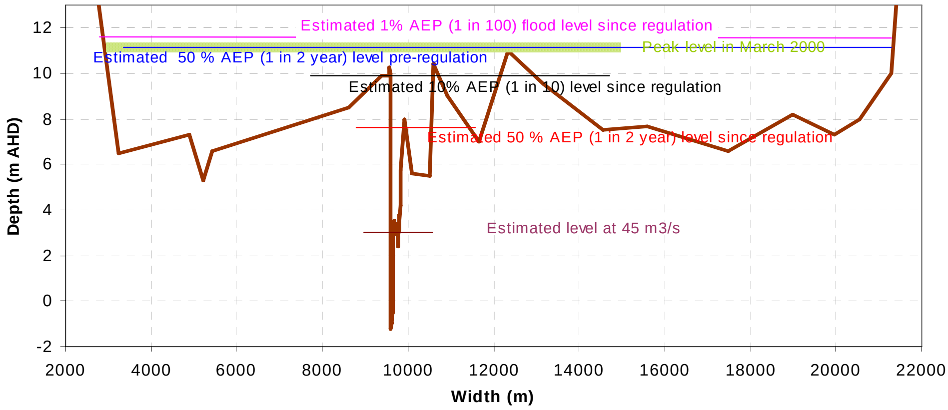
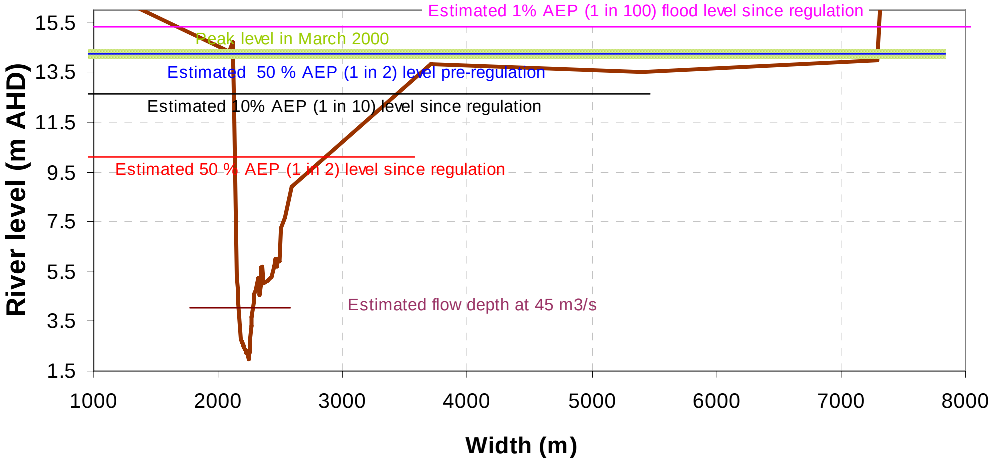


Figure 5: Pre- and post-regulation annual flood frequency distributions of the Ord River downstream of the Dunham River Confluence.

The impact of the Ord River Dam has therefore been a decrease in the magnitude of the high flow events with a corresponding decrease in the extent and duration of floodplain inundation. River levels at two cross-sections along the lower Ord River are shown in Figure 6 for floods of varying return periods (or Annual Exceedence Probabilities) under pre- and post-regulation conditions. The 1 in 2 year pre-regulation return period flood (that is, a flood that has a 50% likelihood of being exceeded in any one year) reached levels at or just above the main levee banks of the lower Ord River. Post-regulation the 1 in 10 year flood is contained well within the main levees at both cross-sections. The effect on reduced flooding is shown diagrammatically in Figure 7, which displays the inundation area under the pre- and post-regulation 1 in 10 year recurrence interval flood (Annual Exceedence Probability of 0.1; Rodgers and Ruprecht, 2000).



(a) Flood levels just downstream of Mambi Island - Cross section 73153



(b) Flood levels just upstream of Carlton Crossing - Cross-section 62827

Figure 6: Flood levels at typical cross-sections along the lower Ord River, pre and post-regulation.

Importantly, peak flows in the lower Ord River are now dominated by flows from the Dunham River. Figure 8 shows the contributions to flow in the lower Ord River just below the Dunham confluence during February 1999, a period without spillage from Lake Argyle. The minor tributaries below Dunham River contribute the remaining variability.

As noted earlier spillage from Lake Argyle contributes significantly to monthly flows in the lower Ord River, especially in the months of March and April in those years when wet season rainfalls in the catchment have been above average. While such spillage often provide a high initial flows (usually < 1000$m^3.sec^{-1}$) the short term flood peaks of the lower Ord River remain dominated by Dunham River floods and floods arising in the catchment between the Dams.

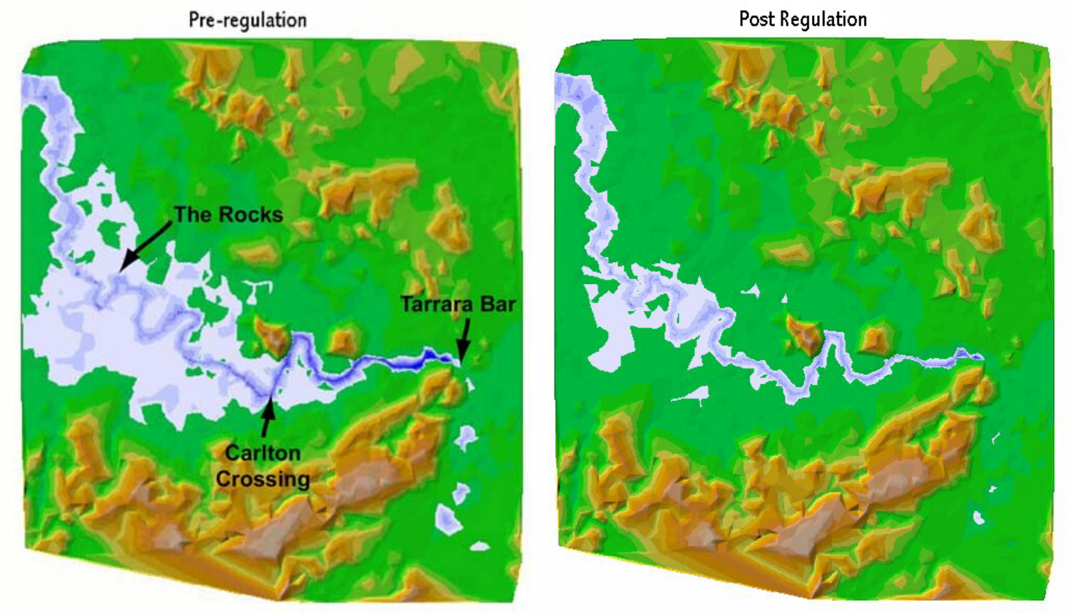


Figure 7: Pre and Post-regulation inundation areas for the 1 in 10 year recurrence interval flood (after Rodgers and Ruprecht, 2000; WRC, 2001).

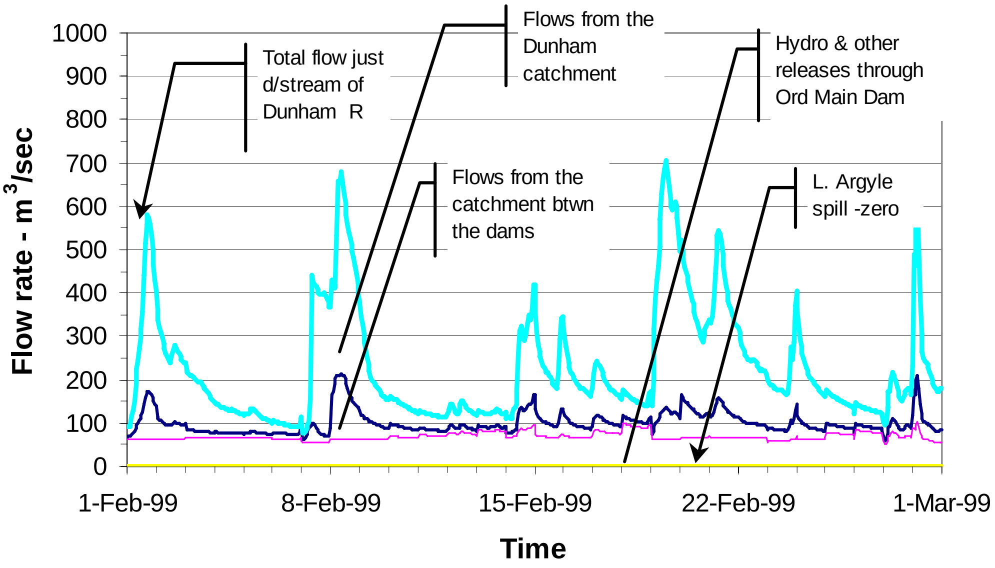


Figure 8: Contributions to lower Ord River flows during February 1999.

3 Environmental Attributes

3.1 Channel Dynamics and Sedimentation

3.1.1 Geomorphology of the Ord River (text adapted from Wyrwoll, 2000)

The lower Ord River exhibits a generally meandering planform. The channel morphology is in part dictated by channel confinement as a result of floodplain/alluvial fill build-up and bedrock outcrop. There are geomorpohological differences between the reaches upstream and downstream of Tarrara Bar. Below Tarrara Bar the river is dominated by large amplitude, rapidly migrating meanders. These have given rise to scroll bar - swale (meander sweep) topography which constitute the flood plain morphology. Upstream of Tarrara Bar the channel is typified by more stable low amplitude, broad meanders. The floodplain of the lower Ord River also exhibits differences, in terms of its stratigraphy and sedimentology, between upper and lower reaches. The lower reaches are actively depositional and the upper reaches are essentially ‘residual’ terraces with limited active deposition.

3.1.2 Pre-Dam channel dynamics (text adapted from Wyrwoll, 2000)

Prior to dam construction the geomorphology and channel dynamics of the river below the dam site were adjusted to the occurrence of the large flood events of the Ord River (as discussed in section 2). The Dunham River and the other downstream tributaries made only a relatively minor contribution to the flow. A strong seasonal flow regime prevailed, with discharge virtually absent for significant parts of the year, but with pools remaining in deeper sections of the channel – such as along the outside banks of meanders. For much of its course, the channel was inset into a strongly defined floodplain, with extensive inundation of the floodplain occurring only during large flow events.

The overall channel morphology and sediment regime were geared towards large flood events with the power to mobilise sand-gravel beds and the ability to ‘flush out’[5] much of the river channel. In its alluvial reaches the river took the form of a broad channel carrying a large bedload sediment component, which on deposition was arranged in large lateral and point bar forms. It had a general meandering planform punctuated by bedrock controlled reaches. The bars were dominated (and stabilised) by the gravel sediments with associated sands. Sand was more prominent in the higher parts of channel margins and especially back-sections of point bars. Large sand waves are likely to have been present and these would have exhibited considerable mobility. Suspended sediment formed a significant component of the total sediment load, and it is likely to have been dominated by silt-sized sediments derived from the severely eroded areas of the upper catchment. Massive deposition of suspended material took place in the lower

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[5] Flush out: Mobilise sediment and macrophyte beds resulting in the net export of materials.

reaches of the river leading to a rapid floodplain build-up, indicating that even in pre-European times the Ord River had a large sediment load (Cluett, 2001).

More recently, floodplain erosion and gully networks were also prominent features along much of the river. The general erosion characteristics were largely the response to loss of vegetation as a result of landuse practices in the catchment. The reduced riparian vegetation fringe also facilitated channel bank instability.

3.1.3 Impacts of Water Management

The Ord River has historically carried large sediment loads (see above). With the construction of the Ord River Dam, the contribution of sediment from the upper Ord Catchment has been essentially removed[6] but the contributions of unregulated tributaries, drains and banks downstream of the dam have increased in relative importance. The large reduction in the magnitude of peak flows post regulation has meant that regulated discharge is of insufficient power to transport large volumes of sediment.

Sediments have now become the driving force behind morphological change and while these will not result in major planform adjustments, altered hydraulic geometry at a reach scale is likely (Cluett, 2001). Investigations of historic aerial photography confirm that the planform of the lower Ord River has not altered significantly in the years post-dam (Cluett, 2000). However, the following changes are evident in response to the lack of large scale flow and altered sediment dynamics (Warman, 1999; Cluett, 2000; Cluett and Radford, 2002):

- the river has become more incised in its traditional floodplain;
- sediment contribution of the Dunham River, other smaller tributaries, drains and bank erosion has attained a greater significance for channel dynamics;
- both active and total channel width have reduced as a result of deposition of sediment supplied by the tributaries and other sources;
- the broader floodplain and large amplitude meander scrolls in the lower reaches have been abandoned and are accessed only under the largest flow events;
- large point and lateral bar forms are no longer regularly modified by peak discharge events;
- riparian and in-channel vegetation patterns have undergone significant change since dam construction; and
- large volumes of sediment are stored at channel margins and in mid-channel bars in association with aquatic and riparian vegetation.

The influence of riparian vegetation on sediment and channel dynamics, mentioned in the previous two dot points, has become of elevated importance. The

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[6] It is acknowledged that there is some contribution of sediment from the dam (and therefore the upper catchment) via hydro-power and regulation releases but comparatively speaking these contributions are very minor compared to pre-regulation contributions from the upper catchment.

decrease in peak flows and constant flow during dry seasons that has resulted from regulation, has in turn lead to increased density of riparian vegetation and alteration of riparian vegetation communities (discussed in detail in section 3.2). Increased in-channel vegetation (aquatic and emergent species) increases channel roughness, which in turn reduces flow velocities and results in the increased deposition of sediment (Croot, 2002; Wyrwoll, 2000). The deposited sediments are then colonised by more vegetation and a feedback loop is established (i.e. more vegetation leads to increased roughness which leads to more sediment deposition that is then colonised by more vegetation and so on). This mechanism is so effective that prior to flood events in 2000, beds of *Typha*, an emergent indigenous sedge, were becoming problematic in terms of ‘choking’ (forming wide dense beds and resulting in a decrease in the width of the active channel) the lower Ord River and effectively reducing channel capacity.

3.1.4 Flow Related Issues

In order to be geomorphologically effective (i.e. to mobilise stored sediment and initiate planform modification), flows need to be of sufficient magnitude and duration so as to generate enough stream power to cross intrinsic thresholds that limit change. The floods of 2000, 2001 and 2002 provide opportunity to examine geomorphological response to large flows, at least in terms of the post regulation flow environment.

Cluett (2001) explored the effectiveness of the 2000 flood event in modifying the channel form. Peak flow in that event is estimated at $5000m^3.sec^{-1}$ in the lower Ord River and while the flood peaked quickly, flows remained high for some 6 months due to infrastructure and logistical constraints. It was concluded that although the flood enabled localized modifications to sedimentary features, there was insufficient power to remove armoured layers, dislodge trees and reshape bar surfaces. Hence, planform modification was minimal and total removal of sediment was not achieved. Established mature trees (although damaged) exerted a stabilizing influence on stored sediment, particularly on mid-channel bars (Cluett, 2001). However, importantly, the flood removed much of the submerged and emergent vegetation from channel margins and some mobilisation of sediment was achieved.

The ineffectiveness of the 2000 flood in removing significant volumes of sediment material may in part be due to the fact that flows broke out over a large area, thereby reducing power. More moderate flows that apply significant force to mould the channel, but which are also retained within the banks over a long duration may be more effective. Croot (2002) examined the effect of flooding further by comparing aerial photographs at five locations taken in 1999 with photos taken after the 2000, 2001 and 2002 flood events. The latter two floods being of lower magnitude than 2000 flood. It was concluded that these flood events activated bar geomorphology by reworking, removal and replacement of sediment. Although, activation of those bar processes can result in planform migration through bar and bank interaction, this would be to a lesser extent than the pre-dam situation (Croot, 2002).

From the work that has been undertaken by Cluett (2001) and Croot (2002) it is apparent that the lower Ord River is still adjusting to changes in the post-dam flow and sediment regime. In order to drive the equilibrium state of the planform, flood events need to be of appropriate magnitude, frequency and duration so as to cross existing threshold conditions provided by the landscape (Croot, 2002). It is not yet known what the minimum requirements of these flood factors are. Further, the situation is complicated by temporal factors, such as sequential flood events of different magnitudes and the interaction they might have through pre-wetting of soils, loosening of vegetation and undercutting of banks (Cluett, 2001). It is therefore impossible at this point in time to be prescriptive of the flood events necessary to influence the planform of the lower Ord River. However, it is important that some effort be made to maximize the power of these events where possible if in the least to 'reset' emergent vegetation beds. In the absence of sufficient stream power, then low flow processes and the interaction between vegetation and sediment, may control channel form and reduce capacity. Importantly, where effort is made through management to influence channel form by manipulation of high flows, then the results should be monitored and evaluated enabling some adaptive management of the system (NB. Croot (2002) outlined an appropriate monitoring program that could be applied to that task).

Flow objectives and considerations:

- 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 sediment (<500 μm). This is complicated by the cohesive effect of vegetation. These events could be about 3 yearly, but if flows are sufficiently regular, then sequential events may contribute to reduced channel encroachment. Reaches: Reach 1 (KDD to Tarrara Bar), Reach 2 (Tarrara Bar to Tidal) and Reach 3 (Tidal Influence).

3.2 Aquatic and Riparian Vegetation

3.2.1 Vegetation Patterns and the Impacts of Water Management

The pre-dam vegetation structure and composition of the lower Ord River was never formally documented. However, information from a variety of sources including photographs (see Start and Handasyde, 2002), oral histories, remnant vegetation and analogy to unregulated areas was used by Start (2000) to compile a summary of the vegetation communities that would have occurred. These are listed in Table 7 along with descriptions of how the communities have altered in response to regulation. Importantly, Start (2000) notes that the pre-dam vegetation communities were not 'pristine', having been impacted by some 60 years of heavy cattle grazing. In addition, the post-dam aquatic and riparian vegetation communities are rich and varied, comprising most, if not all the indigenous components present before regulation (Start, 2000).

Primary amongst the changes identified by Start (2000) were the degeneration of 'old' riparian communities high on the riverbanks and the development of extensive 'new' riparian communities. These 'new' riparian woodlands comprise species that would have previously been present, but were localized in their extent. Aquatic vegetation has also expanded in area and diversified. Start and Handasyde (2002) argue that two hydrological factors – the curtailment of large floods and the provision of continuous flow – are primarily responsible for the vegetation changes that have occurred. Start *et al*. (2002) recently summarized the distribution of vegetation in the present day lower Ord River into four key zones. These included:

- dry upper bank: prior to 1973 this area was exposed to inundation by large floods. Subsequently, seldom or never flooded (although the lower slopes include areas flooded by post 1999 flows);
- flood-prone mid bank: still frequently inundated in post-dams era, especially by Dunham River flows. Typically supporting *Eucalyptus* species dependent on flows for seed set and dispersal;
- damp channel margin: since 1973, soil is permanently damp at or close to the surface. Encounters regular wet season inundation. Typically supporting the 'new' riparian vegetation including thickets of *Melaleuca leucadendra*, *Pandanus aquaticus*, *Nauclea orientalis*, *Ficus* spp. and *Cathormion umbellatum*; and
- submerged channel bed: submerged at normal dry season baseflows. Bare substrata in parts, but typically supporting submerged and emergent aquatic vegetation.

Table 7: Comparative vegetation communities in the pre and post-dam lower Ord River (adapted from Start, 2000).

Vegetation communities	Pre-Dam	Post -Dam
High on Banks	Trees such as river gums, *Eucalyptus camaldulensis* and coolabahs, *E. microtheca* occurred regularly, but often fairly sparsely, along the channel. This community was probably more continuous than any of the following and it was stable over long-time frames. Frequently, non-riparian species of the adjacent savanna (eg. *Bauhinia cunninghamii*) were intermixed with the riparian species. The riparian components required flood events to regenerate.	Many mature trees persist but there is negligible regeneration and crown degeneration is common. Regeneration is blocked by lack of flooding, competition from weeds, and the frequent incursion of fire fuelled by weed species. The allelopathic action of buffel grass would probably impede regeneration in many areas even if the other factors were managed appropriately.
On exposed, unconsolidated sediment (eg. pool margins, gravel bars).	Typical components included thickets of paperbark (*Melaleuca leucadendra*) saplings. The community was highly dynamic and frequently replaced. Seed often germinated on strand lines alongside receding pools after river flows ceased.	This component has expanded and diversified to form a large part of the “new” riparian vegetation, particularly where the banks are accreting through sediment build-up (eg. on the inside curves of meanders and adjacent to straight reaches, especially below Tarrara Bar) Because of the stability of this habitat now, turnover is infrequent and thickets of saplings are able to progress to tall woodlands or forests.
In sheltered sites (eg. backwaters, behind rock bars).	Typical components included *Pandanus aquaticus, Nauclea orientalis, Ficus* sp. and *Cathormion umbellatum*. The communities persisted over long time frames, were often relatively species rich and had relatively dense canopies but they were limited to small, widely separated patches.	This component has expanded and diversified to form extensive fringing woodlands part of the “new” riparian vegetation. This community is best-developed on sites where sediment deposition is not occurring (eg. the outside banks of meanders). In those sites it has stabilised the banks with narrow but diverse and relatively dense woodlands.
On stable in-bed substrates (eg. rock bars).	Typical components included *Terminalia bursarina*. Plants were resilient, tough “well anchored” and stable over long time frames, but the community was often sparse and species-poor.	This component has changed little. The same suite of species still occupies rock bars. They face little competition because few other species can establish on that substrate. Now, as before, it is a species-poor and sparse community, often restricted to scattered individuals of one or two species.
On floodplains (exposed to low energy but longer-term inundation).	Herbs and forbs (eg. grasses, sedges, *Marsilea* sp., *Ipomoea diamantinensis, Sesbania canabina*) and sometimes shrubs were typically dominant. Trees were often associated with depressions (eg. *Excoecaria parvifolia*), billabongs (eg. *Barringtonia acutangula* and *C. umbellatum*) and channels (eg. *E. microtheca and Melaleuca* species). Scroll bars and associated cut-off sections of earlier channels are an important and distinctive component of flood plains.	They are still typically dominated by herbs, forbs and some shrubs and include seasonal aquatics. The same suites of trees are still associated with depressions, billabongs and channels, scroll bars and associated cut-off sections of former channels. There is particularly extensive and important woodland associated with the large series of scroll bars near Goose Hill. While the tree component has probably changed little (except for some localised eucalypt deaths that occurred at least 20 years ago) there is no information on the former floristic composition of seasonal aquatic or terrestrial herbs and forbs of the flood plains. Changed fire regimes may have influenced this community.
Aquatic (submerged and emergent macrophytes).	In the river channel, they were probably associated with semi-permanent or permanent surface water in sheltered sites such as side channels (eg. *Nymphoides indica*) although submerged species may have persisted in permanent pools of the main channel and aggressive colonisers (eg. *Typha domingensis*) probably survived floods or re-established populations in shallow water at the margins of permanent pools. However, on water bodies associated with flood plains (eg. billabongs and cut-off channels) more stable conditions allowed the development a wide range of submerged and emergent aquatic species (eg. several sedges, *Nymphaea violacea, Nymphoides indica, Persicaria attenuata*).	Floristic composition of communities living in water bodies associated with flood plains has probably remained relatively stable, but this is an assumption. In the river channel, these components have expanded and diversified. Submerged species shield the surface and trap finer sediments on the channel bed where, in appropriate situations, they may be the first stage in a successional sequence of colonisation by emergent aquatic and, ultimately, riparian vegetation. The process facilitates encroachment of the banks into the channel as well as the formation and enlargement of islands. Other aquatic components of the sequence include *Nymphoides indica, Typha domingensis, Phragmites karka, Ipomoea aquatica* and *Persicaria attenuata*. *Pandanus aquaticus, Sesbania formosa* and *Melaleuca leucadendra* often establish on *Typha* beds once sufficient sediment and detritus has accumulated but they also occur in the terrestrial riparian communities fringing the channel.

3.2.2 Flow Related Issues

Comparative assessment of riparian communities in terms of richness, distribution and abundance of species was undertaken for the regulated lower Ord River and unregulated Pentecost, Keep and Dunham Rivers (WRC, 2003a). While results were complicated by site differences some general trends were observed. In particular, species richness was generally greater at unregulated sites, which also supported more annual species. This was, in part at least, attributed to differences in the frequency of flooding at the regulated and unregulated sites. The intermediate disturbance hypothesis (Connell, 1978) predicts that species diversity should be highest at sites that have an intermediate frequency of disturbance that prevents any one species from becoming dominant, yet allows sufficient time between disturbance events for species to colonise. Applying this hypothesis to river systems and riparian zones it follows that frequently flooded (flooding is the disturbance) riparian zones are likely to contain fewer species as are river systems that are seldom flooded (as strongly competitive species may be able to dominate). Therefore, the higher species richness observed at the unregulated sites may be a function of more frequent (moderate disturbance) flooding compared to the infrequent (low disturbance) flooding of the lower Ord (WRC, 2003a). Similarly, the relatively high proportion of annual species at unregulated sites compared with the lower Ord River was attributed to more regular flooding events that select for annual species able to complete life cycles between wet seasons. The study also noted that the lower Ord had a greater cover of exotic species compared to the unregulated Keep and Pentecost Rivers (WRC, 2003a). While this issue is difficult to separate from land management issues (such as grazing), more frequent flood inundation may discourage weed species from proliferating.

It is possible that the restoration of more regular flood events in the lower Ord River may encourage vegetative communities more similar, particularly in terms of species richness and abundance of annual species, to the unregulated systems nearby. This would effectively mean the old riparian communities high on the banks, which have been degenerating as a result of lack of flooding, would be restored. However, Start (2000) suggested that even if floods of sufficient amplitude could be reinstated, then regeneration of this zone would not necessarily be successful, due to increased weed invasion and altered fire regimes. In addition, flooding regimes necessary to regenerate these areas may diminish the value of the damp zone which is not desirable given the aim of maintaining post dam environmental values. It is also very unlikely due to the limitations of the dam infrastructure that the frequency and magnitude of flood events required to regenerate old riparian communities could be reinstated. However, occasional flooding of the old riparian zone may help to suppress weed domination, stimulate seed set and retain some value. Start *et al*. (2002) noted that riparian tree saplings had established at the base of the old riparian zone since the 2000 wet season. The survival, or otherwise, of these saplings may be a useful indicator of the value of infrequent, high magnitude flood pulses for regeneration of some riparian plants.

Maintenance of the damp zone riparian community is likely to be of a higher priority than restoration of the old riparian zone. The damp zone supports a mixture of species that previously persisted in sheltered sites (eg. *Pandanus* and *Ficus* spp.) as well as those (eg. *Melaleuca* spp.) that extended from previously exposed areas (Start, 2000; Table 6). At the outer edges of these damp zones, some elements (eg. some *Eucalyptus* spp.) of the old riparian zone persist (Doupe and Petit, 2002; Marshall and Storey, 2005). The extent to which this riparian zone flourishes and maintains its diverse elements, will be determined by the way in which wet season flows are managed. Regular wet season baseflow that inundates the lower riparian terrace (damp zone) will encourage species that prefer a wetter environment (eg. *Pandanus, Ficus, Melaleuca*). Less frequent seasonal pulses of higher flows with short duration that flood the mid-bank area will encourage *Eucalyptus* spp. to persist at the margins of this zone. These pulses should ideally be timed to coincide with the periods of seedfall (typically Feb-April) in order to encourage dispersal (Petit and Froend, 1999; Doupe and Petit, 2002).

The hydrological stability of the post-dam environment that has caused alterations to the damp zone communities has also enabled the colonisation of the channel margins and shallow water by emergent species such as *Typha domingensis* (cumbungi). *Typha* is an indigenous sedge that is often considered a weed in modified systems where it can rapidly invade streams and wetlands. Although *Typha* usually establishes from wind-borne seed on damp ground or in very shallow water, it can spread across deep water as floating mats (Start *et al*., 2002). The development of *Typha* beds in combination with couch (*Cynodon dactylon*) has in places within the lower Ord River stabilised sand deposits and trapped silt. The establishment of a feedback loop of sediment deposition and vegetation expansion was discussed in section 3.1. Prior to the 2000 flood event, these vegetation beds strongly influenced sediment dynamics of the river, increasing channel roughness, decreasing flow velocity and trapping sediment (Start *et al*., 2002). However, the shallow rooted *Typha* is easily displaced by strong currents and the 2000 flood stripped almost all *Typha* from the banks of the lower Ord River (Start *et al*., 2002). Subsequent diminished wet season flows have enabled substantial recolonisation of the lower Ord River by *Typha* since the 2000/2001 floods (A.W. Storey, Uni of W.A., *pers. obs.*).

Since the 2000 flood, another indigenous species (*Phragmites karka*) has become dominant along channel margins. *Phragmites* is a woody, bamboo-like, rush that grows in very dense stands to 4m. It lacks the capacity of *Typha* to form large floating mats. However, it is deep-rooted, capable of withstanding prolonged inundation, strong currents and it can establish from broken sections of stem buried in sediment. This species has the potential to spread rapidly and like *Typha*, influence sediment dynamics in the lower Ord River. It is also possible that *Phragmites* would respond positively to increased flooding (Start *et al*., 2002).

Aquatic emergent and submerged plants are able to respond relatively rapidly to changes in dry season flow (eg. season to season changes). Their distribution within the river channel is determined by tolerances to differing regimes of light availability, water velocity and water depth. Therefore, if dry season flows decrease, from one year to the next, submerged and emergent macrophytes migrate down with the water level, staying within their limits in terms of light availability, water velocity and depth. At the same time, their outward margins reduce, dependent on soil moisture levels and tolerance to seasonal drying. Maintenance of emergent and submerged aquatic macrophyte communities at an extent and condition similar to existing will be achieved by ensuring permanent flow throughout the dry season. Management of submerged and especially emergent species also needs to be considered in the context of managing channel form and sediment dynamics. Management of macrophytes is likely to be achieved by infrequent flood events or at least maximising the power of infrequent flood events similar to the 2000 flood. Maximising the magnitude and power of such events may also assist in the maintenance of mid-bank old riparian communities as discussed previously.

Flow objectives and considerations:

- 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 terrestrialization. Reaches: Reach 1 (KDD to Tarrara Bar), Reach 2 (Tarrara Bar to Tidal) and Reach 3 (Tidal Influence).
- 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 midslope may serve this purpose. Short duration flows (~2-3 days, reaching ~25cm deep in the mid slope zone) may be all that is required. Timing: Feb-April. Reaches: Reach 1 (KDD to Tarrara Bar), Reach 2 (Tarrara Bar to Tidal) and Reach 3 (Tidal Influence).
- The submerged and emergent vegetation of the lower Ord River is likely to be retained provided 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 3 years may be sufficient to minimise Typha and other weedy species encroachment on the channel. Reaches: Reach 1 (KDD to Tarrara Bar), Reach 2 (Tarrara Bar to Tidal) and Reach 3 (Tidal Influence).
- 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 only occur every 1 in 20 years. This objective should not be viewed as a priority. Reaches: Reach 1 (KDD to Tarrara Bar), Reach 2 (Tarrara Bar to Tidal) and Reach 3 (Tidal Influence).

3.3 Fish Assemblages

3.3.1 Pattern and distribution

There are 38 species of fish known to occur in the lower Ord River (Storey, 2003) and 53 species recorded in the Ord overall (Appendix 2). Generally, most taxa that are found in the lower Ord River are distributed along its entire length, with the exception of occasional records of species such as *Elops australis* (Giant herring), *Arramphus sclerolepis* (Garfish), *Arius leptaspis* (Triangular Shield catfish), *Marilyna meraukensis* (Merauke Toadfish), *Thryssa* sp.(Anchovie sp.) and an unidentified sea mullet which were taken from the lower tidally-influenced reach, reflecting their marine/estuarine origins (Storey, 2003). None of the species recorded is listed as threatened in the WA Government Gazette (2005). However, the freshwater sawfish, *Pristis microdon* is listed under the EPBC Act (1999) as vulnerable, meaning that it is facing high risk of extinction in the wild in the mid-term future. This species is also listed as critically endangered by the Australian Society for Fish Biology. In addition, the Freshwater Whipray (*Himantura chaophraya*) is listed as Vulnerable by IUCN and the Ord River is the East Kimberley stronghold for this species

Fish in the lower Ord River show some degree of habitat preference. Storey (2003) found that fish abundance, species richness and biomass differed significantly between various habitats sampled, with the highest number of taxa being found in the shallow backwater and macrophyte habitats. These habitats, together with shallow floodplain habitats also supported the greatest number of fish. These results reflect the high numbers of diverse small species, together with juveniles of larger species that occupy shallow areas. Larger bodied fish tended to be found in deeper habitats such as flooded riparian vegetation, pools and deep backwaters (Storey, 2003). Water depth, velocity and cover (including vegetation, % root mat, bedrock and angle of the bank) were the main environmental factors thought to influence the observed distributions.

Juveniles and more mature individuals do not necessarily occupy the same habitat in the lower Ord River. Storey (2003) found that there was a strong aggregation of size classes into different zones, with juvenile stages occurring in the shallow water habitats and more mature specimens found predominantly in the deeper habitats. Preferences (determined using chi-squared statistics; see Storey, 2003) were more pronounced in the dry period, than the wet, with 42 and 27% of pseudospecies (i.e. species separated into size classes) showing a preference for a specific habitat at those respective times respectively (Table 8).

The strong relationship between fish diversity and habitat diversity in the lower Ord River, as well as the role of depth, velocity and extent of cover in influencing these is consistent with world literature (see Storey, 2003; Wetland Research and Management, 2000). Shallow habitats in the lower Ord River were thought to provide the cover required by small-bodied species and juvenile stages of larger-bodied species to avoid predators (Storey, 2003). Deeper water habitats were thought to provide the necessary requirements for large bodied species, including deep water with reduced visibility for predator avoidance, space for schooling fish, large snags and overhangs in which large fish could reside (Storey, 2003).

While the biology and ecology of some species (eg. barramundi, bony bream, spangled perch and fork-tailed catfish) have been fairly well documented, there are many species in the lower Ord River about which very little is known (see Appendix 2 for a brief summary of available information on fish species recorded for the lower Ord River).

Table 8: Occurrence of fish pseudospecies (species grouped in size classes) in each habitat in late dry season. (+ indicates the species was found in the habitat, ++ indicates the most preferred habitat(s) of each species and – indicates the species did not occur in the habitat; number of samples taken from each habitat is in parenthesis). Adapted from Storey (2003).

	Habitats					
	Shallow			**Deep**		
Pseudospecies	**Shallow Backwaters** (6)	**Gravel runs** (6)	**Submerged macrophyte** (1)	**Emergent Vegetation** (6)	**Flooded Riparian** (6)	**Pools** (6)
*A. graeffei (*large*)*	-	+	+	+	**++**	**++**
*A. graeffei (*medium*)*	-	+	-	+	**++**	**++**
*A. graeffei (*small*)*	-	+	-	+	+	+
*A.macleayi (*large*)*	**++**	-	+	-	-	-
*A.macleayi (*medium*)*	**++**	-	**++**	-	-	-
*A.midgleyi (*large*)*	-	-	-	+	+	+
*A.midgleyi (*medium*)*	-	-	-	+	+	**++**
*A.midgleyi (*small*)*	-	-	-	-	+	-
*A.mulleri (*large*)*	+	+	+	-	+	-
*A.mulleri (*medium*)*	**++**	+	+	-	-	-
*A.percoides (*large*)*	+	+	-	-	-	+
*A.percoides (*medium*)*	**++**	**++**	+	-	-	-
*A.percoides (*small*)*	**++**	-	-	-	-	-
Anguilla bicolour	+	-	-	-	-	-
Arius leptaspis	-	-	-	-	+	+
Arrhamphus sclerolepis	-	-	-	-	-	+
Carcharhinus leucas	-	+	-	-	+	+
Craterocephalus	+	-	**++**	+	-	-
Elops australis	-	-	-	-	-	+
Glossamia aprion	**++**	-	**++**	-	-	-
Glossogobius giuris	**++**	+	+	-	-	-
Goby sp.B	+	-	-	-	-	-
*H.compressa (*large*)*	-	-	**++**	-	-	-
*H.compressa (*small*)*	+	-	-	+	-	-
Hephaestus jenkinsi	-	-	**++**	-	-	-
*L.alata (*large*)*	+	-	-	+	**++**	**++**
*L.alata (*medium*)*	**++**	+	-	+	-	+
*L.alata (*small*)*	+	-	-	-	-	-
*L.calcarifer (*large*)*	-	-	+	+	+	+
*L.calcarifer (*medium*)*	+	+	+	+	+	+
*L.calcarifer (*small*)*	+	-	-	-	-	-
Leiognathus equulus	+	+	-	-	-	+
Leiopotherapon unicolor	+	-	-	-	-	-
*M. australis (*large*)*	**++**	+	+	-	-	-
*M. australis (*small*)*	+	+	-	-	-	-
*M. cyprinoides (*large*)*	-	-	-	+	+	+
*M. cyprinoides (*small*)*	-	-	**++**	-	-	+
Marilyna meraukensis	+	+	-	-	-	-
*N. hyrtlii (*large*)*	-	-	-	+	+	+
*N. hyrtlii (*small*)*	+	-	-	+	-	-
*N.erebi (*large*)*	+	-	-	+	+	+
*N.erebi (*medium*)*	+	-	+	+	+	**++**
*N.erebi (*small*)*	**++**	-	+	-	-	+
Parambassis gulliveri	**++**	-	+	-	-	-
*S. krefftii (*large*)*	+	-	-	+	-	+
*S. krefftii (*small*)*	+	-	-	-	-	-
Syncomistes butleri	-	-	-	-	-	+
*T. chatareus (*large*)*	+	-	-	+	+	+
*T. chatareus (*small*)*	**++**	-	+	+	-	-
Thryssa sp.	-	-	-	-	-	+
Total preferred per habitat	12	1	6	0	3	5

3.3.2 Impacts of Water Management

The Kununurra Diversion Dam (KDD) represents a major barrier to migratory fish movement. Morrissy (2000) reported that barramundi were once found in the canyon pool of the Nicholson River, an upper Ord tributary. Today, this species is restricted to lower Ord River and in the late wet season juveniles are frequently found at the base of the KDD where they are subject to predation and fishing pressure. Morrissy (2000) estimated that the barrier posed by the KDD had diminished access to available habitat for migrating juvenile barramundi by 60%, but there was no indication that adult stock and thereby catch, had been diminished. In addition to the KDD there are a number of smaller man-made and naturally occurring structures that can and do inhibit fish movement during low flows (eg. Carlton Crossing, Bat Alley, Sandy Beach, Mambi Island, rapids above and below Buttons and Ivanhoe Crossing and Ivanhoe Crossing itself). However, the constancy and size of post regulation dry season flows provide greater capacity for fish movement than pre-regulation flows.

It would appear that, with the exception of restricted movement past the large dams, the fish communities of the Ord River are not markedly altered from that which may have been found prior to regulation. The system supports a large number of species (53 overall) consistent with an estimate of 50 made for the pre-dam system (Storey, 2000) based on the size of the Ord catchment (approx. 50 000 km^2) and using an empirical relationship derived by Welcomme (1985) for large floodplain rivers. While little is known of the fish communities that inhabited the Ord River prior to its regulation (at least in terms of documented scientific studies), much can be inferred by comparing the Ord to nearby unregulated systems.

A comparative evaluation was made between fish communities of the regulated lower Ord River and those of the unregulated Keep, Dunham and Pentecost Rivers (WRC, 2003a). That study found that there were no significant differences in species richness, abundance or biomass between the Ord and the unregulated rivers. However, there were differences in the average weight (i.e. fish size) of species (WRC, 2003a). More than half of the thirteen most abundant fish species were significantly heavier in the Ord in comparison to the other rivers (Table 9).

Further examination of length:weight relationships for these species did not suggest that the differences were due to condition and thereby a more productive Ord system (WRC, 2003a). Rather the explanation for the larger fish in the Ord River was that the regulated system offers greater habitat diversity and deeper water in the dry season, thereby decreasing predation and competition pressure which in turn allows fish to live longer (WRC, 2003a). Alternatively, more frequent flooding may limit fish attaining a larger size within the unregulated rivers.

Table 9: Comparative weights of seven abundant fish species in the Ord River with those found in the unregulated, Keep, Dunham and Pentecost Rivers (from WRC, 2003a).

Species	**Lower Ord River – Regulated (g)**	**Unregulated Rivers (g)**
Barred grunter (*Amniataba percoides*)	26.3	7.5
Barramundi *(Lates calcifer)*	1076	725
Mullet *(Lisa alata)*	449	209
Giant glassfish *(Parambassis gulliveri)*	58.9	40.6
Butler's grunter *(Syncomistes butleri)*	279	150
Seven-spot archerfish *(Toxotes chatareus)*	150	96

Species composition in the lower Ord River does not appear to have been affected by regulation. The lower Ord River displays a species composition similar to that of the unregulated, Keep, Pentecost and Dunham Rivers (WRC, 2003a). However the Ord River does appear to support more small species and juveniles of larger estuarine species, including the barramundi, than the unregulated Keep, Dunham and Pentecost Rivers. This may be due to the easy upstream access and connected river – pool sequences in the Ord River (WRC, 2003a). Notably, Dunstan (1959) suggested that rivers with continuous flow in the dry season, which were not subject to extremes in the wet, provided the best riverine habitat for barramundi juveniles. Thereby the regulation of the Ord may have improved the habitat for barramundi, albeit now restricted to the lower Ord River below the KDD. The reproductive success of barramundi and other species may have also improved in the regulated lower Ord River. Species that spawn in salt water are no longer dependant on the timing, duration and intensity of the wet season to determine if and when they can ultimately reach the ocean and spawn (Bishop *et al*., 2001). Mature fish now have year round access to the sea and the chance to utilise optimal spawning conditions every year.

Fish communities in the lower Ord River do not appear to exhibit the profound changes speculated to have occurred since regulation (Storey, 2000). Floodplain inundation is thought to provide an important food rich environment for larval and juvenile fish as well as spawning ground for adult fishes (Balcombe *et al.*, 2005), with the timing and duration of these events being consequently linked to overall fish abundance (Douglas *et al*., 2005). Loss of catchment and floodplain connection were therefore hypothesized to result in decreased diversity and population size due to decreased habitat diversity and productivity respectively. However, the comparable species richness, abundance and biomass of fishes in the lower Ord River and unregulated Keep, Dunham and Pentecost rivers suggest that this is not the case. An explanation for this is that the low energy, relatively constant and higher dry season flow provides sufficient habitat diversity to support an array of species. Additionally, the establishment of substantial riparian and submerged/emergent macrophytes along the river channel may simulate floodplain conditions. Submerged vegetation provides spawning habitat and predator-avoidance habitat for small species, supports food sources (epiphytic growths of algae/diatoms/invertebrates), and riparian vegetation provides carbon inputs to the system (leaf fall and terrestrial insects).

It was also hypothesized that the post-regulation constant dry season water levels would provide for a more stable and predictable fish community with a different dominance hierarchy than in the pre-regulated state (Storey, 2000). There is no evidence of this in the species composition found in the lower Ord River, which is largely comparable to that of the nearby unregulated systems. However, it could be argued that the comparatively larger size of some species found in the lower Ord River may well be a function of that stable and predictable environment.

Although the lower Ord River receives irrigation return water at a number of locations, other than the occasional occurrence of dead fish flushed from irrigation channels, since 1997 there have been no reported fish kills in the main channel of the lower Ord River below the Kununurra Diversion Dam. Between 1997 and 2004 there were however eight recorded fish kill events in the Ord River Irrigation Area. Four of these events primarily affected irrigation channels, the likely cause being herbicides/pesticides (acrolein/endosulfan) or de-oxygenation and high temperature due to irrigation shutdown. Of the remaining fish kills, two were in the Dunham River and endosulfan discharged from the Packsaddle irrigation area was considered to be the probable cause (Dept. of Water, unpublished data). One was in Lily Creek Lagoon (a backwater of Lake Kununurra) and was caused by a sudden three-metre drop in water levels in Lake Kununurra. The remaining event occurred in an isolated spring fed pool and was caused by de-oxygenation due to a lack of flows.

3.3.3 Flow Related Issues

While the current flow regime in the Ord River is markedly changed from that which occurred in the pre-regulation situation, it would appear that fish communities have adjusted to those changes. The system currently supports an extensive array of species occupying a wide range of habitats. If these current values are to be maintained at a low level of risk then care needs to be taken with any further modification to the flow regime.

Changes in discharge are likely to cause alterations in depth, velocity, substrate structure and degree of cover (see review by Wetlands Research and Management, 2000). At least three of these factors have been shown to be important predictors of fish community composition in the lower Ord River (Storey, 2002). If changes to these parameters are sufficiently marked then we may expect to see reductions in habitat availability/suitability, with an associated decline in abundance, biomass and/or diversity of species.

For example, whilst large barriers such as the KDD and the Ord River Dam will remain impassable for upstream movement of fishes in the absence of some form of fish ladder, there are a number of naturally occurring and man-made structures within the system that at low flows would represent barriers to fish movement. Ivanhoe Crossing represents the greatest man made barrier that under the current flow regime is typically passable during wet season flows only. If flows are reduced significantly it is possible that other obstacles and naturally occurring shallow areas (such as Carlton Crossing, Bat Alley, Sandy Beach, Mambi Island and rapids above and below Buttons and Ivanhoe Crossings) would restrict movement of migratory species within the system.

A low flow field trial was conducted in October 2002 to quantify the effects of reduced dry season discharge on fish communities and water quality in the lower Ord River (Wetlands Research and Management, 2002; WRC, 2003B). Discharge below the KDD was reduced from $93m^3.sec^{-1}$ to $30m^3.sec^{-1}$ for a period of three days. The effect on fish community distribution and composition between Tarrara Bar and Carlton Crossing were surveyed, before, during and after the reductions in flow, focussing on three key habitats: pool (>2m); shallow backwaters (<1m with flow $<5cm^3.sec^{-1}$) and beds of the submerged macrophyte, *Vallisneria americanum*. During the period of reduced flow, large areas of macrophyte bed were exposed resulting in a rapid die-off and concurrent increases in temperature, pH and dissolved oxygen within beds of the habitat still inundated. In addition, the average wetted cross-sectional area of backwater was reduced by 80%. Backwaters were not replaced by similar features at a lower stage height.

Despite observations during the trial of schools of large and small fish moving in a fast erratic fashion in the shallows, no significant effect on fish abundance or biomass was observed in the 3 days of low flow in any of the three habitats (Wetlands Research and Management, 2002; WRC, 2003b). Species richness was lower only in the macrophytes after the trial, but there were no marked changes in fish community composition overall. To some extent the results of this trial may be misleading as there was a high degree of variability in catch and the level of replication may have lacked the statistical power to detect an effect. Further, the short duration of the trial may not have been sufficient for the effects on carrying capacity and populations to fully manifest. Importantly, there appeared to be a trend of declining biomass across the trial period in both the backwater and macrophyte habitats.

Reduced discharge in the dry season has the potential to increase risk of anoxia occurring within riverine pool habitats. Dissolved oxygen (DO) concentrations in river pools are governed by the difference between the supply of oxygen to the pool (mixed in from the atmosphere, brought in with inflow and produced by the photosynthesis of the pools aquatic plants and algae) and the consumption of oxygen in the pool (from the respiration of the pool's plants and animals and biological and chemical oxidation processes). This balance usually results in DO levels increasing during the day and reducing overnight. The greatest reductions tend to occur near the base of pools following mild still nights, when warm night-time air temperatures and low wind velocities limit surface water cooling and wind mixing and can result in anoxic conditions. Fish deaths can occur where the whole water column becomes anoxic and sublethal effects on fish (eg. reduced egg viability) can develop where oxygen levels fall below about $2mg.L^{-1}$. This was an important concern raised by the Ord Scientific Panel (WRC, 2000). They recommended that flow in the riverine pools be sufficient to buffer the effects of potentially high oxygen consumption and to ensure that the pools did not become isolated.

In response to these concerns, a low flow field trial and modelling study was conducted to quantify the effects of reduced dry season discharge on dissolved oxygen dynamics of pool water in the lower Ord River (Wetlands Research and Management, 2002; WRC, 2003B) {To complement the dissolved oxygen studies, aquatic fauna responses to the low flows during the field trial were also investigated}.

The low flow trial was carried out in October 2002 and involved detailed physical, chemical and biological monitoring of water in Skull Rock and Carton Crossing pools, respectively ~39 km and ~ 60 km downstream of the Kununurra Diversion Dam. Flow rates at the Diversion Dam for the first two days of monitoring ranged from 85 to 92m^3.sec^{-1}. The gates were adjusted to reduce the flow to ~31m^3.sec^{-1} for the following three days before being returned to rates similar to those at the start of the trial (~85 to 90m^3.sec^{-1}). Monitoring continued while the pool water levels recovered and for a further two days.

Storage volumes, retention times and mean depths of water are presented for Skull Rock and Carlton Crossing pool for the range of flows modelled using results from the trial (Table 10). At the lowest flow rate of 35m^3.sec^{-1} nominal retention times were estimated as 8.4 hours for Skull Rock Pool and 12.7 hours for Carlton Crossing Pool.

Field observations showed that temperature stratification and anoxic conditions did not develop in Skull Rock pool during the trial. That is, sufficient night cooling, wind mixing and inflow entrainment occurred to ensure mixing to the base of the pool and limit the decline in DO levels at depth.

Temperature stratification was observed in Carlton Crossing Pool during the three days of low flow. The maximum temperature gradient (~2º C) developed by early to mid afternoon and then began to decline. Oxygen concentrations in the bottom water reached 5.5mg.L^{-1} compared with 8mg.L^{-1} at the surface for about 2hrs in the late afternoon prior to remixing. No anoxia was observed. No temperature gradient remained after 8:15 p.m., indicating that full mixing, primarily due to a combination of wind strength and surface cooling, had occurred to the base of the pool by 8:30 p.m. Entrainment mixing of inflow, and the probable injection of inflows into the deeper parts of the pool, especially during the evening, are also likely to have contributed.[7]

The risk of lower DO levels than observed during the trial was investigated by using a hydrodynamic/biological model to predict conditions over longer timeframes under a range of meteorological and biological loading conditions (WRC, 2003). The simulations were carried out over a six month period (May to November 2001) using meteorological data recorded at the nearby Mantinea Flats. This data set included several extended periods (typically 3-6 days) where wind

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[7] Entrainment mixing and the level of neutral buoyancy of inflow could not be directly inferred from the observed data, as the temperature of pool inflows were not recorded continuously during the trial.

speeds were low (in July, September and November 2001); meteorological conditions likely to lead to low DO levels in the pool water.

Simulations of dry season scenarios (Scenario No 13, 14, and 15 –WRC, 2003) were carried out at flows rates of 35, 45 and 65m^3.sec^{-1} under current biological loading conditions (as observed during the trial). These showed periods of temperature stratification and low DO at depth, when the wind speed remained low for extended periods. The longest period occurred in July when the model predicted six consecutive days of temperature stratification. Under the 35m^3.sec^{-1} scenario, with a minimum average velocity of inflows of approximately 0.08m.sec^{-1}, temperature stratification resulted in DO concentrations falling to below 3mg.L^{-1} (~ 30% saturation at July temperatures) in the bottom two metres of the pool over four consecutive days. Anoxic or near anoxic conditions lasted for three days in the lowest 1.5 metres of the pool, while the top 2.5 metres remained above 5.0mg.L^{-1} DO (~50% of saturation) over the six days. The predicted DO concentrations were very similar for the other flow rate scenarios.

When higher biological loading conditions were assumed (doubling of pool biological oxygen demand from observed during the trial and a reduction of the incoming oxygen in inflow from 100% to 70% saturation), longer and more severe periods of DO depletion were predicted during the same periods of low wind speed and temperature stratification. At these higher biological loadings, however, differences in flow rates became significant. For example more severe and longer periods of DO depletion were simulated at flow rates of 35m^3.sec^{-1}, rather than at 45m^3.sec^{-1}. This sensitivity analysis emphasised the importance of ensuring that such increases in biological loadings are avoided in the future (see comments under management objectives and considerations below).

*Table 10**:** Summary of water retention times in key pools along the lower Ord River under different dry season minimum flows.*

Identified Pool	Flow into pool	Length(m)	Min. average velocity (m.sec^{-1})	Pool volume (ML)	Retention time(hrs)
Skull Rock Pool	90m^3.sec^{-1}	6500	0.21	1500	4.5
	35m^3.sec^{-1}	6500	0.09	1060	8.4
u/s Carlton Crossing	90m^3.sec^{-1}	5700	0.18	2010	6.2
	35m^3.sec^{-1}	5700	0.08	1600	12.7

Flow objectives and considerations:

- The shallow backwater and submerged macrophyte 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 this it is important that the current area of shallow backwater and submerged macrophyte be maintained in the dry season. Shallow backwaters are characterized as areas of negligible flow velocity, often associated with meanders and point bar formations, with a recorded depth range of between 20 and 85cm (average 45cm; Storey, 2003). In the dry season, submerged macrophyte beds have typically been recorded in water 90cm deep (minimum 47cm) and low flow velocities (average 3cm.sec^{-1}; Storey, 2003). However, submerged macrophytes can occur in much deeper water (>2m; Marshall and Storey, 2005) depending on light availability and substrata composition. Reaches: Reach 1 (KDD to Tarrara Bar) and Reach 2 (Tarrara Bar to Tidal).

- Larger bodied fish tended to be found in deeper habitats such as pools (3-4m), flooded riparian vegetation (average 1m), and deep backwaters (average 2m). The latter two habitats do not exist in the dry season with species exhibiting strong preferences towards them in the wet season. This is presumably a flow avoidance strategy with the flooded riparian vegetation and backwaters having flows at least 4 to 8 times slower respectively than the pools (Storey, 2003). In the absence of floodplain inundation, flooded riparian vegetation offers possible spawning and nursery sites for juveniles. Flooding of riparian vegetation (to ~1m) and 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. Reaches: Reach 1 (KDD to Tarrara Bar) and Reach 2 (Tarrara Bar to Tidal).
- It is recognized that barriers such as the KDD and the Ord River Dam will remain impassable for upstream movement of fishes unless some form of fish ladder is installed (currently under consideration). However, there is 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 is during the wet season with a second peak in the late wet (April) for returning species. A depth of 0.6m over these obstacles during those times should be ample to ensure passage. Frequency and duration of that size of flow events must be evaluated. Reaches: Reach 1 (KDD to Tarrara Bar), Reach 2 (Tarrara Bar to Tidal) and Reach 3 (Tidal Influence).
- 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 2mg.L^{-1} 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 0.08m.sec^{-1}. Requires flow-duration analyses. Reaches: Reach 1 (KDD to Tarrara Bar) and Reach 2 (Tarrara Bar to Tidal).

3.4 Macroinvertebrates

3.4.1 Patterns and Distribution

A survey of macroinvertebrates in the lower Ord River across a range of habitats, including emergent and submerged macrophytes, flooded riparian margins, gravel runs, mud, sand and rapids recorded 171 taxa with insects accounting for approximately 80% of the taxa recorded (Storey, 2002). An additional study in 2003 recorded a further 36 taxa were recorded at two sites in the lower Ord River bringing the total to 207 (WRC, 2003a; Appendix 3). In the wider Ord basin an additional 64 taxa, not recorded in the lower Ord River, have been recorded from the Dunham River and Parry Lagoon floodplain and Lake Kununurra (WRC, 2003a; Appendix 3).

Storey (2002) found that in the lower Ord River, the emergent macrophytes contained the greatest number of taxa, with lowest richness recorded in the sand and mud habitats. The different riverine habitats were found to support different macroinvertebrate assemblages, with the majority of taxa (67%) demonstrating a preference for one or two habitats and only 7 taxa restricted to one habitat - predominantly the submerged macrophytes (Storey, 2002). Generally, most taxa found in the lower Ord River are distributed along its entire length. The habitat descriptors that best explain the patterns in the macroinvertebrate distribution observed by Storey (2002) are water depth and velocity and the proportion of mineral and detrital material in the substrata.

3.4.2 AusRivas Health Assessment

Macroinvertebrate communities were assessed to provide a measure of health of the Ord River using the AusRivAS package as part of the First National Assessment of River Health and State of Environment (SOE) reporting (Halse *et al*., 2001). For SOE reporting, river basins were graded A - D, with A being the highest condition (undisturbed) and D being the poorest condition (extremely impaired). The assessment showed that while most rivers of the Kimberley showed little sign of disturbance, the Ord River was one of the most disturbed, with an average Observed/Expected (O/E) score in Spring of 0.83 (top end of Band B), and an overall basin condition of C. Halse *et al*. (2001) attributed the disturbance to cattle grazing and associated erosion/siltation. Notably, the assessment was based on 10 sites distributed throughout the Ord basin, with only three downstream of the Ord River Dam. Those downstream sites scored as Bands A and B in Spring and Autumn 1998.

Storey (2002) undertook a comparative evaluation using macroinvertebrate samples collected from Gravel, Rapid and Sand habitats of the lower Ord River and applying the AusRivAS Spring season, Channel habitat model. Of the 23 samples analysed, only one was scored as Undisturbed (A), and 16, 4 and 2 were scored as Significantly (B), Severely (C) and Extremely Impaired (D), respectively. The overall average O/E score was 0.57 (Gravel = 0.68, Rapid = 0.66, Sand = 0.41).

While the low O/E scores for the lower Ord River may be interpreted as indicative of further degradation, Storey (2002) suggested that several confounding factors needed to be taken into consideration. Most notably, in the intervening period between the assessments, there had been two large successive wet season floods, followed by high dry season flows. The floods caused considerable mobilisation of fine and coarser sediment in the lower Ord River to such an extent that the structure of the habitat was severely modified. It is possible that, as a result, the value of the habitat for macroinvertebrates was diminished and a more depauperate fauna prevailed.

3.4.3 Impacts of Water Management

Halse (2000) hypothesized that, because there are few biogeographical patterns in the Kimberley, it was likely the number of macroinvertebrate families occurring in the Ord River prior to the construction of the dams, would be similar to that which is seen in the Fitzroy River today (~38 families). He suggested that in the period following regulation, the Ord River had become slightly depauperate (~30 families). However, these figures appear low when compared to the number of families (> 55) listed by Storey (2002) for the lower Ord River. The marked differences are likely a function of the large number of habitats sampled by Storey (2002).

A comparative evaluation of macroinvertebrate richness in the regulated Ord River with nearby unregulated rivers (Keep, Dunham and Pentecost; WRC, 2003a) found the number of taxa to be similar, thus suggesting the Ord River is not depauperate. However, the study also showed that the composition of macoinvertebrate fauna of the regulated Ord River was distinctly different from the unregulated systems. This suggests that in the period following regulation, conditions in the Ord River have altered such that the mix of invertebrate species has changed.

No differences in the richness or composition of macroinvertebrate fauna were observed between seasons (wet and dry) for either the regulated or unregulated sites. This is possibly a result of the difficulties incurred in sampling during the wet, which often pushed sampling back towards the drier period, and therefore was not truly representative of the wet season fauna.

The lower Ord River supports abundant populations of *Macrobrachium* prawns (Cherabun) and Atyid shrimps, which form an important food resource for barramundi and other fish. The migratory Cherabun (*M. rosenbergii*) is of particular interest. This crustacean normally spawns in estuaries in the early wet and juveniles then move upstream as flow recedes at the beginning of the dry season. In the Ord River, juvenile *M. rosenbergii* prawns were recorded in September 2000 and November 2001, approximately nine months after this early life stage would normally be expected to occur (WRC, 2003). This was not observed in the nearby unregulated Keep, Dunham and Pentecost Rivers. The observation suggests that there may be continual recruitment of *Macrobrachium* in the Ord River throughout the dry period in 2000/2001. It has been hypothesized that this may be a function of the high dry season flows following the 2000 and 2001 wet season floods, when the Ord River Dam overtopped for much of the dry season, simulating flood conditions in the lower Ord River (WRC, 2000).

3.4.4 Flow Related Issues

Storey (2002) undertook a preliminary assessment of the susceptibility of macroinvertebrate habitats to reduced flow. This was based on a number of indices including the biodiversity of each habitat, areal extent of the habitat, the likelihood of the habitat being modified by reduced flow and degree to which macroinvertebrate fauna show a preference for the habitat. The results suggested that rapids, gravel bars, submerged macrophytes and emergent macrophytes were the habitats most likely to be susceptible to reduced flow in the lower Ord River. By implication the macroinvertebrate communities that show a strong preference for these habitats would be most vulnerable to change.

The Ord River supports a macroinvertebrate community that is distinct from nearby unregulated rivers. In part this effect may be caused by the altered flow regime. If this is true, then reduced dry season flow and a transition towards a more seasonal system might result in the return of a macroinvertebrate composition that is more typical of the unregulated rivers of the area. This would be dependent on the degree to which the dry season flow changed and how the subsequent changes in depth and velocity influenced habitat. A return to a more seasonal system has implications for water quality, and the reduction to the point where disjunct river pools may increase the risk of deoxygenation and fish kills in the system (WRC, 2000). As discussed in section 3.4, studies undertaken to date identified a threshold velocity of $0.08ms^{-1}$ occurring at an estimated discharge of $35m^3.sec^{-1}$, below which the risk of anoxia increased. Reduced oxygen availability will also impact macroinvertebrate populations. Further, as suggested by Halse (2000), a reduction in cross-sectional habitat area may have implications for macroinvertebrate biomass and thereby diminished food resources for fish in the system. It is also likely that species which require permanent flows and which now inhabit the Ord River would be lost.

Macrobrachium prawns are an important component of the Ord River food web. They occur across a number of habitats, with the exception of sand and mud and one species *Macrobrachium bullatum* shows a strong preference for submerged macrophyte beds (Storey, 2002). The potential effect of reduced dry season discharge on *Macrobrachium* prawns in the lower Ord River was demonstrated in a low flow trial (Wetlands Research and Management, 2002; WRC, 2003b). Discharge below the KDD was reduced from ~$80m^3.sec^{-1}$ to ~$30m^3.sec^{-1}$ for a period of three days. During that time, there were large areas of submerged macrophyte bed exposed, with rapid die off in these areas occurring and concurrent increases in temperature, pH and dissolved oxygen in that habitat. The drawdown resulted in a decline in abundance and biomass of *Macrobrachium* prawns in the macrophyte bed. These did not recover when the flows were subsequently returned, with significantly fewer prawns collected after the trial in comparison to the pre-trial densities and biomass. The results imply that changes in the area of available submerged macrophyte habitat may have implications for reduced carrying capacity of prawns in the system (Wetlands Research and Management, 2002; WRC, 2003b).

Flow objectives and considerations:

- Gravel runs and rapids are important habitats for macroinvertebrates and susceptible to change under reduced dry season flows (Storey, 2002). A reduction in water level (stage height) and subsequently habitat availability will in turn impact macroinvertebrate populations. It is therefore important that a minimum stage height be maintained in these habitats during the dry season if current values are to be preserved. Typically, average depth over these habitats observed in the dry season are ~24cm (Storey, 2002). Reaches: Reach 1 (KDD to Tarrara Bar) and Reach 2 (Tarrara Bar to Tidal).
- 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 1.3m and a minimum of 0.3m should not be exceeded if current values are to be preserved. Reaches: Reach 1 (KDD to Tarrara Bar) and Reach 2 (Tarrara Bar to Tidal).
- 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. If flows are to be reduced it is important, however for water quality reasons, that pools do not become isolated in the dry season and flow velocities in pools should not decrease below $0.08 m.sec^{-1}$. Requires flow-duration analyses: Reaches: Reach 1 (KDD to Tarrara Bar), Reach 2 (Tarrara Bar to Tidal) and Reach 3 (Tidal Influence).
- 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). A reduction in the area of submerged macrophytes is likely to impact macroinvertebrate populations. If current values are to be preserved 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 90cm deep (minimum 47cm) and low flow velocities (average $3 cm.sec^{-1}$; 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). Reaches: Reach 1 (KDD to Tarrara Bar) and Reach 2 (Tarrara Bar to Tidal).

3.5 River-Floodplain: Communities and Process

3.5.1 Ramsar Wetlands

The lower Ord River floodplain and Lakes Argyle, Kununurra & their associated wetlands are listed as Wetlands of International Importance under the Ramsar Convention (1990). Information used to support their nomination against the criteria of the convention is shown in Table 11, with these sites listed on the values and hydrological regimes present after the construction of the KDD and the Ord River Dam.

The Ord River Floodplain site includes two main areas of wetland values: the permanent and seasonal wetlands of the Parry Lagoons Nature Reserve; and the estuarine and marine habitats of the Ord River Nature Reserve and the False Mouths of the Ord River (Watkins *et al.*,1997). Parry Lagoon and the associated floodplain area are important in terms of breeding, species richness and abundance of waterbirds. Up to 27 000 birds of 77 waterbird or water-associated species have been recorded there. Magpie Geese, egrets, ibis and herons are among the species that breed there in the wet. The value of the area for waterbirds is increased by the extent of flooding but is also inversely related to the amount of water elsewhere in the north-west of Western Australia and in the Northern Territory.

The tidally influenced areas of the lower Ord and the False Mouths of the Ord River support some of the most extensive mangrove communities in the region. Fourteen species of mangrove have been recorded from the area. Mangrove communities throughout the site exhibit strong patterns of species zonation reflecting species preferences for particular tidal flooding regimes.

Surveys of the fish fauna of the Marlgu Billabong on the Parry Lagoon floodplain suggest that the floodplain site is depauperate in comparison to the main river with only 9 species being collected (see Appendix 2; WRC, 2003). No fish species were found to show preference for sites on the Parry Lagoon area in comparison to riverine sites. Given that floodplain ecosystems often support high levels of biodiversity, this result was surprising. The low diversity was attributed to the shallow nature of the floodplain habitat (not necessarily suitable to large bodied fishes), the distance of Marlgu Billabong to the main Ord channel and seasonality. Low night-time oxygen levels as a result of high oxygen demand in the heavily vegetated billabong (*viz*. high cover dense macrophyte beds) might also have made this area unsuitable for a wider range of fish species.

In contrast, the Parry Lagoon area supports a rich invertebrate composition with 87 taxa being recorded (see Appendix 3; WRC, 2003a). Overall the average number of taxa in the Parry Lagoon area was similar to that found in nearby riverine environments, but community composition was distinct, with 20 taxa found to have a preference for the floodplain over riverine habitats (WRC, 2003a). This may reflect the preference of some species for non-flowing environments

3.5.2 Functional Ecology and Connectivity – Impacts of Water Management

Like many rivers in tropical Australia the Ord River is influenced by seasonal monsoonal and cyclonic rainfall patterns and experiences high rainfall runoff. Prior to the construction of the dams the Ord had highly seasonal flow with large wet season flood events and little or no flow during the dry season (Ruprecht, 2000). Inundation of downstream wetlands during the wet season occurred in most years. Regulation has resulted in a decreased frequency and magnitude of high flow events in the lower Ord River, with a corresponding decrease in the extent and duration of floodplain inundation. Dry season flows have increased due to releases for irrigation and hydropower generation to the extent that the Ord River is now a perennial system. These changes to the hydrology of the Ord River influence its functional ecology and connectivity with the floodplain (see also section 2, this report).

Until recently our knowledge of the ways in which flows in large floodplain river systems of the Australia's tropics influence ecological processes and how energy is distributed through food webs was limited. A review by Douglas *et al.* (2005) endeavoured to derive a number of principles to highlight predicted key environmental drivers of Australia's tropical rivers, that is, drivers that are likely to influence aquatic food webs and ecosystem processes (Douglas *et al*., 2005). These principles are proposed to be typical of large, free flowing systems in Australian tropical rivers and include:

- seasonal hydrology is the primary driver of aquatic food-web structure and ecosystem processes;
- hydrological connectivity is intact and underpins important lateral and longitudinal food-web subsidies;
- river and wetland food webs are strongly dependent on algal production;
- a few common macro-consumer species have a strong influence on benthic food webs; and
- omnivory is widespread and food-webs are short.

The modified status of the Ord hydrology suggests that the river system is unlikely to behave in the same way as free flowing systems, particularly in relation to principles one and two, above. It is possible to explore these principles further in relation to the Ord River given the number of ecological investigations undertaken in that system and nearby unregulated rivers, in recent years.

The first principle identified by Douglas *et al*. (2005) describes the central role of seasonal overbank flooding and its influence on aquatic food webs and the fluxes of carbon and nutrients that support them. This is consistent with the flood-pulse concept (Junk *et al*., 1989), which suggests that the primary source of productivity in lowland rivers are nutrients and particulate material derived from lateral exchange between the floodplain and the channel. Typically, in tropical rivers the marked seasonal rainfall and runoff drives dramatic shifts in community composition. To date, no evidence of this seasonal shift has been recorded for the regulated lower Ord River. Neither macroinvertebrate richness and composition, nor fish species richness, abundance, biomass and composition have been found to be different between wet and dry season surveys in the lower Ord River (WRC, 2003a). While this could be taken as evidence of the effect of regulation, it is important to note that no seasonal differences were recorded in any of those parameters in nearby unregulated rivers (Keep, Dunham and Pentecost; WRC, 2003a). The absence of a seasonal shift, may well be an artefact of sampling whereby inaccessibility of sites meant that mid wet season samples were not possible.

The second principle identified by Douglas *et al*. (2005) refers to water-mediated transfer (both active and passive) of matter, energy and/or organisms within or between elements of the hydrologic cycle. With its altered hydrological connectivity it would be expected that the Ord River would display a diminished community complexity and species diversity. While it is true that macroinvertebrate composition is distinct in the lower Ord River from that found in nearby unregulated systems, species richness is comparable (WRC, 2003a). In addition, species composition, richness, abundance and biomass of fishes is similar to that of the unregulated Keep, Dunham and Pentecost rivers (WRC, 2003a). An explanation for this is that the low energy, relatively constant and higher dry season flow in the lower Ord River provides sufficient habitat diversity to support an array of fish species. Additionally, the establishment of substantial riparian and submerged/emergent macrophytes along the river channel may simulate floodplain conditions. Submerged vegetation provides spawning habitat and predator-avoidance habitat for small species, supports food sources (epiphytic growths of algae/diatoms/invertebrates), and riparian vegetation provides carbon inputs (leaf fall and terrestrial insects) to the system (WRC, 2003a), as well as foraging and possibly spawning habitat when inundated (Storey, 2003).

Algal production is thought to be an important source of organic matter sustaining the ecosystem food web in the regulated lower Ord River (WRC, 2003a). This is consistent with the 3rd principle developed for tropical river systems (Douglas *et al*., 2005). Net Daily Metabolism in the lower Ord River and Parry Lagoon environments suggest that these systems were relying on in-stream production, to a greater extent than terrestrial sources of carbon to drive ecosystem function (WRC, 2003a). This was supported by isotope analyses to investigate food web dynamics. Food webs in the lower Ord River and the Parry Lagoon area were supported by algal productivity, with algal carbon estimated to comprise >50% of the total biomass of fish and macroinvertebrates (WRC, 2003a). In that study, some species of fish were found to derive nearly all biomass from this source. While not as important as in-stream production, riparian production is still important to the Ord River food-web. It was estimated that approximately 40% of carbon being processed by the Ord River food-web comes from the riparian zone. The results suggest that the functionality of the Ord River today is best described by the Riverine Productivity Model (Thorpe and Delong, 1994) and not by the Flood Pulse Model (Junk *et al.*, 1989).

The Riverine Productivity Model stresses the importance of local autochthonous production (in-stream production) and allochthonous inputs (input from riparian zone close to channel) to food webs of a large river system. It contends that carbon derived from local autochthonous sources is more easily assimilated than refractory carbon arising from the floodplains and tributaries. Further, it suggests that in periods outside flood pulses, the allochthonous material arising from the immediate riparian zone, which accumulates in slow flowing shallow areas at the edge of a river, is also important as a source of carbon since it is available over long periods (Thorpe and Delong, 1994).

Importantly, macrophytes were found to directly contribute little carbon to the food-webs in the Ord River and its floodplain. However, it is important to note that macrophytes are important for habitat (see sections 3.3.1 and 3.4.1) and also provide a large surface area for epiphytic algal growth.

Rates of productivity were generally higher in lower Ord River, Parry Lagoon area and Lake Kununurra than they were in the nearby unregulated rivers (Keep, Dunham and Pentecost) in the region (WRC, 2003a). Although variable, the lower Ord River showed an average Gross Primary Production (GPP) rate that was approximately 25% higher than the unregulated systems. The site sampled in Parry Lagoon (Marlgu Billabong) recorded very high GPP, which may be a function of the high light and shallow nature of that environment

Net Daily Metabolism estimates taken from the Keep, Dunham and Pentecost Rivers suggest that these systems are more reliant on external sources of carbon, either from the riparian sources and their floodplains, or that derived upstream (WRC, 2003a). The greater reliance of the lower Ord River on in-stream sources of carbon and of neighbouring systems on external sources, suggests a shift in ecosystem function following regulation.

The 4th principle identified by Douglas *et al*. (2005) for rivers in the wet-dry tropic relates to the strong influence that large-bodied consumers have on benthic food webs and controlling the flow of energy and matter through the animal community. While fish and prawns are diverse and abundant in the Ord River, their influence on the food web has not been examined.

The final principle identifies that omnivory is widespread in tropical rivers and that food webs are short (Douglas *et al.*, 2005). In the Ord River a large number of the fish species are known to feed on a broad range of dietary items (see Appendix 2). Information obtained from isotope analyses used to trace carbon and nitrogen through the food-web, suggests that barramundi are a 4th order predator in the Ord food web (WRC, 2003a). Similarly, short food-webs were identified for nearby unregulated systems (Dunham, Keep and Pentecost; Douglas *et al.*, 2005).

Table 11: Nomination details for Ramsar-listed wetlands (adapted from Watkins et al.*, 1997).*

Criteria	Ord Floodplain	Lakes Argyle and Kununurra
Criteria based on representative or unique wetlands: • Good example of specific type of wetland characteristic of its region	Yes	Not applicable (Man-made Wetlands)
Criteria based on plants and animals: • Assemblages of rare, vulnerable or endangered spp or in appreciable numbers. • Special value for maintaining the genetic and ecological diversity of a region • Habitat at critical stage of biological cycle	Estuarine crocodile: Located close to major breeding area; Impressive specimens in area. Zitting Cisticola: Rare and threatened bird species. Mangrove habitat: 14 species of mangrove	Freshwater crocodile: Lake Argyle supports population estimated 10-20 000; Lake Kununurra estimates 3-5000.
Specific criteria on waterfowl: • Regularly supports 20 000+ waterfowl. • Substantial number indicative of wetland values, productivity or diversity • More than 1% of a specific waterfowl population	Parry Ck Floodplain: 77 species including 22 listed under international conservation treaties. Estimated >20 000 birds use the area annually Parry Lagoons may be one of five most important wetlands in WA for migratory shorebirds (in terms of species) and ranked tenth most important in Australia. Highest breeding concentration of Magpie Goose in WA. Mangrove areas: Includes almost all specialist mangrove spp in WA. Part of the only population of Black Butcherbird in the state	Lake Argyle: 74 spp recorded (22 listed under international conservation treaties. >100 000 birds use Lake Argyle annually. Lake Kununurra : 160 spp. Significant breeding populations of Little Grassbird, Little Bittern, Spotless Crake and non-breeding migrant population of Oriental Reed Warbler
Description	Mangroves and salt-flats, seasonally flooding plains and permanent freshwater lagoons. Three distinct wetland units: • Parry Lagoon Nature Reserve. Dominated by seasonally flowing Parry Ck running through alluvial complex. Persistent freshwater billabong and swamps • Ord River Nature Reserve. Extends from the Parry Lagoon reserve to the Cambridge Gulf. Saline floodplain soils • False mouths of Ord. Delta of tidally inundated coast mud flats and islands	• Deep lakes and fringing inundated grassland and emergent macrophytes and trees
Area	• 130 000 ha	• 150 000 ha

3.5.3 Flow Related Issues

Both in-stream and riparian productivity support the functionality of the Ord River foodwebs, which show some distinction from un-regulated systems with respect to macroinvertebrate composition. In-stream production was a dominant process supporting ecosystem function in both the wet and dry season. Shifts in flows such that they favour either riparian or in-stream production may alter the mix of macroinvertebrate species in the Ord River, which may in turn affect fish species composition.

In addition to its value in provision of a source of carbon that helps drive the Ord ecosystem, the narrow band of riparian vegetation that lines the post-regulation Ord River, together with submerged and emergent macrophytes may have replaced the functional value of the pre-regulation floodplain, providing spawning habitat and predator-avoidance habitat for small species, and supporting epiphytic growths of food resources including algae/diatoms/invertebrates. Maintenance of the hydrological connectivity with these zones may be critical to ensuring the current extent of community complexity and species diversity are retained.

The Parry Lagoon floodplain supports fish and macroinvertebrate communities that are distinct from the main river. This area is protected under the Ramsar Convention and is an important waterbird habitat. Flooding of this area is derived predominantly from local catchment runoff. A reduction in the extent, duration and/or frequency of flooding of this area is likely to alter fish and macroinvertebrate communities and in turn affect the areas value as waterbird habitat.

Flow objectives and considerations:

- 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. A minimum stage height should be maintained during the dry seasons. Reaches: Reach 1 (KDD to Tarrara Bar), Reach 2 (Tarrara Bar to Tidal) and Reach 3 (Tidal Influence).
- Localized 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 1.20m (photic zone P. Davies *pers. comm*.). Reaches: Reach 1 (KDD to Tarrara Bar) and Reach 2 (Tarrara Bar to Tidal).
- 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 period flood pulses. Flooding of riparian vegetation (to 0.25m) may be sufficient. The frequency and duration of flooding will need to be evaluated. Reaches: Reach 1 (KDD to Tarrara Bar), Reach 2 (Tarrara Bar to Tidal) and Reach 3 (Tidal Influence).
- High magnitude wet season floods arising from the Ord River that are sufficient to inundate the Parry Lagoon floodplain are 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. Reaches: Reach 2 (Tarrara Bar to Tidal) and Reach 3 (Tidal Influence).

3.6 Water Quality

The Ord River Irrigation Area comprises two main areas, Ivanhoe Plain and Packsaddle Plains, totalling approximately 13500ha irrigated by a flow-through system with a network of channels and drains. On the Ivanhoe Plain a single channel (the M1) delivers water via smaller supply channels, which are then diverted onto farm blocks. The drainage channels receive water from irrigation supply, use and wet season flooding through the irrigation system eventually returning water to the Ord River through drains or natural creek lines. There are also a number of irrigated farm blocks pumping water directly from the lower Ord River.

As a consequence of a large number of fish deaths within the Dunham River and Ord River Irrigation Area in 1997, a water quality monitoring program was established in 1998 to monitor levels of chemicals and nutrients in the water of supply channels, drains and the river. The program included 13 sampling sites on the main river between Maxwell Plains and Carlton Crossing (WRC, 2003c). Reference is made here to the published results of sampling 1998-2001 and to more recent data where available. Since 2003, the number of in-river sampling sites has been reduced to five.

The Australian and New Zealand Conservation Council produced fresh and marine water quality guidelines for a range of ecosystems (ANZECC, 2000). Guidelines for lowland tropical rivers are available, but based on a small set of tropical rivers and are not necessarily representative of regulated systems. Interim management protection levels for the Ord River have recently been set in the operating strategy for the Stage 1 area based on ANZECC values for slightly to moderately disturbed lowland tropical systems (WRC, 2004). These interim levels will be refined as site specific data becomes available via the water quality monitoring program. Prior to the development of the operating strategy the water quality monitoring program for the Ord River (WRC, 2003c) used median values derived from its most upstream monitoring site (Maxwell Plains) as a reference against which data collected for nutrients, suspended solids and conductivity at other sites were assessed. The Maxwell Plains site is located downstream of the Ord River Dam and upstream of two diversion channels. The site represents water that is supplied to the irrigation area. Pesticide information is not compared to the reference site, but rather the laboratory detection limit is used as a reference level. Details of the results of the historical water quality monitoring program are provided below.

3.6.1 Nutrient status and suspended solids

Some 71% of Total Nitrogen samples (median TN: 0.23mg.L^{-1}) and 74% of Total Phosphorus samples (median TP: 0.02mg.L^{-1}) were above the median reference levels (TN: 0.17 mg.L^{-1}; TP: 0.01 mg.L^{-1}). Maximum concentration for TN and TP over the period 1998-2001 recorded from river sites were 6.1mg.L^{-1} and 0.54 mg.L^{-1} respectively compared to 6.5mg.L^{-1} and 0.84mg.L^{-1} for drainage sites and 0.69mg.L^{-1} and 0.31mg.L^{-1} for supply sites (WRC, 2003c). It was noted that TN concentrations showed an overall decline in the monitoring period (1998-2001). In contrast there was a slight increase in TP concentrations within the river over the same period (WRC, 2003c). Median concentrations of TP and TN recorded in 2004 were 0.02 and 0.17mg.L^{-1} respectively (DoW, unpublished data).

Fourty-one percent of readings of suspended solid concentrations in river sites were also above reference levels (median reference 8mg.L^{-1}) with highest concentrations of suspended solids recorded 475mg.L^{-1} (WRC, 2003c). Median levels recorded in 2004 were 3mg.L^{-1} (DoW, unpublished data).

3.6.2 Pesticides and Herbicides

A large range of organochlorine and organophosphate chemicals are tested for as part of the Ord River water quality monitoring program. Of these two chemicals widely used in agricultural practice, Atrazine and Endosulphan, are most closely monitored. Atrazine is a herbicide commonly applied within the Ord River irrigation area in order to control broad leafed grasses that compete with sugar cane, which is grown year round. Endosulphan is a pesticide used in the Ord River irrigation area to eliminate insects and mites from fruit, vegetable and cereal crops. The main growing period for these crops and therefore pesticide use is the dry season. Endosulphan has been linked to fish kills in the Dunham River during 1997 (see section 3.3.2)

Only 4% of 233 river samples taken between 1998-2001 showed atrazine present, with median concentrations of 0.32µg.L^{-1}. An increase in atrazine detection and concentration was found over the monitoring period. Median concentrations recorded in 2004 were 0.09µg.L^{-1} with a maximum of 0.32µg.L^{-1} (DoW, unpublished data). For endosulphan, the chemical was detected in 7% of 382 samples taken between 1998-2001, with median concentrations of 0.07µg.L^{-1}. A decrease in endosulphan detection and concentration was found over the monitoring period (WRC, 2003c). Median concentrations recorded in 2004 were 0.12µg.L^{-1} with a maximum of 0.16µg.L^{-1} (DoW, unpublished data).

3.6.3 Salinity

Measurements of salinity (as electrical conductivity) taken in the river between 1998-2001 showed an overall increase in that period. The Ord River is a freshwater system. Median concentrations for river samples were comparable to median concentrations recorded for the reference site, 0.25mg.L^{-1} (approx. 0.15ppt) and 0.24mg.L^{-1} respectively. For the sampling period 1998 – 2001, 50% of river samples exceeded the reference site median level.

3.6.4 Flow Related Issues

Any reductions in flow volume in the lower Ord River are likely to alter concentrations of nutrients, suspended solids and salinity. The effect of this is more likely to be problematic at the end of the dry season, when temperatures are highest. While the system is likely to remain fresh under reduced flow volume, Lund and McCrea (2001) hypothesised that increased nutrient concentrations, coupled with increased hydraulic residence times would increase the risk of ecological consequences in the lower Ord River. They suggested that where hydraulic residence times exceeded 3 days and Total Phosphorus concentrations exceeded 0.1mg.L^{-1}, then cyanobacterial blooms may result. Where Total Phosphorus concentrations were less than 0.1mg.L^{-1} the system would favour the growth of submerged and emergent plants. Reduced dilution and longer hydraulic residence times will also increase chances of herbicides and pesticides reaching toxic levels (Lund and McCrea, 2001). It is important therefore that any reductions in dry season flow give consideration to the effect on reduced hydraulic residence times in pools. And importantly, that efforts to improve drainage water quality and reduce irrigation return flows be maintained. The quality of irrigation return water was also shown to be important in the modelled outputs associated with the low flow field trial in the lower Ord River (WRC, 2003b; see Section 3.3.3).

Hydraulic residence times are also important in terms of pool oxygen concentrations. The isolation of pools, in an enriched system could result in night time anoxia due to high oxygen demand of plants and animals. This issue was discussed in section 3.3.3 of this report in relation to risk to fish populations. In flows in riverine pools are reduced significantly the risk of anoxia and subsequent impacts on fish and macroinvertebrate populations are increased (see Section 3.3.3).

Flow objectives and considerations:

- Maintain sufficient flow velocity in the dry season in order to minimize 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 0.08m.sec^{-1}. Requires flow-duration analyses: Reaches: Reach 1 (KDD to Tarrara Bar) and Reach 2 (Tarrara Bar to Tidal).

4 Environmental objectives and flow considerations

4.1 *Summary objectives and considerations*

The flow objectives and considerations for each environmental attribute discussed in this document have been summarized into a table (Table 12), which outlines:

- environmental objectives for a range of environmental attributes;
- linkage between flow and the environmental objectives;
- broad area of the river that the objectives relate to; and
- aspects of the flow that should be considered, including timing, season, hydraulic factors and constraints, and duration.

4.2 *Limitations of this report*

The environmental objectives and flow considerations listed in Table 12 are based on a suite of investigations undertaken between 1999 and 2003 that have contributed to improved understanding of the Ord River and its biophysical character. It should be noted that the wet seasons of 2000, 2001 and 2002 were three of the wettest recorded since the Ord River was regulated in the early 1970's and as a result of the constraints on flows imposed by the dam and related infrastructure, subsequent dry season flows were also relatively high. For example, mean daily base flows for the wet seasons (taken as January to June) for 2000, 2001 and 2002 were 205$m^3.sec^{-1}$, 232$m^3.sec^{-1}$ and 104$m^3.sec^{-1}$ respectively compared to an overall wet season mean daily base flow for the period 1974 to 2005 of 60$m^3.sec^{-1}$. Where possible and relevant this irregularity and the potential for effect on the investigations will be taken into consideration when developing flow requirement recommendations.

The environmental objectives (Table 12) were developed in consultation with scientific experts (who were part of the original scientific panel – Appendix 1) that undertook a number of the contributing investigations. The flow considerations were developed largely based on interpretation of investigation results and expert judgement, as well as anecdotal information. There is therefore a degree of conjecture associated with the flow considerations. It should also be noted that while the flow considerations relate directly to the objectives, as with all projects utilising the River Assessment Package (RAP) they will need to fit within the limitations of the program (Stewardson and Cottingham, 2002; Cottingham *et al.,* 2003) as part of phase two of the development of ecological water requirements (see section 5 this report). Therefore the flow considerations, and particularly the hydraulic factors and constraints, will need to be interpreted into the hydraulic metrics that can be analysed by the RAP. Whilst this part of the process may present some challenges, with input from the expert panel successful translation and analysis of the flow considerations in RAP will be achieved as it has in other projects completed in WA and other parts of Australia utilising the same process.

4.3 Complementary Management

This report has not attempted to directly address the wider range of management issues facing the Ord River. However, a number of complementary management initiatives will need to be undertaken in order to improve environmental outcomes for the Ord River. These include:

- control of livestock access to the river, particularly in lower reaches;
- implementation of weed control strategies;
- reduction in nutrient and pesticide concentrations in drainage water and reduced tail-water return; and
- consideration of options for migratory fish passage past Ivanhoe Crossing and the Kununurra Diversion Dam.

Table 12: 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 20-85cm (average 45cm)	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 0.45-2m	Event frequency (minimum magnitude)
	1c	Deep pool habitat available for large bodied fish	1,2	Low flows	Dry season	Area of channel depth 3-4m	Event frequency (minimum magnitude)
	1d	Deep backwater habitat inundated and available large bodied fish as habitat and possible spawning site	1,2	Highflow	Wet season	Area of channel with velocity <20cm/sec and depth <2m	
	1e	Riparian bench flooded and available large bodied fish as habitat and possible spawning site	1,2,3	Highflow	Wet season	Area of inundated channel with gradient <0.1 and depth <1m	High flow spells
	1f	Passage over in-stream obstacles by migratory species	1,2,3	Highflow	Wet season – extending through April	Depth over shallowest point 0.5 - 1m	Low flow spells
	1g	Flow sufficient to oxygenate pools and avoid fish kills	1,2	Low flows	Dry season	Pool velocity > 0.08m.sec-^{1}	Low flow spells
Macroinvertebrates							
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 <0.3cm/sec and depth 45-90cm	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 > 16cm. 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 0.3-2.5m (average 1.3m)	Event frequency (minimum magnitude)
	2d	Permanent flows so that pools do not become isolated	1,2,3	Low flows	Dry season	Pool velocity > 0.08m.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 <50cm	Flow duration
	3b	Lower riparian bench (damp zone) inundated to maintain algal production	1,2	Highflow	Wet season	Area of inundated channel with depth <50cm	Flow 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							
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 > 0.08m.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	Highflow	Wet season	Area of inundated channel with gradient <0.1 and depth <1m	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 midbanks 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

5 Development of Ecological Water Requirements

5.1 Approach to establishing Ecological Water Requirements

Ecological Water Requirements will be developed using a process similar to that of the Flow Events Method (FEM; Stewardson and Cottingham, 2002). The FEM was designed to provide a rigorous, holistic, standardised, transparent analytical procedure for the determination of water requirements, while allowing for the inclusion of expert opinion (Stewardson and Cottingham, 2002). Central to the FEM is the assumption that various flow components have different ecological functions and that these need to be considered independently (Cottingham *et al*., 2003)

The development of flow recommendations under the FEM usually takes place as a two stage approach (Cottingham *et al*., 2003). The first phase involves documentation of the representative sites and reaches, field assessment by expert panel members and the development of an issues paper that highlights environmental assets, threats and flow-related ecological objectives that serve as the basis of environmental flow recommendations.

The second phase of the FEM involves hydraulic survey and modelling as well as hydrological analyses to develop flow recommendations (i.e. ecological water requirements) that address the flow related objectives outlined in the issues paper (from stage one). A report is then developed in consultation with key stakeholders.

The FEM process for the Ord River has by necessity been adapted to suit the unique circumstances of the project. Much of the work undertaken towards the development of Ecological Water Requirements for the lower Ord River, was undertaken prior to the development of the Flow Events Method. An hydraulic model was originally created for the lower Ord River as part of the development of the Interim Water Allocation Plan. A Scientific Panel was established and undertook a field visit in order to develop recommendations for that Interim Plan (WRC, 2000b). Given the limited extent of biophysical information on the Ord River in 2000, a large number of scientific investigations were subsequently implemented (see Table 2). This report brings together the findings of those investigations, with input from a small group of scientific experts (who were part of the original Scientific Panel) to provide a summary of key values, flow related issues and objectives for the lower Ord River. This is intended to provide the basis for the development of ecological water requirements. The hydraulic model for the lower Ord River has been updated to conform with the requirements of the River Analysis Package, and a daily flows hydrological model has been developed so that modelled historic, current and potential future flow information can be inputted to the Time Series Analysis module of the River Assessment Package – a software tool that provides the analytical power behind the Flow Events Method.

Given that the FEM was developed as an adaptive approach in recognition of the fact that different environmental flow projects are likely to have different requirements and constraints (Stewardson, 2004), modification of the process for the Ord River will not affect the outcomes for the project. Hydraulic and hydrological analyses will be used to develop recommendations for ecological water requirements that address the flow related ecological objectives outlined in this report. A report on ecological water requirements is expected after consultation with the expert group and other key stakeholders (Figure 9).

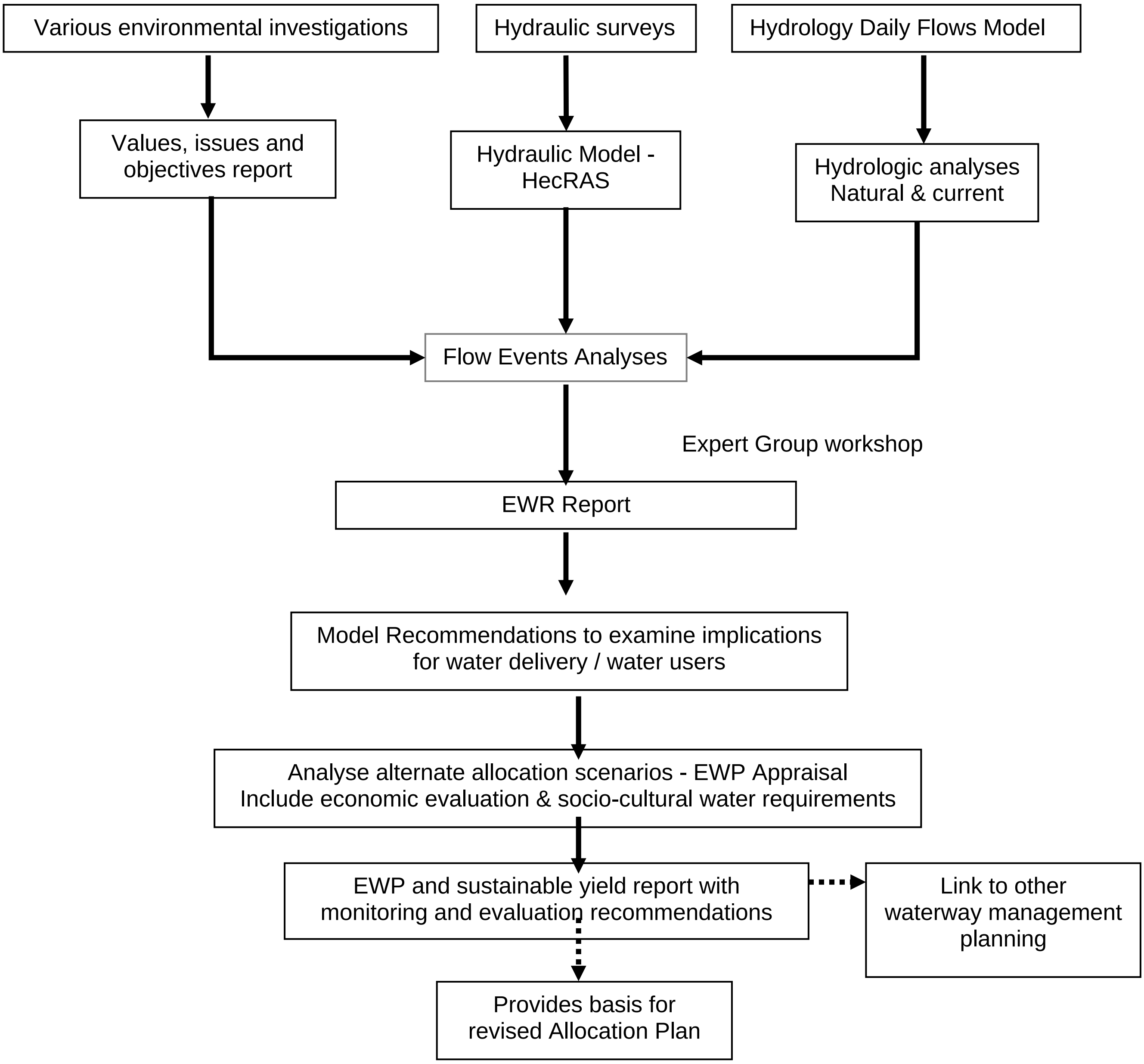

Figure 9: Steps in the process towards Ecological Water Requirements (EWR) and Environmental Water Provisions (EWP) reports and associated linkages.

5.2 Development of Environmental Water Provisions

Under the Environmental Water Provisions Policy for Western Australia (WRC, 2000a), the Water and Rivers Commission's (now the Department of Water) allocation planning process must provide for the protection of water dependent ecosystems while allowing for sustainable use and development to meet the needs of current and future users. The process of determining environmental provisions takes into account ecological and socio-cultural water requirements as well as consumptive demands on the system. Water regimes are derived to maintain ecological values at a low level of risk and wherever possible these are based on the best scientific information available. Where a system, such as the Ord, is partly developed, the Department gives consideration to environmental changes that have occurred due to past regulation, land-use and water quality as well as the capacity for restoration.

Thus, once recommendations for ecological water requirements have been developed, there are a series of steps that must be taken before water provisions to the environment are finalized (Figure 9). These steps include:

- examination of the implications of ecological water requirement recommendations on water delivery and water users;
- analyses of alternate allocation scenarios through an EWP appraisal process. These include the consideration of socio-cultural water requirements and economic evaluation; and
- develop EWP and sustainable yield report, including recommendations for monitoring and evaluation of environmental outcomes.

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Appendix 1 - Membership of the original Scientific Panel (2000)

Member	**Expertise**
Ms Paula Deegan, *Water and Rivers Commission*	Coordinator
Prof Stuart Bunn, *Griffith University*	Stream ecology, environmental flow methodologies.
*Dr Peter Davies, *University of WA*	Ecological processes
*Dr Ray Froend, *Edith Cowan University*	Aquatic and riparian vegetation
Mr Gordon Graham, *Dept of Conservation & Land Management*	Threatened, endangered species
Dr Stuart Halse, *Dept of Conservation & Land Management*	Invertebrate and waterbird ecology
Dr Neil Loneragan, *CSIRO*	Estuarine processes
Dr Noel Morrissy *(representing Fisheries WA)*	Fish species
Mr John Ruprecht, *Water and Rivers Commission*	Hydrology
*Dr Tony Start, *Dept of Conservation & Land Management and CRC for Tropical Savannas*	Aquatic and riparian vegetation
*Dr Andrew Storey, *University of WA*	Ecology of fish assemblages
*Dr Karl-Heinz Wyrwoll, *University of WA*	Channel dynamics and sediment regime
Ms Eve Bunbury, *Department of Environmental Protection*	Liaison with EPA

*Member of current expert panel, whose work forms much of the basis of this report and who contributed to the development of the flow objectives and considerations.

Appendix 2 - Species of fish recorded in the Ord River.

Locational references: 1. listed by Storey for lower Ord River; 2, listed by McKay (1971) for Ord Main Dam (from Allen 1989, Morrissy 2000); 3 abundant in Lake Argyle in 1979, from Fisheries Research net sampling (from Allen, 1989; Morrissey 2000) ; 4. Additional species listed by Allen (1989) for broad Ord area, 5 Additional species listed by Morrissy (WRC 2000); 6 Species found in Lake Kununurra (WRC 2003); 7 Species found in Parry Lagoon (WRC 2003); 8 Species found in the Dunham River – a major tributary of the Ord (WRC 2003). Life history information updated from Allen *et al*.(2002) – use as a guide only

Scientific Name	Common name	Family	Ecology / biology	Locational reference
Ambassis macleayi	Macleay's Glassfish	Ambassidae	Inhabits dense vegetated margins of freshwater streams/swamps. Is mature at 25-35 mm. Maximum size 9cm. Breeds all year round, with peak activity in early wet season. Spawns in vegetation, with demersal eggs adhering to foliage and hatching 12-36hrs later. Diet consists of small crustaceans, aquatic insects, juvenile fish & algae. Most active at night	1,4,6,7,8
Ambassis mulleri	Mueller's Glassfish	Ambassidae	Inhabits freshwater streams, ponds & swamps.	1,4,6,7,8
Amniataba percoides	Barred Grunter	Teraponidae	Inhabits most inland freshwaters, including those with fast to still flows and clear to turbid water. Can tolerate brackish conditions. Spawns mid August to early March. Breeds readily in ponds, diet of insects, crustacea and plant material. Max size	1,2,3,6,8

			18cm	
Anguilla bicolour	Northern Eel	Anguillidae	Lives over rock bottom, in deep freshwater pools of creeks & rivers. May be found in brackish estuaries and tidal flats. Eats fish & crustacea, small frogs, birds. Is widespread in Australasia – but only occurs in the Kimberley in Australia. Catadromous, with mature adults migrating from freshwater to marine to spawn. Max size 60cm.	1,4
Anodontiglanis dahli	Toothless catfish	Plotsidae	Inhabits clear, flowing waters of large coastal rivers and streams. Also found in flooded lagoons. Congregates around snags & deeper rock pools. Bottom feeder. Eats insects molluscs, prawns and detritus. Possibly spawning in early wet season. Maximum size 40cm.	4
Arius graeffei	Lesser Salmon Catfish	Ariidae	Occurs in N. Australia and S. PNG. Inhabits freshwater rivers and as well as estuaries & coastal areas. Is a generalist feeder on detritus, small fish, insects, crustacea and molluscs. Breeding at onset of tropical wet, with oral incubation of eggs by male. Max size 60cm.	1,2,3,6,8
Arius leptaspis	Triangular Shield Catfish	Ariidae	Occurs in N. Australia and S. PNG. Inhabits upper reaches of freshwater streams as well as brackish estuaries and lowland rivers. Is a generalist feeder on detritus, small fish, insects. Breeding between late dry and early wet season (Sept-Jan) in coastal lagoons and flooded swamps. Oral incubation by male and guarding for 4wks afterwards. Max size 60cm.	1,4
Arius midgleyi	Shovel-nosed Catfish	Ariidae	Inhabit turbid freshwater lakes, rivers, reservoirs and waterholes. A diet of fish, prawns & crayfish and various arthropods. Breeds in wet season (Nov – March). Oral incubation of eggs by male. Sexual maturity at 3years. Max size 140cm.	1,2,3,6,8
Arramphus sclerolepis	Garfish	Hemiramphidae	Inhabit shallow coastal/estuarine areas and freshwater reaches of rivers. Commonly found in large schools around dense aquatic vegetation. May move to estuary to spawn: Oct-Dec. Eggs attach to floating objects and vegetation. Eats	1,4

			algae and higher plants. Max size 40cm	
Aseraggodes klunzingeri	Tailed sole	Soleidae	May be marine species moving into freshwater to breed. Typically found on mud or sandy bottom in clear or turbid water of rivers and brackish estuaries. Tolerates temperature and pH range 24°–29°C and 7.0-8.0 respectively. Feeds on aquatic insects and crustaceans. Maximum size ~14cm.	1,4
Carcharinus amboiensis	Pigeye Shark	Carcharhinidae	Inhabits coastal waters, sometimes entering estuaries and rivers. Opportunistic carnivore feeding on crabs, urchins, cephalopods and fishes. Max size 280cm.	5
Carcharhinus leucas	Bull Shark	Carcharhinidae	Primarily occurring in estuaries and lower reaches of coastal rivers. Breed in estuaries, Smaller individuals may penetrate well inland in major rivers, birthing live young. Maturity at 10-15years. Opportunistic carnivore feeding on crabs, urchins, cephalopods and fishes. Max size 300cm.	1,4
Craterocephalus sterc. stercusmuscarum	Fly-specked hardyhead	Atherinidae	Shoal forming subspecies occurring in coastal drainages, preferring still or slow moving sections of rivers, small streams, lakes, ponds and reservoirs. Also found in fast flowing creeks. Generally found in shallow water around aquatic vegetation over substrates of sand, gravel and mud. Breeds from October to February with early peak and capable of multiple spawnings. Generalist diet including small invertebrates, algae and fish eggs. Max size 7.8cm.	1,6,8
Craterocephalus stramineus	Strawman	Atherinidae	Inhabits the surface of well vegetated freshwater stream and lake margins. Abundant in Lake Kununurra). Shoal forming. Spawning is similar to Rainbow fishes in that a few eggs are laid on vegetation each day. There is a 7-9 day incubation period. Eats insects/larvae, crustacea, snails, some algae Maximum size 6.5cm.	4,6,8
Dasyatis sp	Stingray	Dasyatidae	Estuarine vagrant occasionally entering tidally-influenced lower reaches of rivers.	5
Elops australis	Giant Herring	Elopidae	Shoal forming species occurring in coastal waters and estuaries, particularly	1

			around mangroves. Feeds on fishes and crustaceans. Spawns at sea and both eggs and larvae are pelagic. Juveniles often penetrate the lower freshwater reaches of rivers. Max size 120cm.	
Glossamia aprion	Mouth Almighty	Apogonidae	Inhabits still or slow flowing water of freshwater streams, pools, lakes, swamps and reservoirs. Usually found in vegetated shallow margins. Solitary nocturnally active carnivore. Ambushes small fish and crustacean prey from within plant cover. It spawns in summer (although may spawn all year in northern Australia). Mouth brooding by male. Max size 18cm.	1,4,6
Glossogobius giuris	Flathead Goby	Gobiidae	Inhabits clear to turbid freshwater streams, with rock, gravel or sand bottoms. Omnivourous. Species may have a marine larval stage Max size 14cm.	1,2,6,7,8
Glossogobius sp. 2	Square Blotch Goby	Gobiidae	Inhabits clear or turbid, flowing streams over mud, gravel or rock bottoms. Penetrates well inland of coastal drainages. Maximum size 14cm.	4
Goby sp.B	Goby sp.	Gobiidae		1
Hephaestus jenkinsi	Jenkin's Grunter	Terapontidae	Inhabits still or flowing water of clear or turbid streams. Particularly common in deep rocky pools. Feeds mainly on invertebrates (especially prawns) and small fishes. Lays demersal eggs that sink into crevices in the gravel. The young hatch in 3 to 4 days. Maximum size ~ 40cm, commonly to 20cm.	1,2,3,8
Himantura chaophraya	Whipray	Dasyatidae	Bottom dwelling. Occurs in brackish estuaries and the freshwater reaches of large rivers. Often partly buried in mud. Max size 200cm disk.	1
Hypseleotris compressa	Empire Gudgeon	Eleotridae	Most common in the lower reaches of rivers (also found upstream) in flowing or still water around aquatic plants and fallen tree branches. Juveniles found in fast-flowing waters or brackish estuaries. Tolerant of sea water, temperatures up to 35°C and pH 5.0-9.1. Feeds on microcrustacea, larvae, worms, gastropods and algae. The female lays up to 3000 eggs on the bottom substrate. The male guards	1,4,7

			the nest during incubation (10-14 days). Maximum size ~ 12cm.	
Kurtus gulliveri	Nurseryfish	Kurtidae	Inhabits slow-flowing turbid rivers and coastal mangroves. Mature males carry clusters of relatively large eggs on a hook on the forehead during the breeding season. Eggs remain in the ‘pouch’ until hatched. Incubation period is unknown. Diet of fish, prawn, crayfish. Maximum size 28cm.	4
Lates calcarifer	Barramundi	Centropomidae	Inhabits rivers, creeks and estuaries. Juveniles live in the freshwater upper reaches of rivers, favouring the cover of undercut banks, submerged logs, and overhanging vegetation. Adults are typically found in or near estuaries, often around mangroves in clear or turbid water. Predomantly feeds on fish and crustaceans. Juveniles also eat insects. Spawns Sept – March, with peaks in Nov/Dec and Feb/March. Needs water temperature of 25-30^{o}C and salinity of 17-31ppt to spawn. Females release several million pelagic eggs which hatch 15-20 hrs later. The larvae are 1.5 mm long, but reach 20 cm in 10 months and 50 cm by 3 yrs. Males > 5 yrs undergo post-spawning sex transformation. Maximum size 150cm.	1,4,7,8
Leiognathus equulus	Ponyfish	Leiognathidae	Adults are found in coastal marine waters but juveniles are common in mangrove estuaries and tidal creeks, sometimes entering the lower reaches of freshwater streams. Feeds on benthic invertebrates that live in the sand or mud. Maximum size 24cm.	1
Leiopotherapon unicolor	Spangled Perch	Terapontidae	Inhabits range of waters from fresh to saline, pH 4 to 8, 5-44^{o}C. May aestivate. Spawns from November onwards after rains start and water temperatures reach 20°-26°C. Eggs are scattered on bottom substrate. They then hatch after 2 days and larval development takes 24 days. Diet consists of insects, molluscs, crustacea, plants, fishes and frogs. Maximum size ~ 30cm.	1,2,6,7,8
Liza alata	Mullet	Mugillidae	Occurs in coastal waters and estuaries; sometimes ascending rivers into	1,4,8

			freshwater. Prefers slow moving waters or still lagoons. Often found in turbid water, over muddy substrates, and with well-substantiated aquatic vegetation. Feeds on microalgae, detritus, terrestrial plant material, and aquatic insects. Maximum size 75cm.	
Marilyna meraukensis	Merauke Toadfish	Tetraodontidae	Inhabits brackish mangrove estuaries, occasionally found in tidally influenced sections of freshwater creeks and rivers. Maximum size ~ 19cm.	1
Megalops cyprinoides	Ox-eye Herring	Megalopidae	Commonly found in marine and estuarine waters but juveniles and small adults frequent the freshwater reaches of rivers in clear or turbid water. Tolerates a wide range of pH from 5.2 – 9.1. Maximum size 150cm, commonly 50cm.	1,4,7,8
Melanotaenia splendida australis	Australian Rainbowfish	Melanotaeniidae	Occurs in a variety of habitats including rivers, creeks, swamps, marshy lagoons, lakes and reservoirs. Resides near the surface of rocky pools or along stream margins where there is vegetative cover or submerged logs and branches. Maximum size ~ 11cm, commonly 8cm or less.	1,2,6,7,8,
Mimantura sp	Stingray	Dasyatidae	Estuarine vagrant occasionally entering tidally-influenced lower reaches of rivers.	5
Mogurnda mogurnda	Northern Trout Gudgeon	Eleotridae	Occurs in rivers, creeks and billabongs, in quiet or slowly flowing sections among vegetation or rocks. Spawns from Nov-Mar. Females produce several batches of 100-150 eggs which are deposited on logs/rocks. The male guards and fans the eggs until they hatch (8-10 days). Young consume microcrustacea. Older fish consume insects and crustacea, molluscs, fish and plant material. Maximum size 12cm.	2
Mullet sp.	Sea mullet	Mugillidae	Marine opportunist	1,5
Nematalosa erebi	Bony Bream	Clupeidae	Commonly found in the shallows of still or slow-flowing streams and rivers, particularly in turbid conditions. Tolerant of water temperatures from 9° to 38°C and pH 4.8-8.6. Grazes on benthic algae, but may also take insects & crustacea. Susceptible to oxygen starvation in pools in drought/dry season. Spawns several	1,2,3,6,8

			times a year with an early wet season spawning peak. Maximum size ~ 32cm, commonly 15-20cm.	
Neosilurus ater	Black catfish	Plotosidae	Favours the bottom of swiftly flowing sections of streams and rivers. Will also inhabit still or slow flowing water of pools and side channels. Breeding Jan – Mar. Adults migrate upstream to shallow riffle areas to spawn in pairs. Demersal eggs lodge in crevices in riffle zone and hatch 2-3 days later. Diet includes molluscs, insects, worms and crustaceans. Maximum size 47cm.	4
Neosilurus hyrtlii	Hyrtl's Tandan	Plotosidae	Occurs in still or flowing water of streams, billabongs and pools. Typically found close to the bottom where it searches for food including insects, molluscs, small crustaceans and worms. Breeding occurs at the beginning of the wet season (Jan-Mar) in shallow sandy areas in the upper reaches of streams. Maximum size ~34cm, commonly to 20cm.	1,2,3,6,8
Neosilurus pseudospinosus	False spin catfish	Plotosidae	Inhabits pools and flowing streams of coastal drainages. Swims close to rocky or sandy substrates. Maximum size 35cm.	4,8
Nibea squamosa	Scaly Croaker	Sciaenidae	A bottom-dweller that inhabits sandy or muddy areas off beaches or in sheltered bays, estuaries and lower reaches of rivers. Feeds on a variety of small fishes and benthic invertebrates. Maximum size ~ 65cm.	1
Oxyeleotris lineolatus	Sleepy cod	Eleotridae	Inhabits rivers, creeks & billabongs, especially in slow flowing water amongst vegetation/snags. Spawns Oct to Feb. Females produce up to 70 000 eggs. The male guards the nest which is often on the ceiling of a crevice or under a log. Larvae hatch after a 5-7 day incubation period. Adults eat insects, prawns, crustacea, fish. Maximum size 45cm.	4
Oxyeleotris selheimi	Giant Gidgeon	Eleotridae	Inhabits rivers, creeks & billabongs, especially in slow flowing water amongst vegetation/snags. Nocturnally active carnivore, feeding on fish, crustaceans and	4

			insects. Maximum size 55cm.	
Parambassis gulliveri	Giant Glassfish	Ambassidae	Inhabits large turbid rivers and waterholes. Active at night then congregates during the day amongst aquatic plants and log snags. Breeds in the dry season (Jun-Jul). Spawns amongst aquatic plants, scattering demersal eggs which adhere to the foliage. Hatching occurs 12-36 hours later. Diet consists of small fish & prawns. Maximum size ~24cm.	1,2,3,6,8
Plotosid sp.1	Eel-tailed catfish	Plotosidae	See Neosilurus ater and Neosilurus hyrtlii.	1
Plotosid sp.2	Eel-tailed catfish	Plotosidae	As above.	1
Polydactylus spp	Threadfin salmoon	Polynemidae	Marine species that inhabits inshore coastal areas and estuaries with sand or mud bottoms. Maximum size ~ 45cm.	5
Porochilus rendahli	Rendahl's catfish	Plotsidae	Inhabits mud-bottoms of lowland lagoons, flowing creeks and backwaters near aquatic vegetation. Found in clear or turbid water. Sometimes form shoals. Adults migrate into flooded lowland lagoons and swamps to breed early in wet season (Dec-Jan). On arrival of dry season, adult and juveniles migrate back upstream to refuge creeks. Bottom feeder, eating insects, microcrustacea, molluscs and detritus. Maximum size 24cm.	4
Pristis microdon	Freshwater Sawfish	Pristidae	A bottom-dweller found in estuaries and the lower reaches of large river systems. Juveniles (up to ~220cm) penetrate substantial distances upstream (up to 400km in the Fitzroy River) while large mature adults are found in coastal marine environments where it is believed they breed. Prefers sand or silty bottoms with low or little algal or macrophyte cover, low detrital levels and little large woody debris. Feeds on small fish, crabs, shrimps and other bottom dwelling invertebrates. Max size 700cm	1,4
Scat sp	Scat	Scatophagidae		5

Scatophagus argus	Spotted Scat	Scatophagidae	Occurs in sheltered bays, harbours, mangrove creeks and lower reaches of freshwater streams. Feeds on organic detritus and small invertebrates which are scavenged from the bottom. Maximum size ~ 33cm.	1
Strongylura krefftii	Freshwater Longtom	Belonidae	Inhabits still and flowing water of larger rivers from tidal reaches to far inland (also found in Lake Argyle). Often shelters amongst overhanging vegetation or submerged roots. Dwells near the surface feeding on small fishes, insects and crustaceans. Spawning is believed to occur between September and December and probably occurs in freshwater. Maximum size 85cm.	1,2,3,6,8
Syncomistes butleri	Butler's Grunter	Terapontidae	Inhabits slow or fast moving water of rivers in clear or turbid conditions. Most commonly found in deeper sections of larger watercourses. Highly specialised diet primarily consists of filamentous algae. Breeds between November and December when water temperatures rise to about 29°C. Sexual maturity at 20-22cm and maximum size ~ 28cm.	1,2,3,6,8
Syncomistes kimberleyensis	Kimberley Grunter	Teraponidae	Inhabits still or flowing water of pools and streams with aquatic vegetation over mixed rock and sand bottoms. Diet consists primarily of filamentous algae. Maximum size ~ 20cm.	2
Thryssa sp.	Anchovie sp.	Engraulidae	Marine opportunist	1
Toxotes chatareus	Seven-spot Archerfish	Toxotidae	Inhabits mangrove estuaries and freshwater rivers, lakes and billabongs where it is found near the surface around overhanging vegetation. Breeding takes place in the wet season in both habitats. Highly fecund females release buoyant eggs. Feeds on terrestrial insects and aquatic items. Max size ~ 40cm.	1,2,3,6,8
Valva sp	Mullet	Mugilidae		5

Appendix 3 - Macroinvertebrate fauna occurrence

Presence (+) and absence (-) of macroinvertebrate fauna for the lower Ord River, Dunham River, Lake Kununurra and Parry Lagoon Floodplain. Adapted from Storey (2002) and WRC (2003)

			Lower Ord	Dunham	L.Kununurra	Parry Lagoon
MOLLUSCA						
GASTROPODA	**Viviparidae**	*Notopala* sp.	+	-	+	+
	Thiaridae	*Thiara* (*Plotiopsis*) sp.	+	-	+	-
	Planorbidae	*Gyraulus* sp.	+	-	+	+
		Amerianna carinata	-	-	+	+
	Bithniidae	Bithniidae (Gabbia) sp.	-	-	-	+
	Hydriidae	Hydriidae sp.	-	+	-	-
	Lymnaeidae	*Austropeplea lessoni*	+	-	-	+
	Ancylidae	*Ferrissia petterdi*	+	+	+	-
	Hydrobiidae	?Hydrobiidae sp.	+	-	-	-
	Neritidae	?Neritidae sp.	+	-	-	-
BIVALVIA	**Corbiculidae**	*Corbicula* (*corbiculina*) sp. UK1	+	+	+	+
ANNELIDA						
OLIGOCHAETA		Oligochaeta spp.	+	-	-	-
		Allonais ranauana	-	-	+	+
		Allonais pectinata	+	-	-	-
		Branchiodrilus hortensis	-	-	-	+
		Dero ?nivea	-	+	+	+
		Nais variabilis	-	-	+	-
		Nais variabilis	+	-	-	-
		Pristina longiseta	-	+	-	-
		Pristina sp. 1	+	-	-	-
		Tubificidae	-	-	+	-
POLYCHAETA		Nereidae sp.	+	-	-	-
NEMATODA		Nematoda sp.	+	-	-	+
NEMERTEA		Nemertea sp.	-	-	+	-
TURBELLARIA		Turbellaria sp	+	-	+	-
BRANCHIURA		Argulus sp. UK1	+	-	-	-
		Argulus sp. UK2	+	-	-	-
ARACHNIDA						
ACARINA	**Arrenuridae**	Arrenurus (Arr.) sp. cf pseudoaffinis	+	-	-	-
		Arrenurus sp.	+	-	-	-
	Eylaidae	Eylais sp.	+	-	-	-
	Hydrodromidae	Hydrodroma sp.	+	-	-	-
	Hygrobatidae	Australiobates mutatus	+	-	-	-
		Hygrobatidae sp.	+	-	-	-
		Coaustraliobates minor	+	-	-	-
		Dropursa babinda	+	-	-	-
	Limnesiidae	Limnesia parasolida	+	-	-	-

			Lower Ord	Dunham	L.Kununurra	Parry Lagoon
	Torrenticolidae	Monatractides sp.	+	-	-	-
	Unionicolidae	Neumania sp.	+	-	-	-
		Unionicola sp.	+	-	-	-
	Hydracarina sp.	Hydracarina sp	+	+	+	+
CRUSTACEA						
BRANCHIURA		Branchiura sp.	-	+	-	-
COPEPODA		Copepoda spp	+	-	-	-
CYCLOPOIDA		*Macrocyclops albidus*	-	-	+	-
		Macrocyclops darwini	-	-	+	-
		Microcyclops varicans	+	-	-	-
		Mesocyclops sp.	-	-	-	+
CONCHOSTRACA		*Cyclestheria hislopi (Baird)*	-	-	-	+
OSTRACODA		Ostracoda spp	+	-	-	-
	Cyprididae	Bennelongia sp. 673 nr australis	-	-	+	+
		Stenocypris malcomsi	-	-	+	-
		Herpetocypris sp. 676	-	-	+	-
		Cypretta baylyi	-	-	+	-
CLADOCERA		Cladocera spp	+	+	+	-
	Daphniidae	Daphniidae sp.	+	+	+	+
DECAPODA	**Atyidae**	*Caradina serratirostris*	+	+	+	-
		Caradina nilotica	+	-	+	-
		Caridina cf *longirostris*	+	-	-	-
	Palaemonidae	*Macrobrachium rosenbergii*	+	-	+	-
		Macrobrachium bullatum	+	+	+	+
		Macrobrachium australiense	+	-	-	-

			Lower Ord	Dunham	L.Kununurra	Parry Lagoon
	Parastacidae	*Cherax ?quadricarinatus*	-	-	+	-
	Sundathelphusidae	*Holthuisana transversa*	+	-	-	-
INSECTA						
LEPIDOPTERA	**Pyralidae**	*Pyralidae* sp.	+	+	+	-
DIPTERA	**Chironomidae**					
	Tanypodinae	*Larsia ?albiceps*	+	-	-	-
		Procladius sp 1	+	-	-	-
		Coelopynia pruinosa	+	-	-	-
		Nilotanypus sp. nov.	+	-	-	-
		Paramerina sp.	+	-	-	-
		Ablabesmyia sp.	+	-	-	-
		Procladius sp 2	+	-	-	-
		Tanypodinae ?genus	+	-	-	-
	Chironominae	*Tanytarsus* spp.	+	-	-	-
		Cladotanytarsus sp.	+	-	-	-
		Dicrotendipes sp.	+	-	-	-
		Polypedilum (Pentapedilum) *leei*	+	-	-	-
		Chironomini ?genus sp.A	+	-	-	-
		Polypedilum nubifer	+	-	-	-
		Harnischia sp.	+	-	-	-
		Polypedilum watsoni	+	-	-	-
		Chironomini ?genus sp.B	+	-	-	-
		Cryptochironomus ?griseidorsum	+	-	-	-

			Lower Ord	Dunham	L.Kununurra	Parry Lagoon
		Parachironomus sp.	+	-	-	-
		Chironomini ?genus sp.C	+	-	-	-
		Paracladopelma nr. M1	+	-	-	-
		Chironomini ?genus	+	-	-	-
		Rheotanytarsus sp.	+	-	-	-
		Chironomini ?genus sp.D	+	-	-	-
		Stenochironomus watsoni	+	-	-	-
		Xenochironomus sp.	+	-	-	-
	Orthocladinae	Cricotopus sp.	+	-	-	-
		Nanocladius sp. 1	+	-	-	-
		Parakiefferiella sp.	+	-	-	-
		Corynoneura sp.	+	-	-	-
	Ceratopogonidae	Ceratopogonidae spp	+	+	+	+
		Bezzia sp.	+	+	+	+
		Nilobezzia sp.	+	+	+	+
	Forcipomyiinae	*Atrichopogon* sp	+	-	-	-
	Stratiomyidae	Stratiomyidae spp	+	+	+	+
	Culicidae	*Anopheles* sp.	+	-	-	-
		Aedomyia catastica	+	-	-	-
		Annopheles (cel) annulipes sp. D	-	+	-	-
		Anopheles (cellia) farauti	-	-	+	-
		Chaborus sp.	-	+	-	-
		Culex (culex) annulirostris	-	-	+	+
		Culex (culex) sitiens	-	-	+	-
		Culicidae sp.	+	+	+	+

			Lower Ord	Dunham	L.Kununurra	Parry Lagoon
		Culicini sp. (pupa)	+	-	-	+
	Tabanidae	*Tabanus* sp.	+	+	+	+
	Empididae	*Hemerodrominae* sp.	+	+	-	-
	Tipulidae	Tipulidae sp	+	-	-	-
	Simulidae	*Simulium ornatipes*	+	+	-	-
	Ephydridae	Ephydridae sp.	+	-	-	-
	Un Id Diptera sp	Diptera sp UK1	+	-	-	-
		Pupae UK1	+	-	-	-
		Pupae UK2	+	-	-	-
ODONATA	**Zygoptera**	*Pseudagrion microcephalum*	+	+	+	-
		Pseudagrion aureofrons	+	+	-	+
		Agriocnemis rubescens	-	-	+	+
		Ischnura auora	+	-	+	+
		Ischnura heterosticta	+	-	+	+
		Nososticta sp.	+	-	-	-
		Austroagrion cyane	+	-	-	-
	Anisoptera	*Nanophlebia risi*	+	+	-	-
		Austrogomphus mjobergi	+	+	-	-
		Austrocordulia territoria	+	+	-	-
		Crocothemis nigriefrons	-	-	-	+
		Diplacodes bipunctatus	-	-	-	+
		Orthetrum caledonicum	+	+	+	+
		Rhyothemis graphiptera	-	-	-	+
		Trapezostigma ?steneloba/loewii	-	-	+	+
		Zyxomma elgneri	+	-	-	+

			Lower Ord	Dunham	L.Kununurra	Parry Lagoon
		Hemicordulia intermedia	+	+	-	-
		Hemianax papuensis	-	-	+	+
		Antipodogomphus neophytus	+	+	-	-
		Ictinogomphus australis	-	-	+	+
		Diplacodes haematodes	+	+	+	-
		Unid early instars	+	-	-	-
HEMIPTERA	**Pleidae**	*Plea* sp.	+	-	+	-
		Plea brunni	+	+	+	+
	Naucoridae	*Aphelocheirus australicus*	+	+	+	+
		Naucoris subopacus	-	-	-	+
	Notonectidae	*Nychia sappho*	+	+	+	-
		Anisops spp. (female)	+	-	-	+
		Anisops douglasi	-	-	-	+
		Anisops hackeri	-	+	-	-
		Anisops nodulata	-	-	-	+
		Anisops ?semita	-	+	-	-
		*Anisops ?stali (*female)	-	-	-	+
		Enithares nr *loria*	+	+	+	+
		Notonectidae sp. (immature)	+	-	-	-
	Corixidae	Micronecta sp. UK1	+	-	-	-
		Micronecta sp. UK2	+	-	-	-
		Micronecta sp. UK3	+	-	-	-
		Agroptocorixa sp. UK1	+	-	-	-
		Agraptoccharacterixa halei	-	-	-	+
		Micronecta annae sp.	+	-	+	+
		Micronecta halei	+	-	-	-

			Lower Ord	Dunham	L.Kununurra	Parry Lagoon
	Nepidae	*Ranatra* sp.	+	-	-	+
	Hydrometridae	*Hydrometra* sp.	+	-	-	-
	Veliidae	*Microvelia* sp.	+	-	+	+
		Microvelia peramoena	-	+	-	-
		Veliidae spp. (immature)	+	+	-	+
	Gerridae	*Limnogonus (L) fossarum*	+	+	+	+
		Rhagadotarsus anomalus	+	+	+	+
		Limogonus sp.	-	+	+	-
		Rhagadotarsus sp	+	+	-	-
		Tenagogerris sp. (early instar)	+	-	-	+
	Mesoveliidae	*Mesovelia* sp.	+	+	+	+
		Mesovelia vittigera	-	-	+	-
	Hebridae	*Merragata hackeri*	+	+	+	-
		Hebrus woodwardi	+	-	-	-
MEGALOPTERA	**Sisyridae**	Sysira sp.	-	+	+	-
EPHEMEROPTERA	**Baetidae**	Genus 1 WA sp1.	+	+	-	-
		Cloeon sp.	+	+	+	+
	Leptophlebidae	*Genus Z*	+	-	-	-
		Tasmanocoenis arcuata	+	+	+	+
		Wundacaenis dostini	+	+	-	-
		Thralulus sp AV *1*	+	+	+	-
TRICHOPTERA		*Trichoptera* pupae	+	+	-	-
	Leptoceridae	*Triaenodes* sp.	+	+	+	-
		Oecetis sp1	+	+	+	+
		Oecetis sp2	+	+	+	+
		Triplectides helvolus	+	+	+	+

			Lower Ord	Dunham	L.Kununurra	Parry Lagoon
		Triplectides ciuskus seductus	+	+	-	+
		Triplectides sp. (juvenile)	+	-	-	-
	Hydroptilidae	*Orthotrichia* sp.	+	+	-	-
		Tricholeiochiton sp	-	-	+	-
		Hellyethera ?ramosa	+	-	+	-
	Ecnomidae	*Ecnomus* sp.	+	+	+	-
	Polycentropidae	*Paranyctiophylax* sp. AV5	+	+	+	-
	Hydropsychidae	*Cheumatopsyche* sp.	+	+	-	-
	Philopotamidae	*Chimmara uranka*	+	+	-	-
	Calamoceratidae	Anisocentropus sp.	-	+	-	-
COLEOPTERA	**Dytiscidae**	*Bidessodes mjobergi*	-	+	-	-
		Bidessodes flavosignatus	-	+	+	-
		Clypeodytes ?bifasciatus	+	+	-	-
		Clypeodytes migrator	+	+	-	+
		Copelatus nigrolineatus	+	+	+	-
		Cybister godeffroyi	-	-	-	+
		Cybister tripunctatus	-	-	-	+
		Cybister sp. (L)	+	-	-	+
		Hydaticus consanguineus	-	+	-	-
		Hydroglyphus basalis var. fuscolineatus	+	+	+	-
		Hydroglyphus daemeli	+	+	-	+
		Hydroglyphus godeffroyi	+	+	-	-
		Hydroglyphus leai	+	+	+	+
		Hydroglyphus trilineatus	+	+	-	-
		Hydrovatus parallelus	+	+	-	-
		Hyphydrus eligans	-	-	-	+
		Hyphydrus lyratus	+	+	-	+
		Hyphydrus sp. (L)	+	-	-	-
		Hydrovatus ?ovalis	+	-	-	-
		Laccophilus spA	+	-	-	-
		Laccophilus spB	+	-	-	-
		Laccophilus cingulatus	+	+	-	-
		Laccophilus clarki	+	+	+	+
		Laccophilus sharpi	+	-	-	+
		Laccophilus unifasciatus	-	+	-	-
		Laccophilus sp. (L)	+	-	-	-
		Megaporus ruficeps	+	+	+	+
		Necterosoma regulare	-	+	-	-
		Onychohydrus attratus	-	-	-	+
		Onychohydrus attratus (larvae)	-	-	-	+
		Tiporus centralis	+	+	-	-
		Tiporus undecimaculatus	-	+	-	-
	Limnichidae	Linmnichidae sp. UK1	+	+	-	-
	Brentidae	Brentidae sp. UK1	+	-	-	-
		Brentidae sp. UK2	+	-	-	-
	Curculionidae	Curculionidae sp. UK1	+	-	-	+
	Gyrinidae	*Macrogyrus ?paradoxus*	+	+	-	-
		Gyrinidae sp. (L)	+	+	-	-
	Noteridae	*Hydrocanthus waterhouseii*	-	-	-	+
		Neohydrocoptus subfasciatus	+	+	+	-

			Lower Ord	Dunham	L.Kununurra	Parry Lagoon
	Hydrophilidae	*Amphiops duplopunctatus*	-	-	+	-
		Amphiops australicus	+	+	-	-
		Amphiops queenslandicus	-	-	-	+
		Laccobius ?bicuadatus	+	-	-	-
		Laccobius sp.	+	-	-	-
		Berosus australiae	+	-	-	+
		Berosus dallasae	+	-	-	-
		Berosus josephenae	-	-	-	+
		Berosus pulchellus	+	+	-	+
		Berosus sp.	+	+	-	+
		?Coelosoma fabriccii	+	-	-	-
		Enochrus deserticola	+	-	+	-
		Enochrus (methydrus) esuriens	-	-	+	+
		Helochares marreensis	+	-	-	-
		Helochares sp. UK2	+	-	-	-
		Helochares clypeatus	+	-	-	+
		Georissus sp.	+	-	-	-
		Hydrochus sp.	+	+	+	+
		Paracymus pygmaeus	+	-	-	-
		Regimbartia attenuata	+	+	+	+
		Sternolophus marginatus	-	+	-	-
		Hydrophilidae sp. (L)	+	+	+	-
	Haliplidae	Haliplus sp.	-	-	-	+
	Hydraenidae	*Hydraena ?impercepta*	+	+	-	-
		Hydraena sp2	+	+	-	+
		Hydraena trapezoidalis	+	-	-	-
		Hydraena sp4	+	+	-	+
		?Octhebius sp. UK1	+	-	-	+
	Scirtidae	Scirtidae sp. (L)	-	+	-	-
	Staphylinidae	Staphylinidae sp. UK1	+	-	-	-
		Staphylinidae sp. UK2	+	-	-	-
		Staphylinidae sp. UK3	+	-	-	-
	Elmidae	*Austrolimnius* sp. UK1	+	+	-	-
		Austrolimnius sp. (L)	+	+	-	-
	Carabidae	Carabidae sp. UK1	+	-	-	-

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