

## **6. Discussion**

### **Hydrology**

#### *Pre-regulation flows*

The seasonality of flows and frequent flooding are probably the single most important natural influence on the geomorphology and ecology of the region rivers. The east Kimberley region of north-west Australia is located in a climatic zone known as the dry tropics. The climate of the region is arid to semi-arid with two distinct seasons: a warm, dry season between May and October (the 'dry') and a hot wet season between November and April (the 'wet'). Very little rainfall occurs outside the wet season and consecutive dry months are not unusual. During the dry season the unregulated rivers recede to a series of disconnected pool systems.

During the 'wet', the riparian zones and floodplains of the regions' rivers are prone to extensive flooding from due to extremely heavy rainfall associated with monsoonal depressions and tropical cyclones. For example, the largest recorded flow on the Ord River (in February 1956) was 30,800 m<sup>3</sup>/sec measured near the site of the Ord River Dam. The peak flow during this flood is among the largest recorded for any similar sized catchment in the world.

The Kununurra Diversion Dam and Ord River Dam were constructed with little consideration for the Ord River's ecological or social values. Their construction flooded vast areas of traditional Aboriginal lands, with subsequent impacts on cultural value, and markedly altered the hydrology and ecology of the Ord River downstream of the dams.

#### *Post regulation flows*

The Ord River Dam was designed to have extremely large flood storage within the reservoir. The relatively small capacity of the spillway is the mechanism behind this large flood storage. The flow from the dam has not exceeded 1,000 m<sup>3</sup>/sec since its construction in the early 1970's despite the fact that the estimated inflows to the dam have exceeded 10,000 m<sup>3</sup>/sec on occasions. The effect of increased irrigation development on the Ord River has reduced flows to the lower Ord from the KDD by up to 20 %. The changes to the floods is likely to be reduced by only 10 % due to the unregulated flows from the Dunham River and other tributaries downstream of KDD.

The river upstream of the dams has been profoundly changed between the Carr Boyd Ranges and Bandicoot Bar creating Lake Argyle and Lake Kununnura. In addition, the extremely large flood storage capacity of Lake Argyle and its spillway characteristics mean that there is a greatly modified flood discharge pattern. The magnitude and frequency of high flow events have been severely limited by regulation and large flood flows are discharged slowly over a period of many months rather than as the high-energy flows experienced before regulation.

The changes in flood magnitude and frequency have decreased the frequency, extent and duration of floodplain inundation and resulted in a level of disconnection of the river, its riparian areas and floodplain. The flow modelling suggests that the meander loops between Carlton Crossing and The Rocks, and a significant portion of the Mantinea Flats and Parry Lagoon areas to the south of the Ord, would be entirely underwater in a pre-regulation 10% AEP<sup>1</sup> flow. A large area of the Carlton Plain, to the north, would also have been flooded in such an event. An event of 10% AEP following regulation was estimated to inundate only a small to moderate area in the vicinity of Parry Lagoons and the meander loops between Carlton Crossing and The Rocks. The post-regulation 10 % AEP event will not cause major flooding of the Mantinea Flats or the Carlton Plain areas. The probability of an event large enough to break out from the main river channel flood and inundate the floodplain at 'The Rocks' has been reduced by regulation from 50% AEP (1 in 2 year average recurrence interval event) to 1.5% AEP (1 in 67 year average recurrence interval event).

The area flooded by a pre-regulation 1% AEP flow is also significantly larger than the area flood following regulation. The pre-regulation 1% AEP flow would have flooded areas around House Roof Hill and Carlton Plain.

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<sup>1</sup> Annual exceedence probability.

The entire southern floodplain, Mantinea Flats and Parry Lagoons, and much of the current irrigation area on Ivanhoe Plain would also have been inundated by flood waters. Following regulation many of the wetlands on the floodplain south of the main Ord River channel, in the area of the Mantinea Flats and Parry Lagoons, and large areas within the Carlton Plain area will be flooded during a 1% AEP flow event however the area flooded is smaller. For example, the post-regulation 1% AEP event have ceased to cover land to the north of House Roof Hill. The indicative average depth of inundation has also been significantly reduced due to the construction of the dams.

Flood flows in the lower Ord River, downstream of Kununurra, since the construction of the Ord River dams are dominated by the flows from the Dunham River, which enters the Ord River just downstream of Kununurra. This is despite the fact that the catchment area of the Dunham River is less than 10 % of the Ord River catchment. The estimated flow, on the Ord River at the confluence of Dunham River, with an AEP of 10% and 1%, has been reduced by approximately 80% following regulation by the ORD.

Also significant from an ecological perspective is that flows in the river are now permanent rather than seasonally ephemeral. The lower reaches of the river no longer dry out to a series of disconnected pools and there is now a constant baseflow in the lower Ord. The regulation of the Ord River has resulted in a much smaller seasonal variation in the lower Ord River, below KDD, with the Dunham River and other smaller tributaries of the lower Ord (roughly 10% of the lower Ord catchment area) providing the majority of the seasonal variation. Overflow from the Ord River Dam typically only occurs late in the wet season (Mar- May) and has led to a shift in the seasonal streamflow pattern in the lower Ord River by about one month. The design of the spillway at ORD results in extended periods of overflow following large wet seasons such as those observed in 2000 and 2001<sup>2</sup>. In effect, regulation of flows has transformed the Ord River from a 'dry tropics' river to a 'wet tropics' river.

#### *Wetted Perimeter and Channel Morphology*

There were three main findings of preliminary modelling carried out in 2001. Firstly, the greater the reduction in minimum flow rates, the greater the change to wetted perimeters. The greatest risk to the modified river and habitat was found to be on channel sections between Tarrara Bar and the start of the tidal influence. The January 2003 modelling suggests that the original estimates of change in wetted perimeter of >20% for the reach between KDD to Tarrara Bar and from Tarrara Bar downstream to the upper extent of tidal influence were probably high.

The increase in the number of sections that change "significantly" above Tarrara Bar when the flow drops below 40 m<sup>3</sup>/sec is not evident in the January 2003 modelling. The section between Tarrara Bar and the limit of tidal influence was confirmed by the Ord EFI estimates as the reach that undergoes the greatest change with reduced flows, but the number of cross-sections that show a "significant" change is much reduced from the preliminary estimates. The predicted changes in wetted perimeter (>20%) along three separate sections of the river under a range of flow scenarios from the recent analysis of January 2003 are compared to the preliminary analysis estimates.

Lastly, it was also observed that once the flow drops below 40 m<sup>3</sup>/sec, there is an increase in the number of sections that change "significantly" above Tarrara Bar. While the difference was not especially large this does suggest the presence of a threshold flow below which wet perimeter begins to decrease by an increasing amount, and that this threshold flow rate is higher than 35 m<sup>3</sup>/sec. Wetted perimeter is affected by channel shape and form, which is determined by past flow history, especially in the absence of frequent channel-forming flows (Brizga 1998). The current profile of the channel probably therefore may still reflect to some extent flow characteristics established in the 23 years between 1973 and 1996, when average dry season flows were closer to 40 to 45 m<sup>3</sup>/sec. Dry season flows of ~50 m<sup>3</sup>/sec will have changed channel form in the past seven years. Nevertheless the wetted-perimeter result suggests the persistence of a channel shoulder below water depths found in the channel at ~40 m<sup>3</sup>/sec below Tarrara Bar (Hollands 1998).

The wet perimeter modelling suggests possibly large changes under different flow regimes, however it is not possible to assess the ecological significance of these changes. Wetted perimeter itself is a coarse measure of how

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<sup>2</sup> The current dry season irrigation drainage return flows supply on average an additional 5 m<sup>3</sup>/s to the 50 m<sup>3</sup>/s dry season flow.

channel morphology changes under different flow regimes. Furthermore the wetted perimeter technique is broad-brush, and has little relevance to the actual extent and distribution of important invertebrate and fish habitat (Hollands 1998, Storey 2002). The calculation of wetted perimeter also is heavily weighted by the size and shape of the channel, with a wide channel showing smaller changes than a narrow channel of the same depth. Fish habitat tends to be located along the margins, and changes in bank-side habitat condition are probably of more relevance (Pusey and Arthington 2003).

## Biodiversity, Distribution and Abundance

### *Riparian vegetation*

Regulation of river flows may affect riparian vegetation in one of two ways. 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. It may be expected that reduce frequency of flood flows in regulated rivers may allow time for more diverse vegetation to develop. Riparian zones that frequently scoured by floodwaters, may contain fewer species. Alternatively, regulated river systems may also be expected to support fewer species, as they are seldom disturbed and therefore only a few strong competitors are able to dominate. This study found that total species richness was found to be greater at unregulated sites (driven mainly by greater numbers of native species at unregulated sites), lending support to the latter effect.

Unregulated rivers should support a relatively high proportion of annual species, as annual flood events should select for vegetation that is able complete life cycles between severe flooding. River regulation that reduces flow magnitude during the wet season should cause a shift towards vegetation communities containing fewer perennial species. As expected, this study found that the regulated sites on the Ord River supported fewer annual species than unregulated sites. No differences were found in the cover of annual species. Patterns in cover of grasses was were similar to that of the annual species, although no significance differences were found in mean cover of grasses in regulated systems compared to the unregulated systems. Perennial grasses on the lower Ord tended to be hemicryptophytes, which have a similar phenology to annual species, with above ground parts dying back during the dry season and growing rapidly when conditions are favourable in the wet season (Pettit 2000).

### *Size class structure*

The size class structure of overstorey species should be influenced by the frequency of intense flood events because of the potential for floods to remove small trees. If intense floods occur regularly, trees in the flood zone are swept away before they reach a large size. This results in a population of smaller, younger trees, with maximum size depending on the intervals between high-energy floods. Such a system would be said to be recruitment-based, and dynamic. If floods with sufficient intensity to remove trees seldom occur, a population of many large sized trees should develop, with or without recruitment (indicated by small-sized trees). At rivers where intense flooding does occur, there must be some limit to the reach of high-energy flood waters. The area within the flood zone would be characterised by small trees, whilst larger trees would persist beyond this zone.

This study found no clear differences in size class that could be attributed to river regulation. The Pentecost River formed a typical example of an unregulated system where frequent scouring has prevented the development of large, mature trees, with only small trees across one transect, and with large trees limited to higher elevations on the other transect. However the regulated Ord River sites House Roof Hill and Buttons Crossing, as well as the unregulated Dunham River showed evidence of intermediate frequency and magnitude of disturbance, with large trees occurring only a small distance from the watercourse. Finally, the unregulated Keep River showed little evidence of frequent high-energy flows, based on tree size.

Because growth rates of trees differ between species and within species under different growth conditions, diameter at breast height (DBH) measurements are not always a true indicator of tree age. This limits the robustness of the method in drawing conclusions about the age structure (and therefore of the recruitment patterns) of tree

populations. However, tree densities along study transects are generally low, so competition effects are unlikely to distort data, and trees are likely to be under comparable growing conditions within sites.

*Limitations to the sampling design*

The various processes shaping riparian vegetation differ substantially across the study sites assessed, regardless of whether or not each site is affected by regulation of the Ord River. Therefore, relating trends in vegetation characteristics to the regulation status of sites is not strictly valid. There are three main factors, which contribute to uncertainty about the effects of river regulation.

The natural flow regimes are extremely different across sites. For example, whilst the Keep and Pentecost Rivers are both unregulated, the vegetation at these sites will differ due in part to substantially differing flow regimes. As these two unregulated rivers do not appear to be comparable, it may not be valid to compare them with regulated sites on the Ord River. The study sites have also been subject substantially different land use patterns other than river regulation which have also influenced the vegetation. During the period of the study, extremely high rainfall led to two large flood events, which affected the rivers across the region. The lower Ord River twice experienced two closely spaced high-energy flow events immediately before the study, which is a flow regime more characteristic of an unregulated river system.

TABLE 6.1: Summary of site rankings (H=high; M=medium; L=low) with respect to vegetation characteristics.

	Site	Vegetation characteristic				
		Annuals	Grasses	Exotics	Species richness	Foliage cover <sup>1</sup>
Regulated	House Roof Hill	M	H	H	M	M
	Buttons Crossing	M	M	H	H	H
	Lake Kununurra	L	L	H	L	H
Partly Regulated	Parry Lagoons	M	M	L	L	H
Unregulated	Dunham River	H	H	M	H	M
	Pentecost River	H	H	L	M	M
	Keep River	L	L	L	H	L

<sup>1</sup> Sum of cover proportions for all understorey species.

Although differences between regulated and unregulated sites were found when sites were considered to be representative of river type (regulated/unregulated), ranking of the individual sites uncovers unclear relationships between vegetation characteristics and the regulation status of site (Table 6.1). For greater confidence in the conclusions generated by the statistical analyses, it may be more appropriate to compare only sites that have been exposed to similar natural flow regimes.

Three vegetation features (the proportion of cover of annuals, the proportion of cover of grasses and the size class structure of riparian trees) appear to be correlated. However the rank order appears to bear no obvious relationship to whether or not a river system is regulated (Table 6.1). The features may still be seen as a reflection of the recent flow regime experienced at the different sites. In this way, although the flood events which affect vegetation at the Lower Ord River are less intense and frequent relative to the natural regime, they may still be more intense and frequent relative to other unregulated rivers which natural experience lower flows (for instance, Keep River).

To discern with certainty the effects of river regulation on the riparian vegetation in the Kimberley Region a long term time-series comparison would be necessary. In this way, the effects of unusual high rainfall events (such as the two which caused high-energy flows in the regulated lower reaches of the Ord River) could be separated from the

typical state of the system. Alternatively, non-regulated study sites may be selected which experience a comparable flow regime to that of the lower Ord River before regulation began.

*Attributing weed invasion to river regulation*

The stabilisation of river flows due to regulation has been found in several instances to lead to invasion or establishment of exotic species in river systems (e.g. Poff *et al.*, 1997). In an unregulated river system, which receives frequent scouring by floodwaters, exotic species would be periodically removed and prevent exotics from proliferating. Where flooding is reduced in frequency or intensity, any competitive advantage that indigenous species may have through adaptation to the natural disturbance regime would be lost, allowing weeds to establish.

This study found that exotic species contribute greatly to vegetative cover at regulated sites, in contrast with unregulated sites. Moreover, exotic species form high proportions of the foliage cover at the three sites most strongly affected by regulation, that is, House Roof Hill, Buttons Crossing and Lake Kununurra. However, the other two regulated sites show opposite patterns. Two of the unregulated rivers (Pentecost River and Keep River) showed low levels of weed invasion. The Dunham River, which is unregulated, also supports relatively high proportions of exotic species cover, whilst Parry Lagoons, which would be affected by regulation of the Ord River, supports negligible cover of weeds.

Therefore, the disturbance history of the rivers rather than the regulation *per se* may have a greater influence on the level of weed invasion of riparian zones. Both House Roof Hill and Buttons Crossing on the lower Ord have been used historically as stock crossings. The Dunham River area has also been used for stock grazing. The presence of stock is a plausible explanation for high weed invasion in the areas. The effects of both disturbance from stock (creating niches for weed establishment), and the provision of weed propagules, would contribute to weed invasion at these sites. Similarly, Lake Kununurra lies within an area of intensive agricultural production, which would be a major source of exogenous disturbance and weed propagules.

A complicating factor in deducing whether or not river regulation affects the level of weed invasion is the physiological response of weeds to flood scouring, and to inundation. For instance, the high wet season flows of the Pentecost River may have prevented weeds from proliferating by “resetting” the understory composition, thereby preventing weeds from dominating on the basis of higher productivity rates. Additionally, the level of weed invasion at Parry Lagoons may be low because weed propagules are unable to survive in the waterlogged conditions. If so, alterations to the frequency and magnitude of flooding from the Ord may enhance opportunities for establishment of weed species that are intolerant of waterlogging. Species which are tolerant of waterlogging may invade in future. However, given the variety and complexity of ecological interactions that lead to invasion by exotic species it is recognised that it will be difficult to decisively attribute increased invasion by exotic species to regulation of flows at the Lower Ord River.

Despite the limitations of the data, similarities within the Dunham and Pentecost Rivers and within the two Lower Ord River sites appear to be sufficient for comparisons to be valid. Comparing these four sites, it appears that annual species richness and the proportion of annual species cover is greater at sites that are subject to unregulated river flows. River regulation may be correlated with other vegetation parameters considered, however results were not conclusive as different land use histories, physical site differences and compositional differences of the flora are overlie the effects of river regulation and make patterns difficult to discern.

*Macroinvertebrates and fish*

This study found that regulated lower Ord River, its floodplain and the unregulated rivers supported a similar diversity of invertebrates, although they contained difference species. This suggests that flow regulation may have changed the species mix of invertebrates in the lower Ord River. There was no change in the assemblage composition by season. Some species had a preference for floodplain versus riverine sites, and regulated versus unregulated sites.

It was not possible to assess the life history characteristics of invertebrate faunas with respect to key flows during this study. However observations of larger conspicuous invertebrate species indicated that the breeding behaviour has been affected by regulation of flows. During sampling suggested differences in the population structure of the river prawn cherabun between regulated and unregulated rivers. The river prawn (*Macrobrachium rosenbergii*) or Cherabun, which is an important prey species for fish, normally breeds in the wet season. Adults are known to migrate to the estuary to spawn in the early wet, and juveniles move upstream as flows recede at the beginning of the dry season. Juvenile prawns were found in the lower Ord River in September 2000 and November 2001, which is approximately nine months after prawns at this early life stage would be expected. The presence of very juvenile prawns in the river at this time suggests the possibility of continual recruitment throughout the dry season. The lower Ord River effectively was in flood throughout the dry seasons of 2000 and 2001 following above-average wet season rainfall which had filled Lake Argyle, and which then overflowed for most of the dry season. The high dry season flows appear to have simulated a wet season flood and initiated aseasonal breeding in the regulated system. Juvenile prawns were not observed from sites on the unregulated rivers in the late dry season.

There were no differences in the fish species diversity, abundance or biomass between the regulated lower Ord and the unregulated rivers or between seasons. Migratory species (i.e. those that migrate to the estuary or ocean to spawn, and then return to freshwaters, or species more usually resident in the estuarine but frequent freshwaters) were found to be absent from Lake Kununurra. It is likely that the KDD prevented upstream movement of these migratory/estuarine species, resulting in a different community structure in Lake Kununurra compared with downstream, regulated riverine sites.

Allowing for difficulties in sampling the floodplain, it was apparent that the diversity of fish in the Parry Lagoon floodplain was low compared with adjacent riverine sites. The lack of species may be due to the distance from the main river channel to the sampled area of floodplain, the seasonality of floodplain inundation (it may be completely dry in some years), or simply because some larger species may not be inclined to move across the shallow, vegetated floodplain.

It was evident that the fish in the lower Ord were larger on average than fish found in the unregulated sites. The larger size probably reflects greater habitat diversity and deeper water in the lower Ord, especially in the dry season when unregulated sites recede into isolated pools. The deeper, permanent water in the Ord in the dry season would decrease predation pressure and other density dependant factors. In the unregulated rivers predation pressure from birds, crocodiles and humans increases when water becomes shallow during the dry season. Also, flow regulation reduces the frequency of large, scouring floods, which may play a role in limiting fish size in unregulated sites through occasionally "resetting" the system.

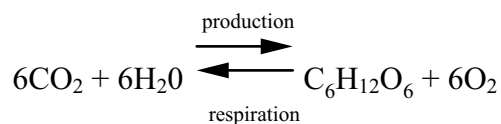
This suggests that the regulated lower Ord River is more productive than unregulated rivers in terms of fish production. If this were the case, length-weight relationships for individual fish species would be different between river types, indicating a difference in condition/growth. For example, within each species, for individual fish of the same length, those in a more productive system (i.e. with plentiful food resources) would likely be in better condition (i.e. heavier) than individuals in a less productive system. However, no such difference was evident in the length-weight relationship individuals from the two river types.

There was a difference in fish species composition in the lower Ord compared to the unregulated rivers. The regulated sites on the lower Ord River contained small species and juveniles of large species that are generally limited to the estuary or estuarine reaches of the river. Species found well unstream included the oxeye herring (*Megalops cyprinoides*), the bull shark (*Carcharhinus leucas*), pony fish (*Leiognathus equulus*), tailed sole (*Aseraggodes klunzingeri*), golden grunter (*Nibea squamosa*), sawfish (*Pristis microdon*), spotted scat (*Scatophagus argus*) and the giant herring (*Elops australis*). Their presence in the lower Ord probably reflects the easy upstream access due to permanent flows in the regulated river and the resulting connectivity of pool/riffle sequences, whereas the unregulated rivers cease flowing in the dry season making them inaccessible to estuarine species. Lentic sites (Lake Kununurra and Parry Lagoon) had also different species assemblages than the riverine sites. The lentic site also appeared to have higher fish abundance than the riverine sites.

Finally, there were no significant seasonal differences in species composition. The absence of seasonal differences probably reflects the longevity and life history of the fish species, with most species resident in the system. Some may leave the system for short periods to spawn (i.e. temporarily move to the estuary during the wet season), however, either not all individuals of a species will leave, or sampling was late in the season and missed these occasions (i.e. species had returned by the time sites were accessible for sampling).

## Ecological Processes

Maintaining the sources and rates of metabolism of carbon in the river is fundamental to the systems function and ecological processing and therefore in protecting current ecological values through the EWP (Bott *et al.* 1978; Bunn & Davies 2001). Many factors including water temperature, light, nutrients and flows influence the production and metabolism of carbon in rivers. A fundamental consideration to maintaining current ecological values in the lower Ord River is understanding the sources and fate of carbon that support lower Ord food webs, and how these change with changes in flow. The measurements of primary production and respiration represent the amount of organic carbon produced and consumed in an ecosystem. The equation below shows the transformation between CO<sub>2</sub> and organic carbon (C<sub>6</sub>H<sub>12</sub>O<sub>6</sub>). When the reaction occurs from left to right light provides the energy to fix CO<sub>2</sub> (i.e. photosynthesis) and when the reaction occurs from right to left energy is released (respiration and/or decomposition).



Conceptual models describing ecosystem function differ significantly in their emphasis on the importance of upstream carbon and direct riparian linkages. Food webs in rivers are generally considered to be reliant on energy inputs (organic carbon) from the surrounding catchment and immediate riparian zone. While this is true for small rivers with forested riparian zones, it may not be the case for dry tropical river systems such as the lower Ord River.

The River Continuum Concept (RCC) emphasises the importance of carbon and nutrients from upstream processes in the forested catchment “subsiding” the productivity of lower river reaches (Vannote *et al.* 1980). According to the RCC, fine particulate organic matter (FPOM) from upstream. Terrestrial vegetation is the principal carbon source for downstream food webs. As the effects of light shading diminish downstream in-stream algal productivity becomes an increasingly important source of organic carbon. It is unlikely that food-webs in the lower Ord are heavily reliant on organic particulates from the upper Ord catchment due to the presence of the Ord River Dam (in-stream production of phytoplankton in Lake Argyll would be released to the lower Ord). Organic carbon is discharged to the lower Ord via the Durham River and other smaller tributaries. If FPOM discharged from the Dunham River is supply carbon to the lower Ord and supporting food webs this would be consistent with the RCC.

Recent work has demonstrated the importance of nearby terrestrial sources of organic matter to the function and maintenance of food webs in floodplain rivers. The Flood-Pulse Concept (FPC) emphasises the importance river-floodplain interactions and proposes that riverine food webs are supported predominantly by carbon entering rivers episodically during floods. Under this model floodplain production has a greater influence on aquatic food webs (Junk *et al.* 1989). The FPC would probably be more applicable to unregulated streams subject to frequent flooding since regulation usually results in rivers becoming disconnected from their floodplains and floodplain derived carbon. If a river production is reliant on floodplain carbon as the FPC model suggests a change in flood frequency and inundation may result in a decrease in total food web biomass unless communities adapt to take advantage of new carbon sources. Any surviving post-regulation connectivity of the lower Ord with its floodplain (Parry Lagoon)

needs therefore to be accounted for in recommending a definitive EWR. The greater significance of flows in the Dunham River needs also to be taken into account.

The RCC and FPC may underestimate the role of non-filamentous aquatic algae, and local in-stream sources of organic carbon. The Riverine Productivity Model (RPM) puts a greater emphasis on in-stream production (phytoplankton and benthic algae). In turbid rivers, in-stream primary productivity may be limited by the rapid attenuation of light with depth. The 'bath-tub ring' concept (BRC) was developed from studies on turbid, slow flowing river systems in arid Australia (Bunn, Davies & Winning 2003) to explain productivity in turbid systems found in the arid areas of Australia. Like the RPM, the BRC puts an emphasis on in-stream production but recognises the importance of a highly productive "ring" of benthic algae in littoral margins in supporting the aquatic food web. Increased clarity has the potential to substantially increase alga productivity in systems that are naturally turbid or coloured.

In management of the lower Ord River particularly for flow regulation, it is important to consider linkages between nutrient/carbon exchange with the 'old' natural flow regime compared to the 'new' artificial flow regime. Any ecological model that underpins the management of the lower Ord River need to describe dominant patterns of energy flow and how these will be modified by varying levels of water abstraction and regulation. The sources of carbon to the lower Ord include natural riverine and riparian carbon as well as that supplied directly by land management systems in the adjacent catchment. The Stage 1 irrigation system is a flow-through system and return flows (including tail –waters) representing approximately 10 percent of the river volume during the dry season. It is possible that nutrients in irrigation return flows contribute to in-stream algal production and food webs.

#### *Benthic Metabolism*

Overall, rates of metabolism measured in the regulated lower Ord River and the unregulated Pentecost, Keep and Dunham were high compared to rivers elsewhere in Australia (Bunn *et al.* 1999) (Table 6.2). This suggests that the rivers of the east Kimberley are naturally high. Similar rates of production measured in temperate Australian rivers would indicate substantial nutrient enrichment.

The range of metabolism values across the sites was considerable. This result illustrates that may vary between times and sites within the regulated and unregulated rivers. Statistical test however confirmed that the mean productivity of the regulated lower Ord was higher (by ~25%) than that found in the three unregulated river sites, which suggests that the overall productivity in the lower Ord River has may have increased since regulation. The rate of respiration was elevated at many sites and tended to be higher in September than in June. The seasonal difference would be related to increased water temperatures resulting in enhanced bacterial decomposition of detrital material. The relationship between production and respiration at the unregulated sites was weak indicating respiration was probably due to consumption of terrestrial carbon rather than in-stream algae.

It is generally considered that when production exceeds respiration the river reach is a net producer of organic carbon and is an autotrophic system. It is either accruing biomass or subsidising downstream reaches with carbon. If production equals respiration the river system is in steady state. If production is less than respiration, the system is a net consumer of organic carbon and is "heterotrophic". It is either being supplied with carbon from upstream (consistent with the RCC model) or is processing floodplain and riparian terrestrial carbon (FPC). The mean daily metabolism values (NDM) for the unregulated rivers of the Ord basin were negative (NDM varied in the Denham), which suggests that the unregulated rivers tended to be dominantly heterotrophic. Overall, mean NDM in the lower Ord River sites were positive indicating that productivity is based on in-stream production and are autotrophic. The results indicate that a typical 100m reach in the lower Ord River produced about  $600\text{gCday}^{-1}$  compared to an unregulated site which "consumed" about  $250\text{gCday}^{-1}$ . The difference between the river types suggests there may have been a fundamental change in the energy basis of the lower Ord ecosystem following regulation.

*Productivity and Water Flow Regulation in the Ord River of north west Australia*

Table 6.2. Rates of net primary productivity from a range of drainage divisions. The table shows steady-state net terrestrial primary productivity per unit area (NPP), spatially averaged across major drainage divisions (Australian Agriculture Assessment, 2001) as compared to estimated benthic NPP measured from sites in the study area. NPP was estimated from GPP by the methodology of Bott et al. (1985).

Drainage	NPP (t Carbon/ha/yr)
Indian Ocean	0.2
Western Plateau	0.3
Murray Darling	2.3
Lake Eyre	0.1
South Western WA	2.1
South East coast	5.5
Timor Sea (includes the Ord catchment in the analysis)	1.0
Lower Ord (Buttons)	1.1
Lower Ord (House Roof)	1.1
Marlgu (Parrys Lagoon)	8.2
Keep River	0.8
Lake Kununurra	3.1
Dunham River	0.8
Pentecost River	0.5

Elevated NDM has the potential to increase consumer biomass, particularly of taxa on the algal grazer pathway. The three unregulated sites generally had low rates of GPP and negative NDM, which is consistent with predictions of contemporary ecological models such as the RCC where detrital carbon is the major driver of aquatic food webs. This is considered to be through a longitudinal linkage (consistent with the RCC) or lateral exchanges during floodplain inundation (the FPC).

The metabolism data shows that the regulated sites produce more algal carbon (measured as GPP) compared to the unregulated sites. Processes that influence the abundance and distribution of the algal source are consequently important for the maintenance of fundamental ecological processes and higher order consumers. The rates of estimated in-stream net primary productivity in the lower Ord River system were greater than that of the surrounding terrestrial system. This highlights the importance of in-stream carbon production and the subsequent capacity of this component of the landscape to support significant consumer biomass and ultimately total biomass in the lower Ord River.

*Riparian Productivity*

Net Primary Productivity (NPP) was not significantly different in riparian vegetation of regulated river reaches, with the exception of Lake Kunnunara. The tall closed forest portions of the riparian vegetation at this site and the dense understorey and vine cover, represented a significant standing biomass and productivity compared to other sites. The significantly greater weed cover at Lake Kununurra also contributed to the high NPP. The Pentecost River site had the lowest riparian NPP due to very open woodland and sparse grass-dominated understorey. A greater frequency of high-energy flow events at the Pentecost would restrict the near-channel riparian flora to small, short-lived (annual-dominated) flora, with scattered trees located at micro-sites able to support them. In contrast, the riparian flora of Lake Kununurra is not exposed to the disruption of large flow events, allowing large biomass, perennial species to persist across the whole riparian zone. Surrounding land use and associated terrestrial disturbance events and exotic flora has also contributed to the band of 'concentrated' riparian biomass at this site.

The two remaining regulated sites, House Roof Hill and Buttons Crossing, did not have significantly different NPP from the other regulated rivers, the Dunham and Keep Rivers. There are however modest differences in the relative contribution of the understorey to riparian NPP, with the Keep River having the lowest understorey NPP of all the study sites. Lake Kununurra again had the greatest understorey NPP, primarily due to the very high weed species productivity (vine growth in particular). Differences in surrounding land use, physical site conditions and composition of terrestrial flora seem to have a significant influence on riparian NPP that overrides floristic

productivity responses to altered flow regimes. Correlation between reach-specific flow regime parameters and riparian NPP across a much greater number of sites would be a better approach to determining NPP – flow regime relationships but the influence of these ‘external’ factors would still account for significant variability.

Frequent floods would be expected to prevent the accumulation of high levels of biomass in the riparian areas, as the system would constantly be scoured of vegetation. Therefore, a high level of riparian production may be expected in systems, which are not disturbed regularly by high-energy flows. In the regulated lower Ord riparian areas were found to have higher levels of understorey foliage cover than unregulated sites. However, the overall productivity of riparian vegetation appeared to be more strongly influenced by invasion by highly productive weed species, physical site conditions, surrounding land use and composition of terrestrial flora than by river regulation.

#### *Sources of organic carbon to food webs*

Ultimately in regulated river systems draining developed catchments, carbon as energy can come from two sources: in-river production (*i.e.* algae, macrophytes) and terrestrial material typically in the form of detritus (Davies 1999). In fact carbon sources in all rivers include upstream, floodplain and local in-stream and riparian carbon. The relative dominance of the source however may vary longitudinally, by season and due to flow regulation. It may be expected that regulation would mean food webs would become more dependant in-stream production of organic carbon.

In a number of studies Australia-wide, filamentous greens and macrophytes have been found to be a largely insignificant component of consumer food webs (Bunn, Davies, & Mosisch, 1998; 1999; Bunn et al. 2001). Comparisons of natural isotopes terrestrial and algal organic material in the Ord River showed that over half the consumer biomass was attributed to the consumption of non-filamentous benthic algae. It was apparent however that there was an inconspicuous (not sampled) source of carbon was supporting a component of the food web at some sites (e.g. Buttons Crossing, House Roof Hill). For example, samples from Parry’s Lagoon showed snails with  $\delta^{13}\text{C}$  values about -15‰ without any obvious matching primary source. As snails are obligate algal-grazers this suggests an inconspicuous source. This source is most likely to be algal (C3 terrestrial values were highly invariant).

The mean %algal contribution to aquatic macroinvertebrate fauna was extremely variable among sites and seasons (8 to 93%). *Caradina sp.* were consistently low in algal material. Crayfish including *Macrobrachium rosenbergii* had elevated %algae values with many sites (e.g. Ord River at House Roof Hill and Dunham River) has values indicating the fauna was ultimately total algal carbon. Important commercial species including Barramundi (*Lates calcarifer*) and to a lesser extent Ox-eye Herring (*Megalops cyprinoides*), had substantial algal carbon in their biomass (*i.e.* 100% in Buttons Crossing and House Roof Hill in the lower Ord River (dry), Keep and Pentecost rivers (wet).

These analyses/results and actual  $\delta^{13}\text{C}$  values need to be assessed in the context of mixing models to determine percentage of different carbon sources to each species (as opposed to above subjective assessment of more / less algae versus riparian carbon). Two-source mixing models showed that there was increased incorporation of algal carbon during the wet season. This may be expected as increased areas of inundation can result in enhanced algal production which has a flow-on effect through the consumer food web. The regulated sites (Buttons Crossing, House Roof Hill and Marlgu) appeared to rely more on algal carbon compared to the unregulated sites. Increased algal incorporation in the regulated sites is possibly a function of the relatively “stable” flow regime post-regulation, which would promote algal growth.

Therefore, based on the analysis of food web structure in the Ord River and unregulated sites, the appropriate ecological model is the Riverine Productivity Model, which identifies the importance of in-stream algal to food webs in the lower Ord River. Factors that influence algal productivity would consequently have a major influence on important ecological processes in the lower Ord River. Clearly, parameters such as area of inundation and subsequent algal growth would be important “drivers” of a model predicting the ecological consequences of flow diversion. Given the shape of the lower Ord River channel and the distinct terracing, different flow regimes could

have disproportionate impacts on local algal growth and subsequently food web structure. Lower flows for example without concomitant reductions of nutrients from the irrigation area may potentially significantly slow nutrient flux and increase in-stream production of algal carbon. However, as food webs in the lower Ord are probably already structured to process algal carbon there should be some capacity for the lower Ord to process increased carbon. This would be highly dependent on the continued presence and abundance of primary and secondary consumers and their important habitats.

Other factors influencing local algal production include nutrients discharged to the lower Ord in irrigation drainage, and nutrients present in sewage effluent discharged to the lower Ord via the MI drainage channel. The significance of which may be increased in lower flow rates.

Rates of net primary productivity of riparian vegetation and from in-river algal growth show that algal productivity was generally higher than riparian understorey productivity. At some sites (*e.g.* Marlgu) rates of riverine production were substantially higher (up about 8x). Inundation of the riparian zone is expected to result in far less increased riparian NPP compared to algal NPP. Consequently, inundation of off-channel river areas would result in large increases in reach scale algal production. Processes that control algal production must be considered the major “driver” of any model predicting the effects of flow regulation.

It appears that algal carbon makes a substantial contribution to consumer food webs in the regulated lower Ord River. However, in some sites (Buttons Crossing, House Roof Hill) in the lower Ord River, it appears that an inconspicuous source of carbon may support a component of the food web. In other studies these sources have been identified as algal and may reflect low biomass (but high turnover rates) or seasonal changes in algal signatures.

#### *Food webs in the Ord River channel and floodplain*

The highest rates of production and respiration were measured at Marlgu Billabong. The extremely high productivity of Marlgu (Parry Lagoon) was probably a consequence of its high light environment (little or no shading), and the fact that it is a still and shallow billabong. The rates of production and respiration at Marlgu were related, which indicates that respiration is predominantly due to breakdown of algal carbon rather than terrestrial material. The productivity of the Marlgu sites suggests that the maintenance of the current levels of flow connectivity of the floodplain with the river channel should be a priority.

The isotope results tend to support the metabolism results and observations made whilst collecting samples. Aquatic invertebrates were abundant at the floodplain sites, but were reasonably scarce at the main channel site. The same applied to the various algal sources. Plankton tows and scrapes of submerged surfaces failed to produce a conspicuous algal source in the main channel. In the floodplain site, the submerged macrophyte (*Myriophyllum* sp), which had a complex structure, supported very large populations of periphyton and associated zooplankton (ostracods, copepods etc) which are a known food source for grazing, filtering and predatory aquatic invertebrates, as well as larval/juvenile fish. Interestingly, small/juvenile *Ambassis* at the floodplain site had a similar signature to the periphyton source, whilst at the main channel site, juveniles of the same species had a very depleted signature (as did juvenile *Nematalosa*). This suggests that juvenile fish in the main channel may feed off either terrestrial insects or benthic detritivores, which consume carbon mostly from riparian sources.

Generally, sampling did not manage to capture larvae/juveniles of each species for reasons given in section on fish community data, and as diet changes most usually occur from juvenile to sub-adult, this may likely explain absence of change with size in most species. Of the few larval/juvenile fish taken, they generally had an enriched  $\delta^{13}C$  signature, indicative of a high algal contribution (*i.e.* algal grazing or feeding on zooplankton), although there were several individuals with very depleted signatures indicative of terrestrial inputs (*i.e.* potentially direct feeding on terrestrial insects or benthic feeding on detritivorous insects).

## **7. Implications for management and adoption of outputs**

### **Water Resource Development in the Ord**

The implications of the results of the EFI program for water resource management of the lower Ord management need to be considered within the context of the development of the regions water resources and the management objectives for the lower Ord. The Water and Rivers Commission has overall responsibility for the coordination of water resource management in Western Australia. It is the lead agency for water resource assessment, protection, planning and management. The Commission is responsible for licensing the diversion and use of water from any watercourse proclaimed under the Rights in Water and Irrigation Act. The Commission manages the allocation of water resources so that water is used efficiently within sustainable limits.

The Commission does not have sole authority or responsibility for management of the Ord River. There are many decision-makers with some control over activities on the Ord River and adjacent land, there are stakeholders that have existing water rights (including cultural rights), and stakeholders that request for increased allocations or new licences to extract water. There are a number of community groups and individuals that have a strong interest in management of the river (WRC 2003).

As discussed earlier, an Interim Water Allocation Plan (IWAP) is about to be released by the Commission. The IWAP specifies the total divertible yield of the Ord River storage and describes the total annual volume for each activity, plus an allocation for economic growth in the Ord region. The provisional environmental water provision (EWP), is specified as a total annual volume that will provide adequate water to ensure that dry season flows do not fall below 45/40 m<sup>3</sup>/sec (upstream/downstream of House Roof Hill).

In addition, the Commission is considering the risk of allowing dry season flows to fall to 35/30 m<sup>3</sup>/sec (upstream/downstream of House Roof Hill) during periods of drought and irrigation restrictions. Based on historical rainfall records, irrigation restrictions will occur in approximately 1 year in 20. Irrigation restrictions will reduce dry season flows to 35 m<sup>3</sup>/sec only with full production in the Stage 2 areas. The development of the Stage 2 irrigation areas is expected to occur progressively over a period of around 5 years. During this period, the average dry season flow will trend down as the M2 irrigation areas come on-line from the current mean dry season flow of ~50 m<sup>3</sup>/sec to a minimum of 45 m<sup>3</sup>/sec. Irrigation restrictions will be superimposed on this regime of increasing demand for water. This 'drought' allocation will only be considered if it can be shown that the risk to the ecology of the river is low.

### **Management Objectives and Interim Flow Recommendations**

When the Water and Rivers Commission (WRC) first undertook the development of a water allocation plan for the Ord (WRC, 1999), the approach taken in determining the environmental provision was a rule of thumb 20<sup>th</sup> percentile of the natural flows. Little ecological data was available to justify a more sophisticated approach. A volume of 600GL.yr<sup>-1</sup> was to be released to meet the environmental provision. In keeping with the precautionary principle, ~265GL remained unallocated. The Commission recommended that this water should be used to meet revised EWPs when adequate data on riverine ecology became available and possibly as an additional dry season provision to mitigate the effects of irrigation return flows (WRC, 1999).

However, public comments on the 1999 EWP recommendation suggested that environmental values that had arisen in the 30 years since regulation had not adequately been protected. Advice from the Environmental Protection Authority (EPA) recommended that the Commission review the proposed EWP and that maintenance of the riverine environmental values established since the construction of the ORD be the basis of that review. The EPA also recommended that the Commission seek advice from an expert panel comprised of scientists with knowledge of tropical river ecosystems. The Commission subsequently established a Scientific Panel to provide on ecological water requirements of the lower Ord River.

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, 2000), 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.
- To maintain present ecological processes, waterbird and aquatic invertebrate values of the Lower Ord floodplain, there should be no significant diminution in the existing frequency and size of flood events.

The Scientific Panel also identified a number of ecological attributes 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 instream 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.

In 1999, 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 EWRs was to assess changes 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 known 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.

The EWP (45/40 m<sup>3</sup>/sec) in the IWAP is intended to minimise the risk of adverse ecological impacts. However, because of assumptions and uncertainties associated with the wetted-perimeter technique and hydraulic parameters, and in the absence of quantitative data on the river’s ecological water requirements, the EWP is precautionary<sup>3</sup>. The EWP is therefore an interim EWP pending the results of further ecological research and a review of the IWAP due in 2007.

In specifying a more definitive EWR/EWP for the lower Ord River, the objective is to protect the ecological and social values that have evolved since the regulation of flows. Further advice from the EPA is that the “maintenance of post regulation values” does not necessarily preclude mitigation of adverse ecological and social effects caused by changes in the natural flow regime<sup>4</sup>.

## Management Implications of the Ord River EFI Results

### *Historic flows and Wetted-perimeter*

Regulation has profoundly altered the hydrology of the lower Ord River. The magnitude and frequency of high flow events have been severely limited and large flood flows are discharged slowly over a period of many months rather than as the high energy, channel-forming flows occurred pre-regulation. The river now flows throughout the year and no longer recedes in the dry season to a series of disconnected pools. Through regulation, the river’s flow regime has been transformed from a ‘dry tropics’ river to a ‘wet tropics’ river. If the post-regulation ecological

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<sup>3</sup> The design of the spillway on the Ord River Dam was altered in 1996 to allow hydro-electricity generation. Water to generate electricity raised the mean dry season flows in the lower Ord River from approximately 45 m<sup>3</sup>/sec to around 50 m<sup>3</sup>/sec. The 45/40 EWP therefore reflects mean dry season flows following regulation in the early 1970s to 1996, and is expected therefore to pose minimal risk to post-regulation ecological values.

<sup>4</sup> Some changes to the river’s ecology have compromised socio/cultural values. For example, large crocodiles have expanded their upstream range and prevented access to reaches used traditionally for swimming and other cultural pursuits.

values of the river are to be maintained, any future EWP will need to maintain the wet tropic character of the river system, especially its perennial flow and connectivity to the estuary.

The decrease in flood frequency has significant implications for geomorphology of the river, vegetation dynamics and habitat condition. Prior to the construction of the Ord River Dam, the river would flood downstream wetlands during the wet season of most years. The impact of the ORD has been to decrease the frequency and magnitude of high flow events in the lower Ord River, with a corresponding decrease in the extent and duration of floodplain inundation. The constant flows and the reduction in high flow scouring events post-regulation have reduced the frequency of germination events and stranded high bank vegetation. Floodplain wetlands are now more influenced by other short, seasonal creeks. There may be scope to recover some wet season 'channel forming' flows while maintaining to basic dry season ecological characteristics.

The loss of the high magnitude floods means that there is greatly diminished stream power and so limited mobilisation of the coarser sediments (gravels, sands). Large sediment load is no longer delivered from upstream (only about 0.06% of the sediment that enters Lake Argyle is released). The relative importance of sediment loads from the Dunham River and other tributaries has increased. Observations and channel surveys have shown extensive deposition of sediments in various parts of the channel, and accretion of point bars. These changes in geomorphology appear to be linked to encroachment of aquatic vegetation. The aquatic vegetation traps sediments and stabilises the depositional forms, which are in turn colonised by more substantial vegetation stands. The result is a gradual decrease in channel capacity, with on-going channel encroachment by aquatic, and riparian vegetation.

Constant flows and reduced magnitude floods have encouraged the development of a more stable, dense band of riparian vegetation approximately 15m wide along the waters edge within the main river channel. Thickets of paperbark saplings and species that once occurred in isolated sheltered sites form tall woodlands in these areas. These new riparian zones provide important fauna habitat and may compensate, to some degree, for degradation of wetland habitats in the wider catchment.

The changes to Ord River flow have greatly increased to relative significance of the remaining unregulated flows to the systems ecology. The flow in the unregulated Dunham River, which joins the Ord River just downstream of the KDD provides some of the residual natural variation but the releases through KDD still dominate seasonal pattern of flow in the Lower Ord. This timing is significant, as this is when irrigation demand declines due to the early wet season rainfall and is prior to the major flow period for the Dunham River and other tributaries. It is important that Dunham River flows remain unregulated.

As a result of water resource development in the Ord region the dry season baseflow of the river will be reduced from its current mean dry season average. Not surprisingly, wetted-perimeter work done during the Ord EFI program suggested that greater reduction in minimum flows from 50 m<sup>3</sup>/sec, the greater the change to wetted-perimeter and the greater risk to post-regulation ecological values. It follows therefore that risk to post-regulation ecological values is minimised by minimising change in dry season flows. The challenge for the Commission is achieve this aim while meeting current water demands and catering for expansion of the irrigated areas.

In specifying the interim EWP, the wetted-perimeter/flow characteristics of the river downstream of the KDD were used to make a first approximation of critically low flows at unmonitored reaches. As flows decrease in the Ord, there will be flow rate below which the loss of w-p accelerates as water shrinks from the channel banks<sup>5</sup> (Hollands 1998). The EFI wetted-perimeter studies was in part designed to identify a threshold flow below which there is a rapid increase in the change to wetted-perimeter, and if possible link it to other hydrological indices<sup>6</sup> and release rates at the KDD. In the reach upstream of Tarrara Bar, the EFI study showed that there was an increase in the

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<sup>5</sup> The rate of loss in wet-perimeter depends on the shape of the channel profile. The wet perimeter of shallow areas tends to change more in response to a change in flow compared to deep reaches with steep-sided banks.

<sup>6</sup> A correlation between wet perimeter, hydraulics and other hydrological indices would support allocation decisions in the absence of fine-resolution (daily) data (Hollands 1998).

number of cross-sections that changed by more than 20%<sup>7</sup> once flows fell below ~40 m<sup>3</sup>/sec. This result suggests that the threshold flow may be somewhere near the interim EWP. This result has management implications associated with the proposed minimum flow rates (35 m<sup>3</sup>/sec) allowed during droughts and periods of irrigation restrictions.

The pools systems are the major habitat type in the lower Ord<sup>8</sup>. Change in wet perimeter of the pools was small compared to shallow areas, such as backwaters and riffle zones. This relationship would suggest that even below the threshold there would be a relatively small change to the volume and extent of the pool systems. However, the fish study showed that many species found in the lower Ord are not usually found so far upstream in unregulated rivers of the dry tropics. The permanent flows have increased the longitudinal connectivity of the river with the Cambridge Gulf. The presence of large predatory species in the lower Ord was linked to the stable dry season flows and the connectivity of the river system, and also probably to the abundance of prey species in the lower Ord (such as mullet), some of which are dependent on the availability shallow water habitat (Storey 2003). If the management objective is to maintain this unusual mix of fish species in the lower Ord, future wetted-perimeter and hydraulic studies should focus on the shallow areas, key habitat and the significance of connectivity between pool-riffle sequences to their presence and the larger average size compared to unregulated rivers<sup>9</sup>.

#### *Ecological Studies*

It is also important to consider that while the effect of the dams on terrestrial and aquatic fauna may have been profound, the system is not without ecological value. As the Ord EFI research has shown, the Ord River supports an extensive array of fauna and flora that have adapted to the system since regulation. Lakes Kununurra and Argyle now provides permanent water and are valuable dry season refuges for waterbirds. The lakes are listed under the International Ramsar Convention. Lake Argyle also supports a large freshwater crocodile population. Downstream on the Ord River Floodplain, an area of extensive tidal mudflats and mangroves, seasonal wetlands and permanent waterholes (~11 6000ha) is also RAMSAR protected. The area is ranked as one of the five most important wetlands in Western Australia for migratory shorebirds.

The interim EWR was specified primarily to maintain dry season flows in the river and the ecology that has evolved to reflect its permanent dry season baseflow. In recommending an EWR, it is also important to consider that while, the effect of the dams on terrestrial and aquatic fauna may have been profound. It may be expected that the lower Ord would have its own unique ecological character. This distinctiveness of the Ord ecology must be considered in recommending an EWR that will protect post-regulation values.

The description the aquatic biodiversity of the lower Ord River will greatly assist the Commission to protect post-regulation values through environmental provisions. The Ord River supports an extensive and distinctive array of fauna and flora that have adapted to the system since regulation. The EFI Study has shown that the lower Ord supports a distinctive community of fish species, which was clearly different to that in the nearby unregulated river systems. Associated aquatic systems, such as Lake Kununurra and Lake Argyle, now provide additional permanent water in a region of highly ephemeral systems and provide valuable dry season refuges for waterbirds and other fauna, and did support a clear and distinctive invertebrate community. The Ord River floodplain is an area of extensive tidal mudflats and mangroves, seasonal wetlands and permanent waterholes. The lakes and floodplain wetlands, which are one of the most important wetlands in WA for migratory shorebirds, are protected under the International RAMSAR Convention.

The flow-dependence of ecological process that supports will also be considered in recommending an EWR for the lower Ord River. This study found that that since the regulation of Ord River flows, food webs have become more reliant on in-stream algal carbon than they were before regulation. The maintenance of post-regulation ecological values of the lower Ord River may depend fundamentally on the maintenance of this production base. Algal carbon

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<sup>7</sup> The Scientific Panel advised the Commission that changes in wet perimeter of more than 20% risk ecological values.

<sup>8</sup> Pools occupy over 80% of the 90 km's between the KDD and The Rocks.

<sup>9</sup> The abundance and larger average size of some fish species in the lower Ord (such as Barramundi) affects the social and economic value of the river.

for example was traced to high order predators such as Barramundi, which were found to be reliant almost entirely on in-stream production. Barramundi is the one of the most valued recreational species in the Ord, and is also the basis of a downstream commercial fishery. The Ord EFI result suggests that the protection of aquatic algal communities has implications for both for post-regulation ecological as well as social and commercial values of the Ord River.

It appears that both in-stream and riparian primary production support the distinctive mix of species currently found in the lower Ord. The Ord EFI research showed that food webs in the unregulated rivers have evolved to process riparian sources of carbon. The EFI study estimated that about 40 percent of carbon being process by the Ord River food web comes from the riparian zone. For example, few individual s of juvenile fish in the lower Ord were had an isotopic signature that suggested either they feed on terrestrial insects (or benthic detritivores that consume mainly terrestrial vegetation). While not as important as in-stream production this is nonetheless a significant contribution to aquatic production and may be linked to the presence of large trees near the river channel. Any loss or decrease in terrestrial carbon (leaf litter, twigs, branches) risks reducing biomass and possibly biodiversity and highlights the need to maintain the diversity of riparian vegetation when considering the EWR of the river (Pusey and Arthington 2003).

Clearly, parameters such as area of inundation and subsequent algal growth would be important “drivers” of a model predicting the ecological consequences of flow diversion. Given the shape of the lower Ord River channel and the distinct terracing, different flow regimes could have disproportionate impacts on local algal growth and subsequently food web structure. Lower flows for example without concomitant reductions of nutrients from the irrigation area may potentially significantly slow nutrient flux and increase in-stream production of algal carbon. However, as food webs in the lower Ord are probably already structured to process agal carbon there should be some capacity for the lower Ord to process increased carbon.

The Ord EFI program showed that regulation of flows in the lower Ord River may have favoured the establishment of exotic species, especially understorey taxa such as grasses and herbs. The greater importance of in-stream algal production to fish may in part be linked to the decreased richness of native species in the riparian zone (Pusey and Arthington 2003). This change in riparian zone vegetation since regulation may be due to a lack of regular disturbance by flood flows and the loss of flow-related cues to trigger seed set and germination of native species. Any future EWR recommendation may consider the possibility of providing important scouring flows and flows related to vegetation phenology<sup>10</sup>.

Decreases in the frequency and magnitude of flooding from the Ord may have enhanced opportunities for establishment of weed species that are intolerant of waterlogging. Alternatively, there is a risk that species which are tolerant of waterlogging may invade in future. However, given the variety and complexity of ecological interactions that lead to invasion by exotic species it is recognised that it will be difficult to decisively attribute increased invasion by exotic species to regulation of flows at the lower Ord River.

Disturbance history of the riparian zones rather than the regulation *per se* may have a greater influence on the level of weed invasion of riparian zones. Both House Roof Hill and Buttons Crossing on the lower Ord have been used historically as stock crossings. The Dunham River area has also been used for stock grazing. The presence of stock is a plausible explanation for high weed invasion in the areas. The effects of both disturbance from stock (creating niches for weed establishment), and the provision of weed propagules, would contribute to weed invasion at these sites. Similarly, Lake Kununurra lies within an area of intensive agricultural production, which would be a major source of exogenous disturbance and weed propagules. Management of the riparian vegetation in the lower Ord will have to consider flow-dependencies of riparian vegetation as well as the impacts of land use.

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<sup>10</sup> The spillway of the Argyle Dam does not have the capacity to provide meaningful ‘channel forming’ volumes of water to the lower Ord River. It may be possible to augment Dunham River wet season flood flows with well-timed releases from the KDD.

*The Ord EFI Program and environmental flow methodologies*

The information generated by the project will be used to help identify Ecological Flow Requirements (EWRs) for the lower Ord River. Early methodologies for assessing environmental flows were developed to protect mainly salmonoid fish in cold water streams of north-west North America. The aim was to maintain the habitat, migration routes and triggers, water temperature and quality for the benefit of trout and salmon populations. These narrow focused assessments did not necessarily protect other important ecological values. Holistic methods take a broader view and aim to sustain flow-dependant ecosystems based on measures of bio-diversity, community structure, recruitment, migration, phenology and processes that maintain ecological integrity.

Until recently, there was no comprehensive scientific or decision-making framework for assessing environmental flows for rivers that have a history of flow regulation. Most holistic ecological flow assessment methodologies, such as the Building Block Method (BBM), were developed for unregulated streams where natural flow regimes are about to be modified by large water infrastructure development (Tharme and King, 1998). Holistic methods have also been used to recommend environmental flows for rivers experiencing low level but increasing regulation due to incremental development such as small diversions, dams, groundwater extractions, and weirs (Arthington, 1998).

Most holistic flow assessments methods employ a multi-disciplinary approach to assessing EWRs and initially consider flows required to maintain geomorphological processes and channel structure, followed by habitat, reproductive and dispersal requirements of riparian and aquatic plants, aquatic macroinvertebrates and fish faunas. Flows are now also being recommended that maintain or restore key ecological process such as nutrient and energy exchange between a river and its catchment (Arthington *et. al.*, 1998). A key element of holistic approaches is the quantification of the ecological features that represent the desirable ecological condition. The ecological data collected during the Ord EFI program fulfil this critical information requirement.

The Flow Restoration Methodology (FLOWRESM) was developed to assess environmental flows for the Brisbane River downstream of the Wivenhoe Dam (Arthington *et. al.*, 2000). A more recent methodology known as 'Downstream Response to Imposed Flow Transformations' (DRIFT) has been developed in South Africa assess EWRs for South African Rivers (Brown and King 2000, 2002). DRIFT has been developed specifically to underpin negotiations associated with water resource allocations.

FLOWRESM and DRIFT consider water provision based on current and future abstraction scenarios. The approaches are being considered by the Commission, in whole or in combination, to provide a structured decision-making process whereby bio-physical data, such as that generated by the Ord EFI study, can be integrated with socio/economic information currently being compiled. FLOWRESM was developed specifically with the aim of mitigating the adverse effects of regulation of the Brisbane River. DRIFT was originally developed with the aim of maintaining pre-regulation ecological values. However, the methodologies need to be adapted to the Ord River requirement to maintain the post-regulation ecological values.

The information and data needs of most holistic approaches to EWR assessment are broadly similar as shown in Figure 7.1. The process towards recommending an EWR for the Ord River did not follow the sequential order shown in Figure 7.1. Many tasks were completed either out of sequence or concurrently, or were carried by other agencies and not directed involved in the EFI program. However, the figure does illustrate the context of the information collected during the Ord EFI program and how this information will be used to assist the Commission to recommend EWR and EWP for the lower Ord River. The Ord EFI program stages 1 and 2 was concerned primarily with the Tasks 1 through 5. Stage 3 of the Ord River program, which is concerned with defining a definitive EWR and EWP, involves Tasks 6 to 11 in Figure 7.1.

The availability of flow data is especially important for holistic methodologies, and is important to support the EWR workshop planned for February 2004. The data is essential for present flow scenarios for group consideration, and the assessment of biophysical impacts of water provisions. Due to the Ord EFI program and other studies data is

now available on the unregulated and regulated flow variations, seasonal variation and longer-term variations in flows and flooding in terms of timing, duration, frequency and magnitude of floods at a range of return intervals.

The holistic methods are based on expert opinion to assess flow-dependence of river ecosystems. The holistic approaches essentially provide the overall framework by which diverse information is incorporated into environmental flow decisions. Both FLOWRESM and DRIFT use a series of structured workshops where scientists are presented with flow scenarios and asked to predict the ecological impacts within their fields of expertise (similar to that shown in Table 7.1). The EFI program research team will be involved in the EWR workshop process. As a result of the Ord EFI program, the views of the scientific team, their opinions and predictions will be based on empirical data and first-hand experience of working on the lower Ord River. The research team are also part of the scientific panel set up to advise the Commission on the proposed flow scenarios and will be attending the 2004 workshop to advise on the fluvial effects of flow recommendations.

The fluvial dynamics were not directly studied as part of the Ord EFI program. However, the funding provided through the program did allow the Commission to use matched funds for a study on the morphology and vegetation of the lower Ord. Both FLOWRESM and DRIFT can be used to address the water requirements of riparian vegetation (Arthington *et. al.*, 2000). Again the major issue for the lower Ord is the application of the methods where the aim is to maintain post-regulation ecological values. The riparian information collected during the EFI studies will assist the Commission in recommending EWRs and to specify the biodiversity and community structures that are currently present in the riparian zones. Riparian vegetation was specifically considered in FLOWRESM (McCosker 2000), including the role of factors extrinsic to flows regulation such as grazing of stock in the riparian areas and the distribution of exotic species.

Further detailed knowledge of the water requirements Ord River riparian vegetation is required if it is to be incorporated into assessing EWRs. Any flow assessment will also require knowledge of soil water content and relationships between riparian zone soil water, Ord River flows and groundwater interactions. Most Australian applications have largely ignored the role of groundwater in sustaining riparian zone vegetation and ecology. There is no data linking Ord River flows, groundwater and moisture content of near-channel soils.

The current level of understanding developed through the EFI program, and other work, however may be used within an Expert Panel Assessment or any method which can be based on expert knowledge. However, the lack of a systematic scientific procedure raises questions about repeatability of flow recommendations for riparian communities using different practitioners in Ord, at different times and in other river systems (McCosker 1998). Expert opinion can be considered in structured holistic methodologies (Arthington *et. al.*, 2000; Arthington and Zalucki, 1998). The holistic approaches require reach scale representation of riparian vegetation communities and make use of site transect information of the type used for the Ord EFI study, although with greater replication within reaches.

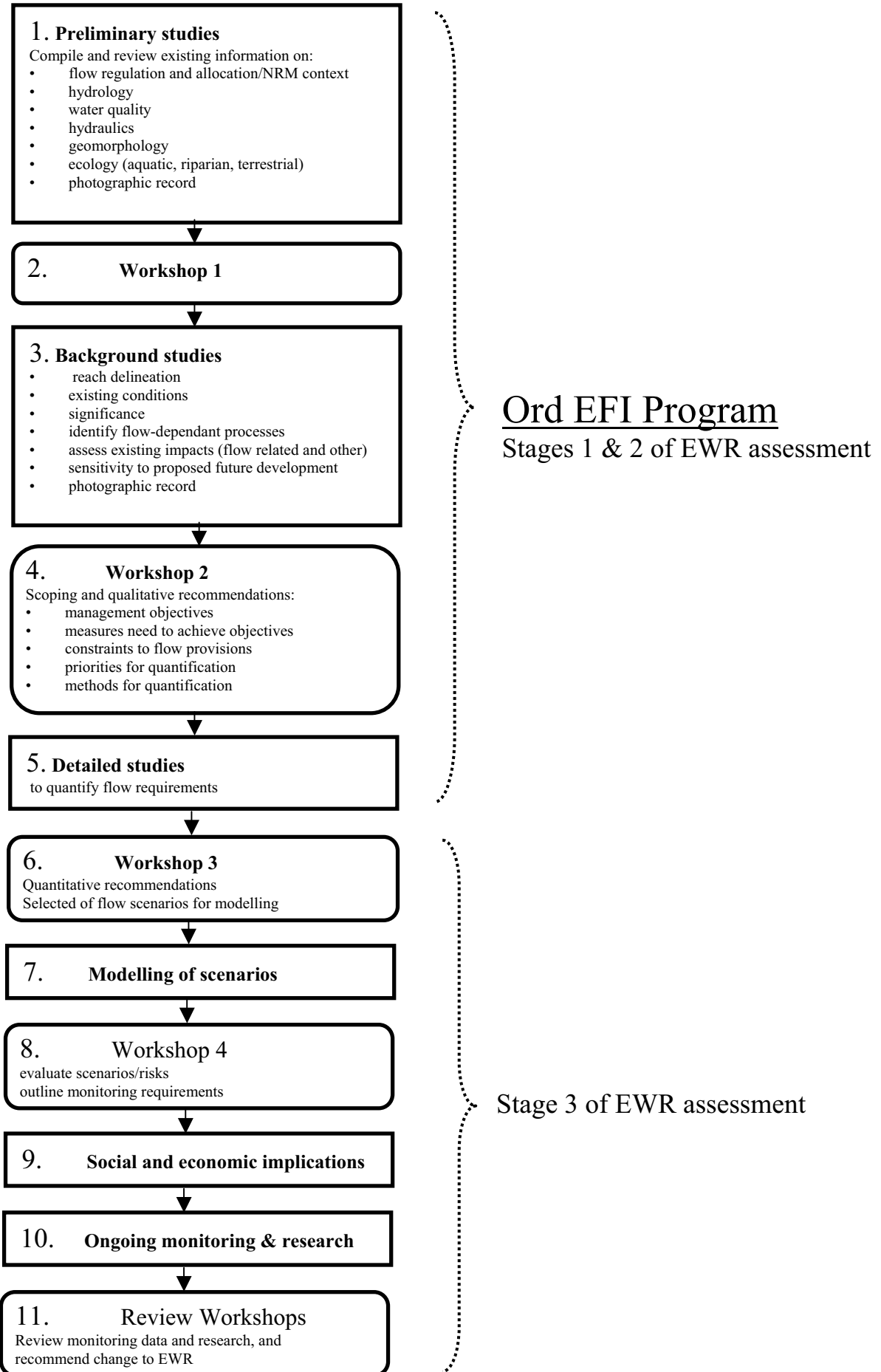


Figure 7.1: Generic framework for assessing environmental flows in rivers (adapted from Arthington *et. al.* 1998).

## **8. Recommendations**

The availability of flow data is especially important for holistic methodologies, and is important to support consideration of flow scenarios the EWR workshop planned for February 2004. It is essential that the hydrographic data is processed into a format better suited to the presentation of flow scenarios. It is recommended that the existing flow data be incorporated into a hydrologic simulation package, either that used by FLOWRESM (based on the Integrated Quality Quantity Model, or IQQM), or the purpose-built hydrological module of DRIFT.

The data for the EFI program has been based largely on monthly time-series and statistics derived from monthly data. The hydrologic modules daily data or flow indices derived from daily data. Daily data is preferred as it is this flow that riverine biota experience and will respond. The data needs to be processed and supplied as daily averages for the final 2004 workshop.

Geomorphological research in Australia has been focused on description and explanation rather than practical solutions to problems. This essentially remains true for the lower Ord River. The lack specific information on fluvial dynamics and habitat availability in the lower Ord that can be linked to flow recommendations remains probably the largest gap in required information for assessing EWRs. Research is required on identifying flow thresholds that are required to perform important functions such as channel maintenance.

Assessing the flow requirements of riparian vegetation in the Ord requires a more detailed field survey and more research to describe the hydrologic requirements of dominant plant species in the riparian areas of the lower Ord. It is recommended that the flow requirements of riparian vegetation is studied in more detail, especially research that relates vegetation with flows, fluvial geomorphology, groundwater levels and soil water content in the riparian areas<sup>11</sup>.

Limited data sets are potentially impacted by antecedent weather patterns and are unable to describe the status in terms the range of variability in species presence/absence and abundance that can be expected. To discern with certainty the effects of river regulation on the riparian vegetation and other aspects of aquatic ecology in the lower Ord a long-term data will be necessary. The effects of unusual high rainfall events (such as the two which caused high-energy flows in the regulated lower reaches of the Ord River) had a significant influence on results (especially riparian vegetation) and could be separated from the typical state of the system. Representative non-regulated study sites may be selected to provide long-term reference conditions, preferably that have a comparable post-regulation flow regime to that of the lower Ord River.

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<sup>11</sup> It is recognised that the detail required to assess the flow dependence of riparian vegetation difficult may be difficult to justify considering the level of disturbance to riparian areas by other anthropogenic factors such as grazing. This may be especially difficult for flow assessments of geomorphology and riparian vegetation which is still probably adapting to the regulated flow environment, and the change in flood flow magnitude and frequency.

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