Ecological risk assessment associated with irrigation in the Ord - Phase 2.

Ecological risk assessment associated with the impact of irrigation return on the risk of algal blooms in the Ord River

Technical Report

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Acknowledgements

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1.0 Introduction

The National Program for Irrigation Research and Development (NPIRD) has established a research project to develop and test a generic framework for assessing the ecological risks associated with irrigation return. The framework development and partial testing will be achieved using three case study irrigation systems – the Goulburn-Broken, the Ord and the Fitzroy (Queensland).

The project will be implemented in two phases:

1. Identification of likely ecological risks associated with irrigation systems within the each case study and ranking of the risk based on the use of conceptual models.
2. Undertake specific studies to validate one or more of the key conceptual models proposed in Phase 1 and then to assess the risks for the specific issues studied in detail

This report focuses on the Ord River Irrigation Area case study. Phase 1 has already been completed (see Lund and McCrea 2001) and this report covers Phase 2.

1.1 Ecological Risk Assessment

Ecological Risk Assessment (ERA) evolved from ecotoxicological risk assessments that examined the risk posed by a toxicant (e.g. heavy metal, pesticide) on a target species. This approach was adopted and broadened in the Australian and New Zealand Water Quality Guidelines (ANZECC and ARMCANZ 2001). The guidelines encouraged risk assessments for specific sites and toxicants (for example see Muschal and Warne 2003). Ecological risk assessment has also been expanded to a more holistic level, covering multiple environmental stressors and ecological consequences (e.g. Hart *et al.* 2003). Although ERA has become an increasing important management tool, much of the assessment remains qualitative. Qualitative assessment while often considered the only possibility given poor data availability are fraught with subjectivity, linguistic uncertainty and rarely adequate recognition of the degree of uncertainty (Burgman 2001). Quantification of ERAs have focused on the development of suitable models, particularly the use of Bayesian modelling, to overcome some of these limitations (e.g. Hart *et al.* 2003; Pollino 2004; Webb and Chan 2004).

Hart (2004), Hart *et al.* (2001) and Hart *et al.* (2003) have proposed models of the ERA process that commence with a problem formulation, issue/hazard assessment followed by a risk assessment. The risk assessment informs decision making which may trigger further more detailed investigations into assessment of the risk, or lead to risk management and monitoring. The whole process is iterative with monitoring results feeding back into the problem formulation stage. Phase 1 of this study included problem formulation, issue/hazard assessment and a preliminary risk assessment. The risk matrix produced was used to identify where more intensive investigations into priority issues were need to develop better risk assessments.

1.2 Key findings from Phase 1

Phase 1 of the project is detailed in Lund and McCrea (2001). In summary, project formulation involved defining the extent of the catchment of interest (downstream of the Ord River Dam) to the estuary, collation and interpretation of existing water quality data in a materials budget and production of some conceptual models of the system. Stakeholder workshops were then used to identify issues/hazards. Finally a risk matrix was produced based on expert opinion and stakeholder input. Five priority ecological issues were identified:

- Occurrence of Algal blooms (particularly cyanobacteria)
- Biota kills (primarily due to biocides)
- Loss of aquatic biodiversity
- Channel infilling leading to loss of habitat and social amenity
- Increased prevalence of aquatic weeds

Stakeholders saw loss of biodiversity as the top priority for future research. Although biota kills were ranked highly, they were not seen as a priority for further research by stakeholders. This was because various Agencies and the irrigator community were already attempting to reduce the risks of pesticide releases occurring. This does not however discount the importance of the ecological effe cts of chronic pesticides releases. The role of pesticides will also be examined as part of the loss of biodiversity consequence. Channel infilling was seen as a low priority as it was believed that it was occurring primarily as a result of changes in flow due to the dams rather than being the direct result of irrigation return. The risk of algal blooms occurring was considered to be low, as the river was considered to have a low hydraulic residence time and a high dilution rate for irrigation return. However, concurrent research undertaken by the Ord-Bonaparte program provided an opportunity for modelling the risks of algal blooms occurring in the Lower Ord River.

The increased growth of aquatic weeds is an important issue, but this will not be examined in this project. Other research associated with determining Ecological Water Requirements involves detailed vegetation surveys, which will allow at least the extent of the weed problem to be assessed. High floods in 2000/01 have removed large proportions of the populations of aquatic weeds in the Lower Ord River. The risk posed by aquatic weeds, at least in the short term is lower than originally believed in Phase 1 (R. Froend and A. Storey *pers. comm.*). In addition, the impact of emergent or submerged aquatic weeds in the Lower Ord will be investigated through their impacts on loss of aquatic biodiversity.

In Phase 2, it was decided to focus on two ecological issues:

- Loss of aquatic biodiversity
- Occurrence of algal blooms

1.3 Study site - The Ord River

The Ord River is located in the east Kimberley region of northern Western Australia (Figure 1). It is an extremely isolated and sparsely populated region (0.06 persons km-2, based on Shire of Wyndham-East Kimberley , KDC 2003) approximately 3000 km from Perth (State capital) and over 825 km from the nearest city, Darwin. The Ord River (650 river km) has an estimated catchment of approximately 50,000 km^2 at the

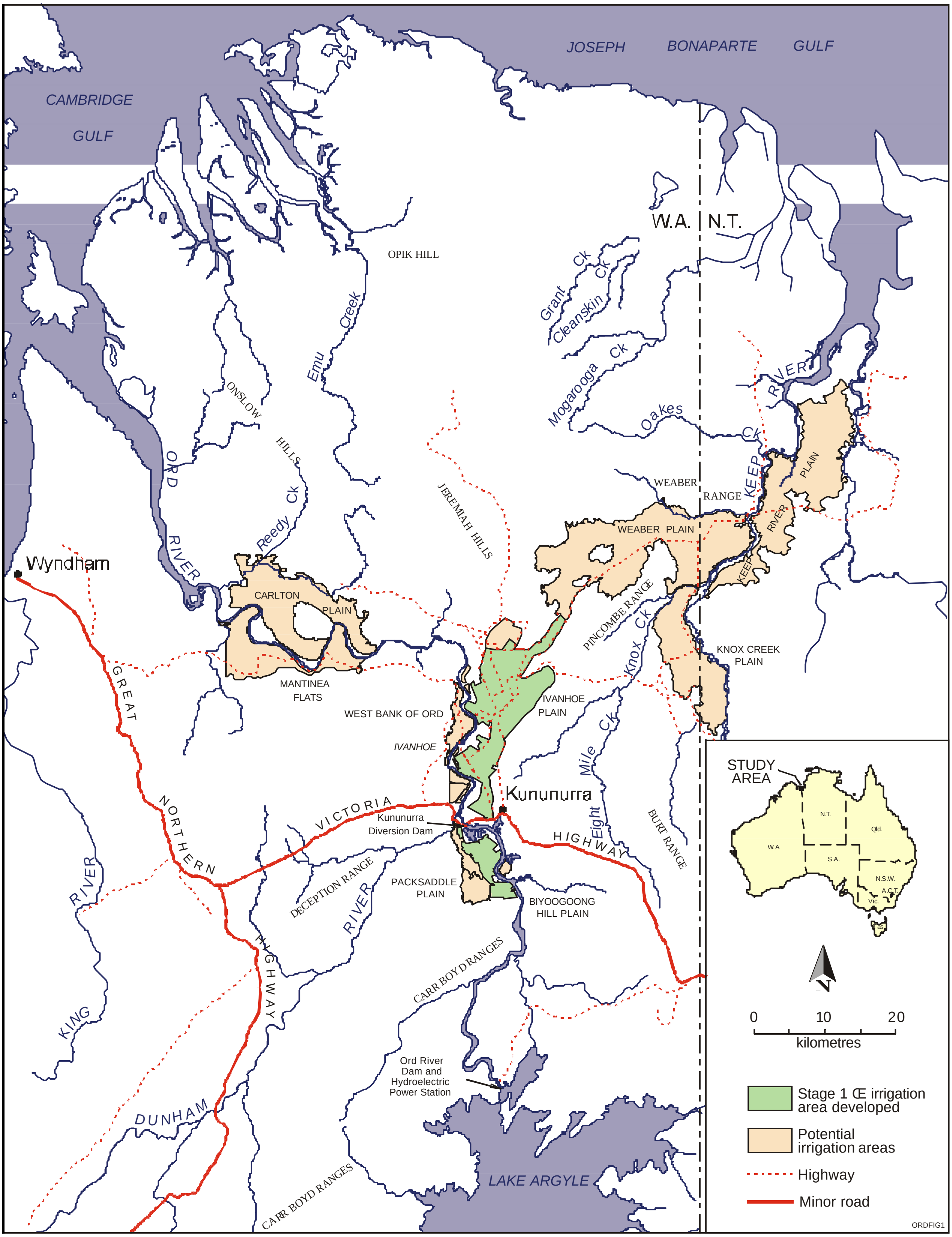


Figure 1 **Map of the Lower Ord River, indicating the location of existing irrigation areas (Stage 1) and proposed areas (Stage 2).**

river mouth, it flows northwards from near Halls Creek to Cambridge Gulf (Ruprecht and Rodgers 1999). Maze (1945) divided the river into 5 sections, starting with the estuary (tidal marshes and mangrove swamps), the Ord River Valley (with sandy loam levees and Cununurra clay plains), Ord River Gorge (where the river cuts through the Carr Boyd ranges), the Middle Ord Valley (basalt and limestone associated clays) and Upper Ord River Basin (flaggy limestones and sandstones). Wasson *et al*. (1994) provides a more detailed overview of the geology of the Middle Valley and Upper Basin, which covers the majority of the Ord catchment (46,000 km^2). Major tributaries in the upper Ord River (upstream of Ord River Dam) are the Wilson and Bow Rivers (6600 km^2), Spring Creek (250 km^2), Stirling and Negri Rivers (7800 km^2), Elvire and Panton Rivers, Nicholson River (2460 km^2), Linnekar River, and Forrest Creek (Wasson *et al.* 1994), while in the lower Ord River the only significant tributary is the Dunham River (4200 km^2).

The wet-dry tropics are dominated by summer rains (wet season) where the majority of rain is derived from cyclonic activity, with virtually no rain during the winter dry season (Figure 2). Indigenous people recognised 6 seasons that were based on key biotic changes in the environment (Braithwaite and Estbergs 1988). The quantity of summer rainfall is extremely variable, with a maximum daily rainfall of 431.4 mm recorded in April 2001 (1944 to present) at the Kimberley Research Station (KRS). Annual rainfall ranges from 555 mm at Halls Creek to 814 mm at KRS. Evaporation rates exceed rainfall rates all year except for January and February at KRS.

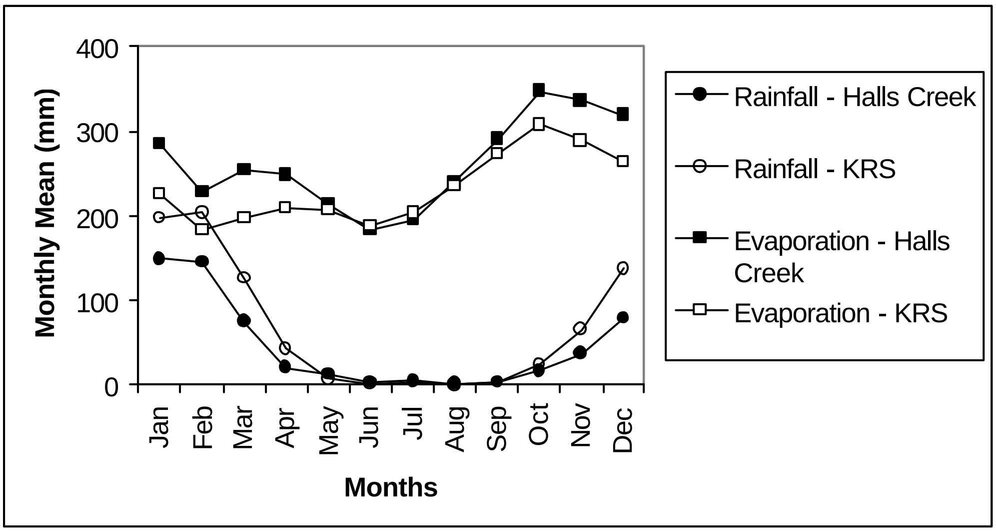
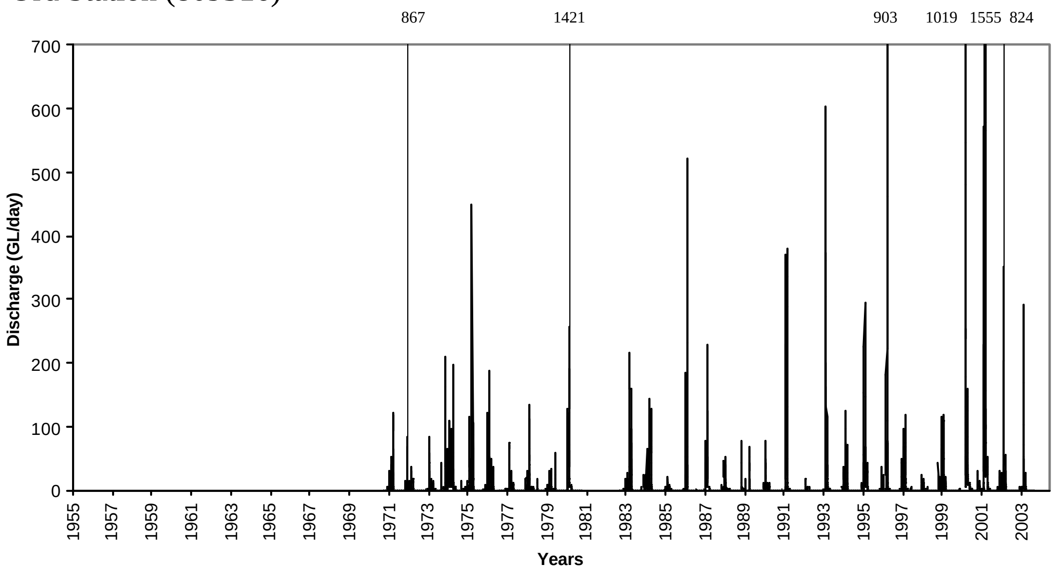


Figure 2 **Mean monthly rainfall and evaporation rates (1944 to 2003) from Halls Creek and Kimberley Research Station (KRS) weather stations (Bureau of Meteorology)**

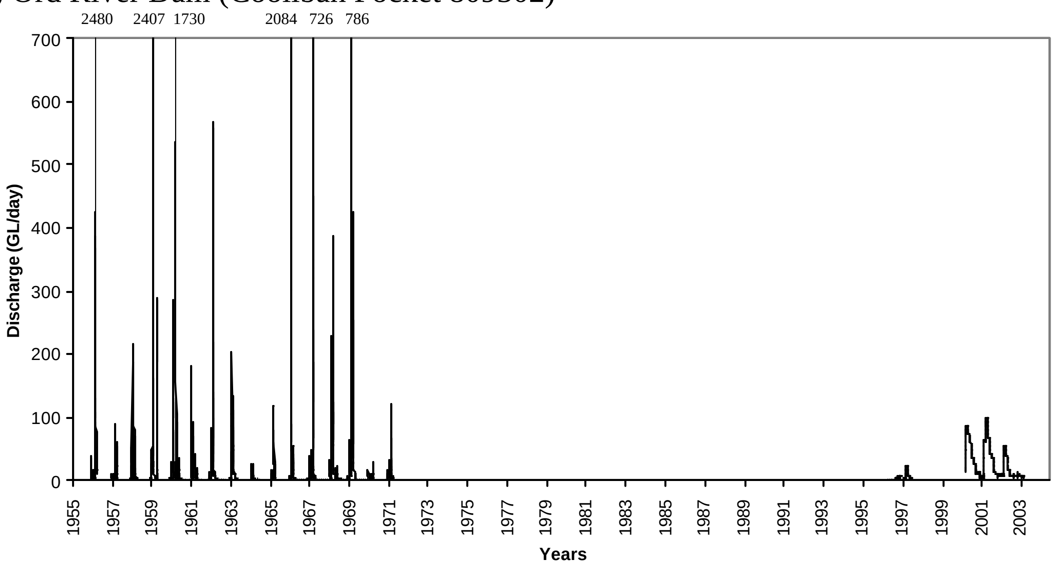
The flows in the lower Ord River are now regulated by the Ord River Dam (ORD) in the Carr Boyd Ranges and the Kununurra Diversion Dam (KDD) near Kununurra Township. The ORD forms Lake Argyle and KDD forms Lake Kununurra. Prior to regulation, the Ord River was reduced to isolated pools during the dry season and subject to large discharges during the wet season (Figure 3). The Lower Ord River is regulated to maintain a permanent flow (typically 70 m^3s^{-1}). The water level in Lake Kununurra is maintained within a narrow range (±1 m) to provide a constant head for the gravity fed main offtake irrigation channel (M1). Releases from ORD are largely determined by the demand for hydroelectric power from Kununurra and Argyle Diamond Mines. The demand for power remains relatively constant throughout the year and therefore largely determines flows in the Lower Ord River. These releases are likely to increase in the future with increased electricity demand. Variability in the flow in the lower Ord River comes from overflow from Lake Argyle (down Spillway Creek) and the Dunham River; there are also a number of minor tributaries and that contribute unregulated flows.

Lake Argyle has a huge capacity to contain flood waters with a maximum recorded volume of 17,800 GL (at maximum probable flood level, the lake has an area of 2,070 km^2) (KDC 2003). This can contain the extreme episodic events typical of the unregulated Ord River; i.e. a maximum discharge of 2,480 GL day^{-1} (28,704 $m^3 s^{-1}$) was recorded on 27/2/1956 at Coolibah Pocket (site of ORD). The large surface area of the lake further reduces the rate of increase in depth of the lake during these events. Overflow from lake is controlled by a channel that connects to Spillway Creek, set at 92.2 m AHD. This has the effect of dampening these extreme events and prolonging

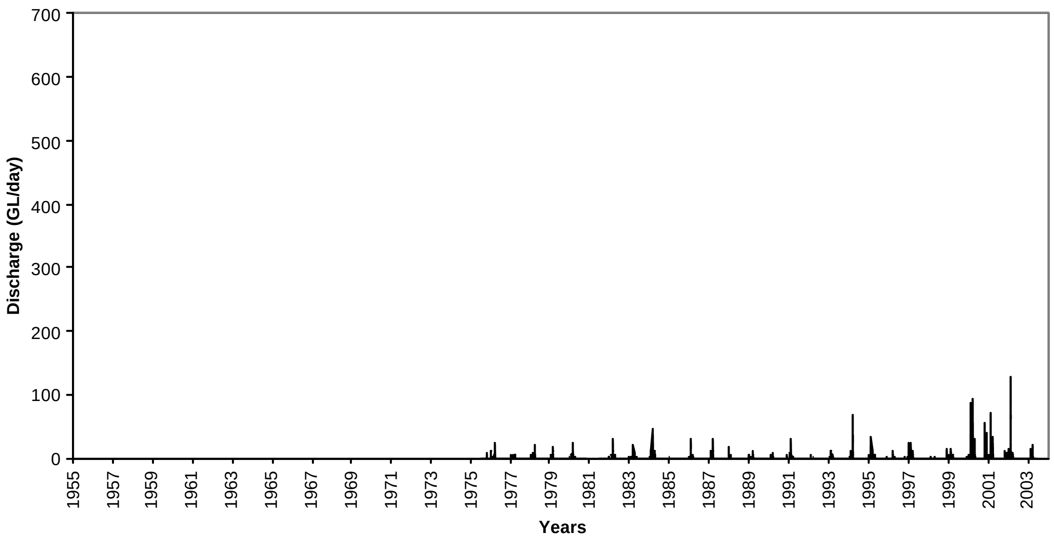
a) Ord Station (809316)



b) Ord River Dam (Coolibah Pocket 809302)



c) Dunham River (809321)



d) Tarrara Bar (809340)

Figure 3 **Discharge (GL day^{-1}) taken from WRC gauged stations (Station Number) at a) Ord River Station (prior to Lake Argyle), b) Ord River Dam (post 1996 data) and Coolibah Pocket (pre 1996 data, now lost under Lake Argyle), c) Dunham River (upper third of catchment only), and d) Tarrara Bar (numbers above graph indicate peak discharge for that event; data supplied by Water and Rivers Commission and Pacific Power)**

them in the lower Ord River. As KDD releases essentially replicate releases from ORD in order to maintain the level of Lake Kununurra, it can be seen in Figure 3 that the flow pattern at Tarrara Bar reflects that seen post 1995 from ORD. Although the Dunham River is unregulated (aside from one small tributary dam – Arthur Creek), its overall influence on the flow pattern at Tarrara Bar is one of adding noise and the occasional spike (see 2002) rather than altering the nature of the flow pattern.

1.4 A brief history of the Ord River Irrigation Area

George Grey after his expeditions to the Kimberley suggested in 1841 that the area would be suitable for some types of cultivation (particularly cotton) (Grey, 1841 cited in Head 1999). In 1913 there was the first suggestion of an irrigation dam on the Ord River (Despeissis, 1913 cited in Walker, 1992). Irrigation in Australia was for many years seen as profitable venture, where the profitability of irrigated farms could be used to repay the State for the large infrastructure costs involved (Davidson 1972). It should be noted that while the inability of Ord farmers to pay back infrastructure costs is frequently held up as a measure of economic failure, this is typical of Australian irrigation. In the late 1930s, interest in creating a Jewish settlement in the Kimberley, increased Government interest in the region particularly towards the possibilities for irrigation (Graham Taylor 1982). In 1942 the possibility of irrigation was investigated in the Ord and Fitzroy Rivers at the Kimberley Research Station (later the Frank Wise Agricultural Research Centre). Initially conceived as a sugar growing region, then rice and finally cotton and safflower were the preferred crops (Davidson 1972). The development of the Ord Irrigation Scheme was agreed to in 1958 and the KDD was built in 1963.

It is clear that there was not strong scientific data or economic analysis to support the decision to commence the KDD (Davidson 1982; Graham Taylor 1982; Walker 1992). An economic analysis in 1963 by Davidson suggested that cotton would only be profitable with a 60% government subsidy and no infrastructure charge applied to the water price (Davidson 1972). Sorghum was grown commercially in 1967, but proved unprofitable. In 1968, a Senate election where the government was likely to lose votes from Western Australia has been seen by many authors as the ultimate reason for the decision to proceed with the development of the ORD (Davidson 1972; Walker 1992). Another justification for the decision to proceed was that the Scheme would provide cheap quality fodder for cattle preventing traditional heavy calving losses in the dry season (Davidson 1972). A private dam on Arthur Creek (67.8 GL storage), a tributary of the Dunham was constructed to supply irrigation water to 10 farms each of approximately 400 ha. By 1969 one farm was operating and fattening cattle on an irrigated oat crop (Kelly 1971). The ORD was completed in 1972 forming Lake Argyle. In 1974 the Commonwealth government's cotton bounty was withdrawn, which saw the end of cotton in the Ord. Cotton failed due to high insect predation, and costs associated with transport, pesticides, fertilisers and in ginning (Graham Taylor 1982). Interestingly KRS had already experienced severe problems with insect pests (including those of cotton) for many years prior to the arrival of farmers (Davidson 1982). Currently there are trials of genetically modified cotton in the Ord River Irrigation Area (ORIA).

In 1994, a small sugar mill was constructed in the ORIA and produced its first batch of sugar in 1996 (KDC 2003). The area of land cropped has increased from approximately 4500 ha in 1991/92 to 11,774 ha in 2001/02, with the area being stable since 1996/97 (KDC 2003). Over that time period the value of crops has almost doubled from $32.5 million (1991/92) to between $56.6 and $67.5 million between 1996/97 to 2001/02 (KDC 2003). This compares to $488.5 million from Argyle Diamond Mines for 2001/02. Melons and sugar account for around 60% of the value of crops (KDC 2003). Business Review Weekly Magazine declared that the ORIA had 'come of age' and had outlived the white elephant tag (Treadgold 1992). Despite this optimism Hassall & Associates (1993) estimated that the ORIA had incurred a nett loss of $497 million (1990/91 values), and suggested that there was considerable potential for increased economic return if the area under irrigation was substantially expanded to utilise the currently under-utilised water resources. The size of ORD was always conceived as providing water beyond the requirements of Stage 1 developments (the current irrigated area) for future expansion. Increased economic viability of existing irrigated farms and the findings of Hassall & Associates (1993) led the Western Australian government in 1994 to decide to proceed with Ord Stage 2. Stage Two (64,276 Ha) developments consist of an expansion towards the Keep River (Weaber Plain, Keep River Plain and Knox Creek – 50,213 Ha) and onto the lower floodplain (Ivanhoe Plain, Mantinea Flats and Carlton Hill Plain – 14,063 Ha) to grow primarily sugar (Government of Western Australia 1994). Proponents for Stage 2 require details of water allocation and certainty of supply. Under current Environmental Legislation this has necessitated determination of water allocations for the environment. The environmental water requirements (EWRs) of the Lower Ord River have been the focus of recent research activities e.g. WRC (2003). The Water and Rivers Commission of Western Australia (WRC, now Department of Environment) produced a draft allocation plan in 1999 (WRC 1999) which was critiqued by Doupé and Pettit (2002). A change in proponents has allowed the allocation plan to be re-examined. At present 300-400 GL are used annually by irrigation, while full development of Stage 2 was estimated to require an additional 1235 GL per year (WRC 1999).

1.5 Aims

In Phase 1, the likelihood of algal blooms occurring was considered to be low and hence was assigned a low risk. As part of the Ord-Bonaparte project, a team from CSIRO modelled the response of the lower Ord River and estuary to changed catchment flows, and nutrients and sediments (Parslow *et al.* 2003). This provided the authors with an opportunity to contribute data to the model development and then use the use the quantitative model developed to better define the risk of algal blooms occurring in the Lower Ord River. The author's contribution was the collection of flow-weighted nutrient data and flows from KDD, Tarrara Bar, D4 and Dunham River.

The initial risk assessment in Phase 1, apportioned a high risk to irrigation return based on the large contributions to the river it made of nutrients (particularly FRP and NO_x). However this was tempered by high dilution rates and low hydraulic residence times believed to exist in the river, so that the overall risk of an algal bloom occurring was low. Initial assessments by WRC suggested that under some potential Ord Stage 2 water allocations, water levels in the river could drop sufficiently to reduce it a series of long pools (as happened prior to construction of the dams). The hydraulic residence time of the pools could be sufficient to allow algal blooms to develop with their associated impacts. The WRC modified their proposed allocations to irrigation to ensure that even at the lowest predicted river flows the hydraulic residence time within the pools would not exceed 4 days. Four days was considered the minimum time needed before algal blooms could form. This information was used in the Phase 1 assessment of the risks of algal blooms occurring.

This project aims to measure nutrient (N and P) and sediment loads and concentrations within the lower Ord River (KDD to Tarrara Bar for one year. Then provide this information to the OBP team for use in their productivity model of the lower Ord River and estuary. A series of alternate flow scenarios would then be tested on the model to provide a quantitative assessment of the likelihood of algal blooms occurring in the lower Ord River. Specifically the project aimed to:

- Establish flow gauging stations at Tarrara Bar, Dunham River (Flying Fox Hole) and D4 drain.
- Collect flow weighted data from these sites and manually from KDD for one year.
- Provide this data to the OBP team for use in their model development.
- Use the OBP model to predict the conditions under which algal blooms might occur in the lower Ord River.
- Assess the risk of algal blooms in the Lower Ord River from irrigation return flows.

2.0 Methods

Gauging stations were established at Dunham River (Flying Fox Hole), Tarrara Bar (Drovers Rest). An existing gauging station on D4 drain operated by Water Corporation was used to measure drain flows. Sheds were constructed at the three sites to house gas powered refrigerators. An Epic autosampler was installed inside each refrigerator. This was designed to maintain the collected samples at approximately 4^{o}C prior to collection. Solar panels were used to supply power to the system. Sheds were located on the levee for the river, at horizontal distances of up to 90 m to the sampling port (vertical height up to 17 m). Sheds were placed on stilts in areas of potential flooding (Flying Fox Hole). The distances that water samples had to be moved over, necessitated the installation of an auxiliary pump along the pipe. Autosamplers, depth sensors (Mindata 2100 gas pressure sensor (river sites), Unidata hydrostatic probe (D4)) and auxiliary pumps were connected to Campbell Data Loggers which were programmed using the WRC developed Planet software to collect flow weighted samples. Photographs of the sampling stations are shown in Figure 4. The autosampler systems were tested for 2 weeks at Canning River in Perth, prior to final installation.

The Planet software attempts to maximise accuracy of load estimations by determining the best way to trigger sampling to adequately capture changes in flow (as determined by changes in water depth – stage height). Initially the software will tend to over sample flow events; however once ‘trained’, a process typically taking a year in areas where no previous data exists, the software can provide sampling approaches that provide accurate load estimates and minimise sampling. The software will also provide an estimate of the error associated with the sampling program used.

Sampling was flow-weighted with frequency determined by the Planet software. Samples were emptied from the autosamplers at a maximum of 3-4 day intervals and were frozen for later determination of silica, total P and total N. Another 500 ml aliquot was filtered through 0.45 µm nitrocellulose filter paper and then frozen for later determination of TSS. Despite refrigeration, it was decided after 3-4 days dissolved nutrient fractions (i.e. FRP, NH_3 and NOx) would have altered from when originally sampled. It was proposed to test this hypothesis after initial test sampling and then adopt approaches (if needed) that would allow an expansion of the range of parameters measured to match those requested by the Ord Bonaparte team for their model. All samples were flown frozen back to Perth for analysis by the NATA registered Australian Government Analytical Laboratories.

a)

b) c)

Figure 4 **Photographs of sites where Autosampler sites have been established a) D4 drain (two photographs), b) Tarrara Bar and c) Flying Fox – Dunham River**

3.0 Results and Discussion

3.1 Trials and problems with the autosamplers

The gauging station at Tarrara Bar has been operational since 8/11/01, the Dunham station since 22/11/03 (although a rating curve is still needed). The D4 drain has had a gauging station on it between 27/8/98 and 29/6/03. The depth sensor at this station belonged to Water Corporation of Western Australia and was removed as part of the transfer of irrigation assets to the Ord Irrigation Cooperative (OIC). The OIC is in the process of replacing it and taking over monitoring of the drain outflows.

The D4 autosampler was operational between 16/12/03 and 17/2/04 and collected 50 flow-weighted samples. The Tarrara Bar autosampler collected 28 flow weighted samples between 9/3/04 and 22/3/04, unfortunately due to a logger malfunction the timing of most of the samples is not known. The autosampler at Flying Fox hole has not collected any data due to pumping problems. No samples were collected from downstream of KDD. The WRC conducts monthly grab samples at the M1 outlet; this was used to represent KDD output concentrations by Lund and McCrea (2001).

Installation of the autosamplers was delayed many times by staff shortages in the WRC Kununurra Office. The long gestation period for the project also meant that when it commenced it was no longer seen as a priority. Clearance was also needed from Indigenous Groups for the installation at the Flying Fox Hole site. The project eventually had to use consultants and contractors to complete the installations. Installation could not be undertaken in the wet season, due to problems accessing the sites. Despite checking in Perth, there were problems with the auxiliary pumps and Campbell loggers. In addition, as Campbell loggers are not routinely used in the Kimberley, there were also problems with staff using the loggers. The Campbell logger was used as the Planet software was designed specifically to program this particular brand. As a result of all these problems, little data was collected and the opportunity to collaborate on the OBP model had passed. Andrew McCrea of WRC is writing a report on lessons that have been learnt from the deployment of this type of sampling equipment in the Kimberley.

3.2 Analysis of autosampler data

The D4 drain autosampler was operational for two months in the wet season of 2003/2004. The Planet software triggered sampling in the D4 drain in a reasonable response to changes in stage height (Figure 5). There were several occasions when multiple maximums were recorded, many times when double samples were taken, and times when minimums missed the bottom of the hydrograph. This indicates that some adjustment of the parameters triggering sampling was required to gain a more representative set of flow-weighted samples. *Further work is required on programming the autosamplers to optimise sampling of the hydrograph*.

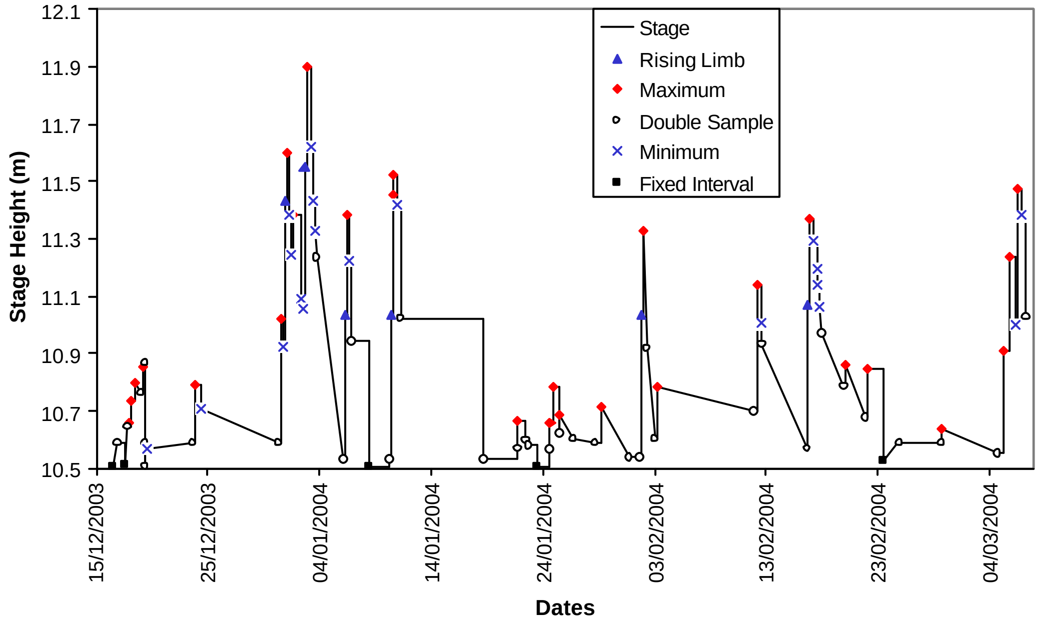
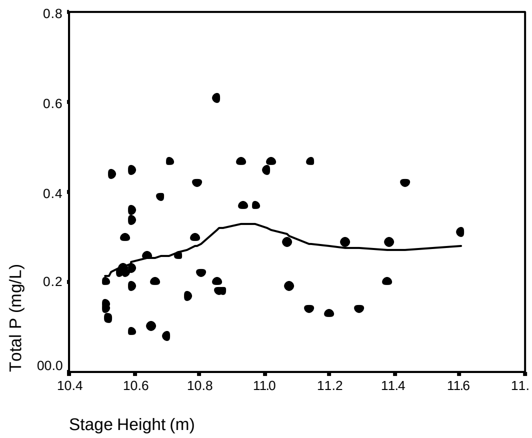


Figure 5 **Trace of D4 stage heights and the timing of sampling by the autosampler (15/12/03 to 7/3/04).**

No samples were collected between 1/1/04 and 4/2/04 for analysis. Flows have not yet been determined from stage heights. Given the relatively small dataset (n=49), there appears to be a no relationship between stage height and concentrations of Total P and Total N, TSS, and Silica (Figure 6). There were strong correlations between TSS and both Total P (r=0.813 P<0.0001) and Total N (r=0.720 P<0.0001) suggesting that particulates were important for transporting nutrients. This relationship was not seen with silica which had a small inverse relationship with Total P (r=-0.495 P<0.0001) and TSS (r=-0.407 P<0.01) and a non significant relationship with Total N (r=-0.190 P<0.897).

a)



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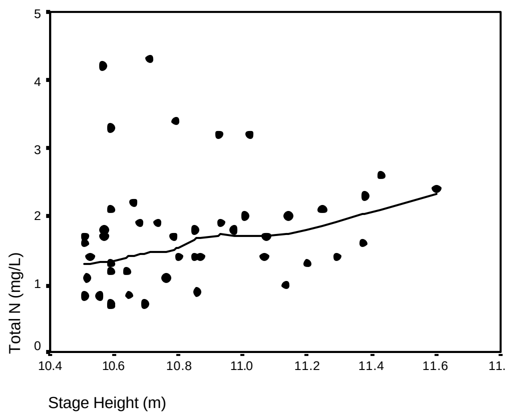

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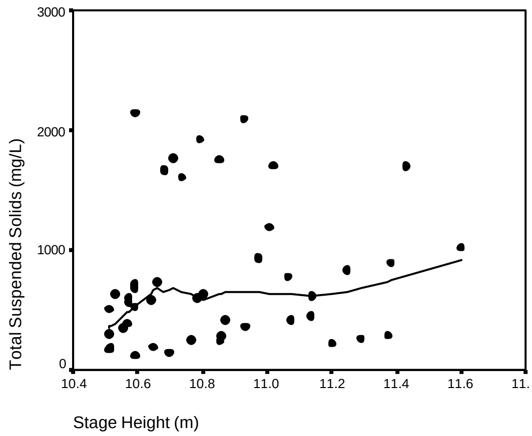

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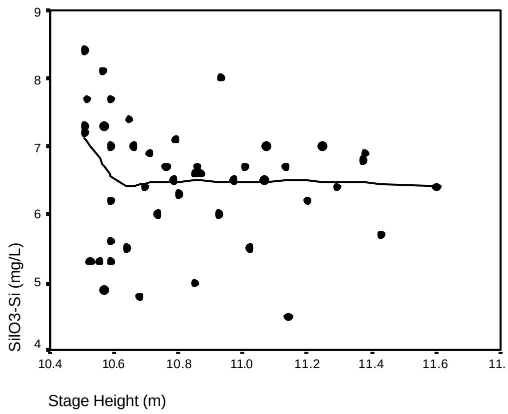
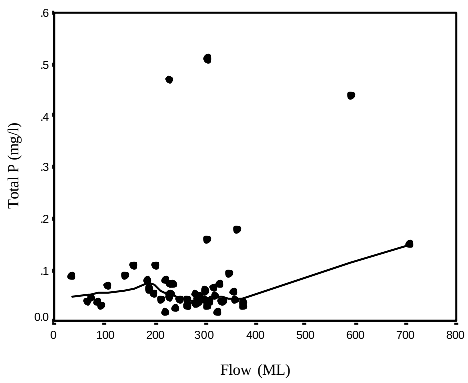


Figure 6 **D4 Stage heights (m) versus concentrations (mg L^{-1}) from the autosampler data of a) Total P, b) Total N, c) TSS, and d) Silica (LOWESS line of best fit shown)**

Nutrient concentrations remain relatively constant regardless of flow rates when regular grab samples are compared with gauged flows in D4 drain (Figure 7). This suggests that the loads determined for the drains by Lund and McCrea (2001) based on monthly grab samples are probably reasonable estimates. Occasional high concentrations were recorded although these do not appear to be associated with particular flow rates and probably reflect localised events (such as a fertiliser application) or sampling errors.

a)



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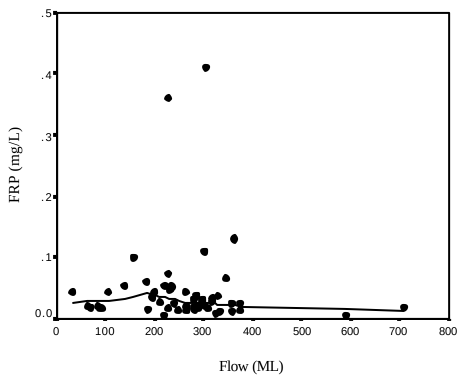

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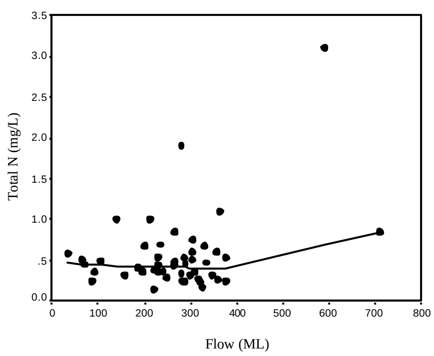

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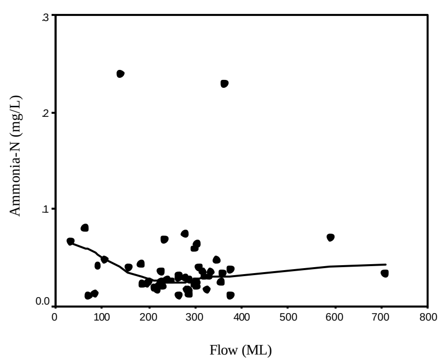


e) f)

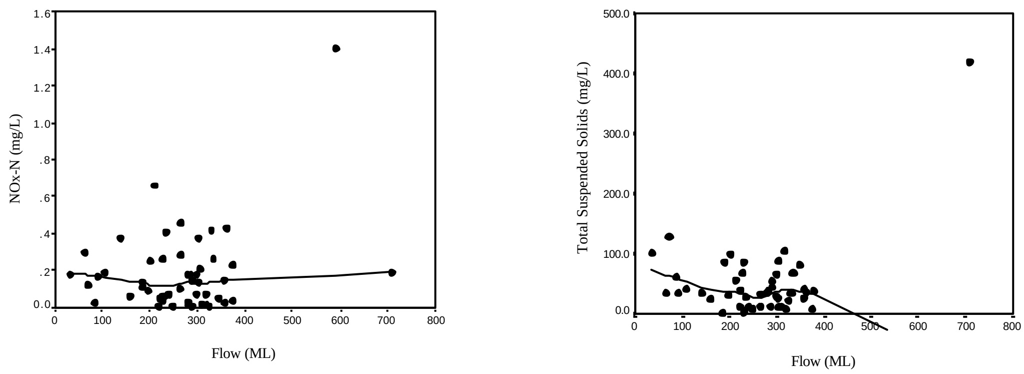


Figure 7 D4 Drain Flows (ML d^{-1}) versus concentrations of a) Total P, b) FRP, c) Total N, d) Ammonia, e) NOx (Nitrate/Nitrite), and f) Total Suspended Solids from 1998 to 2003 (n=50) based on monthly grab samples and gauged flows. (LOWESS fit line shown; Total suspended solids graph does not show one pair of data, Flow 591.7 ML and 2410 mg L^{-1})

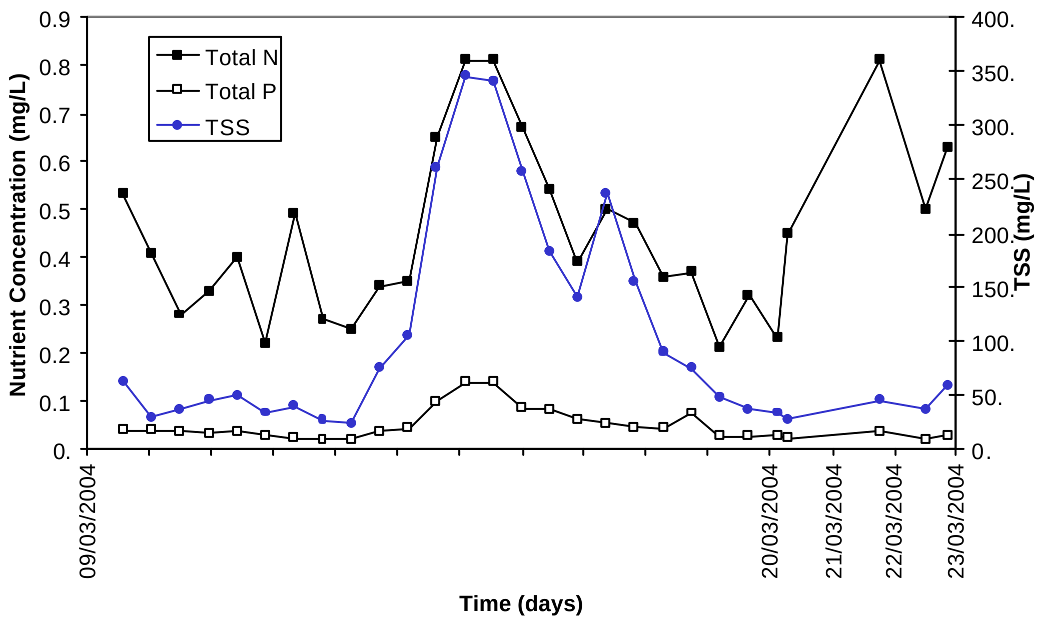
A visual comparison of the range of concentrations for Total P, Total N and TSS from the autosampler data (Figure 6) and the monthly grab samples (Figure 7) suggests that values are higher from the autosampler. The autosampler samples were taken during the wet season, which could potentially explain the discrepancy. There was no significant difference ($P>0.05$) between monthly grab samples and a subset of wet season monthly grab samples for Total P, Total N or TSS (Table 1). Total P and Total N data from the autosamplers were significantly different ($P<0.05$) to the monthly and monthly wet season grab samples, while for TSS the autosampler data was significantly different ($P<0.05$) to the monthly but not the wet season grab samples. These results suggest that 2003/04 wet season had unusually high concentrations of Total P and Total N compared to previous years or that the two sampling methods produced differing results. *It is recommended that an experiment is undertaken to compare the concentrations of TSS, Total P and Total N simultaneously between grab samples and autosampler collected samples to identify the source of any potential discrepancies.*

Table 1 Comparison of mean (± 95% CI) concentrations of Total P, Total N and TSS collected using an autosampler (December 2003 to February 2004), monthly grab samples (1998 to 2003) and wet season only monthly grab samples (December to February 1998 to 2003), at the D4 drain. Means with similar superscripts were not significantly (P>0.05) different using a t-test.

	Autosampler	Monthly Grab	Wet season Grab
Total P (µg L^{-1})	265^{b}±37 (n=49)	88^{a}±25 (n=63)	99^{a}±79 (n=11)
Total N (µg L^{-1})	1734^{b}±243 (n=49)	579^{a}±116 (n=67)	709^{a}±497 (n=12)
TSS (mg L^{-1})	728^{a}±164 (n=49)	90^{b}±71 (n=67)	311^{ab}±474 (n=11)

The autosampler at Tarrara Bar was operational between the 9/3/04 and 22/3/04, however a logger malfunction prevented the samples that were collected from being time stamped. Given the paucity of data collected by the project, the data was still examined. The nutrient concentrations recorded over the sample period have been plotted evenly spaced over the sampling period in Figure 8. This is likely to overemphasis spikes in the data, in terms of their longevity. There was an event that resulted in a substantial increase in TSS concentrations and similar probably related increases in Total P and Total N. Total P and TSS concentrations are strongly correlated (r=0.925; P<0.001) while Total N and TSS were correlated (r=0.686 P<0.001), and Total N and Total P were correlated (r=0.679 P<0.001). Silica remained relatively constant during the period. Limited time stamps on samples indicate that the event occurred prior to the 20/3/04, when flow can generally be seen to be increasing. The variability in nutrient and TSS concentrations seen during a period of relatively constant flow, suggest that the load estimates at Tarrara Bar by Lund and McCrea (2001) are probably relatively inaccurate as they are based on monthly grab samples.

a)



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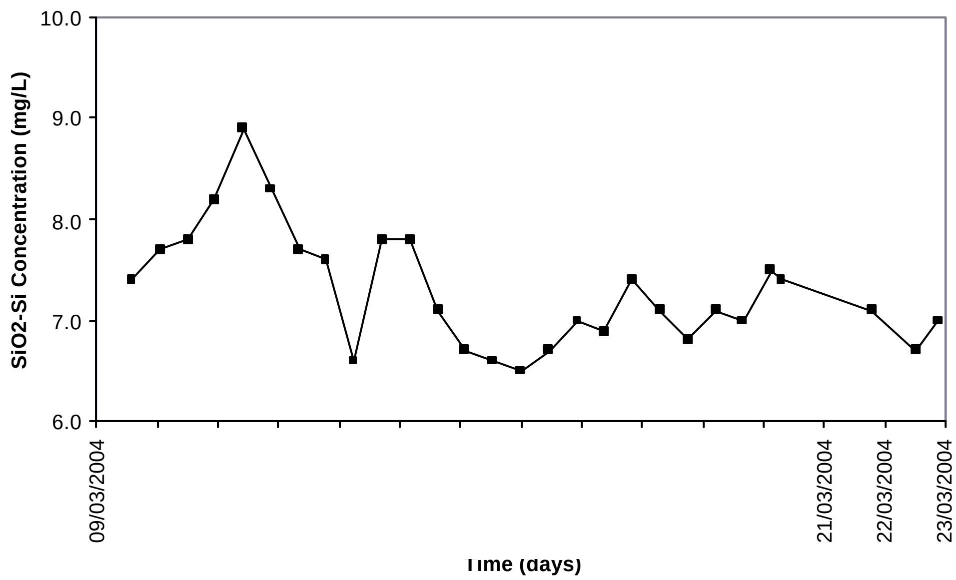

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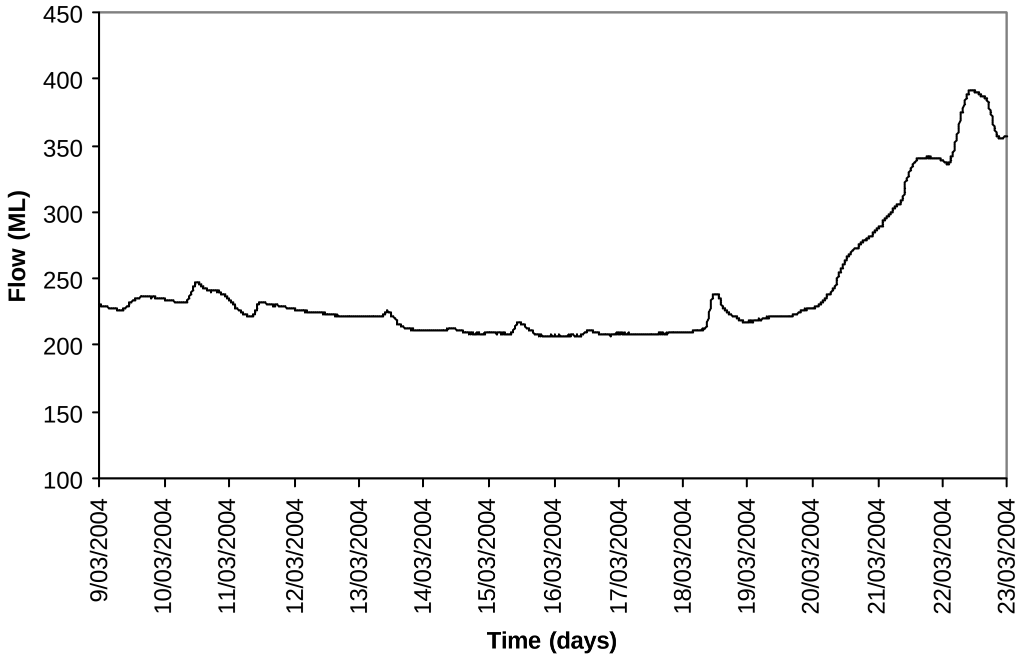


Figure 8 **Concentrations of a) Total P, Total N, Total Suspended Solids, b) Silica, taken by the autosampler at Tarrara Bar between 9/3/04 and 22/3/04, and c) 10 min interval flows (ML) recorded at the gauging station. Times where samples were not time stamped due to logger failure have been removed, concentrations have been evenly spaced for convenience.**

3.3 Gauged flows

The Dunham River is a seasonal river, which dries to a series of pools during the dry season. The Dunham River pools at the confluence with the Ord River during low flow periods. This pool receives irrigation return from Packsaddle Creek which drains the Packsaddle Plains Irrigation Area. The Dunham River has been gauged (Station 809321) in the upper reaches, since 1975. This gauging station accounts for approximately a third of the catchment. Given the significance of Dunham River to variability in lower Ord River flows, accurate flow estimates are needed close to the confluence. Flying Fox Hole was selected for this gauging station, as it is above the confluence pool, accessible (limited in wet season), and is approximately 12 km upstream of the confluence. A rating curve for the gauging station has not yet been completed. Flying Fox Hole is located in a dry season pool. A stage height of 10.228 m is the height of the bubbler unit (depth sensor) and represents when flow stops and an isolated pool forms. There was little wet season flow in 2002/03 and moderate flow in 2003/04 (Figure 9).

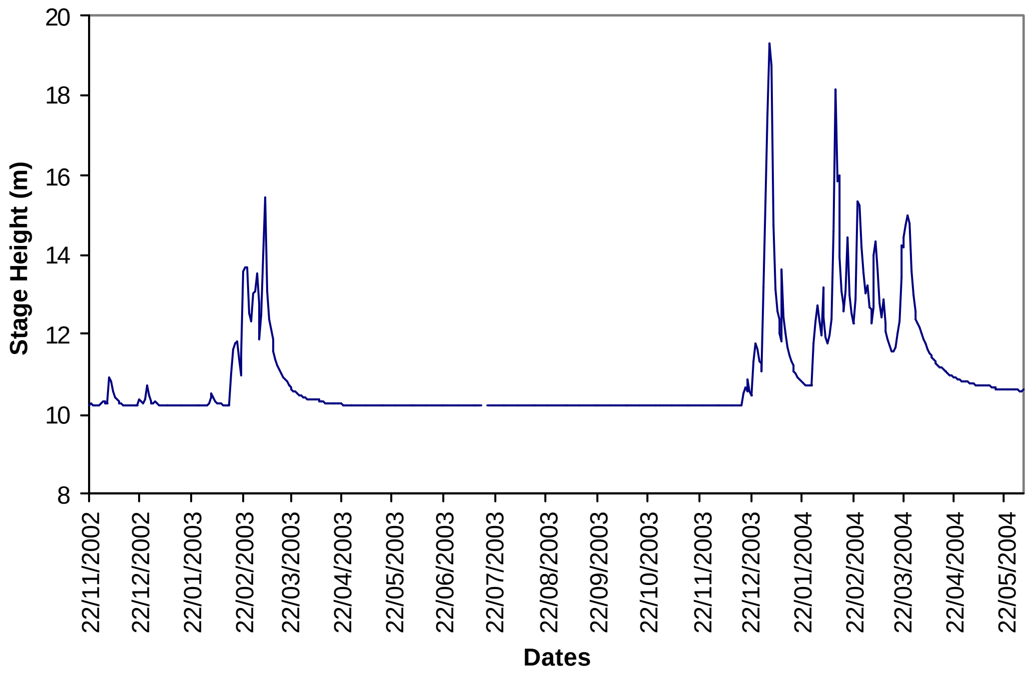


Figure 9 **Stage heights recorded at the Flying Fox Hole (Dunham River gauging station 22/11/02 to 22/5/04. No rating curve is currently available for Flying Fox Hole. A stage height of 10.228 m indicates no flow in the river.**

The daily flow at Tarrara Bar should approximate the sum of flows from the drains (D1, D2B, D2, D4 and D7), KDD releases, Dunham River Gauging Station, lower Dunham River, Spring and Valentine Creeks, direct rainfall, evaporation (loss) and groundwater inflow (Figure 10). Lund and McCrea (2001) estimated the combined contribution of the Creeks at <10 GL per month during December though to April. The contributions of direct rainfall and loss through evaporation can be estimated by using average rainfall and pan evaporation rates for KRS and multiplying by the river length (approx. 28 km) and width (approximately 100m, WRC 2003). Pan evaporation can be corrected for water bodies using an approximation based on average evaporation rates of Lake Argyle (2,130 mm) compared to pan evaporation of 3,000 mm i.e. factor of 0.71 (Ruprecht and Rodgers 1999). The result is a net difference of <0.5 GL per month, positive in the wet and negative in the dry. The lower Dunham flows are not known (until Flying Fox Hole is rated), but can be approximated based on catchment area. The lower Dunham catchment is 2600 km^2 compared to 1688 km^2 for the gauged upper Dunham River. Therefore lower Dunham flows should be approximately 1.54 times larger than the upper Dunham flows, a more conservative figure than the 1.92 multiplier used by WRC (2003). In Figure 11, there are large discrepancies between KDD and Tarrara Bar measures of daily flow following periods of high flow and in the late dry season of 1999, 2000 and 2001. The simple approximation used to estimate Dunham River flows produces some anomalous spikes on occasion as might be expected. It does not appear as if poor estimation of Dunham River flows is likely to account for the major discrepancies seen (Figure 12). In 2002, approximations between cumulative inflows and Tarrara Bar flows are very close. The unavailability of 2003 and 2004 Dunham River flows make it impossible to determine whether this trend continues. *It is recommended that* *the rating curve for Tarrara Bar and the estimation method for KDD releases should be checked for accuracy, and pre-2002 flows recalculated.*

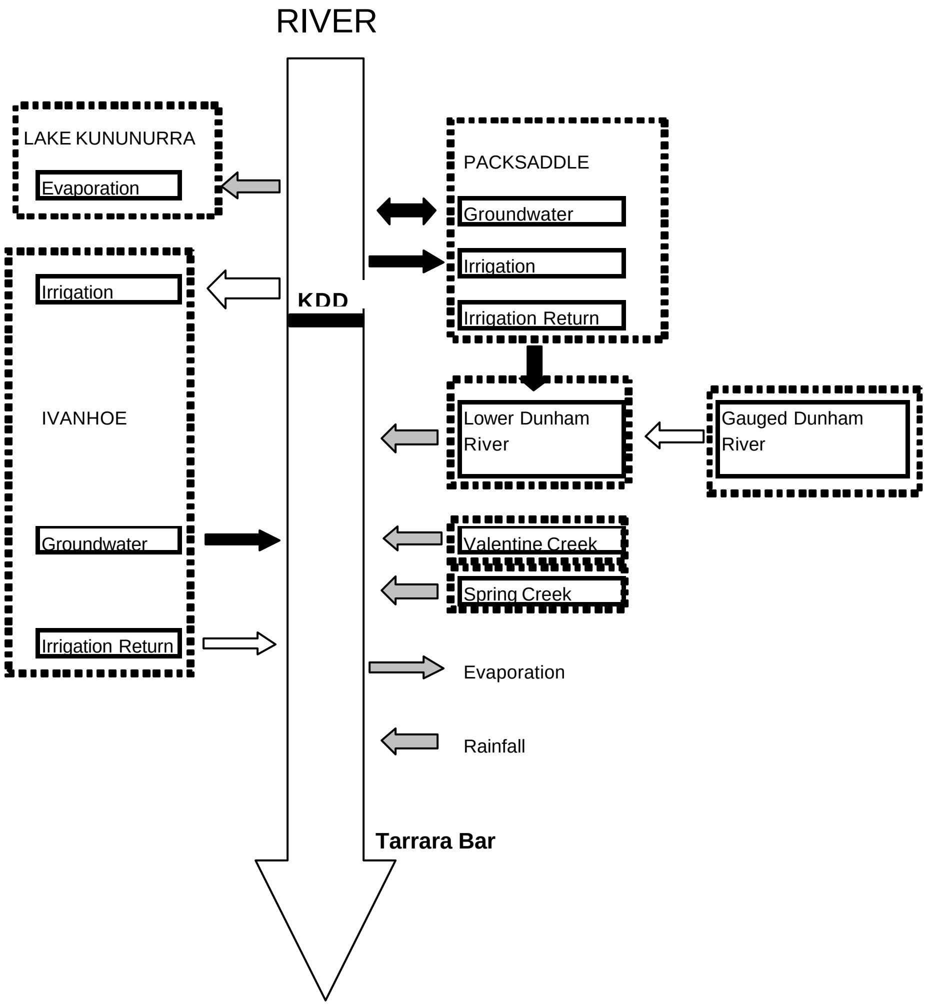


Figure 10 **Diagram of major water movements in the lower Ord River (KDD to Tarrara Bar) (black arrows are unknown components, grey arrows are estimated and white arrows are measured).**

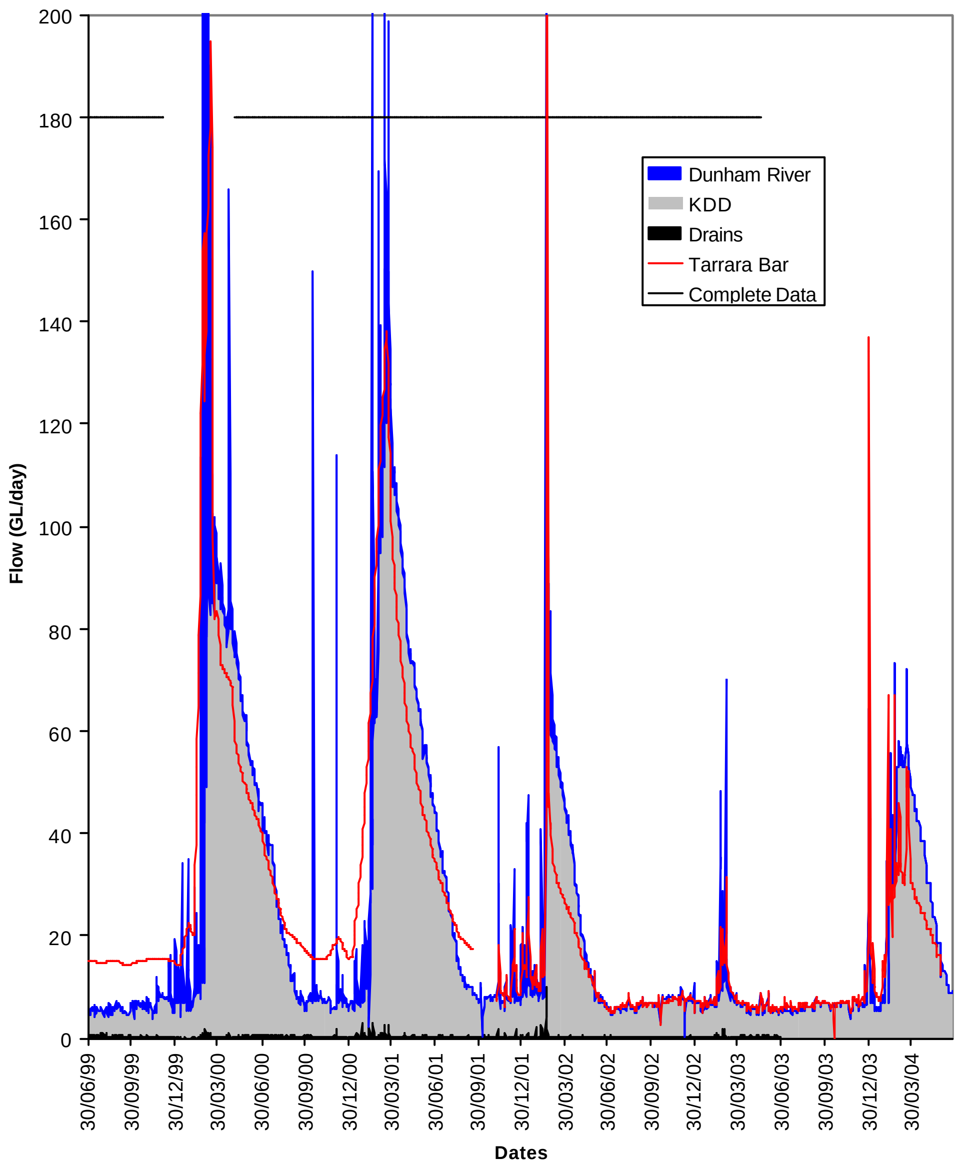


Figure 11 **Cumulative flows (KDD releases, Drains and Dunham River) into the Lower Ord River compared to gauged flows at Tarrara Bar. Dates with complete datasets for all inputs are highlighted by the red line (Missing Data: 1999/00 - D4 drain, 2003 – Dunham River & Drains). Lower Dunham flows approximated as 1.54 times upper gauged flows.**

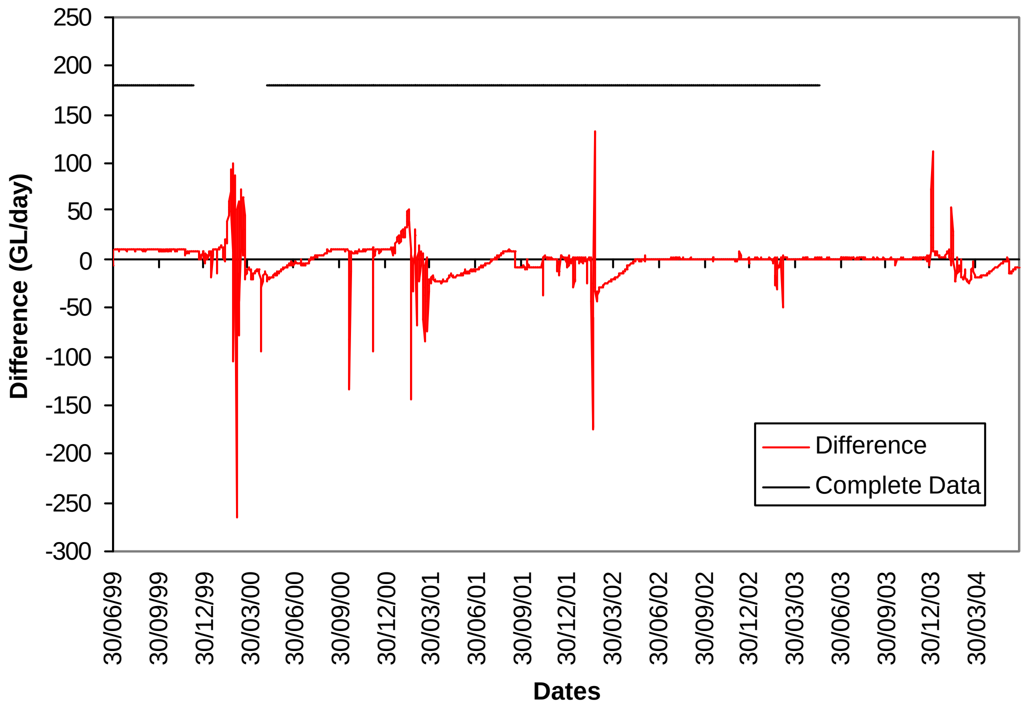


Figure 12 **Difference between cumulative flows (KDD releases, drains and Dunham River) and flows measured at Tarrara Bar. Dates with complete datasets for all inputs are highlighted by the red line (Missing Data: 1999/00 - D4 drain, 2003 – Dunham River). Lower Dunham flows approximated as 1.63 times upper gauged flows.**

4.0 Assessing the risk of algal blooms

Risk in ERA is commonly defined as the product of the likelihood/probability of the hazard occurring and the consequence if that hazard occurs. An important first step is to define the risk we are assessing.

The key value that we aim to protect in the lower Ord River is the health of the river. This health relates to its current flow condition rather than a pre-regulation state. The effects that algal blooms could have on this value and a series of endpoints that could be used to assess the risks to the value are shown in Table 2. It is also necessary to define an algal bloom. There is no single uniform definition of what an algal bloom is across Australia with each state having different criteria. In Western Australia, an integrated algal sample with 15,000 cells mL^{-1} (cell size 10-20 µm diameter) is considered to be an algal bloom – a visible colouring of the water (WRC 1998). The trigger however varies considerably with the degree of toxicity, purpose the water is used for and the size of the alga. For example, a bloom of *Microcystis* is considered to occur when cell counts reach 20,000 cells mL^{-1}, however if the water was used for drinking, a management response would occur at 500 cells mL^{-1}. For the purpose of this study, blooms will be defined as follows:

- Level 1, a bloom of management interest occurs at a cyanobacterial count of >500 cells mL^{-1},

- Level 2, a low level bloom that requires a management action will be taken as an integrated cell count of >5000 cells mL^{-1} (>4 µg L^{-1} chlorophyll *a*[1]), and
- Level 3, a severe bloom as >15,000 cells mL^{-1} (>10 µg L^{-1} chlorophyll *a*).

Table 2 **Ecological effects of algal blooms in the lower Ord River and potential assessment endpoints that could be used to assess the risks to the river health.**

Ecological Effects	Assessment endpoints
Loss of biodiversity due to poor water quality	• Reduction in the diversity macroinvertebrates and fish • Increased abundance of selected (undesirable) taxa of macroinvertebrates and fish. • Reductions in the cover and productivity of submerged macrophytes in the river. • Reductions in the abundance of freshwater and saltwater crocodiles
Loss of aesthetic/recreation values	• Reduction in game fish (i.e. Barramundi) • Reduction in tourism involving the river
Loss of stock watering points	• Death of stock due to toxicity

The risk of algal blooms occurring in the lower Ord River will be examined, using existing data, and considering the probability/likelihood and consequences separately.

4.1 Probability/Likelihood

Three areas will be considered as possible locations for the occurrence of algal blooms, these are the Dunham River pool (confluence to Flying Fox Hole), the lower Ord River (KDD to Carlton Crossing) and Lake Kununurra. The upper Ord River and Dunham River were excluded as they have unregulated flows and do not receive irrigation return. Lake Argyle is extremely large and poorly understood and so algal blooms are considered to be sufficiently unlikely as to require investigation here. However there has been considerable interest in developing aquaculture within Lake Argyle (LeProvost Dames & Moore 1999; Morrissy 1983), primarily focusing on Barramundi. Plans are to site the aquaculture facilities close to the dam wall, allowing nutrients to be withdrawn from the lake by hydroelectric discharges. The Ord River between ORD and Lake Kununurra, has a relatively steep gradient and velocities are unlikely to be conducive to algal development. The selected locations will be examined using data from sites included in the WRC monthly monitoring program:

[1] Chlorophyll *a* concentrations were determined using the estimated chlorophyll *a* content per cell of *Cylindrospermopsis raciborskii* of 0.15 pg; 5,000 cells mL^{-1} is therefore equivalent to 0.76 µg L^{-1} of Chlorophyll *a* and 15,000 cells mL^{-1} is equivalent to 2.25 µg L^{-1} (Bormans *et al*. 2004). Chlorophyll *a* values for the algal bloom levels have been rounded up to allow for variability in chlorophyll *a* content between species.

Lower Ord River	**Ivanhoe Crossing (OIVANX),** downstream of KDD and Dunham River confluence, receives limited irrigation return
	Tarrara Bar (OTARB), situated downstream of all the current irrigation areas
	Carlton Crossing (OCARLX), situated above the peak of tidal influence in the river
Dunham River	**Dunham Road Bridge (ODRRB),** situated close to the confluence with the Ord River and in the dry season pool.
Lake Kununurra	**Maxwell Plains (OMAXP),** considered by WRC as a reference site, not influenced by irrigation and located at upstream end of Lake Kununurra
	Lily Creek Lagoon (OLCLAG), lagoon formed by creek where it joins Lake Kununurra, potentially influenced by urban development.

Reynolds and Descy (1996) in a review of phytoplankton production and biomass in large temperate rivers suggest that reservoirs and backwaters act as sources of phytoplankton to rivers. As many of these species are essentially lentic, they do not survive for long in the normal river flow. The growth of survivors is regulated by the following key factors:

1. Suitable water temperature
2. Water clarity (i.e. adequate light penetration)
3. Suitable nutrient concentrations
4. Suitable hydraulic residence time

These factors will now be examined for the lower Ord River.

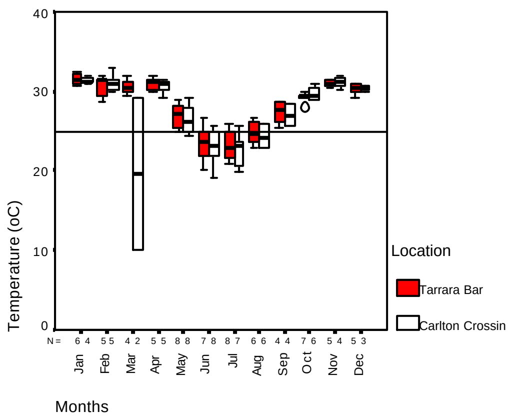
4.11 Water temperature

Water temperature has two potential impacts on the likelihood of algal blooms, one is the role it plays in the growth rate of algae, particularly cyanobacteria, and secondarily its importance in stratification.

The water temperatures of the Ord River varies between 21.5 and 31.9 ^{o}C at Tarrara Bar as recorded by WRC regular monthly monitoring from 1998 to 2004. These temperatures lie within the optimum growth ranges for a number of bloom-forming cyanobacteria, including *Anabaena* and *Microcystis* (Robarts and Zohary 1987). These temperatures therefore should not limit algal growth. Fabbro and Duivenvoorden (1996) found that very similar temperature ranges were conducive to formation of a bloom of the Cyanobacterium *Cylindrospermopsis raciborskii* in the tropical Fitzroy River (Queensland). The 1991 bloom of *Anabaena circinalis* in the Barwon-Darling River occurred at water temperatures of >25^{o}C (Bowling and Baker 1996). Bormans *et al*. (2004) suggest that one difference between temperate and tropical cyanobacterial blooms occurring in Australian impoundments is the species involved, typically *Cylindrospermopsis*, *Limnothrix* and *Planktolyngbya* in the tropics, but *Anabaena* and *Microcystis* in temperate regions. Hawkins (1996) suggested that the dominance of *Cylindrospermopsis* in tropical waters was because of their high growth rates at temperatures over 25^{o}C compared to dominance ranges of 20 to 24^{o}C for *A. circinalis*.

The threshold for cyanobacterial algal blooms has been set at temperatures >25°C, as this is the minimum temperature for tropical bloom forming cyanobacteria. This threshold does not exclude the possibility of blooms occurring at lower temperatures, if other conditions are favourable. It can be seen that in the lower Ord River temperatures not meeting the threshold occur between June and September, May and August for the Dunham River, and May to August for Lake Kununurra (Figure 13).

a)



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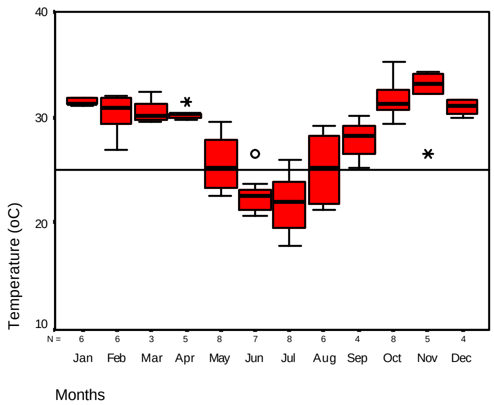

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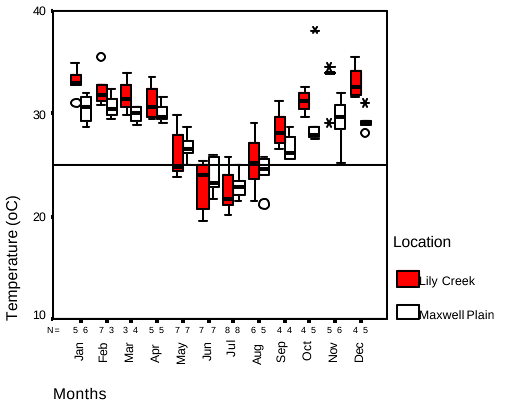


Figure 13 **Boxplots of water temperatures recorded monthly (1998 to 2004) at a) Lower Ord River, b) Dunham River and c) Lake Kununurra. Central bar is the median, the box is the interquartile range, whisker (T) represents largest value within 1.5 interquartile ranges of the box, o and * represent outliers and extreme values respectively; reference line is at 25°C**

In March 2000, a water temperature of 10.2°C was recorded at Carlton Crossing, this exceptionally low temperature occurred at the time of flooding around Carlton Crossing. Mean annual water temperatures vary little between localities, with the possible exception of Lily Creek, which is slightly warmer (Table 3).

Table 3 **Mean (± 95% confidence intervals) water temperatures at selected locations between 1998 and 2004 taken by WRC.**

	Water Temperature (°C)	n
Maxwell Plains	27.4±0.8	65
Lily Creek	28.5±1.1	65
Dunham River (road bridge)	27.9±1.0	70
Ivanhoe Crossing	27.3±0.8	66
Tarrara Bar	27.9±0.8	70
Carlton Crossing	27.0±1.0	62

Water temperature was significantly different between Ivanhoe Crossing and Tarrara Bar ($\log_{10}$ transformation, t=4.456, P<0.001) but not between Ivanhoe Crossing and Tarrara Bar and Carlton Crossing ($\log_{10}$ transformation, t= -1.571, P=0.122). As KDD releases bottom water from Lake Kununurra, then this is likely to be cooler than surface water. WRC (2003) found that Lake Kununurra (maximum depth <12 m) was temperature stratified in the dry season and in a low flow wet season (Table 4). No stratification was recorded at the same times in the Carlton Crossing pool at House Roof Hill (maximum depth <6 m). Stratification was also evident in the Dunham River, with up to 2°C differences over depths to 5 m. There was no clear relationship between stratification in the Dunham River pool and flows.

Table 4: **Stratification events as recorded in WRC (2003) for Lake Kununurra and the Dunham River (~55 km from confluence, in a pool), showing average monthly flows (from ORD and Spillway discharge for Lake Kununurra, and Dunham River Gauging Station (809321)).**

Date	Temperature difference top to bottom of water column (°C)		Average monthly discharge ($m^3 s^{-1}$)		Comments
	Lake Kununurra	Dunham River	Lake Kununurra	Dunham River	
September 2000 (dry)	2	2 (2m depth)	165.0	0.6	
June 2001 (wet)	<1	2 (6m depth)	554.5	1.7	Lake not stratified
November 2001 (dry)	6	1 (2m depth)	80.2	6.5	Lake epilimnion down to 1m, hypolimnion from 6m. River flow very high due to isolated storm event.
June 2002 (wet)	2	<1 (4m depth)	102.8	0.8	Lake epilimnion down to 2m, hypolimnion from 4m. River not stratified

Stratification of river pools has been found to be one of the principal drivers contributing to algal blooms in many Australian temperate and tropical rivers (Bormans *et al.* 2004; Fabbro and Duivenvoorden 1996; Maier *et al.* 2001; Webster *et al.* 2000). Flow velocities of <0.05 m s^{-1} (and low wind mixing) were required for stratification to occur and algal blooms (e.g. *A. circinalis*) tended to occur if the stratification remained for >5 days (Mitrovic *et al.* 2003). The high temperatures, low turbulence waters, reduced turbidities and long residence times allowed algal populations to bloom and particularly favoured cyanobacteria.

4.12 Water clarity

Turbidity in the water reduces light availability and therefore growth of cyanobacteria (e.g. Geddes 1988). In the Fiztroy River in Tropical Queensland, turbidities under 20 NTU were able to support a bloom of cyanobacteria (Fabbro and Duivenvoorden 1996). Bowling and Baker (1996) recorded substantial blooms (>30 000 cells mL^{-1}) of *A. circinalis* in the Barwon-Darling River at turbidities between 30 and 40 NTU. Hart *et al.* (1997, as cited in ANZECC and ARMCANZ 2001) in a decision tree for assessing the risk of cyanobacterial blooms in a lowland river used a turbidity threshold of 30 NTU. The light climate of the Ord River has not been studied, so the relationship between light attenuation and turbidity has not been quantified. However the pools of the Lower Ord River are <7 m deep at flows of 50 $m^3 s^{-1}$ (WRC 2003) and much of the river bed supports large beds of submerged macrophytes. This suggests that light is probably not a limiting factor except when Spillway Creek and/or the Dunham River flow bringing TSS into the lower Ord River.

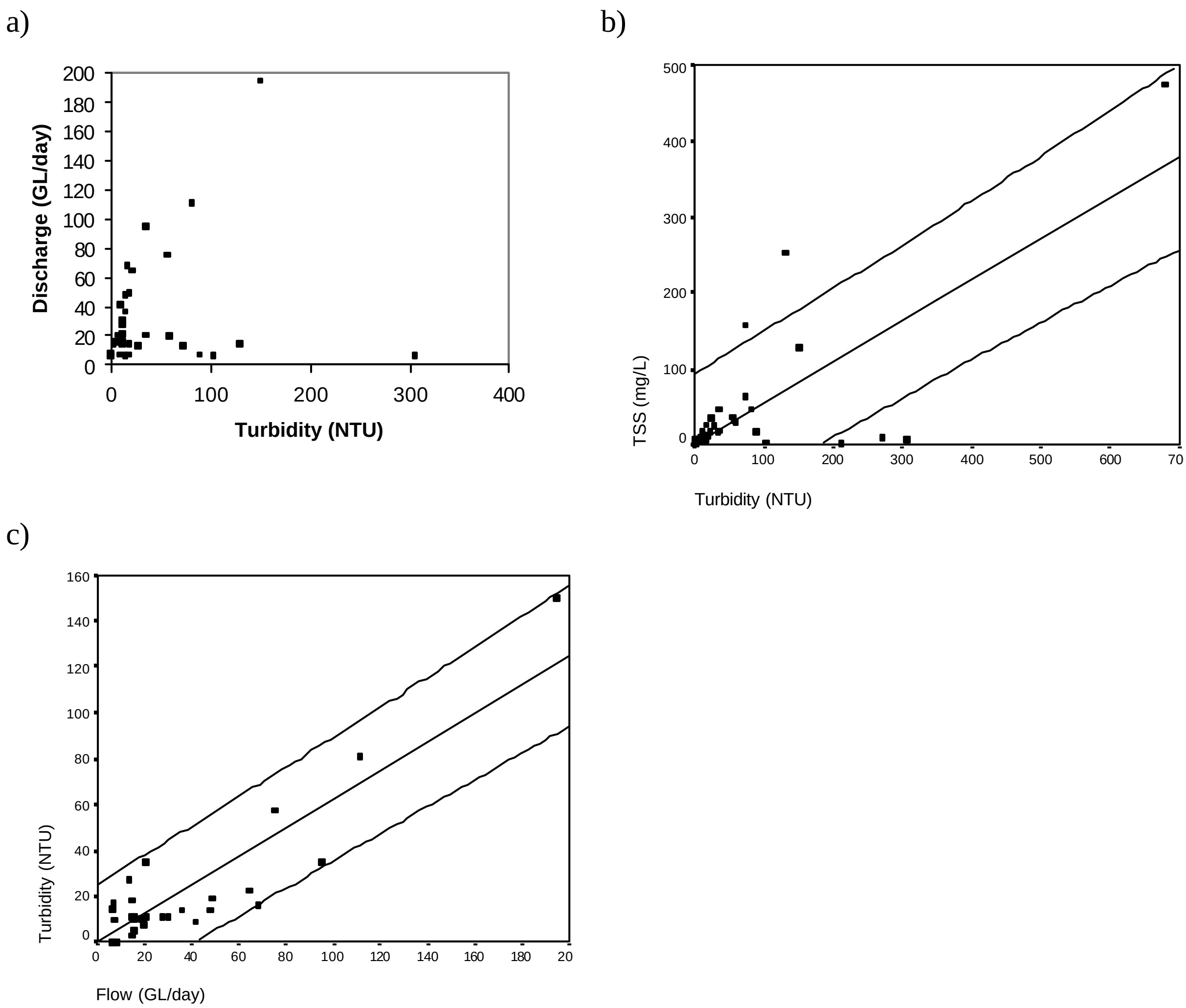
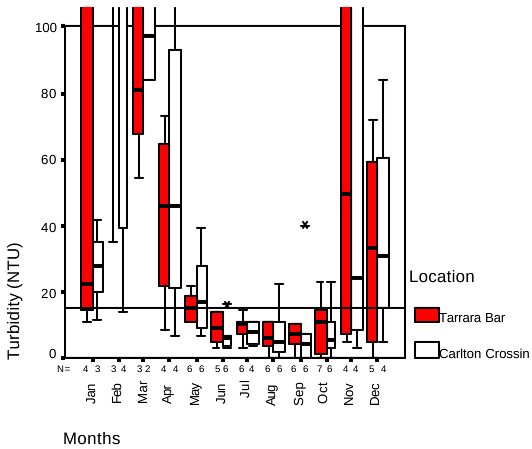


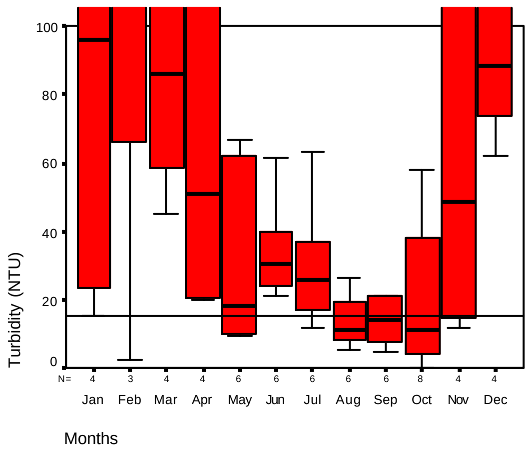
Figure 14 **Turbidity recorded by WRC during regular monthly sampling at Tarrara Bar 1998 to 2004, a) turbidity versus discharge, b) turbidity versus TSS (regression line (centre) and 95% CI shown), and c) discharge versus turbidity (outliers removed, regression line and 95% CI shown)**

When discharge is plotted against turbidity there is generally a strong positive relationship, however a number of high turbidities are recorded at very low flows (Figure 14a). Plotting turbidity versus TSS (Figure 14b) shows a strong linear relationship ($r=0.764$, $n=56$, $P<0.05$), however the samples outside the 95% confidence intervals are also those with high turbidities at low flows. This suggests that instrument/sampling error was responsible for these results.

The lower Ord River generally has low turbidity (<15 NTU) during the dry season, but this can increase substantially in the wet season (Figure 15a). If a threshold for light limitation of 15 NTU is used, then the months where most samples are below the threshold are in the lower Ord River - June to September, Dunham Pool - August to October, and in Lake Kununurra - all months at Lily Creek and May to February for Maxwell Plains.

a) b)





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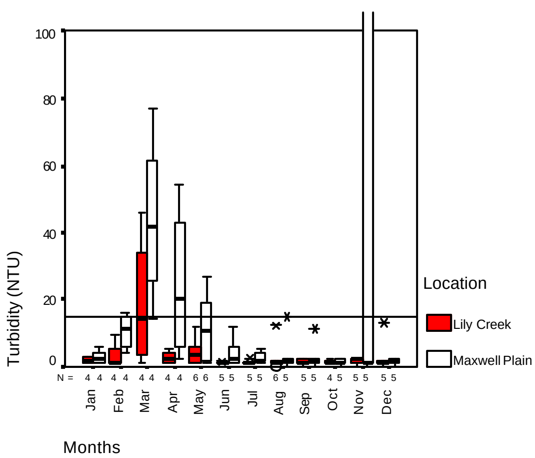

Figure 15 **Boxplots of turbidity recorded monthly (1998 to 2004) at a) Lower Ord River, b) Dunham River and c) Lake Kununurra. Central bar is the median, the box is the interquartile range, whisker (T) represents largest value with 1.5 interquartile**

ranges of the box, o and * represent outliers and extreme values respectively; reference line is at 15 NTU

Increasing the threshold to 30 NTU does not substantially alter the months found below the threshold. Furthermore as the short term (i.e. days) variability in turbidity is unknown, a low threshold allows for a high degree of variability in turbidities while keeping below a level likely to be light limiting (i.e. 30 NTU).

Mean turbidities and TSS concentrations were low in Maxwell Plains and Lily Creek Lagoon (Table 5). Contributions from the high mean turbidites and TSS concentrations in the Dunham River and some drains probably account for the increases seen at Ivanhoe Crossing. There was a significant difference (P<0.0001) in both turbidity and TSS between Ivanhoe Crossing and Tarrara Bar highlighting the contributions from the D4/D7 and D2/D2B drains (Table 6). There appears to have been some sedimentation of suspended loads between Tarrara Bar and Carlton Crossing.

Table 5 **Mean (± 95% confidence intervals) concentrations for turbidity and TSS measured at selected localities between 1998 and 2004 based on monthly data collected by WRC. Concentrations marked below detection level have been included in the analysis, assigned a value equal to the detection limit)**

	TSS (mg L^{-1})	n	Turbidity (NTU)	n
Maxwell Plains	7.7±4.2	73	16.0±10.9	57
Lily Creek	2.6±0.9	74	7.8±8.7	57
Dunham River	40.4±14.1	79	63.8±26.7	61
Ivanhoe Crossing	12.2±5.0	72	29.2±15.0	60
Tarrara Bar	26.9±14.9	76	48.1±26.6	59
Carlton Crossing	18.1±7.4	68	35.5±17.0	55

Table 6 **Results of paired (taken within 24 h) t-test or Wilcoxon signed ranks test for Turbidity and TSS taken at Ivanhoe Crossing and Tarrara Bar by WRC at monthly intervals between 1998 and 2004. Transformations used to achieve normality as determined by Kolmogorov-Smirnov test (P<0.05). Concentrations marked below detection level have been included in the analysis, assigned a value equal to the detection limit)**

Parameter	Transformation	n	Test value	Sig (2 tailed)
TSS	Log10	69	t= 6.303	0.0001 s
Turbidity	Log10+1	57	t= 5.384	0.0001 s

As turbidity is related to flow (Figure 14a), what flows are associated with 15 NTU in the lower Ord River? If the outliers are removed, this produces a significant (P<0.05) regression through the origin (y=0.623x, r^2=0.871; Figure 14c). Using inverse prediction, a turbidity of 15 NTU occurs at discharges of 16.8±3.2 GL d^{-1} (95% CI) or 194.8±43.1 m^3 s^{-1} (Zar 1999).

4.13 Nutrients

The lower Ord River has average nutrient concentrations that exceed the ANZECC & ARMCANZ (2001) default trigger values for tropical lowland rivers (Table 7). However when the number of excluded values that were below detection limits are considered, it is NOx[2] and NH_3 concentrations that appear to naturally exceed these default trigger values. It is possible that these concentrations are higher through the impact of the ORD dam or through grazing in the upper catchment. Irrigation drainage return from Packsaddle Plains is probably responsible for the elevated nutrient concentrations seen in the Dunham River. Releases from the Dunham River and minor irrigation drains probably account for the slight increases in nutrient concentrations that can be seen at Ivanhoe Crossing compared to those sites above KDD. However it is possible that passage of water through Lake Kununurra might increase nutrient concentrations. Between Ivanhoe Crossing and Tarrara Bar the entry of drainage from D2/D2B and D4/D7 drains accounts for the increases in concentrations seen (see Lund and McCrea 2003). Average nutrient concentrations are similar between Tarrara Bar and Carlton Crossing, possibly indicating that grazing along this section of the river has relatively little impact on river nutrient levels.

Table 7 **Mean ± 95% C.I. (number samples below detection limits/n) nutrient concentrations (μg L^{-1}) for 1998 to 2004 sampling of selected areas by WRC, and ANZECC and ARMCANZ (2001) trigger values for lowland tropical rivers. Samples in WRC data that were below detection limits were assigned the value of the detection limit.**

	Total N	NOx	NH_3	Total P	FRP
Detection Limit	25	10	10	5	5
Maxwell Plains	180.7±26.0 (4/74)	23.9±6.0 (43/74)	24.2±4.9 (10/70)	13.7±3.2 (10/70)	7.7±1.1 (31/74)
Lily Creek	321.5±34.0 (0/75)	10.7±1.1 (71/75)	23.8±2.6 (7/75)	14.9±2.5 (4/71)	6.0±0.4 (43/75)
Dunham River	541.1±109.2 (0/79)	142.2±80.4 (27/79)	51.6+11.8 (5/79)	48.7±6.7 (0/75)	18.4±2.9 (5/79)
Ivanhoe Crossing	203.3±28.4 (3/72)	29.9±10.4 (22/72)	27.3±5.9 (9/72)	16.6±2.9 (5/68)	7.8±1.4 (25/72)
Tarrara Bar	232.6±25.7 (1/76)	38.4±8.8 (16/76)	21.5±2.4 (9/76)	24.3±4.8 (0/72)	10.6±1.9 (18/76)
Carlton Crossing	212.4±23.4 (1/68)	25.9±5.3 (26/68)	26.7±4.9 (6/68)	22.2±3.1 (0/64)	9.3±1.2 (13/68)
ANZECC & ARMCANZ (2001)	200-300	10	10	10	4

Concentrations of FRP are typically higher during the dry season (Figure 16) while DIN (NOx + NH_3) is generally higher in the wet season, except in the Dunham River which shows a similar pattern to FRP. The ponding of the Dunham River in the dry season, coupled with inputs from Packsaddle Plains irrigation might account for the buildup of DIN in the water. Irrigation drainage return appears to account for the overall increase in concentrations of DIN between Maxwell Plains and Tarrara bar. Irrigation drainage is the most likely explanation for the high FRP concentrations seen in the dry season at Tarrara Bar, Carlton Crossing and Dunham River and the generally higher concentrations at these sites compared to sites above KDD. There is a suggestion that FRP concentrations were higher in the dry season at the sites above KDD, this might be due to stratification in the lake causing internal release.

a) b)

[2] All reported nutrient concentrations are based on the amount of N or P as in NOx-N, NH_3-N and FRP-P

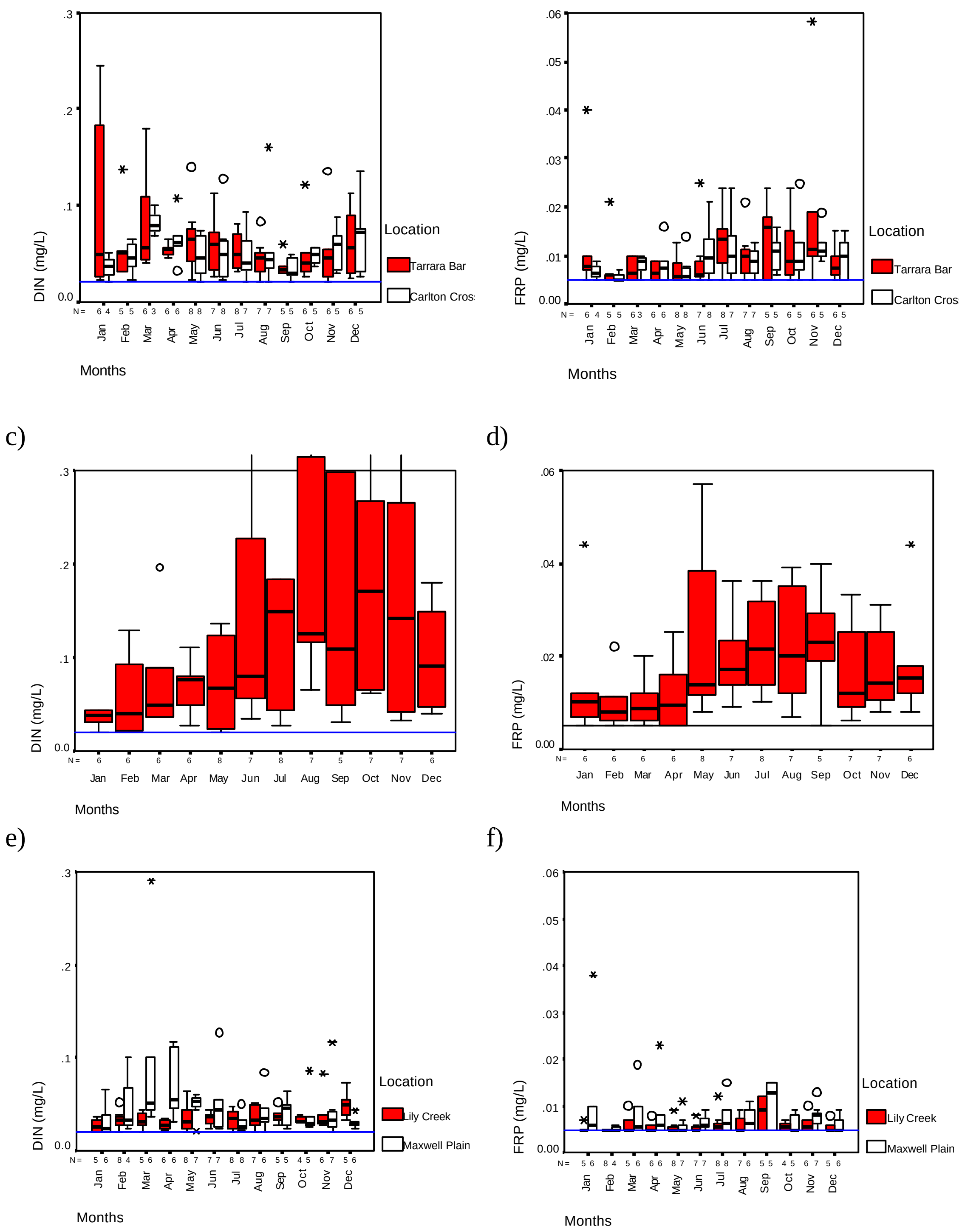

Figure 16 **Boxplots of DIN (NH_3 + NOx) and FRP recorded monthly (1998 to 2004) at a) and b) Lower Ord River, c) and d) Dunham River, and e)and f) Lake Kununurra respectively. Central bar is the median, the box is the interquartile range, whisker (T) represents largest value within 1.5 interquartile ranges of the box, o and * represent outliers and extreme values respectively; reference line is at the detection limit. Values below detection were assigned a value equal to the detection limit.**

Lund & McCrea (2001) estimated that in 1997-2000 runoff from the Ivanhoe Irrigation Area approximately doubled the loads of Total P, FRP, and NOx in the river. The large degree of dilution that occurs once the irrigation return enters the river ensures that these loads result in slight increases in river concentrations. The distributions of concentrations change for Total P, FRP, Total N, and NOx after the irrigation drains have entered the river (after Ivanhoe Crossing; Figure 17). The distribution of ammonia is more tightly grouped at Tarrara Bar than at Ivanhoe Crossing.

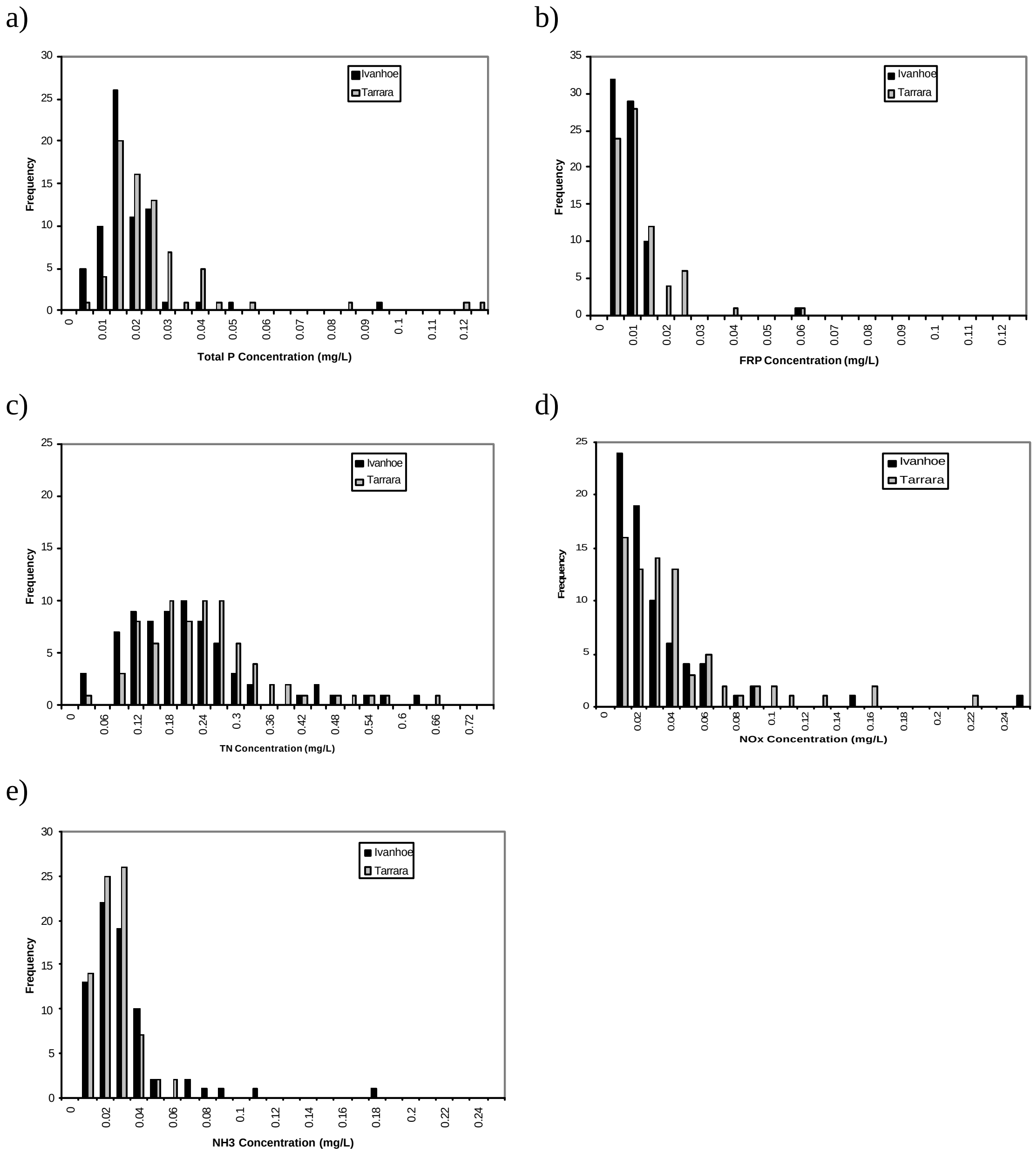

Figure 17 **Histograms of concentrations of a) Total P, b) FRP, c) Total N, d) NOx, and e) NH_3 from regular monthly WRC sampling at Ivanhoe Crossing and Tarrara Bar 1998 to 2004.**

There were significant differences (P<0.05) between paired samples at Ivanhoe Crossing and Tarrara Bar for all nutrients measured (Table 8). This difference was generally an increase in concentration, although for ammonia it was a decrease, possibly due to a number of outliers at Ivanhoe Crossing.

Table 8 **Results of paired (taken within 24 h) t-test or Wilcoxon signed ranks test for selected water quality parameters taken at Ivanhoe Crossing and Tarrara Bar by WRC at monthly intervals between 1998 and 2004. Transformations used to achieve normality as determined by Kolmogorov-Smirnov test (P<0.05). Concentrations marked below detection level have been included in the analysis, assigned a value equal to the detection limit)**

Parameter	Transformation	n	Test value	Sig (2 tailed)
pH	Log_{10}	68	t= -0.687	0.495 ns
Total N	Log_{10}	69	t= 2.969	0.004 s
Total Kjeldahl N	Log_{10}	69	t= 2.103	0.039 s
NH_3-N	Log_{10}	69	t= -2.070	0.042 s
NOx-N	Log_{10}	69	t= 3.011	0.004 s
Total P	Log_{10}	65	t= 5.174	0.0001 s
FRP-P		69	z= -3.833	0.0001 s
TSS	Log_{10}	69	t= 6.303	0.0001 s
Turbidity	Log_{10}+1	57	t= 5.384	0.0001 s

As the current Ord Stage 1 is fully developed it is not anticipated that there will be any major changes in the quality of irrigation runoff. Runoff of nutrients from farms is largely uncontrolled with no physical structures in place to retain or retard the movement of nutrients and other chemicals into the drains. There is currently a move by WRC and irrigators to reduce the nutrient loads in the return by 50%. Methods to achieve this reduction are currently under investigation. At present a large proportion of the water that is returned is unused river water, it is also likely that improvements in monitoring farm usage and in delivery systems will reduce the volume of water returned. This is likely to increase nutrient concentrations within the drain network through reduced dilution possibly increasing algal blooms within them.

Under Ord Stage 2 proposals (as of May 2001), Stage 1 was to be allocated 345GL $year^{-1}$ and the Keep River developments 690 GL $year^{-1}$, with a further 113 GL $year^{-1}$ available for Mantinea Flats and Carlton Hill. There are a number of restrictions based on the height of Lake Argyle that could restrict these allocations. The aim was to maintain a minimum of 30 m^3s^{-1} flow at House Roof Hill during drought years (Lake Argyle <76m AHD) and a minimum of 40 m^3s^{-1} in all other years. These flow rates are equivalent to daily discharges of 2,693 to 3,571 ML d^{-1}.

If the entire discharge from the drains is divided into the Tarrara Bar flows, the overall daily dilution rate for nutrients can be calculated. Low flows only occur during the drier months (May to Sept) representing a worse case scenario and therefore calculations will be restricted to this period. Measured flows are replaced with a flow rate of 3,500 ML d^{-1} at Tarrara Bar under the proposed 40 m^3s^{-1} minimum. The result is that a minimum dilution rate of 9:1 was obtained under current conditions, with over 80% of dilution ratios >20:1 (Figure 18). Under the proposed Ord Stage 2 minimum flow of 40 m^3s^{-1} no dilution rate exceeds 15:1.

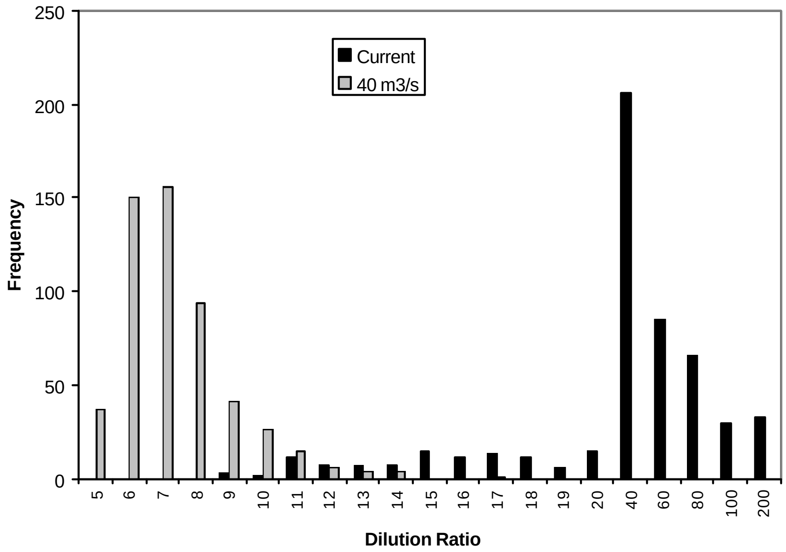

Figure 18 **Frequency distribution of the daily dilution ratio for summed drain discharges into the Tarrara Bar flow between May and September 1999 to 2002 under measured flows and a minimum Ord Stage 2 flow (40 m^3 s^{-1}).**

The weight ratio of DIN to FRP is generally <15:1 and can drop to <3:1 (Figure 19), which suggests that the system is probably N limited. Flows from the Dunham River appear to increase the ratio, by adding both NOx and NH_3 to the river. The particularly low ratio seen in 1998 at Tarrara Bar is due to higher than normal FRP concentrations, presumably from irrigation return drainage. The nutrients added by irrigation return generally appear to have little influence on the ratio.

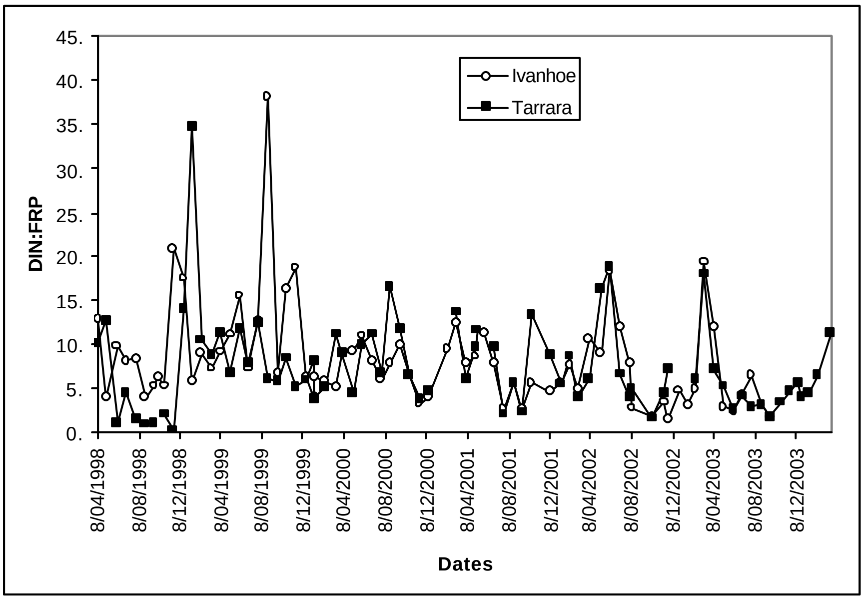

Figure 19 **Changes in DIN (NH_3+NOx) to FRP (weight: weight) ratio in the Lower Ord River based on WRC monitoring data from 1998 to 2004.**

The predicted increase in DIN concentrations expected based on irrigation drainage input load and subsequent dilution, show a minor increase of 10-29 µg L^{-1} on 33% of occasions (Table 9). On the remainder of occasions the increase was <10 µg L^{-1}.

Under the Ord Stage 2 minimum flow of 40 m^3 s^{-1} (3.5 GL d^{-1}), the predicted increases would be >10 µg L^{-1} in 78% of occasions and >20 µg L^{-1} on 61% of occasions. The measured differences between Ivanhoe Crossing and Tarrara Bar which ignore the effects of D1 inputs are often similar to the predicted increases.

Table 9 **Predicted increase in concentrations of DIN in the Lower Ord River at Tarrara Bar on days with WRC monitoring data. These are based on drainage return loads (D1, D2, D2B, D4 and D7) divided by the dilution ratio of irrigation return to Tarrara Bar flows for that day and under and under Ord Stage 2 minima of 40 $m^3 s^{-1}$ (3.5 GL). The actual difference in DIN concentrations on the same days between Ivanhoe Crossing and Tarrara Bar are shown.**

Date	Predicted increases in DIN concentrations: Measured Flows (µg L^{-1})	Predicted increases in DIN concentrations: Ord Stage 2 Minimum Flows of 40 m^3 s^{-1} (µg L^{-1})	Ivanhoe Crossing to Tarrara Bar: Measured increase in concentrations (µg L^{-1})	Tarrara Bar Discharge (GL)
27/07/99	11	47	-13	14.6
24/08/99	2	7	-160	15.2
21/09/99	1	4	-354	14.4
30/05/00	1	9	-5	48.6
27/06/00	3	41	18	41.4
25/07/00	1	11	4	30.2
22/08/00	13	76	44	21.0
19/09/00	2	8	9	18.5
29/05/01	3	37	2	48.3
26/06/01	4	38	14	36.5
21/08/01	7	38	-1	19.9
7/05/02	2	12	37	16.1
4/06/02	14	54	21	13.1
2/07/02	29	48	-28	5.8
6/08/02	11	20	25	6.5
3/09/02	8	15	No data	7.1
6/05/03	13	23	37	6.1
3/06/03	11	29	4	9.4

4.14 Hydraulic Residence Time

Hydraulic residence time indicates the time algal cells have available to grow and reproduce. During periods of high flow (wet season of 2002), hydraulic residence times can drop to a matter of a few days from KDD to Carlton Crossing. In the dry season residence times can increase to 15-23 days. The low rainfall in the 2002/03 wet season had little impact on residence times (Figure 20).

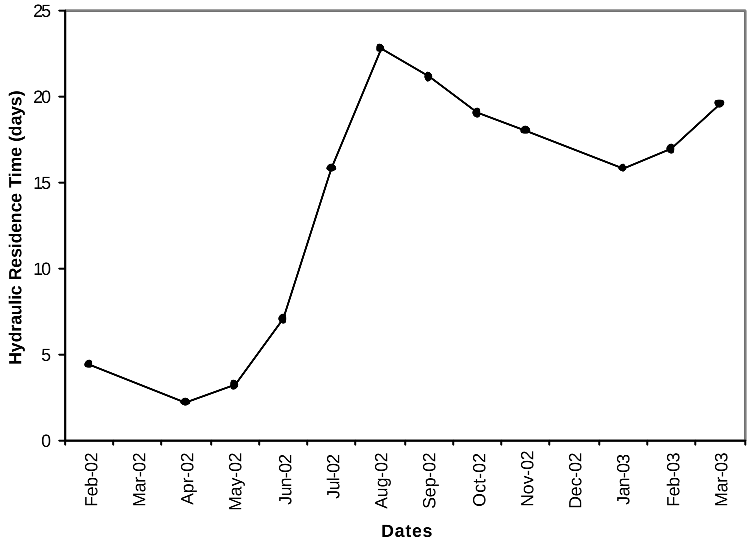

Figure 20 **Hydraulic residence times (days) for the Lower Ord River from KDD to Carlton Crossing as determined by Parslow *et al*. (2003)**

Prior to regulation the lower Ord River would dry to a series of pools (upstream of Tarrara Bar, Skull Rock, Macca's Barra Camp and Carlton Crossing). WRC is committed to maintaining flow in the lower Ord River at levels to prevent isolated pools forming. Preliminary modelling by WRC suggests that flow rates of 35 $m^3 s^{-1}$ would not produce hydraulic residence times of >15.7 hours in any of the pools. This relatively low hydraulic residence time contrasts with the longer times of Parslow *et al.* (2003). The WRC estimations are based on pool size and water velocity and so represent a minimum residence time, while Parslow *et al.* (2003) estimates are based on conservative solute movement and are therefore potentially closer to reality.

Average daily flows are relatively high in the lower Ord River, with most exceeding 70 $m^3 s^{-1}$ (Figure 21). Between 1998 and 2004, three low flows 31, 40 and 41 $m^3 s^{-1}$ were recorded at Tarrara Bar (19-21 Oct 2002), these were from a manipulation experiment carried out by WRC to test the effects of low flows on dissolved oxygen levels with the pools. The period 1998 to 2004 does contain a high proportion of very high flows due to the significant rainfall received in the wet season of 2000/01.

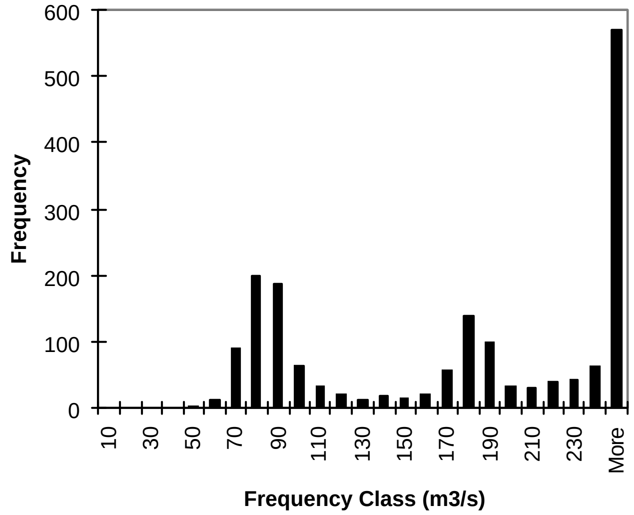

Figure 21 **Frequency distribution of average daily Tarrara Bar flows (1998 to 2004)**

Typically dry season flows of approximately 70 $m^3 s^{-1}$, produce a hydraulic residence time of 18 days, while it could be predicted for the power regression in Figure 22 that reducing the flows to 40 $m^3 s^{-1}$ would increase residence times to approximately 30 days. There is a high degree of uncertainty associated with these estimates given the low r^2 value and the prediction occurring outside the range of the data. It does suggest that long hydraulic residence times would occur with any reductions in flow.

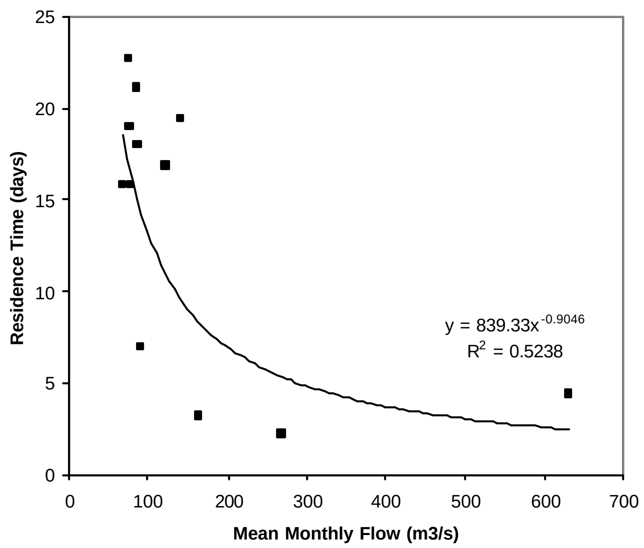

Figure 22: **Mean monthly flows versus residence times (KDD to Carlton Crossing) calculated by Parslow *et al.* (2003). Line of best fit and power regression equation shown.**

4.15 Algal data

There is very little algal data available for the Ord River, as cell counts or chlorophyll *a* are not routinely monitored. *It is recommended that either cell counts or chlorophyll* a *measurements are included in the WRC routine monitoring of the river.*

Cell count data and taxa identifications are available for two snapshot studies by Parslow *et al*. (2003) for the lower Ord River on the 23rd and 24th February 2003 and for an algal bloom in Lily Creek Lagoon monitored by WRC between 21st and 23rd February 2004.

The effect of the 15+ day residence times can be seen in algal counts undertaken by Parslow *et al*. (2003) where there is over an eight fold increase in major phytoplankton cells from downstream of Tarrara Bar to upstream of Carlton Crossing (Figure 23). The main increases were in Diatoms, Chlorophytes (mainly desmids) and Cyanobacteria. Many of the diatoms taxa were considered benthic and it was considered that turbulence had brought them into the water column. Cell counts were extremely low at <5 cells per mL.

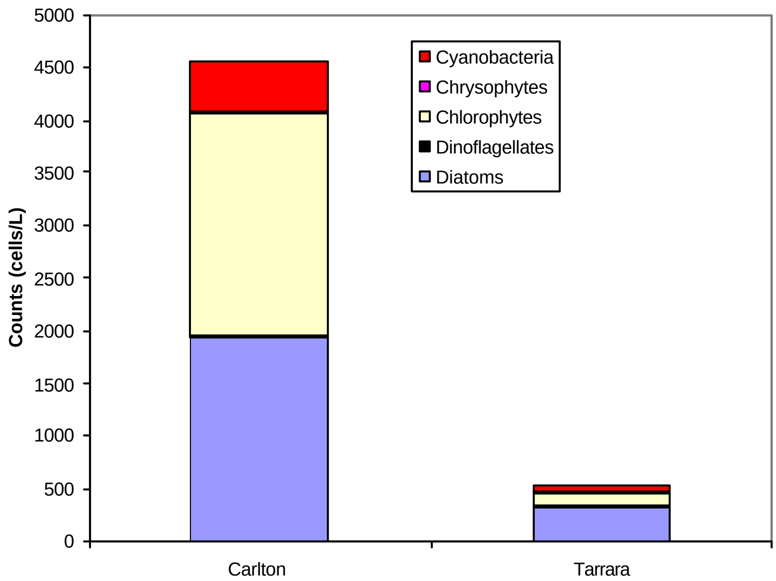

Figure 23 **Cell counts for major phytoplankton groups (excluding nanoplankton) for sites upstream of Carlton Crossing and downstream of Tarrara Bar taken in February 2003 (data taken from Parslow *et al.* (2003)).**

Parslow *et al.* (2003) did not record any water quality parameters during this sampling, however the closest available WRC data for Carlton Crossing is shown in Table 10. At this time chlorophyll *a* measurements were generally <1 µg L^{-1}, while in the dry season they were found to range between 1 and 4 µg L^{-1} with a mean of 1.23 µg L^{-1}.

Table 10: **Water quality parameters and flow measured by WRC on the closest dates to the Parslow *et al.* (2003) algal collection.**

Parameter	11/2/03	8/4/03
Flow (Tarrara Bar) $m^3 s^{-1}$	76.3	77.1
Temperature (^oC)	30.96	30.83
Turbidity (NTU)	297.8	-
TSS (mg L^{-1})	8	2
Total N (µg L^{-1})	160	190
NOx (µg L^{-1})	13	47
NH_3 (µg L^{-1})	10	11
Total P (µg L^{-1})	5	20
FRP (µg L^{-1})	5	7

A Level 1 algal bloom occurred in February 2004 in Lily Creek Lagoon, the key Cyanobacterial species involved were the *Oscillatoria*, cf. *Cylindrospermopsis*, *Planktolygnbya* and *Anabaena* (straight). The particularly high count of cyanobacteria seen on the 23/2/04 (1) was dominated by *Oscillatoria*, probably just a clump of filaments as a subsequent sample taken on the same day contained very little cyanobacteria (Figure 24).

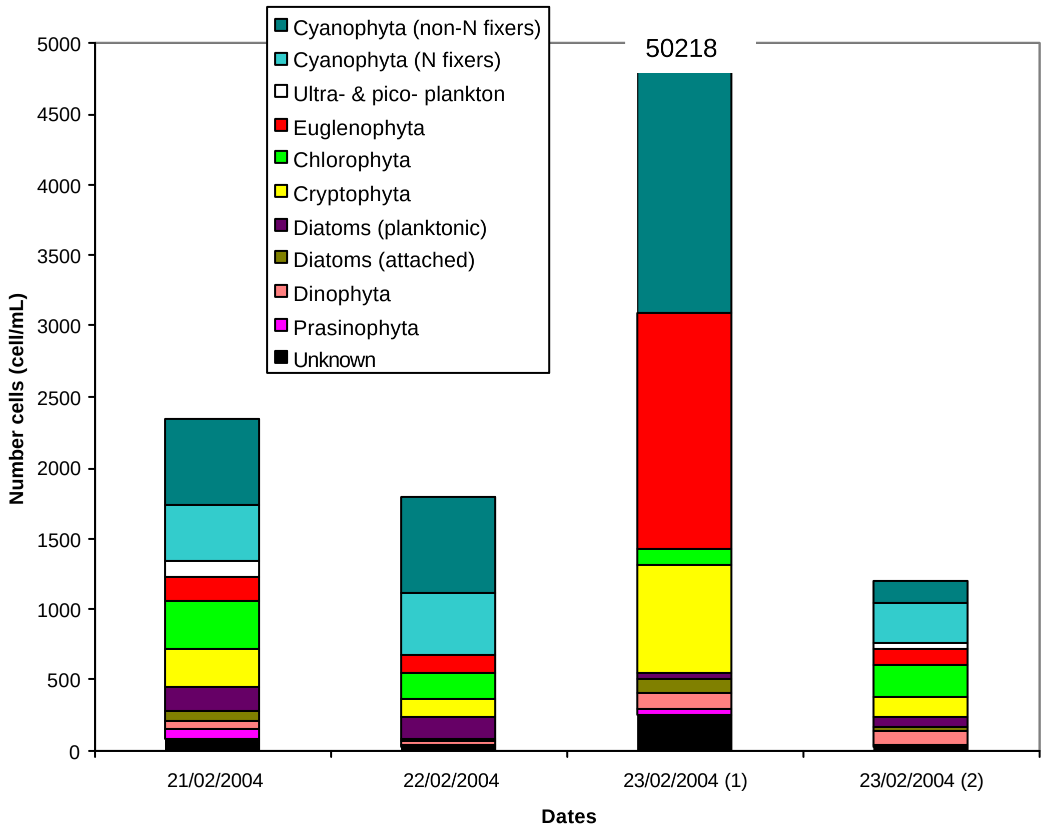

Figure 24: **Algal cell counts on selected dates at Lily Creek Lagoon,**

Water quality during this event was recorded by WRC and is shown in Table 15. The hydraulic residence time of the Lagoon during the bloom is unknown but is likely to be large, as the Lagoon essentially forms a backwater of Lake Kununurra. The longevity of the bloom is not recorded.

Table 11: Water quality parameters measured by WRC during the algal bloom in Lily Creek Lagoon

Parameter	20/2/04	21/2/04	22/2/04	23/2/04
Temperature (^{o}C)	32.8	31.1	32.6	30.8
TSS (mg L^{-1})	6	3	5	2
Total N (µg L^{-1})	140	240	220	320
NOx (µg L^{-1})	12	<10	<10	<10
NH_3 (µg L^{-1})	26	26	24	42
Total P (µg L^{-1})	15	17	16	23
FRP (µg L^{-1})	<5	<5	<5	<5

A Level 3 bloom was also noted by WRC at the Dunham River Road Bridge at the end of dry season in 2003, although the species involved were not identified. Water quality during the period is presented in Table 12.

Table 12: Water quality parameters measured by WRC during the algal bloom at the Dunham Road Bridge site

Parameter	22/10/03	19/11/03	16/12/03
Temperature (^{o}C)	31.9	32.2	31.5
TSS (mg L^{-1})	20	9	27
Chlorophyll *a* (µg L^{-1})	55	19	-
Total N (µg L^{-1})	860	720	920
NOx (µg L^{-1})	<10	<10	<10
NH_3 (µg L^{-1})	54	36	38
Total P (µg L^{-1})	80	83	150
FRP (µg L^{-1})	11	31	44

Cyanobacterial algal blooms have also been recorded in the irrigation channels by Doupé *et al.* (1998) and Jones (1997).

4.16 Likelihood

Likelihood of algal blooms will be discussed for each of the three areas and will be examined initially monthly based on key parameters (Table 13). Median monthly midday water temperatures of <24^{o}C are considered low risk, temperature between 24 and 26^{o}C are considered medium risk, while >26^{o}C are considered high risk. Median monthly turbidities of <15NTU were considered high risk, close to 15 NTU medium risk and >15 NTU low risk. Stratification occurred in Lake Kununurra at flows of <80 m^3 s^{-1}, these flows appear to produce sufficiently low velocities in Lake Kununurra to allow stratification to be maintained. Stratification requires a prolonged period of low velocities to become established and so median monthly flows from ORD <60 m^3 s^{-1} were considered to pose a high risk of stratification, 60 to 80 m^3 s^{-1} a medium risk and >80 m^3 s^{-1} a low risk. The high flows of 2000 and 2001, distort the flows of the lower Ord River, and so medians have been calculated excluding these flows. There is no evidence that stratification occurs in the lower Ord River, although if sufficiently low velocities were obtained for a sufficient period it might. The only evidence of stratification in the Dunham River comes from a site approximately 55 km from the confluence, above the pool at the Road Bridge. Stratification at this site was limited, but is more likely at the deeper Road Bridge pool under negligible flows. Therefore low risk was assigned to monthly median flows >1 m^3 s^{-1}, medium to flows 0<x=1 m^3 s^{-1} and high to 0 m^3 s^{-1} flows. Reynolds and Descy (1996) suggest that nutrients are unlikely to be limiting in lotic waters provided there are 5-10 x 10^{-6} mol N L^{-1} and 3-6 x 10^{-8} mol P L^{-1}. The algal blooms recorded, occurred at relatively low nutrient concentrations DIN between 30 and 50 µg L^{-1} and FRP <10 µg L^{-1}. These concentrations indicate N limitation (2.1 to 3.6 x 10^{-6} mol N L^{-1}), although FRP is probably sufficient (FRP concentrations would need to be >1 µg L^{-1}). These nutrient concentrations are typical of the Ord River. It is therefore suggested that addition of DIN into the river through irrigation return drainage would enhance the likelihood and severity of algal blooms. The N limitation is also likely to favour N fixing cyanobacteria, although in the Lily Creek Lagoon bloom this did not appear to be the case. Hydraulic residence times in excess of two weeks could potentially produced a Level 2 bloom of 5000 cells mL^{-1} at Carlton Crossing given a doubling time of 0.5 d^{-1} and a starting population of 2 cells mL^{-1}. Using the equation in Figure 22 this suggests that a mean monthly flow of 90 m^3 s^{-1} produces a 14 day residence time. As this is very similar to the flows recommended for stratification, the same categories of flows will be used for the lower Ord River. The hydraulic residence time of Lake Kununurra and the Dunham River are unknown, however conditions that potentially allow stratification to occur would be associated with long residence times.

Table 13: Risks of algal blooms occurring in each month, overall risk based on sum of individual risks, where H (high) =3, M (medium) =2 and L (low) =1 (*Flood flows in 2000 and 2001 not included in analysis)

		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Water Temperature	Dunham	H	H	H	H	H	H	H	M	L	L	M	H
Turbidity	River	M	L	L	L	L	L	L	M	L	L	H	M
Stratification		H	H	M	L	L	L	M	M	H	H	H	H
Overall Risk		**8**	**7**	**6**	**5**	**5**	**5**	**6**	**6**	**5**	**5**	**8**	**8**
Water Temperature	Lake	H	H	H	H	H	H	H	M	L	L	M	H
Turbidity	Kununurra	L	L	L	H	H	M	M	M	L	L	L	L
Stratification*		M	M	M	M	M	L	L	L	L	M	M	M
Overall Risk		**6**	**6**	**6**	**8**	**8**	**6**	**6**	**5**	**3**	**4**	**5**	**6**
Water Temperature	Lower	H	H	H	H	H	H	H	H	M	M	M	H
Turbidity	Ord	H	M	M	L	L	L	L	M	H	H	H	H
Hydraulic Residence Time*	River	M	L	L	L	L	L	L	L	M	M	M	M
Overall Risk		**8**	**5**	**5**	**5**	**5**	**5**	**5**	**6**	**7**	**7**	**7**	**8**

The overall risks on a monthly basis are highest in August to October in the Dunham River pool, January to February in Lake Kununurra and July through to October in the lower Ord River. The Dunham River algal bloom occurred at a time of comparatively low risk (5). This is probably because the use of median values misses the high interannual variability seen in river flows.

The likelihood will also vary depending on the severity of the algal bloom, with increasing severe algal blooms becoming less likely. Box 1 shows a simple calculation of algal growth rates from the data of Parslow *et al.* (2003). Doubling times per day between 0.24 and 0.4 are similar to those recorded for other cyanobacteria in Australia. Bormans *et al.* (2004) recorded a very high doubling rate of 0.31 day^{-1} for *Cylindrospermopsis* in the Fitzroy River (Queensland). Webster *et al.* (2000) recorded a doubling rate of 0.37 day^{-1} for *Anabaena* in the temperate Murrumbidgee River. Algal cell counts recorded by Parslow *et al.* (2003) were extremely low, peaking at 2 cells mL^{-1} at Carlton Crossing. Under ideal conditions using current conditions and aiming to achieve a Level 2 bloom, a start concentration of over 2 cell mL^{-1} would be essential. This seems to be very unlikely unless there was a bloom in Lake Kununurra. A Level 1 bloom would be much more likely. No bloom has been recorded in Lake Kununurra, but Level 1 bloom was recorded in Lily Creek Lagoon. Although there does not appear to be any difference in water quality between the Lagoon and Maxwell Plains, it is likely that residence times were longer than in the Lake. Therefore the likelihood of algal blooms in Lily Creek is considered to be higher than in the Lake. The Dunham River pool has had a Level 3 algal bloom. A summary of the likelihood of different Levels of algal blooms is shown in Table 14.

Box 1: Algal cell count required for bloom

*Residence time (February 2003) between KDD and Carlton Crossing

R_{kc}=16.9 days

*Algal counts on 21/2/03 at OB7 (downstream of Carlton Crossing) and OB9 (downstream of Tarrara Bar):

Diatoms increased from	330 cells L^{-1} to 1947 cells L^{-1}
Chlorophytes increased from	110 cells L^{-1} to 2095 cells L^{-1}
Cyanobacteria increased from	59 cells L^{-1} to 495 cells L^{-1}

No changes seen in Dinoflagellates or Chrysophyta (nanoplankton significant but data missing from OB9)

Estimated distance from KDD to Carlton Crossing	D_{kc} =61 km
Estimated distance from OB9 to OB7	D_{97} =38 km
**Average flow for February 2003 at Tarrara Bar	113.0 m^3 s^{-1}
**Flows for the 21 February 2003 at Tarrara Bar	113.4 m^3 s^{-1}
Average velocity	$v= D_{kc} /R_{kc}$ = 0.042 m s^{-1}
Residence time between OB9 and OB7	$R_{97}= D_{97}/v$ = 10.6 days

Number of doublings of algal taxa between OB9 and OB7

Diatoms	D_d	2.56
Chlorophytes	D_g	4.25
Cyanobacteria	D_c	3.07

Growth rate of algae (doublings d^{-1})

Diatoms	$G_d = D_d/10.6 = 0.24\ d^{-1}$
Chlorophytes	$G_g = D_g/10.6 = 0.4\ d^{-1}$
Cyanobacteria	$G_c = D_c/10.6 = 0.29\ d^{-1}$

*Data from Parslow *et al.* (2003)

**Data from WRC

Doubling the growth rates of cyanobacteria (to 0.6 d^{-1}), to allow for reduced turbidities), and using a dry season retention rate of 20 days, then a cell count of 100 cells mL^{-1} is required at KDD to produce a cyanobacteria cell count of 5000 cells mL^{-1} at Carlton Crossing.

Table 14: Summary of likelihood of algal blooms occurring at selected sites in the lower Ord River (1 = very low, 2 = low, 3 = medium low, 4 = medium, 5 = medium high, and 6 = high).

Site	Risk Times	Severity	Likelihood
Dunham River	August	Level 1	6
	to	Level 2	5
	October	Level 3	4
Lake Kununurra	January	Level 1	2
	to	Level 2	1
	February	Level 3	1
Lily Creek Lagoon	January	Level 1	5
	to	Level 2	2
	February	Level 3	1
Lower Ord River	July	Level 1	2
	to	Level 2	1
	October	Level 3	1

Under Ord Stage 2, flows are likely to be reduced in the lower Ord River, possibly on occasion to <40 $m^3 s^{-1}$. There insufficient data to accurately predict the likely impact of these flows on the risk of algal blooms, however the evidence already presented indicates that reducing flow is only likely to substantially increase the risk. This would occur through increased residence times, possible stratification and possibly higher water temperatures (due to shallow depths).

4.2 The Consequences

Algal blooms, particularly of cyanobacteria are a concern for managers of waterways worldwide. They are responsible for or contribute towards a number of negative effects including fish kills, smells, aesthetic degradation, loss of biodiversity (flora and fauna), avian botulism, and in the case of certain cyanobacteria, toxicity. Algal blooms have been recorded in Australian rivers, with the best known one occurring in the Barwon-Darling River in summer 1991 where over 1000 km of river was subject to a bloom of the toxic cyanobacteria *Anabaena circinalis* (Bowling and Baker 1996). The bloom occurred at a time of high nutrient concentrations (Table 15) and very low flows (0-100 ML day^{-1}; 0-1.2 $m^3 s^{-1}$).

Table 15: Nutrient concentrations at the peak (mid November to mid December 1991) of the Barwon-Darling River algal bloom (taken from Bowling and Baker 1996)

Turbidity (NTU)	Total P (mg L^{-1})	Total N (mg L^{-1})	NOx-N (mg L^{-1})	NH_3-N (mg L^{-1})
<40	>0.1	>1	<0.1	>0.1

The lower Ord River supports dense beds of submerged macrophytes in many areas, which provide habitat for fish and invertebrates. Gross primary productivity (GPP) was found to be about 25% higher in the regulated lower Ord River (range 32 to 846 mg C m^{-2} d^{-1}) compared to unregulated rivers (range 137-658 mg C m^{-2} d^{-1}) and net daily metabolism (GPP minus respiration) was generally positive in the lower Ord River and negative in unregulated sites (WRC 2003). This indicates that the lower Ord River was autotrophic (600 g C d^{-1} produced per 100 m reach) while unregulated sites were heterotrophic (250 g C d^{-1} consumed per 100 m reach). The NPP rates for benthic metabolism in the lower Ord River were considered to be relatively high, equivalent to rivers with substantial nutrient enrichment in temperate Australian rivers (WRC 2003). Examination of food webs within the lower Ord River using stable isotopes of C and N, showed a large algal contribution to the diets of many macroinvertebrate and some fish species, although all the sources of the algal carbon were not clear (WRC 2003). The conclusion from these results were that the most appropriate model to describe the ecology of the lower Ord River was the riverine productivity model of Thorp and Delong (1994). This model highlights the importance of locally produced carbon from both algal and riparian sources. Minor changes in algal biomass are therefore unlikely to fundamentally alter the processes occurring within the river. Small increases in algal biomass might actually increase biodiversity by increasing food resources.

The consequences of a bloom are related to its severity. The impacts of a Level 3 bloom would be severe, with loss of submerged macrophytes resulting in loss of macroinvertebrates. Fish and crocodile kills might occur through algal toxicity and/or reductions in dissolved oxygen (although crocodiles are less likely to be impacted due to their physiology and ability to move onto land). The wild and 'pristine' perceived nature of the Ord River contributes to its value for tourism; an algal bloom of the magnitude of the one in Barwon-Darling River would severely undermine this belief. A bloom of toxic cyanobacteria would pose a risk to cattle that drink from the river. The number of cattle likely to be affected is not known but is likely to be large, with much of the river unfenced.

A Level 2 bloom would not impact on the aesthetics of the river, but would begin to impact on submerged macrophytes by competing for nutrients. Cyanobacterial counts would be unlikely to pose a risk to stock (ANZECC and ARMCANZ 2001). A Level 1 bloom would probably have few consequences, except if winds concentrated the cyanobacteria in scums where they could reach toxic levels. The Levels 1 to 3 were assigned a risk of low, medium and high respectively.

The severity of consequences is also dependant on the locality. Blooms in Lily Creek and Lake Kununurra would have a much larger impact on tourism, recreation and aesthetics than in the other areas due to their proximity to Kununurra Township. Lake Kununurra is also a Ramsar site and a severe algal bloom could reduce bird populations. Blooms in the Dunham River Pool would also be relatively high profile, especially given the several fish kills that have occurred there. Blooms in the lower Ord River are likely to occur only near Carlton Crossing, which is relatively remote. A bloom here could be an important threat to stock, but would have a reduced social impact. The impact of locality on severity was then used to modify the initial risk assessments. A summary of the severity of the consequences is shown in Table 16.

Table 16: Severity of consequences under different algal blooms at selected localities in the lower Ord river (1 = very low, 2 = low, 3 = medium low, 4 = medium, 5 = medium high, and 6 = high)

Locality	Algal bloom level	Locality effects	Severity of consequence	Final risk
Dunham River	Level 1	-1	2	1
	Level 2		4	4
	Level 3	+1	6	7
Lake Kununurra	Level 1	0	2	2
	Level 2	+1	4	5
	Level 3	+3	6	9
Lily Creek Lagoon	Level 1	0	2	2
	Level 2	+1	4	5
	Level 3	+2	6	8
Lower Ord River	Level 1	-1	2	1
	Level 2	-1	4	3
	Level 3	-1	6	4

4.3 The Risks

The Ord River provides good conditions for the growth of algae, with warm temperatures, sufficient nutrient concentrations (although N is probably limiting), and low turbidity except during high flows. Flow rates in the river are generally extremely high during the wet season which provides limited opportunity for algal growth before cells are washed into the sea. In the dry season, prior to regulation the river dried to pools, these pools provided longer residence times and the possibility of algal blooms. Regulation has provided flows in the lower Ord River during the dry season. Regulation has created Lake Kununurra, Lily Creek Lagoon and has probably increased the depth of the Dunham River pool. Flows modification in the river is the main factor contributing to the risk of algal blooms. Irrigation is responsible for this regulation, but flows from ORD are largely determined by the PowerStation needs. Irrigation return drainage adds nutrients particularly NOx and FRP to the river. This additional DIN from irrigation does not on average provide enough N to eliminate N limitation. Therefore current nutrient concentrations do not appear to be important for the likelihood of an algal bloom occurring but will probably impact on its likely severity.

The overall risk of algal blooms in the lower Ord River is shown in Table 17. The highest risk is for a Level 1 bloom in Lily Creek Lagoon between January and February, with medium risk of Level 2 and Level 3 bloom. In Lake Kununurra, algal blooms are generally very unlikely but have high consequences if they occurred. Both Lake Kununurra and Lily Creek Lagoon are not impacted by irrigation return drainage. The Dunham River pool has a high likelihood of algal blooms of high severity. Irrigation return drainage from Packsaddle Plains enhances nutrient concentrations to the pool. Unfortunately it has proved difficult for WRC to accurately measure the inputs from this source. The recorded algal bloom in the Dunham River occurred outside the predicted peak risk times; this suggests that more needs to be known to understand the mechanisms controlling algal biomass at this site. There is low risk of algal blooms in the lower Ord River.

Table 17: Overall risks of algal blooms in selected areas of the lower Ord River, overall risk is the product of the likelihood and consequence (L =6, 7< M =12, H =13)

Site	Risk Times	Severity	Likelihood	Consequence	Risk
Dunham River	August	Level 1	6	1	6 (L)
	to	Level 2	5	4	20 (H)
	October	Level 3	4	7	28 (H)
Lake Kununurra	January	Level 1	2	2	4 (L)
	to	Level 2	1	5	5 (L)
	February	Level 3	1	9	9 (M)
Lily Creek Lagoon	January	Level 1	5	2	10 (M)
	to	Level 2	2	5	10 (M)
	February	Level 3	1	8	8 (M)
Lower Ord River	July	Level 1	2	1	2 (L)
	to	Level 2	1	3	3 (L)
	October	Level 3	1	4	4 (L)

The risks under Ord Stage 2 have not been determined, but reduced flows are likely to enhance the likelihood of blooms by increasing the chances of stratification and increasing hydraulic residence times. The severity of blooms would probably increase as the nutrients in irrigation return drainage are substantially less diluted than at present.

The risks determined in this study are based on limited data and would be enhanced by more detailed monitoring of algae within the region.

5.0 References

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