ASSESSMENT OF THE ECOLOGICAL RISKS ASSOCIATED WITH IRRIGATION IN THE ORD RIVER CATCHMENT

Phase 1 – Identification of risks and development of conceptual models

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Assessment of the Ecological Risk associated with Irrigation in the Ord River catchment

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Phase 1 Report: Identification of risks and development of conceptual models

Project Number LWWRDC Project WRC10

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Abstract

The National Program for Irrigation Research and Development has set up a research project to develop and test a generic framework for assessing the ecological risks associated with irrigation return. This study aimed to identify likely ecological risks associated with irrigation systems within the Lower Ord River catchment and rank the risk based on the use of conceptual models. The Ord River catchment considered was bounded by the Ord River Dam and Carlton Crossing (the upper extent of the salt wedge). As there is little data available on water quality within the irrigation area or Ord River, a priority was seen as collating any existing data into a mass balance model. A mass balance model was produced for a range of nutrients and the assumptions made in its determination are listed. A key finding was that irrigation was a substantial contributor of P and nitrate/nitrite to the Lower Ord River. Stakeholder meetings held in Perth and Kununurra identified weeds, channel infilling, biota kills, algal blooms and loss of biodiversity as key ecological consequences of irrigation. Two simple conceptual models were produced. One shows the role water quantity plays in the risk of ecological consequences occurring. The other model takes a different approach and identifies what factors biota require for their continued health and looks at the risks irrigation poses to those factors. Risks were assigned and then averaged to produce a risk assessment matrix. Stakeholder meetings ranked the consequences in terms of priority, with biota kills and loss of biodiversity first, followed by weeds. Algal blooms and channel infilling were seen as being of least importance or not substantially impacted by irrigation. Three areas were identified as areas for future research, improved flow and water quality monitoring, tracing movements of biocides, and investigating the resilience of biodiversity to current and future water quality conditions.

Introduction

The National Program for Irrigation Research and Development (NPIRD) has set up 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 done by working with three case study irrigation systems – the Goulburn-Broken, the Ord and the Fitzroy (Qld).

The project will be implemented in two phases:

1. Identification of likely ecological risks associated with irrigation systems within the Lower Ord River catchment 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,

This report provides the findings of phase 1 of the project for the Lower Ord River catchment.

Purpose and Objectives

The purpose of this project is, as part of a larger NPIRD project, to identify potential ecological risks associated with irrigation systems in the Lower Ord River catchment.

Specifically the objectives of this project are to:

1. Develop a list of up to six ecological consequences of development in the catchment where irrigation is likely to have a significant impact. This is to done in consultation with relevant catchment stakeholders, identified by the Project Manager
2. Develop conceptual models for each of the ecological consequences listed. The models may be overlapping and have common stressors (e.g. phytoplankton bloom, fish kills, etc). The conceptual models will include all relevant data where possible (e.g. some quantification/scaling/trigger levels for the stressors).
3. Complete a matrix table to help establish priorities.
4. Briefly justify the rankings in the ecological effects matrix table and review current and past activities in the catchment to address the effects or issues.

General Approach

A series of informal meetings were held with a group of scientific experts (Water and Rivers Commission (WRC) and Academics) to prepare a broad list of potential ecological consequences associated with irrigation and to determine project boundaries. A follow-up meeting was held in Kununurra on the 6th November 2000, invited guests included Joe Sherrad (Agriculture WA), Andrew Kelly (Ord Irrigation Cooperative), and local WRC staff. Invited but unfortunately were unable to attend at the last minute was the Chair of the Ord Land and Water Management Plan Steering Group (Tim Croot) and George Gardiner. In addition to comments received on the broad list of potential ecological consequences of irrigation, a key priority was seen as the development of the mass balance model for the Lower Ord catchment.

A further workshop was held in Perth on the 14th February 2001 to review the mass balance findings and develop the conceptual models for key ecological consequences of irrigation. The revised mass balance models and conceptual models were then presented in a workshop in Kununurra held on the 16th March 2001. At this meeting, the mass balance was presented and final revisions were made to the models and potential risks determined.

Project Boundaries

The most significant consequence of irrigation in the Ord catchment was the construction of the Ord River Dam (ORD) and the Kununurra Diversion Dam (KDD), which changed the Lower Ord river from a seasonally dry river to a permanent flowing river. Flows are now highly regulated. Consequently there have been substantial changes in river dynamics, sediment transport, channel morphology, biodiversity, and riparian vegetation. The Lower Ord is now currently evolving to suit its new flow conditions, a process which will continue for many years. Currently, water is drawn from Lake Kununurra to support two irrigated areas - Ivanhoe Plains and Packsaddle Plains. Designed as flow-through systems these areas return significant quantities of drainage waters to the river either directly or via Packsaddle Creek into the Dunham River.

The potential ecological consequences of irrigation were highlighted in 1997 with significant fish kills in the Dunham River and D4 drain due to Endosulphan poisoning. The first water quality survey of the area was undertaken by Doupe et al (1998). Although only a short-term study it highlighted the poor state of water quality and associated management practices within the irrigation areas.

Proposals to develop new irrigation areas in Weaber, Knox and Keep Plains (collectively referred to as Ord Stage II) and other proposals for irrigation on Carlton Plains and Mantinea Flats has lead to the evaluation of Interim Ecological Water Requirements (EWR) and the WRC Interim Ord River Water Allocation Plan. Current EWR planning focuses on maintaining and enhancing the post dam modified environmental conditions rather than attempting to return the river to a more natural condition. It is on this basis of a modified system that the ecological consequences of irrigation were determined in this study. As the river is highly modified after passing through the ORD, this was taken as the upper boundary for the study, although most effort was concentrated downstream of the KDD where the effects of irrigation return occurs. As little is known about the ecology of Cambridge Gulf, and it is a focus area for the Ord-Bonaparte Program, the lower limit of the study was taken as Carlton Crossing (the approximate extent of saltwater intrusion up the river). Possible impacts of Stage II developments will be assessed, although water allocations have not yet been finalised.

Priority Ecological Consequences

The development of the Interim Water Allocation Plan and EWRs for the Lower Ord River, led to reports from a Scientific Panel (Deegan, 2000) and a Community Reference Group in June 2000. These reports provided a strong foundation for the subsequent development of a list of ecological consequences of irrigation. Key issues raised in the Community Reference Group was the need to maintain the lower Ord in its current condition, by maintaining riparian zones, fish stocks, water quality, biodiversity and flow (to ensure adequate dilution of irrigation return). The Scientific Panel recommended that water levels should be maintained to prevent pool formation, weed proliferation, and sedimentation causing excessive channel infilling and loss of habitat. These findings were incorporated into list and discussed at the initial workshop and refined into a list of potential ecological consequence.

Table 1: List of ecological consequences illustrating stages of refinement

Initial List	Revised List	Priority Consequences
• Potential for Cyanobacteria/Algal blooms in the river • Increased plant growth (submerged and emergent) through excess nutrients • Potential for fish kills (biocides or through deoxygenation) • Maintenance of fish stocks • Loss of habitat within the river due to silting and loss of biodiversity • Altered water regime due to Argyle and Diversion Dams • Possibility of inter-basin transfers in Stage 2 (Ord to the Keep) • Infilling of the Ord River channel, through sedimentation and vegetation encroachment with subsequent loss of habitat • Invasion by weeds • Increased risk of mosquitoes (disease) under Stage II, under flow regimes where the water pools • Groundwater discharge	• Riparian Zone - Changes in species composition/ abundance --- Increase in weed species - Encroachment into river channel --- Loss of river channel volume • Submerged Vegetation - Changes in species composition/ abundance • Habitat Loss - Changes in vegetation (submerged/ riparian) - Infilling of channel shallows --- Loss of fish, invertebrates, crocodiles and wading birds - Infilling of inchannel rock crevices --- Loss of invertebrates • Biocide Toxicity - Changes in species composition/ abundance of invertebrates, plants, vertebrates (acute/chronic) • Algal Blooms - Toxicity - Loss of dissolved oxygen --- Fish kills and changes in invertebrate composition	• Channel Infilling • Biota Kills • Loss of biodiversity • Algal Blooms • Weeds

Mass Balance for the Lower Ord Catchment

There are many assumptions that have been made in relation to the mass balance model. The calculations and assumptions are fully described in the Appendices. The model for the Ivanhoe Irrigation Area is the most robust, with increased estimation of both flow and nutrient data for the river loads. No error ranges for the data have been provided as in most instances there were insufficient data to assess them. It is also important to remember that although loads permit the relative importance of different catchments to be determined, it is the nutrient concentrations that will result in environmental consequences from a given set of circumstances. Currently although loads of nutrients into the Lower Ord are moderately high, the high flows in the river effectively dilute the nutrients to concentrations that pose reduced risks of adverse ecological consequences.

The proposal for Ord Stage II will reduce the quantity of water available for dilution and thereby substantially increase the risk for adverse ecological consequences. The mass balance presented here is for the Lower Ord under Stage I development.

Ivanhoe Irrigation Area Budgets

The conceptual/mass balance model shown in Figure 1 shows the averaged annual (1998-2000) loads of nutrients and flows entering the Ivanhoe Plains Irrigation Area and discharges back to the river.

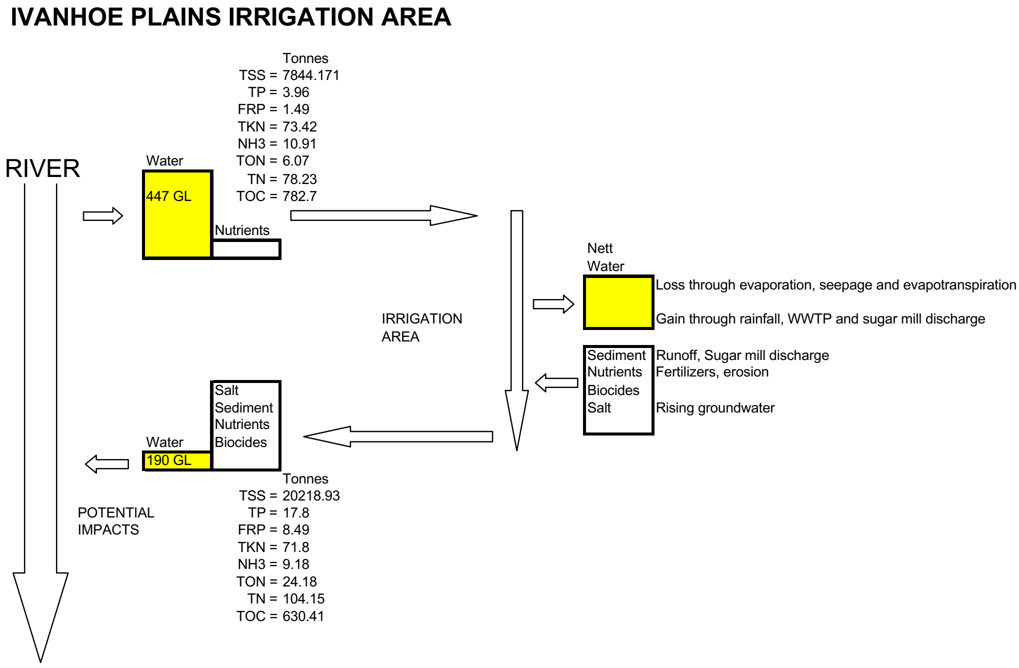
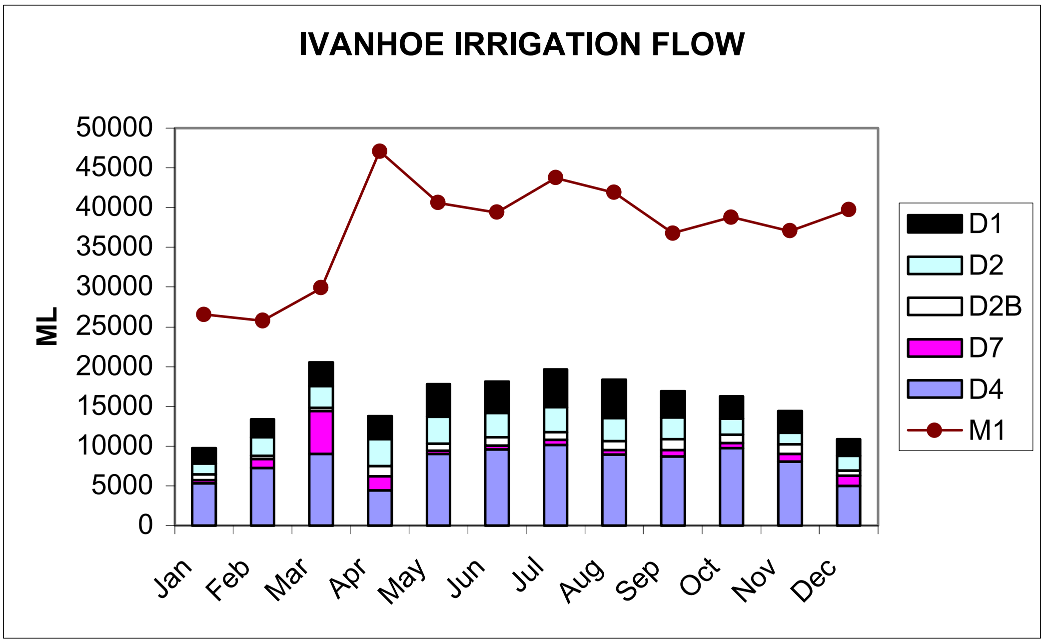


Figure 1: Mass balance model of inputs and outputs for the Ivanhoe Irrigation Area.

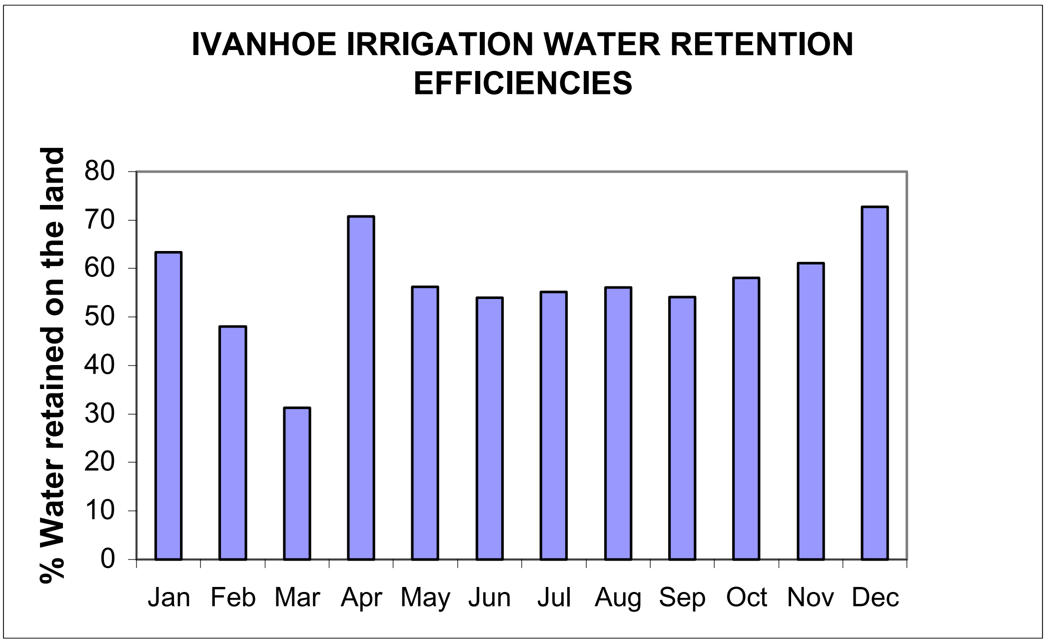
Annual loads in irrigation return are similar or substantially higher to that of the original water in the main offtake channel (M1). In addition, the concentration of nutrients in the return water is typically considerably higher for all nutrients measured than the offtake water. This study examined five irrigation return drains (D1, D2, D2B, D4, and D7), other drains either drain inland or are considered too small to warrant regular sampling. The flows recorded in the irrigation drains (Figure 2) show that greatest contribution is made by the D4, which accounts for typically >50% of the total return (Figure 3).



Assumptions: There are questions related to the accuracy of the M1 gauged data and so some caution is advised for all M1 related flow data.

Figure 2: Monthly total flows into the Ivanhoe Irrigation Area from M1 channel and total flows leaving via individual drains.

The average amount of water retained by the irrigation area is 56.7 % (ie. not directly returned to the river), although performance drops during the wet season particularly February and March (Figure 3).



Assumptions: note that Ivanhoe irrigation water retention efficiencies do not include the effects of natural runoff (rainfall), drains D8 or 2A and contributions to groundwater.

Figure 3: Monthly water retention efficiencies for the Ivanhoe Irrigation Area based on the difference between M1 inputs and drain flows.

Total suspended solids during the wet season are substantially higher from the irrigation return than in the M1 offtake water, which suggests that this load might be due to channel/bank erosion (Figure 4). Previous work by Doupe *et al.* (1998) suggested that at the end of the dry season most of the suspended solid load from Lake Kununurra was organic rather than the return, which is predominantly inorganic.

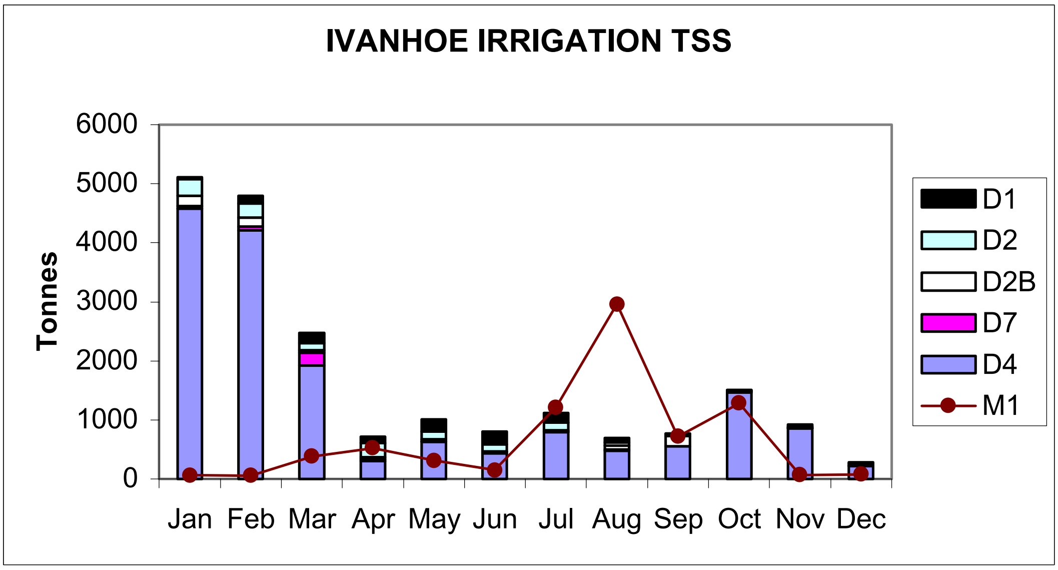


Figure 4: Monthly total suspended solid loads into the Ivanhoe Irrigation Area from M1 channel and leaving via individual drains.

Total P loads are substantially higher in the return compared to the offtake, except in April. Total P loads are highest between October to March (Figure 5). Exceptionally high P loads from D7 in March/April and D1 in May might be related to fertilising of specific crops or on farm management practices within that catchment. Alternatively high flow rates in March and April 2000 in D7 may have substantially increased calculated loads.

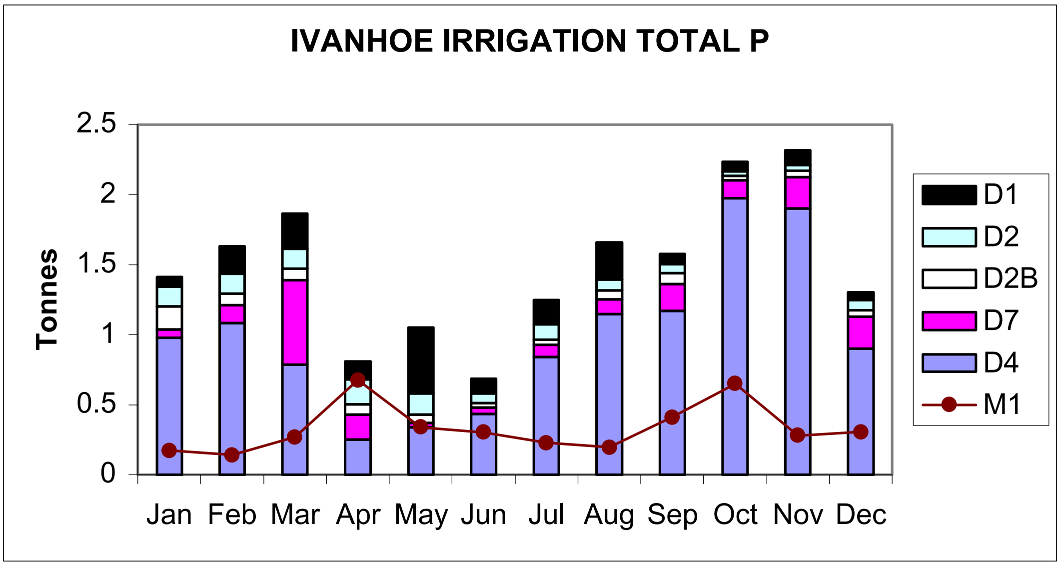


Figure 5: Monthly total P loads into the Ivanhoe Irrigation Area from M1 channel and leaving via individual drains.

The most likely source of the 'soluble' P (FRP) is from the use of fertilisers, although monthly peaks may be through subsequent release from channel/drain sediments (Figure 6). D4 had extremely high and variable flows in January to March 1999, which may account for the high loads recorded during these months. Algae use FRP preferentially over other forms of P for growth, the high contribution of FRP to the Total P is likely to encourage algal or plant growth in the drainage channels (Figure 6).

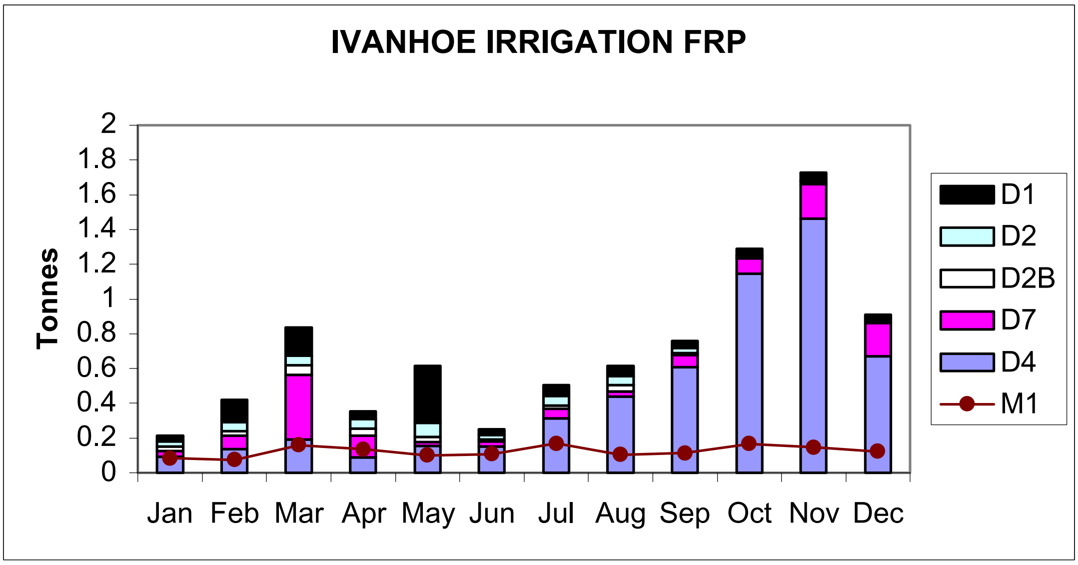


Figure 6: Monthly filterable reactive P (FRP) loads into the Ivanhoe Irrigation Area from M1 channel and leaving via individual drains.

Total Nitrogen loads are slightly higher in the drains compared to the M1 (Figure 7), most of this increase is probably due to a general increase in Total Oxidised N (a measure of nitrate and nitrite).

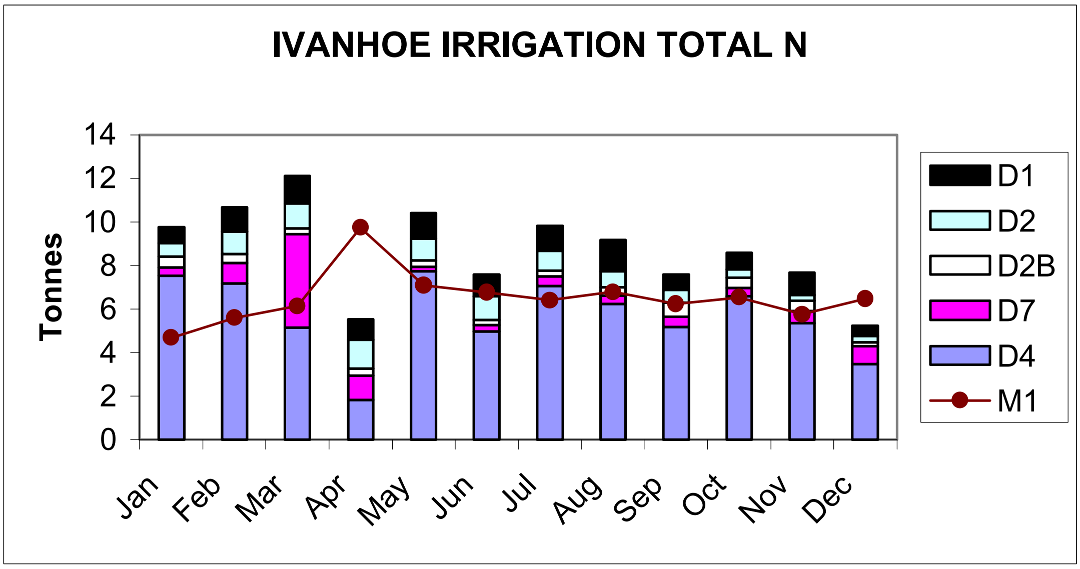


Figure 7: Monthly total N loads into the Ivanhoe Irrigation Area from M1 channel and leaving via individual drains.

Fertilising of the fields is the most likely source of the large increase in Total Oxidised N (TON) recorded in the drains (Figure 8). Peak loads probably follow (re)tilling of fallow land, although the high loads in the wet season are probably due to remobilization of nitrate from sediment. As TON is a preferred source for algal growth, high concentrations in the channels are likely to encourage growth of algae and submerged plants depending on temperature and light availability.

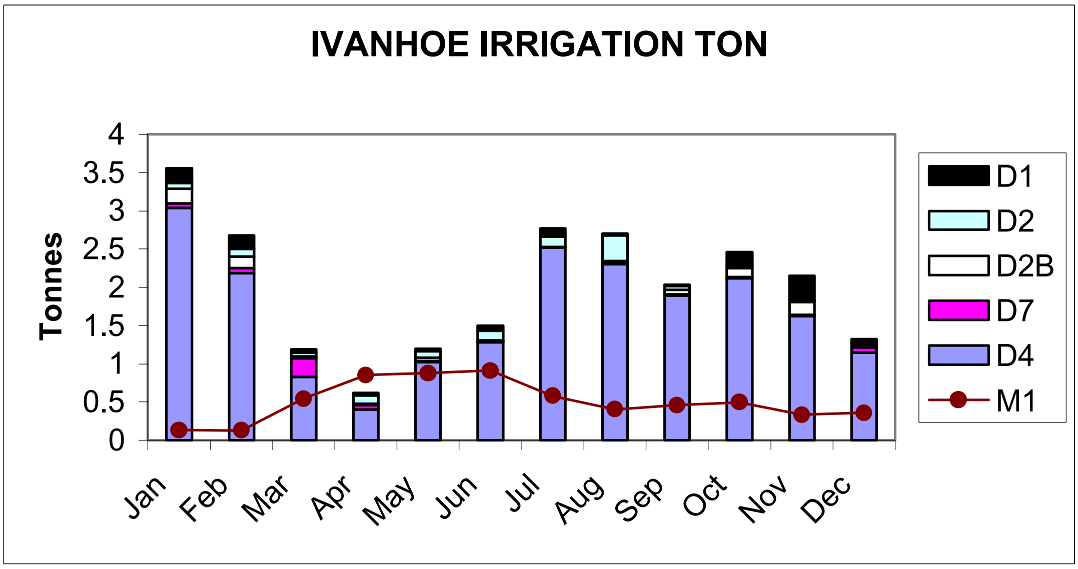


Figure 8: Monthly total oxidised N (nitrate/nitrite) loads into the Ivanhoe Irrigation Area from M1 channel and leaving via individual drains.

Total Kjeldahl N (TKN) is a measure of the organic N and ammonia, as ammonia loads were typically < 1 tonne per month, most of the TKN was organic N (Figure 9). As loads are similar between M1 and the drains we see a substantial increase in concentration in the tailwater. The organic N could be derived from plant material on the farms but also from algal and plant growth within the drainage channels.

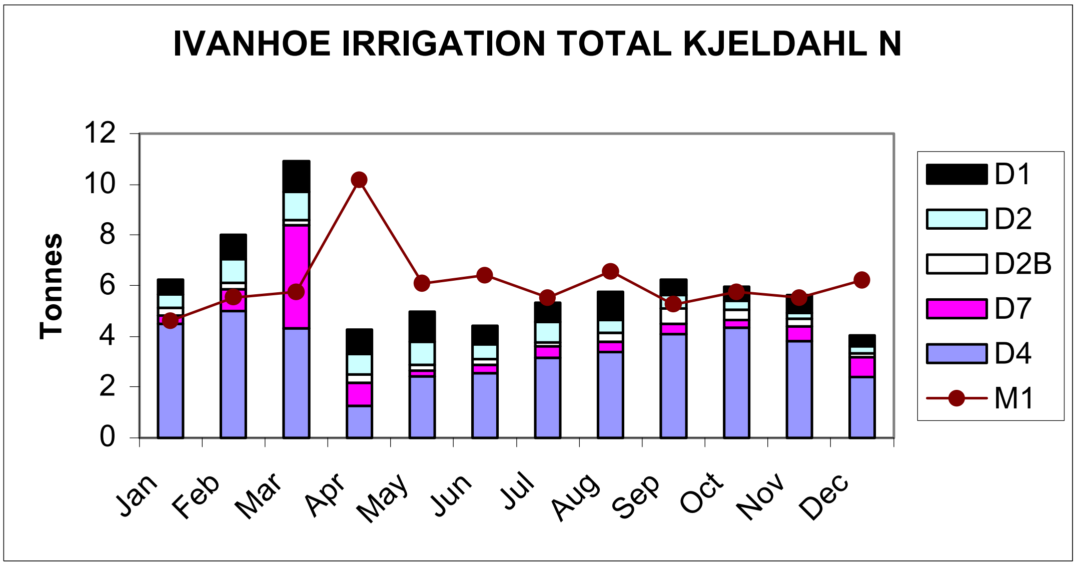


Figure 9: Monthly total Kjeldahl N loads into the Ivanhoe Irrigation Area from M1 channel and leaving via individual drains.

Ammonia levels were similar between M1 and the drains despite ammonia being a common component of many fertilisers (Figure 10). It is believed that oxidation of much of the ammonia to TON is responsible for the low ammonia loads recorded and the high TON seen.

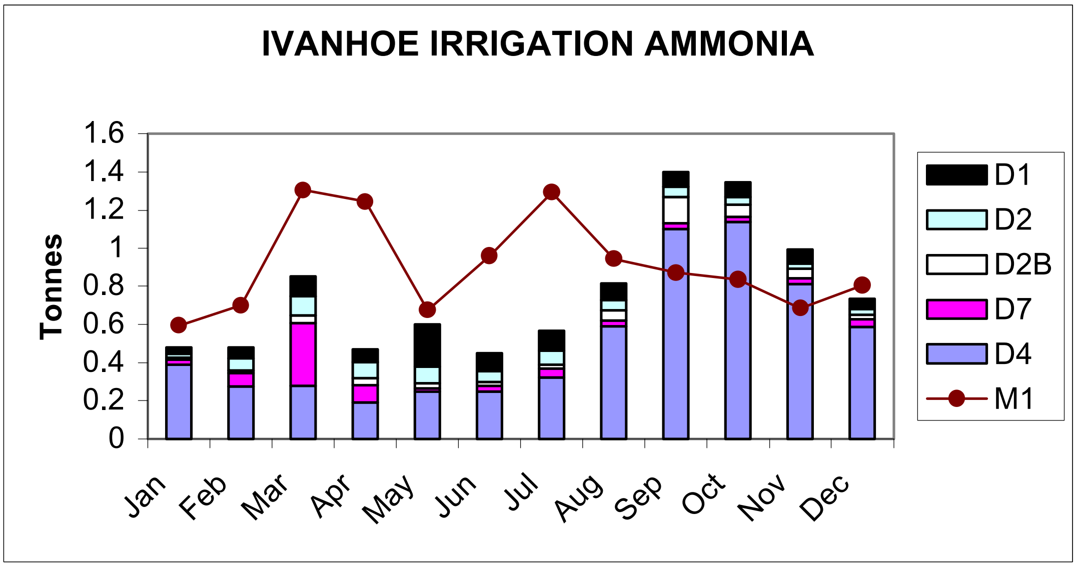
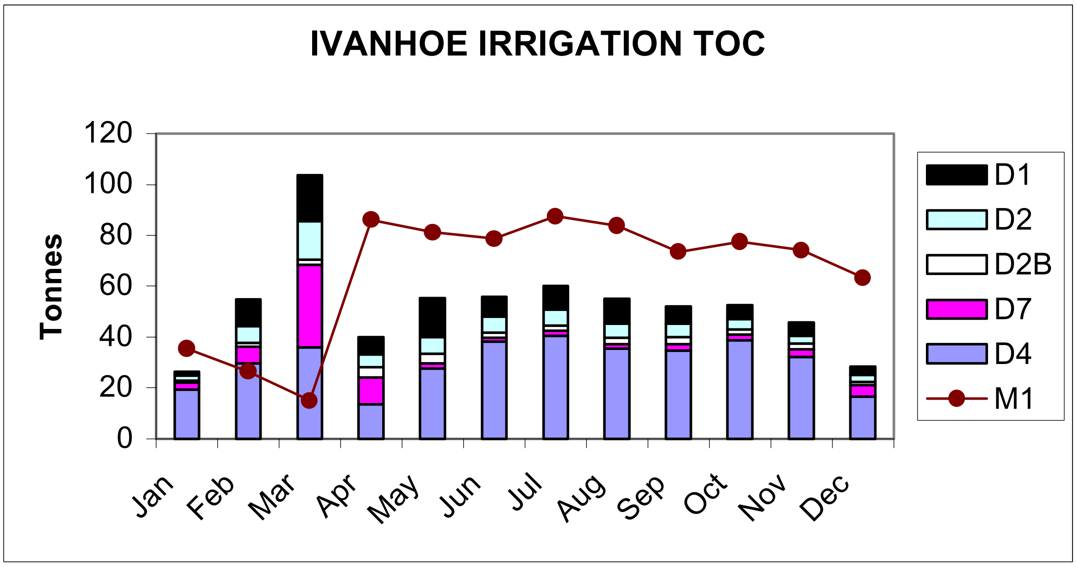


Figure 10: Monthly ammonia loads into the Ivanhoe Irrigation Area from M1 channel and leaving via individual drains.

Little data was available for Total Organic C. However, it does not appear that other than a substantial increase in concentration in the drains, that there is little change in the loads as the water moves through the irrigation area (Figure 11).



Assumptions: TOC had the poorest water quality data set (with a large number of missing data points) and so extreme caution is advised in interpreting these results.

Figure 11: Monthly total organic C loads into the Ivanhoe Irrigation Area from M1 channel and leaving via individual drains.

In most cases there is reasonable agreement between gauged flows between years, although it can be seen that there are occasionally significantly larger flows (Figure 12). These variations can explain some of the high values seen in the preceding data. For example, high flows in the D4 in January to March (Figure 12 - D4) account for the high loads often recorded during these months. D7 often shows high loads in March, which correlate with a particularly high flow event in 2000 during this month (Figure 12 - D7).

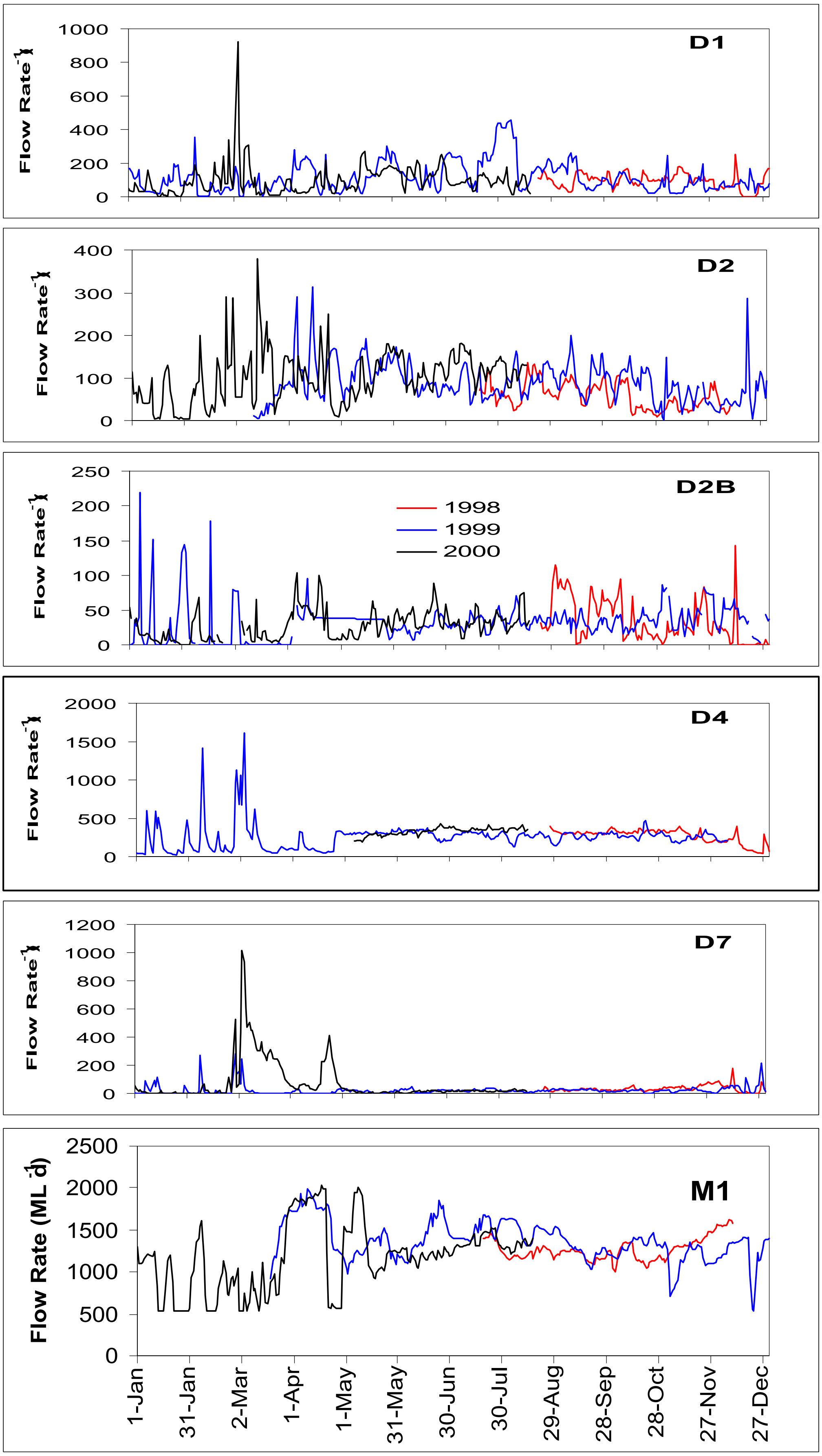


Figure 12: Daily gauged flow rates (ML d^{-1}) for Ivanhoe Irrigation Drains and the M1 offtake

The River

The Ivanhoe Irrigation Area contributes appreciable quantities of nutrients particularly P and TON to the Ord River. The contribution by rangelands are significantly lower on a per area basis (Table 2) even when considered in relation to the catchment (KDD to Carlton Crossing). Interpretation of the rangeland data is however complicated by the absence of data points in September to November (assumed dry) and as there is no gauged flow data with corresponding water quality data. Rangelands do make significant contributions during the wet season especially in terms of flow and selected nutrients due to the large catchment area of the Dunham River.

Discrepancies between river loads and summed input tributary loads can be accounted for by

- particularly high concentrations recorded in one year
- unmeasured inputs from Packsaddle irrigation area
- contributions by or loss to groundwater
- resuspension from the river channel
- poorly quantified flows or nutrient concentrations.

Table 2: Relative contributions to Ord River Loads by rangelands (based on Valentine Creek) and irrigated areas (based on Ivanhoe Irrigation Area) and total loadings (Irrigated areas - 148 km^2; Rangelands - 4760 km^2)

Parameter	**Irrigated Area**		**Rangelands**	
	tonnes 100 km^{-2}	**Total (tonnes)**	**tonnes 100 km^{-2}**	**Total (tonnes)**
Total Suspended Solids	16849.1	24937	136.4	6493
Total P	14.83	22	0.23	11
FRP	7.07	10.5	0.05	2.4
Total Kjeldahl N	59.83	88.5	3.3	157.1
Ammonia	7.65	11.3	0.29	13.8
Total Oxidised N	20.15	29.8	0.08	3.8
Total N	86.79	128.5	3.21	152.8
Total Organic Carbon	52.53	77.7	55.5	2641.8

It was suggested at the last meeting in Kununurra that calculation of loads from the rangelands above KDD could be used to verify the rangeland contributions shown in Table 2. Unfortunately there are no water quality measurements taken from any of the tributaries. The only measurements were taken in Lake Kununurra at Maxwell Plains and as the majority of the water entering Lake Kununurra is derived from ORD releases and indirectly through Spillway Creek (ie. not representative of rangelands), it was not possible to do this.

The KDD releases water throughout the year at a reasonably consistent rate (Figures 13, 14), the only variations in flow are generated by the high wet season flows coming from the rangeland catchments. In the dry season the rangeland streams are typically dry. The Dunham River continues to flow due to irrigation return from Packsaddle Irrigation Area, this has not been factored into the mass balance as currently the data is unavailable.

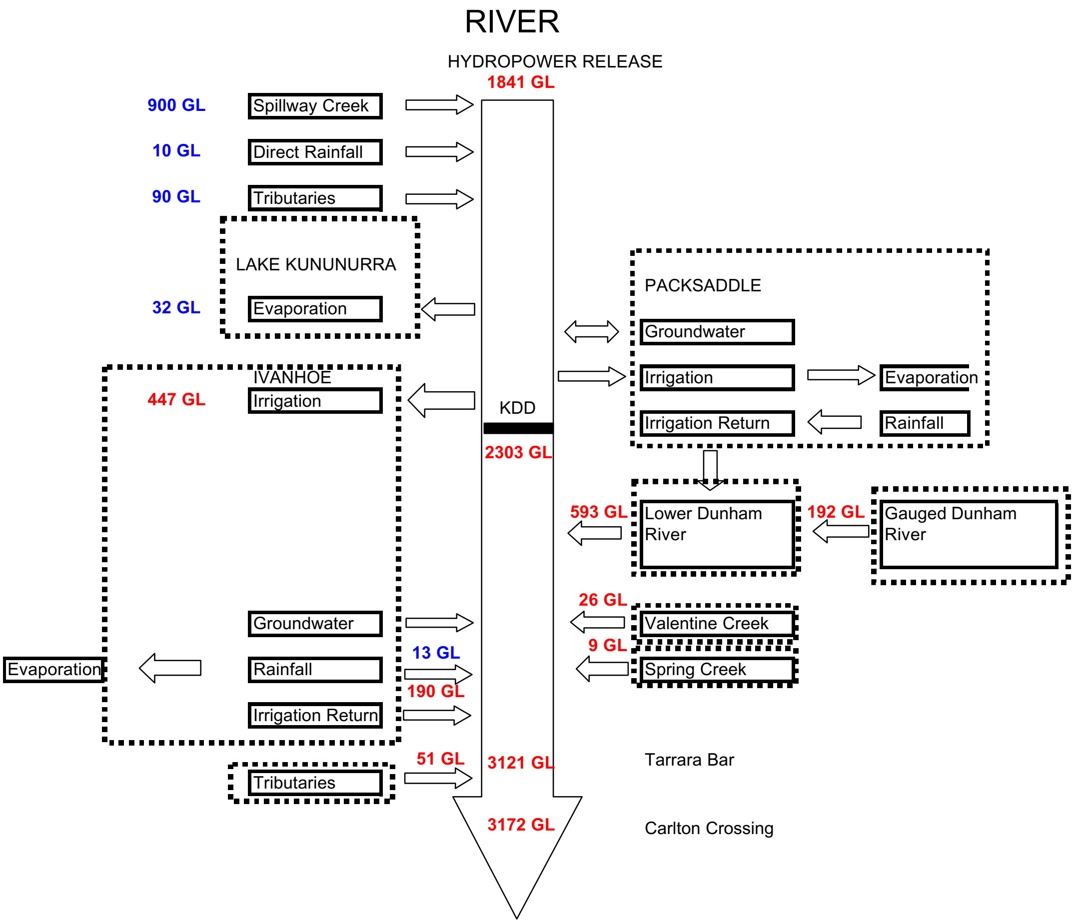


Figure 13: Mass balance model of total water volumes (in GL) contributed to and at various points along the Lower Ord River (red = estimated this study; blue = taken from Ruprecht and Rodgers, 1999)

All the flow data for Ivanhoe Crossing and sites downstream were based on the sum of the inputs, there is therefore exact agreement between River flows and contributions by tributaries and drains (Figure 14).

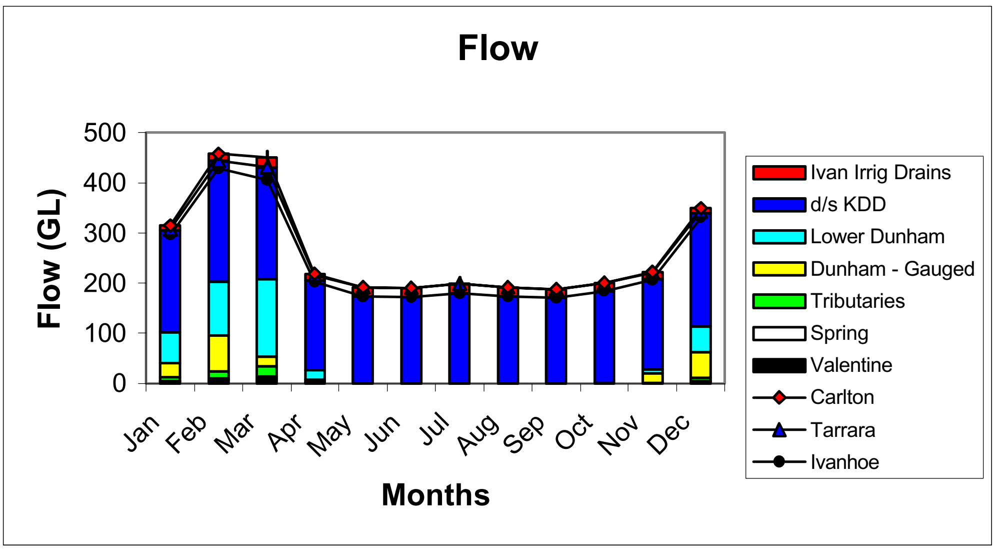


Figure 14: Monthly flow data for all major inputs to the river and at selected points along the Lower Ord River.

The Ivanhoe drains appear to appreciable quantities of TSS to the river during the wet season (Figure 15). Doupe et al (1998) showed that TSS loads at the end of the dry season were typically organic in the river but inorganic in the drains. Loads from KDD are also likely to be inaccurate as they were based on TSS concentrations in the M1 offtake and this may not accurately reflect the sediment carrying potential of the KDD releases. As a comparison, data from the Maxwell Plains monitoring site (upstream of the M1 in Lake Kununurra) was examined. These data suggest that the TSS loads in June, July and September may be over estimated as concentrations at Maxwell Plains were an order of magnitude lower. There was good agreement between M1 and Maxwell Plains concentrations for all other parameters measured. Extremely high loads of TSS were determined for the River especially during the wet season, this is due to high TSS concentrations recorded at this time in 1999.

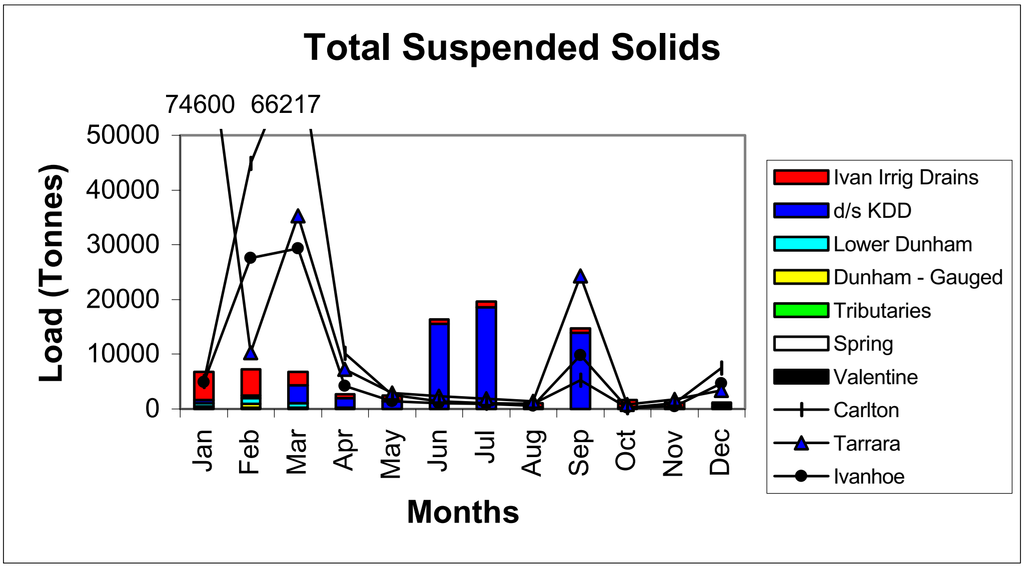


Figure 15: Monthly total suspended solid loads for all major inputs to the river and at selected points along the Lower Ord River.

The mass balance model (Figure 16) shows that inputs and river loads are not in agreement, this is again most likely due to the high wet season concentrations seen in 1999. Alternatively this could be evidence of higher flow rates resuspending sediment from the channel and transporting it downstream.

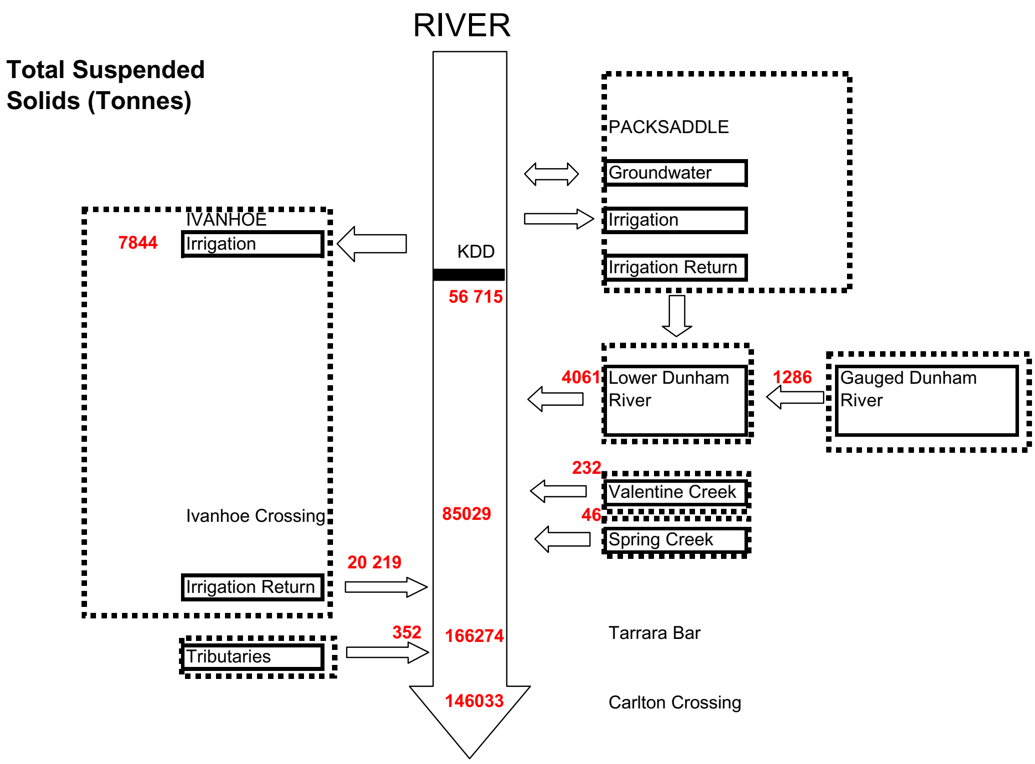


Figure 16: Mass balance model of total suspended solid loads (in tonnes) contributed to and at various points along the Lower Ord River (red = estimated loads)

The Ivanhoe drains make a substantial contribution to Total P loads into the river (Figure 17) as the annual of load from the drains is almost equivalent to that from the KDD (Figure 18). There is close agreement between river and tributary inputs except in the wet season where high river concentrations in 1999 have raised river loads. Highest loads from the drains occur at the end of the dry season presumably as fertilisers are applied to ripening crops.

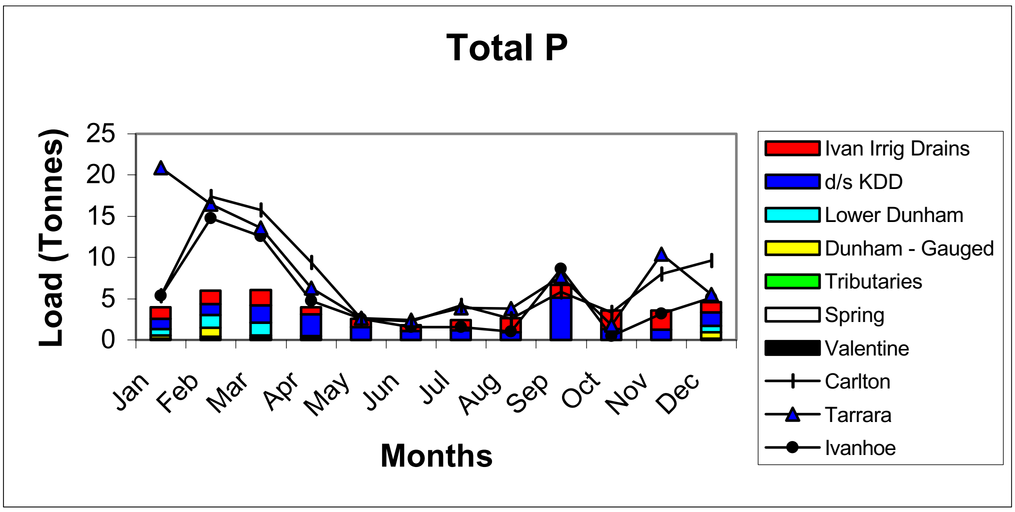


Figure 17: Monthly total P loads for all major inputs to the river and at selected points along the Lower Ord River.

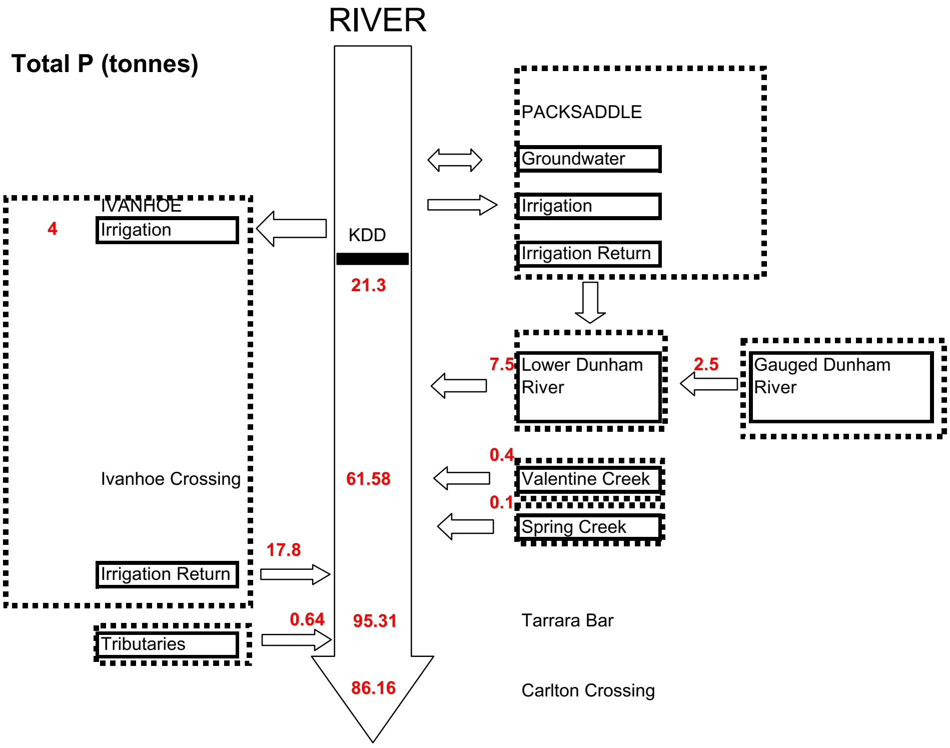


Figure 18: Mass balance model of total P loads (in tonnes) contributed to and at various points along the Lower Ord River (red = estimated loads)

The increase in Total P seen at the end of the dry season is clearly visible in increased FRP loads, further suggesting that the source is fertiliser applications on irrigated areas (Figure 19).

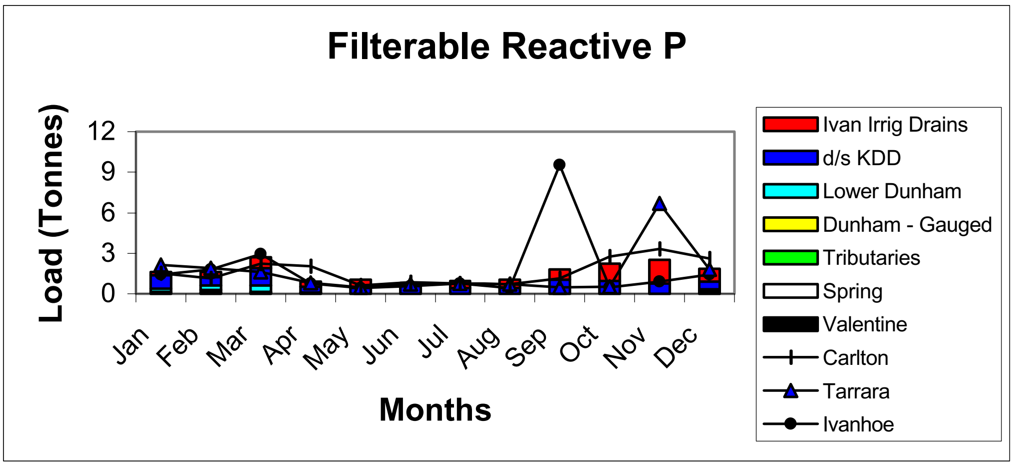


Figure 19: Monthly filterable reactive P loads for all major inputs to the river and at selected points along the Lower Ord River.

The FRP load from the Ivanhoe irrigation area is equivalent to that from KDD releases, showing that appreciable concentrations are present in irrigation return to the river.

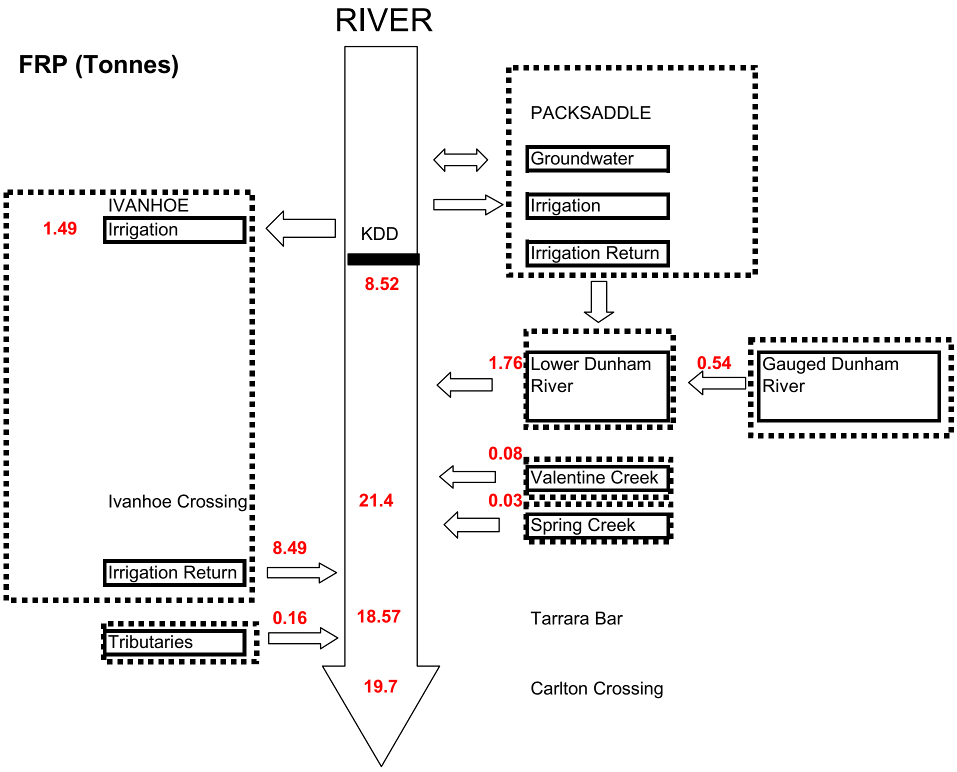


Figure 20: Mass balance model of filterable reactive P loads (in tonnes) contributed to and at various points along the Lower Ord River (red = estimated loads)

There is little seasonal variation in Total N loads, although in the wet season river loads are supplemented by the flows off the rangelands (Figure 21).

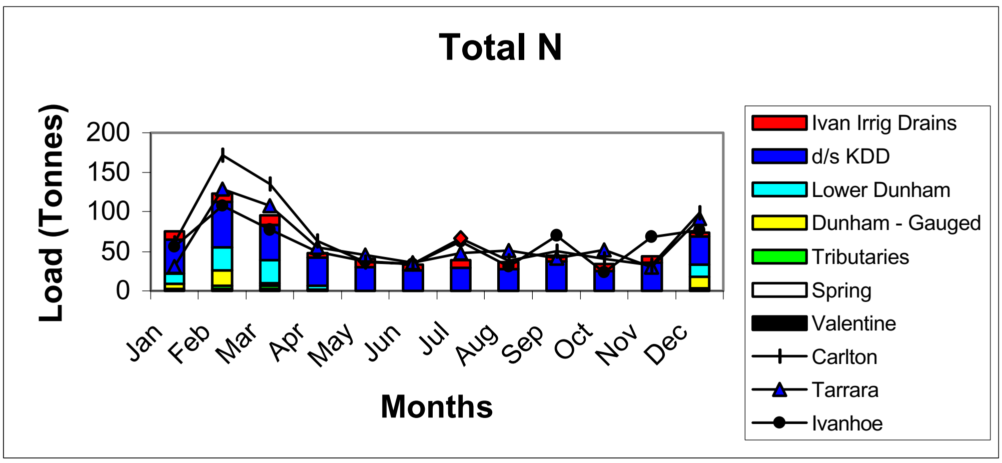


Figure 21: Monthly total N loads for all major inputs to the river and at selected points along the Lower Ord River.

Irrigation return makes a similar annual contribution to river loads compared to rangelands, but both are substantially less than the loads supplied by the KDD releases (Figure 22).

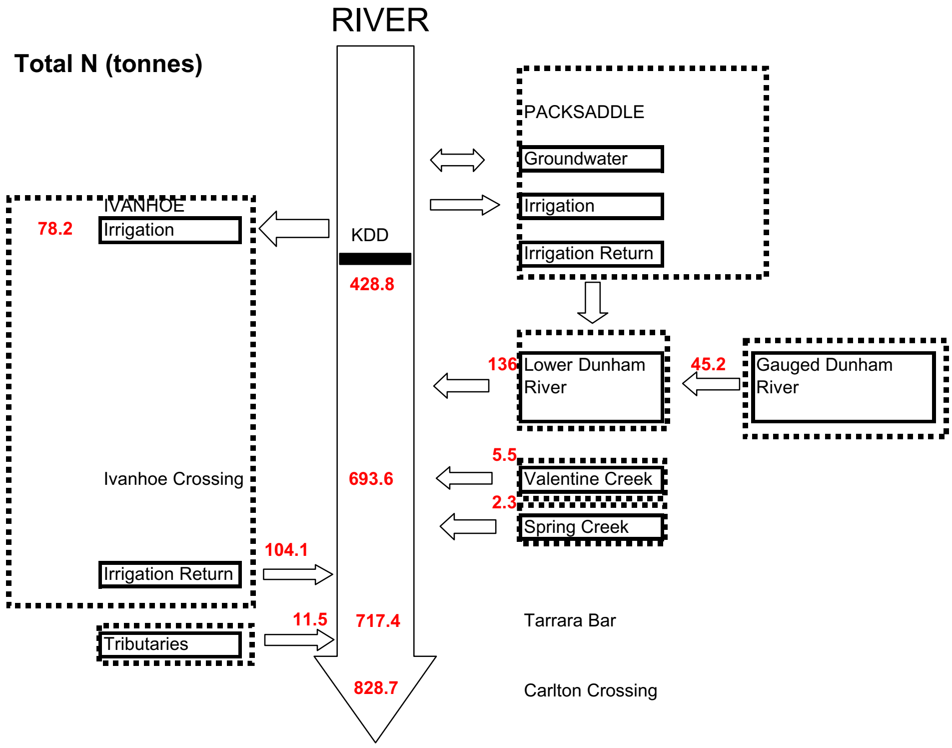


Figure 22: Mass balance model of total N loads (in tonnes) contributed to and at various points along the Lower Ord River (red = estimated loads)

Irrigation return is a substantial contributor of total oxidised N (nitrate and nitrite) (Figures 23 and 24), presumably from fertiliser applications (applications of urea and ammonium salts are also likely to be oxidised in the channels to form TON).

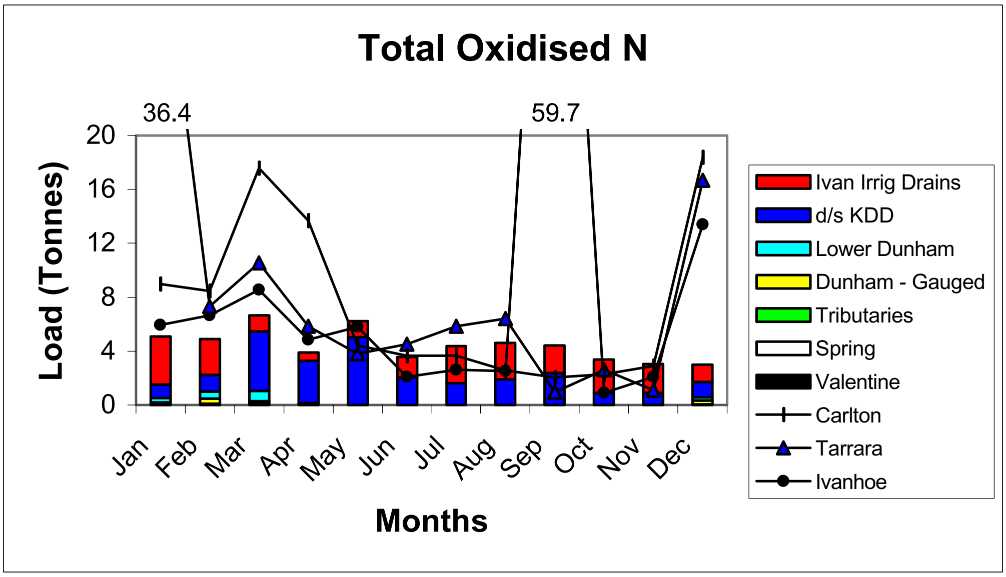


Figure 23: Monthly total oxidised N (nitrate/nitrite) loads for all major inputs to the river and at selected points along the Lower Ord River.

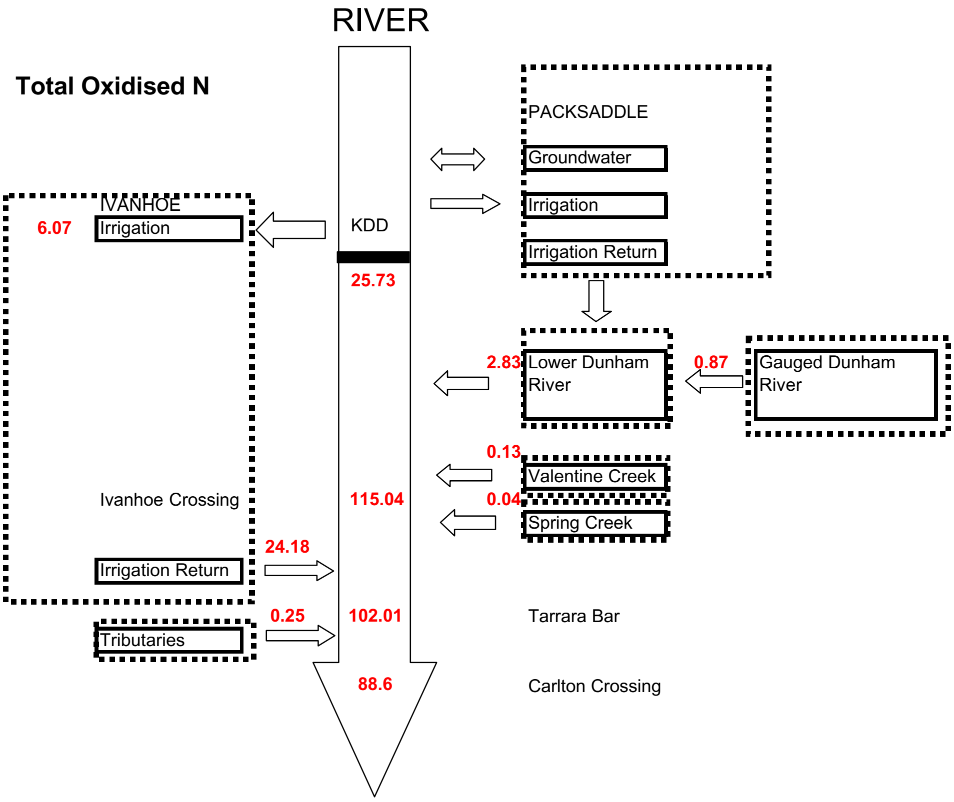


Figure 24: Mass balance model of total oxidised N loads (in tonnes) contributed to and at various points along the Lower Ord River (red = estimated loads)

The contribution of irrigation return to total Kjeldahl N loads appears relatively small reflecting the lower inputs of organic material into the drains compared to KDD releases or rangelands (Figures 25 and 26). Total Kjeldahl N loads are relatively constant throughout the year except in the wet season where loads are supplemented by input from the rangelands.

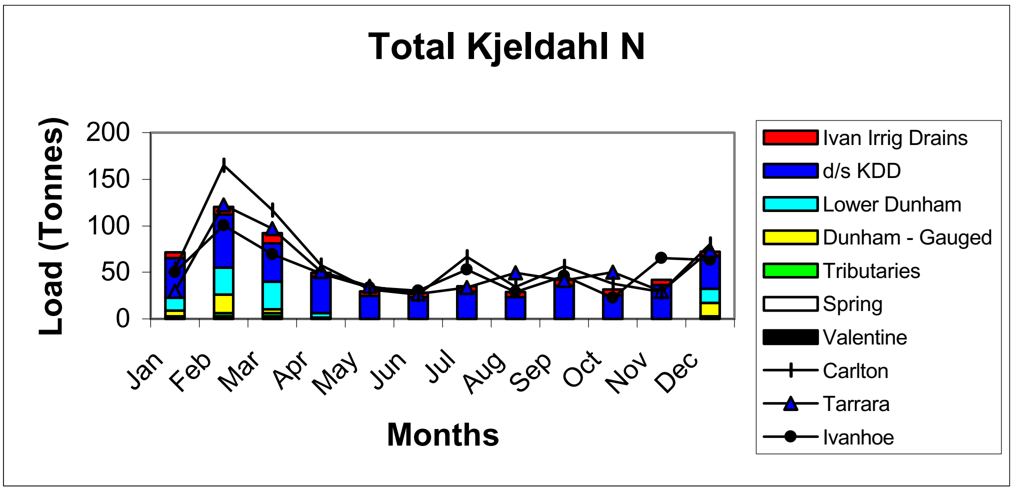


Figure 25: Monthly total Kjeldahl N loads for all major inputs to the river and at selected points along the Lower Ord River.

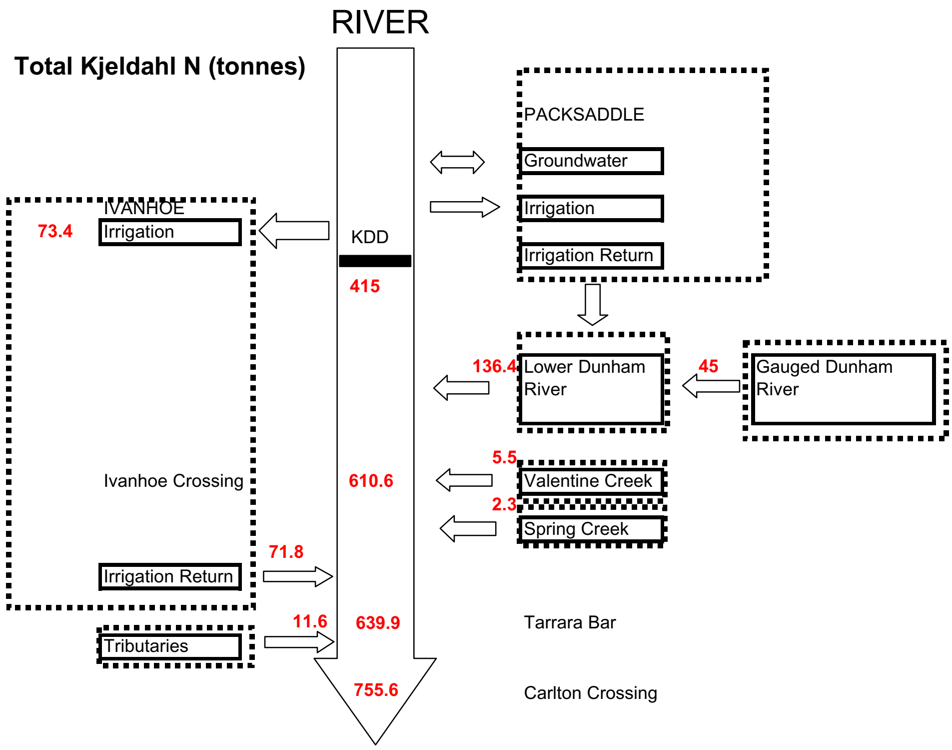


Figure 26: Mass balance model of total Kjeldahl N loads (in tonnes) contributed to and at various points along the Lower Ord River (red = estimated loads)

Irrigation return only makes a relatively small contribution to river ammonia loads, presumably most of the ammonia is converted by natural processes to TON (Figures 27 and 28).

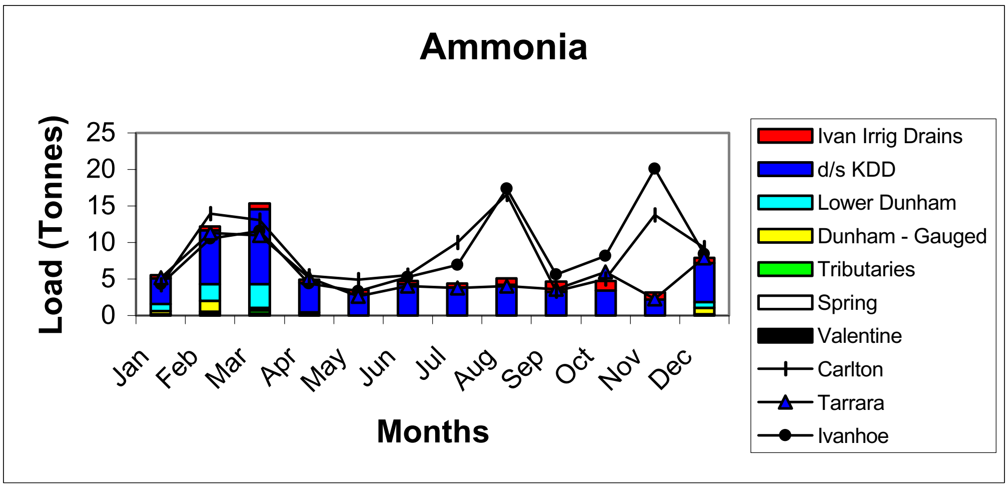


Figure 27: Monthly ammonia loads for all major inputs to the river and at selected points along the Lower Ord River.

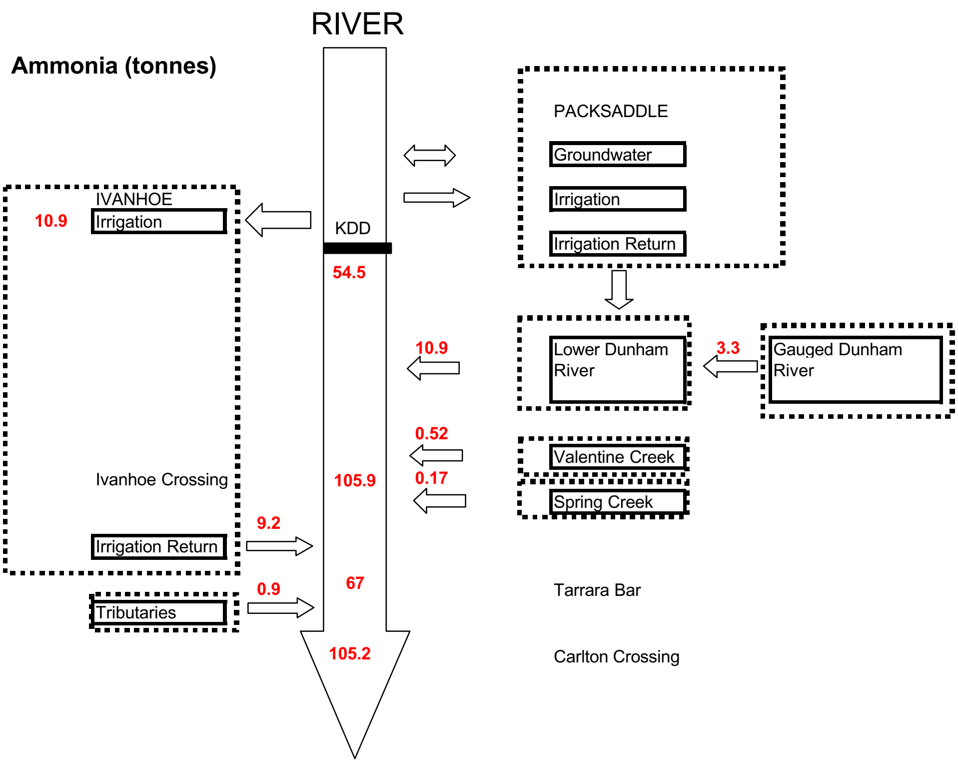


Figure 28: Mass balance model of ammonia loads (in tonnes) contributed to and at various points along the Lower Ord River (red = estimated loads)

There is considerable missing data in the total organic C record, making interpretation of the data difficult (Figure 29). It does appear that total organic C in irrigation return is relatively insignificant compared to contributions from rangelands and KDD releases.

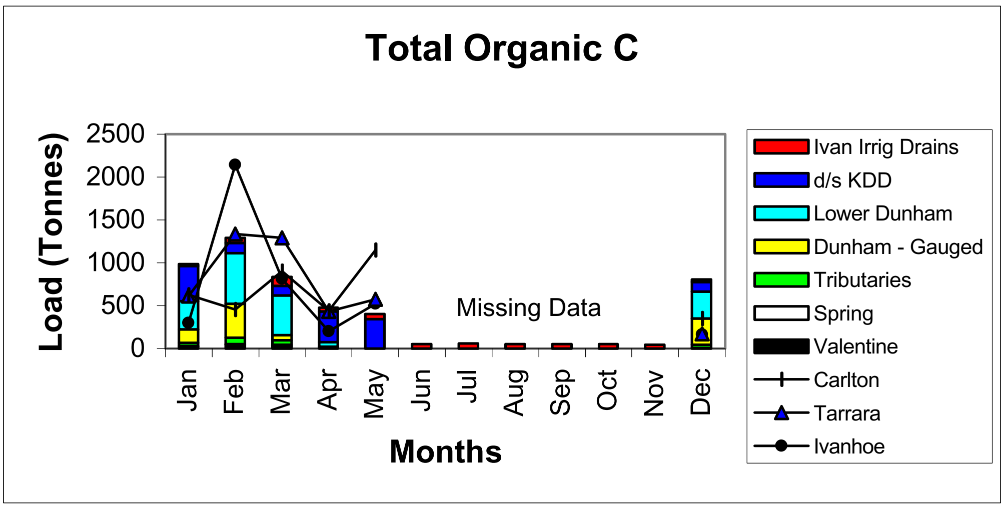


Figure 29: Monthly total organic C loads for all major inputs to the river and at selected points along the Lower Ord River.

Conceptual Models

The production of the conceptual models includes some important assumptions:
- The main effect of Ord Stage II is in reducing water quantity in the lower Ord River rather than changing current nutrient loadings (due to the proposed design and on-farm recycling).
- Although current WRC water allocation planning will aim to prevent the formation of pools in the river, this still remains a risk.

Two simple conceptual models were constructed. It was decided that the lack of knowledge of the system precluded detailed models and it is anticipated that the models developed for the Fitzroy (Qld) and Goulburn Broken will be applicable to the Lower Ord in a generic sense. The models produced are therefore designed to put the assumptions of risk into context rather than explain all possible interactions. The first model (Figure 30) focuses on the effects of altering water quantity within the Lower Ord River. This will occur due to increased removal for irrigation under Ord Stage II and could occur due to poor rainfall events within a year (or successive years).

In the first model as water quantity drops either through increased irrigation usage or below average rainfall or both, that this has two effects. The first is the reduction in the dilution rate of incoming irrigation return, increasing nutrient concentrations within the river. Coupled with this is the possibility of pools forming within the river channel, where the hydraulic residence time (time spent by the water in the pool) exceeds 3 days. This potentially could lead to a variety of ecological consequences, which would depend on the P concentration. Low P concentrations would encourage the growth of submerged macrophytes within the pools. High P concentrations could result in the development of potentially toxic cyanobacterial blooms. Under both scenarios excessive production of organic material could lead to high biological oxygen demand and subsequent reductions in the dissolved oxygen concentrations to levels that will result in the death of fish and other biota in the water. The presence of moderate nutrient concentrations and moderate hydraulic residence will provide a potentially favourable environment for many weed species to proliferate. Reduced dilution and longer hydraulic residence times will increase the chances of biocides reaching toxic levels. As the quantity of water declines its capacity to carry sediment will also tend to be reduced (assuming that velocity declines), this will reduce scouring and resuspension of sediment and encourage sedimentation. As sediment accumulates within the channel, this will be stabilised by vegetative growth (emergent followed by riparian), enhanced by the constant supply of nutrients. This is predicted to result in loss of habitat for benthic macroinvertebrates and shallows for fish.

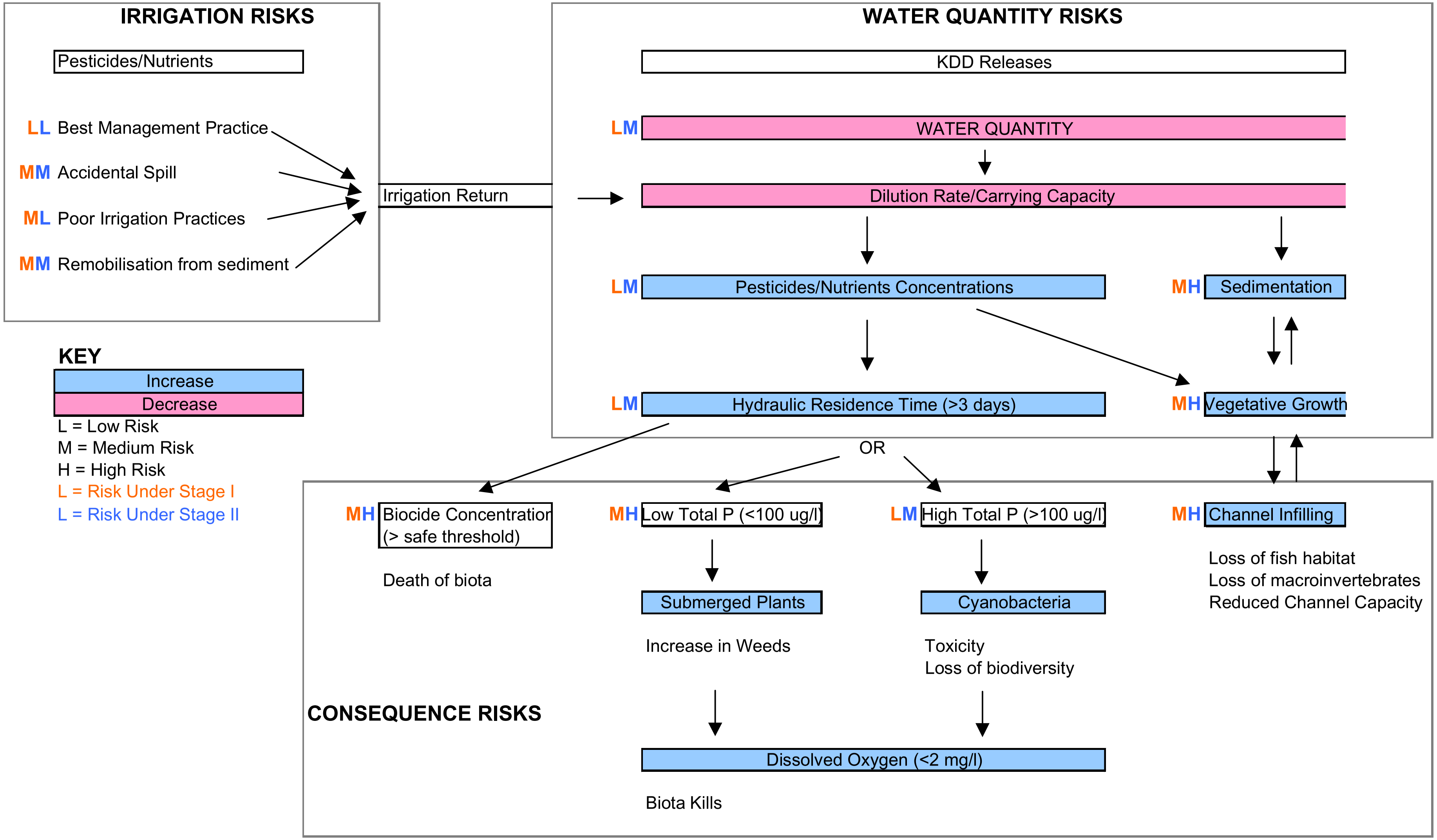


Figure 30: Conceptual model illustrating potential risks of stressors responsible for causing ecological consequences associated with irrigation in the Lower Ord River. The risks associated with water quantity changes are illustrated under Stage I and Stage II developments.

The second model (Table 3) lists the requirements of biota (fish, crocodiles and invertebrates) in general terms, with specific needs highlighted (reasons). The impact of irrigation on each of these reasons is assessed and the risk determined. A healthy animal community (fish, crocodiles and invertebrates) requires adequate flows, habitat (physical and vegetative) and suitable water quality. Low water levels can result in physical barriers restricting the distribution and migration of certain species. Infilling of the channel is likely to reduce habitat for invertebrates, crocodiles, fish and wading birds. Another potential problem identified by Dr Andrew Storey was that the infilling was promoting the growth of emergent C4 plants, which are not believed to contribute to aquatic food chains. The concern is that this could reduce the availability of food sources for biota.

Table 3: Conceptual model of key requirements for the continues maintenance of healthy communities of biota in the Lower Ord River, why they are important and how they are likely to be impacted by irrigation return.

Requirement	Reasons	Impact of Irrigation	Risks Stage I	Risks Stage II
Flows	Provides breeding cues Sufficient to allow migration	Physical Barriers	L	M
Physical Structure	Provides a range of depths and flow regimes	Infilling of channel	M	H
Vegetation (Riparian and submerged)	Provides range of habitats Provides inputs of Carbon Buffers nutrient concentrations Stabilises sediment	Infilling of channel Replacement of useable C3 inputs with that of C4 plants	M M	H H
Water Quality	Dissolved Oxygen (>2 mg/l) Safe levels of biocides	Nutrient loads in concert with low flows and increased hydraulic residence time Derived from irrigation area	L M	M H

Ranking of Risk

Risks of individual components of the conceptual models were determined based on expert opinion, these were then assigned values (L = 1, M = 2 and H = 3). A mean for each component was taken and then averaged to find the risk. The three major components were likelihood of problem in irrigation return, the impact of water quantity and finally the likelihood of consequence occurring (Table 4). The relative ranking of risk (L, M and H) applies only to the Ord and cannot be directly translated to or compared with either Goulburn Broken or Fitzroy (Qld) catchments, as some stakeholders believed that the use of L, M and H could convey an unintended message.

Table 4: Estimating the risk of ecological consequences using the first conceptual model.

Stage I				
Consequence	Irrigation risks	Waterquantity risks	Consequence risks	Overall Risk
Algal Blooms	LMMM = 1.8	LLL = 1	L = 1	1.3 = L
Biota Kills	LMMM = 1.8	LLL = 1	M = 2	1.6 = M
Loss of biodiversity	LMMM = 1.8	LLLLMM = 1.5	LM = 1.5	1.6 = M
Channel Infilling	LMMM = 1.8	LMM = 1.7	M = 2	1.8 = M
Weeds	LMMM = 1.8	LLL = 1	M = 2	1.6 = M
Stage II				
Algal Blooms	LMLM = 1.5	MMM = 2	M = 2	1.8 = M
Biota Kills	LMLM = 1.5	MMM = 2	H = 3	2.2 = M
Loss of biodiversity	LMLM = 1.5	MMMMHH = 2.3	MH = 2.5	2.1 = M
Channel Infilling	LMLM = 1.5	MHH = 2.7	H = 3	2.4 = M
Weeds	LMLM = 1.5	MMM = 2	H = 3	2.2 = M

In comparison a mean was taken of all the listed risks in Conceptual Model 2 to determine the risk of loss of biodiversity. The result was 1.7 (M) for Stage I and 2.7 (H) for Stage II, which closely match the risks obtained in Table 4, although the risk for Stage II was noticeably higher.

The estimated risks are presented in Table 5 for each consequence. The consequences are defined as:

Algal Blooms – blooms of mainly cyanobacteria, although could include green algae.
Biota kills – refers to the death of fish and other biota either through loss of dissolved oxygen or through high concentrations of biocides. It was decided the highest risk was posed by biocides.
Loss of biodiversity – was used to cover loss of fish, crocodiles, wading birds and macroinvertebrates. To a lesser extent loss of significant plants (riparian or submerged) was also included here.
Channel Infilling – refers to the loss of channel width and depth through sedimentation and the stabilisation of deposited material.
Weeds – used to cover invasion by exotic plants and to a lesser extent exotic fauna.

Table 5: Ecological effects ranking matrix table

Ecological Consequence	Importance in catchment		Impact of Irrigation	Risk		Knowledge
	Local	Broad		Stage I	Stage II	
Algal Blooms	M	L	H	L(1.3)	M(1.8)	L
Biota Kills (biocides)	H	L	H	M(1.6)	M(2.2)	L
Loss of biodiversity	M	M	M	M(1.6)	M-H (2.1-2.7)	L
Channel Infilling	M	L	L	M(1.8)	M(2.4)	L
Weeds	M	M	M	M(1.6)	M(2.2)	L

Although there was general agreement amongst all stakeholders on the risk values associated with Table 5, Joe Sherrard of Agriculture WA suggested that weeds posed a lower risk than Loss of Biodiversity.

Priorities were seen by stakeholders as
1. Loss of biodiversity and biota kills
2. Weeds.
3. Algal blooms were believed to be relatively unlikely (low risk), while channel infilling was believed to be happening regardless of irrigation and the contribution of irrigation was believed to be minor.

Knowledge Gaps

This study has been the first attempt within the Ord catchment to quantify nutrient loads within the irrigation area on an annual basis. It utilises all the limited data available on flows and nutrient concentrations. Only one other study (Doupe et al, 1998) has collected this type of data and that was only a snapshot of the system. This poor state of knowledge is reflected in virtually all aspects of the river ecology.

The final stakeholder meeting in Kununurra discussed the following suggestions (by the authors) as priority areas for future research to fill existing knowledge gaps:

1. Improved monitoring programs in the irrigation and especially river areas to allow for substantial improvements in understanding of mass balances of nutrients
2. On farm studies to trace movement of pesticides to the river
3. Attempt to determine the capacity of the river and biota to deal with existing nutrient loads i.e. are the current loads actually causing a problem, such as resulting in loss of biodiversity.

While there was general agreement on these priority areas, Ord Land and Water listed the following priorities taken from the Ord Land and Water Plan (Section 3.3.5):
1. Amount of tailwater leaving the irrigation area
2. Extent of soil loss from farms
3. Impact of first wet season storm events on chemical, nutrient and sediment loads from the irrigation area to the river.

Agriculture WA was keen to see Phase II develop a better understanding of any potential for impact on waterways from movement off farm. Joe Sherrard stressed the importance of making the report available to relevant parties so that findings not listed as priorities for NPIRD could be used to facilitate other research programs or immediate improvements in farm management practices.

There was substantial support amongst all stakeholders for Phase II of the project to be undertaken. Stephen Tapsall (Project Officer for Ord-Bonaparte Project (OBP)) was keen to ensure that Phase II of the project integrates well with the OBP to ensure that research funds were expended in the most efficient way possible. Unfortunately, we are still awaiting feedback from scientists involved in the OBP on the report, however preliminary discussions have already been undertaken. The spirit of cooperation is high from all Kununurra stakeholders. In addition to Agency and Industry support, the community group Ord Land and Water are keen to be involved in Phase II of the project and have offered to provide whatever assistance they can to the project.

References

Deegan, P.(ed.) (2000). *Ord River Scientific Panel Recommendations for estimation of interim ecological water requirements for the Ord River.* Water and Rivers Commission, Perth.

Doupe, R.G., Lund, M.A., & Ranford, S.R. (1998*). A short-term assessment of point source pollution in the M1 irrigation supply channel with notes on agricultural discharge into the lower Ord River*. Water Corporation WA, Perth.

Ruprecht, J.K. & Rodgers, S.J. (1999). *Hydrology of the Ord River*, Rep. No. WRT 24. Water and Rivers Commission, Perth.

Appendix 1: Calculation of Water Quality Data

Water quality data were collected by WRC at approximately monthly intervals from a number of river and irrigation drain sites between April 1998 and August 2000. All flow and water quality data were averaged across 1998-2000 except where noted. Where water quality parameters were below detection, they were replaced with a substituted value (Table A1.1). Missing values were ignored.

Table A1.1: Detection limits for nutrient analysis for WRC water quality data and value substituted in load calculations when concentrations were below detection.

Parameter	Detection Limit (mg L^{-1})	Substituted value (mg L^{-1})
Total Suspended Solids	<1	0.5
Total P	<0.005	0.0025
Filterable Reactive P	<0.005	0.0025
Total Kjeldahl N	<0.025	0.0125
Ammonia	<0.01	0.005
Total Oxidised N	<0.01	0.005
Total N	Not given	NA
Total Organic Carbon	<1	0.5

Water quality parameters were averaged monthly from the data available for calculation of loads (ie. the monthly value for April is the average of 7/4/98, 6/4/99 and 4/4/00). Loads for the Ivanhoe irrigation area were calculated on a daily basis for 1998-00, using all the measured water quality values and assuming that concentrations remained the same from one sampling point to the next. Data from the three years was then averaged and this value used to estimate loads (see example in Table A1.2)

Table A1.2: Example of water quality concentration calculations for Ivanhoe Irrigation Area. Mean values of water quality parameters were averaged across the years after inserting the measured water quality value into a matrix (shaded cells) and using the same value to the next measured value. Leap days were ignored.

Date	1998	1999	2000	Mean
4 Apr		68	55	61.5
5 Apr		68	55	61.5
6 Apr		105	55	80
7 Apr	44	105	55	68
8 Apr	44	105	55	68
9 Apr	44	105	43	64

Individual loads were then summed to into monthly values.

Water quality values for grazed catchments (e.g. Dunham) were estimated using average values from the Spring and Valentine Creeks.

Appendix 2: Calculation of Flow Rates

The data collected at WC gauging stations on Ivanhoe Irrigation Area were compiled into a matrix (see Table A2.1) and then averaged to give a mean daily flow. Missing values were ignored.

Table A2.1: Example of flow rate calculations for Ivanhoe Irrigation Area. Flow rates were averaged across the years after inserting the measured flow rates into a matrix (shaded cells). Leap days were ignored.

Date	1998	1999	2000	Mean
17 Jul		1637	1320	1478.5
18 Jul		1493	1431	1462
19 Jul	1393	1679	1472	1514.6
20 Jul	1399	1677	1490	1522

Monthly flow rates for KDD and Ivanhoe Crossing (d/s of Dunham River Confluence), were based on modelled data supplied by WRC. In addition, flow data for Ivanhoe Crossing, Tarrara Bar and Carlton Crossing were estimated by summing all river, irrigation and tributary data u/s of each site.

Table A2.2 Inputs into the water balance at selected points along the Ord River

Site	Contributors to Flow
Ivanhoe Crossing	KDD Releases Valentine Creek Dunham Gauged Section Lower Dunham Catchment Packsaddle Irrigation Return
Tarrara Bar	Above D4, D7, D2B, D2, D1 Spring Creek
Carlton Crossing	Above Slatey/Mantinea Creeks Homestead Creek Northern Tributaries

The gauging station data (1970-1999) on the upper Dunham was used to estimate monthly runoff coefficients as a function of rainfall at KRS that were then used to calculate flows in ungauged tributaries. Monthly KRS rainfall totals and gauged monthly flow rates from 1970-1999 were used to determine monthly runoff coefficients for each year, these were then averaged to produce an average monthly runoff rate.

Tributaries which had no gauging stations on them had flow estimated on a monthly basis using the runoff coefficients, rainfall totals and WRC estimates of catchment area (Table A2.3).

Table A2.3 WRC estimates of catchment area in the lower Ord.

Catchment	Area (km^2)
Northern Tributaries (near Carlton)	200
Slatey/Mantinea Creek	70
Homestead Creek	60
Spring Creek	60
Valentine Creek	170
Lower Dunham (excluding Packsaddle Irrigation Area drainage)	2600
Gauged Upper Dunham	1600

Appendix 3: Estimated Load Data from Ivanhoe Drainage Areas

Flow Rates (ML)

	D4	D7	D2B	D2	D1	M1
Jan	5278.54	433.015	677.985	1399.66	1940.25	26540.5
Feb	7203.19	1110.48	468	2285.42	2311.935	25763.9
Mar	8959.25	5409.705	463.575	2728.875	3001.86	29888.75
Apr	4416.28	1770.385	1288.125	3369.185	2921.025	47084.35
May	8999.9	369.12	906.875	3404.14	4089	40617.3
Jun	9568.7	498.89	1035.01	3048.445	3964.085	39375.5
Jul	10109.8	668.545	979.27	3143.455	4746.73	43758.67
Aug	8883.9	571.8	1183.355	2867.703	4876.895	41895
Sep	8700.2	793.335	1354.32	2728.595	3319.015	36779
Oct	9705.5	689.33	991.24	2058.2	2835.42	38775.65
Nov	8021.65	1013.845	1196.16	1460.33	2709.44	37069.55
Dec	4959.16	1268.92	684.295	1869.295	2076.935	39717.6

Total Suspended Solids (Tonnes)

	D4	D7	D2B	D2	D1	M1
Jan	4576.676	37.25853	183.0724	277.7545	35.41577	67.8475
Feb	4207.228	62.87937	150.6801	237.2113	134.2319	61.1392
Mar	1920.337	223.6089	38.43604	117.9079	173.7741	385.1966
Apr	311.555	28.88816	36.34918	238.5944	100.1279	525.5283
May	631.0307	5.285458	39.906	129.8304	206.9644	317.3017
Jun	439.6521	14.5264	16.88203	113.9096	221.5217	153.0355
Jul	790.4406	10.38187	25.03173	132.1443	164.7817	1215.613
Aug	483.023	14.99006	71.03492	55.28422	75.85462	2958.608
Sep	559.9957	2.235523	169.2218	30.25499	13.04288	722.0798
Oct	1471.295	2.577838	10.20712	15.46623	4.919113	1283.799
Nov	856.7843	3.870951	14.85946	15.60939	29.88734	70.8836
Dec	215.9557	7.90445	7.751848	27.33795	25.29474	83.1394

Total P (Tonnes)

	D4	D7	D2B	D2	D1	M1
Jan	0.977472	0.058489	0.164803	0.143575	0.064927	0.171017
Feb	1.081928	0.129211	0.083583	0.140235	0.195389	0.140892
Mar	0.785337	0.602571	0.081703	0.144998	0.250261	0.267312
Apr	0.251638	0.1786	0.073097	0.176607	0.128381	0.674798
May	0.33556	0.035498	0.058508	0.152646	0.470856	0.33781
Jun	0.431728	0.04956	0.028926	0.07181	0.104662	0.303369
Jul	0.838955	0.090936	0.032738	0.113188	0.173684	0.226415
Aug	1.148071	0.104219	0.065033	0.073305	0.26547	0.193983
Sep	1.171036	0.191634	0.07804	0.060049	0.075245	0.410065
Oct	1.973858	0.125482	0.034784	0.030365	0.071591	0.649465
Nov	1.899228	0.22583	0.047382	0.039912	0.103694	0.280154
Dec	0.900866	0.229103	0.046071	0.073107	0.055622	0.303766

Filterable Reactive P (Tonnes)

	D4	D7	D2B	D2	D1	M1
Jan	0.091786	0.03344	0.025314	0.028829	0.033778	0.084809
Feb	0.136683	0.076021	0.02765	0.050708	0.127952	0.075707
Mar	0.192138	0.372658	0.054866	0.055062	0.159701	0.160399
Apr	0.090068	0.123629	0.039286	0.057916	0.043354	0.135209
May	0.154373	0.02154	0.031829	0.08017	0.328121	0.101543
Jun	0.14961	0.029721	0.011447	0.026038	0.034407	0.108133
Jul	0.313546	0.055474	0.019038	0.052735	0.062231	0.168721
Aug	0.438485	0.027794	0.037558	0.054158	0.056125	0.104738
Sep	0.609299	0.068369	0.009819	0.02941	0.041034	0.112969
Oct	1.144543	0.088811	0.009142	0.010409	0.034296	0.167283
Nov	1.462412	0.19958	0.012466	0.008049	0.044492	0.146084
Dec	0.668977	0.19442	0.005413	0.011717	0.028874	0.122077

Total Kjeldahl N (Tonnes)

	D4	D7	D2B	D2	D1	M1
Jan	4.48961	0.332026	0.305066	0.543825	0.567969	4.615643
Feb	5.006012	0.863427	0.259366	0.924992	0.957082	5.545272
Mar	4.329764	4.051164	0.21185	1.121134	1.218671	5.755052
Apr	1.245094	0.920894	0.319649	0.82567	0.947641	10.17012
May	2.41945	0.222752	0.229396	0.898566	1.211656	6.094297
Jun	2.548069	0.334974	0.206707	0.582222	0.75624	6.406025
Jul	3.137303	0.468434	0.155833	0.819808	0.734622	5.52239
Aug	3.372409	0.416422	0.343723	0.515192	1.11755	6.55887
Sep	4.083354	0.3994	0.618504	0.543739	0.586147	5.265465
Oct	4.339807	0.31483	0.397551	0.367337	0.54604	5.745478
Nov	3.800297	0.580385	0.31377	0.231969	0.700915	5.519817
Dec	2.387954	0.788606	0.153875	0.277867	0.426262	6.218183

Ammonia (Tonnes)

	D4	D7	D2B	D2	D1	M1
Jan	0.389854	0.024918	0.010247	0.019089	0.034062	0.594169
Feb	0.27311	0.071481	0.013969	0.063327	0.057867	0.69987
Mar	0.27628	0.330557	0.039545	0.100588	0.104703	1.303786
Apr	0.189744	0.091331	0.038522	0.082686	0.065704	1.24345
May	0.247017	0.016915	0.025688	0.087577	0.221626	0.675044
Jun	0.249035	0.028117	0.020668	0.057155	0.093131	0.959564
Jul	0.3226	0.044015	0.020894	0.074886	0.103019	1.292729
Aug	0.591182	0.029308	0.053586	0.054297	0.087377	0.944556
Sep	1.100231	0.029571	0.137619	0.054176	0.079156	0.871056
Oct	1.139043	0.024355	0.064897	0.040562	0.07701	0.835044
Nov	0.812504	0.028956	0.049646	0.028738	0.07382	0.685829
Dec	0.587069	0.041754	0.020581	0.032031	0.05165	0.804424

Total Oxidised N (Tonnes)

	D4	D7	D2B	D2	D1	M1
Jan	3.034078	0.062523	0.192927	0.074702	0.192862	0.132703
Feb	2.182862	0.070502	0.149238	0.097398	0.180175	0.12882
Mar	0.827417	0.243978	0.02487	0.049796	0.040958	0.539125
Apr	0.398011	0.061896	0.018573	0.106818	0.032108	0.850426
May	1.025123	0.012102	0.040679	0.085023	0.036955	0.875352
Jun	1.282774	0.002753	0.02205	0.119236	0.071027	0.909305
Jul	2.5173	0.008055	0.004896	0.1292	0.114153	0.580274
Aug	2.304332	0.01487	0.022654	0.339059	0.024384	0.40439
Sep	1.892294	0.012115	0.062299	0.053208	0.016595	0.458623
Oct	2.1144	0.017196	0.117286	0.037312	0.171323	0.49848
Nov	1.623647	0.021074	0.16096	0.021418	0.321873	0.333626
Dec	1.14514	0.06626	0.029523	0.027416	0.052042	0.357458

Total N (Tonnes)

	D4	D7	D2B	D2	D1	M1
Jan	7.515704	0.394749	0.491746	0.615152	0.750059	4.689475
Feb	7.182494	0.936959	0.40491	1.021535	1.134491	5.596196
Mar	5.144911	4.303539	0.236597	1.16906	1.263699	6.142268
Apr	1.836332	1.12338	0.322564	1.296425	0.945287	9.749577
May	7.732823	0.220975	0.273654	1.009361	1.168758	7.087899
Jun	4.98383	0.296627	0.228929	1.077571	0.982807	6.764509
Jul	7.068524	0.419284	0.268745	0.932773	1.119022	6.400727
Aug	6.241416	0.392813	0.363432	0.749103	1.43209	6.783307
Sep	5.189794	0.468085	0.626553	0.601737	0.686519	6.237523
Oct	6.586244	0.376391	0.467759	0.405376	0.766121	6.544579
Nov	5.357927	0.563548	0.472743	0.264358	1.018144	5.754383
Dec	3.483226	0.810656	0.184052	0.297343	0.468916	6.478387

Total Organic Carbon (Tonnes)

	D4	D7	D2B	D2	D1	M1
Jan	19.42022	2.59809	0.923115	1.92344	1.551295	35.42
Feb	29.63565	6.66288	1.40712	6.58078	10.55581	26.4388
Mar	35.837	32.45823	2.1952	15.16845	18.01116	14.94438
Apr	13.53186	10.62231	4.06116	5.048535	6.69815	86.0927
May	27.62185	2.15034	3.52261	6.74652	15.39747	81.2346
Jun	38.2748	1.49667	2.07002	6.09689	7.92817	78.751
Jul	40.4392	2.005635	1.95854	6.28691	9.49346	87.51733
Aug	35.5356	1.7154	2.36671	5.735407	9.75379	83.79
Sep	34.8008	2.380005	2.70864	5.45719	6.63803	73.558
Oct	38.822	2.06799	1.98248	4.1164	5.67084	77.5513
Nov	32.0866	3.041535	2.39232	2.92066	5.41888	74.1391
Dec	16.49465	4.702418	1.21718	2.709155	3.29965	63.2625

Appendix 4: Concentrations of measured water quality parameters

These tables summarise the data collected by the WRC at selected sites in the Lower Ord Catchment.

Please note that the data tables show the substituted value used when values were below detection.

Total Suspended Solids (mg/l)

Day	Month	Year	D1	D2B	D2	D3	D4	D7	M1	Carlton	Tarrara	Ivanhoe	Spring	Valentine
12	**Jan**	1999	52	948	685	630	2410	306		22	475	27	6	28
11	**Jan**	2000	3	6	7	32	54		3	10	11	6	3	2
9	**Feb**	1999	66	101	44	157	418	76	2	188	0.5	104	8	5
8	**Feb**	2000	77	56	68	316	140		2	8	46	25	5	20
9	**Mar**	1999	14		44	78	68	79	7		36	53	5	4
7	**Mar**	2000		80	38				22	147	128	91	4	8
7	**Apr**	1998	13	9	69	36	44	17	1	2	6	2		
6	**Apr**	1999	77	16	153	127	105	20	4	107	63	25	13	15
4	**Apr**	2000	14	34	15	42	55		25	30	32	35	4	4
5	**May**	1998	31	27	45	52	128	17	2	12	11	2	22	
5	**May**	1999	123	53	59	90	55	15	6	8	11	5	30	4
2	**May**	2000	1	60	2	58	30		16	18	27	18	10	1
30	**May**	2000	10	30	13	23	45	81	8	16	11	8	0.5	0.5
2	**Jun**	1998	143	3	87	47	44	4	1	5	9	2		
30	**Jun**	1998	18	73	90	143	73	5	3	6	8	1		
1	**Jun**	1999	18	16	12	26	38	13	2	6	12	5	7	12
29	**Jun**	1999	78	3	16	12	100	4	2	5	6	2	10	
27	**Jun**	2000	25	10	29	74	69	11	12	9	21	9	2	1
28	**Jul**	1998	30	21	10	21	78	2	2	3	7	2		
27	**Jul**	1999	14	10	47	11	33	4	2	3	6	2	2	
25	**Jul**	2000	13	5	6	21	82	121	307	10	15	11	0.5	0.5
25	**Aug**	1998	8	9	5	31	27	3	1	2	4	1		
24	**Aug**	1999	6	527	23	26	9	4	3	5	9	2	2	
22	**Aug**	2000	0.5	13	13	0.5	37	0.5	3	7	9	8	3	1
22	**Sep**	1998	3	15	8	96	406	3	2	2	6	1		
21	**Sep**	1999	1	1	0.5	3	14	7	161	54	253	114		
19	**Oct**	1999	3	6	5	22	9	9	1	1	4	1		
17	**Nov**	1998	42	5	12	56	86	1	2	5	10	3		
16	**Nov**	1999	22	21	13	52	32	9	0.5	4	6	2		
15	**Dec**	1998	5				35	24	3	42	16	27	5	4
14	**Dec**	1999	6	4	21	28	15	5	1	0.5	4	1	2	

Total P (mg/l)

Day	Month	Year	D1	D2B	D2	D3	D4	D7	M1	Carlton	Tarrara	Ivanhoe	Spring	Valentine
12	**Jan**	1999	0.081	0.44	0.28	0.33	0.44	0.15		0.018	0.12	0.022	0.0025	0.023
11	**Jan**	2000	0.012	0.022	0.012	0.023	0.038		0.006	0.016	0.016	0.014	0.01	0.016
9	**Feb**	1999	0.12	0.076	0.049	0.069	0.15	0.095	0.008	0.059	0.052	0.046	0.009	0.015
8	**Feb**	2000	0.086	0.1	0.04	0.1	0.063		0.003	0.017	0.022	0.023	0.008	0.028
9	**Mar**	1999	0.045		0.046	0.051	0.048	0.091	0.01		0.023	0.024	0.013	0.014
7	**Mar**	2000		0.58	0.063				0.009	0.035	0.04	0.038	0.008	0.005
6	**Apr**	1999	0.051	0.023	0.081	0.046	0.066	0.07	0.011	0.057	0.035	0.022	0.013	0.027
4	**Apr**	2000	0.034	0.056	0.027	0.052	0.05		0.019	0.029	0.023	0.025	0.016	0.011
5	**May**	1999	0.22	0.072	0.065	0.053	0.04	0.068	0.003	0.008	0.015	0.02	0.011	0.006
2	**May**	2000	0.022	0.064	0.023	0.028	0.029		0.013	0.018	0.014	0.015	0.009	0.009
30	**May**	2000	0.016	0.032	0.03	0.038	0.05	0.022	0.011	0.014	0.013	0.01	0.009	0.012
1	**Jun**	1999	0.036	0.025	0.015	0.016	0.037	0.16	0.005	0.012	0.015	0.011	0.009	0.021
29	**Jun**	1999	0.04	0.044	0.044	0.019	0.11	0.11	0.003	0.011	0.014	0.006	0.009	
27	**Jun**	2000	0.018	0.014	0.033	0.029	0.039	0.16	0.008	0.014	0.015	0.012	0.009	0.011
28	**Jul**	1998	0.12	0.03	0.02	0.1	0.26	0.22		0.04	0.04	0.01		
27	**Jul**	1999	0.04	0.091	0.045	0.01	0.032	0.034	0.005	0.012	0.009	0.008	0.011	
25	**Jul**	2000	0.028	0.021	0.009	0.032	0.094	0.18	0.008	0.011	0.01	0.008	0.008	0.01
25	**Aug**	1998	0.025	0.069	0.007	0.14	0.13	0.56	0.003	0.018	0.029	0.0025		
24	**Aug**	1999	0.02	0.12	0.055	0.031	0.043	0.11	0.005	0.01	0.013	0.006	0.014	
22	**Aug**	2000	0.029	0.035	0.018	0.015	0.18	0.15	0.009	0.012	0.017	0.009	0.017	0.01
22	**Sep**	1998	0.015	0.021	0.014	0.31	0.32	0.22	0.009	0.024	0.04	0.008		
21	**Sep**	1999	0.008	0.01	0.012	0.022	0.018	0.099	0.051	0.038	0.042	0.093		
20	**Oct**	1998	0.07	0.13	0.016	0.24	0.51	0.28	0.003	0.027		0.0025		
19	**Oct**	1999	0.025	0.012	0.011	0.02	0.05	0.26	0.012	0.006	0.009	0.0025		
17	**Nov**	1998	0.045	0.003	0.083	0.5	0.47	0.27	0.011	0.061	0.082	0.023		
16	**Nov**	1999	0.029	0.037	0.02	0.03	0.025	0.23	0.003	0.011	0.012	0.008		
15	**Dec**	1998	0.014				0.09	0.13	0.006	0.041	0.021	0.025	0.015	0.015
14	**Dec**	1999	0.017	0.017	0.015	0.036	0.032	0.13	0.008	0.014	0.011	0.006	0.016	

Filterable Reactive P (mg/l)

Day	Month	Year	D1	D2B	D2	D3	D4	D7	M1	Carlton	Tarrara	Ivanhoe	Spring	Valentine
12	**Jan**	1999	0.046	0.12	0.057	0.1	0.0025	0.018		0.0025	0.007	0.0025	0.0025	0.0025
11	**Jan**	2000	0.006	0.007	0.007	0.006	0.017		0.005	0.007	0.007	0.007	0.005	0.006
9	**Feb**	1999	0.093	0.029	0.02	0.019	0.019	0.04	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
8	**Feb**	2000	0.049	0.061	0.02	0.032	0.025		0.0025	0.0025	0.006	0.006	0.0025	0.005
9	**Mar**	1999	0.025		0.015	0.014	0.016	0.036	0.0025		0.0025	0.0025	0.0025	0.0025
7	**Mar**	2000		0.46	0.025				0.009	0.005	0.005	0.012	0.005	0.0025
6	**Apr**	1999	0.011	0.009	0.027	0.009	0.028	0.04	0.0025	0.016	0.005	0.005	0.0025	0.006
4	**Apr**	2000	0.014	0.027	0.008	0.006	0.014		0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
5	**May**	1999	0.16	0.044	0.034	0.025	0.022	0.014	0.0025	0.005	0.0025	0.0025	0.0025	0.0025
2	**May**	2000	0.011	0.031	0.014	0.008	0.011		0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
30	**May**	2000	0.005	0.011	0.01	0.022	0.017	0.009	0.0025	0.0025	0.0025	0.0025	0.0025	0.005
1	**Jun**	1999	0.011	0.011	0.006	0.006	0.013	0.096	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
29	**Jun**	1999	0.022	0.02	0.022	0.009	0.043	0.085	0.0025	0.009	0.005	0.0025	0.006	
27	**Jun**	2000	0.006	0.007	0.011	0.009	0.012	0.11	0.006	0.006	0.006	0.006	0.006	0.008
27	**Jul**	1999	0.016	0.075	0.038	0.006	0.014	0.018	0.0025	0.005	0.005	0.006	0.0025	
25	**Jul**	2000	0.005	0.007	0.0025	0.015	0.065	0.037	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
24	**Aug**	1999	0.007	0.0025	0.022	0.008	0.014	0.056	0.0025	0.0025	0.0025	0.0025	0.006	
22	**Aug**	2000	0.019	0.012	0.007	0.007	0.13	0.11	0.0025	0.005	0.005	0.0025	0.007	0.0025
21	**Sep**	1999	0.0025	0.0025	0.0025	0.013	0.0025	0.076	0.006	0.006	0.0025	0.056		
20	**Oct**	1998	0.017	0.024	0.008	0.18	0.41	0.27	0.0025	0.025		0.0025		
19	**Oct**	1999	0.008	0.0025	0.0025	0.0025	0.033	0.21	0.008	0.0025	0.0025	0.0025		
17	**Nov**	1998	0.019	0.0025	0.006	0.4	0.36	0.25	0.006	0.019	0.058	0.006		
16	**Nov**	1999	0.017	0.011	0.0025	0.011	0.025	0.23	0.0025	0.011	0.0025	0.0025		
15	**Dec**	1998	0.005				0.053	0.092	0.0025	0.01	0.008	0.006	0.0025	0.0025
14	**Dec**	1999	0.006	0.005	0.007	0.019	0.017	0.1	0.0025	0.005	0.0025	0.0025	0.005	

Total Kjeldahl N (mg/l)

Day	Month	Year	D1	D2B	D2	D3	D4	D7	M1	Carlton	Tarrara	Ivanhoe	Spring	Valentine
12	**Jan**	1999	0.51	0.82	1	1.1	1.7	1.1		0.16	0.0125	0.2	0.31	0.0125
11	**Jan**	2000	0.16	0.51	0.17	0.34	0.36		0.21	0.18	0.18	0.14	0.27	0.3
9	**Feb**	1999	0.44	0.4	0.34	0.36	0.65	0.85	0.26	0.34	0.28	0.28	0.22	0.17
8	**Feb**	2000	0.44	0.4	0.39	0.4	0.42		0.21	0.38	0.27	0.19	0.21	0.49
9	**Mar**	1999	0.31		0.37	0.26	0.37	0.81	0.2		0.23	0.12	0.28	0.23
7	**Mar**	2000		0.71	0.47				0.17	0.26	0.22	0.22	0.15	0.11
6	**Apr**	1999	0.3	0.17	0.26	0.21	0.19	0.33	0.2	0.37	0.31	0.29	0.24	0.32
4	**Apr**	2000	0.34	0.27	0.18	0.41	0.34		0.24	0.16	0.16	0.19	0.22	0.15
5	**May**	1999	0.42	0.25	0.33	0.23	0.3	0.66	0.13	0.22	0.26	0.29	0.17	0.079
2	**May**	2000	0.18	0.27	0.21	0.2	0.25		0.16	0.18	0.18	0.2	0.17	0.13
30	**May**	2000	0.16	0.15	0.13	0.15	0.24	0.3	0.14	0.1	0.11	0.093	0.085	0.1
1	**Jun**	1999	0.24	0.26	0.23	0.23	0.29	1	0.19	0.19	0.19	0.41	0.22	0.3
29	**Jun**	1999	0.12	0.14	0.28	0.075	0.41	0.45	0.08	0.13	0.15	0.1	0.16	
27	**Jun**	2000	0.13	0.14	0.28	0.14	0.2	0.87	0.16	0.12	0.13	0.13	0.23	0.079
27	**Jul**	1999	0.3	0.28	0.21	0.21	0.38	0.6	0.2	0.55	0.22	0.47	0.22	
25	**Jul**	2000	0.18	0.17	0.13	0.18	0.27	1.1	0.13	0.12	0.12	0.12	0.1	0.092
24	**Aug**	1999	0.21	0.65	0.27	0.25	0.29	0.5	0.16	0.21	0.36	0.2	0.34	
22	**Aug**	2000	0.18	0.25	0.14	0.14	0.7	0.58	0.11	0.15	0.16	0.13	0.2	0.094
21	**Sep**	1999	0.08	0.69	0.24	0.13	0.14	0.27	0.21	0.3	0.22	0.27		
20	**Oct**	1998	0.45	0.46	0.17	0.23	0.54	0.45	0.079	0.18		0.087		
19	**Oct**	1999	0.31	0.17	0.15	0.17	0.21	0.5	0.2	0.2	0.25	0.16		
17	**Nov**	1998	0.18	0.12	0.14	0.29	0.39	0.45	0.25	0.14	0.11	0.52		
16	**Nov**	1999	0.22	0.34	0.21	0.28	0.29	0.84	0.15	0.12	0.16	0.11		
15	**Dec**	1998	0.27				0.63	0.62	0.16	0.25	0.17	0.19	0.38	0.18
14	**Dec**	1999	0.2	0.22	0.15	0.2	0.24	0.67	0.16	0.21	0.26	0.19	0.4	

Ammonia (mg/l)

Day	Month	Year	D1	D2B	D2	D3	D4	D7	M1	Carlton	Tarrara	Ivanhoe	Spring	Valentine
12	**Jan**	1999	0.014	0.005	0.005	0.017	0.071	0.048		0.005	0.024	0.005	0.012	0.005
11	**Jan**	2000	0.012	0.023	0.017	0.021	0.025		0.017	0.022	0.01	0.024	0.018	0.018
9	**Feb**	1999	0.04	0.08	0.027	0.024	0.034	0.057	0.034	0.033	0.031	0.028	0.018	0.02
8	**Feb**	2000	0.024	0.027	0.034	0.029	0.031		0.027	0.028	0.02	0.021	0.021	0.026
9	**Mar**	1999	0.051		0.028	0.028	0.025	0.043	0.054		0.023	0.024	0.021	0.021
7	**Mar**	2000		0.2	0.048				0.038	0.029	0.028	0.033	0.021	0.02
6	**Apr**	1999	0.02	0.021	0.027	0.022	0.035	0.029	0.023	0.037	0.034	0.032	0.019	0.022
4	**Apr**	2000	0.02	0.021	0.019	0.03	0.054		0.022	0.013	0.014	0.011	0.013	0.014
5	**May**	1999	0.089	0.022	0.033	0.064	0.027	0.018	0.016	0.027	0.017	0.027	0.013	0.012
2	**May**	2000	0.025	0.036	0.019	0.015	0.027		0.016	0.023	0.013	0.014	0.013	0.016
30	**May**	2000	0.016	0.017	0.017	0.016	0.012	0.026	0.019	0.027	0.012	0.017	0.012	0.013
1	**Jun**	1999	0.03	0.022	0.019	0.034	0.038	0.079	0.028	0.038	0.028	0.068	0.032	0.035
29	**Jun**	1999	0.025	0.025	0.025	0.023	0.025	0.036	0.035	0.04	0.025	0.027	0.041	
27	**Jun**	2000	0.024	0.022	0.026	0.025	0.035	0.1	0.028	0.022	0.034	0.028	0.042	0.024
27	**Jul**	1999	0.026	0.026	0.03	0.025	0.032	0.038	0.026	0.078	0.028	0.062	0.033	
25	**Jul**	2000	0.005	0.005	0.005	0.005	0.047	0.081	0.017	0.023	0.01	0.015	0.005	0.005
24	**Aug**	1999	0.02	0.18	0.023	0.03	0.026	0.043	0.024	0.15	0.021	0.18	0.22	
22	**Aug**	2000	0.026	0.053	0.019	0.015	0.23	0.036	0.025	0.023	0.021	0.021	0.04	0.016
21	**Sep**	1999	0.026	0.091	0.017	0.022	0.017	0.029	0.019	0.018	0.019	0.033		
20	**Oct**	1998	0.022	0.094	0.027	0.014	0.064	0.02	0.015	0.022		0.017		
19	**Oct**	1999	0.039	0.021	0.025	0.029	0.03	0.062	0.022	0.028	0.03	0.072		
17	**Nov**	1998	0.02	0.013	0.014	0.005	0.022	0.013	0.005	0.066	0.005	0.11		
16	**Nov**	1999	0.03	0.026	0.014	0.024	0.027	0.01	0.019	0.058	0.016	0.084		
15	**Dec**	1998	0.03				0.24	0.036	0.026	0.036	0.029	0.029	0.012	0.016
14	**Dec**	1999	0.018	0.02	0.02	0.062	0.027	0.073	0.021	0.017	0.017	0.022	0.022	

Appendix 5: Data used to calculate River flows

All the data shown were collated by the WRC from Pacific Power, Ord Irrigation Cooperative, Agriculture WA and Water Corporation.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dunham Gauged Flows (GL)												
1998	10.66	8.07	0.08	2.7	0.01	0	0	0	0	0	26.5	51
1999	46.2	136.4	38.3	3.43	0.6	0.3	0.1	0	0	0	8.8	
2000												
Mean 98-00	28.43	72.235	19.19	3.065	0.305	0.15	0.05	0	0	0	17.65	51
Kimberley Research Station Rainfall Data (mm)												
1998	192	117.7	42.1	40.6	1.2	0	1.2	0	15.2	10.4	38.3	181.4
1999	271	221.7	265.1	94.7	0	0	2.4	0	0	49.5	77.6	183.5
2000	191.1	304.7	466.2	243.2	0	0				73.5	140.9	216.9
Mean 98-00	218.033	214.7	257.8	126.167	0.4	0	1.8	0	7.6	44.4667	85.6	193.933
Kununurra Diversion Dam Releases (GL)												
1998	183.8	169.4	201.6	186.1	187.7	196.4	212.2	193.6	194.7	180.9	188.0	224.8
1999	228.0	246.6	243.3	171.5	158.3	146.3	145.4	152.8	146.5	184.5	172.9	226.0
2000	199.6	310.9										
Mean 98-00	203.8	242.3	222.4	178.8	173.0	171.3	178.8	173.2	170.6	182.7	180.5	225.4
Ord River Dam Releases (GL)												
1998					174.003	173.974	185.206	177.46	183.348	179.219	178.217	182.204
1999	169.918	148.36	160.474	124.387	143.083	137.909	142.455	157.482	128.329	173.038	159.474	161.714
2000	149.88	144.4	130.046	130.388	129.471	124.988	140.582	142.539	147.741	159.829	154.932	149.475
Mean 98-00	159.899	146.38	145.26	127.388	148.852	145.624	156.081	159.16	153.139	170.695	164.208	164.464