ASSESSMENT OF ECOLOGICAL RISK ASSOCIATED WITH IRRIGATION SYSTEMS IN THE FITZROY BASIN

Phase 1 – Identification of risks and development of conceptual models

Final report

February 2001

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National Program for
Irrigation Research and Development

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Front Cover:

Main picture – Planting cotton into recently harvested wheat stubble (Emerald).

Left – Young irrigated cotton planted into wheat stubble (Emerald).

Right - Close view of young irrigated cotton planted into wheat stubble (Emerald).

ABSTRACT

This report describes the outcomes of the first phase of the National Program for Irrigation Research Program Ecological Risk Assessment project for the Fitzroy catchment in Queensland. This project has three focus catchments around Australia, the other two being the Goulburn-Broken in Victoria and the Ord in Western Australia.

The main objectives of this phase were to develop a list of up to six ecological consequences of irrigation within the Fitzroy in consultation with community stakeholders; develop conceptual models containing relevant data for these consequences; complete a table to help establish priorities for future research; provide justification for the rankings within this table; and recommend future priority actions to address information gaps and research needs for phase two of the project.

A community workshop was held in November 2000 and the six ecological effects were identified at each of two different scales – the local irrigation area scale and the entire catchment scale. At the local scale the effects that ranked most highly were decline in water quality, soil degradation, increase in salinity, changes in composition and decrease in abundance of macroinvertebrates, changes in nutrient cycles and decreases in desirable fish populations. The effects at the catchment scale were similar though ranked in slightly different order. The most important ecological effect of irrigation at both scales was decline in water quality, since there was wide acknowledgement that nutrient and pesticide concentrations often exceeded water quality guidelines in irrigation areas. When related to the effects on aquatic communities, concern about the influence of this decline in water quality on macroinvertebrate and fish populations were paramount and hence conceptual models of the effect of irrigation and other factors on macroinvertebrate and fish populations were developed.

Detailed assessment of the models and data for them resulted in the research team ranking decline in water quality, impacts on macroinvertebrates and fish and soil degradation as the four most important ecological effects in the catchment. Knowledge gaps were identified and current past and future projects briefly described during the process of justifying the ranking obtained by the team. Three recommendations for future priority actions to address information gaps and research needs for phase two of the ERA project were then provided. In summary these were:

- that Phase 2 of the ecological risk assessment project research should focus more on the effects of irrigation at the local irrigation area scale than on those at the broader catchment scale;
- that the impact of a decline in water quality on macroinvertebrate (and if possible fish) populations should be investigated in the Fitzroy with focus placed on determining the relative contribution of factors such as rapid water level fluctuations and changes in water quality associated with rainfall and irrigation runoff events to these populations;
- and that studies should, where possible, include comparisons between particular land/irrigation management practices to increase our understanding of the impact of these on aquatic ecosystems in the tropics.

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1 INTRODUCTION

One of the goals of the National Program for Irrigation Research and Development is to gain a better understanding of the ecological effects of irrigation. To achieve this goal an Ecological Risk Assessment project was initiated in 2000. Three focus catchments were chosen: the Fitzroy in Queensland, the Goulburn-Broken in Victoria and the Ord in Western Australia.

The Fitzroy catchment is the largest river basin on the east coast of Australia. The catchment comprises six major sub-catchments that are drained by the Nogoa, Comet, Mackenzie, Isaac, Dawson and Fitzroy Rivers. The catchment totals approximately 14.3 million hectares and has a mean annual discharge of approximately five million megalitres. Land uses include mining, irrigated and dryland farming, grazing and forestry. Irrigation is predominantly for cotton, citrus and grapes at Emerald on the Nogoa River and for cotton near Theodore on the Dawson River.

A number of dams have been constructed within the catchment to supply water for irrigation, urban, stock and industrial use. The largest of these is the Fairbairn Dam that supplies water to the Emerald Irrigation Area and a number of coal mines. Weirs have been constructed on all major rivers. Another large dam is currently planned for the Dawson River (Nathan Dam) that will supply the Dawson Irrigation Area.

This report details the outcomes of the first phase of the Ecological Risk Assessment project for the Fitzroy – the identification of risks and development of conceptual models to more readily prioritise the areas where research is needed.

Specifically, the objectives of this phase of the study were:

- In consultation with stakeholders develop a list of up to six ecological consequences of development in the Fitzroy Basin where irrigation is likely to have a significant impact.
- Develop conceptual models containing all relevant data (e.g. concentrations, loads, fluxes, trigger levels) for each of these ecological consequences.
- Complete a matrix table to help establish priorities for further research. For each main ecological consequence, the table would comprise its relative importance (ranking) with respect to other consequences (at both local and catchment scale); the impact of irrigation on the ecological consequence; and the likelihood or probability of the ecological effect eventuating.
- Provide justification for the rankings and review past, current and future projects in the Fitzroy catchment that address the effects or issues.
- Recommendations on future priority actions to address information gaps and research needs for phase two of the project.

The first objective is addressed in section two that describes the process used to develop the list of ecological effects. Conceptual models for three of these ecological effects are detailed in section three that includes a schematic diagram for each of the conceptual models accompanied by relevant data and a brief description. A completed matrix table, justification of rankings and a brief review of related projects are given in section four. The report concludes with recommendations on future priority areas and research needs for phase two of the project in section five.

2 ECOLOGICAL EFFECTS

2.1 Methodology

The process employed to involve stakeholders in developing a list of ecological consequences of irrigation in the Fitzroy basin began with a letter to the President of the Fitzroy Basin Association (FBA), the peak community forum for the catchment. The FBA supported the idea of a workshop on the issue and came back with a list of people they thought should be invited to attend, bearing in mind that we decided to restrict the numbers attending to about 10 (not including the research team and Dr Jon Brodie from Great Barrier Reef Marine Park Authority - GBRMPA). A letter explaining the purpose of the workshop was written to invitees including an initial list of possible ecological effects. Invitees were asked to add any other effects that they considered important to the list and to have an attempt at ranking the effects prior to the workshop on 9 November 2000.

With regard to ecological effects of irrigation, the issue of scale is a very important one for the Fitzroy Basin because of the sizes of the irrigation areas (Emerald and Dawson) compared to the entire catchment area (which is half the size of Victoria). The two main issues here are the potential impacts of irrigation in the catchment as a whole on the estuary and the Great Barrier Reef and the more localised impacts associated with each of the two irrigation areas. For the purposes of this study the local areas affected by irrigation were defined as follows. The Emerald study area was defined as that catchment between Fairbairn Dam (23.653º S, 148.072º E, Figure 2.1) and Duckponds gauging station on the Nogoa River (23.481º S, 148.474º E, Figure 2.2). This area totals 1 159 768 ha, including 857 964 ha of grazing land and 26 124 ha of irrigated cropping – primarily for cotton production. The Dawson Valley study area was defined as that catchment between Isla-Delusion gauging station (25.882º S, 150.185º E) and Moura Weir (24.602º S, 149.910º E) on the Dawson River. This area totals 369 597 ha, including 292 152 ha of grazing land and 11 976 ha of irrigation activities – primarily for cotton production. Of significance in this area is the planned development of another major dam upstream of the Dawson Irrigation area that is likely to result in a further 20 000 ha of irrigated land.

Immediately prior to the workshop the research team met with Dr Jon Brodie of GBRMPA to discuss the possible ecological effects of irrigation on the offshore areas and minutes of this meeting are provided in Appendix I.

At the workshop the background to, and reasons for the workshop were explained; participants with technical knowledge briefly explained each of the ecological effects (see below) and participants excluding the research team and Dr Jon Brodie were then asked to narrow down the list to the six most important. This was done for both the local and catchment scale via a two-step process: people were first asked to vote on which of the entire list should be included in the top six and in the second round of voting they were asked to rank these top six in order of importance. Minutes and list of attendees at the workshop are provided in Appendix II.

Figure 2.1 Fairbairn dam, completed 1972, capacity 1.3 x 10^6 ML.

Figure 2.2 Nogoa River in the vicinity of Duckponds gauging station.

2.2 Workshop Outcomes

The list of the six most important ecological effects of irrigation at the local scale was very similar to that at the catchment scale, though the order of priority was different (Table 2.1). Decrease in water quality was perceived to be the most important ecological effect at both scales. At the local scale people were also concerned about soil degradation, increase in salinity, changes in composition and decrease in abundance of macroinvertebrates, changes in nutrient cycles and decreases in desirable fish populations (in that order). The ranking at the catchment scale (following decrease in water quality) was an increase in salinity, changes in composition and decrease in abundance of macroinvertebrates, decreases in desirable fish populations, effects on corals and changes in nutrient cycles.

Table 2.1 Ecological effects ranking at local and catchment scale (1 = most important).

Local Scale	Catchment Scale
1. decrease in water quality	1. decrease in water quality
2. soil degradation	2. increase in salinity
3. increase in salinity	3. change in composition and decrease in abundance of macroinvertebrates
4. change in composition and decrease in abundance of macroinvertebrates	4. decrease in desirable fish populations
5. changes in nutrient cycles	5. effects on coral reefs
6. decrease in desirable fish populations	6. changes in nutrient cycles

2.3 Description of ecological effects

During the workshop the meaning of ecological effects of irrigation was discussed but given the time constraints there was still some measure of confusion among participants by the end of the workshop over exactly what is meant by this concept. The issue of a decrease in water quality as an effect was suggested prior to the workshop by one of the participants in the feedback requested by the introductory letter. This is a very broad effect that people can readily associate with, though it has the disadvantage that it is not very precise in identifying which component of water quality people are concerned about. Put in the framework of an ecological risk assessment (USEPA 1998), this effect is probably best placed in the area of 'stressors' – that is, a factor that can result in an ecological effect that describes how a particular component of aquatic life may be impacted. This is illustrated in Figure 2.3, along with all of the other main ecological effects identified during the workshop. Figure 2.3 illustrates various causal anthropogenic factors of significance along the top row, which through the influence of climate and ecological processes lead to various stressors such as the changes in nutrient cycles, decline in water quality and increasing salinity shown in the figure. These stressors in turn lead to the effects on aquatic communities as illustrated by the reduction in macroinvertebrates and desirable fish populations that can be used as indicators of the state of the aquatic environment.

Figure 2.3 illustrates that there are several factors that may lead to a decline in water quality. These include the important influence of rainfall events on a variety of land use types to produce soil degradation by soil loss from farms (Carroll *et al.* 1995, 1997). This produces high levels of suspended sediments in streams that have the immediate effect of reducing the light available to submerged plants and algae, which may alter the abundance of these communities such that animals dependent on them (e.g. fish and macroinvertebrates) may be adversely affected. Many juvenile fish for example, spend the first weeks of their lives in amongst submerged plants, protected from the larger fish. Pesticides and high levels of nutrients that may be associated with the suspended sediments may also adversely affect the biota. In extreme cases, high levels of pesticides have the potential to cause massive fish kills, though other factors such as low oxygen levels may be involved in some circumstances.

Other factors that may lead to a decline in water quality include flow regulation and increasing salinity. Although saline surface water has been recorded in the catchment in a number of places it has been associated with saline groundwaters, and there is little evidence from DNR's ambient Water Quality Monitoring network that salinities are increasing within irrigation areas in the catchment. (Hence the dotted lines in Figure 2.3). One of the ways in which a change in flow regulation may lead to a decline in water quality is by keeping the suspended sediments in suspension for a longer period. It may also affect nutrient cycling by producing a more regular supply of nutrients to streams than the more pulsed supply typical of natural flows. Changes in nutrient cycles can include making more nutrients available to biota or changing the form of the nutrients present. These changes can affect biota of streams via effects on organisms such as algae, bacteria and submerged plants dependent on the nutrients. For example, an increase in nutrient availability may result in an algal bloom if there is adequate light penetration into the water column (Fabbro and Duivenvoorden 1996a, 2000; Johnstone *et al.* 1996). Such blooms may make water bodies unsuitable for drinking by animals and people.

In the following section the relationship between some of the above factors is discussed with reference to various conceptual models and our current knowledge of the significance of some of the processes involved. The models of ecological effects chosen for detailed examination are those considered most important by the research team further to the initial ranking by people at the workshop (see Section 4 for details). The three identified were those dealing with the impact of irrigation on macroinvertebrates, fish and (on a broad catchment scale) coral growth and reproduction.

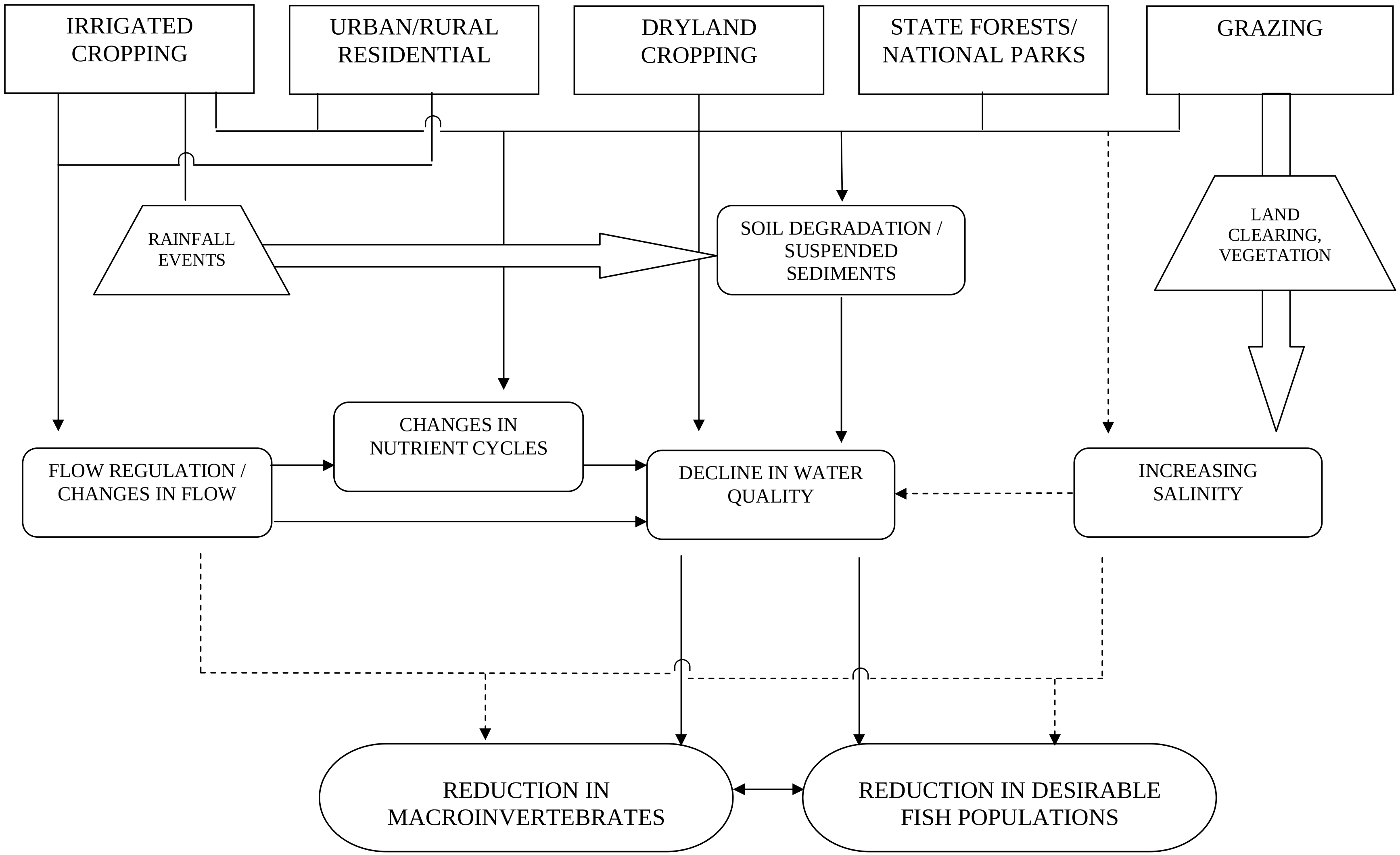

Figure 2.3 Ecological effects of irrigation activities within the Fitzroy Basin; a summary of local and catchment scale concerns raised during a workshop with stakeholders

3 CONCEPTUAL MODELS

3.1 Change in composition and decrease in abundance of macroinvertebrates

The conceptual model developed to show the linkage between decrease in water quality and macroinvertebrates (Figure 3.1) and the relative significance of irrigated cropping is shown in Figure 3.2. The top row of boxes detail the contribution of the major land uses impacting on aquatic environments in the Fitzroy catchment. This occurs via five main processes: clearing of riparian vegetation, increased suspended sediments, release of pesticides, increased nutrient availability and flow regulation. Implicit in this model, but not shown, is the important role that rainfall and irrigation runoff events may have in these processes.

Figure 3.1 Examples of the diversity of macroinvertebrates found in the Fitzroy River. Clockwise from left: Coleoptera, Ephemeroptera, and Gastropoda.

To determine the relative contribution of irrigated lands (as compared to other major land use types) to nutrient load in streams of the Emerald and Dawson study areas, data from a recent study by Joo *et al.* (2000) were obtained to calculate loads from specific areas. Calculations by Joo et al. (2000) were based on the determination of particular nutrient generation rates from particular land use types. Results are illustrated by the bar graphs of total nitrogen and phosphorus supplies in the top row of Figure 3.2 for each of the major land use types within them. These data do not include contributions from the main river entering each study area but serve to illustrate the relatively small contribution of irrigated lands to the total nutrient load of the streams. Irrigated lands in the Emerald study area total 2.25% of the local catchment and contribute 6.2 and 11.0% of the Total P and N loads for this catchment respectively. The corresponding figures for the Dawson study area are 7.9 and 15.4% for Total P and N respectively, with irrigated lands comprising 3.24% of the local catchment (see Appendix III for further details). Increased nutrient availability leads to increases in algal production that may affect macroinvertebrates by changing the relative proportion of foods available to them. Some algae, for example, are not readily consumed by macroinvertebrates and if they dominate at the expense of others invertebrate populations may decline. Increases in algal populations may occur when nutrient concentrations increase above the ANZECC (1999) trigger levels of 340-1 600 µg L^{-1} of Total N and 35-37 µg L^{-1} Total P (Appendix IV). These values are commonly reached in water bodies of the Fitzroy (Jones *et al.* 2000), though algal blooms usually occur only when the turbidity drops (Fabbro and Duivenvoorden 2000).

Of interest is how a crude approximation of Total N and P loads for the Dawson study area (based on simple median concentrations multiplied by flow volumes per year) compare with those calculated by Joo *et al*. (2000). Results of such crude approximations based on the data of Noble *et al*. (1996) shown in Table 3.1 indicate that values underestimate the load calculated by Joo *et al.* (2000) by a factor of about 10. Of note however is the fact that the crude estimates still fall within the confidence levels of the data provided by Joo *et al*. (2000) (Table 3.1). Using a similar crude method to estimate total sediment load for the Dawson study area suggests that the load is about 7 300 tonnes per year (Table 3.1), and possibly 10 times more than this if the above argument is followed. In comparison, an estimate of total sediment load

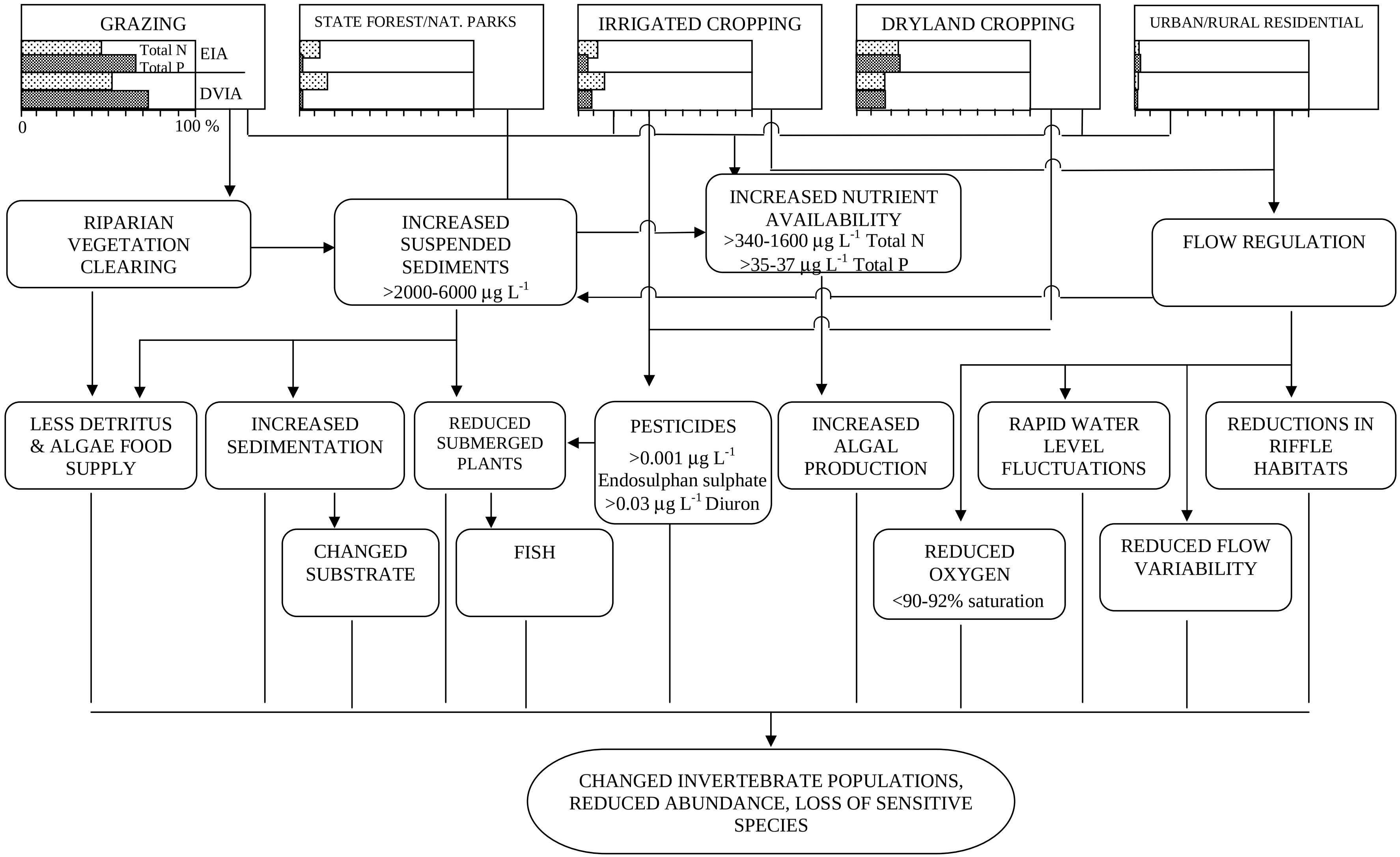

Figure 3.2 Conceptual model of factors leading to a change in composition and decrease in abundance of macroinvertebrates at the local irrigation scale.

from the entire Fitzroy catchment is about four million tonnes per year (Horn *et al*. 1998). Of note is the relatively high proportion of Total N that was calculated for loads emanating from State Forest (Joo *et al.* (2000) Appendix III). This is unexpected and suggests the need for further investigation.

Table 3.1 Total N, P and suspended sediment loads (tonnes per year) calculated for the Dawson study area (between Isla Delusion and Moura Weir gauging stations): a comparison of results derived from Noble *et al*. (1996) and Joo *et al*. (2000). Note, suspended sediments were not calculated by Joo *et al*. (2000).

Nutrient/Source	**Average (t/yr)**	**Range (t/yr)**
N		
Joo *et al.* (2000)	402	102 - 703
Noble *et al.* (1996)	43	42 - 226
P		
Joo *et al.* (2000)	124	36 - 212
Noble *et al.* (1996)	12	2 - 65
Suspended Sediments		
Noble *et al.* (1996)	7 300	3 650 – 138 700

Range of values depicted for Joo *et al*. (2000) are based on minimum and maximum uncertainty limits. Values depicted for Noble *et al.* (1996) are based on medians (= average) and 25^{th} and 75^{th} percentiles (range).

Since much of the nutrient load entering streams is associated with the sediments entering via runoff, it may be argued that the data for Total N and P load may be used to provide a course approximation of the sediment loads entering the study areas. Hence grazing land is still by far the largest contributor of sediment load to the river system as a result of the proportionally large areal contribution of this land use type (see Appendix III and Moss *et al*. 1992). The main mechanisms by which increased suspended sediments may act on macroinvertebrate populations are the impact on algae and submerged plants, and interference with filtering mechanisms by increased sedimentation. The latter may also change the relative proportion of substrate types within the water body and so lead to changes in the composition of macroinvertebrate populations. Reductions in submerged plants due to high levels of suspended sediments or herbicides may directly reduce invertebrate populations by reducing available habitat or indirectly affect them by reductions in fish populations.

Two other main processes that can impact on macroinvertebrates are the release of pesticides from irrigated and dry land cropping and flow regulation (Figure 3.2). Pesticides may act directly on macroinvertebrates or on the plants within river systems such that habitat for invertebrates is lost. Draft ANZECC (1999) trigger levels of two important pesticides in the Fitzroy catchment are provided in Figure 3.2 (see Appendix V for others). At a concentration of greater than 0.001 $\mu g\ L^{-1}$, endosulphan sulphate may produce undesirable effects on invertebrates and the equivalent level of diuron are concentrations greater than 0.03 $\mu g\ L^{-1}$. These levels are often exceeded in irrigation areas of the Fitzroy (Appendix VI) but the significance of this to macroinvertebrate and fish populations in the tropical turbid conditions of the Fitzroy is not known - illustrating an important information gap. Flow regulation can act through a variety of ways to reduce macroinvertebrate populations or change their composition (Figure 3.2). Reduction in habitat variability and type will reduce populations directly or alter community structure, while rapid water level changes and reduced oxygen levels are two major factors that can severely affect the survival and growth of these populations. Biotic factors such as interspecies competition may also be of consequence in some circumstances, though this factor is not shown in the model.

The relative importance of the various factors that may affect macroinvertebrate populations in the two study areas shown in Figure 3.2 is currently not known. Increasing our knowledge in this area would help to identify the management practices that would most effectively enhance the ecological health of receiving waters.

3.2 Reduction in desirable fish populations

The conceptual model produced to describe the relationship between irrigation and reduction in desirable fish populations (Figure 3.3) includes several components that overlap with those in the macroinvertebrate model. The three major processes that link irrigation to fish populations are the effect of flow regulation, increased suspended sediment and the release of pesticides. Flow regulation may affect fish populations through changes in the stratification and mixing processes within the river that may lead to reduced oxygen levels, and through the barrier effects that interfere with fish migration (e.g. the Fitzroy barrage, Figure 3.4, Long and Berghuis 1996). On some occasions barrier effects have resulted in fish kills where large numbers of fish are trapped in small pools below weirs when the water flow is suddenly stopped. As discussed above, increased suspended sediments may lead to reductions in water plants and also reduce the oxygen levels in streams for extended periods as occurs in the Dawson (Fabbro and Duivenvoorden *in press*). The reduction in submerged macrophytes may also be affected by pesticides released from cropping areas, though whether this occurs in the Fitzroy catchment is not known at present. Pesticides may also act directly on fish populations and result in fish kills if pesticides levels are high enough. Occasional fish kills have been reported in the Dawson River downstream of irrigation areas but the causes have not been thoroughly investigated. For the Emerald and Dawson study areas, levels of the pesticide endosulphan sulphate regularly exceed ANZECC (1999) trigger levels (see Appendix VI). Such events may have chronic influences on fish life cycles that are as yet unknown for the Fitzroy. Indirect effects of pesticides on fish populations may also occur via reductions in macroinvertebrate populations as discussed in Section 3.1.

3.3 Decline in coral reproduction and growth

The links between irrigation and coral reproduction and growth for the Fitzroy are shown in Figure 3.5. This conceptual model illustrates that the major links are the release of pesticides from cropping and increased sediment and nutrients to offshore areas. To estimate the relative significance of nutrient loads from irrigated lands on a catchment scale, the nutrient generation rates for particular land use types determined by Joo *et al.* (2000) were used in conjunction with land use areas from the National Land and Water Audit (Calvert *et al.* 2000, see Appendix III). The relative contribution of Total N and P to offshore areas from irrigation is minimal (Figure 3.5) and this is also most likely the case for sediment load. Levels for inorganic nutrients that may impact on corals are illustrated on the Figure and these may have chronic effects if prolonged for more than one week or pulsed for more than one month (Ferrier-Pagès *et al.* 2000). One result is the production of 'marine snow' that can cause smothering and rapid death of coral reef organisms (Fabricius and Wolanski 2000). Results from the Fitzroy Basin National Land and Water Audit suggest that these levels are occasionally exceeded for nitrate and phosphate in the mid Fitzroy estuary, though they decline with distance towards the mouth of the estuary (Jones *et al.* 2000). Data on these levels on offshore reefs in the vicinity of the Fitzroy is limited (Furnas and Brodie 1996, Brodie and Furnas 1996).

The more direct linkage between irrigation and coral reproduction and growth is via the release of pesticides such as diuron. The concentrations of diuron known to reduce photosynthesis in marine periphyton is 2 µg L^{-1} and concentrations of 10 to 170 µg L^{-1} may result in reduction in growth in marine phytoplankton (see Haynes *et al. in press* and references therein). Predicted chronic water column diuron concentrations near the mouths of most Queensland wet tropics rivers range from 0.1 to 1.0 µg L^{-1} and concentrations are likely to be greater during the wet summer months (Haynes *et al. in press*). These authors predicted diuron concentrations of 0.3

μg L^{-1} in waters in the Fitzroy. Sediment concentrations of diuron are also of concern with concentrations of 0.9 μg kg^{-1} having been recorded for the Fitzroy (Haynes *et al. in press*).

Figure 3.4 Fitzroy barrage looking downstream.

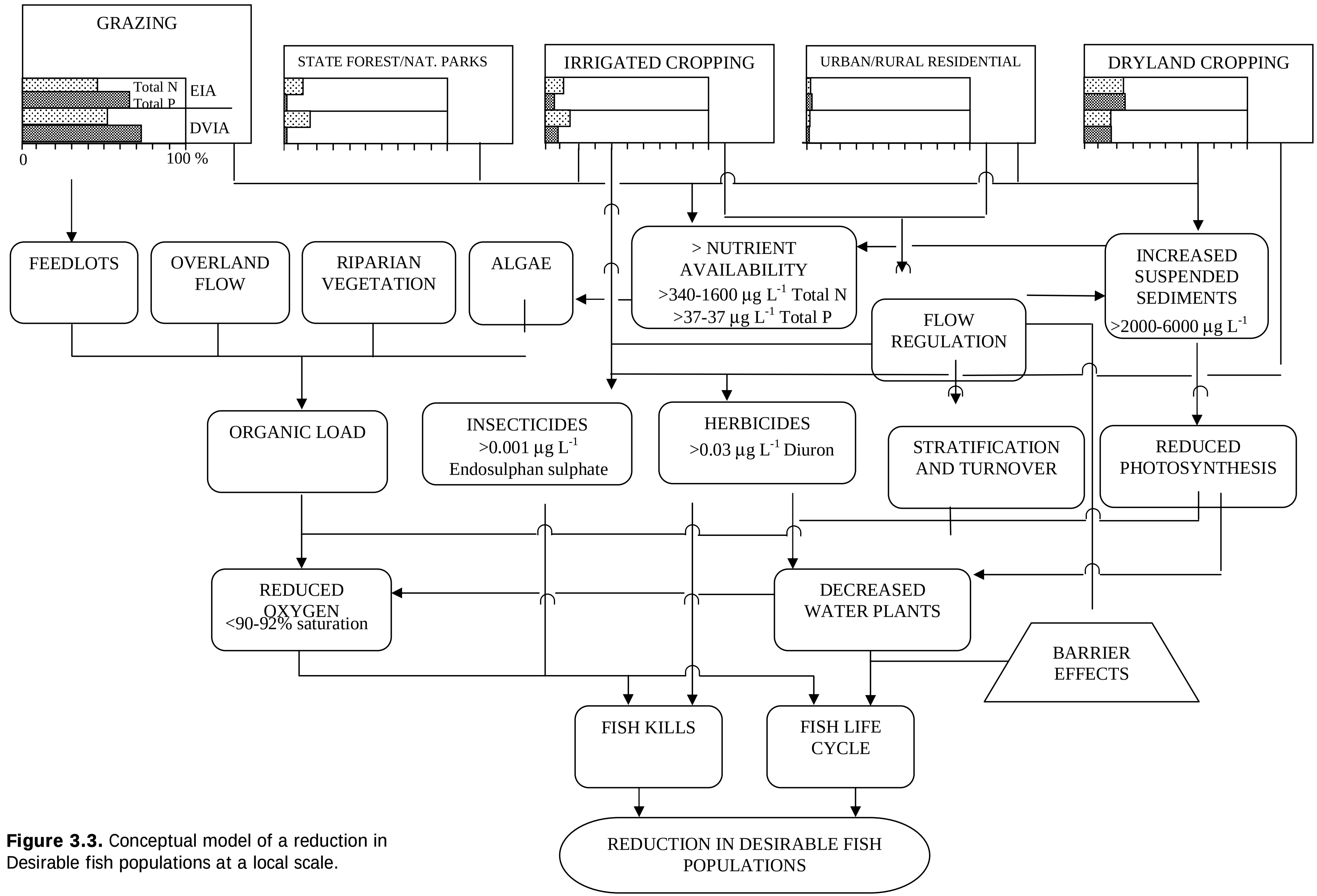

Figure 3.3. Conceptual model of a reduction in Desirable fish populations at a local scale.

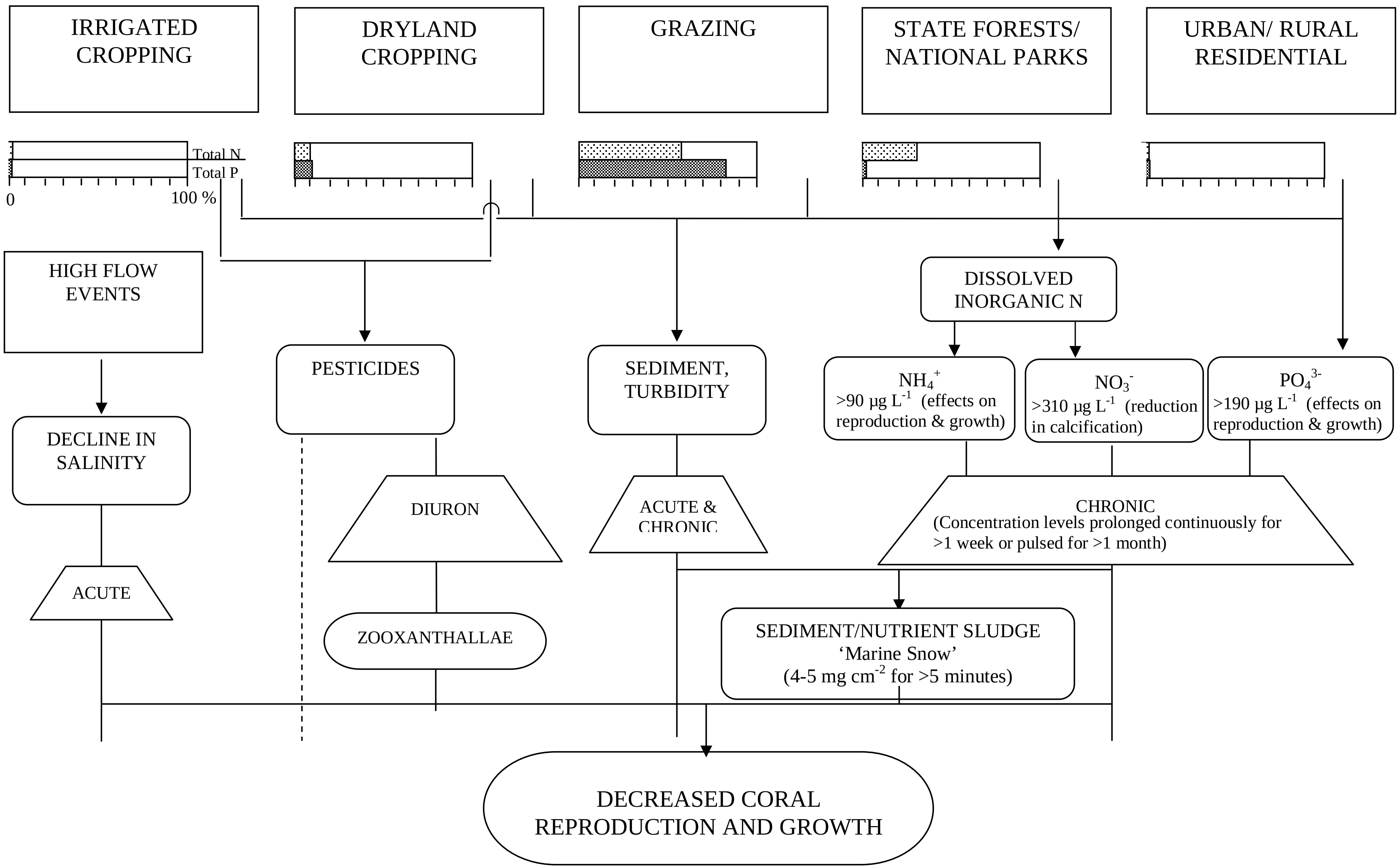

Figure 3.5 Conceptual model of the decrease in coral reproduction and growth at the catchment scale at a temporal scale of 10 years.

4 ECOLOGICAL EFFECTS RANKING MATRIX TABLE

4.1 Matrix table, justification of ranking and review

The ranking of a decline in water quality as the most important issue by the community stakeholder group and soil degradation as the second most important on a local scale suggests that increased sediment loads and associated issues are of most concern in this catchment (Table 2.1). Of interest is that increasing salinity was ranked third on the local scale and this may reflect concerns about this issue generally, since even though there are some areas with surface waters of high salinity associated with saline groundwater (e.g. Callide catchment) there is little evidence of irrigation resulting in increasing salinity in surface waters in the Fitzroy catchment.

Further to the initial ranking of the ecological effects by the stakeholder group the research team also ranked ecological effects in order of relative importance in the catchment for both the local irrigation area and broad catchment scales. This ranking was based on the impact of irrigation and the probability of the impact occurring. Results of this ranking by the team are presented in Table 4.1.

Overall, the importance of effects of irrigation on a local scale was considered to be much greater than the effects on the catchment scale. This was generally due to the very minor contribution of irrigation to sediment loads at the catchment scale (the exception being the possible effects of pesticides on marine organisms, which may still be of significance).

The effects considered to be of highest importance on a local scale by the research team were those on water quality, macroinvertebrates, fish and soil degradation (Table 4.1).

Table 4.1 Ecological effects ranking matrix table (H-high, M-medium, L-low).

Ecological effect	Relative importance in catchment (priority)[1]		Impact of irrigation		Risk (probability of impact occurring)		Knowledge[2]	
	Local	Broad	Local	Broad	Local	Broad	Local	Broad
Decline in water quality	H	L	H	M	H	L	H	M
Decrease in abundance / change in composition of macroinvertebrates	H	L	H	L	H	L	M	M
Decline in desirable fish populations	M	L	H	L	M	L	M	M
Soil degradation	M	L	M	L	M	L	H	M
Changes in nutrient cycle	L	L	M	L	H	L	M	M
Increasing salinity	L	L	M	L	L	L	M	M
Decline in reproduction and growth of coral		M		M		L		M

[1] Based on consideration of impact of irrigation and probability of the impact occurring.
[2] Identify level of knowledge in area from existing and past projects. Document proposed research projects.

In an ecological risk assessment framework, decline in water quality may be presented as a stressor resulting in ecological effects on macroinvertebrate and fish populations and hence conceptual models relating water quality to the latter two ecosystem components were developed (as described in section three). These two models also incorporate aspects of some of the other ecological effects identified as important by the community stakeholders.

Effects on macroinvertebrates was ranked highly because of their important functions within river systems and the high probability that irrigation will affect their populations through either flow regulation, release of pesticides or increases in suspended sediments. Once-off sampling and analysis of macroinvertebrates in the Emerald irrigation area during the cotton season in 1996 suggested that there was a decrease in species richness and abundance in the Nogoa River (Duivenvoorden and Roberts 1996). More recently, a two-year study of macroinvertebrates in the Dawson river showed that species richness within the irrigation area significantly decreased on a number of occasions and was likely the result of flow regulation via artificial water level fluctuations (Duivenvoorden *et al. in press*). Knowledge gaps in this area include the significance of various factors on macroinvertebrate populations particularly in relation to the impact of particular rainfall and runoff events in comparison to the effects of water level fluctuations. Also of interest to our understanding of the ecological effects on macroinvertebrates is the recovery time of the biota from various irrigation impacts and its resilience in the medium term. This is particularly of significance with respect to highly turbid tropical environments where the response of these organisms at higher temperatures may be quite different from that of organisms in the cooler temperate regions of Australia. Quantification of the off-farm movement of sediments and associated nutrients and pesticides in relation to these processes is an important aspect to increasing our understanding of these processes. A current project led by Chris Carroll is examining related sediment issues for two relatively small sub-catchments in the Fitzroy. Similarly, fluxes of nutrients within rivers are important and a current National Eutrophication Management Program project led by Phillip Ford and Myriam Bormans is examining such fluxes in relation to water column dynamics in the Dawson River. This study began last year and data from it are not yet readily available.

Fish populations may also be affected via flow regulation (barrier effects and reduction in oxygen levels), release of pesticides and increased suspended sediment load, though probably to a lesser extent than macroinvertebrates. Recent construction of fish ladders on weirs in the lower part of the Dawson River should help to ameliorate some of these effects. Occasional fish kills in the Dawson Irrigation area have been reported but thorough scientific studies have not yet been made to determine the cause. This is one area that may benefit from further investigation since information in this area is very poor.

Ranking of soil degradation lower than the above effects was a function of the relatively small contribution that irrigation makes to the total sediment load on the local scale (as described in section 3.1). Of note, however, is the large amount of sediment that has been removed by backhoes from drains in the Emerald Irrigation area. Increase in salinity, though perceived to be a problem by the stakeholder group, is not a significant issue with respect to irrigation in the Fitzroy catchment, though there may be small localised patches within the irrigation areas. The concern over salinity increases may well be related to the concern over the extensive clearing of the brigalow belt, as well as the occurrence of saline ground waters in some parts of the catchment. There is however currently no evidence of increasing salinity levels in surface waters within irrigation areas (see Jones *et al.* 2000). Hence this effect was not rated as highly as some of the others.

A third model was also produced to illustrate the most important ecological effect of irrigation on a catchment scale: that of the relationship between irrigation and offshore impacts. The possible link between pesticides and decreased reproduction and growth of corals (section 3.3) is one area about which our knowledge is limited for the Fitzroy.

5 RECOMMENDATIONS ON FUTURE PRIORITY ACTIONS

Based on the details of the conceptual models in section three and the relative weightings of ecological effects in Table 4.1, the following recommendations for future priority actions with regard to Phase 2 of the ERA project are made:

1) For Phase 2 of the ecological risk assessment project research should focus more on the effects of irrigation at the local irrigation area scale than on those at the broader catchment scale. A possible exception to this may be a project aimed at assessing for the Fitzroy the significance of the pesticide diuron to coral growth and reproduction in near shore areas.

2) Given that decrease in water quality was identified as the most important ecological effect in this study its impact on macroinvertebrate (and if possible fish) populations should be investigated in the Fitzroy. The conceptual model described in Figure 3.2 can be used as a basis for such a study in that it outlines the major water quality issues impacting these communities in the catchment. *Focus should be placed on determining the relative contribution of factors such as rapid water level fluctuations (Figure 3.2) and changes in water quality associated with rainfall and irrigation runoff events to these populations in the Fitzroy.* This will aid our understanding of these ecological effects in turbid tropical environments where information on these issues is very limited. Use of the model in studies in other areas of Australia via further development of the ecological risk assessment framework would assist in gaining a more holistic view of the ecological effects of irrigation across the nation. Results of such studies would have very important implications for farm and river management by identifying where the management focus should be in attempts to maintain healthy aquatic ecosystems.

3) Studies should, where possible, include comparisons between particular land/irrigation management practices to increase our understanding of the impact of these on aquatic ecosystems in the tropics. This approach would have the benefit of quantifying the savings possible for farms by adopting particular practices that minimise the loss of valuable nutrients and pesticides to waterways. An example of this may be a study of the benefits of having tail drain recirculation in Emerald versus areas in the Dawson Irrigation area where runoff from farms directly enters local streams.

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7 APPENDIX I

Minutes of the pre-workshop meeting held with Dr Jon Brodie to discuss possible ecological effects of irrigation on offshore areas.

NPIRD PRE-WORKSHOP MEETING

Assessment of Ecological Risk associated with irrigation systems in the Fitzroy Basin:

Phase 1 – identification of risks and development of conceptual models.

9 November, 2000

Central Queensland University, Rockhampton

Ecological effects of irrigation on the Fitzroy estuary and adjacent Great Barrier Reef.

ATTENDENCE

Dr Leo Duivenvoorden	CLWRM, CQU
Dr Sabine Kasel	CLWRM, CQU
Dr Jon Brodie	GBRMPA
Chris Carroll	DNR
Bob Noble	DNR

DISCUSSION

General introduction to this afternoons session, people attending – their individual backgrounds.

List of ecological effects:

Leo - Algal blooms, submerged plants, fish kills, fish populations, habitat variability, zooplankton, < number and composition of macroinvertebrates.

Discuss changes in nutrient cycles at both scales.

Bob - Chemical residues in aquatic life.

Chris – Chemical residues in cattle, increasing salinity.

Human health effects – effects on water quality. Contamination of rainwater and groundwater.

Jon – fish kills do not just include fish, there are a wide range of other animals involved (e.g. macroinvertebrates etc.). Leo – people's views are directed towards what they can see. Seagrasses and nutrient enrichment.

Effects include irrigation, irrigated pastures

Catchment includes Shoalwater bay and ~200 km offshore. Near field and far field areas (e.g. Heron Island) where effects are less severe.

Jon – cumulative effects at a catchment scale. Effects may be more than additive. Reduction in growth of coral reefs in offshore areas. Effects on offshore fisheries (include that in reduction in desirable fish populations). Think of fisheries and not just fish. Offshore and near-shore fish populations (fisheries). Reduction in desirable fish populations needs to include reduction in connectivity, e.g. installation of barrages and weirs.

Discussion on how ecological effects are going to be ranked. Recognize 6 most important, give one point to each, then from the initial list of six most important, distribute 20 votes to order then 1 to 6.

Jon – need to look at causes that lead to the effects. Leo – that is later part of the process.

Some confusion about causes and effects.

End point is a model – not a quantitative one, but one that highlights information gaps which is the critical factor. Jon – suggests we already have information on all aspects of some models, so we need to recognize areas that have the least or least reliable data – yet the data will never by 'perfect'.

Need to look at links within models and how reliable each of these links are.

IDEAS CONCEPTUAL MODELS

Start at the effect and work backwards.

Jon – off shore model.

Have near shore and far shore effects. Fine sediment from the Fitzroy get driven north. We don't know if sea grass areas are decreasing in the GBR. Can't make claims about trends given the low-intensity surveys conducted in the past.

1991 – low salinity for about three weeks, lead to coral death. Long term effects from this deluge. Long-term studies in the Whitsundays – reefs close to the river are no longer growing. Sediments, decrease in salinity, light penetration and nutrient availability all play a role but it isn't possible to separate these causes. Coral recruitment, reproduction and mortality rates are affected.

Trigger levels in coral – have numbers for dissolved inorganic N, dissolved inorganic P which lead to reduced recruitment, reproduction and some mortality. Some species mortality up to 40% following the 1991 event.

Have some trigger levels for seagrasses, however they are more complicated. Slight increases in nutrient favour seagrasses, large increases lead to a decline in seagrass beds (e.g. through algal blooms, increase in epiphytic algae).

Some information about salinity triggers for corals and invertebrate populations.

Trigger levels for sediment/turbidity. Sediment in itself is probably not having an effect on the reef. Sediment regime in nearshore area is not limited by sediments in the Fitzroy.

Combination of sediment and nutrient however is a different issue (marine snow). Low nutrient waters with high sediment – soft and hard coral can cope with this. Where high nutrient levels are associated with sediments – a gluggy, sticky 'marine snow' forms and the coral have difficulty in removing the sediment. The problem here is caused by the nutrients rather than the sediments on their own.

Each of these trigger levels are based on doses (i.e. concentrations versus time).

Off shore – affected by dissolved components (only affected by large flows).

Nearshore – affected by suspended and dissolved components from a greater number of flows.

Major impacts are within the nearshore area as it's affected by more flows at greater concentrations.

Fitzroy system is the most irregular (perhaps 1:10) in terms of flow events (compare with Tully which is a more regular river – 2 regular flows a year).

Nutrient loads in Tully may be more important in the GBR than that from the Fitzroy system.

Pesticides off shore – diuron (mainly used on cotton in the Fitzroy) found in sediments and seagrasses. Convert levels found in seagrasses to concentrations, concentrations were found to be greater than recommended trigger levels for seagrasses.

Marine Pollution Bulletin – relevant papers being released end of November.

Endosulfan? Atrazine (local, offshore?)

COMMENTS

Timeframes, scales. Problem with the Fitzroy being such an irregular river.

Effects on the river at base flow condition are important.

Offshore, it's the flood flows that are more important.

Because the Fitzroy is more irregular there are greater time periods for organic matter to decay, dentrification etc. before a large flood event when this material is washed into the river.

In the Tully, a more regular river, organic waste (e.g. Cane offcuts) are washed into the river more frequently, greater nutrient load.

USEABLE DATA FROM OTHER CATCHMENTS??

SPECIFIC CONCEPTUAL MODELS

10 year time period. Chronic and acute effects.

Inshore effects on marine fisheries (finfish, scallops, prawns). Temporarily ~10 years. Need to talk with John Platten.

CLOSE

10.30 am

8 APPENDIX 2

Minutes of the workshop held with stakeholders within the Fitzroy Basin: a discussion of ecological effects of irrigation activities at the local and catchment scale.

NPIRD WORKSHOP

Assessment of Ecological Risk associated with irrigation systems in the Fitzroy Basin:

Phase 1 – identification of risks and development of conceptual models.

9 November, 2000

Central Queensland University, Rockhampton

ATTENDENCE

Technical advice

Dr Leo Duivenvoorden	CLWRM, CQU
Dr Sabine Kasel	CLWRM, CQU
Dr Jon Brodie	GBRMPA
Chris Carroll	DNR
Bob Noble	DNR

Participants

Alicia Dunbar	Emerald Irrigator (via video link)
Cameron Millar	Emerald Irrigator (via video link)
Kym Thompson	Irrigator on channel west side of Emerald (via video link)
Trevor Brownlie	Theodore Irrigator
Robert Hutchinson	Theodore Irrigator
Peter Dunne	Landcare (Duaringa and Mackenzie River)
Graham Lightbody	Fitzroy Basin Elders Commitee
Sharon McClelland	Agforce, Theodore Grain Grower
Susan Cunningham	Water Resources Environmental Planning, EPA
Sara Cooke	Waterwatch coordinator

Apologies

Nick Goodhew	Emerald Irrigator
Ian and Rhonda Burnett	Emerald Irrigator
Charlie Wilson	Cotton Australia
Jo Wearing	Wildlife Preservation Society of Queensland
Bood Hickson	Arcadia valley
Mark Gooding	Chairman Callide Valley Irrigators Association, DCCA
Lindsay Black	Fitzroy Basin Elders Commitee
Trevor Acfield	Capricorn Conservation Council
Adrian Ross	Callide Irrigator
Kim Martin	SunFish
Bill Sawynok	Queensland Fish Management Authority

INTRODUCTIONS

Introductions between Emerald and Rockhampton participants.

Format of meeting.

PRESENTATION by Leo Duivenvoorden (interactive with questions asked throughout).

Project funded by NPIRD – through LWRRDC, state governments, water authorities and private irrigators.

Challenges of NPIRD.

Background – original NPIRD application.

Why have ecological risk assessment approach? Quantitative method for assessing level of risk to health.

What is involved in ecological risk assessment? (see www.epa.gov/ncea/ecorsk.htm).

Trevor B – current environment, or environment as it was previously? For example, a dam is a new environment. In this new environment, you may strive to achieve healthy populations of fish, while prior to the dam being built, there were no fish populations to worry about.

Risk characterization.

Leo D - Differences in scale between irrigation areas in Ord (relatively new system, although second stage development is being planned), Goulburn-Broken (large, highly developed) and Fitzroy (small areas, although more developed than Ord).

Methods for addressing ecological effects.

Alicia D – similar things have been done before, e.g. report card process. There are many other land uses in the areas described (Fairbairn dam to Duckponds). Concerned that this information will be used as a whipping stick against the irrigators. Leo emphasized that the information will be used to identify information gaps rather than to 'place blame'. The report will be sent to NPIRD.

Jon B – It is not possible to address the effects, need to address the source of the problem.

Robert H – Re: NPIRD funding: no point in chasing funding for the sake of funding (i.e. identify a problem and then get funding for the problem – rather than have funding and then try to find problem to solve).

Lunch (12.30-1.20 pm)

Sara C – cumulative effects of irrigation or separate effects? (this will become clearer after example of conceptual model is shown).

WORKSHOP

Leo D – of necessity, 'negative' effects of irrigation are considered in this phase of the ecological risk assessment process, there are several positive effects of irrigation, these will be investigated during other (latter) parts of the risk assessment.

Example of a conceptual model – fish kills – was presented. Trying to quantify how important different processes are in producing the observed effect. Fish kills from reduced oxygen levels may be a natural process.

Sharon Mc – how do you distinguish between the inputs from different land uses in a runoff event. Leo – area of land uses and rates calculated for each of those land uses.

Model (sources, stressors and effects).

It was proposed that the ecological effects be dealt with at two scales: local and whole of catchment.

Local Scale

Discussion of each of the ecological effects.

Jon B – algal blooms are more frequent than 100 years ago, inshore areas have elevated algal growth, not the case in the north where there are catchments with no development (e.g. Normanby).

Trevor B – is the increase in algal blooms due to catchment development/irrigation etc. Where are the links, have causes been attributed? Perhaps this is just due to a change in temperature?

Submerged plants – the idea of a shift in domination from aquatic plants to algae was discussed.

Bob N – release of nutrient rich water below barrage.

Graham L – is there any evidence that algal blooms affect vegetation? Leo D – yes competition for nutrients, effects on nutrient cycle. Graham L - Concerned that effects are really interrelated. Leo D – these steps should be clarified in the models and links investigated.

Fish kill – example given of one recently in Dee River, due to acid mine drainage. Frequency of fish kills?? Occasionally? Theodore – very occasionally. Emerald – participants not aware of fish kills or turtle deaths.

Leo D – difference between frequency of events and frequency of recording events. For example, exponential increase in recorded algal blooms during the last 10 years is more due to people looking and recording them, than an actual increase in algal blooms. 'Just because you are not aware of something doesn't mean it's not happening.'

Bob N – limited data on detection of contaminants in aquatic life. Some chemicals are picked up with fish kills. Wondered why it was ranked so high in the initial email survey?

Graham L – by itself, chemical residues are not a problem, unless they cause a problem, i.e. an effect.

Peter D – disagrees, believes any chemical residue in aquatic life (e.g. fish), beef is of concern.

Alicia D – perception that chemical residue is a problem. Chemical residues in cattle are more of a trade barrier than anything else.

Jon B – perception of chemical residues, high levels of chemicals in dugongs, but it is a concern because chemicals (such as diuron) are highly toxic. How these chemicals affect dugongs is not known at this stage.

Alicia D – chemical residues in cattle – doesn't know of any except for down south where a farmer contaminated his own cattle.

Peter D – chemical residues in cattle within guidelines.

Trevor B, Robert H – where are the chemical residues in cattle coming from?

Use of macroinvertebrates in assessing how healthy a system is. Fitzroy catchment is fairly good in terms of health as indicated by macroinvertebrate indices (except for Dee River due to acid mine drainage). Importance of both abundance and composition of macroinvertebrates: excellent indicators.

Changes in nutrient cycles.

Bob N – runoff in tail drain water, very high concentrations of nutrients, wastewater also has high concentrations of nutrients. Need to investigate the contribution of the different land uses in nutrient enrichment.

Jon B – effects of nutrient enrichment to coastal zone. Documented changes for monitored rivers. Good indicator for changes in land management practices.

Human health effects.

Chris C – human health effects mainly related to perceptions than reality? People are familiar with leukaemia scare during the 1980s in the Emerald area. Intense monitoring into spray drift. Report found no connections between spray drift and leukaemia.

Graham L – concerned that listed effects in email survey are based on perceptions (political, economical). List of effects is not extensive enough. Chemical residue in cattle is not an ecological effect?

Leo D – we need to have an attempt at narrowing issues down. This is a process of narrowing down issues. Aware that there is extensive overlap between effects.

Reduction in growth of seagrasses in the Bay.

Jon B – probably a lower priority one for the GBRMPA as there aren't any extensive beds in the Fitzroy area. Corals are more of a concern. Raise the question of whether there were seagrass beds off the Fitzroy catchment originally but we don't have the data to investigate this. Believe that there were few seagrass beds in the past.

Nutrient enrichment in the GBR.

Peter D – is there data to suggest there has been nutrient enrichment?

Jon B – we do have extensive data for some systems which show an increase in nutrient loads. Modelling for catchments with less data (e.g. Fitzroy) also suggest an increase in nutrients.

Increase in salinity.

Chris C – there are salinity issues in the Emerald Irrigation Area. What ecological effects this may produce is not known.

Leo D – ecological effects of increasing salinity in Murray-Darling – loss of most freshwater life forms.

Jon B – economic versus ecological effects. Can this be included in the models somewhere in the beginning. For example trace toxins in fish and their saleability?

Leo D – emphasizing the positive effects of irrigation again and scope for economic consideration at another stage in the ecological risk assessment.

Jon B – economic effects outside the scope of irrigation. Chemical residues in cattle, fish, humans? More economic than ecological. These may be just as important as direct effects.

Leo D – ecological risk assessment is focussed on ecology more than economics.

Alicia D – need to consider paying primary producers to attend meetings as it costs them in terms of loss in production etc. Concerned about application of these processes to produce on ground/management results which will in turn lead to a financial benefit to irrigators.

Leo D – add coral reefs to list.

Additions to list.

From initial email responses: increased habitat fragmentation, degradation of riparian zones, decrease in water quality, reduction in aquatic life populations (need to be more specific). Others added during workshop:

Susan C – geomorphology

Graham L – soil loss, soil quality, biodiversity, environmental flows.

Alicia D – soil or soil once it reaches the stream? Graham L – Don't know, just trying to be broad.

Leo D – effects of soil on environment – more of a stressor in terms of runoff. Soil degradation.

Graham L – still concerned about the process. List of effects too ill defined and too much overlap.

LOCAL SCALE

Results of first round votes (to narrow down the number of effects to six):

1. Changes in composition of macroinvertebrates (7votes)
2. changes in nutrient cycle (6 votes)
3. increase in salinity (6 votes)
4. soil degradation (5 votes)
5. changes in desirable fish populations (4 votes)
6. tie human health effects and decrease in water quality. Show of hands excluded human health effects (3 votes)

Results of second round votes (to distribute votes amongst the 6 effects remaining):

7. decrease in water quality (41 votes)
8. soil degradation (38 votes)
9. increase in salinity (35 votes)
10. decrease in composition of macroinvertebrates (33 votes)
11. changes in nutrient cycles (26 votes)
12. decrease in desirable fish populations (12 votes)

CATCHMENT SCALE

Results of first round votes (to narrow down the number of effects to six):

1. decrease in composition of macroinvertebrates (6 votes)
2. changes in nutrient cycles (6 votes)
3. effects on coral reefs (6 votes)
4. increase in salinity (5 votes)
5. decrease in desirable fish populations (4 votes)
6. decrease in water quality (4 votes)

Results of second round votes (to distribute votes amongst the 6 effects remaining):

7. decrease in water quality (46 votes)
8. increase in salinity (33 votes)
9. decrease in composition of macroinvertebrates (29 votes)
10. decrease in desirable fish populations (25 votes)
11. effects on coral reefs (24 votes)
12. changes in nutrient cycles (23 votes)

CONCLUDING COMMENTS

Process from here – take results, develop models, write document, submit to NPIRD. Leo will need to check with NPIRD about distribution of the document. Stakeholders are keen to receive the document.

Graham L – did NPIRD insist on this process? Leo D – yes they were very keen on getting input from the community. Graham L – concerned about small sample and that effects were predetermined. Difficult to separate between local and catchment scale effects. Doesn't think the process has led to a useful decision making.

Peter D – believes the process isn't too bad. Doesn't believe a full room of people would lead to large differences in the outcome.

If people want to feed in further information they are more than welcome to.

9 APPENDIX 3

Land use areas and P and N loads for the entire Fitzroy catchment, Dawson Study Area (Isla Delusion to Moura Weir) and Emerald Study Area (Fairnbairn Dam to Duckponds) (based on rates by Joo *et al.* 2000).

Land Use	Area (ha)	Area (%)	P kg/ha /yr	N kg/ha /yr	P kg/yr	% P load	N kg/yr	% N load
Dawson Study Area								
grazing of native pasture	292 152	79.05	0.710	0.310	90 567	72.83	207 428	51.55
irrigated improved and fertilized pasture	1 077	0.29	4.000	0.525	565	0.45	4 308	1.07
cropping/ non-row	42 399	11.47	1.550	0.490	20 776	16.71	65 718	16.33
irrigated cropping/ cotton	10 899	2.95	5.300	0.850	9 264	7.45	57 765	14.36
horticulture	13	0.00	11.000	1.550	20	0.02	143	0.04
irrigated horticulture	0	0.00	11.000	3.000	0	0.00	0	0.00
urban (sandy soil)	0	0.00	5.500	3.000	0	0.00	0	0.00
urban (clayey soil)	415	0.11	15.000	3.000	1 245	1.00	6 225	1.55
rural residential	0	0.00	5.500	0.650	0	0.00	0	0.00
national park	11 547	3.12	1.250	0.070	808	0.65	14 434	3.59
state forest / granitic sedimentary	11 095	3.00	4.180	0.100	1 110	0.89	46 377	11.53
state forest / basaltic	0	0.00	4.180	0.165	0	0.00	0	0.00
TOTAL	**369 597**	**100.00**			**124 355**	**100.00**	**402 398**	**100.00**
Total Irrigation	**11 976**	**3.24**			**9 829**	**7.90**	**62 073**	**15.43**
Emerald Study Area								
Crop/pasture rotation	17 883	1.54	0.49	1.55	8 763	2.14	27 719	2.08
Grazing	857 964	73.98	0.31	0.71	265 969	64.98	609 154	45.80
Improved & fertilized pasture	1 196	0.10	0.525	4	628	0.15	4 784	0.36
Institutional uses	32	0.00			0	0.00	0	0.00
Intensive primary production/processing	4	0.00			0	0.00	0	0.00
Irrigated crop/pasture rotation	500	0.04	0.85	5.3	425	0.10	2 652	0.20
Irrigated horticulture	1 490	0.13	3	11	4 470	1.09	16 389	1.23
Irrigated improved & fertilized pasture	10	0.00	0.525	4	5	0.00	39	0.00
Irrigated permanent cropping	24 124	2.08	0.85	5.3	20 506	5.01	127 859	9.61
Managed resource protected area	14 019	1.21	0.1325	4.18	1 858	0.45	58 601	4.41
Mining/extractive industry	6 291	0.54			0	0.00	0	0.00
National park	588	0.05	0.07	1.25	41	0.01	735	0.06
Permanent cropping	194 382	16.76	0.49	1.55	95 247	23.27	301 292	22.65
Rural residential	1 974	0.17	0.65	5.5	1 283	0.31	10 854	0.82
State forest	36 455	3.14	0.1325	4.18	4 830	1.18	152 384	11.46
Transport & communication	214	0.02			0	0.00	0	0.00
Urban uses	1 764	0.15	3	10	5 293	1.29	17 642	1.33
Utilities	693	0.06			0	0.00	0	0.00
Waste treatment & disposal	56	0.00			0	0.00	0	0.00
Water	126	0.01			0	0.00	0	0.00
TOTAL	**1 159 768**	**100.00**			**409 317**	**100.00**	**1 330 104**	**100.00**
Total Irrigation	**26 124**	**2.25**			**25 406**	**6.20**	**146 939**	**11.04**

Appendix 3 (cont.)

Land Use	Area (ha)	Area (%)	P kg/ha /yr	N kg/ha /yr	P kg/yr	% P load	N kg/yr	% N load
Entire Fitzroy Catchment								
Grazing	11 740 587	82.29	0.31	0.71	3 639 582	83.42	8 335 817	57.18
State Forest	806 019	5.65	0.13	4.18	104 782	2.40	3 369 159	23.11
Permanent Cropping	670 011	4.70	0.49	1.55	328 305	7.53	1 038 517	7.12
National Park	508 108	3.56	0.07	1.25	35 568	0.82	635 135	4.36
Crop/pasture rotation	280 002	1.96	0.49	1.55	137 201	3.14	434 003	2.98
Irrigated permanent cropping	65 570	0.46	0.85	5.3	55 735	1.28	347 521	2.38
Mining/extractive industry	54 603	0.38			0	0.00	0	0.00
Managed resource protected area	38 984	0.27	0.13	4.18	5 068	0.12	162 953	1.12
Institutional uses	31 944	0.22			0	0.00	0	0.00
Utilities	17 444	0.12			0	0.00	0	0.00
Improved and fertilized pasture	13 744	0.10	0.525	4	7 216	0.17	54 976	0.38
Water	11 698	0.08			0	0.00	0	0.00
Urban uses	10 470	0.07	3	10	31 410	0.72	104 700	0.72
Irrigated crop/pasture rotation	4 831	0.03	0.85	5.3	4 106	0.09	25 604	0.18
Rural residential	4 385	0.03	0.65	5.5	2 850	0.07	24 118	0.17
Irrigated horticulture	3 064	0.02	3	11	9 192	0.21	33 704	0.23
Transport and communication	1 316	0.01			0	0.00	0	0.00
Unused land	1 078	0.01			0	0.00	0	0.00
Horticulture	999	0.01	1.55	11	1 548	0.04	10 989	0.08
Industrial	855	0.01			0	0.00	0	0.00
Irrigated improved and fertilized pasture	512	0.00	0.525	4	269	0.01	2 048	0.01
Intensive primary production/processing	396	0.00			0	0.00	0	0.00
Waste treatment and disposal	228	0.00			0	0.00	0	0.00
Plantations	12	0.00			0	0.00	0	0.00
TOTAL	**14 266 860**	**100.00**			**4 362 832**	**100.00**	**14 579 244**	**100.00**
Total Irrigation	**73 977**	**0.51**			**69 302**	**1.59**	**408 877**	**2.80**

10 APPENDIX 4

Environmental guidelines for physico-chemical indicators in freshwater.

	1992 ANZECC Water Quality Guidelines for the protection of aquatic ecosystems	1987 NHMRC/AWRC Raw water for drinking subject to coarse screening	1992 ANZECC Raw water for drinking subject to coarse screening	1992 ANZECC Irrigation water	1999 Draft ANZECC Water Quality Guidelines for the protection of aquatic ecosystems
DO	>6 mg L^{-1} 80-90% saturation				<92% upland rivers <90% lowland rivers
pH	6.5-9	6.5-8.5	6.5-8.5		6.5-7.5 upland rivers 6.6-8.0 lowland rivers
Suspended sediments (µg L^{-1})					2000 upland rivers 6000 lowland rivers
Electrical conductivity (µS cm^{-1})	<1 500 µS cm^{-1}		<1500 (human) <4400 (livestock)	<280 (low) 280-800 (medium) 800-2300 (high) 2300-5500 (very high) >5500 (extremely high)	>500 µS cm^{-1} initiates further investigation
Total N (µg L^{-1})	100-750 rivers and streams 100-500 lakes and reservoirs				340 upland rivers 1600 lowland rivers
Total P (µg L^{-1})	10-100 rivers and streams 5-50 lakes and reservoirs				35 upland rivers 37 lowland rivers
TN/TP	NSW Blue-Green algal task force (1992) <29:1 conducive to growth of blue-green algae				

At <4 mg L^{-1} DO fish can die or leave the location (Fairweather and Napier 1998).

11 APPENDIX 5

Environmental guidelines for pesticide concentrations in freshwater (all values in μg L^{-1})

Pesticides	1992 ANZECC Environmental Guidelines	1996 NHMRC Drinking Water Guidelines	1996 NHMRC Drinking Water Guidelines Action Levels	1999 Draft ANZECC Environmental Guidelines
Alpha-Endosulfan	na	na	na	
Beta-Endosulfan	na	na	na	
Endosulfan sulphate	na	na	na	0.001
Total Endosulfan	0.010	30.00	0.05	
Endo Alcohol	na	na	na	na
Trifluralin	na	50.00	0.10	1
Diuron	na	30.00	na	0.03
Fluometuron	na	50.00	na	na
Prometryn	na	na	na	na
Synthetic Pyrethroids	na	na	na	na
Organophosphorus	na	na	na	na
Methomyl	na	30.00	5.00	na
Thiodicarb	na	na	na	na
DDE	0.014	na	na	0.03
Parathion methyl	0.004	100.00	0.30	na
Profenofos	na	0.30	na	0.00002
Atrazine	na	20.00	0.50	0.5

	1987 NHMRC Australian Drinking Water Guidelines	1996 Draft NHMRC/ ARMCANZ Australian Drinking Water Guidelines**	1993 WHO Drinking Water Guidelines	1992 ANZECC Water Quality Guidelines for the protection of aquatic ecosystems	1998 USEPA Ambient Water Quality Criteria for protection of aquatic organisms (acute exposure)	1993 Canadian Water Quality Guidelines for the protection of freshwater aquatic life	1999 Draft ANZECC Water Quality Guidelines for the protection of aquatic ecosystems.
Insecticides							
Endosulfan	40	0.05	na	0.01	0.22	0.02	0.001
Profenofos	0.6	0.3	na	na	na	na	
Parathion	30	10	na	0.004	0.065		0.0004
Chlorpyrifos	2	na	na	0.001	0.083	na	0.001
Herbicides							
Atrazine	na	0.5	2	na	na	2	0.5
Glyphosphate	200	10	na	na	na	65	na
Diuron	40	na	na	na	na	na	0.03
Flurometuron	100	na	na	na	na	na	na

Metolachlor	800	2	10	na	na	8	na
Prometryn	na	na	na	na	na	na	na
Pendimethalin	600	na	20	na	na	na	na
Trifluralin	500	0.1	20	na	na	0.1	1

na – not available

* USEPA note that all systems should monitor for matolachlor unless shown not to be present.

**Guideline Action levels – if pesticides exceed this level, then investigate source and rectify where possible.

12 APPENDIX 6

Pesticide concentrations at various gauging stations (from DNR 1998 and Jones *et al.* 2000). Guidelines follow the Draft ANZECC (1999) report (0.001 µg L^{-1} for endosulphan sulphate and 0.03 µg L^{-1} for diuron).

Location	Pesticide			
	Endosulphan sulphate (µg L^{-1})		Diuron (µg L^{-1})	
	n	% above guideline	n	% above guideline
Fitzroy Outlet				
Fitzroy (Eden Bann) 23.088° S, 150.114°E	12	0	-	-
Emerald Irrigation Area				
Nogoa (Raymond) 24.150° S, 147.383°E	5	0	1	0
LN1 Drain (EIA) 23.515° S, 148.149°E	6	100	6	100
LN3 Drain (EIA) 23.546° S, 148.132°E	7	100	7	86
RR4 Drain (EIA) 23.448° S, 148.167°E	4	100	7	86
Retreat (Main Road) 23.430° S, 148.149°E	5	100	7	71
Nogoa (Duckponds) 23.483° S, 148.473°E	45	16	17	18
Dawson Valley Irrigation Area				
Dawson (Wide Water)	6	0	3	0
Drain 1 (Gap Creek) 24.944° S, 149.968°E	13	92	12	100
Drain 3 (Dawson River) 24.940° S, 150.084°E	11	82	10	80
Drain 4 (Castle Ck) 24.964° S, 150.074°E	12	83	12	100
Dawson (Theodore) 24.953° S, 150.072°E	26	19	16	44
Dawson (Below Theodore) 24.940° S, 150.068°E	21	19	6	17