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LITERATURE REVIEW AND SCOPING STUDY OF THE POTENTIAL DOWNSTREAM IMPACTS OF THE PROPOSED NATHAN DAM ON THE DAWSON RIVER, FITZROY RIVER AND OFFSHORE ENVIRONMENTS

A report prepared for the Great Barrier Reef Marine Park Authority

Report No 98/18

September 1998

FINAL REPORT

(Finalised June 1999)

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EXECUTIVE SUMMARY

It is proposed to construct a large dam on the Dawson River and to develop 30,000ha of irrigation, mostly cotton and mostly along the margins of the river channel. The Dawson is a heavily regulated river and over two-thirds of the river's length below the dam site is already inundated by weir pools.

The IAS for this proposal largely focuses on the impacts of the impoundment and some aspects of the river channel down to the Dawson/Mackenzie River junction. There is only minor discussion of the impacts of the irrigation area and no assessment of the impacts on downstream environments below the Dawson/Mackenzie River junction. For all dam and irrigation developments, the issues associated with the irrigation area and the downstream environments warrant as much attention as does the impoundment area itself. This report reviews the issues that have been neglected or improperly covered in the decision-making process thus far.

In the absence of the outcomes of the WAMP process, consideration of the impacts of irrigation area development, consideration of downstream effects and the other potential impacts listed below, **it is not possible to conclude that the proposal can proceed without significant environmental harm**. The conclusion that no significant harm will occur is in our opinion, unjustified and incorrect for the following reasons:

1) the failure to consider the downstream effects of the proposal, particularly in relation to the estuarine and marine environments;
2) the failure to appropriately consider the environmental effects of the irrigation developments likely to result from the dam construction;
3) the proposed development of irrigation parallel to and within 5km of the river channel rather than as distinct blocks away from any river;
4) the use of concepts such as 'Best Farm Practices' to conclude, without any evidence, that there will be no impacts of irrigation area development on the riverine environment;
5) the unavailability of the Water Allocation Management Plan (WAMP) or data being collected for that process;
6) failure to determine environmental flows requirements for specific important or sensitive habitats;
7) lack of discussion on potential changes to riverine geomorphology and coastal erosion resulting from reduced sediment supply;
8) the failure to sample or even discuss, the aquatic invertebrate fauna and potential impacts of the proposal on this important group of organisms;

The potential effects of terrestrial runoff to the Great Barrier Reef are of great concern. There is already evidence of coral reef decline in the Capricorn-Bunker group and of the fringing reefs in Keppel Bay although the cause is not clear. The proposed dam will be effective at retaining sediment emanating from its catchment area. We have calculated that at average levels of catchment discharge, the new irrigation area would have to result in a 7-43 fold increase in sediment loss to cause a net increase in sediment export from the Dawson River catchment. Literature estimates of the increase in sediment export from cropping areas versus grazing areas range from 2.5 - 4 fold. The current poor condition of the catchment suggests that this figure may be even less. This implies that there will be no net export of sediments to the offshore environments, unless instream erosion below the regulated river section is significant.

Due to the high rate of nitrogen application applied to irrigated crops and the high mobility of this nutrient, it can be expected that only the strictest controls for on-farm nutrient retention will prevent an increase in nitrogen export to downstream environments such as the Great Barrier Reef. Nutrient data from existing cotton tailwaters in the Fitzroy catchment do not inspire confidence in this being achieved under the current management regime.

The Capricorn region is very important for commercial and recreational fisheries. A positive relationship between the volume of freshwater flow emanating from the Fitzroy River and the fishery catch offshore has been demonstrated. There is evidence that this effect also extends out to fishery species on coral reefs. Thus, reductions in the volume of freshwater flow emanating from the Fitzroy River can be expected to reduce fishery catches in the estuary and nearshore environments. Reductions in freshwater delivery to estuarine habitats may also cause large scale changes in the areal extent of mangroves. The extent and magnitude of these effects require assessment and are an essential requirement of any proposal to regulate waterflow in rivers discharging to the ocean.

Extensive evidence from other regulated catchments suggests that river regulation reduces instream habitat and fish faunal diversity and favours introduced fish species over native fish species. Within the Fitzroy River, it has been shown that the magnitude and frequency of flooding affects barramundi recruitment and movement patterns as well as the distance moved and growth rates. Although we know that increasing regulation of riverflows has a negative impact on fish communities, we do not have enough biological knowledge of most fish species to determine what their flow requirements are. We do however, know that the majority of waters in the weir pools will for many months of each year not contain sufficient amounts of oxygen to support fish life. Providing sufficient flows to manage fish habitat conditions should be a primary consideration for environmental flows.

Two-thirds of the Dawson River has already been turned from productive riffles and natural pools into large, deep weir pools. With the addition of a dam and more weirs, a greater amount of river length will be inundated. Deep weir pools provide poor habitat as stratification renders up to 70% of the water column and 95% of the river bed anoxic. This proposal only serves to further exacerbate these problems unless it can be proved that appropriate environmental releases and standing water levels in the weir pools can be managed in such a way that important habitats such as riffles and runs are maintained and stratification is minimised. This has not yet been shown to be the case.

The quality of water within the Dawson River is not high. Several parameters regularly exceed ANZECC water quality guidelines and at most sites, for most of the time, conditions are conducive for the development of blue-green algal blooms. These are a rare occurrence, however, due to the high turbidity levels restricting light penetration and thus algal development. Further pressures on the water quality of the river, especially in the weir pools, would create even greater problems. The limnological performance of the proposed dam has also not been determined, but will have a significant impact on the quality of water released downstream and net exports of nutrients and sediment to the Great Barrier Reef. The lack of consideration given to several water quality issues such as metals, pesticides and oxygen demand needs to be addressed, as these may be further impacted by the proposal.

The WAMP process for the Fitzroy catchment is nearing completion, but was unavailable for the IAS. The environmental flow considerations in the technical reports released for the WAMP do not consider the unique requirements of the Dawson River. Due to the highly modified nature of the Dawson River, attempting to apply the same flow regimes as the other sub-catchments in the Fitzroy basin may not be beneficial. Water quality requirements, especially the dissolved oxygen requirements discussed at length in the IAS, also do not appear to be considered in the WAMP.

Cotton is expected to be the major crop in the proposed irrigation area. This requires the use of aerially-applied pesticides, most notably endosulfan, which is toxic to a wide range of fauna, particularly fish. The proposed location of the irrigation land within 5km of the Dawson River channel will greatly increase endosulfan export to the riverine environment. Modelling suggests that even when applied 5km from the river, spray drift could result in aquatic endosulfan concentrations in excess of ANZECC guidelines. Even with adherence to tight regulatory controls, we suggest that a 5km wide buffer is required to prevent aerially-applied pesticides from entering the riverine environment. The irrigation area should be created as a discrete block, or several smaller blocks, remote from the river, so as to increase the ability to monitor and regulate environmental exports and to reduce impacts on the riverine environment. Groundwater quality and potential salinisation problems have only been superficially considered. Given the nationally-significant problems caused by these issues in other irrigation areas, it is imperative they be given more consideration here.

We conclude that this proposal as it currently stands will result in significant impacts to the riverine environments and floodplain and estuarine habitats and may increase nutrient loadings to the Great Barrier Reef. These impacts have not been adequately addressed in studies done to date. It is hoped that this report will highlight the deficiencies related to assessing impacts on downstream environments such as the Great Barrier Reef and that these will be considered in this and all future dam and irrigation area proposals before development approvals are given.

The principal adverse effects on the downstream environment predicted by this assessment are associated with altered river flows and pollutant runoff from irrigated cropping. Both these impacts may be minimised by an effective environmental management regime for activities associated with the project. Recommendations for the environmental management plan are outlined below.

A Water Allocation and Management Plan must be implemented which preserves satisfactory environmental flows for the Fitzroy system. The plan should also take into account the individual flow requirements for the Dawson River. In particular the use of environmental flows to maintain habitat quality in the Dawson through maintenance of oxygenation is a key issue. Trigger flows to meet the environment stimulus for brining on spawning of important fish species are also desirable.

In addition to environmental water flows the Dawson irrigation system should be designed to maintain and enhance connectivity for fish passage. This should include provisions to improve fish passage on existing weirs on the Dawson River and any new weirs built as a part of the development.

For all irrigated cropping systems utilising water from the project implementation of the Codes of Best Practice for each crop should be mandatory. Monitoring and auditing of compliance with the Codes should also be implemented by the regulatory agency (EPA). Cotton, sugar and horticulture have existing Codes. Codes for grain crops and other broad-acre crops are required. For cotton, as the indicative crop for the project, the following components of the Code of Best Practice are relevant to reducing pollutant discharge:

1) Pesticide Management:
- Promotion and adherence to integrated pest management techniques.
- Selection of appropriate pesticide application techniques to minimise off-target movement.
- Use of vegetative buffer strips (at least 30m wide) adjacent to watercourses and wetlands.
- Vegetative strips planted to attain a minimum height of 1.5 times the height of the spray release.

2) Erosion control:
- Limit furrow length and slope to allow uniform water application and flows at non-erosive velocities.
- Utilise and maintain sediment traps.

3) Minimising storm impacts:
- Retain at least the first 10-15mm of run-off water from fields.
- Recirculate all tail water.
- Direct all stormwater overflow structures and blow out points away from watercourses and wetlands.

4) Irrigation efficiency:
- Adapt farm plans to maximise water use efficiency.

5) Fertiliser use efficiency.
- Utilise management techniques to correlate fertiliser application to the nutrient requirements of the crop.

Mandatory water quality industry performance standards for wastewater discharge to the river system from irrigated cropping should be introduced under Queensland Environmental Protection Act. The standards should cover dissolved oxygen (DO), nitrogen, phosphorus, suspended solids and relevant pesticides. Standards should be developed in association with the cropping industries so they are achievable but still achieve satisfactory environmental outcomes. A monitoring and auditing program is essential to assess compliance. A program to establish satisfactory buffer zones along the river system with a riparian revegetation component should be implemented. A riparian vegetation buffer will reduce spray drift to the river, stabilise river banks and trap a component of surface and sub-surface flows of sediment and nutrients.

It is critical that the Impact Assessment process for dam proposals includes consideration of the full impacts of the altered flow regime and any irrigation developments or other water uses (eg, mining, urban) on downstream environments.

1.0 INTRODUCTION

The Australian Centre for Tropical Freshwater Research (ACTFR) was commissioned by the Great Barrier Reef Marine Park Authority (GBRMPA) to examine the potential downstream effects of the proposed Nathan Dam on the Dawson River and downstream environments. An Impact Assessment Statement (IAS) has already been prepared by Hyder Consulting (Hyder Environmental 1997). However, this IAS did not address many of the downstream effects of the dam, resulting in concerns over the adequacy of the assessment and prompting the preparation of this report. The reason for not examining the downstream effects of the proposal in the IAS is stated there as being "..largely because there are no credible baseline data available on system inputs from other sub-basins.. or point and non-point sources to the Fitzroy from the lower reaches" (p.4).

This ACTFR report is the result of a literature review and scoping study only. It is not intended to be a research document or to supplement the IAS by assessing the likelihood and extent of impacts on downstream environments that were not considered there. Not all impacts associated with dam and irrigation developments which have been reported in the literature will necessarily occur as a result of this particular proposal. There are a variety of potentially significant, large scale impacts that have not been discussed or considered in the decision-making process for this project. This review is intended to highlight impacts that have a reasonable probability of occurring if this development proceeds. Further investigation may reveal that some of the identified impacts are unlikely for this particular proposal. We are not in a position to quantify the impacts, but have raised issues that should be addressed in all dam and irrigation area proposals. We welcome comments and research that would demonstrate otherwise. Indeed, it is the contention of this report that further data collection and consideration of a wider array of potential impacts is required in order for a sound decision to be reached with regard to the proposal proceeding.

Put more colloquially, this report does not answer all of the questions on downstream impacts, but raises the questions that must be answered before decisions can be made on this and other similar proposals.

2.0 DESCRIPTION OF THE EXISTING ENVIRONMENT

2.1 Description of the Fitzroy Catchment

At 142,645km^2, the Fitzroy is the largest catchment along the coast of Queensland (QDPI 1993). Almost 84% of the catchment area is used for grazing and there has been a significant alteration of catchment habitats since European occupation, with brigalow habitats in particular declining from 30% of the original catchment area to less than 1% today (QDPI 1993). Much of this vegetation was cleared under the Brigalow Development Scheme in the 1960's for grazing. More recently, crop production, which has a higher rate of return per unit area, has increased in the catchment.

The catchment contains six major sub-catchments centred on the Nogoa, Comet, Isaac, Mackenzie, Fitzroy and Dawson rivers. There are weirs and/or dams in all major sub-catchments of the Fitzroy basin. As noted by Hyder Environmental (1997), since the beginning of the areas development in the 1920's, there has been no overall strategy to integrate water supply. Many of the recent proposals (although these date back many years) are largely driven by economic and engineering considerations (Hyder Environmental 1997) and do not consider downstream environments such as the estuary and inshore reefs, or the cumulative impacts of other proposals. The WAMP process will increase the level of integrated planning and introduce considerations for downstream environments and cumulative impacts of water storage proposals. However, the results of this process were not available for consideration in relation to this proposal. This has justifiably brought major criticisms of the decision-making process.

There are already 3 dams and 16 weirs in the Fitzroy River catchment. The proposal for the Starlee Dam on the Comet River (one of the major sub-catchments of the Fitzroy), near Rolleston, was recently rejected by the state government on environmental grounds. Information regarding this proposal can be found in the IAS for that dam (PPK 1997).

2.2 Description of the Dawson River

The Dawson River is one of five major tributaries of the Fitzroy River in central Queensland. Its headwaters are towards Wandoan and in the Carnarvon Ranges. Its major tributaries are the Dee and Don rivers. The Dee River sub-catchment included mining operations which left the water polluted by acid mine drainage, and has been the subject of several scientific studies (eg: Mackey 1988, Duivenvoorden 1995). The Dawson River terminates at its junction with the Mackenzie River to become the Fitzroy River. Like most other Australian rivers, the Dawson River (and all other rivers in the Fitzroy catchment) has a highly variable pattern of streamflow. Though annual variation is high, the highest flows occur seasonally in the summer and autumn months.

The channel of the Dawson River is characterised by a series of long and deep permanent pools separated by runs (Telfer 1995, Hyder Environmental 1997). The middle and lower reaches are long and winding and have steady gradient, producing uniform characteristics. Nathan Gorge has a narrow valley, but is not associated with any falls or steep gradients. It has high habitat value due to low levels of human intervention, retention of riparian and valley slope vegetation and the presence of riffle and boulder habitats. Many of the Dawson's tributaries run dry during the dry season, although there is always water in the Dawson River. Extensive land clearing in the catchment has occurred since the 1920's. The Dawson River valley has wide and fertile alluvial plains, apparently suitable for agriculture.

The Dawson River catchment area is 50,830km^2 and the proposed dam site has a sub-catchment area of 14,400km^2 (Hyder Environmental 1997). Apart from the upper reaches, which has gorges and undulating plains, most of the river is of a low gradient with increasingly broad alluvial plains and a meandering river pattern. Over the 550km length of the river, there is only a 300m drop in elevation, with over half of that occurring in the first 125km, well upstream of Taroom (Hyder Environmental 1997). The climate at Taroom varies from 20.7-33.4°C for maximum average temperatures to 5.0-20.5°C for mean minimum temperatures. Mean annual rainfall varies from 600-750mm with about half falling between November and February. Rainfall at Theodore is 732mm/yr with 40% falling in summer. The mean annual discharge is 1,127,000ML (Hyder Environmental 1997) relatively low for such a large catchment. Evaporation rates are around 2,000mm/yr, three times the rainfall, and droughts occur regularly.

There are already two dams (Callide and Mount Morgan) in the Dawson River catchment though neither are on the Dawson River itself. There are however, six weirs on the Dawson River (Neville Hewitt, Moura, Theodore, Orange Creek, Gyranda and Glebe), all of which are below Taroom. The first weir on the Dawson River was constructed at Theodore in 1926. The yield from these six weirs is approximately 60,000ML/year, though current water use is significantly less (Markar 1997). Water levels in these weirs are sometimes very low and they may occasionally dry out. The weirs presently service 7,500ha of irrigated land, mostly on alluvial soils of the Dawson River valley (Hyder Environmental 1997). There are also 15-20,000ha available upstream of the dam site and 5,000ha can be irrigated directly from the impoundment (Hyder Environmental 1997). Construction of the Nathan Dam would flood Glebe Weir (17,300ML). The Nathan Dam proposal also includes two new weirs, which would bring the total storage downstream of the Dawson River weirs to 61,400ML.

More than 350km of the length of the Dawson River is regulated for water consumption and only 115km of the distance between Taroom and the Fitzroy confluence is not modified by weir pools (Hyder Environmental 1997). In addition, 44% of the Fitzroy River (downstream of the Dawson) is also inundated (DNR 1998a). Thus, much of the river is already heavily impacted by water storage developments. Five additional weirs (at Paranui, Duaringa, below Dawson River/Mimosa Creek junction, on Mimosa Creek and at Baroondah) are also proposed for the Dawson River by the Water Infrastructure Taskforce and rated as Category 1, which carries a recommendation as a priority for implementation or further investigation (Hyder Environmental 1997). The potential impacts of these are not included in the IAS, nor are any cumulative impacts beyond the Dawson-Mackenzie junction (which then becomes known as the Fitzroy River). Cumulative impacts of river regulation on the whole Fitzroy system, including downstream effects were considered by the consultants to be beyond the IAS but that it was "..strongly advocated and as a matter of priority" (IAS p.2).

3.0 DESCRIPTION OF THE PROPOSED PROJECT

A dam on the Dawson River at Nathan Gorge was first proposed in 1922, 8km downstream of the site currently proposed. That proposal included a dam with a 225m FSL and a capacity of 3 million ML, that would have inundated the town of Taroom to a depth of 25m (Hyder Environmental 1997). The currently proposed dam site is upstream of Nathan Gorge, at 315.3km AMTD. Two weirs, Paranui and Duaringa at AMTD's 169.7km and 30.1km respectively, are also part of the proposal. When discussing the scope of the study in the IAS (p.2), it is indicated that there are four additional weirs proposed for the Dawson River by the Water Infrastructure Taskforce that are dealt with in the IAS. However, only the two weirs named above are mentioned any further. On page 11 of the IAS, when describing the weirs proposed by the Water Infrastructure Taskforce, only five new weirs are listed in total - these being Paranui, Duaringa, on Mimosa Creek, at Baroondah and below the junction of Dawson River and Mimosa Creek. On page 135 of the IAS, the proposed Baroondah Weir is included in the discussion, but not the proposed weir below the Dawson River/Mimosa Creek junction. The weir on Mimosa Creek is also not mentioned there, presumably because the discussion only related to storages and proposed storages on the Dawson River itself. The river is not perennial above the Baroondah Weir site. If the Nathan Dam, Paranui, Duaringa and Baroondah weirs all proceed, 60% of the river distance between Baroondah and the junction with the Fitzroy River will be inundated by artificial pools (Hyder Environmental 1997). This would make the Dawson River one of the most regulated rivers in Australia. The IAS (p. 136) compares the situation with that of the Murray-Darling River and recommends the need for further research. It will later be seen that almost all of the riverbed and most of the water column within the existing impoundments is at times, unsuitable for supporting most aquatic life.

Capacities for the proposed Paranui and Duaringa weirs are expected to be 11,000ML and 6,000ML respectively. Capacity for the Nathan Dam is expected to be either 521,000, 880,000 or 1,079,000ML according to three potential supply levels of 180m, 183.5m, and 185m AHD respectively. The IAS also discusses a storage level of 172m FSL, at which level the dam would essentially be a series of within-river channel weirs. This level of storage is not likely to be considered as a serious option. It is also not expected that all of the weir proposals will proceed.

The location of the current dam proposal was first identified at 313.9km AMTD, but was moved to 315.3km AMTD to protect the environments of Price Creek (aboriginal heritage significance and 12 boggomoss habitats) and the upper Nathan Gorge area (aboriginal significance and environmental importance).

The purpose of the dam is to supply water to an expanded irrigation area. No water delivery channels are proposed and the IAS assumes that water will not be taken more than 5km either side of the river. Thus the proposed irrigation area comprises a linear strip along the Dawson River plus some additional land irrigated directly from the impoundment. The IAS indicates that there are 66,290ha of potentially suitable land within the 10km wide strip of the Dawson River but that there will only be sufficient water to irrigate 30,000ha in addition to that currently under irrigation. This was based on an average irrigation requirement of 6ML/ha. It is anticipated that cotton will be the most common crop to be planted in the irrigation area and the economic analysis of the project was based on this crop, though the exact mix of crops to be planted cannot be determined at this stage.

4.0 REVIEW OF THE IAS

As the major criticisms of the assessment of this proposal relate to omissions, including those relating to issues not included in the Terms of Reference for the IAS, it is not intended to blame the consultant for all of the shortcomings of the IAS. Rather, it is our contention that the budget, the timeframe and the Terms of Reference should have provided for greater consideration of these issues. Most of the issues raised in this report are also relevant to the IAS recently prepared for proposed Starlee Dam on the Comet River (PPK 1997). It would seem that the problems of Impact Assessment Statements for dam and irrigation developments not incorporating all of the relevant points starts with the process itself. Compared to other states, such as NSW, in Queensland, there are no fixed guidelines for what potential impacts various types of developments should include for consideration. In order for Impact Assessment Statements for dam and irrigation developments to provide consideration of all relevant potential impacts, it is important that the shortcomings recognised in this document are specifically included in the Terms of Reference for all such developments. The timing and budget should allow for an appropriate level of information gathering and synthesis. Current IAS requirements for dam and irrigation developments fall considerably short of our knowledge and understanding of the environmental impacts they are likely to cause. Thus, from the outset, they are not able to provide consideration of the relevant issues in sufficient detail for a credible assessment of the likely impacts to be made.

Some of the criticisms of this review involve the IAS, some the ToR and some reflect on the IAS process itself. It is only the intent here to concentrate on the major issues that affect downstream environments and on the decisions made with respect to the dam proceeding. The major criticisms are listed below but will be discussed in their relevant sections. They relate partly to what was written in the IAS, but even more attention has been focused on what was excluded from consideration or adequate discussion in the report. This includes:

- absence of the WAMP data and conclusions even though they are of vital importance
- absence of environmental flow requirements for specific important habitats
- no sampling of aquatic invertebrates or even consideration of issues relating to this group
- failure to discuss impacts of the proposal downstream of the Dawson-Mackenzie junction including the estuary and offshore seagrasses and coral reefs
- failure to discuss the limnology of the proposed dam, including its depth, profiles and sediment-trapping capacity, particularly of fine suspended sediment
- failure to discuss toxic metals and pesticides in the Dawson River even though these are known to exceed ANZECC guidelines and are associated with dam construction and irrigation development
- low oxygen levels are considered a major issue for the Dawson River but there has been no consideration of the role of oxygen demand in contributing to this problem
- failure to fully examine the environmental impacts of the proposed irrigation area development

- dismissal of the effects of agriculture by claiming that farm management plans and other mechanisms will prevent and/or solve such problems
- failure to appropriately consider groundwater issues
- limited comparison with the environmental impacts resulting from nearby dam and irrigation projects within the catchment to predict the performance of this proposed scheme
- failure to consider cumulative effects of development within the catchment
- limited incorporation of environmental costs and recommendations of the Environmental Management Plan in the economic analysis. This will not be discussed further in this report, but it is clear that the large costs of environmental management may not been adequately accounted for. Several submissions to the IAS discuss this point, some in substantial detail.

It should be noted that the coverage of issues examined in dam and irrigation development IAS's is many years behind our current level of knowledge and understanding of the likely impacts of such proposals. Under the timing, budgets and Terms of Reference for this proposal, it is simply not possible to fully examine and assess the potential impacts with any degree of confidence or acceptability by scientists, environmental managers or the concerned public.

Despite numerous statements throughout the report lamenting that time and budgetary constraints prevented discussion of many extra topics and emphasising the importance of several of these topics (eg: WAMP data, consideration of the catchment-wide and cumulative effects of river regulation), the IAS concluded that there are "..no adverse impacts of such magnitude that it should interfere with the development of the proposed dam" (Executive Summary, p.F). Many of the potential mechanisms for causing environmental harm have not been raised or taken into consideration. There has not been sufficient consideration of all the relevant issues for this conclusion to be reached at this stage. For a variety of reasons the IAS process in this case has fallen well short of providing the information required to properly assess the proposal. The shortcomings should be addressed for this and future proposals, to avoid the problems that have arisen in this case.

5.0 FLORA

Inundation of vegetation communities within the impoundment area was a major focus of the IAS. The issue of land clearing for agricultural development was only briefly touched upon as the topic was considered more appropriate for future studies assessing the proposed irrigation areas themselves. This is an example of piecemeal development without considering the full consequences of the entire proposal at the onset. The irrigation area and dam proposal are intricately linked. Although full details of the irrigation area would not yet be available, there are many issues related to irrigation development which can be considered at this stage. Likely areas for irrigation development are known and their soil types have been mapped, and these could be assessed now, lest the irrigation area be found to contain rare or endangered plants or communities after dam development has begun. Due to high rates of land clearing in the catchment, the remaining habitats have a higher probability of being of some conservation value. Although some of the land to be used for irrigation development may already be cleared, the IAS admits (p.219-220) that the land clearing required for the irrigation area will impact adversely on Endangered, Vulnerable and Rare fauna and that the impact will be significant. This finding alone is justification for further study of the potential irrigation areas as part of the decision-making process.

5.1 Terrestrial and Riparian Flora

A detailed survey of aquatic habitats of the Dawson River catchment using the State of the Rivers methodology (Telfer 1995) found the riparian habitats to be in poor to very poor condition. As they play crucial roles in aquatic ecosystems, the protection of riparian vegetation is a key element in all catchment management strategies. The draft Regional Ecosystems Report of the Department of Environment (QDEH 1995) examines the conservation status of vegetation communities in Queensland. It recognises 147 regional ecosystems within the brigalow belt (which includes the Dawson Valley), including 21 that are 'endangered', 19 that are 'vulnerable' and 30 that are 'of concern' (Melzer and Childs 1995).

For the IAS, the riparian communities downstream of the dam site were examined at three river crossing points and from LANDSAT imagery, but not mapped, though they are considered to be the same as the riparian vegetation within the impoundment area. This vegetation consists of Vegetation Map Unit 1 (Tall open forest of *Eucalyptus camaldulensis* with *E. tereticornis*, *E. coolabah* and *Melaleuca linariifolia*) whose conservation status is listed as 'of concern'.

The Dawson and Fitzroy rivers include meanders, billabongs and a floodplain with swampy areas. Alterations to the frequency and magnitude of flood events resulting from this proposal will result in changes to the plant species composition of these communities, with increasing replacement by drier vegetation types likely. Existing regulation may have partly affected these communities already, but the imposition of a large dam could have more significant changes. While the locations of many of these habitats have been recorded in the IAS, there has been no significant survey of the vegetation upon which to judge their susceptibility to changes in the hydrological regime.

Of particular concern in the region are the boggomosses. These are a specialised wetland habitat (a type of mound spring) fed by groundwater in a region where other permanent water sources are rare. They thus support flora and fauna that are not found elsewhere in the region and, as they were also used by indigenous Australians, are of cultural significance. Fensham and Wilson (1997) found the boggomosses to have a vascular flora of 170 native species, 44 of which were only associated with dry mounds. Four types of boggomosses were identified in five geographical groupings. Of the 69 boggomosses found in the dam vicinity, 34 will be flooded by the dam at 185m FSL. The assertion that new boggomosses will form elsewhere does not substitute for the loss of existing boggomosses that have highly developed vegetation communities that may take many years to replace.

Apart from the concern about land clearing and irrigation development leading to increased erosion and sediment/nutrient export (see sections on Irrigation Development and Water Quality), the highly important issue of the effect of land clearing on conservation of flora will not be dealt with further in this report.

5.2 Aquatic Plants

Duivenvoorden (1995) summarises surveys of the aquatic macrophytes of the Fitzroy River conducted over three years (1989-1991) at 101 sites, including 39 sites in the Dawson River sub-catchment. A total of 105 aquatic and semi-aquatic species were noted, with most sites having only 2-5 species present at any one time. Throughout the year, species diversity was similar although the taxa present were different. Desiccation-resistant species dominated in May/June while submerged and floating species were common in October. This may have been due to settling of suspended sediment and increased light penetration. As part of the Downstream Effects of Land Use Study, Duivenvoorden (1997) surveyed aquatic plants at 11 sites in the Fitzroy catchment, including 3 in the Dawson River sub-catchment on three occasions over two years (1994-1995). Results from this survey include the finding that the two sites on the Nogoa River downstream of the Emerald Irrigation Area had a markedly lower diversity of aquatic plants than the two sites on the river upstream of the irrigation area.

Increased river regulation may also favour the prolification of introduced aquatic and riparian weed species such as water hyacinth (*Eichhornia crassipes*), paragrass (*Urochloa mutica*) and hymenachne (*Hymenachne amplexicaulis*) as the adaptation of native species to variable environments becomes less of an advantage. Water hyacinth and paragrass are already widely present throughout the Fitzroy catchment with hymenachne being a more recent invader. Water hyacinth covers the surface of the water, blocking light and primary production in the water column below, and restricting access to surface water for waterbirds. The impacts of paragrass include reducing water flows in channels and promoting sedimentation. In north Queensland, this has been found to reduce channel capacity of a small creek by 85% (Bunn *et al.* 1998). Such effects reduce aquatic habitat for a variety of fish species and waterbirds. Paragrass also increases fire frequency and intensity and restricts tree regeneration in riparian habitats. As shading from riparian trees is a controlling factor for paragrass growth, their elimination enables further spread of this weed. These effects lead to greater riverbank erosion and reduced habitats for fauna species.

Fabbro *et al.* (1997) studied the phytoplankton and zooplankton of the Fitzroy basin, also as part of the Downstream Effects on Land Use Study (Noble *et al.* 1997). Samples with high suspended sediment loads had lower phytoplankton densities and cyanobacteria (blue-green algae) dominated the phytoplankton that were present. The blue-green species present include those known to be toxic and to form blooms. Cyanobacteria density was high throughout the catchment. These are adapted to lower light conditions than other phytoplankton. The light conditions, high nutrients, absence of the nitrate form of nitrogen, low dry season flows and high pH also favour cyanobacteria. Nutrients are not limiting, so suspended sediment loads are the controlling factor for algal growth. Reduced sediment loads such as predicted in the IAS will improve some aspects of water quality but may also allow blooms to occur. This possibility is discussed in more detail in the Water Quality section.

6.0 TERRESTRIAL FAUNA

Like flora, many of the impacts associated with terrestrial fauna are not associated with downstream impacts, so only limited attention will be given to them here. For this group, loss of habitat is the major issue.

6.1 Terrestrial Vertebrates

The IAS (p.219) concedes that "Further clearing of remnant vegetation downstream of the Dawson Dam for expanded agricultural production can be expected to impact adversely on the Endangered, Vulnerable and Rare fauna species..". The species referred to come from Jansen (1997) and Stanisic and Ingram (1997) and include 16 bird, 3 mammal, 1 frog and 9 reptile species. Stanisic and Ingram (1997) conclude that there are at least 30 vertebrate species in the area listed under Queensland conservation legislation as well as 4 species extinct to the Taroom area. Jansen (1997) further states that because of the extensive loss of habitat that has already occurred, and the comparatively small areas of remaining habitat, **the impact is likely to be significant.** The extent of this impact, deemed as significant by the fauna specialists contracted for the surveys, has not been determined.

Apart from loss of habitat to be inundated by the dam and cleared for the irrigation development, further significant impacts are likely to come from loss of riverine vegetation and from isolation of Lake Murphy (listed in the Directory of Important Wetlands in Australia) and other ephemeral wetlands of Robinson and Palm Tree creeks. The Dawson River forms a linkage to these important habitats from downstream and coastal areas. Jansen (1997) recommends re-establishing a 50-100m wide corridor of vegetation on the north side of the dam to recreate the lost corridor and to connect the isolated remnants. This recommendation is adopted in the IAS and we agree that it is vitally important to retain a movement corridor for fauna of at least 100m width. However, the viability of re-establishing the riparian zone seems dubious given the greatly fluctuating water level and shoreline of the dam, and the unnatural setting for riparian vegetation which are developed on alluvial soils that are unlikely to be present around the dams perimeter.

Downstream, the lower Fitzroy River wetlands, are also listed in the Directory of Important Wetlands (ANCA 1996). Houston and McCabe (1996) identified 79 waterbird species there, with at least 38 species breeding. A dry season census counted 24,000 individual birds, which meets the RAMSAR criterion of 20,000 birds to be regarded as an internationally important site for waterfowl. Dam construction may impact upon these wetlands and waterbirds in many ways, including loss of habitat and nesting/roosting sites and reduced food supply such as invertebrates, plants and plankton. Several waterbirds species are dependent on wetting and drying cycles and have lesser reproductive success under stable water levels. Many waterbirds are also dependent on shallow wetland habitat, which is highly vulnerable to small changes in water levels. The environmental flows requirements for these habitats need to be determined with a high degree of accuracy.

6.2 Terrestrial Invertebrates

The moist riparian habitats of the Dawson River and its tributaries, particularly in Nathan Gorge, support considerable invertebrate diversity, including components that demonstrate the regional significance of these refugial habitats (riparian, vine-thickets, boggomosses) within the Brigalow Belt, which has already been extensively cleared and fragmented.

Stanisic and Ingram (1997) report that the Isla-Delusion Road crossing of the Dawson River downstream of the dam is a particularly important habitat. It is relatively undisturbed compared to other habitats along the river and was recommended to be set aside for conservation. It is, however, likely to be affected by water flow interruptions. Apart from these values which remain improperly assessed, it represents one of only two known sites for the land snail, *Adclarkia dawsonensis*. The only other known site is Begums No. 8 on Mt. Rose Station - a site which will be inundated by the proposed impoundment. The snail is associated with riverine coolibah communities, a community already listed as 'of concern' and that needs to be periodically inundated (Hyder Environmental 1997). The environmental flows required for these communities have not been determined (p. 228). Thus, of the only two known sites for this snail, one will be inundated and the effect of altered hydrological regime on the other is unknown but likely to be significant.

Another potentially significant impact on terrestrial invertebrates may come from spray drift and volatilisation of agricultural chemicals used in the proposed irrigation areas. Under the Irrigation Development and Pesticides sections of this report, evidence is presented that pesticides such as endosulfan, are aerially transported to adjacent environments in sufficient quantities to cause fish kills in aquatic environments. The impacts on terrestrial invertebrates adjacent to sprayed fields have never been studied but given that pesticides are designed to kill insects and are known to impact on aquatic invertebrates, they will be significant.

7.0 GEOMORPHOLOGY

The IAS did not assess the potential physical changes that may occur in the landscape resulting from altered flow regimes. This mostly pertains to the riverine channels. Any proposal that involves large modification to flow regimes should consider the geomorphological impacts. Often, these will be specific to the river channels in question and field effort and modelling time is required to ascertain the true nature of the impacts. The susceptibility of river channels in catchments such as the Fitzroy to major change as a result of landuse practices is demonstrated by the upper Nogoa River where the change in the river channel from an anastomosing to a single large channel has been attributed to grazing effects (Finlayson and Brizga 1993).

7.1 Within Channel Changes

Construction of major dams will result in alterations in the supply of sediment and water as both become trapped behind the dam wall. Dams trap the majority of the bedload sediment and a high proportion of the suspended load as well. Alterations to a rivers' hydrologic regime and/or sediment load are likely to lead to changes in channel morphology, bed channel sediment size distributions and the dimensions of the river channel as the downstream sediment carrying capacity of the available water increases due to the entrapment of sediment behind the dam wall (Kondolf 1997). The response of river channels downstream of impoundments varies greatly over time and space and different sections of the downstream environment will respond differently to the same development. While erosion is reduced in some areas, significant aggradation of sediments is likely in other areas due to reduced water velocities or less frequent flooding. Changes in channel morphology may take many years (even many decades) to stabilise. As many of the changes will be episodic and controlled by thresholds (Petts 1980), it may also take many years before any changes are noticed, especially if there are no large flow events after initial construction.

Benn and Erskine (1994) noted that responses of the Cudgegong River in New South Wales to the Windamere Dam simultaneously included channel contraction, degradation, aggradation and various other forms of accommodation adjustments such as the formation of instream sediment bars and instream vegetation islands. In the lower Murray River (regulated by 10 weirs), the width-depth ratio of the channel between Locks 3 and 4 has increased by 23% due to erosion and bank slumping, while between Locks 2 and 3, the ratio has decreased by 22% due to deposition of soils eroded from elsewhere (Walker *et al.* 1992). The sediment eroded from below each weir is deposited behind the next weir downstream. The changes observed in the lower Murray River have largely been attributed to bank slumping due to rapid changes in water levels and have also been accompanied by equally large changes within instream habitats, such as loss of deep pools and sand bars. Bank slumping due to regular changes in water levels associated with operational use of water, has caused significant bank erosion. In 1989, 1.04 million tonnes of bank soil was lost over a 153km stretch of river and the bank slope increased from 72° to 81°, rendering the banks even more prone to slumping (Walker *et al.* 1992).

As noted in the IAS (p. 197), the existence of several weirs downstream of the proposed dam on the Dawson River will create significant areas of low flow and reduced hydraulic power which may reduce sediment mobilisation downstream of the dam, except during large flow events.

Yet it is during these infrequent events that most changes are likely to occur, and the impacts of this process should be considered.

With projects such as the Nathan Dam, which greatly affect small and medium-sized flows but have only minor effects on large flows, there is an even greater potential for major geomorphological changes, especially considering the large sediment load carried by the Fitzroy catchment and the episodic large flood events. Thus, river regulation can lead to contraction of river channels over periods when no large floods occur. When a large flood does occur, the channel is no longer able to contain the floodwaters, leading to increased flooding and possibly rapid creation of new channels (avulsion). Vegetated islands form within the channel if low flows occur for a prolonged period. These then require large flood events to be washed away. Such islands affect the hydraulics of the system and may promote further bank erosion, resulting in the loss of established riparian vegetation which then impacts on the flora and particularly the fauna, much of which requires old growth trees. Contraction and expansion of channels is a natural process, as is deltaic avulsion. However, alterations to the existing morphology, natural or regulation-assisted, have greater consequences in developed catchments with intensive land uses and considerable infrastructure already in place. The social and economic costs of repairing infrastructure could be very high in such instances.

7.2 Coastal Erosion

As for much of the Queensland coast, sediment supply from the Fitzroy catchment is important to maintenance of coastal habitats to the north of the estuary due to the northerly longshore drift of sediments. Increased erosion from land practices within the catchment has probably elevated the total sediment loads being exported from the river, despite the existing dams and weirs trapping all of the coarse sediment emanating from their sub-catchment areas. Much of this would be finer suspended sediment rather than coarser bedload sediment. Reduction in the supply of coarse sediment to the coast due to dam entrapment, reduced competence of river flows, may promote coastal erosion along the northern coast.

On the Barron River in northern Queensland, a weir with a capacity of only 1,690ML is affecting sediment delivery to the Barron River delta, even during large floods (Brizga and Associates 1997). This reduced sediment supply is considered to be a contributing factor in coastal erosion of beaches immediately north of the delta, as the remaining sediment is insufficient to replace the sediment lost to the natural process of longshore drift (Brizga and Associates 1997), thus contributing to coastal erosion occurring along the beaches immediately north of the delta (Pringle 1991). While floodplains are naturally dynamic, reduced flows in this catchment resulting from river regulation (including the Tinaroo Dam) have also been implicated in deltaic sediment deposition which has resulted in channel avulsion and bank erosion problems on the floodplain that have affected agricultural land, infrastructure (eg, Captain Cook Highway and the international airport) and urban areas of Cairns. Works to stabilise these processes have cost millions of dollars.

As an extreme example of coastal erosion, reduction in sediment discharge to the delta of the Rioni River, in the former U.S.S.R., resulted in shoreline erosion rates of 30m/year (Makkaveyev 1970 in Petts 1984). The Aswan High Dam on the River Nile in Africa traps 100 million tonnes of silt annually, thus contributing greatly to erosion of the extensive and economically important delta area (Petts 1984). Deltaic erosion has been recorded at rates of 9-275m/year since construction of the dam (El-Sayed 1996).

The Fitzroy River is interesting in that it appears to have limited delta formation and essentially only one distributory channel. This contrasts with the Burdekin River that has a very large delta with several distributory channels spread over a large floodplain. Another obvious contrast is the fate of sediments emanating from the Burdekin River (eg, they have formed Cape Bowling Green) compared to no such obvious deposits from the Fitzroy River. It is not possible here to define the changes that will occur in the Fitzroy catchment and along the coastline. Examination of historical aerial photographs, hydrographs, sediment transport records and maybe some modelling, should allow some interpretation of the geomorphological changes occurring in the catchment that will allow a prediction of potential changes that may result from altered sediment delivery. Relevant examples from similar rivers may also provide some indication of the extent of changes that may be expected.

8.0 DOWNSTREAM ENVIRONMENTS AND IMPACTS

The downstream effects that may result from increased river regulation are:
- altered magnitude and pattern of flow
- increasing regularity of flow changes biotic community composition and where they are present, often favours exotic species over native species
- altered abundance of important habitat types eg, less riffles
- water does not have enough power to maintain stream channel dimensions, leading to aquatic weeds and other vegetation choking the water channel and further reducing its dimensions and habitats
- reduced flow concentrates water quality impacts such as cattle, nutrients and chemicals. This can lead to increased algal production and lower oxygen levels
- loss of connection between the river and its floodplain leading to loss of wetland productivity and biodiversity and reduced reproduction of fish, birds, turtles and plants, changes in nutrient cycles which shift species dominance patterns and reduced seed germination and production dynamics
- barrier effects for migration and dispersal of fish and other organisms
- releasing poorly oxygenated water from impoundment areas
- releasing cold water influences distribution of mobile animals, growth, reproductive cycles, adult emergence of insects, spawning and fish egg survival
- altered physical and chemical conditions of estuaries which in turn influence distribution and production of commercial and recreational fish and invertebrate species
- loss or alteration of mangrove habitat and reduced estuarine productivity
- reduced production, areal extent and species diversity of wetlands
- reduced sediment supply except for flood events
- altered patterns of channel contraction and erosion

As downstream effects of the Nathan Dam proposal were not considered in the IAS, most of these issues were also not considered but are discussed in the following sections.

8.1 Freshwater Habitats

The Dawson River has a wide variety of freshwater habitats, including channels, floodplains, billabongs, floodways, anabranches and wetlands (Long and Berghuis 1997). These are important habitats for plants, fish, invertebrates and other fauna and for major processes such as nutrient and sediment retention. Similar habitats are also found on the Fitzroy River downstream of the Dawson.

Water storages affect instream habitat by diverting water, altering natural flow events and creating artificial flow regimes. The six weirs on the Dawson are mostly located at sites with long deep pools with high banks, containing their water within the channel. The water storages are thus long and narrow, and as a consequence 57.9% of the original 273.5km of river bed between Glebe and Neville Hewitt Weirs is now inundated by man-made impoundments (Hyder Environmental 1997 p.126). In the 52km between Orange Creek Weir and Glebe Weir walls, there is only 5.2km of natural river bed remaining, and this will be inundated by the proposed dam (Hyder Environmental 1997 p.126). It is not clear what the remaining 40% of the river length will be like, but the IAS mentions at least two more weirs below the dam site which would further increase the length of river inundated by weir pools. This greatly reduces the availability of riffle and run habitats and the availability of sand and gravel beds, resulting in a more uniform environment. The decreased habitat diversity then leads to decreased biological diversity. Remaining natural waterholes may be infilled by silt deposition and this may promote oxygen-reducing conditions, thus exacerbating such problems. Silt may also cover remaining riffle habitats that do not receive appropriate levels of flushing. Areas immediately downstream of the weirs may be subject to scour as sediment transport capacity exceeds supply.

Floodplains are very productive habitats that are dependent on periodic flooding. When the frequency and magnitude of such pulses are reduced, so too is the productivity of the habitats. Reduced magnitude of flooding will reduce the area of floodplain habitat and also reduce the length of time for which flooding persists. This will affect organisms that have limited time to complete the aspects of their life-cycle linked to the floodplain habitats. Reduced frequency may restrict populations of these organisms through reduced opportunities for reproduction.

The Dawson and Fitzroy Rivers both contain significant floodplain habitats, including the wetlands of the Fitzroy River floodplain which are listed in the Directory of Important Wetlands in Australia (ANCA 1996). The floodplain includes 152 wetlands, covering an area of 11,172ha in 73 aggregations (Houston and McCabe 1996). The bird surveys of Houston and McCabe (1996) demonstrated that these are critical habitats for a number of waterfowl species of conservation significance.

8.2 Estuarine and Coastal Wetlands of the Fitzroy River

There are 375 large dams in Australia, but in very few cases have the ecological needs of the associated estuaries and coastal zone been taken into consideration (Zann 1996 in Loneragan and Bunn in press). As estuaries are the link between freshwater and marine ecosystems, and can be defined by the fluxes in freshwater input, any changes to that regime will lead to discernible changes in the nature of the estuary. Mangroves produce a large amount of organic matter and have a high biomass and abundance of plant and animal life. The complex food webs ensure tight recycling of nutrients and high productivity. Export of nutrients and organic matter from estuaries, mainly in relation to flood events, contributes significantly to offshore fisheries production. Recent stable-isotope research (Loneragan *et al.* 1997) has indicated that inputs of organic material from river discharge may be more important contributors to estuarine productivity than inputs from within the estuary itself. This indicates that river flow is crucial to the productivity of these habitats.

The coastal region around Rockhampton is particularly valuable and productive due to the extensive size and diversity of habitats available. These include the large Fitzroy River estuary with extensive mangroves and salt marsh habitats and the offshore coral reefs, as well as seagrasses and rocky habitats around the islands, mudflats and sandbanks and tidal creeks of varying sizes. The Fitzroy estuary itself is a complex system of mangroves, tidal creeks, salt marshes and mudflats. It also forms the northern end of the Narrows, the straight between Curtis Island and the mainland that supports extensive mangroves and is very important to the mud crab fishery (Walker 1997). The Fitzroy River delta is listed in the Directory of Important

Wetlands in Australia (ANCA 1996) in national recognition of its important habitat values.

Estuaries and coastal wetlands are very productive habitats, especially for fisheries. These habitats provide nursery grounds for juvenile fish and crustaceans (Robertson and Duke 1987) and have higher abundances of fish and crustaceans than nearby environments (Robertson and Duke 1990). Most fishery species in Queensland are estuarine-dependent, needing to spend at least part of their life in such habitats, or feed on species that have this requirement. This dependency is related to one or more of the following requirements: availability of food, favourable physio-chemical conditions (eg, turbidity, salinity) and shelter from predators, especially for juveniles. Thus the extent and condition of these habitats will have a strong bearing on recruitment of fishery species to the adult stage where they can become part of commercial and recreational fisheries.

Threats to coastal fisheries include: population increase related to urban, industrial and agricultural expansion in coastal areas; poor water quality emanating from terrestrial sources; loss of riparian vegetation; coastal wetland modification; dam/weir construction; barrages; bund walls and sedimentation. Loss of significant estuarine and fishery habitats have already been recorded for the central Queensland region. Between 1941 and 1989, reclamation of tidal areas and coastal wetlands in Gladstone resulted in a 24% loss of saltmarsh and a 17% loss of mangroves (Arnold 1996). A symposium on mangroves convened in Gladstone in 1995 by the Australasian Marine Science Consortium supported the adoption of a policy of no net loss of mangrove habitat and the principle of no net loss of biodiversity and abundance resulting from activities that may impact on mangroves and coastal wetlands (Anon 1996).

One of the best known examples of the effects of river regulation on estuarine environments is that of the Indus River in Pakistan. At over 250,000ha, the Indus River delta is one of the largest mangrove deltas in the world. Harrison *et al.* (1994) found that diversion of water for dams and irrigation has caused an increase in the salinity of the mangrove habitats leading to hypersaline conditions. This has produced a large change in the species composition of the mangrove communities whereby tree species less tolerant of saline conditions have largely disappeared. Even the more tolerant species that remain (mostly *Avicennia marina*) have become reduced in abundance and the trees are less productive and have a more stunted growth form as a response to increased salinity stress. Only 15% of the forests in the delta were classified as healthy. A six-fold decrease in sediment discharge to the delta is also resulting in erosion of the delta, loss of aerial extent of mangroves and sediment deposition in upstream reaches of the river, causing further impacts to the freshwater habitats. Over 80% of the water is diverted by barrages. The remaining 20% of the unimpacted annual flow that previously reached the estuary now does so only during the wet season and only along channels, rather than across the floodplain. Thus the only remaining healthy mangrove habitats are concentrated along the channels and not across the broad floodplain. This has in turn greatly reduced fisheries production from the estuary. Although a more extreme example than would be allowed to occur in Australia, it nonetheless demonstrates the effects on estuarine habitats that can occur from river regulation. The nature and extent of these impacts must be investigated for all large dams proposals but this has not occurred in this case.

Reduced flow will impact on the mangrove floodplain more than the channels. The floodplain is very important, as it is where fish, crabs and other organisms obtain much of their food supplies. Small changes in the volumes of flow may have large changes in aerial extent of mangroves and their floodplain environments across such low profile habitats. Changes in environmental conditions will affect seed and propagules more than the adult trees that have larger metabolic stores of energy to cope with the increased stress. Most mangrove propagules have enough endosperm reserves to establish themselves but mass mortality may result when the reserves are expended. More subtle sub-lethal effects of reduced freshwater flows include reduction in tree height which is a response to water deficit and a reduction in leaf area index which reduces primary production (Harrison *et al.* 1994). Although freshwater discharge is highly variable in the Fitzroy catchment, new dam and irrigation development proposals will reduce the long-term average. As freshwater flow and estuarine productivity are linked, long-term reductions in mean flow reaching the estuary can be expected to be reflected in reduced estuarine productivity.

8.3 Marine Habitats Offshore from the Fitzroy River

The surveys of Lee Long *et al.* (1993) found 6km^2 of seagrasses around Great Keppel Island, with a further 192km^2 along the coastal areas of Cape Byfield north of the Fitzroy estuary. This constitutes one of the largest seagrass aggregations along the eastern Queensland coast. Much of the seagrass occurs in Port Clinton and around Townshend Island which is probably protected from the influence of Fitzroy River outflows, though longshore drift would pass these locations.

The Fitzroy River discharges into the ocean at the northern end of Curtis Island, a low energy environment resulting in deposition of riverine sediment (O'Neill *et al.* 1992). As for most of central and northern Queensland, most of the river outflow moves northward along the coast into Keppel Bay. The sediment here is largely of terrestrial origin, but wind and strong tidal action prevent deposition of fine mud fractions (O'Neill *et al.* 1992). These conditions favour the development of fringing coral reefs around many of the islands within the bay (eg, Great Keppel Island). The islands in this bay and their fringing reefs support a large tourist industry as well as other commercial values.

8.4 Terrestrial Runoff to Marine Habitats

Moss *et al.* (1993) have estimated that sediment runoff from Queensland coastal catchments has increased by 3.8 times over the last century (in Neil and Yu 1996). This analysis was undertaken at a coarse resolution so the accuracy of the estimate is open to challenge. Nevertheless, the notion that sediment runoff has increased is generally accepted in the scientific community. More recent estimates of sediment delivery have found it to be an overestimate (Mitchell *et al.* 1996) or an underestimate (Neil and Yu 1996).

As up to 80% of phosphorus and 40% of nitrogen carried in river runoff is attached to fine soil particles (Furnas *et al.* 1995 in Furnas and Brodie 1996), the levels of nutrients exported to the reef must also have increased substantially with the increase in sediment export. Both of these nutrients are also transported in soluble form. Increased nutrient inputs to coral reefs are known to have damaging effects and there are many examples all over the world of chronic nutrient pollution degrading coral reefs. Whether damage has resulted from increased nutrient loads in the Great Barrier Reef is not yet proven, but it is strongly implicated in at least some sections of the reef. There are many nearshore coral reefs in the Great Barrier Reef that have been severely degraded or destroyed since European settlement, though changes in land use have not been conclusively implicated in these occurrences.

The Burdekin and Fitzroy rivers both have low nutrient export levels per unit area. However, their large catchment areas and high nutrient concentrations result in these rivers having the highest total nutrient export on Queensland's east coast (Moss *et al.* 1993, Mitchell *et al.* 1996). These rivers thus dominate nutrient export to the Great Barrier Reef. It has been estimated that these two rivers contribute 68% of the total sediment load to the inshore Great Barrier Reef (Neil and Yu 1996). The variability of flow in these rivers will cause great variation in sediment and nutrient export to the Great Barrier Reef. Despite these rivers having the highest potential for nutrient export to the Great Barrier Reef, via sediment export (especially during flood events), their impact on nutrient budgets is yet to be determined (Furnas and Brodie 1996, Mitchell *et al.* 1996).

The first State of the Marine Environment Report (Zann 1995) listed declining marine and coastal water and sediment quality due to inappropriate land use practices as the number one concern of the marine environment. Despite our heightened awareness of the ability of catchment land use practices to influence downstream environments and its universal recognition as a major influencing factor, this was not included in the Terms of Reference for the IAS.

Although opinions may vary on the extent of influence land use practices are having on the GBR, it is clear that the marine environment, including coral reefs of the Great Barrier Reef Marine Park is influenced by terrestrial catchment condition. There is insufficient knowledge of sediment transport, transport of sediment-bound nutrients, and the processes that control the fate of nutrients once in the marine environment to achieve highly reliable estimates. Nevertheless, first order estimates can be generated using crude models and such estimates should be undertaken before any major land use changes are endorsed within the catchment.

8.5 Estimates of the Effect on Fine Sediment Exports From the Dawson Catchment

There has been considerable concern and research over the last decade into the potential impact of increasing sediment and nutrient loads exported from catchments to the GBR. As part of the broad-scale monitoring program of the Great Barrier Reef, Oliver *et al.* (1995) noted that there had been a significant change in coral cover in the Capricorn-Bunker reefs between 1987 and 1990 but could not identify the cause of the decline.

During the floods following Cyclone Joy in early 1991, 18.5 million ML of water entered Keppel Bay from the Fitzroy River. Brodie and Mitchell (1992) estimated that 11,500 tonnes of nitrogen and 2,900 tonnes of phosphorus was discharged during this event. Most phosphorus discharged from rivers does so attached to particulate matter, but desorbs from this upon contact with seawater (Brodie and Mitchell 1992). This allows the phosphorus to remain in the water column as the particulate matter settles out on the bottom, though readsorption and uptake by phytoplankton also appear to have occurred during the 1991 flood (Brodie and Mitchell 1992).

Byron and O'Neill (1992) noted large scale coral mortality on the fringing reefs of the islands in Keppel Bay after the 1991 flood event, including variation in the location and extent of damage. These authors believed that increased silt deposition from the catchment increased mortality rates and reduced recovery abilities of these reefs in some parts of the bay. Where tidal currents allow, the silt will be carried away, but where tidal currents are insufficient to carry the silt away, or do so over a long time period, then the reefs may be more seriously affected than they would otherwise be from flood events with natural levels of silt deposition.

It was noted in Section 7 that all bedload (ie, coarse particulate sediments such as sands and gravel that are transported along the bottom of the river) from above the proposed dam will be trapped by the dam, leading to potentially far-reaching geomorphological impacts downstream in the river and along the coastline. In contrast most of the washload (ie, fine silt and clay particles that are transported in suspension in the water column) is likely to be freely carried over the dam spillway during major flow events.

Kelly and Wong (1998) showed the sediments suspended in the water column of the Fitzroy during a 2700 m^3/sec discharge event comprised 53% clay, 44% silt and only 3% sand. Most of this suspended material would be expected to settle far too slowly to become trapped in the dam during a short duration flow event and would pass over the spillway. This prediction is supported by the findings of 10 years of monitoring in the Burdekin Falls Dam (Faithful in prep) which has shown no measurable difference between suspended solids concentrations entering and leaving the dam.

It is important to recognise that this applies only to waters that pass over the spillway – the sediment suspended in the water column within the impoundment will be detained more or less permanently and in a large impoundment this can amount to a significant reduction in the quantity of sediment being transported downstream.

Although the IAS used five major scenarios for the size of the proposed dam, the WAMP technical reports concentrated on the 183.5m FSL option, which was the second largest. With this option, the initial effect of the dam when first constructed will be to trap 880,000ML of water (and the sediment it contains) which represents ~78% of the average annual export from the Dawson River. This is a one-off event that will cease once the dam has filled. In subsequent years, the average amount of water trapped by the dam will be equal to the annual consumption, evaporation and transmission losses. For a dam of this size, the IAS uses an annual consumption figure of 154,000ML/yr as the water allocation to new users after dam construction. The WAMP technical reports use a figure of 170,000ML/yr after the maximum environmental flow allocation is subtracted, and a figure of 227,000ML/yr with environmental flows. Taking evaporation into consideration, this would equate to approximately 300,000ML per year or about 27% of the average annual runoff from the Dawson sub-catchment (1,127,000ML) and 5.4% of the average annual runoff from the Fitzroy catchment (5,574,000ML). The IAS on the other hand, suggests that the dam will collect between 15 and 20% of the average annual discharge from the Dawson sub-catchment. It therefore seems conservative to assume that the dam will trap between 15% and 27% of runoff from the

Dawson sub-catchment.

Based on the limited data available for the Dawson River Weirs (discussed in the water quality section) it is likely that around 5% of sediment contained in the impoundment waters will remain in suspension for most of the year and will be distributed back onto farm lands via the irrigation system. The remainder will settle to the bottom of the impoundment either in shallow sections where it could be resuspended or in deeper more stable parts where permanent accretion is likely to occur. Based on experience with other impoundments it can be assumed that between 20 and 95% of the solids that settle in the impoundment will be permanently retained.

The Dawson impoundment is likely to be 10,000 ha in area. This inundated area, which constitutes 0.2% of the Dawson catchment, will no longer contribute runoff. Although the area is quite small it comprises mainly stream banks and sloping land surfaces that are likely to have higher than average sediment yields. Hence inundation is expected to result in a significant reduction in sediment export loads.

Two contrasting scenarios can be considered. The first assumes that the dam will trap 15% of the mean annual run-off with 20% sediment detention efficiency. The second scenario assumes that the dam will trap 27% of the mean annual run-off with 95% efficiency. From these two scenarios, it can be calculated that the instream effect of the dam will be to reduce exports of fine sediment by between 4 and 25%. These two figures represent the minimum and maximum estimates of sediment detention. However, the proposal will also result in the creation of 30,000 ha of cropping land and there is little doubt that this will increase sediment yields from that section of the catchment. The pertinent issue is whether this increase will be offset by the dam's sediment retention capabilities.

The new cropping land will constitute only 0.6% of the Dawson River catchment. So, depending on which of the above dam scenarios prove to be correct, sediment exports from this small section of the catchment would be able to increase by a factor of between 7 and 43 before there would be any net increase in sediment exports. For catchments discharging into the east coast of Queensland, Moss *et al.* (1993) estimated that cropping land has a 2.5 times greater sediment yield than that of grazing land. Rayment and Neil (1997) suggest that cropping results in a 4-fold increase in sediment yield over grazing.

The accuracy of the estimates for runoff from cropping land compared to grazing land will obviously have a major bearing on conclusions from the proposed dam and irrigation area. Such estimates can only be made based on the actual catchment being assessed. We could not find such information for the Dawson River sub-catchment. If the grazing land to be converted to cropping land is already in poor condition and highly eroded, then the change to cropping will produce less increases in sediment yield than if the land is in good condition. This is because sediment concentration in runoff is strongly affected by vegetation cover. Rates of sediment yield in overgrazed or poorly-managed grazing land may be 3-7 times higher than for well managed grazing land (Neil and Yu 1996). The Dawson catchment is already considered to be in poor condition with regard to land and vegetation cover and the Fitzroy catchment (mostly grazing land) has the highest unit sediment yield of any Queensland east coast catchment (Neil and Yu 1996), so the difference in sediment loss between grazing and cropping lands in this catchment may be considerably less than the reported literature values.

Obviously there is a great deal of uncertainty involved, but based on these considerations, we suggest that the increase in sediment export from the proposed irrigation area will be less than the amount of sediment trapped by the dam, thus resulting in no net sediment export from the proposal. In fact, it is possible that there will be a measurable reduction.

We feel that under the condition of small and medium flows, there will no net export of sediment to the reef. During a large flow event, there may be a small increase, but this will be minor compared to runoff from other parts of the catchment. In fact, with the level of fine sediment that is likely to be retained by this proposal in the majority of years, it is most likely that there will be a shortage of sediment and nutrients reaching the estuarine zone where such inputs contribute significantly to estuarine productivity and fisheries production. Additionally, the holding of water in the dam and weirs prior to gradual release as environmental or irrigation flows may promote settling of fine sediment and nutrients and further lower the nutrient content of the released water. The reduction in sediment and nutrient transport to the estuary in most years may have a larger impact on that environment than any possible increases in export to the offshore reefs during large flood events.

The crude model presented in the previous discussion was based on mean annual flows. This can be misleading. Even in dry years when there is 100% detention, water extraction from the dam will continue. Hence in the following years, a much greater percentage of the total flow will be detained in the dam. In the worst case scenario of a drought, the downstream environment could, in the absence of suitable environmental flows, be starved of essential nutrients required to maintain productivity. While environmental releases from the dam will partially compensate for this, it is quite likely that the sediment and nutrient content of water released from the dam during prolonged dry spells will be substantially lower than they would be in natural runoff. This deficiency will not be compensated by the elevated nutrient loads caused by catchment land use changes as these are not delivered to the estuary during the dry years but instead occur as large, short duration pulses during storm events.

The Dawson River sub-catchment is relatively dry compared to the rest of the Fitzroy catchment. Though it comprises 36% of the area of the Fitzroy catchment, it contributes only 19% of its average annual discharge. Hence a 1% increase in contaminant yield from the Dawson would constitute only a 0.2% increase in export from the Fitzroy River if specific sediment yields were the same. However, this may not the case. Neil and Yu (1996) found that unit sediment yields (t/km^2/mm/yr) on Queensland's east coast varied from 0.012 in the wet tropics to 0.362 in the Fitzroy catchment under natural pre-European conditions and from 0.023 in the wet tropics to 1.474 in the Fitzroy catchment under existing conditions. Within the Fitzroy, the yields would vary between the different sub-catchments. There is inadequate existing data to test the suggestion that sediment yields in the Dawson sub-catchment are different from those of the other sub-catchments, let alone quantify any existing differences. However, it is clear that our crude model should not be applied to the whole Fitzroy catchment. As the range of sediment yields for Queensland east coast catchments spans one and a half orders of magnitude, there may be considerable differences in sediment yields between the different sub-catchments.

Clearly, all of the issues relating to sediment and nutrient transport need to be examined in more detail, and additional data needs to be collected in order to develop more realistic models.

8.6 Estimates of the Effect on Nutrient Exports From the Dawson Catchment

It is not possible to quantitatively predict the effects of the proposal on nitrogen and phosphorus export rates – the data required are simply not available. Nonetheless, it is well known that large quantities of nutrients are added to cropping lands in the form of fertilisers and that the quantities lost to the aquatic environment can be very significant especially during storm events. Nitrogen fertilisers are particularly problematic because they are applied in very large quantities and generally occur in highly mobile water soluble forms that are extremely difficult to contain on farm during rain events. Phosphorus is also an issue but it is generally applied in much smaller quantities and is more easily retained on farm or within the drainage system because it will sorb tenaciously to soil particles.

Cotton growing requires annual nitrogen applications in the order of 150 kg/ha (Jon Brodie, pers comm). This is significantly less than some other crops but still represents a massive increase over natural levels. The 150 kg/ha application rate can be put into context by considering that 30,000 ha of crop would require 4,500 tonnes of nitrogen per year, which is approximately equivalent to the total nitrogen load carried by the Fitzroy River during a major storm event. For instance, Kelly and Wong (1998) reported nitrogen loads ranging from 4,000 to 6,260 tonnes during 3 separate 2.5 million ML discharge events between 1994 and 1997.

Nitrogen concentrations in the Dawson River during large scale flow events generally average 1 to 2 mg/L. As discussed previously, the proposed dam will detain somewhere between 170,000 and 300,000 ML of this water and this will prevent, on average, between 170 and 600 tonnes of nitrogen from flowing downstream. This is the maximum quantity of nitrogen that could be lost into the rivers from the new cropping lands before there is any net increase in nitrogen export. In other words if more than 3.8 to 13.3% of the nitrogen applied to farms is lost to the aquatic environment then there will be a measurable increase in nitrogen export load.

There are currently no data available to indicate what percentage of applied nitrogen is lost from cottonfields under different management practices, but available tailwater quality data are not encouraging. Noble *et al* (1997) reported nitrogen concentrations ranging from 2.4 to 42.6 mg/L in cotton irrigation taildrains of the Fitzroy catchment. The reported median value of 12 mg/L is an order of magnitude higher than the concentrations observed in the Dawson River during flow events and is more than 5 times higher than the concentrations observed in the Fitzroy during flood events (Kelly and Wong 1998, Mitchell and Furnas 1997). There are no flowrate data associated with these concentration measurements so it is not possible to evaluate the quantities of nitrogen involved. It must also be stressed that there are no data for stormwater runoff from cotton farms. Nevertheless, the data that are available do not inspire confidence in the capacity of cotton farmers to control losses of nitrogen.

In contrast, the median concentration of phosphorus in the irrigated cotton taildrain samples discussed above was 458µg/l which is comparable to the levels reported in the Comet and Fitzroy sub-basins (440 and 396µg/l respectively) and only a factor of two higher than in the Dawson River. Noble *et al.* (1997) comment on the relatively high nitrogen to phosphorus ratios in cotton farm run-off. This highlighted the particular difficulties involved in controlling movements of soluble nitrogen compared to phosphorus which is more often sediment-bound.

It is apparent that if the proposal were to proceed it would be necessary to apply extremely tight controls over farming practices and especially nitrogen usage in order to ensure that downstream environments are protected from the adverse effects of increased nitrogen loading.

9.0 TURTLES AND AQUATIC INVERTEBRATES

9.1 Freshwater Turtles

Three species of freshwater turtle were collected during the IAS surveys and a fourth is known to occur within the Dawson River. Three of these species are cloacal ventilators, taking in oxygen through their cloaca. They are thus dependent upon high oxygen levels in the water and tend to be associated with riffles or areas just downstream from riffles. Regulation of the Dawson River has greatly reduced the availability of riffle habitats and has rendered most of the large pools anoxic for much of the time. Of the three cloacal ventilator species, one, *Elseya latisternum* is widely spread across northern Australia. The newly described *Elseya irwinii* (listed as *Elseya* undescribed species in the IAS) is known from the Fitzroy, Burnett and Mary Rivers. The third species, *Rheodytes leukops* is endemic to the Fitzroy catchment. It is listed as a *Vulnerable* species under the Queensland Nature Conservation Act (1992). This species was not collected during the IAS. Apart from requiring riffle and high oxygen habitats which are threatened by the level of river regulation, this turtle also nests in low, sandy banks adjacent to waterways during the dry season. This is also the time of greatest irrigation water demand. Relatively small rises in water levels (up to 1m) during this time of year would flood their nests and eliminate the years breeding. It is possible the turtles will adapt to the new water regime, but this is an unknown factor. Further survey effort is required to determine the locations of these turtle species within the Dawson River and their ecological requirements. Without this information, there is grave doubt as to their ability to tolerate further river regulation.

9.2 Relevance of Aquatic Invertebrates

There has been considerable research on the use of aquatic invertebrates as indicators of riverine ecological condition. Indeed, this very topic is the subject of a nationwide, multi-million dollar federal government-funded monitoring program (Monitoring River Health Initiative). Aquatic invertebrates are the most widely accepted faunal indicators in aquatic environments and cannot be overlooked in any impact assessment that involves considerable modification to aquatic habitats.

For the aquatic habitats in the IAS, much discussion centred around fish species. This was mostly in relation to water quality and habitat availability. However, as an integral part of the food chain, nearly all freshwater fish species rely, at least for some part of their life cycle, on aquatic invertebrates as food. Availability of aquatic invertebrates as food resources has been shown to be an important factor affecting fish assemblages and populations in the Burdekin River (B. Pusey, Griffith University, pers. comm.).

Besides not sampling aquatic invertebrates for the IAS, there was no analysis of the existing data sets available on this topic within the Dawson and Fitzroy catchments. Duivenvoorden and Roberts (1997) have sampled aquatic macroinvertebrates throughout the Fitzroy River system, including sites (Baroondah and Beckers) on the Dawson River. Significantly, they found that the two sites sampled below the Emerald Irrigation Area had reduced abundance or absence of pollution-sensitive species compared to the two sites sampled upstream of the irrigation area.

Four sites within the Dawson River system have been selected for sampling as part of the National Monitoring River Health Initiative (MRHI). This national program utilises a standard methodology that allows comparison across the country for data collected. Two of the Dawson sites are Baroondah and Beckers. Monitoring River Health Initiative data from four sampling events over two years indicated that most sites in the catchment were in moderate condition.

The IAS did not sample aquatic invertebrates because it was considered that the regulated nature of the catchment and subsequent low diversity of habitats meant that no meaningful data could be collected. If the existing river regulation has affected the invertebrate community, this needs to be assessed in order to predict the effect of further increasing the level of river regulation. The Supplementary Report to the IAS stated that invertebrate species are too diverse to warrant survey. Detailed taxonomic surveys are not necessary. There are several widely adopted rapid assessment techniques, including that of the MRHI, that even community groups with no formal scientific training are now successfully implementing. There is also a considerable dataset of aquatic invertebrates collected within the Fitzroy and Dawson catchments and spanning several years, but these were not interpreted or discussed. The failure to assess potential impacts on aquatic invertebrates is at odds with accepted practices and standards of aquatic environmental assessment. Although monitoring of sensitive invertebrate species such as land snails would be of benefit in a monitoring program, these are a less appropriate indicator of riverine health than the aquatic invertebrates that actually live within the water itself.

9.3 Impact of River Regulation on Aquatic Invertebrates

The impacts of river regulation on aquatic invertebrates are not well documented. As most aquatic invertebrates are benthic and of a small size, sediment composition has a strong influence on their assemblage composition. River regulation alters sediment composition. In the weirs of the lower Murray River, median sediment grain size has decreased by 30% (Thoms and Walker 1992 in Arthington 1997b) due to deposition of fine sediment. Downstream of other dams, Benn and Erskine (1994) have noted an increase in sediment grain size at depositional sites and decreases at other sites where flows have the ability to wash away finer material but not the coarser material. Such large changes in benthic sediment composition are likely to produce considerable changes in the composition of benthic invertebrate communities, as will channel sedimentation or scouring and erosion. The diversity of invertebrate species can also be expected to decline significantly due to decreased habitat diversity resulting from increased river regulation. In the Burdekin River, aquatic invertebrate communities upstream and downstream of the Burdekin Falls Dam are similar, but are very differently affected by floods. Downstream, the normal seasonal resetting of habitats and communities after wet season flows does not occur, thus long-term change from the 'natural dynamics' of the system is expected (Pearson 1991).

Fabbro *et al.* (1997) studied the phytoplankton and zooplankton of the Fitzroy catchment. Zooplankton follows a similar pattern to phytoplankton (discussed in the Flora chapter) where reductions due to increased suspended sediment levels leads to reduced zooplankton abundance. Zooplankton were absent from lower Nogoa River samples (a heavily regulated river) which also had low macroinvertebrate abundance (Duivenvoorden and Roberts 1997), thus indicating possible effects from increased river regulation.

Most aquatic invertebrates are found in the benthos, as well as in the water column and among macrophytes. Due to the high turbidity limiting light penetration there is a limited abundance of macrophytes available, though Duivenvoorden (1995) has found a high diversity present. A major finding of the IAS was that due to the low plant growth restricting photosynthetic oxygen production and thermal stratification restricting oxygen exchange, up to 70% of the water column and 95% of the benthos were anoxic and unavailable to aerobic organisms. Depending on the distribution of organic matter in the weir pools, this also means that 95% of the organic matter upon which these invertebrates rely would also be unavailable. This has obvious implications for the food chains and productivity of this system, especially considering that most fish species include invertebrates in their diet for at least part of their life cycle.

10.0 FRESHWATER FISHERIES

10.1 Effects of River Regulation on Freshwater Fish

Studies on the effects of river regulation on freshwater fish in Australia, particularly in the Murray-Darling basin indicate the positive influence of natural patterns of river flow on fishery values and productivity. Gehrke *et al.* (1995) have shown a significant relationship between the degree of river regulation and reductions in fish species diversity. Unpublished data (P. Gehrke cited in DNR 1998a) also indicate a relationship between the degree of river regulation and increased recruitment of exotic fish species. In the upper Burdekin River, the successive years of low flow during the drought of the 1990's has favoured the spread and increased dominance of sleepy cod (a native species translocated into the upper part of the catchment in the 1970's) to the detriment of several local species (B. Pusey pers. comm.). Cadwallader and Lawrence (1990 in Loneragan and Bunn in press) also found a positive relationship between riverflow and golden perch (*Macquaria ambigua*) catches in the lower Murray River. This was attributed to the river flow stimulating migration of this species. In the Fitzroy catchment, Long and Berghuis (1997) indicated that the lower Nogoa River, a heavily regulated river, had reduced fish diversity compared to other similarly-located sites in the other sub-catchments of the Fitzroy basin.

Sawynok (1998) studied the effects of freshwater flows on the migration and movements of barramundi in the Fitzroy River. Barramundi are one of many fish species that migrate between freshwaters and the marine environment, including the waters of the Great Barrier Reef World Heritage Area. They are thus relevant to management of the GBR marine park and GBR World Heritage Area. The barramundi population between Bundaberg and Mackay is considered to represent a genetically different stock from populations elsewhere and the Fitzroy River holds the largest barramundi population within that stock (Sawynok 1998). Their movements are thus important to maintaining the diversity of the genetic pool of this discrete stock. Sawynok (1998) found a strong positive correlation between barramundi recruitment and summer riverflows of 1.4m ML or more. Poor recruitment was found to follow summer flows of less than 0.4m ML. Minimum flows of 2.0m ML are required to connect the Fitzroy River with important off-river barramundi sites such as Gavial Creek and the Lagoons (Sawynok 1998).

In addition to recruitment, barramundi movements were also positively correlated with the volume of riverflow. During high flows, twice as many barramundi moved (defined as moving >2km) and they moved for double the distance compared to low flow conditions. Barramundi movement was negligible for flows <0.1m ML. Another important finding from the study was that barramundi growth rates were up to 50% faster under high-flow conditions than under low-flow conditions. Thus, reduction in the size and frequency of flows due to river regulation in the Fitzroy River catchment can be expected to reduce the recruitment, movements and growth rate of the barramundi population.

River regulation also affects the species composition of fish communities. Research on the relationship between fish assemblages and river flows in several Queensland rivers has established that regulated reaches have different fish assemblages than unregulated river reaches (Arthington 1997b). In the Burdekin River, a river with similar fish habitats to the Fitzroy, Pusey and Arthington (1996) have found that although large flow events are beneficial to fish assemblages and are the dominant influence on assemblage composition, two years of reduced flows had a greater impact on the fish assemblage than did a 1 in 25 year flood event. Thus even when recruitment is high following a good wet season, low baseflows in subsequent years can reduce the survival of the cohort. This has implications for reduced baseflows resulting from river regulation.

Appropriate timing, duration or release patterns for environmental flows from the proposed Nathan Dam have not yet been determined. The amount of water required for these are a critical factor in determining the operation of the dam and would seem to have important ramifications for other aspects of the dam such as the amount of irrigation area it can support. In Australia, our knowledge of the basic biology and life-history requirements of our freshwater fish species is very poor. Thus we do not fully understand their ecological requirements and the relationships between instream habitat, environmental flows and fish communities (Arthington 1997b). We do know however, that regulation will affect the fish communities and the determination of the type and extent of effects should be determined for all dam proposals.

10.2 Fish and Fish Habitat in the Dawson River

Long and Berghuis (1997) summarise what is known of fish in the Dawson River. They concluded that there were 33 fish species from 21 families in the river, a level of diversity comparable to the other sub-catchments in the Fitzroy basin. Species of conservation concern are also discussed. Nathan Gorge itself was recognised as being a particularly important habitat for fish species in the river.

Freshwater fish were surveyed at 16 sites for the IAS in October 1996. The sites showed pronounced stratification and deoxygenation below the thermocline. This is due to low flow conditions, as is common in the long, narrow, deep pools and weirs and would not be the case throughout the entire year. Only the top 1-2m of the weir pools were generally oxygenated and wind and waves can only break down the stratification to a maximum depth of 2-3m (Anderson and Howland 1998). Thus for many months of the year, the anoxic conditions exclude 70% of the water column and 95% of the benthic substrate and benthic detrital area from contributing to aquatic productivity (Anderson and Howland 1998). In highly turbid aquatic systems such as the Dawson and Fitzroy Rivers, algal and plant production is limited, so access to benthic habitats and benthic detritus is critical to the food chain and aquatic productivity. This has obvious implications for the fish of the Dawson River, especially considering that most freshwater fish species rely on invertebrates as food sources for at least part of their life cycle. River regulation has increased the proportion of this type of habitat at the expense of more viable and productive habitats such as riffles, runs and gravel, thus having a very large effect on the overall aquatic fauna habitats of the Dawson River. At least seven species of fish in the Dawson River are known to require rock or gravel for breeding sites (Anderson and Howland 1998) and six require aquatic vegetation (Hyder Environmental 1997). Access to rock and gravel is limited by the deoxygenated benthos of the weir pools and aquatic plant growth is limited by the turbidity of the main Dawson River channel.

Flushes of water released from storage impoundments may break down the stratification.

However, the volume of flows required to achieve this is unknown. For logistical reasons related to early release of water from the existing storages, the study of Anderson and Howland (1998) to determine the volume of flow required to break down stratification in the weirs and natural pools was unable to conducted in the originally intended manner. However they have suggested that flows of 25-50ML/day for riffles and runs and at least 50ML/day for deeper pools are appropriate. This is based on studies of the Wimmera River in Victoria (Anderson and Morrison 1989). The strength of stratification in Victorian rivers may be less than in the Dawson, so this should be treated as a minimum. The authors also recommended that even greater flows would be required to maintain depth in the riffles and to provide for fish passage past barriers. In addition to these base flows, flood releases would also be required to stimulate other key biological processes. Water for such releases would have to come from the impoundments. This water could itself be oxygen-depleted and could cause fish kills. The IAS has suggested that some benefits will be provided by the dam's ability to regulate environmental flows to an extent that is not possible with the existing six weirs. This idea has merit. However, no evidence has been provided to show that the flows required can be provided or that any such benefits attained outweigh the negative impacts created by increased river regulation. The type of study attempted by Anderson and Howland (1998) to determine the amount and type of flow required to breakdown stratification in the weir pools can and should be repeated using flows released from the existing storages.

The study by Anderson and Howland (1998) for the IAS showed that within 9 days of the cessation of water releases from the existing weirs on the Dawson River, 70% of the water column in the weir pools had become deoxygenated below levels required to sustain aquatic life. This indicates that continuous releases will be required to maintain good habitat conditions in the river pools. Although such effects are natural phenomena and do occur in natural pools, the severity and regularity of their occurrence have been substantially increased by the effects of increased river regulation and may be further exacerbated by the effects of the proposed dam and almost certainly by increased irrigation development. It is likely that increased nutrient and organic matter in the water resulting from land use practices have also contributed to the problem by placing a greater oxygen demand in the water. It is anticipated that this situation will get worse when the area of cultivation increases after dam construction. Sharper runoff peaks have also reduced the perenniality of water flows in the river which further contributes to the problem by cessation of flows earlier in the year than would otherwise occur and shorter flows resulting from rain at other times of the year that would normally break down the stratification. Anderson and Howland (1998) recommended removing Orange Creek Weir and rehabilitating its bed, to alleviate the environmental problems it causes.

10.3 Fish Passage Barriers

A significant proportion of Australia's freshwater fish species are catadromous, moving to estuarine areas to spawn. The juveniles then return upstream to freshwater habitats to mature. Populations of these species, including barramundi, that cannot reach the estuary or cannot return from the estuary cannot sustain themselves in freshwater habitats. Barramundi once occurred in the lower reaches of the Dawson River, but construction of the Fitzroy barrage, in 1971, provided an effective barrier to juveniles moving upstream. The introduction of a vertical slot design fishway into this barrage in 1994 has reopened passage for 20 fish species, including barramundi (Sawynok 1998). However, passage further upstream is still prevented by the weirs on the Dawson River. The IAS has discussed the need for fish passages to be incorporated into the design of the Nathan Dam. However, this will be of limited value if the downstream weirs remain effective barriers.

10.4 Fish Stocking Programs

Fish stocking programs are an attractive idea and can provide a wide range of benefits, although these are most often described in terms of benefits to recreational fishers rather than to the fish or their environments. Fish stocking as a means of protecting declining fish populations does not address the cause of the decline, such as poor environmental quality. In some cases the resources used in fish stocking programs may be better utilised in habitat research, habitat rehabilitation programs and habitat retention. The submission to the IAS from the DPI indicates that fish stocking is not acceptable mitigation for loss of fish passage or natural stocks. Stocking also has several problems of its own that are not often considered. These include introduction of diseases from hatchery reared stock and translocation of fish from other catchments that represent species or populations that are not native to the new catchment. Additionally, there is often little research into stocking programs regarding the numbers of fish appropriate to the system. This could lead to overstocking of predatory fish, resulting in large ecological alterations to the smaller faunal elements in the water body. This creates unstable ecological conditions which promote boom and bust type situations.

The IAS suggests (p. 136 and p.225) that the high costs of fishways lends support to the establishment of permanent fish breeding and stocking programs. This creates a long-term dependence on restocking without addressing the habitat issues and the needs of other fish species not included in the stocking program. The DPI submission in response to the IAS stated that they did not see fish breeding and stocking programs as substitutes for natural patterns of population replenishment.

11.0 ESTUARINE/MARINE FISHES

11.1 Value of Coastal Fisheries in the Region

Coastal fisheries are very important and productive in the Capricorn Region. These fisheries comprise 17.7% of the Queensland total for fish, crustaceans and molluscs, including 37% of the Queensland crab catch and 74% of the Queensland scallop catch (Walker 1997). The importance of the region for fisheries is demonstrated by the declaration of 19 Fish Habitat Areas along the Capricorn coast. In the Port Curtis area, commercial fishing is worth $11.3M/yr (Walker 1997) and gross expenditure in recreational fishing is estimated at $9.6M/yr (DNR 1998a). Over 3,200 people are employed through the recreational and commercial fishing industries in the Fitzroy statistical division (Sawynok 1998).

11.2 Effects of River Regulation on Offshore Fisheries

Throughout the world, there are numerous examples of river regulation devastating estuarine and marine fisheries resources due to 1) greatly reduced freshwater flow drastically reducing export of nutrients that forms the basis of food chains, 2) coastal erosion and habitat loss due to reduced sediment supply and 3) the loss of mangrove habitats due to hypersaline conditions resulting from restricted freshwater flows. Among the better known examples is the Aswan Dam on the Nile River, which has caused a 95% decline in sardine catches in the eastern Mediterranean Sea (Petts 1984). The extensive regulation of the Indus River and the loss of estuarine habitat and productivity it has caused are discussed in the estuarine habitats section.

Within Australia, positive correlations between river flow and coastal prawn catches have long been recognised, being demonstrated for the Hunter River (Ruello 1973) and Clarence River (Glaister 1978), both in northern New South Wales. Staples and Vance (1985) found a direct positive correlation between rainfall and prawn catches in the south-east Gulf of Carpentaria, with the river flow stimulating emigration of the prawns from the estuary to the nearby seagrass beds where they can be caught in the fishery. Loneragan and Bunn (in press) have recently demonstrated a similar relationship for prawns and some fish species in the Logan River in south-east Queensland. They found significant positive relationships between river flow and the catches of prawns, crabs and fishes. Blaber *et al.* (1990) found that total rainfall over a period of six weeks prior to their sampling showed a significant positive relationship with fish catch rates in Albatross Bay, Gulf of Carpentaria. Salini *et al.* (1998) found that the volume of freshwater input has a strong effect on predator populations and their prey in estuaries, thus altering the species composition of fish and their prey items in these habitats.

Loneragan and Bunn (in press) concluded that river regulation will have a dramatic effect on coastal fishery production and that the pattern of flow may be even more important than the magnitude of the annual flow. Reductions in flow can be expected to reduce the abundance of commercially and recreationally important species.

Within the Fitzroy River region, Byron (1992) observed reduced offshore fish catches in the three months following floods in 1988 and 1991. However, much of this reduction was related to inaccessibility of the resource, debris fouling nets and generally poor fishing conditions as the flood waters were high and holding together offshore for several weeks. When conditions improved, the catch rates returned to normal.

Platten (1997) examined correlations between fishery catch rates on coral reefs offshore from the Fitzroy River and flow volumes emanating from that river. Based on 18 years of standardised records from a local fishing club, as well as commercial fishing records, he found a significant correlation between catch rates and flood events and that the strength of the relationship diminishes with increasing distance from the river mouth. The relationship encompassed species at different trophic levels, from detritivores such as prawns, to carnivorous fish. Each large increase in catch rate following a flood event was also followed by higher than expected catch rates for the next 2-3 years, suggesting that residual benefits from flood events such as increased reproductive success and recruitment to the adult population is also occurring.

The short time lag between the flood event and the beginning of the increased catch rates indicates that at least the initial response was not due to population increases, but other factors such as movement of fish into new areas or increased feeding rates. The links between river flow and fisheries productivity may arise through different mechanisms such as nutrients stimulating primary production, river flow stimulating emigration from estuarine nursery habitats or increased catchability of species due to their movement into areas where they are more likely to be caught. Juvenile fishes and several prawn species are known to move offshore in response to flood waters, thus demonstrating translocation of fisheries species as one mechanism for the increased catch. High catch of some fish species may be related to their moving to the point of river discharge to feed on the prawns and juvenile fishes emigrating from the estuaries with the river discharge (eg, Blaber *et al.* 1990). However, several of the fish species studied by Platten (1997), whose catch rates increased following flood events, do not move far as adults (eg, coral trout).

Increased feeding rates may be the mechanism explaining the increased catch rates of species such as coral trout. Increased feeding rates do not just imply an increase in catchability but also an increase in fish size resulting from increased feeding activity. Platten (1997) reports that local fishermen believe that coral trout caught in the Capricorn-Bunker reefs are larger than those of the Swain reefs which are beyond the influence of Fitzroy River discharge. Thwaites (1994 in Platten 1997) summarised catch data from charter vessels and found that coral trout from the Capricorn Bunker reefs were of a larger average size than those from the Swain reefs. The analysis of Platten (1997) also shows that the average size of fish caught recreationally increased following flood events. Sawynok (1998) also found a positive relationship between river flow and growth rates of barramundi within the Fitzroy River system. Such effects are probably related to stock structure where cohorts from strong recruitment events dominate the catch for several years. Large, episodic events have a strong role in structuring fish populations, thus providing some resilience for the populations during years of lower recruitment. More uniform flow regimes that reduce the variability of flow and the frequency of strong recruitment events may reduce the heterogeneity of the stock structure and the resilience of the populations.

Increased food availability is commonly associated with river runoff to the ocean. Within north Queensland, Brodie and Mitchell (1992) report an extensive phytoplankton bloom associated with the Fitzroy River flood plume after Cyclone Joy may have contributed to greater food availability. As would be expected when a pulse of nutrients becomes available from large flow events, McKinnon and Thorrold (1993) noted that the zooplankton populations were considerably enhanced after flood events discharging from the Burdekin River. Robertson *et al.* (1993) found that benthic standing stocks and production in the Gulf of Papua were mainly supported by detritus exported from rivers entering into the gulf. While these results relate to large flood events, the same processes also occur during smaller events which occur with much greater frequency. This is shown for the Fitzroy River by the data of Platten (1997) and Sawynok (1998) where increases in fish growth and numbers also occur after medium-sized flow events. Thus, for inshore and estuarine fisheries, small and medium-sized floods, which stand to be most affected by increased regulation of the Fitzroy River, still play a important role in fisheries productivity.

Apart from food supply, river discharge affects the geomorphology, salinity and turbidity of an estuary. Geomorphology has already been discussed in a previous chapter. The effects of salinity and turbidity on the distribution and abundance of fish and crustaceans has been demonstrated in several Australian estuaries. Both salinity and turbidity are related to river discharge which lowers salinity and often increases turbidity. Both factors have been found to have a strong influence on fish distributions within estuaries. Salinity, and more importantly, turbidity, were found to be responsible for determining the seasonal distribution of many fish species in the Embley River estuary near Weipa (Cyrus and Blaber 1992). Blaber and Blaber (1980) found that turbidity was the most important factor influencing juvenile fish entering the estuaries of Moreton Bay and hypothesised that this may be due to reduced predation pressure or increased food supply. In addition, research on temperate and tropical estuaries has demonstrated that the fish faunas of different sections of the estuary are very different. This would be partly due to variation in structural habitat but as many fish also respond to salinity, changes in salinity may produce changes in the fish assemblages within the estuary itself, as well as potential changes to their productivity. Whitfield (1994) found that the diversity and abundance of ichthyoplankton was greater when riverine inputs to estuaries are higher and salinity gradients better developed.

Different species will respond in different ways, but the relationship between river flow and fishery catches is a common theme and should be considered when assessing the economic merits and environmental impacts of river regulation schemes. This has been recommended as far back as 1973 (Ruello 1973). DNR (1998a) examined the impact of various water resource proposals in the Fitzroy catchment on fishery production and expenditure, and concluded the impact to be up to $1.3M/yr without taking multiplier effects or effects on profitability into account.

12.0 WATER QUALITY

The review of water quality in the IAS was essentially a summary of the work of Noble *et al.* (1997). This document is itself a summary of a much larger data set and provides no raw data or descriptions of site conditions at the time of sampling. Thus, the raw data was not examined by the IAS and there has been no critical evaluation of the impacts of this proposal on water quality in the Dawson River or the Fitzroy River downstream. The report by Noble *et al.* (1997) was not related to the IAS and thus had different objectives and research goals. The reliance on this data without collecting any new data (apart from that relating to the fish studies), or re-interpreting the existing data in relation to the impacts of dam and irrigation development, is disappointing.

Information not included in the IAS that relates to water quality include groundwater quality, toxic metals, pesticides and oxygen demand. Groundwaters were discussed in the IAS, but in a general overview. There is no basis presented to allow an accurate assessment of the quality of the groundwater present and potential impacts resulting from the proposal. Groundwater in other irrigation schemes in Queensland has deteriorated when irrigation has occurred, and there has been no assessment of the potential here.

Though metals and pesticides were included in the report of Noble *et al.* (1997) and were found to commonly exceed ANZECC guidelines, they were not discussed in the IAS as the data was regarded as inconclusive. The lack of discussion on these topics is a major omission, especially considering the potential for this proposal to increase the levels of these contaminants in the aquatic environment.

The aquatic fauna reports show that low levels of dissolved oxygen is undoubtedly one of the major constraints on the maintenance of healthy aquatic ecosystems in the Dawson River. There has been no attempt to understand the sources of biological or chemical oxygen demand. It is to be expected that oxygen levels in the weir pools would be lowered through stratification but the high demand for oxygen, which clearly contributes significantly to many of the current problems in the Dawson River, has not been assessed. There is no understanding of what is causing the oxygen demand or how it is partitioned.

12.1 ANZECC Water Quality Guidelines

At this point it is worth discussing the relevance of the ANZECC water quality guidelines. These are more often than not misused, leading to incorrect interpretations regarding water quality status, particularly for nutrients. The ANZECC guidelines were derived from data predominantly from temperate waters. These are considerably different from the warm, turbid, heterotrophic, seasonally intermittent, strongly stratified waters found in the Dawson River.

The ANZECC nutrient guidelines comprise 10 pages of text explaining how a complex array of interacting factors affect ecosystem responses to nutrients. Most of these factors are site-specific. Thus guidelines need to be derived from site-specific studies. This review has found no studies capable of deriving site-specific guidelines appropriate for the Dawson River.

The ANZECC guidelines treat different types of aquatic environments separately. The weir pools of the Dawson River (which comprise over half of its length below the proposed dam site) will behave more like lakes, at least seasonally. It may therefore be argued that the guidelines for lakes and reservoirs are more applicable than those for streams, used by Noble *et al.* (1997) and in the IAS. The indicative nutrient concentrations given by ANZECC (1992) for freshwater impoundments are: Total Nitrogen 100-500μg/l and Total Phosphorus 5-50μg/l. The ANZECC guidelines state that these ranges "..are provided as an indication of levels at or above which problems have been known to occur, depending upon a range of factors". They are not water quality **criteria**, hence the more appropriate usage of the term **guidelines**. Unfortunately, they are more often than not used as criteria which usually leads to misleading interpretations. For example, total nitrogen levels in the Dawson River during periods of low flow are commonly compared to the indicative levels for rivers (100-750μg/l) and are said to be 'within range' or 'below the maximum limit' and therefore tend to be treated as acceptable. However, they actually fall within the range at which problems "..have been known to occur" (ANZECC 1992).

Accordingly, the discussion of nutrients in the IAS, which only makes comparisons with ANZECC guidelines, does not contribute to the understanding of the health and potential vulnerability of the Dawson River system. Nutrients tend to be strongly associated with suspended sediments. In the case of the Dawson River, the naturally turbid waters, at least seasonally, probably have naturally higher levels of nutrients without causing environmental harm and it would be difficult to compare these with guidelines derived largely from systems with less turbid water and a greater susceptibility to nutrient impacts.

12.2 Existing Surface Water Quality in the Dawson and Fitzroy Rivers

The existing water quality of the Fitzroy River catchment was studied as part of a catchment-wide program for three years from 1994-1996 and the results were summarised in Noble *et al.* (1997). Parameters collected for this study were dissolved oxygen (DO), pH, conductivity, turbidity, suspended solids, total Nitrogen and total Phosphorus. There was also limited sampling of pesticides, heavy metals and major ions. This report also used data collected since 1990 by the DNR Ambient Water Quality Monitoring Network. The Dawson catchment was represented in that study by seven primary sites sampled during baseflow conditions and after significant rain events. The raw data from Noble *et al.* (1997), including information on the number of samples and flow levels, was not available for the IAS so only summary data presented in Noble *et al.* (1997) was used. The IAS took water quality readings (temperature, pH, dissolved oxygen, conductivity and turbidity) at 10 sites in conjunction with the aquatic habitat surveys (Anderson and Howland 1997), mostly related to conditions in the weir impoundments and larger natural pools.

Noble *et al.* (1997) emphasised the need to consider climatic extremes and caution against the use of or reliance on means, which are insensitive to high variability. The same authors also recommended that the nutrient and cotton-chemical related problems in the catchment be addressed before any further dam and irrigation developments occur. This has not happened. Thus the extent of nutrient and water quality problems in the Fitzroy catchment is well known, but there are further proposals to increase river regulation and irrigation activities without addressing these problems.

The following discussion is based on Noble *et al.* (1997) and the summary of that document prepared for the IAS by Markar (1997).

Dissolved oxygen was within ANZECC guidelines at most sites on most occasions. Some low levels were recorded in the mid-Dawson River and in water >1.5m deep. The ANZECC guidelines stipulate that dissolved oxygen measurements should be taken over a 24-hour period. There is no indication that this was done and it can be assumed that all measurements were spot readings done during the daytime when dissolved oxygen levels are usually at a maximum. Though this is of almost ubiquitous occurrence in environmental monitoring, it does not alter the fact that dissolved oxygen levels taken on the basis of daylight spot measurements can be very misleading. Anderson and Howland (1998) have assumed that photosynthetic oxygen production in the habitats of the Dawson River that they studied is negligible. Noble *et al.* (1997) have shown that phytoplankton concentrations (dominated by blue-green algae) can be significant when turbidity is low and that even at moderate turbidities, there is likely to be some photosynthetic oxygen production. Thus the dissolved oxygen status of the Dawson River cannot be properly assessed without diel (24-hour) monitoring of oxygen. This technique is simple and cost-effective, yet has not been undertaken in the Dawson River even though the ANZECC guidelines require that it be undertaken when assessing oxygen levels.

All pH samples met ANZECC guidelines, and ranged from 7.1-7.3 for baseflow conditions and 7.4-7.9 in flow events. Like dissolved oxygen, pH levels are variable depending on time of day and the prevailing site-specific conditions, thus precluding generalisations based on uninterpreted summary data. Conductivity levels also satisfied ANZECC guidelines, generally being 150-200μS/cm under baseflow conditions and 200-250μS/cm after flow events. The Queensland Water Quality Atlas (QDPI 1994) shows salinity trends over the period 1970-1995 at river-gauging sites in Queensland. Over the 25-year period, there is a trend of increasing surface water salinity at three of the four sites below Theodore.

Turbidity was measured by a secchi disk. Water was generally more turbid in the upper and lower reaches of the Dawson River than the middle reaches. Minimum and maximum readings (0.05m and 1.9m) were both made at the same site on the lower Dawson indicating the level of variability present. Median values for suspended solids range from 25mg/l at the most upstream site to 219mg/l at the most downstream site. A reading of 337mg/l was reported at Taroom after a flow event. Dawson River water has a hardness of <200mg/l $CaCO_3$, but one of its tributaries - Castle Creek - has reported values of 200-500mg/l $CaCO_3$.

The median concentration of total Nitrogen (TN) was <0.75mg/l under baseflow conditions and >0.75mg/l under higher flow conditions. The median value for all 102 readings was 1.065mg/l (ANZECC guideline upper limit for rivers = 0.75mg/l). Median values at all sites except the uppermost site, exceeded 0.75mg/l. Higher values were recorded in mid and lower river sites. The median total Phosphorus (TP) value for all 102 samples was 0.215mg/l (ANZECC guideline upper limit for rivers = 0.1mg/l). Under baseflow conditions, the values were generally <0.1mg/l, but consistently higher than 0.1mg/l under flow conditions, and with the highest values in the mid and lower reaches.

Median values for Total Nitrogen (178 samples) and Total Phosphorus (179 samples) exceeded ANZECC guidelines, particularly in the Dawson River sub-catchment. There are no guidelines for suspended solids, though these are important as a major source of nutrient transport, especially for phosphorus, which adsorbs to sediment particles. Noble *et al.* (1997) found that more than 60% of the phosphorus in river samples in the Fitzroy catchment is associated with suspended solids.

12.3 Water Quality in the Weir Impoundments and Proposed Dam

Between the site of the proposed Nathan Dam and the ocean, there are six weirs on the Dawson River (plus more proposed as part of the dam and irrigation scheme) and a barrage on the Fitzroy River. Algal outbreaks are common within the impoundment behind the Fitzroy River barrage and it has been found that substantial flows or heavy rainfall are required to improve the water quality or to break down established phytoplankton blooms (Duivenvoorden 1995). For the Dawson River, Duivenvoorden (1995) concluded that the algal populations were light-limited. With the current nutrient levels, it is not likely that algal populations are nutrient-limited at most locations. Generally in the Fitzroy catchment, algal species richness and cell densities are relatively low at most locations (Duivenvoorden 1995). Blooms have only been recorded on two occasions in the Dawson River, at Moura Weir December 1994 and Rannes May 1995, though high algal levels of species that do not form blooms are more common.

Deoxygenation is common in the weir impoundments and the IAS discusses this at length, particularly in relation to fish habitat. The IAS itself (p. 131) recommends that further studies are required to determine the flows required to prevent stratification developing and to assess the impact of deoxygenation on the aquatic ecosystems. To our knowledge, this has not occurred.

Although not assessed in the IAS, it is apparent that the oxygen demand of the turbid waters of the Dawson River is very high and that photosynthetic oxygen production is often very low (due to turbidity limiting light penetration and plant growth). Thus the oxygen status of the weir pools is heavily dependent on the physical exchange of gases with the atmosphere and mixing within the water column. The Dawson River is heavily regulated with six long and deep weir pools, covering over half of the river length below the proposed dam site. The weirs are thermally stratified much of the time, even when moderate flows are present, and the bottom strata are anoxic. The shallow upstream areas of the weir pools do not stratify markedly when flows are adequate to maintain aeration but low flows and flow stoppages as short as a few days lead to deoxygenation to within 1-2m of the surface, even in the shallow sections of the pools, rendering most of the water column anoxic and unable to support aerobic life. According to the IAS, this means that approximately 70% of the water column and 95% of the river bed is unavailable to aerobic organisms. The implications of this on the aquatic fauna was discussed in the section on invertebrates and freshwater fish.

As pointed out by Anderson and Howland (1998), oxic stratification would almost certainly have been a natural feature of the deeper waterholes in the Dawson River prior to regulation, but human land-uses have exacerbated the situation by increasing the organic load and oxygen demand of the waterholes, as well as the depth, extent and permanency of the stratification in them.

There is little doubt that even prior to agricultural development in the area, stormwater runoff in the Dawson catchment would have been very turbid, but the baseflows which followed these events are much more likely to have been clear. The early explorers through the area noted that the waters were clear (Neil and Yu 1996). Even the water in the deeper waterholes may have been clear, allowing aquatic plant assemblages to proliferate which would have enhanced oxygen production. Algal blooms would also have been likely at times. Thus in some years, maybe even most years, by the time water flows receded in the dry season, the oxygen status of the permanent waterholes would have been controlled by photosynthetic production which provides more favourable environmental conditions. The advent of river regulation is likely to have caused retention of turbid waters that would normally have passed through the system, contributing to the heterotrophic conditions observed today.

12.4 Cyanobacteria (Blue-Green Algae)

The NSW Blue-Green Algal Taskforce (1992) indicated that a TN:TP ratio of less than 29:1 is conducive to blue-green algal growth. Median values for all sites in the Dawson River were less than 10:1 and no individual value was greater than 25:1. Despite this, cyanobacterial blooms are not common in the Dawson River. Other factors such as low light levels in the water column due to the high turbidity may be limiting algal growth. The Moura Weir algal bloom of December 1994 followed a reduction in the sediment load (Markar 1997) which would have increased light availability for the algae.

It seems clear that nutrient levels in the Dawson River and also in the Fitzroy River are regularly high enough to provide favourable conditions for the formation of cyanobacterial blooms, but this occurrence is limited by the high turbidity. The IAS believes the impoundment would promote settling of sediment and may thus contribute to increased algal outbreaks. In the Burdekin Falls Dam, the large amount of fine material carried in the water from eroding topsoil in the catchment rarely settles out in the impoundment. This result was not predicted for the Burdekin Falls Dam which most observers thought would have mainly clear water. As is discussed in the next section, high turbidity cannot be guaranteed and even in the Burdekin Falls Dam, settling of fine sediments has occurred on one occasion. Another factor that may promote settling of fine sediments is the potentially increased conductivity of the water resulting from use in irrigation areas. This promotes flocculation of fine sediment particles which increases settlement rates, thus reducing turbidity and improving conditions for algal outbreaks.

As part of the IAS, Anderson and Howland (1997, 1998) emphasised the need for streamflow to induce aeration because of its direct significance to aquatic fauna, especially fish, which they were studying. Similar considerations could be applied to controlling algal growth. Cyanobacteria strongly favour still, poorly mixed waters with low CO_2 availability and high pH (Paerl 1988, Shapiro 1990). Flows capable of aerating the water column will also promote mixing, prevent CO_2 depletion and stabilise pH, so removing several of the competitive advantages that cyanobacteria would otherwise have over (more desirable) green algae.

Algal blooms are not a chronic problem in the Dawson River, but the proposed development could impact on algal dynamics in many ways, such as altering suspended sediment patterns and therefore light penetration. The use of on-farm detention basins to prevent release of irrigation tailwaters and first flush stormwaters (as mentioned in many parts of the IAS) should reduce sediment loads late in the dry season, a time when climatic conditions (high temperatures and light intensities) are conducive to algal blooms. Although the detention basins would also reduce nutrient runoff, the nutrient levels of the Dawson River from other sources are more than enough to sustain significant blooms.

The IAS greatly understates the potential for outbreaks of blue-green algae. The issue has not been properly dealt with. Management recommendations in the supplementary report include declaring the water unfit for consumptive use but no further statements are made on the problems this may cause.

12.5 Dam Performance

In the IAS, there is little discussion of the effects of a greater percentage of the river being impounded within artificial pools and no discussion of the limnological performance of the proposed dam. Issues that should be considered here include likely morphometry, turbidity characteristics, settling time for suspended particles, risk of algal blooms or other problems if the water clarifies, the likely nature of the stratification or other criteria which would be required to determine the depth at which the multi-level outlets should be placed to ensure the flow of reasonable quality water downstream. The likely nature of the impoundment could be discussed by reference to existing impoundments such as the Burdekin Falls Dam (another large dam in a similar catchment) and the Fairbairn Dam within the Fitzroy catchment itself. Comparisons with existing data on the limnology and water quality of these impoundments (eg, DNR 1997) would be of great benefit in predicting the performance of the proposed dam. Even some examination of the composition and particle size characteristics of the suspended sediment in the existing weirs of the Dawson River, especially Glebe Weir (which would be inundated by the proposed dam), would be of value in predicting the likely performance of the proposed dam.

For the Burdekin Falls Dam, it was predicted that all of the bedload material entering the dam would be trapped, but that much of the washload (suspended clay particles) that are the primary contributors to turbidity and elevated nutrient levels, will pass over the spillway. Ten years of dam operation have shown that these predictions were qualitatively correct (Faithful in prep.). This finding has two important ramifications:

1) Downstream environments will be starved of coarse sediment once the existing bedload in the unregulated sections of the river move downstream. Some extra material will be provided from watercourses entering the river below the impoundments or from increased instream erosion. In the case of the Dawson River, the Dee and Don rivers are also regulated and there are proposals to regulate Mimosa Creek with a weir which will also trap sediment. The process of sediment reductions may take decades, but has very important ramifications for the geomorphology of the river channels, downstream environments, estuary/delta and the coast. These have already been discussed in the sections on Geomorphology and Estuarine habitats.
2) The proportionate reduction in fine sediment export is often approximately equivalent to the

proportional reduction in storm flows. That is, for a given flow reduction, there will be a reduction in fine sediment export of similar magnitude. This is the basis of the sediment transport model developed in section 8.5.

Prior to construction of the Burdekin Falls Dam, it was predicted that during the dry season or drought, when water and sediment inputs are low, the water in the impoundment would clarify. This has not proven to be the case. Faithful (in prep.) has studied the limnology of the dam since its construction. In the ten years since the dam filled, it has only clarified once. This event lasted for nine months and followed the massive inflows of water from Cyclone Joy in 1990. After the flood event had receded, relatively clear baseflows in the impoundment's feeder streams were sufficiently high and prolonged to influence the water quality in the dam. Additionally, the baseflows were largely derived from groundwater, thus having a higher ionic strength, promoting flocculation of fine particles. As a consequence, the water clarified and algal blooms developed for several months. The limnology of large impoundments is thus not always straightforward and the potential for water quality problems and algal blooms needs to be determined.

12.6 Impacts on Downstream Surface Water Quality

The water quality of the Dawson River weirs and deep pools is poor and may be further impacted by dam and irrigation development. Apart from deoxygenation, the potential for further deterioration of water quality, especially in relation to irrigation development, was not addressed in the IAS, and is not being covered by the WAMP process. With the addition of the new developments, the quality of the water within the waterways, wetlands and downstream environments will most likely deteriorate further if its importance is not given sufficient weighting during the assessment stage. The water quality of the Dawson and Fitzroy rivers is already coming under close scrutiny, even at a national level. This is exemplified by the blue-green algal blooms that regularly occur within the Fitzroy barrage (Fabbro and Duivenvoorden 1996), fish kills (Ian Cowley DoE, pers. comm; Jo Wearing, WPSQ, pers. comm.), the poor water quality within the many weir impoundments and by the selection of the Fitzroy catchment as a focus catchment in the National Eutrophication Management Program. The poor quality water is transported downstream to coastal habitats and also affects marine organisms such as many fish species that migrate up the river into freshwater habitats.

13.0 IRRIGATION DEVELOPMENT

Though irrigation development is often mentioned in the IAS, especially as part of the economic analysis, the environmental impact of irrigation and cropping associated with the dam proposal received only cursory treatment there. This is a major area of criticism. All IAS/EIS for dam proposals should give full consideration of the issues related to associated irrigation development. In this case, the description of the proposed irrigation area and development are insufficiently detailed to enable any kind of reasonable assessment of the potential impacts.

13.1 Existing Irrigation Area Development in the Fitzroy River Catchment

Nearly 40,000 hectares of crops are irrigated in the Fitzroy River catchment (DNR 1998b). The largest irrigation area within the Fitzroy catchment is that of the Emerald Irrigation Area which has 70 farms with water supplied from Fairbairn Dam, which was completed in 1976 (DNR 1998b). Cotton is the major crop in this area, as will be discussed in the section on pesticides.

Within the Dawson catchment, the Dawson Valley Irrigation Area at Theodore comprises about 9,000ha with water coming from Theodore Weir or directly from the Dawson River. There is also an irrigation area in the Callide Valley section of the Dawson sub-catchment. Low level irrigation also occurs using water pumped from the weirs along the Dawson River. Modelling simulations for the period 1900-1995 shows that the existing irrigation developments have had little or no impact on "natural" flow behaviour of the Dawson River, although flows downstream of Glebe Weir have been decreased by about 10% (Markar 1997). Total reductions in natural riverflows after the dam (including existing weirs) are estimated to be 25-30% (Markar 1997).

Current yield from Dawson River is 60,000ML/yr, but significantly less is used. The dam will provide 152,000 to 260,000ML/yr under various scenarios. DNR estimates demand from irrigation to be 220,000/yr by 2005, plus 33,100ML/yr for industrial use. This equals the maximum likely to be available without taking into account environmental releases which will reduce the available yield but were not assessed in the study. Further, more detailed modelling is suggested due to perceived uncertainties in the yield estimates.

13.2 Proposed Irrigation Development

As no water delivery channels are proposed, the IAS believed that water would not be taken more than 5km from the river, thus indicating the nature of the irrigation area as being a linear strip along the length of the Dawson River. The IAS only undertook soil suitability mapping within this 10km wide strip. This indicated that 66,290ha of land was potentially suitable for irrigation within the study area (5km either side of the river, plus further land surrounding the impoundment). However, the IAS indicates that the water yield from the Nathan Dam will only allow for 30,000 additional hectares to be irrigated. Most of this will be downstream from the dam, though up to 5,000ha may be irrigated directly from the impoundment. Due to fluctuating dam water levels, any irrigation from the impoundment would be more problematic.

No assessment of land outside of the 5km zone in the downstream area has been undertaken.

The IAS admits (p.75) that an accurate assessment of land condition downstream of the proposed dam site has also not been undertaken due to the large area and short time available, but assumes it to be similar to that upstream. Additionally, no mapping of land degradation hazard was undertaken downstream, though it was undertaken upstream of the proposed dam site.

13.3 Irrigation Area Runoff

Irrigation and rainfall runoff from the Emerald Irrigation Area have elevated nutrients and metals (Carroll *et al.* 1992). Noble *et al.* (1997) sampled runoff from irrigated cotton areas in the Emerald Irrigation Area. They found that suspended solids levels were several to many times higher in runoff water than in the water used for irrigation. The elevated levels remained high for at least 1.5km of the river channel to the downstream sampling point at Crump Weir. Total Nitrogen values for this runoff water were at least an order of magnitude higher than the upper limit specified in the ANZECC (1992) guidelines for ecosystem protection. Median values at Crump Weir were 10 times higher than for the intake water coming from Selma Channel (originated from Fairbairn Dam). The median values for Total phosphorus were well within ANZECC guidelines for the water delivery channel, but several times higher than the ANZECC guidelines for the runoff water.

The intensive cropping proposed for the new irrigation areas will involve the use of large volumes of fertiliser, pesticides and weedicides. Due to farm drainage entering the Nogoa River from the Emerald Irrigation Area, this river consistently exceeds ANZECC guidelines for total nitrogen and for endosulfan (a pesticide used in cotton production) in 3 of the 6 sampling events within the receiving waters of the Nogoa River at the Duckponds, despite this site being substantially diluted by water releases from the Fairbairn Dam (DNR 1998b).

Between 1994 and 1996, endosulfan levels in the Fitzroy River exceeded ANZECC guidelines for aquatic ecosystem protection and the draft National Health and Medical Research Council Australian drinking water guidelines on many occasions (Noble *et al.* 1997). The herbicide, atrazine, was also widely detected. Thus the catchment has existing problems related to nutrients, sediments and chemicals under the current levels of cultivation.

13.4 Regulatory Controls on Irrigation Development

The faith of the IAS in the farmers' ability and desire to control runoff is not justified. The environmental impacts resulting from non-compliance with the proposed environmental controls are not assessed or considered. This highlights one of the deficiencies in the IAS process. That is, the recommendations and guidelines included in the IAS/EMP on which approval of the project is based, may never be implemented, so that projects often fail to live up to the standards upon which approval was provided.

In a survey of cotton growers in the Namoi River area, O'Brien (1996 in NRA 1998) indicates the problems of compliance with environmental guidelines. These include not spraying if rain is forecast and not irrigating shortly after spraying. The survey found that 55-77% of farmers (depending on the district) would spray even if rain was forecast and that irrigation shortly after spraying is widespread including 73-90% of farmers (depending on the district) who sprayed while water was still in the furrow ditches. There were numerous reports of farmers spraying just hours before rain, even though pest pressure was low. High levels of non-degraded endosulfan parent isomers were detected in the waterways, indicating that the sprayed endosulfan had entered them during the rain event. The cotton industry's Best Management Practices Manual does not mention the practice of spraying while irrigating (NRA 1998).

While the contention in the IAS that failure to follow regulations is not the fault of the IAS is correct, if it is to comply with the principles of Ecologically Sustainable Development, the IAS should provide a realistic appraisal of the likelihood of compliance and should assess the environmental consequences of non-compliance rather than assuming it will not occur. The notion of zero runoff is unproven, unrealistic and not achievable during storm events. There is no indication provided that the level of monitoring suggested in the IAS will actually occur and what exactly this would involve. As the submission from the Ecological Water Alliance of Queensland states, the IAS assumes with regard to regulating irrigation development that "..the irrigators, government agencies and politicians will have the economic capacity, the technical means, the legal mechanisms and the political will, as appropriate, to ensure that the project operates without detriment to the environment or other affected parties, no matter what circumstances arise". The NRA review (1998) of endosulfan indicates that although noteworthy improvements in controlling agricultural impacts on riverine environments have been made, there are still significant problems, despite the high levels of regulatory control in industries such as cotton.

The DPI submission in response to the draft IAS raised a number of concerns regarding lack of information available on potential salinity problems, the preparation of Land and Water Management Plans, determination of suitable soils for irrigation, and the use of a linear strip of alluvial soils for irrigation rather than a large block area. They note that without this information, a proper assessment of the environmental impacts cannot occur.

The IAS argued that market forces and new technologies would ensure that the level of environmental control assumed will be achieved. Justification for this argument was not provided. A realistic appraisal of the ability of regulatory controls and other factors to achieve the stated environmental standards is critical to this proposal. This is especially so given the proximity of the proposed irrigation development to the Dawson River channel where the risk of contaminant transferral to surface waters in the river is greatly increased. The use of a linear irrigation strip on alluvial soils along the Dawson River poses distinct and unavoidable threats to the riverine environment. A single large irrigation block, or several smaller blocks, remote from the river would be far more preferable for the protection of riverine environments.

The IAS recommends a vegetated buffer zone between the top levee of any stream and any cultivated land, but provides no recommendations on buffer width. The determination of this width will have a strong bearing on the impacts upon the riverine streams. The purpose of the buffer zone is described in the IAS as being for soil conservation. Given the problems related to spray drift of aerially-applied cotton chemicals as discussed in the section on Pesticides, the definition of a buffer zone should be expanded to include the prevention of spray drift from entering the riverine environment. As discussed in the next chapter, an absolute minimum of

5km would be required for this purpose. It may be that crops that do not require aerial application of chemicals and that use chemicals with lower volatilisation rates would be allowable within this buffer, but they would still require a substantial margin from the top levee of the river banks.

13.5 Groundwater Quality in the Dawson River Catchment

There was limited information presented on groundwater quality for the IAS, but it was claimed that it is unlikely to be affected. The problems with salinity in the Murray-Darling system are known by all. There are already salinity problems resulting from irrigation in the Dee and Don rivers. In the Burnett catchment and the lower Burdekin irrigation district, there are also emerging salinity problems and rising watertables that threaten further problems. In some of these areas, the salinity problems appear soon after the initial clearing of land in preparation for irrigation development, even before irrigation has commenced.

Roberts (1996) warns that salinity prediction studies are warranted in the Dawson, Comet and Mackenzie sub-catchments of the Fitzroy River. In a CSIRO report on groundwater research, Williamson (1984) describes the potential for salinisation of brigalow lands (including the Fitzroy catchment), resulting from the extensive land clearing there, as enormous, and states that increases in stream salinity in the catchment can be anticipated. Although some of the land may already be cleared, development of the irrigation area would involve further large-scale clearing. This in itself may cause rapid development of salinity problems. There has been no proper assessment of the potential for this occurrence, or of the development of other salinity problems related to irrigation area development.

In order to avoid the issue, the IAS argues that salinity will be caused by individual farming practices and not the dam or water supplied from it and is therefore not relevant to the IAS. This is an example of why irrigation developments should be included in any IAS for a dam. * Good farm management practices will only alter the rate and mechanisms of salt accession, not whether or not it will occur. With total on-farm containment which is proposed as a condition of water allocation, salts will only be able to leave by the irregular and rare stormwater occurrences and will otherwise be leached into the groundwater or accumulate in surface soil. The suggestion that individual land holders who contribute to salinity problems will be responsible for rehabilitation is also unrealistic. Besides being a prohibitive cost, it will be very difficult to determine or apply blame, especially if the salinisation occurs away from the source, in groundwater for example. The DPI submission to the draft IAS expresses their concern that the responsibility for providing information on salinity and waterlogging has been left up to individual farmers, when the problems are not confined to property boundaries.

It would seem inevitable in irrigation areas that salinity problems would develop over time. Through appropriate land selection and management the rate at which salinity problems develop can be reduced, but they are likely to occur eventually and will only be countered at considerable cost. It is therefore imperative that a full evaluation is made of salinisation rate before the development proceeds.

The IAS notes that the dam and irrigation area would cause the groundwater table to rise due to irrigation and more regular river flows. Rising groundwater tables are one of the major mechanisms associated with the extensive salinity problems being faced in agricultural and pastoral areas in this country. It is critically important that these be evaluated before any large proposals are progressed. To base decisions on rudimentary consideration of such an important issue cannot be justified. The conclusion of the IAS (p. 197) that "..because this section of alluvium is currently dry, it is unlikely to cause significant problems for many years" does not give the issue the level of consideration it requires. The IAS (p. 92) notes the high variability of groundwaters in the area with respect to conductivity, ranging from 3,000 - 20,000µs/cm. The IAS recommends (p. 202) that groundwater and irrigation management data from the Theodore area should be reviewed to more thoroughly understand the groundwater hydrology of the area and to predict long-term mitigation strategies. This should be done before any decisions are made regarding the dam proposal.

The IAS (p. 230) admits that the prospect of regional groundwater rises "..remains uncertain and largely unquantified" and whether soil salinisation will result is unclear. On page 233, they further state that no firm conclusions can be drawn on whether deep drainage containing excess salts and nutrients "..will render parts of the local groundwater unsuitable for domestic and stock use" or whether increased baseflow into the river will cause the water quality to deteriorate during low flow periods. These issues were presumably regarded as more appropriate for consideration at a later date when the irrigation area is being developed. However, as stated elsewhere, this step-by-step assessment and development will only lead to erosion of environmental values and loss of confidence in coordinated planning and the notion of environmentally sustainable development.

14.0 PESTICIDES IN THE AQUATIC ENVIRONMENT

Endosulfan and several other relevant agricultural chemicals were not mentioned in the IAS. Although it might be argued that such consideration was beyond the scope of the IAS, unfortunately, this is part of the issue. Development of new irrigation areas is the purpose of the dam proposal and should have been part of the IAS. The use of harmful pesticides should be an important part of the environmental assessment of any irrigation area.

One of the most likely crops to be planted in the irrigation area downstream of the proposed Nathan Dam is cotton. In a survey of potential farmers conducted for the DNR (Rolfe and Teghe 1997), 50% of respondents indicated they would plant cotton. This does not take into account the average size of plantings which may see cotton occupying a greater proportion of the irrigated area. Cotton was used as the dominant crop in the IAS economic analysis and is being used in the analysis of water needs for the WAMP. If the crop configuration could be different, then a range of different scenarios should have been pursued as part of the IAS. In the cotton industry, many different pesticides are used, with endosulfan being the most common and the one most often implicated in the contamination of aquatic environments. Endosulfan is an organochlorine insecticide consisting of two isomers - alpha and beta in a ratio of 7:3 (Nowak *et al.* 1995). It has been used in Australia for over 30 years. When degrading, endosulfan initially breaks down to endosulfan sulphate and then to other less toxic metabolic products, or hydrolyses to endosulfan diol. The sulphate is just as toxic as the parent product but the diol is not toxic. Endosulfan is less persistent than other organochlorine pesticides. Its half-life varies depending on environmental conditions. In water its hydrolysis is greatly influenced by pH with a half-life of a few weeks at neutral pH, a few hours at pH of 9 and is stable at acidic pH (NRA 1998). Small changes in pH may produce large changes in half-life. Low temperatures also significantly reduce the hydrolysis rate (Peterson and Batley 1993). Half-lives in soil vary with soil type and moisture content, generally ranging from one or two months in moist alkaline soils, to many months or even six years in dry soils (NRA 1998).

The ANZECC guideline for the protection of aquatic ecosystems is 0.01µg/l. This is derived from applying a factor of 50 to the lowest acute LC50 for native Australian fish (bony bream at 0.02µg/l). This guideline has been criticised as being too low (NRA 1998). The relevant Canadian guideline is 0.02µg/l. The US EPA guideline for endosulfan is 0.22µg/l (acute) and 0.056µg/l (chronic), though the US National Academy of Sciences recommends a stringent guideline of 0.003µg/l. South Australia has established a guideline for estuarine and marine waters under the Environment Protection (Marine) Policy 1994 of 0.034µg/l (acute) and 0.0087µg/l for the average concentration over a 24-hour period (NRA 1998).

Australia imports 900 tonnes of technical grade endosulfan each year which is turned into 2.9 million litres of concentrate of which 70% is used for cotton and 20% for vegetables (NRA 1998). Virtually all research on the environmental effects of endosulfan in Australia is on minimising the incidence of fish kills and other short-term acute events, rather than chronic sub-lethal effects. The National Registration Authority on Agricultural and Veterinary Chemicals (NRA) has recently published a comprehensive review of endosulfan in Australia. This review (NRA 1998) found no evidence that endosulfan is causing significant long-term damage to the environment, though some severe effects, such as fish kills, have often been reported during the cotton spraying season. However, there has not been a study to prove that long-term effects have not occurred.

14.1 Why Use Endosulfan

The continued use of endosulfan is of great importance to the cotton industry. It is especially suited to Integrated Pest Management as it has a low toxicity to most predatory and parasitic insects and spiders. It is a different class of chemical from most other insecticides and resistance is therefore less likely to develop. The recent NRA (1998) review concluded that its continued use is warranted on the grounds that it is of great importance and the alternatives may be worse. The introduction of transgenic (Bt) cotton (genetically altered by the inclusion of a bacterial gene to produce a toxin) may reduce endosulfan usage but it will continue to be essential for the cotton industry (NRA 1998).

The National Registration Authority have sanctioned the continued use of endosulfan for the next three years, but consider that the high environmental concentrations detected in cotton-growing regions is not acceptable on an ongoing basis. Accordingly, continued use of endosulfan will be reviewed again in three years time. Basically, NRA are satisfied there has been marked improvement in reducing endosulfan input to the environment, but that further improvement is required to justify its use beyond the next three years. The NRA (1998) reviews the methods and research into minimising endosulfan runoff from farms.

14.2 Off-farm Movements of Endosulfan

Much research has been undertaken by the cotton industry and the LWRRDC program - Minimising the Impact of Pesticides on the Riverine Environment - to develop best management practices to reduce off-farm movement of endosulfan (and other pesticides). These strategies have reduced the levels of endosulfan in the environment. However, surface water concentrations of endosulfan in areas of intensive use still routinely exceed ANZECC guidelines for the protection of aquatic ecosystems. In the cotton-growing areas of northern New South Wales, the ANZECC guideline has been exceeded in at least 50% of samples through the 1990's, with particular problems occurring after rain events that result in surface run-off (NRA 1998).

Endosulfan can be transported from sprayed cotton fields to the riverine environment by four main pathways (described in Raupach and Briggs 1996). These are dust transport, water runoff, spray drift and vapour transport (volatilisation). Dust transport occurs when endosulfan particles adhere to dust particles which are then transported by wind to the riverine environment. This is not considered to be a significant pathway. Spray drift and water runoff produce the highest endosulfan concentrations, with vapour transport being an order of magnitude smaller. However, vapour transport results in a greater area of water being affected and also has the highest probability of occurring as spray drift and runoff depend on climatic events (high winds or high rainfall).

Runoff provides sudden, high concentrations of endosulfan to receiving water bodies and has been implicated in many fish kills, including in the Fitzroy catchment. The impact of runoff as a pathway for environmental contamination can be greatly lessened by regulatory mechanisms as has been part of the cotton industry's best practices program. However, as seen in section 14.4, the introduction of such practices does not totally alleviate the problem.

To date the main consideration used to devise recommendations for buffer zones around crops such as cotton, appears to be the effects of spray drift directly onto water. NRA (1998) points out that spray drift of 1% would cause a concentration of 4.7µg/l in a shallow water body 15cm deep. This concentration could be toxic to many fish species. Losses to the environment from spray drift may approach 10% at a distance of 200-400m downwind of target (Ahmad *et al.* 1996 in NRA 1998) and field experiments have shown that fish kills can occur in shallow water bodies at distances of 200m from the application point. Irrigation within 5km of the Dawson River will carry a particularly high risk of spray drift problems, in addition to volatilisation and runoff. The calculation shown below indicates that the planting of crops that require aerial application of pesticides within 5km of any waterway, conservation area or natural habitat will almost certainly result in impacts being transferred to these environments at some time.

The weir pools that comprise two-thirds of the length of the Dawson River below the dam site have been shown to be strongly stratified during the dry season and summer months. Indications are that the water column is only mixed in the top 1-1.5m. Accordingly, in its capacity to dilute endosulfan spray, the weir pools (most of the river) will behave as shallow water bodies despite actually being up to 10m deep. Applying the reasoning used by NRA (1998) to the Dawson River, it is possible to crudely calculate the percentage drift allowable to achieve a target concentration in a 1.25m deep water column. We will use two target concentrations - 1) the ANZECC guideline of 0.01µg/l. This may be conservative because exposure time will be relatively low as endosulfan will volatilise and sorb to sediment. Monitoring records show that fish are surviving in waters where concentrations commonly exceed this level (NRA 1998); 2) 0.1µg/l which is the laboratory concentration lethal to European carp (used as a conservative yardstick because although it is an introduced pest, it is the most sensitive fish species for this pesticide known in Australia).

Calculation:
Volume of water per square metre of water surface area = $1m^2$ x 125cm = 1,250L
At a concentration of 0.1 µg/l, there would be 125µg of endosulfan per 1,250L
125µg/m^2 is equivalent to 1.25g/ha
Application rate for endosulfan = 700g/ha (data from NRA 1998)
Thus 1.25/700 = 0.18% of spray drift

The same calculation at 0.01µg/l = 0.02% of spray drift.

Though simplistic, this model does demonstrate the importance of the buffer zone. Using Gaussian plume modelling, Raupach and Briggs (1996) derived fractional deposition for spray drift at distances of 1 and 5 km from the crop. Low, medium and high scenarios, depending on wind speed and direction, were utilised. The percentages of spray drift were as follows:

	LOW	MEDIUM	HIGH
1 km:	0.3%	1%	3%
5 km:	0.03%	0.1%	0.3%

Using their more sophisticated model, they predict initial concentrations in water 1km distant from the application point to be 1.4, 0.7 and 0.35μg/l for mixed water bodies 0.5m, 1m and 2m deep respectively. Due to revolatilisation, these concentrations are expected to decline rapidly to 0.08μg/l (in the 2m deep water body). This concentration is still eight times the ANZECC guideline and is likely to persist for tens of days (Raupach and Briggs 1996). It is assumed that this only occurs over an isolated reach of the stream and that starting concentrations are zero. Neither of these assumptions are likely to be true for the proposed developments in the Dawson River because most (or all) farms will be within 5km of the river and the potential for cumulative impacts would be very high.

From the above data, it can be seen that 1km is not a sufficient distance to prevent spray drift from causing endosulfan concentrations in water that are known to be lethal to fish in the laboratory. To prevent spray drift from causing endosulfan levels in excess of the ANZECC guidelines, at least for short periods of time, a distance of 5km would be needed.

It is clear from these considerations that there would need to be a substantial buffer zone between the farms and the Dawson River or any other waterbody. These models also demonstrate the distance that aerially-dispersed endosulfan may be transported within adjacent terrestrial communities. The above models do not consider the role of trees in the buffer zone as interceptors of spray drift. This would presumably significantly reduce the dispersion of endosulfan, but only at the expense of the faunal communities, especially insects within the buffer zone.

So far, we have seen that endosulfan decays slowly in dry soils such that with repeated applications, it may accumulate there. This may be removed as runoff during the next overland flow event, resulting in potential toxicity problems in any aquatic receiving environments. Thus we suggest that any irrigation area where endosulfan is sprayed aerially must have a buffer zone of up to 5km surrounding it. This includes irrigation areas that are remote from riverine environments. Within the buffer zone, an irrigated crop that does not requires endosulfan application may be planted. This will keep the soils there moist and more rapidly degrade the endosulfan received through aerial spray drift. This area will also protect the surrounding environment from the effects of spray drift on their invertebrate communities.

When endosulfan is aerially-sprayed, it can be volatilised from the crop, dispersed in the air and deposited in downwind water bodies. Raupach *et al.* (1996) studied this vapour transport pathway and found that water bodies 5cm deep within 1km of a sprayed cotton field will have an aqueous concentration of 0.2-1.0μg/l over the first few days after spraying has taken place. This level in itself is an exceedence of ANZECC guidelines.

Volatilisation increases with temperature and NRA (1998) recommend avoiding application when temperatures exceed 30°C, a common occurrence in the Dawson area, especially as the spraying season is during Spring/Summer. Studies in NSW and Queensland done mostly at temperatures less than 30°C have shown that more than 70% of the endosulfan applied to the cotton crop is lost by volatilisation within 7 days (NRA 1998).

14.3 Effects on Mortality of Aquatic Organisms

Endosulfan has often been implicated in fish kills in cotton-growing areas in Queensland and New South Wales where it is used as a pesticide. Its low persistence in water reduces the usefulness of water sampling in attributing endosulfan as the cause of fish kills, unless the water samples are taken very soon after the event occurs. Thus, much of the effort has involved sampling for residues in fish tissues. Endosulfan residues found in fish usually consist of endosulfan sulphate and the alpha isomer, indicating a shorter persistence of the beta isomer (Nowak and Julli 1991). Thus, higher proportions of beta isomers present in fish samples may indicate more recent exposure to endosulfan.

Napier *et al.* (1998) examined records for 98 fish kills in rivers in northern NSW and southern Queensland. Over half of the fish kills were attributed to pesticides, with a further third having unknown causes, some of which may also have been pesticide related. The study also found that during the cotton-growing season, fish kills were more common in cotton-growing areas than in non-cotton-growing areas, providing further evidence linking this industry with fish kills. The pesticide 'endosulfan' was implicated in 78% of the pesticide-related fish kills. Tailwaters, runoff and aerial drift were all common sources of pesticide contamination. Runoff was the most common source of pesticides in aquatic environments and 15% of fish kill events occurred after storms or flood events exceeded the capacity of water retention devices.

The actual level of endosulfan that results in mortality is variable between and even within fish species. Sunderam *et al.* (1992) used several methods to test the toxicity of endosulfan to the native eastern rainbowfish. They found that the 96hr LC50 varied from 0.5μg/l to 11.4μg/l. These results span most of the range reported for all fish species worldwide.

There have been very few studies on the effects of endosulfan on aquatic invertebrates. However, endosulfan is known to be toxic to benthic worms, estuarine crustacea and mayfly nymphs, as well as algae (NRA 1998). Aquatic monitoring suggests that macroinvertebrate community structure is altered downstream from cotton-growing areas, with reduced diversity and abundance of species known to be sensitive (NRA 1998). However, other impacts of agricultural development may also contribute to this result.

Endosulfan has a very high acute toxicity to aquatic invertebrates, particularly estuarine species such as prawns (NRA 1998). Endosulfan bound in sediments may be more relevant to aquatic invertebrates as they are predominantly benthic. Hyne *et al.* (1997) studied macroinvertebrates upstream and downstream of the cotton-growing region in the Namoi River in New South Wales. Populations of the five reference taxa were similar at all sites at the beginning of the investigation. However, within a few months, four of the taxa had shown a 1-2 order of magnitude difference in their populations between exposed and reference sites. Run-off from cotton farms after rain events was found to be the mechanism for entry of the pesticide into the river. In artificial pond studies using silver perch (*Bidyanus bidyanus* - which is common in the Dawson River), they found that endosulfan concentrations as low as 5.2μg/l resulted in 100% mortality of the fish within 24 hours. Within 96 hours of endosulfan application, the mortality rate was less than 5%, indicating a rapid dissipation of endosulfan.

14.4 Toxicity Effects on Other Organisms

Endosulfan is toxic to bees and earthworms in the laboratory, with field evidence of negative effects on the latter, including protracted suppression of populations, even at typical rates of application (NRA 1998). The longer persistence of endosulfan residues in soil over seasons means the effects will not be reduced before a new season of application begins. As it is designed to kill red-legged earth mites (NRA 1998), endosulfan has persistent negative impacts on soil arthropods and possibly soil microbes, though soil microbial processes do not appear to be affected (NRA 1998).

Endosulfan is found as residues in cattle (from stock feed) and is toxic to some birds though no field incidents have been studied. It has caused death in humans, but only from large short-term doses, not as a result of long-term, low level exposure. It is not carcinogenic to humans and does not accumulate in human tissue (NRA 1998).

Of particular concern is the effect of endosulfan on riparian insects and invertebrates. Endosulfan residues on foliage are toxic to predatory insects and mites over short time spans (NRA 1998). Though no detailed references could be found on this topic, the fact that endosulfan is an insecticide and toxic effects have been noted on many other organisms, suggest that there is likely to be some level of impact. Riparian insects are of vital importance for fish communities, providing a major source of food. In the Dawson River, it has already been discussed that much of the river length is inundated within weir pools where for severalmonths of the year, 70% of the water column and 95% of the riverbed may be unavailable due to anoxic conditions. Thus, the contribution of terrestrial riparian insects and invertebrates as food sources is probably even more critical in this system. The high level of volatilisation of endosulfan, particularly in warmer areas, also has implications for terrestrial vegetation remnants and conservation areas within or near the proposed irrigation areas. There would need to be substantial buffers between these zones and any farm that uses endosulfan.

14.5 Effect of Environmental Variables on Endosulfan Toxicity

The biological toxicity of endosulfan (and other chemicals used in cotton and other crop production systems) in natural water bodies is not well understood. The ameliorating effect of other environmental factors such as aquatic plants, turbidity, water temperature and pH are not well understood in field situations. Some authors have noticed that at sites with high abundances of aquatic plants, fish kills are less likely to occur. One reason for this may be the generally improved water quality created by aquatic plants, especially in relation to oxygen levels. More favourable water quality makes fish less susceptible to other impacts. A second benefit of aquatic plants may be that algae and aquatic macrophytes raise the pH of water when they photosynthesise, thus increasing the rate of endosulfan breakdown. As pH rises, the plants use more carbon dioxide, thus further reinforcing this cycle. Ironically, atrazine, a herbicide commonly used in irrigation areas to rid of aquatic plants, is known to restrict algal development and therefore photosynthetic rates. This will lower pH and increase the half-life of endosulfan. As atrazine is applied to irrigation channels to control plant growth, it readily occurs in the aquatic environment and its presence may increase the effects of endosulfan.

Using a U.S. database of 4,910 tests with 410 chemicals (mostly pesticides) on 66 species of aquatic animals, Mayer and Ellersieck (1986) attempted to summarise general effects of such chemicals on aquatic organisms. They found that toxicity increased with increasing length of exposure in only 11% of tests involving variable time exposure. These tests did not allow for accumulation through the food chain, though, as they only involved direct exposure. Although pH only altered the toxicity of 20% of chemicals tested, the changes when they did occur were larger than that for any other factor examined. Temperature affected the toxicity of 40% of the chemicals tested, with toxicity generally increasing with increasing temperature, though the reverse was occasionally noted. For most Australian fish species, endosulfan is more toxic at higher water temperatures (Chapman and Sunderam 1992 in Arthington 1995). Toxicity of organophosphate chemicals was particularly susceptible to increases in water temperature. It was concluded that generalisations could be made for the toxicity of chemicals ~80% of the time, but that field tests under the actual environmental conditions concerned are needed if more specific information is required.

Uptake of the endosulfan by different fish species is affected by lipid content, trophic level, reproductive season and the ability of fish to detoxify endosulfan products also varies between species (Nowak and Julli 1991). There is also variation between individual fish, especially in relation to lipid content.

Nowak and Julli (1991) investigated endosulfan levels in three fish species of different trophic levels. The fish species were catfish *Tandanus tandanus*, bony bream *Nematolosa erebi* and European carp *Cyprinus carpio*. Mean and seasonal endosulfan residues were similar in all three species, suggesting limited or no effect of food chains or trophic levels. This suggests that the fish do not obtain endosulfan from these pathways and that exposure in aquatic habitats is the mechanism for uptake.

14.6 Sub-Lethal Effects of Endosulfan

In addition to fish mortality, there are significant sub-lethal effects of endosulfan on fish. Nowak (1996) found that exposure to sub-lethal levels of endosulfan caused ultrastructural changes in the livers of catfish (*Tandanus tandanus*) and that endosulfan levels in wild-caught catfish in the Gwydir River, northern NSW were within the range known to cause these changes (Nowak 1990). Nowak (1992) found that endosulfan also significantly decreased respiratory diffusion of the gills of the same species.

Nowak (1991) found that in catfish (*Tandanus tandanus*), endosulfan was accumulated in the liver, kidney, brain, gills, muscles, skin, intestine and gonads, with the first three having the highest accumulation. The distribution of endosulfan residues between organs differed among individual fish, presumably due to variable lipid content, but the highest concentrations were always found in the liver which is the main site for endosulfan accumulation and detoxification.

14.7 Interaction of Endosulfan With Sediments

Field studies of endosulfan indicate that it is more persistent than laboratory studies have indicated in many instances (Peterson and Bately 1993). Sorption to sediment is the major pathway for disappearance of endosulfan in water bodies although the models of Raupach and Briggs (1996) found that for riverine particle concentrations of 0.05g/l, adsorption of endosulfan to sediment particles only had a minor influence on its riverine concentration. The affinity of endosulfan for sediment may reduce the impact of acute short-term events in water bodies, but also reduces its rate of decay and promotes the potential for gradual loading of the aquatic habitat, and may have greater impacts on benthic organisms such as invertebrates.

Despite the equivocal evidence regarding sediment interactions, it appears that in most streams, endosulfan will move into the bottom sediment which serves as a sink. Hyne *et al.* (1997) found that endosulfan was less toxic to aquatic taxa when in the sediment than in the water column. Sediment loads up to 51.8g/l were found to significantly reduce endosulfan toxicity to eastern rainbowfish (*Melanotaenia duboulayi*). There was no effect at sediment loads of 1.4g/l suggesting that a low level of sediment failed to ameliorate the effects of endosulfan. Above the 51.8g/l level of sediment, there were no further reductions in the ameliorating effects of the sediment on endosulfan toxicity.

14.8 Persistence and Transport of Endosulfan

Several studies have found that endosulfan does not persist in cultivated soil from season to season, thus indicating that it will not accumulate on farms. However, this is not always the case for other areas, especially in dry soils where endosulfan residues often remain between seasons. Residues found in wild fish outside of the cotton-growing season in northern NSW, probably resulted from release from bottom sediments during events such as floods (Nowak 1990, Nowak and Julli 1991). Thus endosulfan can be present year round and also impact upon fish populations outside of the cotton-growing season.

Although in waterways and the moist alkaline soils of irrigation areas, endosulfan mostly degrades over the course of a year, low levels are carried over from one year to the next. There is not usually season to season build-up of endosulfan, but the organisms in the soil and waterways do not have relief from exposure (NRA 1998). In dry soils, anaerobic soils and acidic pH soil and water, endosulfan breakdown is much slower, further exacerbating problems. Decay of endosulfan is also very slow in anoxic soils and therefore may also be slow in bottom sediments of the Dawson River, most of which are known to be anoxic.

The furthest recorded distance we could find for transport of endosulfan downstream from a cotton-growing area is 100km (Hyne *et al.* 1997). As endosulfan probably sorbs to very fine particles, it can be transported in the same manner as a soluble pesticide, due to the transportability of the very fine sediment. There have been no studies of endosulfan attenuation downstream, and very few of any other pesticide. However, the processes of degradation, uptake by sediments and interception by vegetation along with significant dilution suggest that concentrations will decrease downstream. Due to its preference for sorbing to fine particles, endosulfan concentrations in farm run-off are often higher than the concentration in the soils on the farm as the finer particles are more easily transported during overland flow (NRA 1998).

When volatilised, endosulfan is fairly mobile and can contaminate non-target areas. However, it is generally only dispersed at regional scales and residues found within the general environment can be expected to reflect regional usage of the chemical (NRA 1998). NRA (1998) reports data from the NSW Environment Protection Agency that 61% of rainwater tanks in the Namoi Valley had detectable levels of endosulfan at distance up to 3.6km from the nearest possible source. One tank at Narromine had detectable levels 11km from the nearest source. NRA (1998) reviews findings of global studies of lipids in bark samples (like many other pesticides, endosulfan has a high affinity for lipids). Endosulfan was one of the compounds found in the highest quantities throughout the world. Agricultural regions, including NSW, had higher levels than areas with lesser levels of agricultural development, such as Tasmania. This suggests that endosulfan is a regional rather than global pollutant. There are some noteworthy exceptions though. Endosulfan residues thought to have come from the tropics or sub-tropics have been detected in the Canadian arctic region.

Australia imports 900 tonnes of endosulfan annually, including 157 tonnes to Queensland and 400 tonnes to NSW (NRA 1998). If 70% of this is lost to volatilisation (NRA 1998), there are more than 630 tonnes released to the atmosphere each year in Australia, primarily in a few intensive cotton growing areas. We are unaware of any attempts to model the behaviour of this vapour so we have no idea of where it goes or what happens to it. It appears to mix efficiently with raindrops which may reconcentrate dispersed vapour.

Despite the considerable research on endosulfan, we still have no idea of its transport capacity, especially over longer distances. If it can be found in Canadian pack-ice, it could presumably be found in coastal areas and on the Great Barrier Reef. Intuitively, it seems likely that dilution factors would be high and that the probability of aerial transportation to the reef would be low. However, the quantities involved are large and the pathways of vapour transport unknown such that it would be wise to check the fate of volatilised endosulfan.

The NRA review concluded that buffer zones of 2-10km are required from watercourses to prevent chemicals from entering these systems through the pathways of aerial transport and/or volatilisation. The rate of volatilisation increases markedly with temperature, such that the problem is greater in central and northern Queensland than in New South Wales from where much of this data is derived. No pipeline or distribution schemes have been proposed by DNR and the IAS thus considers it unlikely that water would be taken more than 5km from the river. The 5km minimum required to prevent direct entry of pesticides into the river provides some conflict with the proximity of the proposed irrigation strip to the Dawson River. For crops that require aerial application of pesticides, the development of irrigation areas away from the riverine environment and other natural environments of importance is required.

Pesticides have been used along Queensland's east coast for many years, but there have been few studies of their intrusion into aquatic environments and dispersion downstream. Current studies are examining pesticide runoff from the Burdekin River Irrigation Area to environments up to 20km offshore. Russell *et al.* (1996) sampled pesticide residues in aquatic biota collected from the Johnstone (large agricultural impacts) and Daintree (less impacted) catchments in northern Queensland. The study included two sampling periods 1975-1978 and 1990-1993. They found that the number of insecticides detected declined from eight to two and the number of detections also declined from 68.9% to 27.6%, despite improvements in detection limits. There was less pesticide contamination in the Daintree catchment than the Johnstone catchment.

With short-lived pesticides now more common, there has been a change in emphasis from chronic effects to acute effects. These include higher mortality of larval and juvenile stages, behavioural changes, physiological effects, effects on prey sources, reduced growth rates and loss of vigour.

14.9 Higher Order Effects of Endosulfan on Ecological Systems

Little is known of the higher order effects that endosulfan or other pesticides in the water may have on aquatic ecosystems. Examples of such effects are known for other chemicals. For instance, in ponds treated with Dursban (an organophosphate pesticide not commonly used in cotton farming but still providing a relevant example) phytoplankton populations increased due to pesticide-induced mortality of crustacean zooplankton that grazed upon them (Hurlbert *et al.* 1972). Artificial stream research with chlorpyrifos (another organophosphate pesticide) has shown that pesticide-induced mortality of invertebrates alters ecosystem functioning through mechanisms such as build up of benthic periphyton due to grazer mortality and large reductions in the breakdown of organic detritus (Ward *et al.* 1995 in Arthington 1997a). Both alterations will have flow-on effects along the food chain as nearly all fish species utilise invertebrates as food sources during at least part of their life cycle.

14.10 Other Chemicals Used in Agriculture

The second most common agricultural chemical occurring in the riverine environment associated with irrigation areas is atrazine. Although not applied to most crops, this herbicide is often used to control weeds in irrigation channels. As expected it has strong effects on aquatic macrophytes, algae and also seagrasses. It is virtually impossible to prevent its escape into the aquatic environment. Atrazine is commonly found in cotton growing districts and impacts upon native aquatic plant communities with additional effects through the food chain. The interesting possible synergy between atrazine and endosulfan, where the presence of atrazine reduces the decay of endosulfan, is discussed in section 14.5.

This review has concentrated on endosulfan as it poses the greatest risk to aquatic ecosystems in cotton growing districts. However, there are 60 chemical pesticides available in 180 commercial formulations used in the Australian cotton industry (Schofield *et al.* 1998). Most cotton growers use 10-14 of these. Bowmer *et al.* (1996) presents summary information on the toxicity of many of these compounds to aquatic organisms. Pesticide usage in Australia has increased fivefold over the last 30 years (Schofield *et al.* 1998). About 50% of the cotton industry's substantial research and development budget is devoted to IPM and achieving reductions in pesticide requirements.

14.11 Cotton Pesticides in the Fitzroy Catchment

Cotton is not a widespread crop in the Fitzroy catchment, being grown in a small area in the Dawson Valley near Theodore and in a larger area within the Emerald Irrigation Area of the Nogoa River sub-catchment. These locations however, form a significant part of the Australian cotton crop. The two most common chemicals found in aquatic environments adjacent to these cotton-growing areas are endosulfan and atrazine.

Noble *et al.* (1997) found endosulfan and atrazine within the Fitzroy River catchment, including the Dawson River sub-catchment, exceeded the 1992 ANZECC guidelines for ecosystem protection, and often the 1996 NHMRC Australian drinking water guidelines. Atrazine was also detected at most sites in that study and on several occasions exceeded Australian drinking water guidelines.

Simpson *et al.* (1996) studied a cotton farm in the Emerald Irrigation Area and found that within the top 5cm of soil, endosulfan residues did not accumulate during the spraying season, and there was no build-up from season to season. The Emerald Irrigation Area has alkaline soils that allow rapid breakdown of endosulfan. The high levels of volatilisation in the area (due to high temperatures and dry weather) would also reduce soil concentrations though not necessarily ameliorating environmental problems as the fate of the volatilised endosulfan is not known. Endosulfan concentration in tailwater drains is typically 8-15µg/l during the peak of spraying season, with higher concentrations expected during storm events (Simpson 1994 in NRA 1998).

Endosulfan concentrations in Queensland cotton growing areas are similar to those in New South Wales (NRA 1998). DNR (1998b) studied the Emerald Irrigation Area from 1993-1995 and found that endosulfan levels in the receiving waters of the Nogoa River at the Duckponds site, exceeded ANZECC guidelines of endosulfan in 3 of the 6 sampling's. Endosulfan concentrations in the Dawson River (from Theodore cotton area) and in the Nogoa River (from Emerald cotton area) are generally one or two orders of magnitude above the ANZECC guideline. The occurrence of similar problems cannot be dismissed for the proposed new irrigation area.

14.12 Conclusions on the Potential Impacts of Endosulfan

Although becoming less so with new advances in farming practices, cotton growing is still dependent upon endosulfan and this situation will remain into the foreseeable future. There is clear evidence that the levels of cotton pesticides in the waterways of the Fitzroy catchment, including the Dawson River, are already significant even though cotton farming is not yet extensive. Future expansion of cotton needs to be contingent on demonstrated improvements in farm management. There is evidence that improved farm management practices in other Australian cotton-growing areas is decreasing contamination levels in riverine environments, but the performance to date is still not considered adequate by NRA and other environmental authorities.

Runoff and spray drift are usually the principal sources of riverine contamination. On-farm retention of irrigation tailwater can prevent chronic releases of contaminated runoff but containment of all stormwater runoff is unlikely to be feasible, so periodic releases to the riverine environment seem inevitable. Modelling suggests that unacceptable levels of contamination will occur up to 1km and often even 5km downwind from the target even when wind speeds are quite low (Raupach *et al.* 1996). Normally only a small portion of an irrigation area lies within this distance of a major watercourse so spray drift is normally considered to be a secondary, though still significant, concern. As presented in the IAS, the proposal for the

Dawson River assumes that all irrigation downstream of the dam will take place within 5km of the main river channel. This would greatly enhance the hazards of spray drift and create a particularly difficult situation to manage. The location of the irrigation area, as it is currently proposed, will almost certainly exacerbate water quality problems in the Dawson River.

Despite substantial investigation, the fate of endosulfan in receiving waters and the factors which influence its toxicity are not well understood. In particular the evidence regarding the role of sediments in partitioning, transportation and toxicology is often contradictory. These issues need to be resolved in order for accurate predictions on effects to be made. Most researchers generally accept that endosulfan sorbs strongly to fine sediment particles. It would thus be expected to enter the anoxic bottom sediments in the Dawson River weir impoundments. There is evidence that endosulfan degrades very slowly in saturated anoxic soils and it is possible that there would be a net long-term accumulation within the weir pools of the Dawson River should the current proposal proceed. The probability of this contaminated sediment being carried downstream will be dependent on sediment transport patterns which are unclear within the regulated Dawson system. Detectable levels of endosulfan have never been reported more than 100km downstream of cotton-growing areas. However, this topic has also rarely been studied and the rivers where it has been examined may behave differently to the Dawson. Transportation of endosulfan to downstream environments of the Fitzroy River is likely to be minor, but there is no certainty. During large flood events, endosulfan could be readily transported to the marine environment in just a few days, well within its half-life. In low pH rainwater, its half-life is extended, thus further promoting the potential for it to be transported a greater distance before breaking down. However, during such events, dilution factors will be very high. When endosulfan comes into contact with seawater (which has a pH of 8.3), it will rapidly decay, probably in a mater of hours, unless taken up by organisms. On balance, it appears that endosulfan could readily reach the waters of the Great Barrier Reef World Heritage Area, but extensive dilution suggests that any impacts are unlikely to be significant.

Bowmer *et al.* (1996) has reviewed the status of endosulfan research and found a long list of equivocal findings regarding its mobility and environmental fate. Several priorities for further research to address these uncertainties were identified. Currently it is impossible to predict the long-term effects of endosulfan use. The task of predicting effects in the Dawson River is further complicated by the paucity of key physical, chemical and limnological data for the weir pools. These will ultimately determine the mobility and toxicity of endosulfan. Although the risk to the marine environment is small, until all of these deficiencies and the proximity of the irrigation development to the Dawson River, have been addressed, it would be conservative to assume that the risk of significant environmental harm to the riverine environment is substantial.

15.0 ENVIRONMENTAL FLOWS

The provision of environmental flows is a crucial factor in the decision on whether the impacts of the proposed dam will be acceptable. The Water Allocation and Management Planning (WAMP) process was not completed in time for the IAS (nor this report), thus not allowing for an appropriate evaluation to be made in either document.

The average annual discharge from the Dawson River is 1,127,000ML, which is 19% of the mean annual flow of 5,574,000ML from the Fitzroy catchment as a whole. However, variability is high and the minimum and maximum annual flows for the Dawson River are 110,000 and 6,645,000ML. Gauging station records for the Dawson River are available from 1910 and demonstrate the highly variable flows, but generally with 50% of the flows occurring from January to March, with the lowest months being September and October. The Dawson River may cease flowing in the dry months (May to November). Seven major floods have been recorded in the Dawson River from 1954-1997, including 1954, 1955, 1956, two in February 1971 and two in May 1983 (Hyder Environmental 1997).

The IAS (p. 187) lists the hydrological impacts of the proposed dam as being:
- impacts on flow behaviour, including flooding
- impacts on other storages on the Dawson River
- impacts on groundwater recharge
- impacts on sediment transport and deposition
- impacts on water quality
- impacts on environmental sensitive features
- impacts on environmental and riparian flows

The impact of several of these will be greatly affected by the provision of appropriate environmental flows. This proposal will likely result in longer periods of low flow, reduced variability of flows, reduced frequency of small to medium-sized flows, increased discharge of dry season water to meet irrigation demands, poor quality water released from impoundments and also poor quality water from tailwaters and farm runoff.

The IAS concluded that additional information was required on environmental flow provisions to ensure the project proceeded in an ecologically sustainable manner, but that this did not constitute grounds for delaying the decision on the dam. Without such information, an informed, responsible decision cannot be made. Evidence that the proposed dam has the ability to provide the appropriate level and pattern of environmental flows to maintain the important aquatic features along the river is one of the most crucial aspects of the proposal. Failure to provide for these flows will have serious environmental consequences that should be addressed before any decision is taken.

15.1 Impact of the Dam on Natural Flow Regime

Generally, the dam will decrease the occurrence of high flows and increase the occurrence of low flows and alter the pattern of water delivery. The impact of an altered water regime may be more significant than the change in mean volumes. The existing water storages and water uses in the Dawson River have reduced water flow at the Woodleigh, Beckers and Boolburra gauging stations by 9.8%, 10.7% and 11.4% respectively (Hyder Environmental 1997). The existing storages have little impact on high flows but do influence downstream flow behaviour of low flows, and can even cause cessation of flow in dry seasons. Regular water releases from Nathan Dam will reduce inflow variability to the weirs, thus increasing the likelihood of flow being sustained year round. Including the proposed dam, natural flows will be reduced at the three gauging stations by 25.3%-33.4%, 25.4%-35.2% and 23.5%-32.8% respectively, depending on the level of the dam capacity (Markar 1997).

The dam will also impact significantly on small-moderate floods (50-100ML/day flows) but will have little impact on large floods (>200,000ML/day) (Hyder Environmental 1997). The number of days in which flows in the Dawson River are expected to exceed a variety of flow levels under several dam storage options is shown in Markar (1997, p.52) and the IAS (p. 195). The maximum impact is on flows greater than 50,000ML/day at the Woodleigh gauging station which will be reduced by up to 47% compared to natural flow rates. The impacts of such large changes in water delivery have not been adequately assessed at this stage.

15.2 Habitats Requiring Environmental Flows

An inventory of environmentally sensitive areas along the Dawson River or the Fitzroy River is not available, but the IAS listed generalised aquatic features along the Dawson River downstream to its junction with the Mackenzie River and estimates of the flows they require. The information was supplied by DNR and is presumably being used as part of the WAMP process. Apart from a few specific habitats, it is a list of non-specific habitat features that could be for a number of rivers. There is very little specific information relating to the known habitats of the Dawson or Fitzroy rivers. All of the specific habitats of high value or high sensitivity should be identified and their flow requirements determined. The National Principles for the Provision of Water for Ecosystems (ARMCANZ/ANZECC 1996) require that the ecological values be identified as a prerequisite to sustainable management and determination of environmental water requirements. Most of the wetlands listed require 30,000-70,000ML/day to connect with the river. However, frequency of flows >50,000ML/day were found to be reduced up to 47% over natural flows. The impacts of the dam on the wetlands was considered beyond the scope of the study (Hyder Environmental 1997), but obviously requires further examination.

The downstream habitats have different waterflow requirements. Some require large pulses, some more regular flows. Developing a flow strategy that meets the requirements of the different habitats present will require more analysis than has been presented in the IAS. The IAS has allowed for up to 50% of yield from the dam as environmental flows but provides no evidence of timing requirements, operational abilities to meet the requirements or that this will be a sufficient level of allocation. Environmental flows have been defined in terms of volumes required, but the ability to simulate natural flows has not been demonstrated or convincingly argued. In addition, the potential conflict of the highest irrigation demand beginning during the period of the lowest natural flows (late in the dry season) has not been addressed. This situation is likely to result in high and continuous base flows at a time when natural base flows are very low or may have ceased. The supplementary report of the IAS concedes (p.28) that periods of high demand may compromise the environmental flow provisions.

Anderson and Howland (1998) had planned to test several hypotheses regarding the water flows required to break down stratification in the weir pools of the Dawson River. Although the logistics did not allow for this to occur, they suggested that 25-50ML/day would be required to breakdown the thermal stratification observed in the Dawson River during their investigation. Although this is at least partly related to experiences in the Wimmera River in Victoria, it would seem a reasonable starting estimate.

In the environmental flow allocations, there is no consideration of the effects of large releases (eg: trigger events) in causing fish kills. This issue was discussed by Anderson and Howland (1998) with regard to first-flush events causing fish kills. This is a consequence of the weir walls providing a fish barrier, not for fish migrating upstream, but for fish trying to move downstream to escape poor quality that is entering the weir pool. The IAS discusses oxygen levels, fish and fish barriers at length, but endosulfan and other agricultural toxicants will add to the problem. Endosulfan could accumulate in the weirs after the first flush and storm events that exceed the on-farm detention capacity. For example, a first-flush storm event early in the wet season may bring a large contaminant load, including agricultural chemicals and poor oxygen conditions. The weir pools at this time will be highly stratified and behave like a shallow (~1.5m) lake with a greatly reduced dilution capacity due to their stratification. The incoming lethal water can trap fish against the weir wall with no available means of avoidance.

Anderson and Howland (1998) also point out that depending on the morphometry of the weir pools, lowering the water level of the weirs will reduce the proportion of anoxic water and increase the availability of shallow habitats. They also suggest that flows to support riffles and runs and promote aeration could be provided by changing the management of irrigation releases. These ideas have some merit, but it is not known if they are feasible or are compatible with operational irrigation requirements.

The suggestion in the IAS that environmental flow releases could contribute to mitigation of the effects of river regulation and thus be of benefit to the Dawson River system have merit but the idea has not been tested and remains unproven. This is in contrast to the proven downstream impacts of increasing river regulation. The IAS does not address environmental flows further downstream of the Dawson/Mackenzie confluence, yet somehow concludes that they will be sufficient to meet downstream needs. This is despite the admission (p.263) that "The ultimate pattern of use of this water is unknown so it is very difficult to understand the impact particularly in terms of the downstream delivery. It is also likely that the water use pattern will change in time".

15.3 Water Allocation Management Planning (WAMP)

The WAMP is central to the environmental flow issue. With the WAMP process now almost complete for the Fitzroy catchment, there is a major expectation that this document would be consulted extensively in relation to water resource developments. Although preliminary data WAMP modelling data was supplied for the IAS, the non-availability of the full WAMP outcomes resulted in many important aspects of environmental flows not being assessed in the IAS. While decisions can only be made on the basis of information that is to hand, expediency should not be allowed to intrude into the inclusion of the WAMP in the decision-making process.

The WAMP technical reports do not consider in detail, the use of environmental flows to maintain water quality even though this is a critical issue, particularly for the Dawson River. The IAS provides valuable information on the relationship between flow requirements and dissolved oxygen levels, but neither document provides information on the requirements for specific key sites. Additional benefit would be obtained by assessing the individual needs of specific critical sites.

The environmental flows required to maintain suitable dissolved oxygen levels and to control algal blooms has to be determined. The WAMP technical reports consider various flow supply scenarios including releases during the summer season, short, intense releases as trigger events etc. However, the data of Anderson and Howland (1998) indicate that the maintenance of dissolved oxygen levels are the main determinant on habitat values of the weir impoundments and thus of most of the Dawson River. Their data further indicates that flow stoppages of just a few days duration may be sufficient to revert to stratified and anoxic conditions. Thus, flows will be required constantly to prevent this from occurring. The provision of constant flows is not considered in the WAMP technical reports and is contrary to natural conditions of low baseflow during the dry season, which may be the reason for its exclusion. The need to provide constant flows to prevent stratification from occurring during the dry season may conflict with the aim of replicating natural flow patterns.

The existing condition of the Dawson River is a central issue in the consideration of environmental flows. A large section of the Dawson River is so highly regulated that natural conditions or behaviour may not be able to be recovered. Attempts to introduce natural conditions into the regulated sections of the Dawson River may be wasteful and even potentially harmful. From the WAMP technical reports (DNR 1998a) that have been released so far, it is clear that all the sub-catchments are being treated equally. There is no attempt to differentiate the different characteristics of each sub-catchment, even though these are as large as most entire catchments. There is also no attempt to take into account the already highly-modified conditions of the regulated sections of the Dawson River.

DNR (1998a - Technical Report No. 7) presented an analysis of the estimated impacts of flow regimes for various ecological aspects of the Fitzroy basin. The analyses were performed for seven locations in the basin with the two relevant locations for this report being the Dawson River at the Neville Hewitt Weir and the lower Fitzroy River. Eight different flow scenarios were assessed. These related to: no regulation (Model 1A); existing water entitlements, with and without environmental flows (Model 20A and 20D respectively); triple existing levels of water harvesting (Model 21A); existing water entitlements plus proposed developments in the Dawson (Nathan Dam) and Comet (Starlee Dam) rivers, with and without environmental flows (Model 30A and 30D respectively); Model 30A plus additional water harvesting throughout the basin (Model 40A) and Model 30A with possible extra development in the Isaac, Mackenzie, Dawson and Fitzroy rivers (Model 40B).

requirements should then underpin the allocation of environmental flows from the proposed dam. Anderson and Howland (1998) recommend that this could be achieved by continuous monitoring at different flow rates and times of the year. This may prove to be a successful approach. Another approach would be to measure reach-averaged oxygen consumption rates (nominally respiration rates) and photosynthetic oxygen production rates at key sites and at different times of the year. Models can then be used to determine the current velocities necessary to achieve acceptable aeration coefficients. It would then just remain to determine the flow rate required to generate the target current velocities in each reach. Obtaining accurate simulation models capable of achieving this objective would require considerable effort, but first-order estimates of the flow rates necessary should be obtained quite easily. Monitoring efforts can then be focused on these flow regimes and the sites where flow requirements are the highest or of most importance.

15.5 Potential Benefits of the Proposal in Providing Environmental Flows

This report has discussed many negative impacts of the proposal on the environment. As mentioned in the IAS and DNR (1998a - Technical Report No. 4), a potential benefit of the proposal would be to provide sufficient environmental flows to permanently break down the stratification and resultant water quality/habitat value problems currently being experienced in the weir pools, whilst still allowing for habitat maintenance in other habitats, such as those requiring trigger processes and flood flows. It is only because much of the Dawson River below the proposed dam site is so heavily regulated that there may be some benefit from the dam in providing environmental flows. This is because the availability of excess water offers the potential to better manage the quality of the downstream weir impoundments. However, it has not been proven that the environmental flows required can be provided or that they can achieve an improvement in the aquatic values of the Dawson River of sufficient magnitude to overcome the potential negative effects that are likely to be caused by other aspects of the proposal.

16.0 CONCLUSIONS

There are numerous environmental issues to be considered in the development of large dams and irrigation areas. This document has been particularly critical of the large number and range of issues that have been omitted or neglected from consideration in the dam proposal and IAS. The IAS focuses mostly on the area of the impoundment and lands nearby, with minor discussions of the impacts of the irrigation area and virtually no consideration of downstream impacts below the Dawson/Mackenzie River junction. For all such developments, the issues of irrigation development and the downstream impacts warrant as much attention as does the impoundment area and surrounds.

This report has concluded that the proposal will result in significant impacts to instream riverine environments and floodplain and estuarine habitats and lead to potentially increased nutrient loadings to the Great Barrier Reef during flood events. The major instream impacts will be instream erosion, loss of critical habitats and reduced diversity of habitat due to the conversion of valuable riffle and run habitats into weir pools. The existing weir pools have been shown to have very poor water quality, and 70% of the water column and 95% of the benthos are anoxic and unavailable to contribute to instream productivity. Estuarine habitats are likely to be impacted by reduced freshwater flows which may reduce habitat availability and productivity. In addition, lowered nutrient levels reaching the estuarine area during the low baseflow periods may also have an impact on productivity, especially in relation to fisheries production which has been shown to be positively correlated to river flow. Crude modelling has shown that a net increase in sediment export from the irrigation area is unlikely to occur as any increases will most likely be offset by the sediment retention properties of the dam. However, considerable doubt is cast on the ability of the project to achieve no net increase in nitrogen loadings to the reef.

Under the existing proposal whereby irrigation development is proposed within 5km of the Dawson River, export of contaminants to the riverine environment cannot be prevented, particularly if crops which require aerial application of chemicals such as endosulfan are to be grown. Experience in other cotton-growing areas, including in the Fitzroy catchment, suggests that heavily utilised pesticides such as endosulfan, cannot be prevented from entering the riverine environment and causing significant impacts such as fish kills. We recommend that the proposal be amended to include water distribution works and the establishment of an irrigation area remote from the river.

The Dawson River system below the dam site has already been heavily degraded by extensive river regulation. A new dam with sufficient reserves to provide environmental flows to improve water quality and enhance aquatic habitat values downstream could potentially ameliorate many existing problems, and with careful management, achieve a net improvement in environmental conditions for the regulated reaches of the Dawson River. However, it has not been demonstrated that this potential could ever be realised in practice.

Even if the environmental flows needed to improve the existing conditions of the regulated Dawson River were provided, these benefits would have to be weighed against the potential for other impacts, especially on downstream environments. Modelling undertaken as part of the

WAMP process thus far suggests that the impacts of reduced frequency of floodplain inundation and reduced river flow to the estuary, cannot be alleviated by the provision of environmental flows and that for several key parameters, the construction of the Nathan Dam will result is flow reductions of a level known to have caused significant environmental impacts in other systems.

There are insufficient data available to properly assess most of the potential environmental impacts of the proposal and we believe that the information presented in the IAS does not justify the conclusions made there. Even with the anticipated outcomes of the WAMP, there are many other major issues that have to addressed before any decision can be made regarding whether to proceed with the dam.

17.0 MANAGEMENT REGIME TO MITIGATE DOWNSTREAM ENVIRONMENTAL EFFECTS OF THE PROJECT

The principal adverse effects on the downstream environment predicted by this assessment are associated with altered river flows and pollutant runoff from irrigated cropping. Both these impacts may be minimised by an effective environmental management regime for activities associated with the project. Recommendations for the environmental management plan are outlined below.

17.1 Water Flows

A Water Allocation and Management Plan must be implemented which preserves satisfactory environmental flows for the Fitzroy system. The plan should also take into account the individual flow requirements for the Dawson River. In particular the use of environmental flows to maintain habitat quality in the Dawson through maintenance of oxygenation is a key issue. Trigger flows to meet the environment stimulus for brining on spawning of important fish species are also desirable.

In addition to environmental water flows the Dawson irrigation system should be designed to maintain and enhance connectivity for fish passage. This should include provisions to improve fish passage on existing weirs on the Dawson River and any new weirs built as a part of the development.

17.2 Pollutant Discharge

For all irrigated cropping systems utilising water from the project implementation of the Codes of Best Practice for each crop should be mandatory. Monitoring and auditing of compliance with the Codes should also be implemented by the regulatory agency (EPA). Cotton, sugar and horticulture have existing Codes. Codes for grain crops and other broad-acre crops are required. For cotton, as the indicative crop for the project, the following components of the Code of Best Practice are relevant to reducing pollutant discharge:

1) Pesticide Management:
   Promotion and adherence to integrated pest management techniques.
   Selection of appropriate pesticide application techniques to minimise off-target movement.
   Use of vegetative buffer strips (at least 30m wide) adjacent to watercourses and wetlands.
   Vegetative strips planted to attain a minimum height of 1.5 times the height of the spray release.
2) Erosion control:
   Limit furrow length and slope to allow uniform water application and flows at non-erosive velocities.
   Utilise and maintain sediment traps.
3) Minimising storm impacts:
   Retain at least the first 10-15mm of run-off water from fields.
   Recirculate all tail water.
   Direct all stormwater overflow structures and blow out points away from watercourses

and wetlands.

4) Irrigation efficiency:
   Adapt farm plans to maximise water use efficiency.
5) Fertiliser use efficiency.
   Utilise management techniques to correlate fertiliser application to the nutrient requirements of the crop.

Mandatory water quality industry performance standards for wastewater discharge to the river system from irrigated cropping should be introduced under Queensland Environmental Protection Act. The standards should cover dissolved oxygen (DO), nitrogen, phosphorus, suspended solids and relevant pesticides. Standards should be developed in association with the cropping industries so they are achievable but still achieve satisfactory environmental outcomes. A monitoring and auditing program is essential to assess compliance. A program to establish satisfactory buffer zones along the river system with a riparian revegetation component should be implemented. A riparian vegetation buffer will reduce spray drift to the river, stabilise river banks and trap a component of surface and sub-surface flows of sediment and nutrients.

It is critical that the Impact Assessment process for dam proposals includes consideration of the full impacts of the altered flow regime and any irrigation developments or other water uses (eg, mining, urban) on downstream environments.

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