Planning and Assessment Commission – Watermark Project Evaluation

Submission by Gerard McDonald, B Bus(Mgnt), MBA, MAICD *26 June 2014*

1. Introduction

This submission goes to the social and economic issues and benefits of the project. The submission is a supplement to the verbal presentation provided by Gerard McDonald to cover what could not be covered in 5 minutes and to provide data and substance to support specific statements made in that talk.

Three points are made:-

a) The assessment requires a balanced overview to counter narrow sectional interests;
b) The project is balanced and thus it is now primarily a matter for local residents and local interests to have their say not external vested interests; and
c) Many people miss what is really the key social issue for the region, State and for that matter the world. It is the issue with the greatest impact on social and economic stability.

2. Declaration of Interest

After 8.5 years of having to commute out of town for work, last year I finally obtained a position in Gunnedah when Shenhua created a job that fitted my experience and qualifications. My family is very pleased. My employer did not ask me to speak and nor has there been any incentive to do so.

I decided to speak because, while I was delivering Meals on Wheels recently, I discovered that the false, alarmist information being spread by some project opponents was having an adverse impact upon the wellbeing, health and happiness of some of our most vulnerable citizens. It incensed me and caused me to resolve that I would speak. One might say that unreasonableness has awoken the dragon.

3. Right to Speak

First and foremost, Gerard McDonald and his family are local residents of Gunnedah who chose to move to and live in Gunnedah 10 years ago, probably for the rest of their lives. The McDonalds have been married 43 years, made three children and adopted three more. The adopted children are alternately abled with a mix of intellectual and physical disadvantage and a mix or race backgrounds. The family is involved in community activities including the GS Kidd School for Special Purposes P&C and Meals on Wheels. The family has much 'skin in the game' here in the Gunnedah community.

Gerard has a Degree majoring if Behavioural Science and Human Resources and a Master of Business Administration majoring in Strategy and Finance. He has also completed a European Leadership Study Program with Macquarie University and an Ethics and Anti-corruption Program jointly run by ICAC and the Australian National University. He is a Member of the Australian Institute of Company Directors.

Gerard has been an environmentalist, conserver and bushwalker since a very young age and as with most of the farmers around the district, that is long before it became a fashion or political statement.

He spent several years volunteering as a Chair of a Catchment Management Committee and has worked in a variety of industries for over 40 years including manufacturing, the power industry, soft and hard rock mining, local government and state government in water resource management.

4. We need a Balanced Perspective

(i) It is very understandable that people get suspicious and create conspiracy theories. The Catchment Management Committee (CMC) Gerard chaired was abolished by a Carr Government Minister who did not like the balanced development propositions the CMC were putting to him. Not long after that the private housing development went ahead and appeared not to have the balance mechanisms the CMC was seeking. However that does not mean that all the conspiracies people develop are in fact true.

(ii) It is very understandable that people close to the project area will have some concerns and uncertainties about the project and its impact on health and amenity. In particular the possibility of noise and dust. However:-

a. One could look at the amount of dust and noise created by broad acre farming;
b. One could suggest that Breeza residents at the northern end of the village will get more noise from the highway than from the mine; and
c. The McDonald residence gets considerably more dust and noise from the young trail bike riders who use the Council's vacant lot over the road every weekend, public holiday and summer evening but that activity provides a social good because it is far better than having those youth bored down town.
d. The difference between my situation and theirs is that they can access Shenhua provided mitigation if they do get an impact including double glazing, air-conditioning or dust filtration on their tanks.

(iii) It is very understandable that people might be upset and angry when they missed out on having their properties purchased at significantly higher prices than market price.

A balanced perspective is essential.

Agriculture is our most precious industry and must be both supported and further developed. It is one of the key industries in New South Wales and is extremely important to this region. However let us not get carried away in assuming that agriculture holds the high ground. I have already mentioned the potential for agriculture to produce noise and dust, but there are other balancing factors.

a) One might examine the many degraded aspects of the Mooki and Namoi Rivers in the 1999 Environmental Scan of the Namoi River Valley prepared for the Department of Land and Water Conservation (Appendix 1);
b) The 1997 paper by Leonard et al "Effects of Endosulfan Runoff from Cotton Fields on Macroinvertebrates in the Namoi River (Appendix 2)
c) One can find a multitude of studies around the world that point to the adverse health outcomes resulting from agricultural chemicals including a 2007 study by the California Department of Public Health found that women in the first eight weeks of pregnancy who live near farm fields sprayed with the organochlorine pesticides dicofol and endosulfan are several times more likely to give birth to children with autism, a Childhood Cancer Cluster in California's Central Valley. There was also one recent study found what it calls "high" levels of glyphosate in 30% of the samples it analysed: between 76-166 microgrammes per litre (μg/L) in breast milk. This is 760-1,600 times higher than the current maximum level allowable under the European Drinking Water Directive. And finally what of the cancer cluster in Emerald, Queensland before mining was anywhere near the town where aerial

spraying drift was the indicator. These documents have not been included because it is not directly related to this project.

d) One might discuss with Breeza Plans Graziers, the (indicated 7 metre) drop in Gunnedah aquifer bore levels following the introduction of large scale irrigated pastures.

e) One might ask where the ecosystems and heritage clearances are in the broad acre farming industry or what impact the 'Water Trigger' may have on farm developments.

Agriculture is very quick to withdraw expenditures from local business in times of drought and poor commodity prices. This is why the town must have diversity of industry. The Brickworks, Sawmill, Leather Processing and mining are all essential to keep the town viable and socially stable.

Agriculture, particularly cotton, has significantly improved its practices over recent years and so too has the mining industry. The point is not to denigrate agriculture but to simply point out that all our industries require and evaluation on balance of environment, costs and benefits without distortion.

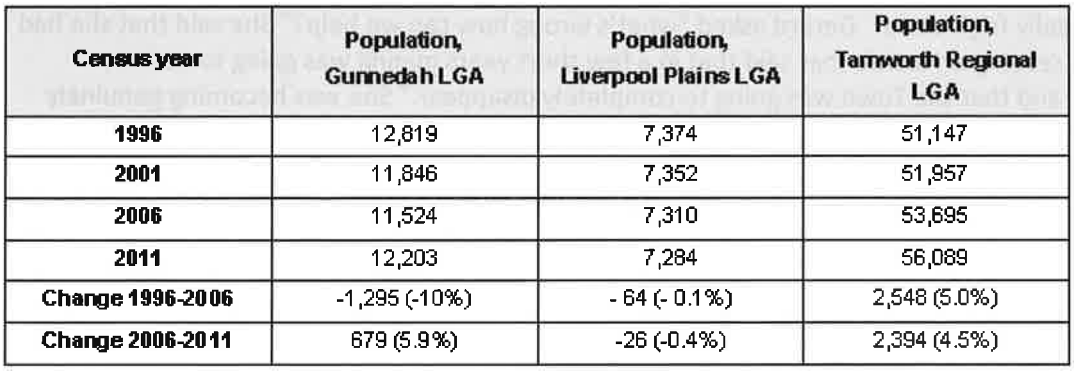
5. The Right of the majority of Local Residents to Decide

From Gerard's Catchment Management experience he has some ability to make a personal judgement about the balance of a project and having looked at all of the material in the public arena he is of the view that this is very much a balanced project. The critical agricultural aspects of land and water are protected, environmental balance is well achieved, the project is economically positive and the social benefits are substantially positive.

That means that the rest of this decision is a matter for local input, not to be decided by a noisy crowd bussed in by outside vested interests.

10 years ago Gunnedah was in a sorry state; the meatworks had closed, other employers had left town, the farmers and graziers had no money to spend after droughts and commodity price difficulties. The main street was dismal. Even more importantly, 2 bus loads of our kids were walking off farms and out of the villages and heading away for job opportunities. 10% of the population had left the shire.

Table 14
Population - Gunnedah, Liverpool Plains and Tamworth Regional LGAs, 1996 to 2011



Census year	Population, Gunnedah LGA	Population, Liverpool Plains LGA	Population, Tamworth Regional LGA
1996	12,819	7,374	51,147
2001	11,846	7,352	51,957
2006	11,524	7,310	53,695
2011	12,203	7,284	56,089
Change 1996-2006	-1,295 (-10%)	- 64 (- 0.1%)	2,548 (5.0%)
Change 2006-2011	679 (5.9%)	-26 (-0.4%)	2,394 (4.5%)

Source : ABS, 2007d and ABS, 2012c
Note : Population based on place of enumeration

That situation has begun to turn around with a 6 % increase over recent years.
The only reason, the one and only reason the town has recovered is that Whitehaven created jobs. We are now probably only losing one bus load of our children now.

Gerard McDonald's first 3 years in Gunnedah he had to make his own job travelling and working around the whole of the New England and North West doing water conservation, specialised coatings and safety flooring work. When he did jobs on rural properties he took his swag to sleep in rest areas because if he used motels there would not be enough money left to pay for food at home.

The next 5 and a half years he commuted; first to Cobar, then Newcastle and later Narrabri. Last year he finally obtained a job in town here because Shenhua created an opportunity. The people of this community deserve the same opportunity Gerard had.

Our Community is entitled to choose these job opportunities when there is a balanced development.

The people who protested today will get on their busses and in their cars to go back to Sydney and the coast. At home they will sit on their lounges made at least 50% of petrochemical products, buy drinks and milk in PET bottles converted from coal, turn on their lights, heaters or air conditioners, turn on their televisions, lap top computer and mobile phones at night when the sun does not shine or on days when the wind does not blow and they will not want to discuss where that power comes from.

They may want to live in some idealistic dream but by failing to analyse the full story they place themselves at the highest risk of being manipulated into doing the bidding of people with their own vested interest, financial or political. For example many of them may still think that E10 fuel is good for the environment.

In regard to E10 let's say you ask why oil companies will not publish fuel consumption figures and why the exhaust out of a car run on E10 smells like raw ethanol. The answer comes from doing the research. Gerard has done this on 3 different sized cars used for 3 different purposes. Each comes up with the same answer. You pay 7% less for the fuel but you use 10% more fuel, because E10 burns less efficiently, leaving oil companies with an additional 3% margin on their sales. The same amount of petroleum is used and the additional 10% is wasted meaning that the land used to produce the ethanol biomass is entirely wasted and food production on that land is compromised. That is what is meant by a full analysis of the story.

Don't make the mistake of thinking those vested interests are just a nuisance. They are dangerous.

A fortnight ago, when delivering meals on wheels, a woman, probably in her eighties, said she was having a terrible day when asked her how her day was going. In response to the question of why, she said "I'm really frightened". Gerard asked "what's wrong how can we help?" She said that she had "just been reading an article that said that in a few short years mining was going to destroy Gunnedah and that the Town was going to completely disappear." She was becoming genuinely frightened about what was going to happen to her, where would she go?

The truth is that Gunnedah has lived in peace and benefited from mining for the past 130 years. The fabrications put out by these people are total rubbish. Gunnedah is not going to disappear. It will prosper and grow because of coal mining. Coal mining will help this community to live by the axiom that 'the quality of a society will be best judged by how well it treats its most vulnerable members'.

These people are not only dangerous to the economy they use dangerous tools of fabrications, half-truths and distortions to try to manipulate and scare. The result can be to terrify our mothers and grandparents in their homes and the most vulnerable in the community are the most likely victims

We find this totally unacceptable. We will not go quietly into the night.

6. The most critical issue for this and all societies.

There are 7.2 Billion people in the world; of these 3 billion are of working age wanting meaningful jobs to support their families. The problem is that there are only 1.2 Billion proper jobs. That leaves 1.8 Billion would-be bread winners for families who are destitute, starving, scrounging on rubbish dumps or are turning to unsociable behaviour, joining militias to get a feed or turning to piracy or taking the most desperate step of all to blow up themselves and other innocent people in the promise by terrorists that their family will be looked after.

This research comes out of the book, *The Coming Jobs War*, Gallup Chairman Jim Clifton asserts that job creation is the world's most pressing issue, outpacing runaway government spending, environmental degradation, and even the threat of global terrorism.

These assertions are based on very extensive research and surveys in 160 countries where the Gallup World Poll, is designed to give the world's 7 billion citizens a voice in virtually all key global issues. The Gallup World Poll provides a scientific window into the thoughts and behaviours of 98% of the world's residents through nationally representative samples. Those people all want, as a first priority, a decent job. The survey describes a decent job as at least 30 hours per week and sufficient to feed, house and clothe the family.

Does anyone think this has nothing to do with Gunnedah? Well there are people living in cars travelling around the North-West staying only long enough so that Councils and National Parks won't move them on or Police pick them up for vagrancy. Read our papers where cars get stolen, trashed and burned, people turning to drugs and alcohol all because they have lost the self respect from providing for themselves and their families. There are many people in our villages and towns with teeth rotting out of their heads because they cannot afford to go to a dentist. This community also needs good jobs.

7. Conclusion

The vast majority of the Gunnedah community will not choose to spend their lives running around playing 'Chicken Little'.

The Gunnedah community is a community of 'Doers'.

We Do look after our elder citizens.
We Do take care of those in our community who are least able to look after themselves.
We Do seek opportunities to provide jobs for our children and grandchildren.

This is what we ask the Planning and Assessment Commission to help us with - to create a heritage of jobs for our children and grandchildren.

Thank you for this opportunity to speak.

Attachment 1

Environmental Scan of the Namoi River Valley

Prepared for the Department of Land and Water Conservation and the Namoi River Management Committee

December 1999

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Executive Summary

The Department of Land and Water Conservation (DLWC) and the Namoi River Management Committee (NRMC) are currently developing a river management plan for the Namoi River and its tributaries. An assessment of the current biophysical condition of the Namoi River (environmental scan) is essential to develop a common understanding of the processes and management activities that affect the health of the river. This work, along with other socio-economic information, forms the basis for the development and implementation of the river management plan for the Namoi River.

This report of the environmental scan draws on previous investigations of the Namoi River system to identify the key ecological issues to be addressed in the river management plan, and important scientific knowledge gaps to be addressed in order to overcome barriers to, or improve the implementation of, management actions aimed at improving the ecological health of the river. The specific issues addressed are:

- The importance of maintaining riverine health;
- The nature of the catchment;
- The level of knowledge of the biophysical condition of the Namoi;
- Threats to riverine health along the Namoi;
- A program to address scientific knowledge gaps.

A watershed or catchment focus is required for managing river health so that the interaction of landscapes, rivers and humans may be considered. Humans may alter the biological systems in a river by altering physical habitat, modifying seasonal water flow, changing the system's food base, changing interactions among stream organisms, and contaminating the water with pollutants.

The connection of the riparian (stream bank) zone and floodplain with a river system is also important, as riparian vegetation and the floodplain provides organic matter (energy) and nutrients that drive primary production, and shade and refuge for biota such as fish. The linkage of rivers with their floodplains also helps maintain wetlands that are often important sources of local and regional biodiversity (e.g. populations of birds, fish and invertebrates).

The flow regime of a river plays a major role in river processes, as flow helps shape the river (affects geomorphology), provides cues for key biological processes (e.g. breeding cycles) and links the river with its floodplain. Flow regulation through dam and weir construction and water abstraction has led to severe stress being placed on many river ecosystems in the Murray Darling Basin, including the Namoi. Changes to flow and sediment regimes following catchment modification can markedly alter the physical nature of the channel and consequently the habitats that support organisms. We now recognise the need to allocate water to fulfil the needs of riverine environments and to protect these systems.

The health of a river may be assessed by comparing a site or area of interest with another thought to be in good condition (the reference condition). The reason for establishing reference conditions is to compare like with like. The approach most commonly used has been to select reference sites that are 'minimally disturbed'. Often, pre-European disturbance conditions are set as restoration goals, but those conditions may not be attainable as this denies the place of humans in the landscape. In such circumstances, management targets

should initially be set so they are achievable. A key aim should be to maintain the biological integrity of a system, that is "*the ability of a system to support a balanced, integrated, adaptive community of organisms with a species composition, diversity and function comparable to that of natural habitat in the area*".

An assessment of the current condition of the Namoi identified the following as major contributors to the generally moderate to poor riverine condition that prevails:

- Degradation of the riparian zone, or complete lack of riparian zone;
- Channel morphology impacts such as bank instability, riverbed instability, and aggradation of sediments. This is primarily due to two factors: 1) excessive sand and gravel extraction, and 2) fluctuating water levels;
- Morphological and biological effects of dams and river regulation;
- Poor land management practices;
- Poor water quality, mainly because of high total phosphorus, turbidity and salinity levels, and localised incidence of pesticide contamination;
- Poor native fisheries, with low species diversity and abundance, especially in upland areas due to the presence of barriers to fish migration.

Seven river zones have been identified for the Namoi River system: pool, constrained, armoured, mobile, meander and distributary. A total of 23 major threats to river condition have been identified, with the anabranch, distributary and meander zones most at risk to environmental degradation. The alteration of river flows, clearing or absence of riparian vegetation, and threats resulting from land management activities (e.g. nutrient and pesticide transport to waterways) are threats common to each of the river zones. Addressing these threats is consistent with the aims and objectives of the Integrated Monitoring or Environmental Flows (IMEF) program, which is part of the NSW Water Reforms, and the recommendation of numerous reports on the state of natural resources in the Namoi River catchment. The NRMC has identified the following key issues to be addressed in their river management plan:

- Fish passage;
- Thermal pollution;
- Floodplain management;
- Off-allocation access;
- Wetland status and other riparian vegetation;
- Operation of dams and weirs;
- Cultural and spiritual issues;
- Carp reduction.

These issues are a mixture of ecological, water management and social-economic issues. In terms of managing environmental conditions, the above issues may be considered as part of two key questions:

1. How do we maintain or improve native fish populations?
2. How do we manage our river system to maintain or improve biodiversity and important functions such as riverine and wetland productivity?

Native fish populations are often used as an indicator of river health, as their presence is dependent on a number of factors such as energy (food) availability, water quality, flow regime and habitat availability. Maintaining biodiversity, and riverine functions such as production and respiration, are also important because they help maintain the resilience of ecosystems upon which we all ultimately depend; the connection of a river with its floodplain and floodplain wetlands is a key component in maintaining riverine health. Maintaining or improving the condition of Namoi River system is therefore dependent on the management of both in-stream and floodplain processes, and factors that threaten them.

Establishing a reference condition that serves as a target for future management in catchments that have been extensively modified (e.g. for agriculture) can be a difficult task, and will largely depend on the values attached to the riverine system by local communities. This can be achieved for in-stream conditions by the use of tools such as the Index of Biotic Integrity (based on fish populations) and AUSRIVAS modelling (based on macroinvertebrates). Both models use regional data sets to identify 'reference' sites where human impacts are considered minimal and conditions are indicative of healthy ecosystems. Comparison of the fish and invertebrate populations at test sites in the Namoi system with that expected to occur at reference sites can be used to establish the relative in-stream health of the Namoi. The reference sites may also serve as targets against which the effects of future management in the Namoi may be assessed.

While the IBI and AUSRIVAS are valuable tools for identifying in-stream reference conditions, no such formal tools are currently available for assessing riparian and floodplain conditions. Given that the riparian zone and the floodplain have been extensively modified and will often not be economically returned to their pre-development state, it is unrealistic to develop reference conditions based solely on pre-development (pre-European) conditions and use them as a target for future management. In this case, measures of intactness and functionality (e.g. length of stream with riparian vegetation that performs key ecosystem functions), or biodiversity and connectivity in key floodplain wetlands are likely to provide a guide to targets that may realistically be achieved or the result of best management practices.

In-stream priorities

The following recommendations are drawn from assessments of riverine condition and consideration of other factors:

- The MacDonald River above Lowry is considered to be in excellent condition and may be considered as a reference site for upland streams in the Namoi. The maintenance of its condition should receive the highest priority in future management and restoration efforts.
- Given its impact on biological and ecological function (e.g. breeding and growth of fish and macrophytes), a review of the extent and persistence of cold-water releases from major dams should be undertaken as soon as possible. This is especially important to ensure that future environmental flows are effective and that cold-water pollution does not prevent migratory fish from using fishways when installed.

- The Peel and Cockburn Rivers are in relatively good condition, as is the Manilla River above Split Rock Dam, and should be given the next highest priority in management and restoration efforts. Important issues to be addressed include improving riparian zone condition, reducing the transport of nutrients from the catchments above Chaffey and Split Rock Dams that help sustain algal blooms, managing the salinity threat and managing the effects of stream instability resulting from sand and gravel extraction. The effectiveness of the fishway at Split Rock Dam should be evaluated and research undertaken to develop fishways for high dams such as Chaffey.
- The priority given to the remaining rivers or river zones requires further consideration by the NRMC. Opportunities may exist to significantly improve the relative condition of rivers by addressing one or two factors (e.g. improved riparian condition along the Namoi River between the Manilla River confluence and Narrabri; effective fishways at Weeta, Gunindera and Mollee weirs). The effect of environmental flows should also be reviewed as recommended by the IMEF process, especially in terms of their effects on creeks, flood runners and wetlands in the lower Namoi distributary zone.

Floodplain priorities
Increased salinity is expected to continue as a major land and water management issue. The ecological effects of increased salinity have the potential to negate improvements achieved through management efforts such as the delivery of environmental flows and installation of fishways. Salinity management should continue to have a high priority in floodplain areas. While high stream salinity is already evident in the streams of the Liverpool Plains and areas of the Peel catchment, a review of trends in groundwater levels will be useful for identifying other areas at risk to salinity.

Surveys of the riparian condition should be undertaken to identify the remnant stands of intact vegetation in each of the major river zones. Existing high quality riparian vegetation should be protected as an example of realistically achievable conditions (future targets for improvement) and as natural seedbanks that will assist efforts for improving degraded riparian habitat.

The condition and biodiversity of key wetlands should be reviewed to provide a baseline to measure the effectiveness of future management, including environmental flows delivered through the NSW water reforms. Given their history in supporting a diversity or abundance of bird and fish populations, or habitat complexity, the following wetlands may be considered as part of this review: Lake Goran, and Gunnible, Gulligal, Barbers and Wirebrush Lagoons. Other wetlands may be added, depending on community priorities.

Assessing the effectiveness of the river management plan currently being prepared by the DLWC and NRMC will require a specifically designed monitoring and evaluation strategy such as the Integrated Monitoring of Environmental Flows (IMEF) program. With the establishment of this program in the Namoi Valley, particularly if the IMEF is further integrated with the Central and North West Regions Water Quality Program, a greater understanding of the linkages between catchment management practices and processes affecting water quality and biotic response to river flows may be achieved. Both the plan and associated monitoring and evaluation programs may be modified in the future as new information and insight becomes available (i.e. within an adaptive management framework).

Other areas of research that will provide valuable information for future riverine management include:

- Biological control methods for carp as part of national efforts;
- The effects of persistence of cold-water releases on fish, invertebrate and macrophyte biology;
- Improved fishway design, especially for high dams.

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Glossary

Acute	Sharp, short term
Alien species	Native or introduced species not previously found in the area
Alluvial	Transported by water
Anabranch	A branch of a river that either rejoins the main stem or reaches a wetland
Antagonistic effect	The tendency of processes or chemicals that together have a less powerful effect than when acting separately
AUSRIVAS	A model developed in Australia to assess stream health based on macroinvertebrates
Benthic	Living in or on the bottom sediments of a river, lake or wetland
Billabong	A water hole or wetland formed from an old river channel
Biochemical	The chemistry of living organisms
Biodiversity	The range of living organisms
Biological monitoring	The measurement of biological changes in an environment
Biophysical	The biological and physical components of an ecosystem
Biota	Plants and animals
Biotic (biological) integrity	The ability of a system to support a balanced, integrated, adaptive community of organisms with a species composition, diversity and function comparable to that of natural habitat in the area.
Blue-green algae	Algae-like organisms (Cyanobacteria) capable of photosynthesis
Chronic	Long term
COAG	Council of Australian Governments
Concave	Curving inward, sunken
Consumptive uses	Used for drinking or preparing foods
Cretaceous	Geological period from 135 until 70 million years ago
DDT	Pesticide previously used in agriculture
Detritus	Decomposed plant or animal material
Devonian	Geological period from 400 until 350 million years ago
Ecological function	Key function (e.g. primary production) upon which ecosystems are dependant
Embeddedness	Extent to which physical features such as rocks are buried in sediment
Environmental flows	Flows required to maintain key biological or ecological processes (e.g. breeding cycles in fish)
Endosulfan	Insecticide used in agriculture
Fishways	Structures built to enable fish to pass in-stream barriers such as weirs
Flow regime	Pattern of changes in flow in a river, lake or wetland

Food webs	The network of food pathways in an ecosystem
Geoindicators	Indicators of the geological state of a waterway or catchment
Geomorphology	Study of the origin and character of land, rivers and lakes
Habitat	An area used by an organism during its life cycle
Hydrology	The study of the behaviour of water
IMEF	Integrated monitoring of environmental flows
Index of Biotic Integrity	A tool for measuring stream health based on fish populations
Index of Stream Condition	A tool for measuring the physical, chemical and biological state of rivers
Invertebrate	An animal without a backbone
Lateral extent	The extent of movement into the floodplain
Landscape level	Regional or catchment scale
Leaf Litter	Leaves, twigs and bark dropped by trees and shrubs into water
Macroinvertebrate	Animals without backbones that are visible to the naked eye
Macrophytes	Plants that are visible to the naked eye
Meander	A twist in a river
Metamorphic	Rock that has changed character in response to changes in temperature, pressure and chemical environment
Metrics	Different measures of a particular characteristic (e.g. fish populations)
ML	Megalitre or 1,000,000 litres
Organic material	Material derived from living plants and animals
Planforms	Aerial views of the shape of a river
Planktonic	Of microscopic plant and animals that float in the water column
Primary production	Production of organic material by living organisms
Riffle	Section of river with fast, shallow water over large sediments (e.g. rocks and stones)
Riparian	Of the banks of a river or stream
RIVPACS	A model developed in Britain to assess stream health based on macroinvertebrates
Secular change	Periodic change
Silurian	Geological period from 440 to 400 million years ago
Spatial	Distance related
Species diversity	The range or number of species in a given area
Substratum	The base material of a river, lake or wetland
Surface waters	Waters flowing or contained in rivers, lakes or wetlands

Taxa	Plants or animals contained in discrete levels of a classification systems (e.g. family, genus, species)
Taxonomic richness	The abundance of a particular taxa
Temporal	Time related
Toxicant	Poison
Turbidity	Opaqueness of water
Weir	Small dam across a river
Weir pool	The area of water held behind a weir
Wetland	An area that is permanently or temporarily inundated

Acknowledgements

The assistance, information and feedback received by Anna Bailey and Warwick Mawhinney (DLWC) was greatly appreciated.

1 INTRODUCTION

1.1 Background

In 1995, the NSW Government introduced its water reform agenda to provide the framework for the sustainable use of the states' waterways. Key objectives of the water reform agenda are related to the equitable sharing and management of water resources, and developing investment strategies and new institutional arrangements for water resource management. Implicit in this approach is the development of clear and agreed environmental objectives.

In response to the framework set by the water reform agenda, the Department of Land and Water Conservation (DLWC), and the Namoi River Management Committee (NRMC) seek to use a strategic and scientifically based approach to the development of a river management plan for the Namoi River. An assessment of the current biophysical condition of the Namoi River (environmental scan) is essential to develop a common understanding of the processes and management activities that affect the health of the river. This work, along with other socio-economic information will form the basis for the development and implementation of a river management plan for the Namoi River.

This report of the environmental scan draws on previous investigations of the Namoi River system to identify the key ecological issues to be addressed in a river management plan, and important scientific knowledge gaps to be addressed in order to overcome barriers to or improve the implementation of management actions aimed at improving the ecological health of the river.

1.2 Project Terms of Reference

The project terms of reference were to:

1. Identify the critical environmental parameters, biophysical condition and ecological functions being affected by current water resource management;
2. Identify the change in the riverine environment as a consequence of catchment development;
3. Provide a detailed list of research that supports the above conclusions;
4. Comment on and recommend where necessary, flow management practices that impact on environmental values;
5. Comment on the critical gaps in research and comment on a critical path analysis for the development of a strategic Environmental Water Management Program.

1.3 Project Scope

As described in the project brief, this study was limited to an evaluation of the biophysical condition of surface water systems of the Namoi River and associated wetlands. The project drew upon existing scientific and technical information relevant to the Namoi River environment and was not expected to generate new data.

River management planning requires an adaptive approach, in that it often starts with very limited knowledge but improves on this by action designed to improve the basis for decision making, particularly through system monitoring and experimentation. The focus of this report is on the scientific information required for management of the Namoi River system. These need to be integrated into planning along with other necessary social, economic and engineering inputs. The specific issues addressed are:

- The importance of maintaining riverine health;
- Nature of the catchment;
- Level of knowledge of the biophysical condition of the Namoi;
- Threats to riverine health along the Namoi;
- A program to address scientific knowledge gaps.

The findings of this report are based on consultation with DLWC, existing scientific and technical reports, discussions with various research organisations and a field inspection of the catchment undertaken by the project team on the 27th and 28th April, 1999.

2 THE IMPORTANCE OF MAINTAINING RIVERINE HEALTH

2.1 Why do we need healthy rivers?

Society benefits greatly from rivers. Yet over the past century, humans have changed the nature of our rivers markedly. Do those changes mean that people have degraded river health? The answer depends on whom you ask. To irrigators, rivers are healthy if there is enough water for their fields. For a power utility, rivers are healthy if there is enough water to turn the turbines. For a drinking-water utility, rivers are healthy if there is enough pure, or purifiable, water throughout the year to meet customer needs. To sport or commercial fishers, rivers are healthy if there are fish to harvest. For recreationists, rivers are healthy if contact with water during swimming, water skiing, or boating does not make people ill. Each of these perceptions assign a value set, that when considered in isolation, provide only part of the river health picture, and may trivialise other uses of the river. The conflicts between competing uses are the concern of water managers who must put in place strategies that maintain the quality of the resource for all its uses. As a country can be considered healthy when a flourishing economy provides for the well being of its citizens, an environment may be considered healthy when the supply of goods and services required by both human and non-human residents is sustained.

Human activity has a great potential to change biological systems. The amount of biological and ecological change that is acceptable to society is a ‘value’ decision - do we value biological elements and processes that may be lost over the returns we may expect from the use of natural resources? Such decisions ought to be grounded in a broad understanding of the consequences of loss, for we may ultimately lose the systems that provide the basis for our own existence. Karr (1996) proposed two criteria for assessing whether or not changes might be acceptable. First, human activity should not alter the long-term ability of places to sustain the supply of goods and services that those places provide. For example, agriculture should not deplete soil or water so that agriculture cannot be sustained; industrial sites should not become so polluted that people cannot continue to work at those sites. Second, human uses should not degrade other areas (e.g. downstream or downwind), a provision that requires a landscape-level perspective in modern decision making. Such criteria in decisions about environmental policy would avoid the depletion of living systems.

The bounds over which a river changes as a result of most natural events are narrow in comparison with the changes that result from human actions such as cropping, forestry, grazing, or urbanisation. Normal, or expected, conditions constituting healthy rivers vary geographically because each river’s biota evolves in the context of local and regional constraints and opportunities. Understanding this baseline must be the foundation for assessing change caused by humans. Only then can we make informed decisions in response to the questions, ‘Is this level of change acceptable? Are the landscape and its rivers healthy?’

Initially managers attempted to ensure that the human-waste-absorbing capacity of rivers was not exceeded. Several decades ago, the model changed to control chemical contamination: rivers would be healthy if we just avoided discharging excessive toxic chemicals into them. More recently we have come to understand that a watershed or catchment focus is required for managing river health, which considers the interactions of landscapes, rivers and humans. Incorporated into this, partly through new water quality guidelines, has been a focus on biological measures of river health (e.g. based on fish or invertebrate populations). Biological monitoring is particularly useful because living systems are likely to respond to the many forms of degradation caused by human actions. Humans may alter the biological systems in a river by altering physical habitat, modifying seasonal water flow, changing the system's food base, changing interactions among stream organisms, and contaminating the water with chemicals. These five factors provide a critical conceptual and analytical framework from which to judge the interactions of human activities and biological change (Karr, 1991).

Can the physical features of rivers (channel geomorphology and hydrology) be considered 'healthy'? Certainly it has been argued that if the physical habitat were in poor condition we would expect the biological health of the stream to be affected adversely (Plafkin *et al.*, 1989; Brookes and Shields, 1996). Earlier, Hynes (1975) argued that 'in every respect the valley rules the stream' where catchment character influences a river by large-scale controls on hydrology, sediment delivery and chemistry. It follows that if we have an unhealthy catchment or valley, we will have an unhealthy stream. Usually, assessment is done in reverse: a stream may be assessed as being unhealthy and then it is concluded that the catchment is unhealthy. The connection of the riparian (stream bank) zone and floodplain with a river system is also important, as riparian vegetation and the floodplain provides organic matter (energy) and nutrients that drive primary production, and shade and refuge for biota such as fish (Sweeney, 1992; Osborne and Kovacic, 1993). The linkage of rivers with their floodplains also helps maintain wetlands that are often important sources of local and regional biodiversity (e.g. populations of birds, fish and invertebrates).

The flow regime of a river plays a major role in river processes, as flow helps shape the river (affects geomorphology), provides cues for key biological processes (e.g. breeding cycles) and links the river with its floodplain. Flow regulation through dam and weir construction and water abstraction has led to severe stress being placed on many river ecosystems in the Murray Darling Basin (e.g. Walker and Thoms, 1993; Thoms and Sheldon, 1997). Changes to flow and sediment regimes following catchment modification can markedly alter the physical nature of the channel and consequently the habitats that support organisms. We now recognise the need to allocate water to fulfil the needs of riverine environments and to protect these systems (e.g. Richter *et al.*, 1997). Unfortunately the connections between the disciplines of hydrology and biology have been poor (Statzner and Higler, 1986; Statzner, Gore and Resh, 1988; Newbury and Gaboury, 1993), especially at larger scales (Frissell *et al.*, 1986). Thus, identifying the timing and duration of flows required to maintain ecological processes, while still providing water for irrigation and consumptive use, remains a major challenge.

The health of a river may be assessed by comparing a site or area of interest with another thought to be in good condition (the reference condition). The reason for establishing reference conditions is to compare like with like. The approach most commonly used has been to select reference sites that are 'minimally disturbed' (e.g. Wright, 1995; Parsons and Norris, 1996; Reynoldson *et al.*, 1997). Often, pre-European disturbance conditions are set as restoration goals (e.g. Chapman, 1992; Scrimgeour and Wicklum, 1996), but those conditions may not be attainable. This target denies the place of humans in the landscape. Britain, China and India have been settled for thousands of years: can rivers in these countries never be regarded as 'healthy'? The majority of human land uses are not going to be removed from the landscape. Perhaps then, management targets should initially be set so they are achievable.

Clear definitions of desired conditions, given surrounding land uses, are required for effective management and assessment (Rogers and Biggs, 1999). The primary needs for a healthy ecosystem are biotic integrity and sustainability (Karr, 1991, 1999). Biotic integrity is defined as *the ability of a system to support a balanced, integrated, adaptive community of organisms with a species composition, diversity and function comparable to that of natural habitat in the area.* Ecosystems need not be pristine (few are, now, because of large-scale changes such as the ozone hole, acid rain, global air pollution), but still can be judged healthy (Rapport, 1989; Chapman, 1992). The final conclusion on health may be dependent on social issues. For example, a river may be judged healthy if a single species commercial fishery is sustainable, but not healthy if a varied recreational fishery is lost. Judgements of ecosystem health take into account more than strictly ecological functions - uses or human amenities derived from the system, for example (Rapport, 1989).

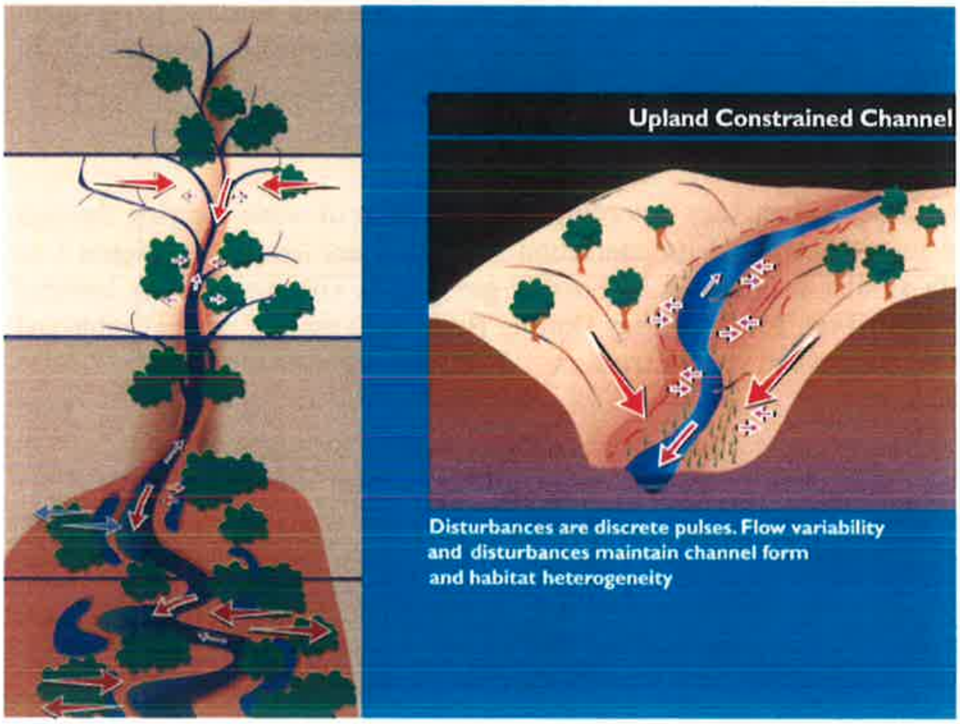
Rivers can be restored (Brookes and Shields, 1996; Gore, 1985) and also enhanced (Rapport, 1989). A more useful target for management may be the best possible condition, given acceptable land or water use. Many baulk at this suggestion, afraid that it will lead to a downward spiral in environmental quality. However, the reverse may be true. For example, if conditions in the upper part of a catchment are improved so that fewer problems are exported downstream, acceptable targets downstream may be raised rather than lowered.

We contend that acceptable reference conditions for river health should be based on ecological understanding (e.g. biotic integrity). The features of, and sites selected to represent the reference condition should be selected and classified to allow site-specific comparisons of indicators of river health.

2.2 How do rivers work?

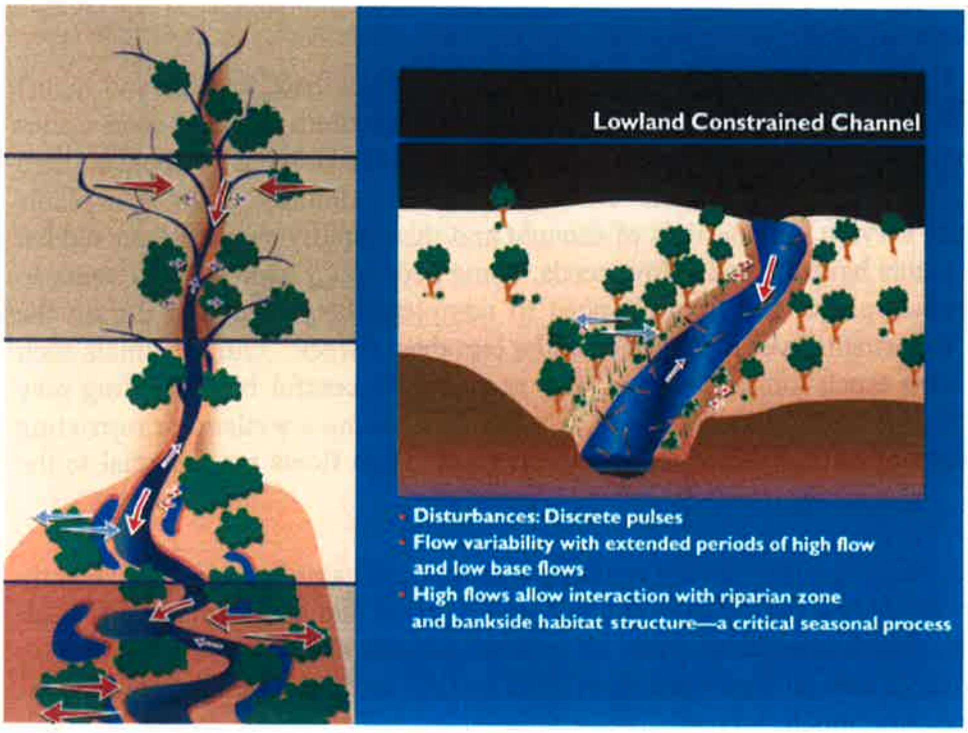
No two rivers are the same. Rivers vary according to the amount of water flowing through them, when and how fast it flows and its interaction with the local landscape (Figure 1 to Figure 4). Rivers with similar habitat can be broadly grouped as either upland or lowland constrained, or floodplain rivers. In the Murray-Darling Basin each type of river is subjected to some level of flow regulation and water diversion.

Figure 1: Components of a river system



Disturbances are discrete pulses. Flow variability and disturbances maintain channel form and habitat heterogeneity

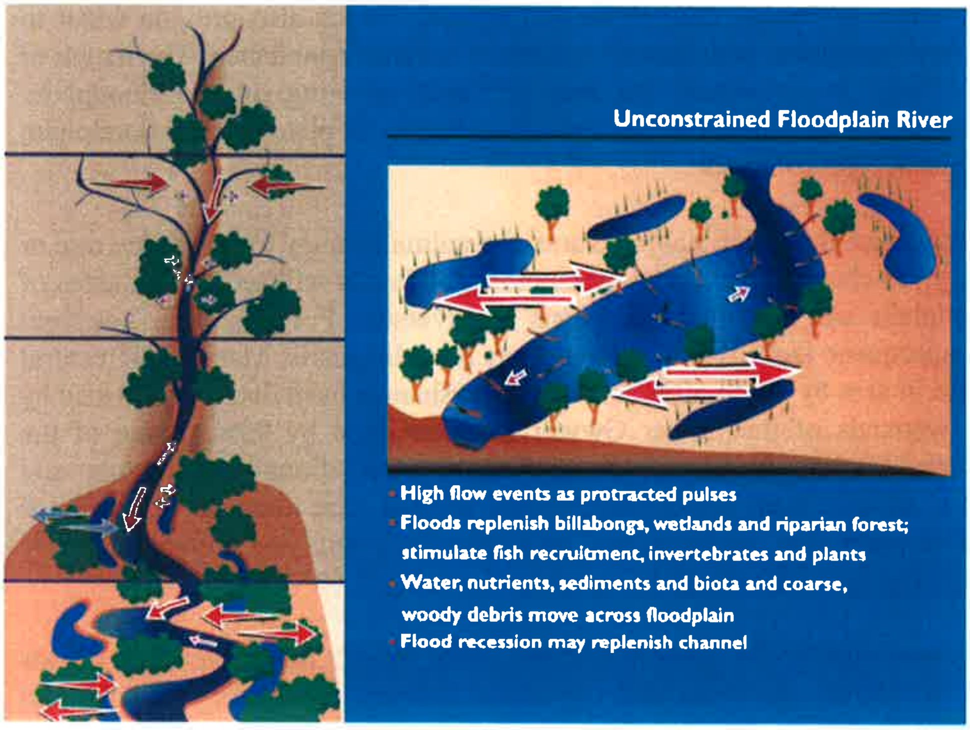
Figure 2: Processes in upland rivers



Lowland Constrained Channel

- Disturbances: Discrete pulses
- Flow variability with extended periods of high flow and low base flows
- High flows allow interaction with riparian zone and bankside habitat structure—a critical seasonal process

Figure 3: **Processes in lowland constrained rivers**



Unconstrained Floodplain River

- High flow events as protracted pulses
- Floods replenish billabongs, wetlands and riparian forest; stimulate fish recruitment, invertebrates and plants
- Water, nutrients, sediments and biota and coarse, woody debris move across floodplain
- Flood recession may replenish channel

Figure 4: **River – floodplain interactions**

2.2.1 Natural flows are variable

The Murray-Darling Basin has a highly variable and unpredictable climate; rainfall and runoff vary from month to month and from year to year. Within this variability, longer-term cycles of droughts and floods appear, cycles that are strongly influenced by El Niño-Southern Oscillation episodes. Australia's river systems evolved with this variability. Our native plants and animals are able to survive long periods of drought and then rapidly capitalise on sudden floods. Animals and plants have different flow needs. Some need low flows and still water to breed successfully. Other plants and animals need to complete their lifecycles during the period of flooding. For a small invertebrate this can be less than a week. Other animals such as birds and fish require much longer flooding. For example, successful bird breeding may require months of flooding. Cutting short a flood, whether by draining a wetland or restricting the supply of water dramatically, reduces its ecological value. High flows are essential to the floodplain.

The floodplain surrounding lowland rivers contains a mosaic of habitats-from permanently wet billabongs, to wetlands that periodically dry out, and to areas that are normally dry in all but the biggest floods. Floods are a time when all of these habitats are connected to the river channel: a period when plants, animals and their food can move from one area to another. Determining what and how much moves between these areas during floods is very difficult and is a topic of ongoing investigation.

On the usually drier areas of the floodplain, flooding gives plants that are able to withstand waterlogging a competitive advantage over those that cannot. Floods also provide water to young trees, such as river red gums, which enables them to become established. The length of time between floods helps to determine the mix of plants growing on the floodplain. Decreasing the number of floods is likely to decrease the diversity of plants on the floodplain, and this may allow alien species to invade.

Wetlands and billabongs have their own unique plants and animals, many of which are rare or absent from the main river channel. Reducing the numbers of floods will reduce the areas of wetland on the floodplain and inevitably threatens biodiversity. For example, upstream diversions and the consequent lack of water have seen the Macquarie Marshes of central western NSW decrease in area by about 50%, Victoria's marshlands have decreased in size by 70% and the couch wetlands of the Lower Gwydir have declined by 90%. Some of the wetlands in the Murray-Darling Basin are recognised as internationally important and Australia has agreed to protect them under international treaties. The message is simple: if wetlands do not receive water they disappear and with them the plants and animals that rely on the wetlands for all or part of their lifecycle.

High flows are vitally important to the success of many of the Basin's freshwater fish. Floods stimulate some fish to migrate upstream and reproduce. Golden perch, for example, can migrate over 1000 km. Floodplains can be used as spawning sites. The abundant food of the floodplain, such as small invertebrates, promotes the survival for young fish during the delicate first few months of their life. Some native fish breed only in flood years. Reducing the numbers of floods will surely reduce the numbers and types of native fish in the Basin's rivers.

2.2.2 High flows feed rivers

The supply of organic material (all matter derived from living organisms, including detritus such as leaf litter) underpins all river foodwebs by providing the food energy needed to drive life. Put simply, carbon dioxide is converted into organic material by plants and algae living either in the river or in the surrounding catchment, and once the plants and their products are in the river, animals, fungi and bacteria feed on them. The sources of organic material, the timing of its delivery and how long it remains in a section of river depend very much on the flow regime and the nature of the riparian vegetation.

In lowland rivers without floodplains, such as the Campaspe River, much of the organic material is washed down from the upper catchment. River regulation results in organic matter being trapped behind dams and weirs where it settles to the sediments-often fuelling high rates of bacterial activity which can reduce the oxygen content and increase the dissolved phosphorus levels of the water. Loss of floods and sustained low flows reduce the delivery of organic material from upstream. The combined impacts of dams and water diversions effectively starve the constrained river of food energy.

In floodplain rivers, such as the Murray, it is likely that much of the organic material is transported to the river channel as floodwater returns from the floodplain. Without regular flooding the river is isolated from its main source of food energy.

At the same time that the river is being starved of organic material from the floodplain the amount of nitrogen and phosphorus entering the rivers has risen through changed land management. Increased amounts of these nutrients, combined with periods of low flow, have fuelled the growth of blue-green algae in the river. Reductions in organic material from the floodplain and increased algal growth in the river has changed the dominant source of food energy in the river. Changing the basic food sources in the river is likely to change the species of animals that feed upon them. In turn, these animals may have different predators, and so on up the food chain.

While we are still not sure exactly what impact changing the amount and source of food energy in the river is having, it is likely to be profound (Thorp and Delong, 1994). What we do understand is that mid-sized floods are a major factor in controlling the supply of organic material from catchments and also the critical exchanges between the floodplain and the river. It is the mid-sized floods that are usually affected most by water harvesting and river regulation.

2.3 Assessing River Health

2.3.1 Physical and chemical indicators

Physical and chemical indicators (mostly of water quality) are the most commonly used and largest variety available (e.g. ANZECC, 1992; Hart, Maher and Lawrence, 1999; Maher, Batley and Lawrence, 1999). Most are highly specific measurements of single chemicals and offer little integration. Interpretation comes largely from experimental tests on the effects that they have on biota and results from these are used to set guidelines to protect rivers. Such measures are distinctly ‘bottom up’ and may explain causes of damage to river health and biotic integrity rather than ecosystem condition (Chapman, 1992; Karr, 1991). Application of standardised criteria for chemical values fails to recognise natural geographic variation in water chemistry and resulting impacts, e.g. antagonistic interaction of heavy metals with major cations and effects of pH on solubility. Developments are now proposed for Australia's national water quality guidelines that aim to provide measures that are more ecologically meaningful and integrative (Hart *et al.*, 1999; Maher *et al.*, 1999).

Process geomorphology is concerned with factors operating at various scales that affect the function and form of rivers (e.g. de Boer, 1992). Changes to catchment conditions and flow regimes can markedly alter the functioning of river channels and thus the habitat available for organisms. Biota aside, changes to catchments and flows modify river channels via changes in erosion rates after catchment and riparian clearing, channel infilling from reduction in flow, and separation from floodplains resulting from drainage and flow reduction. Therefore, it is sensible to consider indicators of the geomorphological condition of rivers in their own right. It may be quite possible to have degraded channels that have a quite healthy biota associated with them.

2.3.2 Biotic indicators

There are many biological indicators from which to choose (Norris and Norris, 1995; Cranston *et al.*, 1996). The most commonly used have been benthic macroinvertebrates, the small animals without backbones (e.g. insects, worms, molluscs etc.) that live in the sediments of rivers and lakes (Resh and Jackson, 1993). Other commonly used groups are fish (Harris, 1995) and plants (Whitton and Kelly, 1995). Regardless of the taxonomic group used, taxonomic richness, or a subset of it (e.g. richness of particular group of invertebrates), has been frequently selected as a robust indicator. Poor environmental conditions are usually indicated by a loss of taxa. Taxonomic richness of invertebrates is central to the British RIVPACS (Wright, 1995) and the Australian AUSRIVAS (Simpson *et al.*, 1997) methods for assessment of rivers.

2.4 Why is a river management plan important?

A plan is essentially a strategy aimed at achieving a desired outcome(s). The long-term economic and ecological sustainability of land and water resources is a desired outcome for local government and the community. This does not imply stability, rather an ability to adapt to changing pressures and issues. Knowledge is an essential element of adaptive capacity. There are five elements to any knowledge strategy:

- What do we need to know?
- How will we get the information?
- How do we store the information so it is available when we need it?
- How do we update and check the information
- How do we review and update the knowledge strategy.

A knowledge strategy is an integral part of any organisation's business plan. River management agencies are required to manage a variety of issues, therefore it is important for them to focus on the key issues. Given past mistakes of managing rivers, especially in semi arid and arid river systems like the Namoi, it is worthwhile considering what knowledge a government or a community group, needs before it can make responsible river management decisions. Information on the extent and 'state' of the resource, as well the ability to predict the impact of various actions on the long-term sustainability of the system are required.

COAG has recognised the fundamental importance of a 'whole catchment' approach in natural resource planning. For example, water entitlements, both consumptive and non-consumptive, must be allocated and managed in accordance with comprehensive planning systems. This is based on a complete assessment of the river system. Hence, State or regional borders are not an appropriate planning boundary, despite the difficulties this causes. This allows a group to consider all downstream impacts of river development. In this case the impacts of river management in the Namoi valley on the Barwon Darling itself need to be assessed.

Defining the river floodplain system, its structure and functioning over a variety of time scales is important. Areas of inundation associated with different floods are necessary, despite the resistance of some development interests in having this information publicly available. Ecological communities need to be assessed along with their dependence on various wetting and drying periods. This should include fish, birds, aquatic macrophytes, invertebrates and riparian vegetation and indicate how these elements interact at the community level. Rare or endangered species need to be identified, as do 'hot spots' of high biodiversity potential (Cullen and Lake, 1995)

Governments, developers and conservation interests all seek to have robust predictions of how river systems may change with the implementation of various development options. Such predictions require models as well as appropriate data. Although the prediction of hydrological outcomes is developing, ecological outcomes are more difficult and less advanced. Even in the Murray-Darling Basin where water management has been active for over 70 years, there has been little effort in the development of ecosystem models. Instead 'expert judgements' by experienced ecologists are relied upon for many of our present water allocation issues.

3 THE NAMOI RIVER CATCHMENT

3.1 Catchment Character

The Namoi catchment drains an area of 42,000 km^2 in northern New South Wales. The main river system of the catchment, the MacDonald/Namoi, has its headwaters in the Great Dividing Range, and flows in a westerly direction for approximately 850 km from near Walcha, on the New England Plateau, to the Barwon River at Walgett. The Namoi River system is a major left bank tributary of the Barwon-Darling River, contributing an average 800,000 ML $year^{-1}$ to this river or 25 percent of its long term annual flow at Menindee. The catchment is bounded by the Nandewar Ranges in the north, the New England Plateau in the north east, the Liverpool Plains in the south east and the Warrumbungle Range in the south west. In addition to the MacDonald and Namoi rivers, other important tributaries include the Cockburn, Peel and Mooki Rivers and Coxs Creek.

There are two main physiographic regions in the Namoi catchment:

- the mountainous eastern region; and,
- the low angle plains of the west.

The eastern region, in which most of the rivers rise, is the highly dissected New England Range. The New England Granite Batholith is the characteristic geologic feature of this region. It is Silurian in age and also consists of metamorphic sediments. These sediments dip steeply and are overlain by Devonian-Carboniferous tuffs, lavas, shales and some limestones. Granites outcrop in the margins of the basins. In places tertiary volcanics and lavas, which are over 150 m thick, occupy elevated positions and form the more rugged topography of the region, for example the Nandewar and Liverpool Ranges.

A distinct physiographic boundary located slightly east of Narrabri separates the eastern and western regions of the catchment. This boundary, best defined in the vicinity of Mt Kaputar, corresponds to a north-south line of folding and faulting. Generally, the low angle alluvial plain slopes uniformly towards the west and lacks any significant relief. This alluvial plain consists of alternating strata and lenses of gravel, sand and silt-clay sediments up to 150 m thick. The Cretaceous rocks of the Great Artesian Basin underlie these sediments. Riley and Taylor (1978) suggest there are three main sub regions this western area of the catchment, namely:

- the area of most recent stream activity and fluvial deposits;
- older areas of alluvial deposits; and,
- an area of interaction between the Namoi and Gwydir fans

There are a variety of soil types through out the catchment. Soil type is closely associated with the underlying geology and the geomorphological evolution of the region. Soil erosion is prominent throughout the catchment, accounting for 37.9 % of the total degraded area (Thoms, 1998). Sheet and rill erosion is the dominant erosion form, especially in pasture areas where vegetation cover is minimal or where pastures are cultivated for fodder crops. The Liverpool Ranges and land along the Tamworth fault, which includes the headwater tributaries of the Mooki and Peel Rivers, are also severely affected. Sheet erosion is more prominent in the hills and foot slopes and rill erosion is common on the lower slopes. Extreme gully erosion is present in the upper slopes of the Liverpool Ranges and the southern end of the Tamworth fault. There is extensive to severe gully erosion in the Manilla and Barraba areas and also areas to the east of Manilla. Other areas of severe gully erosion exist west of Coxs Creek and throughout the Tamworth district and the MacDonald River. Gully erosion is responsible for large quantities of soil loss and increased sedimentation and turbidity of rivers.

3.2 River Geomorphology

The geomorphology of the Namoi catchment has an important influence on the hydrology and physical character of a river system. River channel planforms (styles) are largely controlled by the valley slopes and the width of the valley floor trough. For example in constrained valleys of the headwater regions, the presence of bedrock outcrops influence the slope of the river channel (energy slope) and the mobility of the river channel and its ability to respond to changing discharges. The geomorphology of Namoi and its main tributary valleys are different and some change markedly in a downstream direction.

All the main rivers of the Namoi catchment have typical concave long profiles, although there is a wide variation between them (Thoms, 1998). The Namoi/MacDonald River has its headwaters in the Great Dividing Range at an elevation of approximately 1,200 m above mean sea level (ASL). It flows in a predominantly westerly direction and drops quickly in elevation to 340 m near Manilla, some 200 river kilometres downstream. The river valley in this section is heavily constrained and has a small valley floor width. The river therefore has a high gradient as it flows through a gorge zone until it reaches Manilla. Downstream of Keepit Dam, the valley slope decreases dramatically to an elevation of 200 m at Narrabri, a further 200 km downstream. As the valley slope decreases, the valley floor increases in the width to become a large floodplain. Downstream of Narrabri the floodplain is essentially a flat featureless surface associated with an unconstrained valley. Elevation is 120 m at the Namoi-Barwon confluence, some 710 km downstream from its headwaters. The extensive floodplain areas contain a number of features such as billabongs, anabranches and effluent streams such as Pian and Gunidgera Creeks.

Like the Namoi, the Cockburn River and Cox's Creek both drain areas of relatively high relief (960 m and 1,060 m respectively), while the Peel and Mooki Rivers drain areas of low to moderate relief (480 m and 500m respectively).

Thoms (1998) has identified seven river zones in the Namoi catchment each with its own set of physical characteristics. The location of the zones reflects the variable control of the discharge of water and sediment in relation to catchment size and geological influences on the nature of the valley. Similarly, the extent of each zone varies according to the overall geomorphology of the region. Details of each zone are presented in (Figure 5 and Table 1).

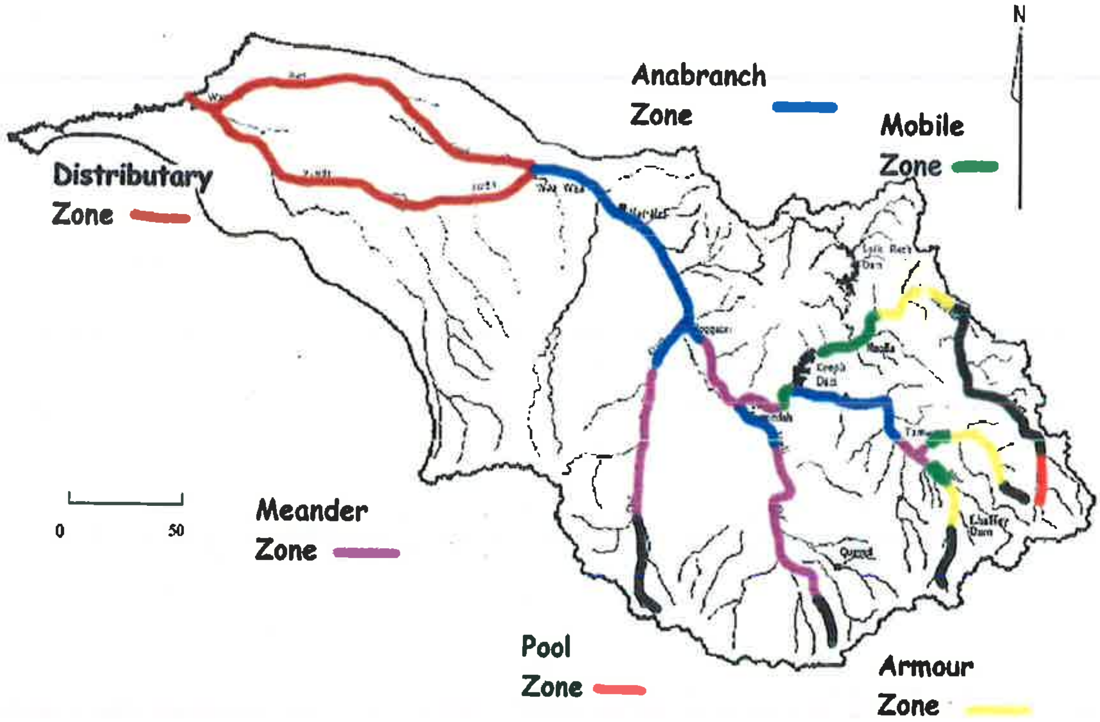


Figure 5: River zones in the Namoi catchment

The anabranch zone is the dominant river zone, in terms of length, in the Namoi catchment. However, within the individual sub catchments the dominance of individual zones varies. For example, the meander zone is dominant in the Mooki River and Coxs Creek, whilst the mobile zone is the dominant zone in the Cockburn River.

All of the rivers in the Namoi catchment have a variable form and character. Different river zones respond in a different manner to physical disturbances, whether they be natural (e.g. flood) or human induced (e.g. sand and gravel extraction). Hence, management activities should be conducive to the natural character and functioning of river systems.

There is generally a continuity of water and sediment movement in river systems. Because of this continuity, activities in one river zone can influence the character and functioning of other zones both upstream and downstream of the zone undergoing change. For example, sand and gravel extraction in a mobile zone can create riverbed erosion problems in an upstream armoured zone and fine sediment deposition issues in a downstream meander zone. River management activities should be mindful of this connectivity within river systems.

Table 1: Geomorphological zones of the Namoi Catchment.

River Zone	River	Character
Pool	MacDonald	Stable channel Deep pools are important habitat.
Constrained	MacDonald Cockburn Peel Mooki Coxs	Stable channel Sediment supply area. Plunge pools and runs are important habitat.
Armoured	MacDonald Cockburn Peel	Relatively stable channel but can become active and unstable. Temporary sediment stores within the channel. The gravel bed/bars are important habitat.
Mobile	MacDonald Cockburn Peel	Very active channel and bed sediment – sediment transfer area with numerous temporary sediment stores. The sandy gravel deposits are important habitat.
Meander	Namoi Cockburn Peel Mooki Coxs	Active channel in which bank erosion is common. Sediment transfer area with some sediment stores. Floodplain functioning increases in importance to the river system
Anabranch	Namoi Peel Mooki Coxs	Main channel is relatively stable but can experience bank erosion. River system is multi-channelled during floods. Secondary channels may erode if they become the main flow path. Both the main and anabranch channels are important habitat. Floodplain functioning important to the river system.
Distributary	Namoi	Multi channelled - secondary channels are the dominant habitat area. The condition of the floodplain vital to river functioning.

3.3 Hydrology

The long term average annual runoff for the Namoi River is 770,000 ML at Gunnedah, which represents 6 % of the average annual catchment rainfall and is only 33 % of the New South Wales average rainfall-runoff. Most of the runoff is generated in the headwater regions of the catchment; 90 % of the total runoff comes from 40 % of the catchment area. The Cockburn, Peel and MacDonald catchments yield the greatest runoff per area of catchment (Table 2). Generally, annual flows increase with increasing catchment area, but downstream of Gunnedah annual flows decrease due to increasing evaporation, transmission losses and water use.

Table 2: Total Annual Flow Statistics for the Namoi River (ML).

	Narrabri	Gunnedah	MacDonald	Peel	Cockburn	Mooki	Coxs
Median	403,500	415,200	242,600	130,300	58,500	36,700	24,500
Mean	629,000	734,000	381,600	196,700	81,400	92,500	77,300
Min	19,000	33,300	14,500	4,500	600	1000	500
Max.	3,624,000	3,871,000	1,905,000	994,000	315,000	388,000	344,000
Catch. Area (km^2)	25,100	17,100	5,180	2,410	907	3,630	4,040
Yield	16	24	46	56	65	10	7

Flow variability is a feature of the Namoi River. For example, long term variations in average annual flow for selected stations throughout the catchment range from 23 to 660 percent (Thoms, 1998). In general, discharges recorded at the main gauing stations are skewed, with a large proportion of average flows occurring in wet years and during major floods.

Riley (1988) has reported secular changes in the hydrological regime of the Namoi catchment over the last 100 years. The period 1900-1946 differs significantly in term of annual flows and flood activity in comparison to preceding and succeeding periods; conditions were wetter prior to the 1900 and since the mid 1940's.

Flows in the Namoi catchment are regulated by three head water storages: Keepit Dam on the Namoi River upstream of the Peel River confluence, Chaffey Dam on the Peel River upstream of Tamworth, and Split Rock Dam on the Manilla River. Keepit Dam, constructed in 1960, has a storage capacity of 427,000 ML and is a concrete gravity dam with a gated spillway. There is a small hydroelectric power station that operates at the dam when releases are made. Split Rock Dam was constructed in 1988 to augment the supply to Keepit Dam by an average of 53,000 ML per year. It also supplies water to users along the Manilla River. Split Rock is a concrete faced rock fill dam and has a maximum storage capacity of 397,000 ML. Chaffey Dam was constructed in 1979 and has a maximum storage capacity of 62,000 ML.

Downstream of Keepit Dam there is a series of regulating weirs at Mollee, Gunidgera and Weeta. Mollee Weir (3,300 ML) was designed to hold and regulate flows to improve the precision of supply. Gunidgera Weir has a storage capacity of 1,900 ML and its main function is to raise water levels to enable regulated flows to be diverted to Gunidgera and Pian Creeks. Weeta Weir has a storage capacity of 280 ML and provides storage for downstream irrigators. On the Gunidgera-Pian Creek system there are a number of works to control flows. A regulator on Gunidgera Creek controls the rate of diversion of flows from the Namoi River to the creek. Flows may then be diverted into Pian Creek via The Cutting (Knights Weir) or The Supplementary Pian Creek Channel, which was constructed in 1992 to allow water transfer into Pian Creek and to prevent overbank flow. Four privately owned weirs owned by irrigators are also present in the Gunidgera-Pian Creek system, Knights, Hazeldean, Greylands and Dundee Weirs.

Hydrological assessment of the Namoi River system undertaken by the DLWC has been used to identify changes to the nature of river flows as a result of water regulation (Thoms, 1998). Typically, river flows across the catchment are variable, and regulation has altered some seasonal flows (Figure 6). In addition, water resource development has significantly reduced the frequency and size of in-stream flood flows in the Namoi system. A comparison of simulated natural with current (regulated) flow data from three key sites in the Namoi catchment indicates that the peak discharges associated with flood flows have been reduced following regulation (Table 3). For example, the peak discharge associated with a 1 in 5-year flood at Gunnedah under natural conditions has been reduced by 35% since river regulation. The results suggest that the impact of regulation is most pronounced on the small to medium (1 in 2-year to 1 in 5-year) flood events.

Table 3: Percentage reduction in peak discharges associated with floods at selected

sites in the Namoi River system. Source: DLWC, Integrated Quantity and Quality Model (IQQM) – monthly timestep model

Station	2 year ARI	5 year ARI	10 year ARI	20 year ARI	50 year ARI
Peel River	-10	-5	-2	-2	0
Gunnedah	-37	-35	-9	-12	0
Narrabri	-8	-12	-2	-2	-1

Note: ARI - average return intervals based on Log Pearson 3.

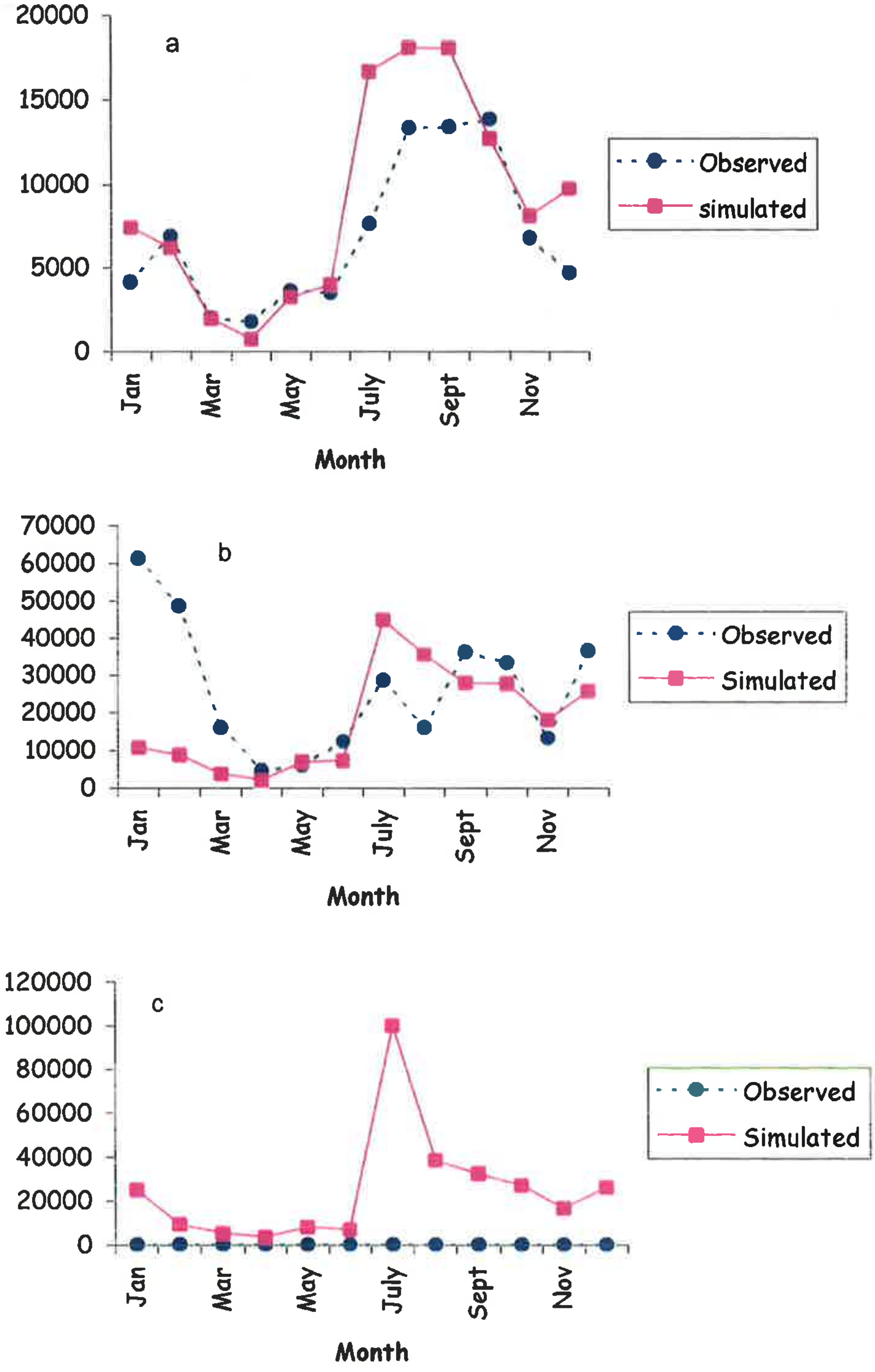


Figure 6: Long-term monthly flows (observed and simulated natural) for the Namoi River system: a) Peel River; b) Gunnedah, and c) Narrabri. Source: DLWC, Integrated Quantity and Quality Model (IQQM) – monthly timestep model

4 THE CURRENT CONDITION OF THE NAMOI RIVER SYSTEM

4.1 Physical Condition

The in-stream environment of any river system is a complex array of physical features, or habitat areas. Typical of habitat features that can be found in a river channel include riffle, run, pool, bank and edge margins, snags, and the substrata associated with each feature. The dominance of various habitats will change along a river and the importance of each will also change for different organisms depending on their habitat preferences. The nature of the riparian zone, the size, shape, stability of the river channel, banks, in-stream substratum, habitat types (riffle, run, pool, edges, snags), and catchment land use all determine the type and quality of habitat within a river system.

The in-stream habitat at a range of sites (Table 4) throughout the Namoi catchment has been investigated by Thoms (1998). At each site a qualitative assessment by undertaken using a method adapted from the US EPA procedures for rapid biological assessment (Plafkin *et al.*, 1989). This method allows the in-channel habitat to be given a score based on its ability to support macroinvertebrate communities. A score for eight components (bottom substratum/available cover, embeddedness, channel alteration, bottom scouring and deposition, pool/riffle run/bend ratio, bank stability, bank vegetative stability, and streamside cover) is calculated with the total habitat score expressed as a percentage of the maximum possible score with > 80 % excellent, 55-80 % good, 25-55 % fair and less than 25 % poor habitat. The results of the habitat assessment are presented in Table 5.

Overall, the physical condition and quality of habitat for benthic organisms within the Namoi River catchment was in poor to moderate condition. Generally, the upper parts of each of the river systems were in better physical condition than the lower sections. However some river systems within the Namoi catchment were in very poor condition, particularly the Mooki River and Coxs Creek.

The MacDonald and Namoi River was in excellent physical condition upstream of Keepit Dam (sites N3, N1 and N2). Downstream of the dam the physical condition was good with some evidence of bank erosion and channel alteration. Further downstream at Carroll the nature of the river changes to a sediment depositional zone and the quality of the physical habitat declines. The quality and density of vegetation in the riparian zone is reduced, bank erosion and bed degradation is apparent, and the lack of habitat complexity is obvious. This is not associated with natural changes to the river and is influenced by regulation of flows downstream of Keepit Dam. A further decline in the quality of the physical habitat is evident between Boggabri and Wee Waa where bank erosion is more apparent, and the riparian zone and the condition of the riverbed is severely degraded.

The Peel River is in moderate physical condition. Upstream of Chaffey Dam the physical condition of the river was good, however, relatively minor bank instability and evidence of channel degradation was present and habitat complexity was also reduced. Downstream of the dam channel degradation was apparent with in-stream substratum embedded and surrounded by finer particles. However, bank stability and riparian vegetation cover was in better condition compared to sites upstream of the dam. Further downstream at Calala the riparian vegetation was encroaching on the river channel. Otherwise the river was in relatively good physical condition with some channel degradation and bank instability. Downstream of Tamworth at Appleby Bridge, the physical habitat had declined with moderately unstable banks and degradation of the stream channel and bed.

Table 4: Characteristics of sites sampled in the Namoi River Catchment.

Site	River	Location	Altitude (m)	Longitude	Latitude
N1	MacDonald R	u/s Woolbrook	900	151.39	30.98
N2	MacDonald R	@ Lowry	400	150.95	30.66
N3	MacDonald R	@ North Cuerindi	360	150.81	30.71
N4	Namoi R	@ Gunnembene Crossing	280	150.48	30.97
N5	Namoi R	d/s Carroll	260	150.34	31.03
N6	Namoi R	@ Uralla	240	150.15	30.90
N7	Namoi R	d/s Boggabri	220	150.06	30.70
N8	Namoi R	@ Wee Waa			
N9	Namoi R	@ Pilliga			
P1	Peel R	@ Nundle	580	151.13	31.48
P2	Peel R	d/s of Nundle			
P3	Peel R	d/s Chaffey Dam	460	151.12	31.25
P4	Peel R	@ Calala	380	151.03	31.15
P5	Peel R	@ Appleby Bridge	340	150.89	31.02
C1	Cockburn R	near Limbri	460	151.16	31.05
C2	Cockburn R	d/s Limbri			
C3	Cockburn R	@ Ballantine Bridge			
C4	Cockburn R	@ Nemingah	380	151.02	31.13
M1	Mooki R	@ Pine Ridge	320	150.46	31.53
M2	Mooki R	@ Long Point Bridge	260	150.46	31.20
CX1	Coxs Ck	near Boggabri			
CX2	Coxs Ck	@ Warragrah,	240	150.04	30.80

Table 5: **Physical habitat assessment of sites in the Namoi River Catchment.**

Site	N1	N2	N3	N4	N5	N6	N7	N8	N9	P1	P3	P4	P5	C1	C4	M1	M2	Cx1	CX2
Substrate (20)	19	20	19	19	5	11	11	5	10	17	18	17	15	18	19	11	5	5	5
Embeddedness (20)	15	20	19	19	5	11	8	2	2	18	11	15	11	12	19	11	5	5	4
Velocity/Depth Ratio (20)	15	15	15	12	5	6	8	5	6	10	10	10	8	10	6	8	5	0	3
Channel Alteration (15)	10	11	9	12	3	8	7	4	5	11	14	13	12	15	7	5	3	5	4
Bottom	11	11	11	11	7	7	7	7	7	11	12	8	8	12	11	8	3	5	7
Scouring/Deposition (15)																			
Pool/Riffle/Run/Bend (15)	11	12	12	11	3	4	6	3	3	10	11	11	6	11	4	6	3	0	3
Bank Stability (10)	8	8	10	5	6	5	2	1	6	5	9	8	5	10	9	3	3	4	6
Bank Veg. Stability (10)	9	10	10	9	10	9	8	9	6	8	10	8	9	10	10	9	8	6	10
Streamside cover (10)	10	10	9	5	10	9	10	9	9	7	8	7	9	9	8	5	5	7	5
Total	108	117	114	103	54	70	67	45	54	97	103	97	83	107	93	66	40	37	47
% of maximum (135)	80	87	84	76	40	52	50	33	40	72	76	72	61	79	69	49	30	27	35

The Mooki River was in poor physical condition. Unstable banks, degradation of the stream channel and bed, deposition of fine materials such as silt and clay, and no riparian vegetation were indicative of the poor physical nature of this stream. Farming practices were present up to the stream banks and were a major factor contributing to the declining physical nature of this stream.

The Cockburn River was in poor physical condition. The upper parts of the Cockburn River catchment showed some signs of channel instability and bed degradation, but was generally in good physical condition, with stable banks, and good riparian vegetation. Further downstream, the channel was very unstable, lacked habitat complexity and was highly degraded.

Coxs Creek was in poor physical condition throughout its length. In-stream substratum was primarily silt and clay, indicating that a considerable amount of fine sediment transport was occurring. Poor riparian vegetation cover, unstable deeply eroded banks, and an unstable stream channel indicate the poor physical nature of this stream.

Overall, the Mooki River and Coxs Creek were in very poor physical condition, along with the lower parts of the Namoi River and Cockburn River. Factors influencing all streams were poor land use practices, a lack of adequate riparian vegetation, and bank instability. The impact of sand and gravel extraction was obvious on the physical condition of the various river systems.

4.2 Physico-Chemical Water Quality Conditions

A review of the water quality of the Namoi River was undertaken by Arthington (1995), who identified the major water quality issues in the cotton growing areas as salinity, turbidity, nutrient enrichment and contamination with agricultural chemicals, and problems with urban and mine wastes. These findings are supported by recent investigations by Brooks (1998), Deal and Wood (1998), Mawhinney (1998a,b,c), Muschal (1998), Nancarrow (1998), and O'Brien (1996) as part of regional or local water quality monitoring programs. Thoms (1998) also investigated aspects of water quality when applying the Index of Stream Condition (ISC - see section 4.4) at 18 sites across the Namoi. The ISC examines 6 environmental variables, including water quality and biological condition, to provide an overall assessment of the condition of rivers.

Salinity is widely recognised as a land and water management problem across the region. The recently released salinity audit by the Murray Darling Basin (MDBC, 1999) has highlighted the Namoi as a catchment where salinity problems are expected to worsen considerably in coming decades if the long-term trend of rising groundwater tables is not reversed. Interestingly, recent analyses of salinity trends at river sites in the Namoi have recorded no, or decreasing, trends in stream salinity. Nancarrow (1998) examined 8 years data (1991-1998) collected from 9 sites across the Namoi catchment as part of the Central and North West Regions water quality program, while Preece (1998) examined five years data (1992-1997) from 8 sites across the catchment as part of the NSW Key Sites monitoring program. Three sites were common to each investigation, and Nancarrow using the 8-year data set did not record the two decreasing trends in stream salinity recorded by Preece based on a 5-year data set. This highlights the care that must be taken when drawing conclusions on long-term trends based on data collected over relatively short periods. Evaluations of trends in stream salinity undertaken by the MDBC indicated rising salinity and salt export from the Namoi over the period 1975 to 1995 (Williamson *et al.*, 1997; Jolley *et al.*, 1996; http://www.mdbc.gov.au). Long term trends may also be modified by climatic events (e.g. ENSO) or management practices (MDBC, 1999).

The salinity audit undertaken by the MDBC (1999) indicated that salt concentrations and loads in the Namoi were expected to rise significantly over the next 50-100 years, based on current trends and management practices. The management of salinity in both dryland and irrigated areas should continue as an important component of catchment management efforts in the Namoi. Current 'high salinity' areas include the Mooki River and Cox's Creek catchments (Mawhinney, 1998) and the Peel River catchment (Nancarrow, 1998). In light of the MDBC salinity audit results, consideration should be given to evaluating the rates of groundwater rise across the Namoi to identify areas most at risk of future salinity impacts.

The increased presence of sediments in waterways contributes to increased turbidity, which in turn may affect processes such as photosynthesis by aquatic plants. The sediments also carry attached pollutants such as heavy metals and pesticides, and plant nutrients such as phosphorus and nitrogen. Water with high turbidity will also require higher levels of treatment if required for human consumption. Stream turbidity in the Namoi catchment generally increased with distance downstream (Nancarrow, 1998; Mawhinney, 1998). Highest turbidities were recorded in the lower sections of the Mooki River, Cox's Creek and Namoi River, most likely due to the transport of sediments following disturbance within catchments, stream bed and bank erosion, or direct access by livestock. No trends in turbidity were recorded at sites reported by Nancarrow (1998) for the 8 year period between 1991-1998, although both increasing and decreasing trends were recorded for the five years between 1992-1997 at sites monitored by Preece (1998). As sources of turbidity are likely to vary from site to site, management of turbidity must also be site specific. Management should focus on reducing the effects of catchment and bed and bank erosion, and stock access that are usually the most common causes of increased turbidity. An understanding of stream geomorphological processes will be important so that the underlying causes of bed and bank erosion are addressed.

Nutrient (phosphorus and nitrogen) concentration measured at various points across the Namoi catchment were variable but generally high, responding to inputs such as STP effluent and diffuse runoff, and in-stream processes (Mawhinney, 1998; Nancarrow, 1998). No trends in phosphorus concentration were recorded, but nitrogen levels increased significantly in the Namoi at Gunnedah between 1991 and 1998 (Nancarrow, 1998). This trend is likely to have resulted from increases in catchment erosion, and bank and bed erosion, and increased land use. While nutrient concentrations measured at river sites have been at levels that can support nuisance algal growth, algal blooms are most likely to occur in the still, warm conditions that prevail in reservoirs such as Chaffey, Keepit and Split Rock dams, especially during summer and autumn (DLWC, 1996). Research at Chaffey Dam has found that the nutrients (e.g. phosphorus) that support algal growth come from both internal (in-reservoir) and external (catchment) sources (Whittington *et al.*, 1998). This highlights the need for a combination of catchment and reservoir management actions if algal growth is to be managed and algal blooms avoided. While nutrients, combined with climate and the dam morphology and dynamics are all involved, management strategies to control the problem require further resolution.

Dams and weirs may also cause water quality problems in downstream areas. Thermal stratification can lead to low dissolved oxygen and increased nutrient and heavy metal concentrations in bottom waters; this poor quality water can adversely affect biota such as fish and invertebrates if released. Cold-water released during summer for irrigation can reduce stream temperature and affect the biology (e.g. growth) of biota such as fish. Dams and weirs can also be a source of algae that help 'seed' blooms in downstream areas, should conditions be suitable. While little information is available to assess the prevalence of these issues, they are being considered in the development of programs to monitor the effects of environmental flows in the Namoi.

Pollutant transport along the river system of the Liverpool Plains was highest during relatively infrequent flood events. While nutrients carried during storm flows were mainly in particulate form (bound to sediments), the proportion of particulate and bio-available (i.e. readily available for uptake by plants and algae) forms varied, suggesting that a number of pollutant generation, transport and transformation processes operate (Mawhinney, 1998). In general, Mawhinney found that water from the Liverpool Plains was of poorer quality and was diluted by water from the upper catchment areas when it reached the Namoi River. The pattern of high pollutant transport during flood events recorded for the Liverpool Plains is likely to apply elsewhere across the Namoi catchment.

The Namoi River system has been shown to contribute the largest loads of salt, suspended solids and nutrients of the northern rivers flowing to the Barwon-Darling system (Nancarrow 1998). Given the relatively large pollutant loads discharged from the Namoi to the Barwon-Darling, catchment and river management plans for the Namoi need to consider both local and regional objectives. Monitoring programs should also be considered in this light. While the Liverpool Plains Water Quality Project is focussed on local issues, other water quality monitoring in the Namoi is undertaken as part of regional programs to meet the management needs of determining trends, developing existing linkages with the Phosphorus Reduction Campaign, Nutrient Management Plans, Riverwatch, Rivercare 2000 and other community awareness programs, and to refine these plans and to assess their effectiveness (Wood, 1997). These are all broad issues rather than questions that might be better stated as hypotheses along the lines of those being proposed for the IMEF plan being developed for the Namoi by DLWC. Monitoring could be developed to address more specific issues, and this would require more targeted site selection and sampling frequency, as suggested by Nancarrow (1998). Nancarrow also suggests that the results of nutrient and general water quality, pesticides and biomonitoring should be integrated and this view is strongly supported.

An issue that is being targeted with more specific studies is that of agricultural chemicals, in particular pesticides (sampling is orientated around spraying seasons and specific areas such as the Liverpool Plains). The 97/98 report on pesticide monitoring found that 65% of samples collected exceeded the ANZECC recommended endosulfan guidelines, and this was similar to the previous three seasons (Muschal 1998). Pesticides may also enter the groundwater (Timms and Cooper, 1998). A study of pesticide use on the Liverpool Plains (Mawhinney 1998b,c) highlighted two issues. Firstly, where agricultural chemicals were used, a wide range of chemicals were detected, often at high concentrations. These included atrazine, endosulfan, metolachlor, and less often or at lower concentrations, prometryn, diuron, dimethoate and parathion methyl. Secondly, the levels often exceeded those for drinking water and for protection of aquatic ecosystems. While pesticide application practices have improved considerably in recent years, therefore reducing the level of pesticide drift that reaches waterways, further efforts to reduce pesticides transported in surface runoff are needed, especially in dryland areas.

Microbiological testing in the Namoi River Catchment has shown contamination downstream of Narrabri to originate from the Narrabri sewage treatment plant and from sheep upstream of the STP (Deal *et al.*, 1995; Deal and Wood, 1997). Sample sites are too sparse to gain a detailed picture of possible microbiological contamination in the catchment although problems may be expected at more sites because of the intensive land use of much of the catchment.

In conclusion, the chemical water quality of the Namoi River system is generally moderate to poor, with high levels of nutrients, areas contaminated by agricultural chemicals, and areas with on-going salinity problems. While trends for parameters such as salinity, turbidity and nutrients may vary in the short term, longer term trends show little signs of a decline through time. This may be interpreted as management strategies barely keeping pace with pressures on water quality, or the ineffectiveness of the strategies. It is recommended that water quality monitoring programs are reviewed so that the effects of catchment and river management plans currently being developed may be clearly evaluated.

4.3 Biological Conditions

4.3.1 Invertebrates

Invertebrates can be a sensitive way of assessing the ecological condition of rivers and lakes including the effects of flow regulation, habitat modification and water quality. Several studies on invertebrates have been done on the Namoi and other rivers in the region. Biological monitoring has been undertaken in the Namoi River catchment since 1992/93 (Royal and Bales 1994). This initial work began using artificial substrata at 17 sites. The work was expanded to 39 sites in 1993/94 (Royal and Bales 1994) with a change of method to collections from natural habitats. This change of methods did not allow direct comparisons between the years. Moroney *et al.* (1997) could not detect any harmful effects of pesticide applications on the re-establishment of macroinvertebrate assemblages at the large spatial scales monitored until 1995. It may be that effects occur only over small spatial and temporal scales and these may be hidden among the broader patterns found with the current monitoring design.

Intensive sampling in 1995/96 along the Macquarie River found correlation between sediment bound endosulfan but not water column concentrations (Moroney *et al.,* 1997). A recommendation to establish the causal mechanism of this relationship apparently was not pursued in favour of studying areas that had higher pesticide use (Moroney *et al.* 1997). Unfortunately, high flows disrupted the 1996/97 sampling period. Invertebrate sampling undertaken in 1997/98 (Brooks 1998) did not follow up on previous year's recommendations (e.g. an intensive study along a single river or concentration on areas of higher pesticide use). Sampling was at 22 sites throughout the Central and North West regions, five of which were in the Namoi River catchment. The study was based on the hypothesis that impact caused by pesticides would cause macroinvertebrate communities to become more dissimilar in irrigated and non-irrigated areas during the spraying season, and should become more similar afterwards if recovery occurs. The study failed to clearly demonstrate this effect and the changes observed could not be clearly related to endosulfan (Brooks 1998).

It was suggested that chronic rather than acute effects of endosulfan might be the cause of changes and that experimental studies should be instituted to elucidate such effects. It was also recognised that the current program was unlikely to establish the effects of endosulfan because the control and test sites were in different geographic regions. Sampling from the First National Assessment of River Health (FNARH) will be undertaken in the region, which may help to address the problem because the methods match test and reference sites based largely on their physical characteristics. Unfortunately, no indication was given that further thought was given to the study design for FNARH sampling with regard to assessing the effects of pesticides. It was recommended that a risk assessment should be undertaken to determine the likely risk to biota from pesticides and that this should provide direction for experimental studies.

In conclusion, studies on invertebrates to assess the effects of pesticides have been designed on the assumption that pesticides would cause damage. Unfortunately, methods have changed from year to year and recommendations from previous studies have not been followed up. Relatively few sites scattered over a large area and the confounding effects of multiple land uses have probably caused the studies to have a low power (ability to detect change), resulting in inconclusive findings. A reason for using invertebrates to assess water quality is that they should summarise water quality for some time before their collection. As such, it is unlikely that they would be correlated with spot water quality measurements taken at the time of collection. Marchant *et al.* (1997) showed that correlations between invertebrates and water quality in the Yarra River were only found when water quality variables were averaged over a period before the biota were collected. More intensive study designs with experimental work are probably warranted.

4.3.2 Fish

The CRC for Freshwater Ecology and NSW Fisheries conducted the NSW Rivers Survey, a state-wide survey of riverine fish communities and their habitats (Harris and Gehrke 1997). Three sites in the Namoi catchment have been sampled regularly since 1994 (Table 6) and one site (Cockburn River) was sampled once. A total of 18 native and six alien fish species were predicted to occur in the Namoi catchment, but only 11 and 3 species, respectively, have been found (Harris and Gehrke 1997). Seven native fish either no longer occur in the catchment or, at best, are in sparse and fragmented populations. Four of these are threatened species (Pollard *et al.* 1990; Wager and Jackson 1993; Harris and Gehrke 1997). Two additional species, brown trout, *Salmo trutta* and rainbow trout, *Oncorhynchus mykiss,* continue to live in headwaters streams but these trout habitats were not chosen among the three randomly allocated Namoi sites of the NSW Rivers Survey.

Fish in the Peel River downstream of Chaffey Dam were sampled twice in 1990 by NSW Fisheries (Bishop and Harris 1990). Five native species were recorded (Australian smelt, *Retropinna semoni*; Freshwater catfish; River blackfish, *Gadopsis marmoratus*; western carp condition. Native fish are few in number; many of the previously recorded species can no longer be found; fisheries productivity has declined alarmingly except in the artificial water storages and the fish fauna is dominated by alien pest species such as carp, *Cyprinus carpio*, and gambusia, *Gambusia holbrooki*. Substantial aquatic biodiversity has been lost as a result of this deterioration. Nevertheless, some recreational fisheries remain in the Namoi catchment. In the lower river channels, these are mainly based on wild populations of native fish including Murray cod, *Maccullochella peelii*, and golden perch, *Macquaria ambigua*. Freshwater catfish, *Tandanus tandanus*, are also present although the numbers of this species have declined greatly in recent decades. The threatened species, silver perch *Bidyanus bidyanus*, still occurs in the catchment. Substantial fisheries in Keepit, Rocky Creek and Chaffey dams depend on stocked and wild populations of native fish. Rainbow trout, *Oncorhynchus mykiss* and brown trout, *Salmo trutta*, occur in cooler headwater streams over 600 metres in altitude and are regularly stocked.

4.3.3 Instream and Riparian Vegetation

The only reported study of the Namoi's aquatic vegetation recorded (in 1994) some well-established populations of common species in the Macdonald and Manilla, but few in the Cox's, Mooki, upper Peel and Namoi main stem (North-West Catchment Management Committee, 1996). Therefore there is a clear need for a more thorough characterisation of the species distribution patterns and habitat preferences. Aquatic macrophytes are a major provider of in-stream habitats for fauna, including acting as a reservoir of populations of plankton.

There has been no specific survey of the condition of the riparian vegetation throughout the Namoi River system, and there is only a broad knowledge of vegetation composition and changes arising from land clearance. This knowledge comes from various regional land use, river corridor, wetland and vegetation studies, which have described the general nature of the riparian zone and the dominant plant species. The data from the Wetlands Survey (DWR, 1992) provides an overview of the Namoi systems, although the focus of this survey was on wetlands and the data are limited to a general description of the dominant species along major channels and tributaries and around wetlands. These data are lacking in that they do not provide information on the lateral extent (with respect to the floodplain limits) and longitudinal continuity and condition of riparian systems (vegetation, fauna, soils), nor about the relative importance of impacting processes (grazing, flow regulation etc.) in the different regions.

Along the Namoi main stem there is a characteristic longitudinal and lateral continuum of riparian vegetation which can be recognised, at least for the dominant woody species (Table 7). In the upper mobile and meandering zones, the dominant species are river oak and red gum, with the former extending downriver mainly as a bank and bar species. Red gum continues through the anabranching zone and is found with coolibah, which is often the dominant in the lower distributary systems. It is not clear what the structure of the riparian vegetation on the Liverpool plains might have once been, but presently it is perceived as poorly developed in terms of woody plants. This requires investigation.

Despite the lack of basic and specific inventory data, there is a widely stated belief in many reports that the in-stream and riparian vegetation is severely degraded in various parts of the gudgeon, *Hypseleotris klunzingeri*, and carp gudgeon, *Hypseleotris* sp.). Australian smelt were abundant and river blackfish were common, but few of the other species were collected. Alien fish present were rainbow trout, goldfish, *Carassius auratus* and carp. Several native species that were predicted to occur in this reach were not recorded, including silver perch, Murray cod and golden perch. Sick and dead fish, especially river blackfish, were collected near the dam wall. Fish losses were attributed to poor water quality below the storage.

A river-health study using the Index of Biotic Integrity (IBI) has recently been completed with data from the NSW Rivers Survey (Harris and Silveira 1999). The IBI uses 11 metrics based on fish-community data to rank the river health of sites. As well as an IBI score, river health is generally expressed qualitatively, ranging from 'Excellent', 'Good', Fair', 'Poor' to 'Very Poor'. The three regular Namoi sites were classed as either 'Poor' or 'Poor-Fair', and their IBI scores were lower than many other Darling Region river sites.

Table 6: Abundance of fish species recorded at sites in the Namoi River catchment. Data from the NSW Rivers Survey (Harris and Gehrke 1997). Surveys 1 – 5 occurred from October 1994 to April 1999.

River & Town*	Species name	Survey 1	Survey 2	Survey 3	Survey 4	Survey 5	Total
Cockburn,	Cyprinus carpio			1			1
Limbri	*Gambusia holbrooki*			2127			2127
	Hypseleotris spp			33			33
	Tandanus tandanus			2			2
	Carassius auratus		19		18	6	43
MacDonald,	*Gadopsis marmoratus*	2	19		4	4	29
Bendemeer	*Gambusia holbrooki*	3	2091	3	9		2106
	Hypseleotris spp	2	28	7	49	32	118
	Macquaria ambigua					2	2
Namoi,	*Bidyanus bidyanus*				2		2
Boggabri	*Carassius auratus*	1		4		2	7
	Cyprinus carpio	10	10	9	3	22	54
	Hypseleotris spp	4	2	16	11		33
	Leiopotherapon unicolor					1	1
	Maccullochella peelii				1		1
	Macquaria ambigua	2		2	7		11
	Melanotaenia fluviatilis	4		2	26	103	135
	Nematalosa erebi	2	1	3	5	88	99
	Retropinna semoni	3	6		6	27	42
	Tandanus tandanus	1	1		2		4
Peel,	*Carassius auratus*	2	1	3			6
Attunga	*Craterocephalus stercusmuscarum*					1	1
	Cyprinus carpio	52	35	14	12	54	167
	Gambusia holbrooki	6	1	3	15		25
	Hypseleotris spp	5		3	10	1	19
	Macquaria ambigua	12	8	2	4	2	28
	Melanotaenia fluviatilis		3		9	55	67
	Nematalosa erebi		3	22		8	33
	Retropinna semoni	1	7	3		1	12
Totals		112	2235	2259	193	408	5207

* Town nearest the NSW Rivers Survey site.

The poor condition of native fish in the Namoi catchment reflects the river's degraded

Namoi system. This has occurred, not surprisingly, in those areas that have experienced the most intense land pressures for agricultural development. In many areas the floodplain has been largely cleared and the only riparian vegetation is that left in the bank and channel zones. Although limited in extent compared with the whole floodplain, these zones may have a functional importance much greater than their area would suggest, especially in terms of sediment retention and nutrient interception (Brunet *et al.* 1994).

As well as changes due to human influence, the dominant riparian species are related to climate, soil texture, depth and stability of the river sediments. However, very few studies have been made of the dynamics of riparian vegetation in Australia. Recent studies elsewhere have demonstrated that the temporal dynamics of river deposits is a key factor in understanding the plant species patterns. Much of the biotic diversity in the riparian system is dependent on the formation and reformation of sedimentary patches. This means that the wide range of space and time scales within which river processes operate must be taken into account when studying and managing their riparian zones.

Table 7. Summary of dominant riparian species in various reaches of the Namoi system (Source DWR 1992).

River	Reach	River Oak	Red Gum	Willow	Cooba	River Cooba	Coolibah	Apple	Lignum	Riparian Width & Condition
Namoi	Keepit – Peel	P	P	P						narrow
Namoi	Peel-Mooki	P	D	P						mostly narrow
Mooki		P	P	P				P		mostly cleared, narrow
Namoi	Mooki-Cox's		D	P				P		slumping common
Namoi	Cox's-Maules		D	P						narrow strip
Namoi	Maules-Mollee		D	P						narrow
Maules	Maules	D	D	D						degraded
Pilliga Creeks			D							intact, no floodplain
Nandewar Creeks			D		D	P				some intact, some fully cleared
Namoi	Mollee-Gunidgera		D			P	D			floodplain woodland relatively intact
Namoi	Pian Creek		P			P	D		P	tree death and cumbungi spread related to water storage
Namoi	Gunidgera Creek		D			D	D			
Namoi	Gunidgera weir - Weeta Weir		D				D			most floodplain cleared
Namoi	Weeta-Barradine		D							intact narrow
Namoi	Myall Camp						D			intact?
Namoi	Lower Namoi Warrambools						D			intact band
Namoi	Baradine						D			intact?
Namoi	Baradine-Barwon		P			D	D			intact?

D = dominant, P = present

4.4 Stream Condition Assessment

In Australia, broad objectives of river management include improving the condition of degraded rivers, and protecting healthy rivers, to provide for the environmental, social and economic needs of current and future users.

River management initiatives include programs on water quantity, bed and bank erosion, riparian vegetation, water quality, fish, and aquatic animals. Strategies to address these include licensing of water withdrawals (diversions), structural works to protect streambanks, controlling riparian clearing, riparian planting, weed control, licensing wastewater discharges, licensing of sand and gravel extraction, provision of environmental flows and increasing in-stream habitat. Each of these programs would have specific objectives but they would also be intended to contribute to overall management and enhance the environmental condition of streams. The Index of Stream Condition (ISC) was developed to assist with this overall management of rivers (DNRE, 1997). Assessment of stream condition is fundamental to the setting of priorities and the allocation of resources amongst the various strategies by state and regional managers. The ISC can also be used to measure the effectiveness of the integrated management effort and provide information with which to set benchmarks for stream condition throughout the state. The ISC is available for on-going assessment where information is collated, processed and used by waterway management agencies; it provides direct input to management decisions.

Thoms (1998), using the Index of Stream Condition, has surveyed the overall condition of rivers in the Namoi catchment. Five components are included in the ISC:

- Hydrology (an assessment of flow);
- Physical form (condition of the channel and physical habitat);
- Streamside zone (measurement of quantity and quality of streamside vegetation and wetlands);
- Water quality; and,
- Aquatic life (macroinvertebrate populations).

There are five sub-indices, one for each of the five chosen components of stream condition. Scores for each of the sub-indices are summed to provide the overall score of the ISC. The sub-index scores are determined by assessing and summing the scores of indicators. The choice of indicator determines the actual measurements that are required. Most indicators are given a numerical value or rating based on a five-point scale that provides a comparison with natural conditions, as shown in Table 8. Categories within each of the sub-indices are rated from 0 (far from ideal) to 5 (ideal), where the rating provides an indication of deviation from natural or ideal conditions. Summed rating scores are determined from the various categories for each sub-index and a factor is applied to adjust the score to a maximum of 10. The aggregate of the sub-indices gives a maximum ISC index score of 50, and gives an indication of the stream condition at each site or reach. A site with a total ISC score below 25 is considered to be in **poor** condition, 25-35 in **good** condition and 36-50 in **excellent** condition. However, it is important to note the contribution of each sub-index to the overall index, where a site may boast a good or excellent total ISC score despite having a low score for one of the sub-indices.

Table 8: Five-point scale for indicator measurements.

Category	Numerical Value

Essentially natural	4
Near natural	3
Moderate modification	2
Major modification	1
Highly modified	0

Output from the ISC is presented in Figure 7. The ISC scores at sites across the study area ranged from 18 to 41.7 with a mean of 27.3. Of the sites examined in the Namoi River Catchment 50 % were in poor condition, 33.3 % in good condition, however, all but one of these had an ISC score less than *29*, and only 16.7 % were in excellent condition. Generally, the upland sites were in excellent condition and lowland sites in heavy agricultural areas were in poor condition.

On the Peel River ISC scores were 33.7 to 24.1. Impacts included flow regulation and major degradation of the streamside zone and riparian vegetation. Peel River sites also had poor water quality sub-index scores, mainly because of elevated total phosphorus concentrations. On the Cockburn River ISC scores ranged from 25.9-27.1, and were both considered to be in good condition with physical form and streamside zone sub-indices having very low scores. On Coxs Creek very low scores for the streamside zone and water quality sub-indices resulted in a low ISC score of 23.8. Sites upstream of Keepit Dam on the MacDonald River have excellent ISC scores with moderate to high scores for all sub-indices. Downstream of Keepit Dam on the Namoi River ISC scores ranged from 18 to 24.4 with low to moderate scores for the hydrology, physical form and water quality sub-indices and very low scores for the streamside zone sub-index condition score.

Sites with excellent stream condition were only those on the MacDonald River (sites N1, N2 and N3), situated in native forest upstream of Keepit Dam. Sites with good stream condition were on the Cockburn River (sites C1 and C4), and the Peel River (sites P1, P3 and P4) and site M1 on the Mooki River. Sites in poor stream condition were those on the Namoi downstream of Keepit Dam (sites N4, N5, N6, N7, N8 and N9) and Coxs Creek (sites CX1 and CX2) and most downstream sites assessed on the Peel (site P5) and Mooki (site M2) Rivers. The streamside zone sub-index and the physical form sub-index were very low for many of the sites examined in all of the river systems in the Namoi River catchment, and are areas that require urgent attention.

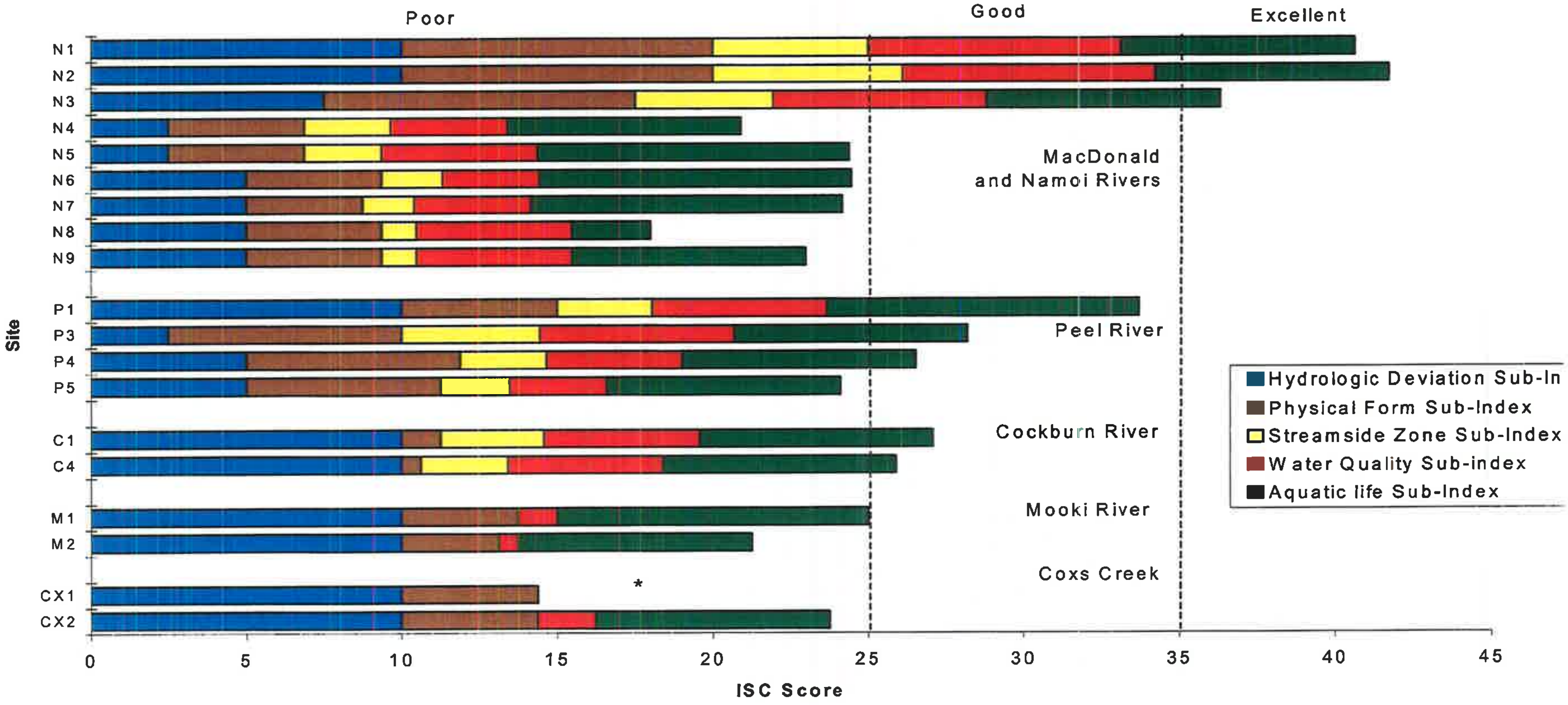


Figure 7: Namoi River Catchment Index of Stream Condition. * - Water Quality and Aquatic Life sub-indices could not be calculated.

4.5 Summary of Condition

Major impacts on the rivers in the Namoi catchment include:

- Degradation of the riparian zone, or complete lack of riparian zone;
- Channel morphology impacts such as bank instability, riverbed instability, and aggradation of sediments. This is primarily due to two factors: 1) excessive sand and gravel extraction, and 2) fluctuating water levels;
- Morphological and biological effects of dams and river regulation;
- Poor land management practices;
- Poor water quality, mainly because of high total phosphorus, turbidity and electrical conductivity levels; and
- Poor native fisheries, with low species diversity and abundance, especially in upland areas due to the presence of barriers to fish migration.

Examples of problems requiring attention are:

- Peel River at Calala (site P4) - vegetation encroachment, log jam;
- Cockburn River - poor riparian vegetation and unstable river channel due excessive sand and gravel extraction;
- Mooki River - no riparian vegetation buffer zone, cropping up to the river banks, sedimentation, unstable river channel;
- Namoi River - relatively poor riparian vegetation cover downstream of Keepit Dam; and,
- Namoi River - between Carroll and Narrabri, bank erosion resulting from a lack of riparian vegetation, fluctuating water levels and sand and gravel extraction.

5 THREATS TO RIVER HEALTH

Major threats

Threats to the environmental condition of the Namoi River system have been listed for the 7 river regions identified in section 2 (Table 9). A total of 23 threats were identified, with the anabranch, distributary and meander zones of the river system most at risk to environmental degradation. This is consistent with the results of physical habitat assessments and ISC scores recorded for sites across the study area (Table 5 and Figure 7). The alteration of river flows, clearing or absence of riparian vegetation, and threats resulting from land management activities (e.g. nutrient and pesticide transport to waterways) are threats common to each of the river zones. Addressing these threats is consistent with the aims and objectives of the IMEF program, which is part of the NSW Water Reforms, and the recommendation of numerous reports on the state of natural resources in the Namoi River catchment.

Confounding of environmental objectives

A major issue for rehabilitation in the Namoi catchment is the confounding of environmental objectives. Rehabilitation is unlikely to succeed unless the main degrading influences are dealt with in a comprehensive way. For example, riparian regeneration, carp control or environmental flows will not produce the desired results if toxic agricultural chemicals still flow into the rivers, or if coldwater pollution prevents normal biological functioning in major parts of the river channels (Table 10). Native fish communities cannot respond effectively to rehabilitation programs that do not include all the relevant environmental factors: habitat structure, water quality, fish passage, alien species and energy flow. Programs need to emphasis the functioning of the whole ecosystem.

Table 9: Major threats to environmental condition of the 7 river regions in the Namoi

	Active in-channel physical structure	*Riparian Vegetation*	*Floodplain functioning*	*Water quality*
Pool	• Flow alteration • Decrease in riparian vegetation • Alien species • Stock access • Dams and weirs	• Flow alteration • Clearing • Stock access • Alien species		• Flow alteration • Lack of riparian buffer • Increased nutrients from agriculture • Increased toxicants from agriculture • Increased sediment input • Dams and weirs
Constrained	• Decrease in riparian vegetation • Alien species • Stock access	• Stock access • Alien species		• Increased nutrients from agriculture • Lack of riparian buffer • Increased toxicants from agriculture • Increased sediment input

Table 9: Major threats to environmental condition of the 7 river regions in the Namoi

	Active in-channel physical structure	*Riparian Vegetation*	*Floodplain functioning*	*Water quality*
Armoured	• Flow alteration • Decrease in riparian vegetation • Alien species • Stock access • Sand and gravel extraction	• Flow alteration • Clearing • Stock access • Alien species	• Flow alteration • Levees • Floodplain land use change	• Flow alteration • Lack of riparian buffer • Increased nutrients from agriculture • Increased toxicants from agriculture • Increased sediment input • Dams and weirs • Genetically modified organisms (GMO)
Mobile	• Flow alteration • Decrease in riparian vegetation • Alien species • Stock access • Sand and gravel extraction	• Flow alteration • Clearing • Stock access • Alien species	• Flow alteration • Levees • Floodplain land use change	• Flow alteration • Lack of riparian buffer • Increased nutrients from agriculture • Increased toxicants from agriculture • Increased sediment input • Dams and weirs • Genetically modified organisms (GMO)
Meander	• Flow alteration • Decrease in riparian vegetation • Alien species • Stock access • Sand and gravel extraction • Dams and weirs	• Flow alteration • Clearing • Stock access • Alien species	• Flow alteration • Farm Dams • Levees • Draining of wetlands • Floodplain land use change	• Flow alteration • Lack of riparian buffer • Increased nutrients from agriculture • Increased toxicants from agriculture • Increased sediment input • Dams and weirs • Genetically modified organisms (GMO)
Anabranch	• Flow alteration • Decrease in riparian vegetation • Alien species • Stock access • Sand and gravel extraction • Dams and weirs	• Flow alteration • Clearing • Stock access • Alien species	• Flow alteration • Farm Dams • Levees • Draining of wetlands • Damming of anabranch channels • Floodplain land use change	• Flow alteration • Lack of riparian buffer • Increased nutrients from agriculture • Increased toxicants from agriculture • Increased sediment input • Dams and weirs

Table 9: Major threats to environmental condition of the 7 river regions in the Namoi

	Active in-channel physical structure	*Riparian Vegetation*	*Floodplain functioning*	*Water quality*
				• Genetically modified organisms (GMO)
Distributary	• Flow alteration • Decrease in riparian vegetation • Alien species • Stock access • Dams and weirs	• Flow alteration • Clearing • Stock access • Alien species	• Flow alteration • Farm Dams • Levees • Draining of wetlands • Damming of anabranch channels • Floodplain land use change	• Flow alteration • Lack of riparian buffer • Increased nutrients from agriculture • Increased toxicants from agriculture • Increased sediment input • Dams and weirs • Genetically modified organisms (GMO)

Table 10: Interaction of effects associated with degrading influences

Threat (if...)	Outcomes (then...)	Basis (because...)
• Continuing high nutrient and pesticide exports to channels	• algal blooms – public health • fish kill • turbidity • Reduced capacity for assimilation of wastes • Reduced public amenity	• limited and reduced capacity for riparian and channel assimilation • Simplified aquatic communities • Habitat degradation – light limitation, blanketing of substratum, loss of macrophytes
• Increasing water demand for irrigation	• reduced channel maintenance flows • Increased flood effects • Loss of habitat for aquatic organisms	• resource competition • Reduced channel capacity • Channel contraction
• Continued mineral resource extraction from active channels	• channel degradation • Loss of habitat • Reduced water quality	• river activates new bedload from the channel and banks • Increased turbidity
• Continuing bank erosion	• channel degradation, bed erosion • loss of habitat for aquatic fauna and flora	• increased sedimentation • Bank slumping • Loss of riparian zone • Incised or broadened channels
• Grazing and clearing of riparian vegetation and desnagging	• bank instability • increased sediment and pollutant inputs • reduction of habitat and biodiversity • reduced capacity for natural revegetation in riparian zones • increased weediness • reduction in water quality	• reduced buffering capacity for surface and groundwater flows • Channel degradation • Stock damage to banks • Increased nutrient levels
• Spread of riparian weeds	• reduction of habitat and biodiversity • increased management costs	• influence on riparian and aquatic environment; competitive nature of certain weeds
• Continuing lack of baseline data on channel morphology, aquatic and riparian environment	• inability to detect and manage specific and significant change in river and floodplain systems • Inability to determine if management strategies have been effective	• little basis for priority setting
• Floodplain management without environmental values considered	• reduced value of the floodplain to the channel • Loss of biodiversity • Altered nutrient cycling and carbon processing	• river-floodplain connections function to increase retention of sediment etc. and source for aquatic biota recolonisation of channels

5.1 Current Threats and their Scientific Basis

5.1.1 Physical condition of the river channel

The physical nature of a river channel will reflect many factors. Of primary importance are the volume and distribution of water and sediment supplied from upstream. Factors such as channel morphology, riparian vegetation and valley condition also contribute to the physical condition of a river. These controlling processes and factors help to define the habitat available for animals and plants to live. Habitats may be considered at a number of scales (functional sets), all of which relate to the stream-forming processes occurring within the river. These 'functional sets' may include large-scale features such as flood runners. Medium scale features include high and low flow channels of streams, riffles, pools, in-channel gravel bars, backwaters, billabongs and anabranches. Small-scale features include emergent and submerged vegetation, submerged wood (snags) and other substrata.

The physical condition and quality of both in-stream and floodplain habitat for the aquatic organisms of the Namoi River catchment has been assessed by Thoms (1998) to be poor. However, it is not clear at what scale this degradation occurs, i.e. large, medium or small. An improved understanding the scale of degradation is important for future river restoration purposes.

5.1.2 Riparian and aquatic vegetation

The threats to the quality and functioning of riparian and aquatic vegetation come from many directions, but most stem from human activities. These influences arise from changes both in water quality and flow regimes in streams and rivers, as well as from land-based pressures to modify or eradicate the riparian vegetation or to remove its valuable soil and sediment resources. Reduction of habitat value for riparian and aquatic plants arises through combinations of the following factors:

- clearing vegetation for farmland and other development;
- mining sand and gravel sediments;
- introduction of alien species;
- vegetation conversion through stock grazing and forestry activities;
- river regulation and water harvesting;
- thermal pollution from storages;
- human recreation and associated infrastructure.

The impacts of these activities are site-specific and inter-related. For example, reduction in the area of riparian vegetation will lead to a reduction in detritus inputs to the stream and increases in summer water temperatures and light levels, which in turn will increase the growth of aquatic primary producers, including algae. Changes in water quality and terrestrial habitat values follow.

Secondary effects may take some years to appear. For example, grazing by domestic stock, loss of high flows and shortage of seed sources are factors most likely to lead to regeneration failure in riparian vegetation. For a tree-dominated system this may not show until present stands age and die, and it is noticed that they are not being replaced.

5.1.3 Fish

Degraded water quality

The New South Wales Government published a set of environmental objectives (Environment Protection Authority, 1997) as part of the NSW Water Reforms. These objectives included a discussion paper on the condition of the Namoi River catchment and dealt with land and water use, water resources and development and related environmental issues. Many problem areas were identified in each of these topics. Only three of 14 sites in the catchment met selected water quality criteria for fish in better than 75% of samples, and eight of the sites met the criteria in less than 25% of samples. Particular water-quality problems include high phosphorus concentrations, agricultural chemicals that are directly toxic to fish (notably endosulfan) or can destroy aquatic plant beds that are critical habitat features (e.g. atrizine). Coldwater pollution from dam releases, faecal coliform bacteria and turbidity are other important water-quality problems affecting fish in the catchment (Environment Protection Authority 1997).

Bishop and Harris (1990) recommended remedial works to avoid the cold-water and toxic effects of hypolimnetic (bottom water) releases in the Peel River below Chaffey Dam. Coldwater pollution in the Macquarie River catchment has a profound effect on river health and extends for more than 300 kilometres downstream of Burrendong Dam (Harris 1997). A comparable effect is expected to occur below Keepit Dam and, to a lesser degree, Chaffey Dam. Although full data are not available, it is understood that the multi-level offtake at Split-Rock Dam is not currently operated so as to prevent downstream coldwater pollution.

Altered flow regimes

The NSW Water Reforms' environmental objectives also described substantial disruption of the river's natural flow regime, with a range of impacts on riverine ecology and native fish communities. Depleted river flows, altered seasonality, reduced incidence of medium and high-flow events and reduced small-scale variability affect native fish either directly or indirectly, and alien species such as carp and gambusia are also favoured by river regulation (Walker and Thoms, 1993; Mallen-Cooper *et al.,* 1995; Gehrke *et al.*, 1995; Gehrke 1997; Driver *et al.,* 1997).

Floodplain anabranches and flood-runners are a major component of habitat for lowland native fish. These periodically-flooded habitats provide food resources that stimulate growth pulses that are in turn essential for successful fish spawning and population recruitment (Thoms *et al.,* 1997). Suppression of high-flow events and building of block-banks and levees have greatly altered this ecological process in the lower Namoi valley, impacting on native fish.

Obstructed fish passage

All native freshwater fish require free passage between sub-habitat areas and many migrate over long distances to complete their life-cycles (Thorncraft and Harris 1999). In the Namoi River, Bony herring, *Nematalosa erebi*, Murray cod, golden perch, silver perch, spangled grunter and Australian smelt are known to be migratory. Weirs and dams that block fish migrations can lead to local extinctions upstream (Harris and Mallen-Cooper, 1994) and to general population declines. The effects of such barriers are cumulative in river systems. The six dams and seven major weirs in the Namoi catchment have undoubtedly contributed significantly to the decline of native fish. Until 1999, none of these barriers had an effective fishway fitted, but the two weirs at Manilla have had rock-ramp fishways completed recently and these are expected to restore fish passage in that particular reach of the Namoi River. Occasional high flows can provide brief periods of fish passage at low weirs, but these are too infrequent and brief to sustain populations without additional passage (Harris *et al.* 1992), although 'drown-out flows' are a component of the Department of Land and Water Conservation's North-West Flow Management Plan for the Barwon-Darling River.

Carp

Carp are both a symptom and a cause of river degradation. Their spread and dominance have been promoted by the various changes that have occurred in river habitats and by the consequent decline in predation by and competition with native fish (Roberts and Tilzey 1997; Harris 1997; Driver *et al.* 1997). Carp do best in turbid, warm, nutrient-enriched waters where flow is sluggish, water-levels are stable and flow disturbances are minimal. Whilst small (less than 200 millimetres), they are prone to population control through severe predation from carnivorous fish and fish-eating birds such as cormorants and pelicans, especially where cover is limited. At larger sizes, carp are subject to few threats.

Carp degrade habitats mainly through their feeding, which disturbs bottom sediments, creates turbidity, releases nutrients and prevents plant growth. These effects are most marked in slow-flowing or still waters with silty or muddy substrates. The enormous biomass-densities of carp that develop in suitable habitats (Driver *et al.* 1997), of up to one carp per square metre of river surface, mean that enormous amounts of soluble nutrients are excreted into the water, providing a further powerful stimulus for blue-green algae (Gehrke and Harris 1994).

5.2 Emerging Threats

5.2.1 Water Quality

The number of cattle feedlots has decreased within the Namoi River catchment in recent years (Mawhinney, DLWC, pers. comm.). However, changed economic circumstances and management methods are may see a resurgence in this form of intensive agriculture. Careful waste treatment at the feedlots will be required in any future expansion to avoid the threat of increased discharge of effluent high in organic and nutrients loads, microbiological contamination and hormone contamination (growth and reproductive hormones).

The discharge of effluent from sewage treatment plants has received much attention in recent years because of its potential role in eutrophication and algal bloom formation in inland waters. There has also been considerable discussion, especially in the U.S., of the role of effluent disposal on growth abnormalities in aquatic biota through endocrine (hormone) disruption. Increasingly, sewage effluent in the Namoi catchment is being disposed of on land rather than discharged directly to rivers. The quality of the effluent is also being improved. However, treated sewage will continue to be discharged to waterways and it is not clear what effect, if any, hormone contamination may have.

Currently about 15% of the cotton crop is genetically modified to produce toxins to control insect attack and this could be expected to increase markedly in the near future (about 30% of cotton in the USA and up to 60% of canola and soy crops are modified). This may be a much safer and more efficient way of applying toxins than spraying but it is possible that the overall loads of toxin produced by the modified plants in the catchment are greater than that applied previously. Additionally, many novel genetic modifications will be forthcoming in the near future. This will be a major change to agriculture and it would seem foolhardy not to consider possible impacts and benefits at the outset so that appropriate management strategies can be formulated.

New pesticides will be developed and applied. These may have unforeseen effects themselves but may also interact with those already being used, or that remain as residues. The possible synergistic effects of various pesticides have received little attention in studies to date.

The effects of habitat degradation on aquatic fauna and the functioning of the river ecosystem are probably extreme throughout most of the Namoi catchment. The effects will be different in different zones of the catchment but little work seems to have been done to link changes in river geomorphology with retention and processing of organic load, nutrients, toxicants or with changes in the biota. Habitat degradation is almost certain to have been a confounding effect in biomonitoring studies looking at the effects of pesticide application.

5.2.2 Riparian and aquatic vegetation

Emerging threats to the existing riparian and aquatic vegetation include:

- more rapid spread of woody and herbaceous weeds in highly disturbed riparian areas;
- complete loss of native woody riparian vegetation over large reaches; among other things, this will make any revegetation work very costly, as it won't be possible to rely on the facilitation of plant spread from remnant patches;
- continued decline of aquatic macrophytes caused by sedimentation and thermal effects, thus reducing in-stream habitat further;
- increased channel sedimentation in lower reaches, exacerbated by infill growth by river engineer plants such as cumbungi.

5.2.3 Fish

The proposal for a radical increase in the height of Walgett Weir is a threat to rehabilitation of Namoi River fish communities. It is estimated that the proposal would inundate 60 kilometres of the Namoi River and 80 kilometres of the Barwon River. The usual ecological problems of stabilised water-levels, bank erosion and slumping, loss of riparian vegetation, stratification and water-quality problems, interrupted food-chain production, loss of biodiversity, blue-green algal blooms and carp dominance can be predicted to follow such a development.

Disease is emerging as an increasing threat to inland native fish. The disease status of Australian fish is poorly understood, but worrying indicators have been documented. Redfin perch, *Perca fluviatilis*, spread EHN disease (epizootic haematopoietic necrosis), a virus which is acutely fatal for several native fish including silver perch and mountain galaxias, *Galaxias olidus*, in the Namoi system, and it also affects other species such as Murray cod (Langdon 1989). The pathogenic tapeworm, *Bothriocephalus* sp. is spreading in native fish with unknown effects after its apparent introduction with carp. In the NSW Rivers Survey (Harris and Gehrke 1997), 4.9% of all fish caught in the Darling River region had externally visible abnormalities such as infections, parasites, tumours and wounds. Approximately one-quarter of all Murray cod and golden perch were affected by such abnormalities. Increasing densities of carp were associated with increasing incidence of visible abnormalities.

Introductions of new fish species unfortunately continue to threaten inland waters. For example, the alien fish, tilapia, *Oreochromis mossambicus,* is abundant in some coastal Queensland waters and has been translocated by bait anglers (Pollard 1990). While intentional and accidental fish translocations continue there is a significant risk that tilapia could enter the Darling drainage system. Tilapia and other similarly invasive species have caused profound ecological disruption in other parts of the world. Once present, control would be no less difficult for tilapia than it is for carp.

5.3 Prioritisation of Threats

There is a number of ways in which threats to the waterways of the Namoi may be prioritised for action. Rutherfurd *et al.* (1998) propose eight categories of river condition, with the greatest priority given to the maintenance or protection of existing high-value or refuge reaches and lowest priority to reaches with little hope of recovery without significant intervention. This approach offers the greatest benefit for money and effort, but may carry with it the risk of perceived inequity within a catchment community. For example, the highest quality river reaches of the Namoi system occur mainly in the upper catchment areas and would therefore have highest priority for protection and improvement effort. The community of the lower catchment areas may resent the resources diverted to the upper catchment, as it is they who must cope with the most degraded components of the river system, that to a significant degree, have been affected by upstream activities. Clear communication of the rationale behind the approach will therefore be required.

In prioritising broad-scale threats, the issue of confounding environmental factors needs evaluation. For example, problems such as toxicants and coldwater pollution grossly modify ecosystem function and need to be resolved so that the rehabilitation of flows, habitat structure, riparian vegetation or fish passage can produce the desired responses in the river's ecology. The resolution of these issues is best achieved via a river management plan, where stakeholders and the community may give due consideration to objective setting and securing the appropriate knowledge of the system, as described in Section 2.4.

5.3.1 Recommended DLWC and NRMC Priorities

The NRMC has identified the following key issues to be addressed in their river management plan (A. Bailey, DLWC, pers. comm.):

- Fish passage;
- Thermal pollution;
- Floodplain management;
- Off-allocation access;
- Wetland status and other riparian vegetation;
- Operation of dams and weirs;
- Cultural and spiritual issues;
- Carp reduction.

These issues are a mixture of ecological, water management and social-economic issues. In terms of managing environmental conditions, the above issues may be considered as part of two key questions:

1. How do we maintain or improve native fish populations?
2. How do we manage our river system to maintain or improve biodiversity and important functions such as riverine and wetland productivity?

Native fish populations are often used as an indicator of river health (Harris and Silveira, 1999), as their presence is dependent on a number of factors such as energy (food) availability, water quality, flow regime and habitat availability. Maintaining biodiversity, and riverine functions such as production and respiration, are also important because they help maintain the resilience of ecosystems upon which we all ultimately depend; the connection of rivers with floodplain and wetland areas is a key component of maintaining riverine health. Maintaining or improving the condition of Namoi River system is therefore dependent on the management of both in-stream and floodplain processes, and factors that threaten them (Figure 8).

Identifying the in-stream reference condition

Establishing a reference condition that serves as a target for future management in catchments that have been extensively modified (e.g. for agriculture) can be a difficult task, and will largely depend on the values attached to the riverine system by local communities (see discussion in Chapter 2). This can be achieved for in-stream conditions by the use of tools such as the Index of Biotic Integrity (based on fish populations) and AUSRIVAS modelling (based on macroinvertebrates). Both models use regional data sets to identify 'reference' sites (not necessarily in the Namoi catchment) where human impacts are considered minimal and conditions are indicative of healthy ecosystems. Comparison of the fish and invertebrate populations at test sites in the Namoi system with that expected to occur at reference sites can be used to establish the relative in-stream health of the Namoi. The reference sites may also serve as targets against which the effects of future management in the Namoi may be assessed.

While the IBI and AUSRIVAS are valuable tools for identifying in-stream reference conditions, no such formal tools are currently available for assessing riparian and floodplain conditions. Given that the riparian zone and the floodplain have been extensively modified and will often not be economically returned to their pre-development state, it is unrealistic to develop reference conditions based solely on pre-development (pre-European) conditions and use them as a target for future management. In this case, measures of intactness and functionality (e.g. length of stream with riparian vegetation that performs key ecosystem functions), or biodiversity and connectivity in key floodplain wetlands are likely to provide a guide to targets that may realistically be achieved or the result of best management practices.

In-stream priorities

The physical habitat, ISC and AUSRAS assessments reported in Chapter 4 were used to provide a relative assessment of in-stream condition across the Namoi catchment (Table 11). This approach may be termed using 'multiple lines of evidence' to establish priorities. The following recommendations are drawn from this assessment and consideration of other factors:

- The MacDonald River above Lowry is considered to be in excellent condition and may be considered as a reference site for upland streams in the Namoi. In keeping with the priorities proposed by Rutherfurd *et al.* (1999), the maintenance of its condition should receive the highest priority in future management and restoration efforts.

- Given its impact on biological and ecological function (e.g. breeding and growth of fish and macrophytes), a review of the extent of cold-water releases from dams should be undertaken as soon as possible. This is especially important to ensure that future environmental flows released as a result of the IMEF process are effective and that cold water pollution does not prevent migratory fish from using fishways when installed.
- The Peel and Cockburn Rivers are in relatively good condition, as is the Manilla River above Split Rock Dam, and should be given the next highest priority in management and restoration efforts. Important issues to be addressed include improving riparian zone condition, reducing the transport of nutrients from the catchments above Chaffey and Split Rock Dams that help sustain algal blooms, managing the salinity threat and managing the effects of stream instability resulting from sand and gravel extraction. The effectiveness of the fishway at Split Rock Dam should be evaluated and research undertaken to develop fishways for high dams such as Chaffey.
- The priority given to the remaining rivers or river zones requires further consideration by the NRMC. Opportunities may exist to significantly improve the relative condition of rivers by addressing one or two factors (e.g. improved riparian condition along the Namoi River between the Manilla River confluence and Narrabri; effective fishways at Weeta, Gunindera and Mollee weirs). The effect of environmental flows should also be reviewed as recommended by the IMEF process, especially in terms of their effects on creeks, flood runners and wetlands in the lower Namoi distributary zone.

Floodplain priorities

Increased salinity is expected to continue as a major land and water management issue. The ecological effects of increased salinity have the potential to negate improvements achieved through management efforts such as the delivery of environmental flows and installation of fishways, therefore salinity management should continue to have a high priority in floodplain areas. While increased salinity is already evident in the waterways of the Liverpool Plains and areas of the Peel catchment, a review of trends in groundwater levels will be useful for identifying other areas at risk to salinity.

Surveys of the riparian condition should be undertaken to identify the remnant stands of intact vegetation in each of the major river zones. A survey of riparian condition is discussed further in Chapter 6. Existing high quality riparian vegetation should be protected, as an example of realistically achievable conditions (future targets for improvement) and as natural seedbanks that will assist efforts for improving degraded riparian habitat.

The condition and biodiversity of key wetlands should be reviewed to provide a baseline to measure the effectiveness of future management, including environmental flows delivered through the NSW water reforms. Given their history in supporting a diversity or abundance of bird and fish populations, or habitat complexity, the following wetlands may be considered as part of this review: Lake Goran, and Gunnible, Gulligal, Barbers and Wirebrush Lagoons. Other wetlands may be added, depending on community priorities.

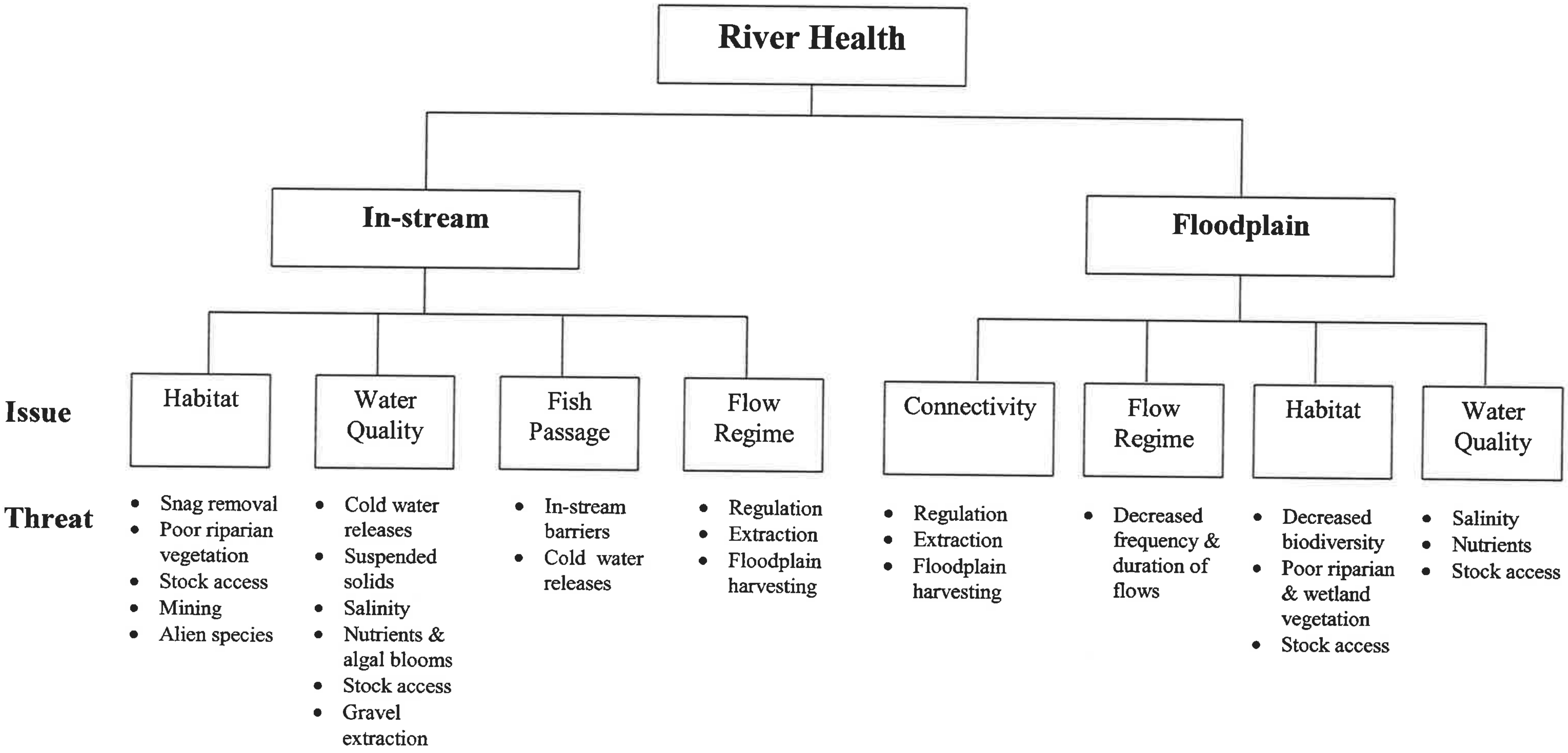


Figure 8: **Summary of key issues confronting riverine management in the Namoi catchment**

Table 11: Combined assessment scores for sites across the Namoi catchment

Site	**N1**	**N2**	**N3**	**N4**	**N5**	**N6**	**N7**	**N8**	**N9**	**P1**	**P3**	**P4**	**P5**	**C1**	**C4**	**M1**	**M2**	**Cx1**	**CX2**
Physical Habitat Assessment*	3	3	3	2	1	1	1	1	1	2	2	2	2	2	2	1	1	1	1
ISC rating*	3	3	3	1	1	1	1	1	1	2	2	2	1	2	2	1	1	1	1
AUSRIVAS rating*	3	3	2	2	3	3	3	2	1	3	2	2	2	3	2	3	2	3	3
Total	9	9	8	5	5	5	5	4	3	7	6	6	5	5	6	5	4	5	5
Revised Rating**	E	E	G	P	P	P	P	P	P	G	G	G	P	P	G	P	P	P	P

* Ratings from the three assessment methods were assigned a score of 3 = excellent, 2 = good and 1 = poor.

** 9 = Excellent, 6-8 = Good, <6 = Poor

6 PROGRAM TO ADDRESS SCIENTIFIC KNOWLEDGE GAPS

Assessing the effectiveness of the river management plan currently being prepared by DLWC and NRMC will require a specifically designed monitoring and evaluation program. With the exception of the Liverpool Plain Water Quality Project, much of the current surface water monitoring is undertaken in the context of the Central and North West Regions. While this might address questions at this broad scale, many issues important within the Namoi catchment may not be adequately covered. Currently, several studies appear to continue with little integration. For example, the water quality and nutrients, pesticides and biological monitoring programs seem to be largely conducted in isolation, or at least reported that way. Monitoring and evaluation arrangements should be reviewed as the NRMC and DLWC develop their plans.

Another consideration is that there is often a mis-match between the predicted and observed physical impact for current levels of catchment change in river systems. This commonly is the result of a 'lag-time' effect, where recent hydrological and catchment development takes some time to be transferred into environmental impact. Hence, monitoring of the river system needs to occur over extended time periods.

6.1 River Geomorphology

The International Union of Geological Sciences (IUGS) recently constructed a list of 27 geoindicators, within 16 fields that assist with the assessment of the condition of abiotic components of the environment. Seven of these 27 geoindicators are directly related to the condition of river systems (Table 12).

Table 12: Physical indicators of river system condition

Indicator	Components
Sediment sequence and composition	Rate of accumulation Sediment calibre Mineralogy Geochemistry
Soil and sediment erosion	Rate of erosion Source of sediment Mode of transport
Stream flow	Total annual flow Variability
Stream Channel morphology	Slope Pattern Cross-sectional dimensions
Stream sediment storage and load	Sediment flux Mode of transport
Surface water quality	Turbidity Total suspended solids
Floodplains/wetlands structure and hydrology	Wetting and drying regimes Connectivity with the river Area

These indicators are suggested to indicate local, regional and global change during observational periods up to 100 years (Osterkamp and Schumm, 1996). To use the physical character of rivers as indicators of environmental conditions, one must understand that rivers are inherently unstable. Natural changes, as well as those induced by humans, can be interpreted as resulting from environmental change. The challenge is to separate the two. Change can occur over a variety of time scales, and effort must be directed to assess not only what is the main stimulus of change, but also over what time scale this is occurring. In addition, river systems vary greatly among themselves and each river exhibits change along its length. The use of indicators, such as those contained in sediment deposits, are useful for extending direct observations to longer time scales (Thoms *et al.*, 1999). Overall the most valuable observations from rivers for use as indicators, are the continuing measurements of water and sediment discharge (Osterkamp and Schumm, 1996).

In order to monitor the condition of the physical character of the Namoi river channel, a number or, all of these variables could measured at established sites within each of the identified river zones. In particular, the condition of important in-stream habitats needs to be assessed. However, the first step must be the establishment of management objectives and goals, identification of the issues to be managed, and the construction of clear questions (hypotheses) to answer. For example, we might hypothesise that with the cessation of sand and gravel extraction, the rates of stream bed erosion and sediment transport in a river reach will decrease and that surface water quality will improve. Variables to measure in this case may include soil and sediment erosion, stream channel morphology, stream sediment storage and load, and surface water quality.

6.2 Water quality

The water quality sampling design has mostly been on the basis of fixed site and times, with a small number of sites dispersed widely over a large area. The ability (power) of such a design to answer any but the broadest scale questions is limited. Study designs linked closely to specific questions or problems within the Namoi catchment are more likely to provide information of direct relevance to management. Similar observations can be made of the pesticides, microbiological and biological monitoring programs.

Revised ANZECC guidelines have recently been released that describe approaches to establishing and monitoring water quality based on, and adapted to local conditions (ANZECC and ARMCANZ, 1999). The guidelines provide a contextual framework for the development of monitoring programs as part of well-defined management experiments, underpinned by statistical designs that will generate meaningful information for future management. The first steps in this process are the establishment of management goals, the issues to be managed, and the questions (hypotheses) a monitoring program is to answer. The following are examples of hypotheses that might be developed by the NRMC and DLWC as they prepare monitoring programs as part of their river management plan:

- Catchment works have resulted in a long-term decrease in salinity in the major rivers and streams of the Namoi Catchment;
- Catchment works have resulted in a long-term decrease in phosphorus load transported to major reservoirs such as Chaffey, Keepit and Split Rock Dams.

6.3 Macroinvertebrates

Reports of previous macroinvertebrate investigations indicate that study designs and sampling methods have changed from year to year and with little apparent coordination. Also, it is not clear whether recommendations for improved information collection and interpretation reported in previous years have been acted on. In general, sampling is at too broad a scale to be of great use for resource managers who usually deal with issues at smaller scales than that served by current monitoring, or in situations where results may be confounded by land use and habitat degradation. Monitoring approaches should be reviewed and developed in response to, and at a scale appropriate to address specific management questions.

Examples of hypotheses to be tested include:

- The improvement of riparian vegetation and bank stability in a river reach has led to an increase in macroinvertebrate diversity and abundance;
- The delivery of environmental flows to wetlands has led to an increase in macroinvertebrate diversity and abundance.

In order to build on previous pesticide toxicity studies, future works should aim to validate laboratory results in the field. This will include consideration of synergistic effects and the effects of toxicants on local species.

6.4 Fish

There is an urgent need to provide effective, broad-scale measures to control carp. Studies on genetic controls are in progress within CSIRO, and on selective baiting within the Cooperative Research Centre for Vertebrate Pest Control. But these are only two of the potential avenues for biological control and their outcomes remain uncertain. There is a need for a concerted national approach to finding the best methods for biological control of carp. Local control measures are being developed for enclosed waterbodies at NSW Fisheries' Narrandera Research Centre and the Cooperative Research Centre for Freshwater Ecology's Lower Basin Laboratory at Mildura. These smaller-scale approaches offer more immediate but smaller-scale prospects for effective control of this pest fish.

Refinement of fishways technology continues to be a knowledge gap. While there has been extensive recent progress (Thorncraft and Harris 1999), ways are still needed to provide effective passage at the numerous fish-passage barriers among the 3500-4000 dams and weirs in New South Wales inland waters. Prioritising sites for restoration of fish passage poses a number of issues. These relate generally to costs and benefits and include factors such as lengths of stream habitat affected, location of the barrier in the system, its height, and the nature of the nearby fish community. These factors have been combined into a fish-passage priority ranking scheme that enables priorities to be objectively determined with all relevant issues being considered (Thorncraft and Harris, 1999). The cost of fishways is often a major disincentive and cheaper designs need to be refined and tested. In addition, the effectiveness of partial-width rock-ramp fishways such as those recently built at Manilla needs to be carefully assessed and an effective design for high dams, such as Keepit, is still needed.

The health of the Namoi River system will need to be monitored to assess the effectiveness of rehabilitation. The Index of Biotic Integrity (IBI) using fish provides a validated and sensitive means of ecological modelling (Harris and Silveira 1999). To make best use of the IBI, suitable sites need to be chosen and fish-community sampling along the lines of the NSW Rivers Survey (Harris and Gehrke 1997) need to be implemented. This work may be provided as part of the Department of Land and Water Conservation's program on Integrated Monitoring of Environmental Flows (IMEF), which are part of the NSW Water Reforms.

6.5 Riparian Inventory and Priorities

The riparian zone demands management as an entity within the landscape and this can form the starting point for catchment management (Petersen *et al.* 1987). This approach requires that inventory of the riparian zone be based on stream and catchment systems rather than regions chosen to represent primarily land-based concerns. Such surveys must be designed to identify the inter-relations between the hydrological, geomorphological and ecological processes determining the structure and function of the riparian zones. The following inventory tasks in approximate order of priority for implementation are suggested to meet the identified needs.

6.5.1 Collation of existing knowledge of riparian systems

This baseline compilation survey would enable more detailed surveys and planning to target priority areas and problems. The following features should be covered:

- Mapping of vegetation, floodplains, distributaries, streams and rivers from remote imagery;
- Broad characterisation and mapping of the extent and condition of each riparian type, and recreational and adjacent land use pressures;
- Collation of available data on riparian fauna, indicating, where possible, its degree of dependency on rivers and streams.

6.5.2 Vegetation and geomorphic survey of riparian zones

This survey would aim to determine the following features:

- Regeneration status and requirements of the dominant species;
- Patch structure and spatial interrelations of vegetation and sediments defined in terms of river flow and habitat requirements of flora (and fauna where possible);
- Actual and potential contribution of riparian vegetation as large woody debris to the channel;
- Rating of stream and river sections in terms of degree and rate of riparian modification;
- Biodiversity survey of riparian zones including their use by aquatic fauna and non-riparian terrestrial fauna;
- Vulnerability map, indicating sensitivity of communities or component species to environmental change and their rehabilitation potential.

When these data are available it will be feasible to identify priority areas for riparian management. At the moment it is difficult to determine priorities owing to the lack of comprehensive information, even at a low level of resolution. Once the current condition of riparian communities has been better described, research into the patterns and dynamics of the following species and processes is likely to emerge as of high priority for ongoing management:

- Determination of the water flow and habitat requirements for natural regeneration of river oak, river red gum and other dominant plant species;

- Examination of the impact of the most common invasive perennial species, on stream fauna, flora and channel dynamics;
- Assessment of the suitability of control methods for noxious plants;
- Comparison of the effects of various riparian types on water quality and stream communities;
- Detection of longer-term adjustment response of riparian zones to recent river and stream modifications, such as channelisation, de-snagging and flow reduction/regulation;
- Development of methods for restoration of riparian vegetation after clearing or invasion;
- Determining the riparian habitat requirements of fauna species of concern and the use of riparian zones by fauna as corridors, including migration movements;
- Development of a set of permanent vegetation monitoring plots at sites selected to detect change.

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ATTACHMENT 2

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Effect of Endosulfan Runoff from Cotton Fields on Macroinvertebrates in the Namoi River

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Of the several pesticides used in the pest management strategy for cotton, endosulfan is ranked as having the greatest impact on the riverine ecosystem. A survey of changes in the densities of six abundant macroinvertebrate taxa (ephemeropteran nymphs *Jappa kutera, Atalophlebia australis, Tasmanocoenis* sp., and *Baetis* sp. and two trichopteran larvae, *Cheumatopsyche* sp. and *Ecnomus* sp.) between upstream and downstream zones of the cotton-growing region in the Namoi River was conducted between November 1995 and February 1996. In November and December 1995, there were few differences in population densities between all sites. In January and February 1996, population densities of the study taxa increased 7- to 10-fold higher at the two reference sites, with low concentrations of endosulfan in sediment and in passive samplers placed in the water column. In contrast, densities of these taxa at sites with exposure to 25-fold higher concentrations of endosulfan remained static and were between one and two orders of magnitude lower than densities at the reference sites in January and February. Population densities of *Baetis* sp., a mobile ephemeropteran, did not indicate any inverse relationship with endosulfan concentrations. Multivariate redundancy analysis indicated that endosulfan concentrations were the leading environmental predictor of changes in density of the five benethic taxa. Laboratory 48-h LC_{50} values of technical endosulfan in river water were 0.6, 1.3, and 0.4 ppb for early-instar nymphs of *A. australis* and *J. kutera*, and larvae of *Cheumatopsyche* sp., respectively. Endosulfan sulfate formed a large proportion of the total endosulfan concentrations measured from *in situ* passive samplers, indicating that its main route of entry into the river is through surface runoff during storm events. © 1999 Academic Press

INTRODUCTION

Approximately 175,000 ha of cotton is grown in northwestern New South Wales, and about 20% of this is grown in the catchment of the Namoi River. The Namoi River is a tributary of the Murray–Darling river system. Agricultural and other activities within the Namoi River catchment, including the production of cotton, have affected the aquatic and riparian environments of the catchment (Arthington, 1995). The construction of dams and water abstraction for irrigation purposes have altered flow regimes, resulting in habitat loss and disruption to flood cycles vital to wetlands and native fish reproduction. Mobilization of top soil in floods leads to siltation in the river, altering flow and substrate morphology, and smothering of organisms. Pesticides used within the catchment may enter the riverine environment either by spray drift or from land runoff during storm events (Arthington, 1995; Cooper, 1996). Large fish kills have been recorded in association with pesticide contamination of water bodies, particularly endosulfan (Bowmer *et al.*, 1995). A suite of pesticides is used by the cotton industry. Of these, endosulfan, a cyclodiene ester insecticide (Fitt, 1994; Shaw, 1995), is ranked as having the highest potential for impact on the riverine environment using risk assessment models (Batley and Peterson, 1992).

The α and β isomers of endosulfan have half-lives of only a few days in water but the toxic biological metabolite, endosulfan sulfate, has an aqueous half-life of several weeks (Peterson and Batley, 1993; Miles and Moy, 1979). Both isomers and the sulfate metabolite of endosulfan are more persistent when sorbed to soil and sediment (Stewart and Cairns, 1974; Rao and Murty, 1980). The longer persistence of endosulfan in soil suggests that field runoff during storm events may be the major source of endosulfan in fish kills.

Although it is well documented that endosulfan affects nontarget fish species at low environmental concentrations (Sunderam *et al.*, 1992), its effect on riverine macroinvertebrates has not been well established (Ernst *et al.*, 1991). Benthic macroinvertebrates are more suitable than fish in field surveys as bioindicators of contaminants because of their relatively large size, ease of collection, predictable phenology, and sedentary nature. By selecting few populations, more effort can be spent collecting precise data on sensitive taxa that are most vulnerable to the potential hazard. In recent surveys, ephemeropteran populations were found to be adversely affected by unidentified environmental

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factors in rivers of the Murray–Darling system, including the Namoi River, where cotton growing is prominent (Brooks and Cole, 1996). It is suspected that pesticides may be one of the factors affecting these macroinvertebrates, as ephemeropterans and trichopterans are known to be sensitive to such chemicals (Muirhead-Thomson, 1973; Hatakeyama *et al*., 1990; Maund *et al*., 1992; Schulz and Liess, 1995).

In a preliminary survey in the Namoi River using a random stratified sampling strategy in riffle habitats, ephemeropterans, trichopterans, and chironomids were found to be the dominant taxa. To study the impact of pesticides on the biota in the Namoi River, the following dominant taxa were selected as bioindicators: three sedentary ephemeropteran nymph species, *Jappa kutera*, *Atalophlebia australis* (Leptophlebiidae), and *Tasmanocoenis* sp. (Caenidae); a riffle ephemeropteran nymph, *Baetis* sp. (Baetidae); and two trichopteran larvae, *Cheumatopsyche* sp. (Hydropsychidae) and *Ecnomus* sp. (Ecnomidae). This study was conducted in late spring and summer during a wet season when flow in the Namoi River was influenced by inputs from the Peel River. The population densities of the selected study taxa at sites with different endosulfan exposures were examined. Three questions were addressed in this study: (a) Are populations of the selected mayfly and caddisfly taxa correlated to endosulfan exposure? (b) Are the selected mayfly and caddisfly taxa sensitive to endosulfan in laboratory toxicity tests? (c) Does endosulfan enter the riverine environment as overspray aerosol or in land runoff?

MATERIALS AND METHODS

Description of the Mayfly and Caddisfly Taxa Studied

Jappa kutera (Ephemeroptera, Leptophlebiidae) is a slow-swimming mayfly nymph found burrowing in gravel and sediment of stony streams in eastern and northern Australia (Peters and Campbell, 1991; Suter, 1992). *Atalophlebia australis* (Ephemeroptera, Leptophlebiidae) is a nonburrowing mayfly nymph, living on the surfaces of rocks in fast-flowing or lentic conditions and is common in temporary to permanent streams throughout eastern Australia (Peters and Campbell, 1991). *Tasmanocoenis* sp. (Ephemeroptera, Caenidae) is widespread in Australia in slow-flowing or standing water and will hide in soft sediment (Peters and Campbell, 1991). *Baetis* sp. (Ephemeroptera, Baetidae) inhabits relatively fast-flowing reaches of streams and is widespread in Australia (Peters and Campbell, 1991). Larvae of the two caddisfly species, *Cheumatopsyche* sp. and *Ecnomus* sp. (Trichoptera, Hydropsychidae and Ecnomidae, respectively), use mucal threads to attach themselves to large rocks and may build a tubelike retreat (Williams, 1980). These macroinvertebrates were identified using recent taxonomic keys (Williams, 1980; Dean and Cartwright, 1991; Dean and Suter, 1996)

Study Design

The study was designed to examine, spatially and temporally, the relationships between the densities of the selected taxa and selected abiotic variables, particularly endosulfan concentrations. Changes in abundances of the macroinvertebrates at reference sites were compared with those at exposed sites between November 1995 and February 1996. The sampling interval was 1 month, as the minimum emergence time for closely related macroinvertebrate taxa was 75 days (Marchant *et al*., 1984; Campbell, 1995). Study sites were at least 25 km apart to minimize the effect of macroinvertebrate downdrift. Altitude decreased only 100 m between the most upstream and downstream sites, minimizing any altitude-associated habitat changes. Eight sites were selected along the Namoi River to represent reference sites (sites 1 and 2 upstream of the cotton-growing areas), sites with low pesticide exposure (sites 3 and 4), sites with high pesticide exposure (sites 5–8) (Fig. 1). The riverine zone is characterized by very flat topography of alluvial deposits and the development of numerous anabranches, but otherwise had no distinct longitudinal physiographic zones (Arthington, 1995). The habitat criteria for the stratified sampling design were rocky substrates in pools in close proximity to riffles. The six most upstream sites all had igneous pebble substrate, while the substrate of the two most downstream sites was of sedimentary cobble.

Measurement of Site Descriptors

For each of the four sample units taken at each site, width and depth of the river were measured with a measuring tape and meter ruler, respectively, and the average was calculated. Average current speed at each sample location was measured with a flowmeter (Model CMC 200, Hydrological Services). Mean daily water flow rates between sampling times were calculated from data recorded at six hydrological gauging stations (Department of Land and Water Conservation) located in the vicinity of the eight sampling sites. Substrate was characterized by measuring the longest axis of the 60 largest rocks within the sampled area. The estimated length of the submerged rocky riffle and its geology were noted. Water quality parameters (temperature, pH, dissolved oxygen, conductivity) were measured at each site after sampling using a multiprobe Hydrolab (Scout 2 model) and turbidity was measured with a Hach portable turbidimeter (Model 2100P).

Macroinvertebrate Collection, Storage, and Enumeration

A Surber sampler with a 500-μm-mesh net was used to collect quantitative macroinvertebrate sample units. Each quadrat area (0.16 m^2) was sampled for 2 min by disturbing substrate by hand to a depth of 20 cm and four sample units

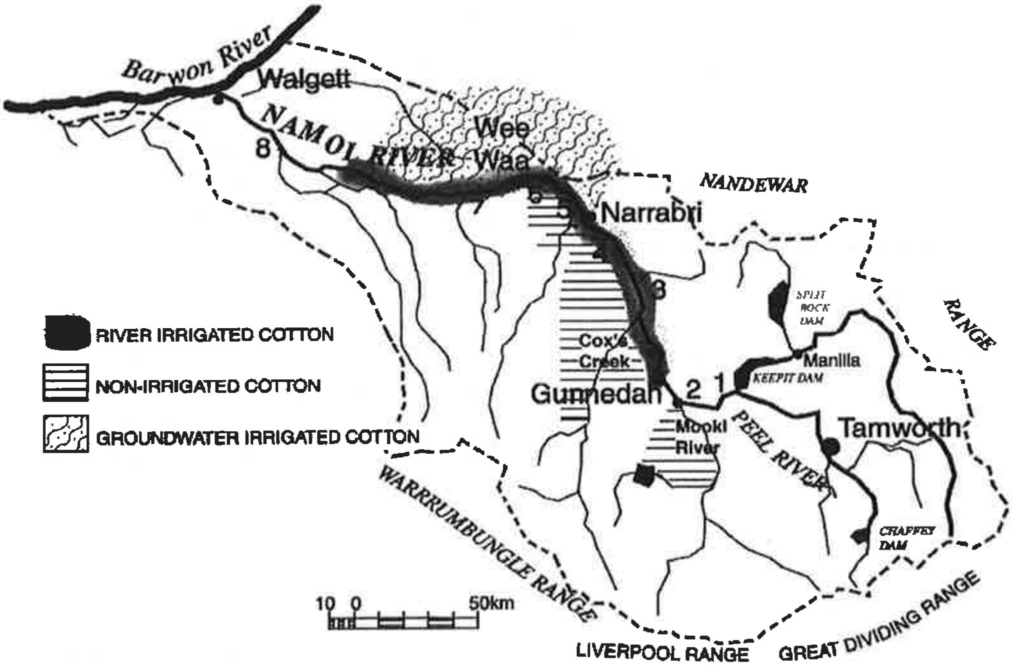

FIG. 1. The Namoi catchment showing the sampling sites (1–8), the major towns, and the cotton-growing areas.

were taken at each site. Each sample unit was transferred to a 500-ml plastic container and preserved in 10% formalin. In the laboratory the selected taxa were sorted and counted using 3 × magnification Magilamp. Individuals were identified under a dissecting microscope (Wild M3C). Each taxon was counted and analyzed separately except for the trichopterans in which the abundances of *Cheumatopsyche* sp. and *Ecnomus* sp. were combined for analysis due to initial taxonomic difficulties.

Pesticide Sampling

At each site, three soft bottom sediment samples were taken from eddies. The top 2 cm of sediment was transferred into brown glass jars (500 ml) that had been rinsed with pesticide-grade solvent and wrapped in foil. The samples were stored at 4°C for less than 4 days before extraction and analysis at the Chemical Laboratories of the NSW EPA. The sediment samples were extracted using the USEPA 3550A methodology and analyzed by gas chromatography with electron capture detection (GC-ECD) for organochlorines (USEPA Method G19) and GC–nitrogen phosphorous detection for organophosphates (USEPA Method 507). Pesticide concentrations were expressed as micrograms per kilogram of wet sediment (ppb) with a detection limit of 0.5 ppb.

For quality assurance an interlaboratory program was instituted between three laboratories using randomly selected subsets of the sediment samples. A subset of samples collected each month was mixed and split into two sets of pooled samples and given to each laboratory for endosulfan analysis. Variations between the three laboratories were within 10–15%.

In situ passive samplers containing trimethylpentane were used to quantify the bioavailable fraction of endosulfan (Peterson *et al.*, 1995). One passive sampler was placed inside each of three large rock-filled nylon mesh bags (0.8-mm mesh). The mesh bags were secured by cable ties and anchored to 1-m-high metal fencing posts hammered into the substrate. The passive samplers were replaced monthly and the recovery of trimethylpentane was more than 90%. The solvent containing the pesticides was analyzed directly by GC-ECD and the results were confirmed using GC-MS.

Toxicity of Technical Endosulfan in Namoi River Water to Selected Macroinvertebrates

Early-instar mayfly nymphs were collected for toxicity testing using hand nets (500 μm mesh), at or upstream of reference sites 1 and 2. Caddisfly larvae, *Cheumatopsyche* sp., were collected by placing several rock-filled nylon bags (800 μm mesh) at the reference sites for several months to allow colonization of larvae inside the bags. For transport to the laboratory, the macroinvertebrates were placed in water in a portable cooler containing nylon mesh (60 μm) and conditioned leaves, collected at the site, to provide substrate and food, respectively. On arrival at the laboratory, the leaves were removed and the nymphs and larvae were acclimated to the test temperature under subdued light conditions for 18 to 36 h.

The toxicity of technical endosulfan to the mayfly nymphs and caddisfly larvae was determined under static, nonrenewal test conditions in Namoi River water. Although turbidity was low (10 to 30 NTU), aliquots (2.8 liters) of the river water were sonicated (Branson 450 Sonifer, 100% power for 3 min), to disperse the suspended particle aggregations that formed rapidly following sampling. Each test was conducted in triplicate and consisted of six treatments. For each taxon, a test was conducted using both the smallest and largest individuals (Table 1). Nymph and larval body lengths were measured using an ocular graticule fitted onto the eyepiece of a dissection microscope. *A. australis* was exposed to an acetone solvent control and 0.31, 0.95, 3.2, 10.0, and 32.0 ppb of endosulfan (technical grade). *J. kutera* and *Cheumatopsyche* sp. were exposed, as for *A. australis*, with endosulfan concentrations of 0.15, 0.31, 0.62, 1.24, and 2.48 ppb. The organisms were randomly allocated to each of the test containers (1 liter glass breakers). These containers were then randomly placed inside an incubator set at 26 ± 1°C. Mortality and the immobilization of the nymphs and larvae were recorded at 24, 48, 72, and 96 h. Immobilization was defined as a lack of movement (except for gill movement) when the nymphs were gently prodded with a pair of forceps. If mortality was $> 10\%$ in the control treatment or dissolved oxygen was $< 60\%$, the test was aborted. The concentrations of endosulfan at the commencement of each test were measured by gas chromatography (Sunderam *et al.*, 1992).

Statistical Analysis

The dataset between November and February originally contained eight sites in each month but initial technical problems with the passive samplers measuring pesticides (endosulfan, profenofos, chlorpyrifos, trifluralin, prometryn) caused loss of data, leaving only four sites in November, four sites in December, six in January, and seven in February.

A canonical ordination technique was selected for linking the species data to environmental variables (Palmer, 1993; Jongman *et al.*, 1995; Ruse, 1996). To select the canonical technique, detrended correspondence analysis was applied to determine the standard deviation (SD) units in the taxon response curves (Jongman *et al.*, 1995). The results indicated

TABLE 1

Sensitivities of Two Mayfly Nymphs, *Jappa kutera* and *Atalophlebia australis,* and Larvae of the Trichopteran *Cheumatopsyche* sp. to a Single Exposure of Technical-Grade Endosulfan in Static Namoi River Water

Test						Endosulfan concentration (ppb)			
	Length[a]					EC_{50}		LC_{50}	
Taxon (95% Cl)		Date	Time	NOEC	LOEC	Mean	95% Cl	Mean	95% Cl
Japp[b]	5.1–5.8	14/11/96	24	0.6	1.2	1.0	0.6–1.5	2.0	1.5–2.8
			48	0.6	1.2	1.1	0.8–1.6	1.3	0.8–2.2
			72	0.6	1.2	1.1	0.8–1.5	1.0	0.8–1.4
	9.0–10.4	14/11/96	24	2.4		Outside testing range			
			48	2.4		Outside testing range			
	5.7–6.0	12/12/95	24	0.1	0.3	1.2	0.9–1.6	3.6	0.8–16.0
			48	0.3	1.0	1.1	0.8–1.5	2.0	1.6–2.6
			72	0.3	1.0	1.0	0.7–1.3	1.9	1.4–2.5
			96	0.3	1.0	0.8	0.6–1.1	1.2	0.9–1.6
Atal	4.2–4.6	31/10/96	24	0.3	1.0	0.6	N.R.[c]	0.6	N.R.
			48	0.3	1.0	0.6	N.R.	0.6	N.R.
			72	0.3	1.0	0.6	N.R.	0.6	N.R.
	6.8–7.2	31/10/96	24	0.3	1.0	0.5	0.4–0.6	1.0	0.7–1.3
			48	0.3	1.0	0.6	0.5–0.7	0.7	0.6–0.9
Cheu	5.7–6.3	13/11/96	24	0.3	0.6	0.5	0.4–0.6	0.8	0.7–1.1
			48	0.2	0.3	0.4	0.3–0.5	0.4	0.3–0.5
	9.8–10.3	13/11/96	24	0.6	1.2	Mortalities not monotonic			
			48	0.6	1.2	1.0	0.8–1.4	1.8	N.R.

[a] Length is body length in mm.

[b] *Japp, Jappa kutera*; *Atal, Atalophlebia australis*; *Cheu, Cheumatosyche* sp. Additional data on *Japp* were included from a test in December 1995.

[c] Not reliable.

that a linear model best described the data and the canonical form of principal component analysis, redundancy analysis (RDA), should be used on log transformed taxon densities. The CANOCO program (ter Braak, 1987) was used to analyze the data. All taxon data were log transformed. Environmental predictor transformations (log, square root, square and untransformed) were selected using scatterplots and Pearson coefficients. Environmental variables with poor correlations were indicated by low correlation to the ordination axes and low t values (ter Braak, 1987), which were used as criteria for excluding environmental variables from the analyses or plotting them passively using the results of post hoc tests (ter Braak, 1987). Dissolved oxygen in the river water, flow rates measured during sampling, and total organochlorines (lindane, DDT, DDE) measured in the bottom sediment at each site and had little correlation to taxon densities and were not included in the analysis. Passive variables in the ordination plots included habitat length (length of submerged rocky substrate), pH, temperature, as well as chloropyrifos, prometryn, and trifluralin measured in the passive samplers. Unless otherwise stated, all other options in the CANOCO program (ter Braak, 1987) followed the default settings.

The proportional data from each toxicity test were arcsine transformed and examined for normality and homogeneity of variance. If acceptable, the replicate data from each treatment were then combined and the data analyzed using Dunnett's test to obtain the lowest-observable-effect concentration (LOEC) and the no-observable-effect concentration (NOEC). An LC_{50} or EC_{50} value and its 95% confidence intervals were calculated, where possible, using the trimmed Spearman–Karber method (Hamilton *et al.*, 1977).

Chemicals

Pesticide-grade isooctane (2, 2, 4-trimethylpentane) was obtained from Mallinckrodt. Pesticide standards for GC analysis were purchased from Alltech (Chem Service Inc., West Chester, PA). Endosulfan (technical grade, 96% purity) was supplied by Hoechst Schering AgrEvo Pty., Ltd.

RESULTS

Pesticide Concentrations

Total endosulfan concentrations, that is, the sum of the concentrations of the α and β isomers and endosulfan sulfate, were high in the solvent of the passive sampler (Fig. 2). The only other chemical that had concentrations close to these concentrations was the herbicide prometryn, which is not likely to be toxic to aquatic fauna (Tomlin, 1994). The organophosphate pesticides, chlorpyrifos and profenofos, as well as the herbicide trifluralin were present in very low concentrations (Fig. 2). In November 1995 there was little difference in the total endosulfan concentrations between the reference and the exposed sites (Fig. 2). However, from December 1995 to February 1996, the total endosulfan concentrations at the exposed sites increased. In February 1996, the endosulfan concentrations at the exposed sites were about 25 times higher than those at the reference sites. In January and February 1996 approximately 50 and 80%, respectively, of the total endosulfan were in the form of endosulfan sulfate (data not provided).

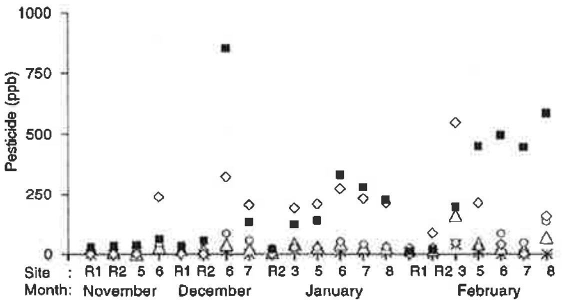

FIG. 2. Pesticide concentrations (ppb) detected in *in situ* passive samplers at the sampling sites in the Namoi River between November 1995 and February 1996. R1 and R2 are the two reference sites. Total endosulfan (sum of α isomer (+) β isomer (+) endosulfan sulfate concentrations) ■; prometryn ◇: trifluralin, △; profenofos, ○, chlorpyrifos, *.

In contrast, total endosulfan concentrations in bottom sediment were all low (Fig. 3). Bottom sediment endosulfan concentrations were very variable between sample units,

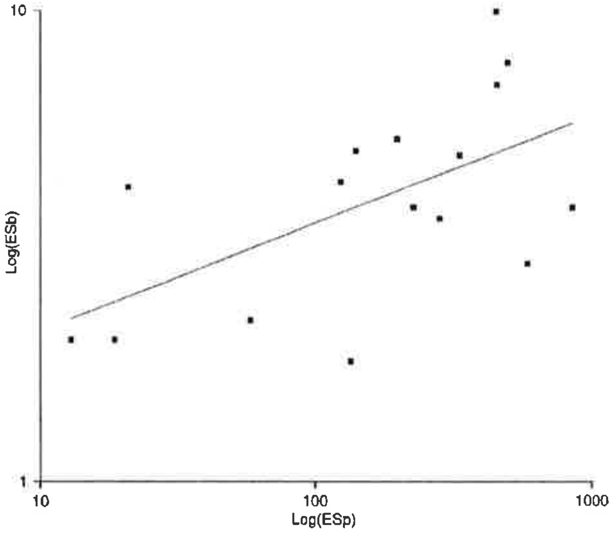

FIG. 3. Regression between log total endosulfan (ppb) in Namoi River bottom sediment (ESb) and log total endosulfan in passive sampler solvent (ESp) between November 1995 and February 1996. $r^2 = 0.426$ and significance $(P) = 0.001$. Total endosulfan (=) sum of the α isomer (+) isomer + endosulfan sulfate concentrations.

whereas *in situ* passive samplers had low variances between sample units. Other pesticides detected in the bottom sediment were low concentrations (< 5 ppb) of organochlorines (DDE, DDD, lindane). There was a significant regression ($r^2 = 0.426$, $P < 0.001$) between total endosulfan concentrations in the bottom sediment and those in the passive sampler solvent (Fig. 3).

Summary of Temporal and Spatial Trends in Densities of Individual Taxa

The following analyses examine the correlations of pesticide concentrations measured in solvent-filled passive samplers and other abiotic variables with densities of the study taxa. At the beginning of the study, the passive samplers were damaged and not available for collection at all sites. Passive samplers were available for collection and analysis at only four sites in November, four in December, six in January, and seven in February 1996. The study was conducted during late spring and summer when the river flowed continuously, with two major flood events in late December 1995 and late January 1996.

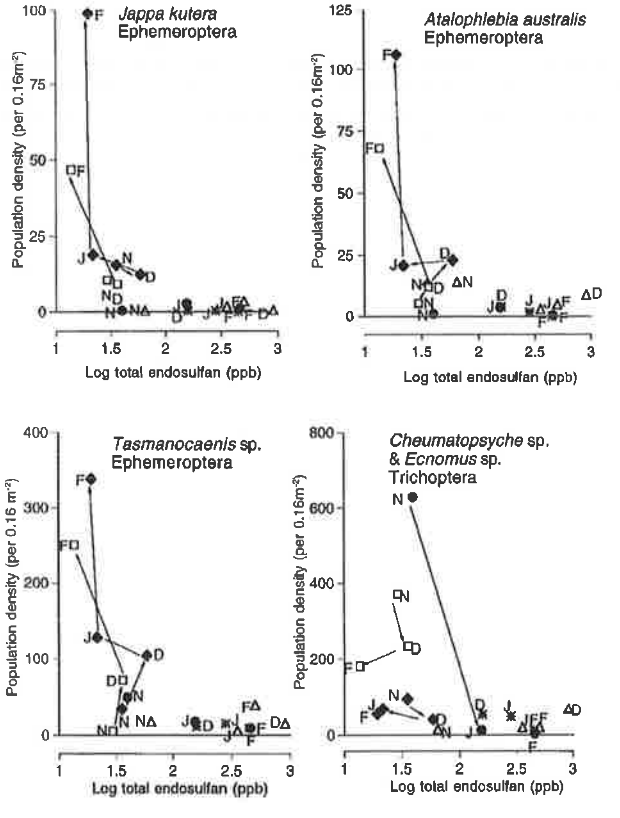

FIG. 4. Densities of four macroinvertebrate taxa dominant in the Namoi River between November 1995 and February 1996, and changes in total endosulfan (ppb) in the passive samplers. Letters denote month: N, November; D, December; J, January; F, February. Sites are described by symbols: □, 1; ◆, 2; ●, 5; △, 6; *, 7. Total endosulfan (=) sum of concentrations of α isomer + β isomer (+) endosulfan sulfate.

Patterns between densities of the study taxa, total endosulfan concentrations in the passive samplers, and sampling times are summarized in Fig. 4. In November 1995, except for *J. kutera*, a one-way ANOVA and Tukey's multiple comparisons indicated that the reference sites did not have significantly ($\alpha = 0.05$) higher densities than the exposed sites. There were 7-, 10-, and 10-fold increases in *J. kutera*, *A. australis*, and *Tasmanocoenis* sp. densities, respectively, from November 1995 to February 1996 at the two reference sites (sites 1 and 2). In contrast, densities of these species at the three exposed sites did not increase through the study period although endosulfan concentrations did increase (Fig. 4). Densities of the caddisfly species (*Cheumatopsyche* sp. and *Ecnomus* sp.) exhibited a different pattern, with sites 1, 2, and 5 having high densities in November 1995, declining in December 1995, and declining further in January and February 1996 (Fig. 4). However, densities of all study taxa except *Baetis* sp. at the reference sites were significantly higher by 6- to 107-fold ($P < 0.05$) compared with those at the exposed sites downstream in February 1996 (Fig. 4). In January 1996, total endosulfan concentrations in the passive samplers were significantly negatively regressed with densities of *J. kutera* ($r^2 = 0.676$, $P < 0.04$) and *Tasmanocoenis* sp. ($r^2 = 0.871$, $P < 0.001$). In February 1996 densities of *J. kutera*, *A. australis*, *Tasmanocoenis* sp., and the trichopterans were significantly negatively regressed ($P \leq 0.022$) with total endosulfan concentrations in the passive samplers, with r^2 values of 0.886, 0.853, 0.595, and 0.682, respectively. *Baetis* sp revealed no temporal or spatial relationships with passive sampler endosulfan concentrations.

Redundancy Analysis of Abiotic Variables

The seven active variables used in the RDA explained 59.2% of the variation in the first two axes (Fig. 5). The first axis of the RDA (eigenvalue = 0.421) is about 2.5 times as important as the second axis (eigenvalue = 0.171) in explaining variance in the densities of the study taxa. In the more important first axis, the variables most correlated to the densities of the study taxa were log-transformed endosulfan concentrations measured in the passive samplers (ESp) and distance downstream. The effect of distance downstream was not significant on densities of the study taxa (except *J. kutera*) in November and December. In January and February distance downstream became significant (data not provided).

The covariances of all seven active variables were subtracted from that of ESp using partial RDA analyses. Monte-Carlo permutations in the first ordination axis indicated the fact that total ESp uniquely explains a significant ($P = 0.02$)

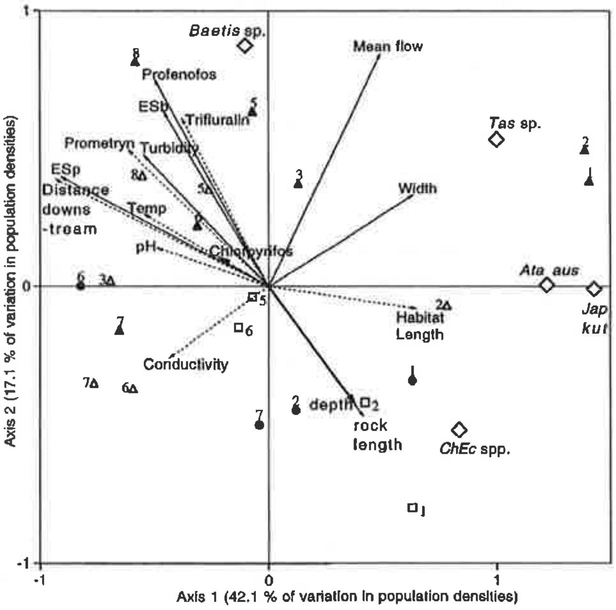

FIG. 5. RDA ordination diagram of mayfly and caddisfly taxon densities, with environmental variables including pesticides measured using passive samplers, in the Namoi River, November 1995 to February 1996. Solid-line arrows indicate active variables used to constrain the ordination axes; dashed arrows indicate passive variables. There were no collinearity problems between variables (inflation factors were < 3.3), (ter Braak, 1987). Scales of the axes: 1 unit = 1 unit site scores; 1 unit = 2 taxon units; 1 unit = 0.30 and 0.60 environmental units for axes 1 and 2, respectively. Esb and ESp, concentrations of total endosulfan ($\alpha + \beta +$ sulfate) in the bottom sediment and passive samplers, respectively. All other pesticides were measured in the passive samplers. Taxon centroids (◇) are given for the ephemeropterans of *Jap kut, Jappa kutera*; *Ata aus, Atalophlebia australis*; *Baetis* sp.; *Tas* sp., *Tasmanocaenis* sp.; and the trichopterans *ChEc* spp., *Cheumatopsyche* sp., *Ecnomus* sp. Sites are numbers and months the following symbols: □, November 1995; ●, December 1995; △, January 1996, ▲, February 1996.

amount of variation in the densities of the study taxa. Endosulfan concentrations measured in the passive samplers (ESp) are most negatively correlated to the mayfly nymphs *J. kutera* and *A. australis*, followed, in decreasing negative strength, by the caddisfly larvae *Cheumatopsyche* sp. and *Ecnomus* sp. and the mayfly *Tasmanocoenis* sp. In contrast, the mayfly *Baetis* sp. has a weakly positive correlation to total ESp. Correlations to the first axis indicate width and turbidity to be the next most important variables. Turbidity has similar correlations to ESp except being weaker, while width has a positive correlation to *Tasmanocoenis* sp.

In the second axis, mean flow is the most important variable, being positively correlated to all the mayfly taxa and negatively correlated to the combined caddisfly taxa *Cheumatopsyche* sp. and *Ecnomus* sp. The next most important parameter in the second axis is profenofos concentrations measured in the passive samplers followed by total endosulfan concentrations measured in the bottom sediment (ESb). Compared with the total endosulfan concentrations measured in the passive samplers, the profenofos concentrations and ESb are more weakly, negatively correlated to the mayfly taxa and more strongly correlated to the caddisfly taxa *Cheumatopsyche* sp. and *Ecnomus* sp.

Laboratory Studies on Endosulfan Toxicity to Study Taxa

Baetis sp. and *Tasmanocoenis* sp. were not tested in the laboratory due to the former having poor survival rates and the latter having very low densities in the river at the time of testing (November 1996). Apart from the largest size group for *J. kutera*, all LOEC (0.3–1.2 ppb; refer to Table 1) and EC_{50} values (0.4–1.2 ppb) (endpoint was loss of forward mobility) were within the same range as total endosulfan concentrations measured in rivers during storm runoff events (Bowmer *et al.*, 1995; Cooper, 1996). The smaller-size groups were more than twice as sensitive as the larger-size groups for *Cheumatopsyche* sp. and *J. kutera* (Table 1). Comparing the 48-h LC_{50} values between the taxa. *Cheumatopsyche* sp. was the most sensitive (0.4 ppb), followed by *A. australis* (0.6 ppb) and *J. kutera* (1.3 ppb).

DISCUSSION

Endosulfan Concentrations in the Riverine Environment

Peak concentrations of pesticides in rivers are rarely measured during storm runoff events as sites are often inaccessible and these peaks may last only a few hours (Cooper, 1996). However, the persistence of endosulfan in the river system is due to the fact that it adsorbs onto sediment (Peterson and Batley, 1993). In this study, pesticide concentrations in bulk sediment (μg pesticide/kg wet wt sediment) had large variances between sample units compared with organic solvent-filled passive samplers. Major sources of variance include the unknown exposure history of the sediment to the water column and endosulfan losses by hydrolysis between the time of sampling and analysis. The immediate exposure history of the sediment to the water column could vary because sediment sampled immediately after a flood event would have a short exposure history, while sediment sampled during a period when no floods have occurred for an extended period would have a longer exposure history. Using *in situ* passive samplers negates these sources of variation.

Endosulfan sulfate formed a large proportion of the total endosulfan measured in the *in situ* passive samplers and bottom sediment. Martens (1976, 1977) attributed the formation of endosulfan sulfate to the enzymatic action of soil fungi. In addition, it has been found that endosulfan sulfate can be formed on the leaves of plants (Chopra and Mahfouz, 1977). Biologically catalyzed oxidation appears to be the only process by which endosulfan sulfate is formed in the environment. The presence of endosulfan sulfate several weeks after most endosulfan spraying ceased indicated that field runoff during storm events was a major route of entry into the river. Endosulfan sulfate is known to be at least as toxic as technical endosulfan to biota (Barnes and Ware, 1965; Barry *et al.*, 1995).

Changes in Densities of the Six Taxa

In the summer months between December 1995 and February 1996, the populations of the six study taxa in the Namoi River were expected to continue to increase from the winter populations at all sites, due to increased flow rate and temperature stimulating growth and recruitment. The fecundity of adult females was known to be several thousand for at least the two leptophlebiids (Peters and Campbell, 1991). Preliminary cohort analyses (between October 1995 and February 1996) indicate at least two generations should have recruited to each site. Between December 1995 and February 1996, densities sampled revealed a continuous increase in population densities of all study taxa at reference sites 1 and 2, but no increase in *J. kutera*, *A. australis*, *Tasmanocoenis* sp., and the two caddisfly species (*Cheumatopsyche* sp. and *Ecnomus* sp.) at exposed sites 3 to 8. However, *Baetis* sp. did increase at these sites. Therefore, it is suggested that a perturbation(s) present at sites 3 to 8 restricted the increase in density of all taxa except *Baetis* sp.

Similar patterns were detected in the univariate analyses and the multivariate RDA. The overall indication is that the densities of the study taxa (except *Baetis* sp.) were significantly negatively correlated to both total endosulfan in the passive samplers and distance downstream in January and February 1996. When endosulfan concentrations were low in the study sites in November and December 1995, distance downstream did not have a significant correlation with abundance. Therefore, unless an important variable correlated to distance downstream has not been measured, endosulfan in the riverine environment is the most likely factor explaining these low densities.

Although RDA indicates endosulfan in the passive samplers as the most important correlate with the study taxon abundances, other factors are collinear with endosulfan and could be important in explaining the variation in the densities of the study taxa. One of these factors, water temperature, could not explain decreases in densities of taxa between sites in January and February 1996 as the differences between sites was less than 2°C. High turbidity levels can potentially affect aquatic biota by impeding respiration (Auld and Schubel, 1978; Servizi and Martens, 1991). As most of the study taxa are benthic and one (*J. kutera*) has a burrowing behavior, it is unlikely that the turbidity levels recorded would affect them. The turbidity measurements can be used as an estimate of suspended sediment loads since Namoi River suspended sediments consist of silts and fine clays (Gippel, 1989). However, the turbidity levels are more likely to be indicative of surface runoff after heavy rainfall, carrying endosulfan into the river. Turbidity also had weaker correlations with the taxa compared with endosulfan. The herbicides prometryn and trifluralin are less toxic to macroinvertebrates (Tomlin, 1994) and have a weaker correlation to the densities of the study taxa. Profenofos, like endosulfan, is extremely toxic to fish and macroinvertebrates. A similar organophosphate pesticide has been known to have a toxicological synergistic effect with endosulfan (Arnold *et al.*, 1995). The effect of profenofos on the overall toxicity cannot be discounted, despite profenofos having a weaker correlation to the densities of the study taxa than endosulfan.

RDA indicated that endosulfan in the passive samplers was the leading predictor for changes in densities of all taxa, except *Baetis* sp., in January and February 1996. It is possible that *Baetis* sp. was resistant to endosulfan or was able to avoid high exposure since it is the most mobile of the study taxa. Since a proportion of endosulfan in river water is sorbed to particulate material (Peterson and Batley, 1993), the benthic taxa *J. kutera* and *Tasmanocoenis* sp. could be exposed to more endosulfan sorbed to settled particulate material than *Baetis* sp., which clings to rock surfaces in riffle areas.

Laboratory Toxicity Testing

A. australis, *J. kutera*, and the trichopteran *Cheumatopsyche* sp. are very sensitive to endosulfan in laboratory toxicity tests. The LOEC of total endosulfan to the smallest size class of field-collected nymphs of *A. australis* and *J.* kutera as well as larvae of the *Cheumatopsyche* sp. was 0.3 ppb. This is less than the concentration of total endosulfan in the water column of 0.8 ppb measured during a storm runoff event in a creek close to site 3, a low-exposure site (Cooper, 1996), which is 80 times above the Australian water quality guideline for endosulfan (ANZECC, 1992). Small individuals were more sensitive to endosulfan than large individuals, indicating that earlier instars could perhaps be the most sensitive stage in the life cycle of these macroinvertebrates.

Mitigation strategies to reduce inputs of endosulfan into the riverine environment are currently ongoing through the development of Best Management Practice protocols and their implementation (Schofield and Simpson, 1996). These strategies are based on extensive studies on the transport and fate of endosulfan on land, modeling its transport to rivers and its impact on the riverine ecosystem. It is envisaged that significant reductions of endosulfan in the riverine environment will occur once these strategies are implemented throughout the Namoi River catchment.

CONCLUSIONS

Because of the many sources of potential variation in measuring pesticide concentrations in bottom sediment, the use of *in situ* passive samplers in comparative field studies on the effects of pesticides on aquatic biota is a useful adjunct. Multivariate redundancy analysis identified endosulfan concentrations in passive samplers as the most significant measured environmental variable that predicted changes in densities of the nymphs of three sedentary mayfly species as well as that of the combined densities of the larvae of two caddisfly species. The more mobile mayfly nymph, *Baetis* sp., exhibited no temporal or spatial relationships with endosulfan concentrations in passive samplers. Data on toxicity to three of the species strongly suggest that endosulfan had contributed to the decline in their densities in January and February 1996. As endosulfan sulfate constituted a significant proportion of total endosulfan in January and February 1996, it is believed that the source of endosulfan contamination in the river was through storm runoff events.

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