ECOLOGICAL RISK ASSOCIATED WITH IRRIGATION IN THE GOULBURN BROKEN – STAGE 2

GMW 11

FINAL REPORT

May 2004

NATIONAL PROGRAM FOR
Sustainable Irrigation

Contents

1 Project Number

GMW11

2 Project Title

Ecological Risk Assessment associated with Irrigation in the Goulburn Broken – Stage 2

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4 Project Collaborators

The project was carried out with the strong collaboration of staff from the Water Studies Centre, Monash University, including:

Dr Carmel Pollino	(fish component)
Dr Angus Webb	(algal component)
Dr Terry Chan	(algal component)
Dr Mike Grace	
Prof Barry Hart	
Owen Woodberry	Honours student – School of Computer Science and Software Engineering, Monash University – fish component

5 Project Duration

15/04/2002 to 30/12/2003

6 Due Date for Milestone Report

30 December 2003

7 Project Objectives

The purpose of this project is to implement Phase 2 of the project "Assessment of ecological risk associated with irrigation systems in the Goulburn Broken catchment." This will assist development of a generic framework for the Ecological Risk Assessment (ERA) of irrigated agriculture in a catchment context. Specifically, the objectives of this project are:

1. Document what we know about each of the risk factors associated with two of the priority risks (blue green algae and fish survival) identified in Phase 1
2. Complete the ecological effects semi quantitative ranking table prepared in Phase 1
3. Develop ecological models to quantify the relationships between risk factors and the identified risk
4. Undertake limited research to gather missing information and further quantify key relationships
5. Provide input to the ERA linkage project that is to develop a generic framework for applying the ERA approach to assess the ecological risks from irrigation systems at the catchment level.

8 Alteration to Original Objectives

Nil

9 Milestones and achievement criteria

9.1 Milestone 5, Final Report

Prepare a draft report on all completed work, including

- A brief abstract
- Results of the desktop assessment of what is known about each of the risk factors identified with priority risks
- Ecological effects table completed semi quantitatively
- Rankings on each of the risk factors
- Relationships between key risk factors and identified risk quantified
- Final results published
- Final report completed to L&W specifications, including a section on each objective and future R&D needs
- Copies supplied to the NPIRD communications Consultant in the required format.

9.2 Achievement criteria

1. Draft report scrutinized by the Linkage Team
2. Final documents supplied in hard and electronic copy
3. NPIRD sponsorship clearly identified on any material and presentations
4. Final reports accepted by Land and Water

10 Communication Achievements

- Project summary to Shepparton Irrigation Region Plan Implementation Support Committee May 2001
- Phase 2 update January 2002 – to members of original "community" group
- Summary of progress – July 2001
- Various project summaries and presentation have been circulated within G-MW and to catchment partners.
- An outline of the ERA approach and Goulburn Broken project was made to Victorian nutrient/water quality coordinators November 2002.
- Project details have been posted on the Water Studies centre website:

  http://www.wsc.monash.edu.au/sresearch.htm

Project outputs

Conference Presentations

Pollino, C.A., Feehan, P., Grace, M., Hart, B. (2002) Using Ecological Risk Assessment to quantify the risks to fish in the Goulburn Broken Catchment. Australian Society for Limnology, 29 September – 30 October 2002, Margaret River. Platform presentation.

Pollino, C.A., Feehan, P., Grace, M., Hart, B. (2003) Quantifying the risks to fish in the Goulburn Broken catchment. Ninth International Conference on River Research and Applications, 6 - 11 July 2003, Albury. Poster presentation.

Pollino, C.A., Feehan, P., Grace, M., Hart, B. (2003) Quantifying the risks to fish in the Goulburn Broken catchment (Victoria, Australia) using Bayesian networks. Society of Environmental Toxicology and Chemistry (SETAC), 26 - 1 September 2003, Christchurch. Platform presentation.

Pollino, C.A., Feehan, P., Grace, M., Hart, B. (2002) Quantifying the risks to fish in the Goulburn Broken catchment (Victoria, Australia). Australian Society for Limnology, 1 – 5 December 2003, Warrnambool. Platform presentation.

Invited Presentations

Pollino, C.A., Feehan, P., Grace, M., Hart, B., (2003) Adverse changes to the abundance and diversity of native fish in the Goulburn catchment. River & Catchment Health: Presenting current research in the Goulburn Broken catchment, 5 August 2003, Dookie, Victoria.

Publications

Pollino, C.A., Feehan, P., Grace, M., Hart, B.T. (submitted Nov 2003) Fish communities and habitat changes in the highly modified Goulburn Catchment, Victoria, Australia. *Marine and Freshwater Research*

Pollino, C.A., Woodberry, O., Feehan, P., Hart, B.T. (in prep.) Quantifying the risks to fish in the Goulburn Broken Catchment (Victoria, Australia) using Bayesian networks. To be submitted to *River Research and Applications* (Submit Feb 2004)

Woodberry, O., Pollino, C.A., Korb, K., Nicholson, A. (in prep.) Development of AI support tools for Bayesian Networks. To be submitted to *Uncertainty in Artificial Intelligence* (Submit Mar 2004)

11 Listing of Attachments

- *Attachment 1 – Milestone Report – Fish Component*
- *Attachment 2 – Milestone Report – Blue-Green algae component*

12 Other Comments

Nil

13 Report – Milestone 5 and Final Report

This Section presents brief summaries of the work undertaken by the project. Substantially more detail is given in Attachments 1 - 4.

13.1 Abstract

During Phase I of the project "Assessment of Ecological Risk Associated with Irrigation Systems in the Goulburn Broken Catchment" (Cottingham *et al.*, 2001) adverse changes to the abundance and diversity of native fish and the occurrence of cyanobacterial (or blue-green algal) blooms were identified as priority ecological issues to be further investigated in Phase II of the project. Investigations have now been carried out to further assess the risks associated with these two issues.

Ecological risk assessment (ERA) is designed to assess the level of risk to ecosystems posed by either single or multiple stressors (e.g. salinity, toxicants, nutrients, temperature, flow, habitat, exotic species). Risk is often defined as the product of the *probability or likelihood* of a hazard occurring, and the *consequence* if that hazard occurs. Thus we have the concept:

Risk = Likelihood x Consequence

ERA provides a basis for comparing and ranking risks, so that natural resource managers can focus attention on the most severe risks first. Ideally, the ERA process should be iterative, allowing new information to be incorporated into the risk assessment as it becomes available.

A detailed investigation of native fish abundance and diversity was undertaken, as well as identification of the current knowledge of the status of native fish communities and priority stressors to fish. A predictive model to inform future land use decisions in the catchment and its impact on the native fishery was constructed.

The lowland Goulburn Broken Catchment (refer to Attachments for maps) has a long history of irrigation and has been highly modified primarily for the purpose of irrigation. Multiple barriers constructed in rivers and streams have altered the hydrology of the system, and in some cases the system's water quality. Barriers have also prevented the movement of native fish. Irrigation and urban run-off have further reduced water quality in the lower part of the catchment, contributing to increased turbidity and nutrient concentrations. Physical changes to the habitat of fish have also occurred as a result of extensive desnagging, removal of native riparian vegetation, and loss of complexity to river and stream geomorphology. Biological interactions have also been altered due to the introduction of recreational salmonids and the proliferation of habitat generalists. These changes have occurred both in the main channel and tributaries of the catchment.

The study identified and aggregated fisheries data from multiple sources. Multivariate statistical techniques clearly showed fish communities were fragmented and that different communities exist in the upper tributaries and upper main channel, Lake Nagambie/Goulburn Weir, and in the lower tributaries and lower main channel.

Barriers to migration, temperature changes and the altered flow regime are identified as the priority risks to fish in the catchment.

Further analyses were undertaken using the predictive Bayesian network (BN) model. Using the BN, scenarios for optimal management of fish populations at different sites and reaches within the catchment can be determined.

The model construction process involved extensive liaison with expert stakeholders, both in the building of the model structure (qualitative component) and input of model relationships between model variables (quantitative component). Expert elicitation was conducted over two workshops.

Tools for sensitivity analysis were developed to test the robustness of the model qualitative and quantitative components. Predictive accuracy tests were also conducted on the model. Tests indicate that the accuracy of the model is high; however, given the absence of variability in many of the catchment variables contained within the model, testing the model performance over the full range of parameters cannot be done. When charting the predicted model endpoints under existing environmental condition against current fishery data, the model outputs showed similar trends to the real data. In the tributaries, where fishery data is sparse, the model did not precisely identify all trends. Further data is required to improve the accuracy of the model prediction for these areas.

An ecological risk assessment designed to assess the risks associated with algal blooms and how those risks might be affected by factors associated with irrigation was also undertaken. The likelihood of bloom occurrence was assessed through numerical modelling of four ecosystems. Phase 1 of this project identified two case study systems: Lake Nagambie / Goulburn Weir, and the lower Goulburn River. In addition, another two systems (East Goulburn Main Channel, Lake Mokoan) were modelled to assist in validation of the assessment technique.

Modelling enabled integrated examination of a number of environmental stressors, including nutrients, temperature, light, and flow regime within each system. The potential impact of these stressors on the likelihood of algal blooms was investigated.

The level of filterable reactive phosphorus (FRP) was identified as the primary factor influencing the likelihood of algal blooms, and any future or current irrigation developments that increase the levels of FRP should be assessed carefully as they may increase the likelihood of bloom formation. As current concentrations are relatively low, the magnitude of environmental perturbation required to increase bloom risk is quite large. However, it should also be noted that a lack of site-specific data makes risk prediction very uncertain. Further monitoring, and possibly modelling, of the case study sites and alternative proxy sites may assist in reducing this uncertainty.

13.2 Key Project Messages and Results

13.2.1 Fish component

- Water resource development in the Goulburn catchment has had substantial impact on native fish abundance and diversity.
- Fish communities are fragmented (ie non-continuous) within the catchment due to physical barriers and other habitat changes

- Barriers to migration, temperature changes due to bottom water releases from Lake Eildon and the altered flow regime are identified as the priority risks to fish.
- Strategies for optimal management of fish at different sites have been investigated using Bayesian network models. The model construction process involved expert stakeholder liaison and incorporation of data from multiple fish management projects. The Bayesian network model is composed of 4 sub models describing water quality, hydraulic habitat, structural habitat and biological potential. (***Biological potential*** is a function of current abundance, potential recruitment, stocking and alien threat to native fish. It represents the biological constraints on population resilience, productivity, and size, and is used in the same way as Rieman *et al*. (2001).)
- Collection of fishery data was not consistent at any site or between sites, indicating a need for improvements in the design of monitoring protocols
- Application of a data mining technique indicated the presence or absence of a fish barrier as being the primary driver of fish abundance in the catchment.
- Scenario testing using the Bayesian model suggests the following priority risk factors:
    - *Upper main channel* – water quality (especially temperature), altered hydrology
    - *Upper tributaries* – biological potential (potential recruitment and current abundance due to barriers) and water quality
    - *Mid main channel* – biological potential (current abundance and future potential due to barriers) and water quality (possibly due to lack of data)
    - *Lower main channel* – Biological potential (potential recruitment and current abundance) and water quality (turbidity, dissolved oxygen and pH)
    - *Lower tributaries* – biological potential and water quality.
- Biological recruitment is influenced in many cases by low current fish stocks and barriers.

13.2.2 BGA component

- A blue green algal model developed for the Bourke Weir Pool on the Darling River was adapted for use in the Goulburn catchment. It was applied to two case study systems (Goulburn Weir/Lake Nagambie and the Lower Goulburn River) and two analogue systems (Lake Mokoan and East Goulburn Main Channel).
- The two case study systems seem to be relatively resistant to formation of algal blooms.
- Within the Lake Nagambie system, the main factor increasing the likelihood of bloom events is an increase in the level of filterable reactive phosphorus (FRP). Thus management of nutrient inputs to the systems should be considered as a priority.
- Increased temperatures will also increase the likelihood of blooms, but this parameter is effectively beyond the control of managers. Unusually warm summers will lead to an increased likelihood of blooms.

- No factors were identified that could significantly increase the likelihood of blooms in the Lower Goulburn River. However, a lack of validation data, and the qualitatively different nature of this system compared to the other modelled systems, means that there is a high degree of uncertainty associated with all conclusions for this site.
- The conclusions of the modelling are associated with a high level of uncertainty. This derives from three principal sources:
    1. A lack of blooms within the study systems, requiring models to be validated on analogous systems that behave in slightly different ways.
    2. A relative paucity of data on algal blooms at the analogue sites, resulting in the models not being properly validated for these sites either.
    3. The apparent importance of phosphorus limitation within the case-study systems, whereas the system for which the model was originally developed (Bourke Weir) is almost never phosphorus limited.
- Despite the uncertainty associated with the model output, the models were able to reproduce the shape of monitored population trace (i.e. simulated population increases coincided with monitored increases). The models did a poor job of predicting cell numbers, but this is of secondary importance to understanding biomass dynamics.
- Further research work could be undertaken, but this needs to be considered in light of apparent low algal abundances and low apparent risks of blooms in the case study systems.

13.2.3 Key Products from this Project

In addition to the above key findings, a number of products or techniques were developed or applied during the course of the project that could be of use to others. These include:

Fish component

- o Development of the Bayesian Network model – and lessons on the process of extracting knowledge from experts
- o Collation and analysis of fish survey data for the Goulburn catchment
- o Application of data mining tools (CaMML – Causal Minimimal Message Length – see Section 13.4.1 and 13.8.2)

Blue green algal component

- o Application of a management oriented model for prediction of blue green algal blooms
- o Investigation of light attenuation coefficients in the Goulburn Main Channel and Lake Nagambie.

In addition, both components have produced ecological effects tables that provide guidance to managers on the relative importance of a range of parameters that may have ecological effects.

13.3 How these messages and products can be used in the catchment

The messages and products produced by this project potentially have a number of applications within the Goulburn Broken catchment and elsewhere in northern Victoria. Some potential applications include:

> *Goulburn Broken Regional Catchment Strategy*
> The Goulburn Broken Catchment Management Authority has prepared a Regional Catchment Strategy, as well as a number of related strategies and plans. These include the Goulburn Broken Water Quality Strategy and the Goulburn Broken River Health Strategy.
>
> Development of the Water Quality Strategy commenced in 1994. Strategy development was based on risk assessments using imperfect data, information and knowledge. The outcomes of both components of this project will be used to further refine the water quality strategy. The outcomes of the blue green algal component, in particular, will help managers focus limited resources away from areas identified as having likely low risk of blue green algal blooms.
>
> The outcomes of the fish component will be important in the development of the catchment's River Health Strategy. The idea of a fishway at Goulburn Weir had previously been discounted because of perceived downstream impacts of thermal pollution from Eildon Reservoir. This project has shown that such a concept is worthy of further investigation.
>
> *Goulburn Bulk Entitlement*
> Another potential application would be to critically examine the need for the water quality component of the Goulburn Bulk Entitlement. An allocation of 30 000 ML is held in Eildon Reservoir to provide opportunities for flushing flows should blue green algal blooms develop in the Goulburn River. This project indicates that the need for this allocation is questionable.

Catchment managers would need to undertake further detailed work, including sensitivity analyses, to substantiate the findings of this project before committing substantial resources to the applications mentioned above.

Project outcomes have been widely circulated to key decision makers within the catchment and at State level.

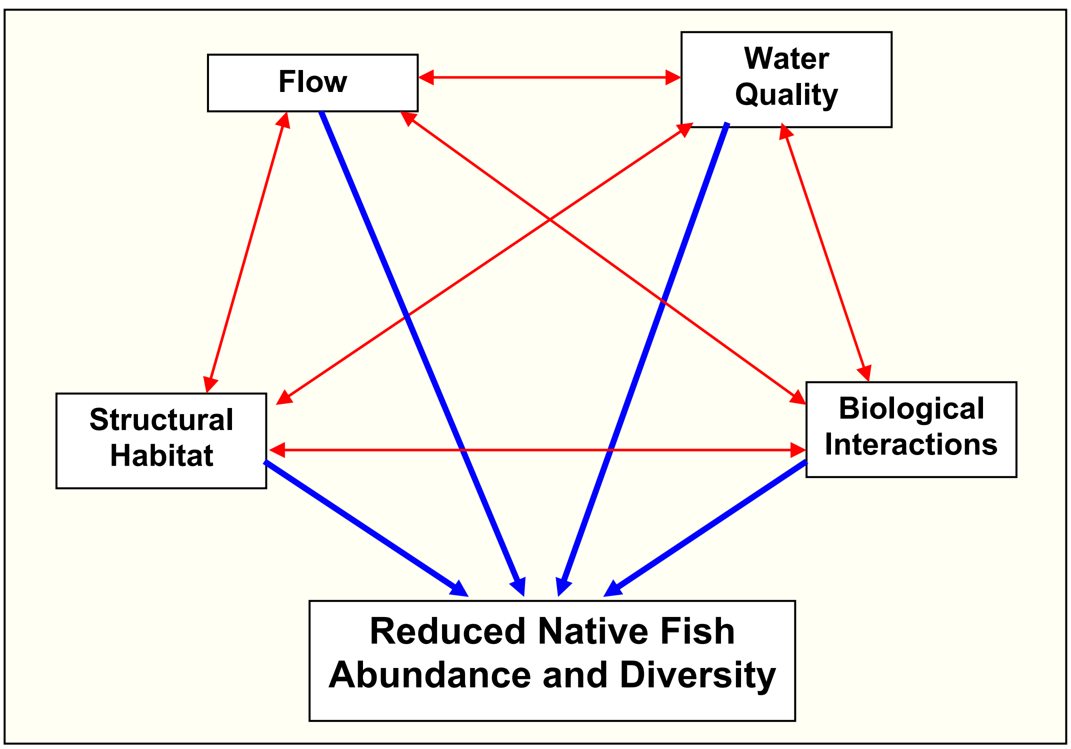
13.4 Results of the desktop assessment

Results of the desktop assessment of what is known about each of the risk factors identified with priority risks - Document what we know about each of the risk factors associated with two of the priority risks (blue green algae and fish survival) identified in Phase 1

13.4.1 Fish component:

A number of risk factors for native fish abundance and diversity were identified during the course of the project. At a simple conceptual level these factors are described in Figure 1. During the course of the project a substantially more complex conceptual model was developed, which underpinned the development of the Bayesian Network model (Figure 2). <u>A summary of the fish factors is given below and substantially more detail is available in the Milestone report (Attachment 1) and the paper submitted to the journal *Marine and Freshwater Research.*</u>

Figure 1 - Basic Native Fish Conceptual Model



The lowland Goulburn Broken Catchment has a long history of irrigation and has been highly modified primarily for the purpose of irrigation. Multiple barriers have been inserted in rivers and streams that have altered the hydrology of the system, and in some cases the water quality of the system. Barriers have also prevented the movement of native fish. Irrigation and urban run-off have further reduced water quality in the lower part of the catchment, contributing to increased turbidity and nutrient concentrations. Physical changes to the habitat of fish have also occurred as a result of extensive desnagging, removal of native riparian vegetation, and loss of complexity to river and stream geomorphology. Biological interactions have also been altered due to the introduction of recreational salmonids and the proliferation of habitat generalists.

These changes have occurred both in the main channel and tributaries of the catchment.

The first task of this study was to identify and aggregate Goulburn Broken Catchment fisheries data from multiple sources, and investigate whether different fish communities exist in different parts of the catchment. Multivariate statistics were used and analyses showed that clearly the fish communities were fragmented. For the purpose of this study only, upper refers to the region below Eildon Dam, through to upstream of Lake Nagambie. The lower section refers to below Goulburn Weir, through to the confluence with the Murray River.

Collation of fisheries data was not consistent at any site or between sites, and therefore no temporal analyses were conducted. Fisheries data (collected after 1970) was obtained from the Department of Sustainability and Environment, the Department of Primary Industries and the Lake Nagambie Angling Club. Data consisted of the site location, date of sampling (often not recorded), the sampling technique (often not recorded), and the number and species of fish collected.

Given that data collection was not routine at any site and information about data collection was not always available, the change in the abundance and diversity of fish communities at site locations over time could not be investigated. However, examination of fisheries data suggests that the fish communities were stable from 1970 at the majority of sites, with the exception of Lake Nagambie.

Different communities existed in the upper tributaries and upper main channel, Lake Nagambie/Goulburn Weir, and in the lower tributaries and lower main channel. The findings of this component of the study identified barriers to migration, temperature changes and the altered flow regime as being the priority risks to fish in the catchment.

Interestingly, application of the CaMML (Causal Minimum Message Length) modelling tool identified the presence or absence of a barrier being the primary driver of fish abundance in the catchment.

CaMML is a program that learns Bayesian networks from raw data. It is an automated learning tool that uses the inference technique, Minimum Message Length (MML) to compare different potential models. Using a Bayesian approach it searches for the simplest Bayesian network model to explain the data, without over-fitting. It does not just investigate statistical equivalence classes, but uses the MML (Minumum Message Length) principle as its metric. It uses the Metropolis algorithm for stochastic sampling.

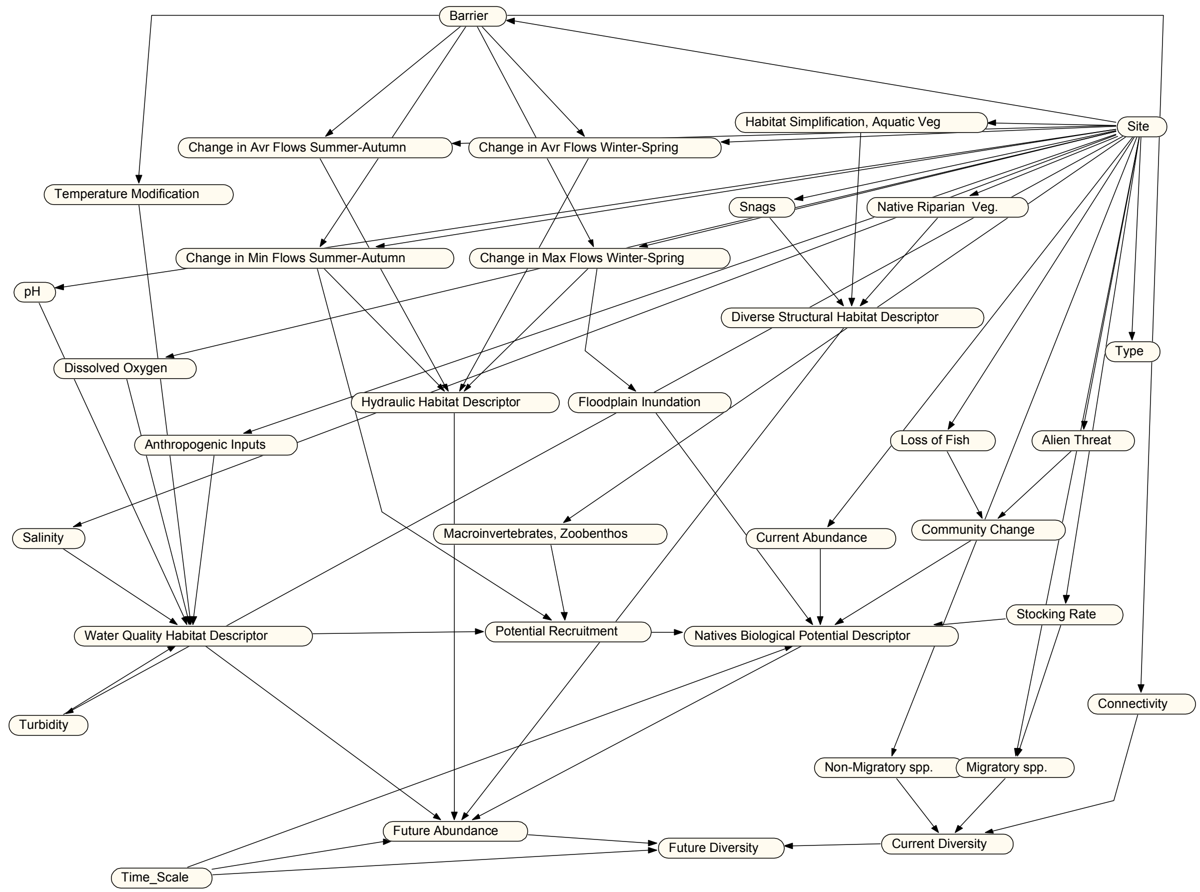
As an exercise it is interesting and informative to compare a CaMML generated model based on data with a model developed via expert elicitation (modified from Woodberry (2003) Twardy (2004)).

13.4.2 Blue green Algal Component

This component was driven by the outcomes of a modelling exercise. The model is described conceptually, below (Figure 4) and further detail can be found in the attachments and Webb et al (in prep).

The data available for the two case study sites (and for the East Goulburn Main Channel) do not cover the range of parameters necessary to drive some of the more detailed algal models that have been produced. Moreover, the specific knowledge of the systems that would be required to parameterize the models is also unavailable. As such we are unable to apply models that can give a detailed representation of algal population dynamics.

Figure 2: Structure of the BN model



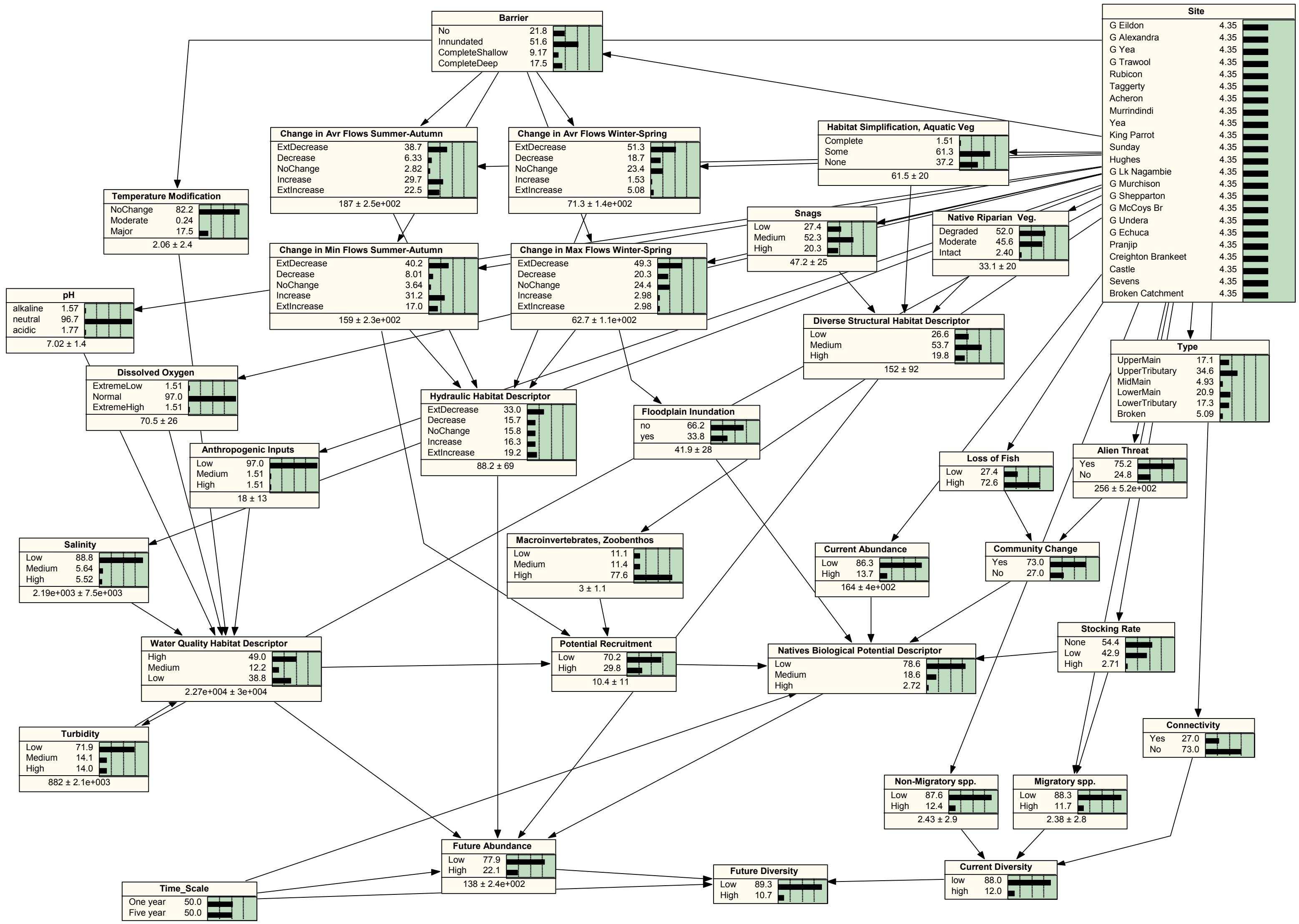


Figure 3: Generic BN model

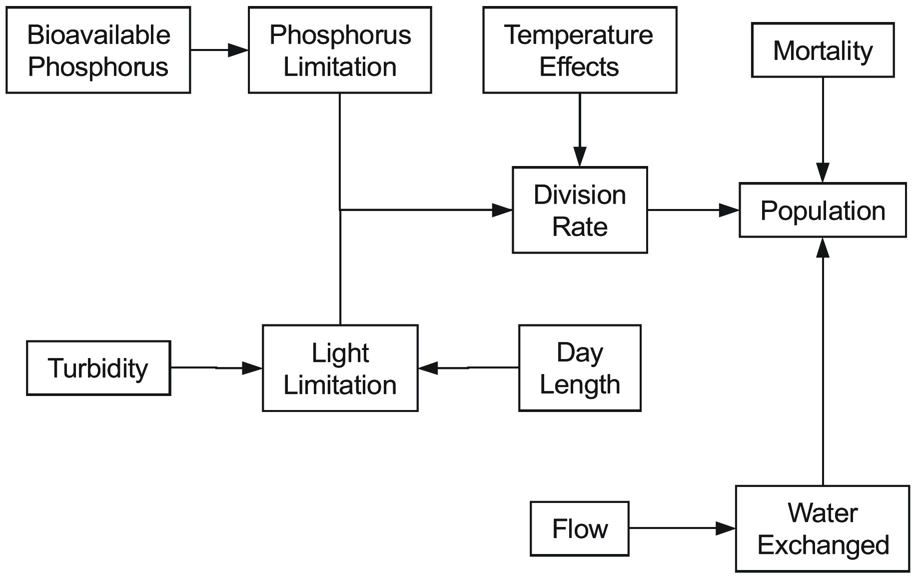


Figure 4: Conceptual model of cyanobacterial population dynamics. The population is governed by the rate of mortality, the rate at which cells are washed from the system, and the rate at which cells are produced. Reproductive rate is governed by either light or phosphorus limitation, and is scaled according to temperature. Phosphorus limitation is dictated by the amount of dissolved reactive phosphorus available, and light limitation by the combination of day length and water turbidity.

However, this is a minor concern for an ERA-based modelling exercise. Our primary aim is to be able qualitatively track biomass dynamics, and identify the types of conditions that could lead to blooms in the systems.

As a result of application of the model described in the attachment the following statements can be made about blue green algal risk factors:

- The two case study systems identified during the problem formulation stage of this project appear to be relatively resistant to formation of algal blooms.
- Within the Lake Nagambie system, the main factor that could increase the likelihood of bloom events appears to be an increase in the level of filterable reactive phosphorus (FRP). The model indicated an increased likelihood of blooms at a level of FRP that is still less than that commonly observed in Lake Mokoan. Thus management of nutrient inputs to the systems should be considered as a priority, although this is already acknowledged in GBCMA (2002).
- Increased temperatures will also increase the likelihood of blooms, but this parameter is effectively beyond the control of managers. Nevertheless, unusually warm summers will lead to an increased likelihood of blooms.

- No factors were identified that could significantly increase the likelihood of blooms in the Lower Goulburn River. However, a lack of validation data, and the qualitatively different nature of this system compared to the other modelled systems, means that there is a high degree of uncertainty associated with all conclusions for this site.
- The conclusions of the modelling are associated with a high level of uncertainty. This derives from three principal sources:
  1. A lack of blooms within the study systems, requiring models to be validated on analogous systems that will behave in slightly different ways.
  2. A relative paucity of data on algal blooms at the analogue sites, meaning that the models are not properly validated for these sites either.
  3. The apparent importance of phosphorus limitation within the case-study systems, whereas the system for which the model was originally developed (Bourke Weir) is almost never phosphorus limited.
- The uncertainty of the modelling results means that the ecological risk assessment can only deliver a qualitative assessment of the risks associated with various scenarios, and the uncertainty associated with these predictions.
- Despite the uncertainty associated with the biomass of algae produced, the models were able to recapitulate monitored biomass dynamics with a reasonable level of concordance.

13.5 Ecological effects table completed semi quantitatively

13.5.1 Native Fish

Semi-quantitative ecological effects tables were prepared for each reach of importance identified in the Phase 1 NPIRD report. The Goulburn main channel (Tables 1 to 3) and tributaries (Tables 4 to 5) are considered independently. Effects tables show the environmental stressors of importance, provide an estimate of risk (probability adverse effect will occur) to native fish for each stressor, and give the level of uncertainty for that estimate. Estimates were developed using BN model findings, existing knowledge of stressors and fisheries data. The level of uncertainty in that knowledge is identified for each parameter.

Ratings for the fish study were established using the model output and the outputs of the sensitivity to findings analyses (provided in full for each site in Appendix 3 of Attachment 1). However, it should be noted that the ratings are considered to be semi-quantitative, and there is no direct or single measure for assignment of the Low, Medium or High criteria.

All variables in Tables 1 – 5 are data variables, and no expert opinion was incorporated into these nodes. Generally, the 'risk' ratings were established using the following criteria:

- If sensitivity analyses indicate that a variable is sensitive to model endpoints (allocated a sensitive variable if the variable changes the endpoint by more than [or close to] 0.05%) and the model output defines a data-driven variable as being clearly inside what is considered to be natural (e.g. P(Dissolved Oxygen = Normal) ≥ 85 %), then risk was classified as Low.
- If sensitivity analyses indicate that a variable is not sensitive to model endpoints (allocated a sensitive variable if the variable changes the endpoint by less than [or close to] 0.05%) and the model output defines a data-driven variable as being clearly inside what is considered to be natural (e.g. P(Dissolved Oxygen = Normal) ≥ 85 %), then risk was classified as Low.
- If sensitivity analyses indicate that a variable is not sensitive to model endpoints (allocated a sensitive variable if the variable changes the endpoint by less than [or close to] 0.05%) and the model output defines a data-driven variable as being variable (e.g. P(Dissolved Oxygen = Extreme Low) = 15 %, P(Dissolved Oxygen = Normal) = 70 %, P(Dissolved Oxygen = Extreme High) = 15 %), then risk was classified as Low.
- If sensitivity analyses indicate that a variable is sensitive to model endpoints (allocated a sensitive variable if the variable changes the endpoint by more than [or close to] 0.05%) and the model output defines a data-driven variable as being variable (e.g. P(Dissolved Oxygen = Extreme Low) = 15 %, P(Dissolved Oxygen = Normal) = 70 %, P(Dissolved Oxygen = Extreme High) = 15 %), then risk was classified as Medium.
- If sensitivity analyses indicate that a variable is sensitive to model endpoints (allocated a sensitive variable if the variable changes the endpoint by more than [or close to] 0.05%) and the model output defines a data-driven variable as being clearly outside what is considered to be natural (e.g. P(Dissolved Oxygen = Extreme Low) ≥ 85 %) then risk was classified as High.

Sensitivity analysis tests were used in this study to identify probabilities that are likely to be very influential to network outputs, and those that are not. If variables were found to have only a minor influence on the network, thus contributing little to the network findings, they were considered as not requiring a high degree of accuracy (Coupe *et al.* 1999). Therefore, both sensitivity analyses, and the certainty of the data in allocating whether a variable was in or outside what can be considered to be 'normal', were used to categorise risk. More information about the sensitivity analyses are contained in the Fish Report.

For quantification of uncertainty, the availability of monitoring data for these sites was considered. This measure is essentially qualitative. For complete information on the data used to develop the Bayesian network, refer to Tables 1, 7, and 8 of the Attachment 1.

Table 1 Phase 2 Semi-quantitative ecological effects table - Goulburn River – Eildon to Trawool

Parameter		Risk (Probability)	Uncertainty
Water Quality	Temperature	H	L
	Turbidity	L	L
	pH	L	L
	DO	L	L
	Salinity	L	L
	Excess nutrients	L	L
	Toxicants/Organic C	L	L
Barriers	Change in flow regime	H	L
	Prevent migration	H	L
Instream Structural Habitat	Geomorphology	M	M
	Riparian vegetation	M	M
	Snags	M	M
Alien species		H	M

Table 2 – Phase 2 Semi-quantitative ecological effects table - Goulburn River – Lake Nagambie/Goulburn Weir

Parameter		Risk (Probability)	Uncertainty
Water Quality	Temperature	L	M
	Turbidity	L	H
	pH	L	H
	DO	L	H
	Salinity	L	M
	Excess nutrients	L	L
	Toxicants/Organic C	L	L
Barriers	Change in flow regime	H	L
	Prevent migration	H	M
Instream Structural Habitat	Geomorphology	M	M
	Riparian vegetation	M	M
	Snags	M	M
Alien species		H	M

Table 3 – Phase 2 Semi-quantitative ecological effects table - Goulburn River – Murchison to Murray confluence

Parameter		Risk (Probability)	Uncertainty
Water Quality	Temperature	L	L
	Turbidity	M	H
	pH	L	L
	DO	L	L
	Salinity	L	M
	Excess nutrients	L	L
	Toxicants/Organic C	L	L
Barriers	Change in flow regime	H	L
	Prevent migration	M	M
Instream Structural Habitat	Geomorphology	L	M
	Riparian vegetation	M	M
	Snags	M	M
Alien species		H	M

Table 4 – Phase 2 Semi-quantitative ecological effects table - Tributaries – Eildon to Lake Nagambie

Parameter		Risk (Probability)	Uncertainty
Water Quality	Temperature	L	L
	Turbidity	M	H
	pH	L	L
	DO	L	L
	Salinity	M	M
	Excess nutrients	L	L
	Toxicants/Organic C	L	L
Barriers	Change in flow regime	M	L
	Prevent migration	H	L
Instream Structural Habitat	Geomorphology	M	M
	Riparian vegetation	M	M
	Snags	M	M
Alien species		H	M

Table 5 – Phase 2 Semi-quantitative ecological effects table - Tributaries – Murchison to Murray confluence

Parameter		Risk (Probability)	Uncertainty
Water Quality	Temperature	L	L
	Turbidity	H	H
	pH	L	L
	DO	L	L
	Salinity	L	M
	Excess nutrients	L	L
	Toxicants/Organic C	L	L
Barriers	Change in flow regime	H	L
	Prevent migration	H	L
Instream Structural Habitat	Geomorphology	M	M
	Riparian vegetation	M	M
	Snags	M	M
Alien species		H	M

13.5.2 Blue Green Algae

Scenario modeling (see Section 13.7.2) and existing knowledge of algal processes only allowed formation of qualitative ecological effects tables for the two systems of interest (Table 6 and Table 7). These present the environmental stressors of importance to risk of algal blooms in each system, along with an estimate of the probability of an increase in the risk of algal blooms given the stressor, plus an estimate of the uncertainty in these findings. The lack of validating data mean that our estimates must be considered preliminary, and thus the uncertainty is fairly high. Table 6 and 7 show the magnitude of the perturbation for which the probability and uncertainty are estimated qualitatively.

Attachment 2 discusses why we did not attempt to put numbers on probabilities of bloom occurrence, and if we cannot estimate probability, then we cannot estimate uncertainty numerically. A deterministic model does not give a likelihood of bloom occurrence given a certain set of environmental conditions. Because the models were so poorly validated, it was not reasonable to introduce stochastic elements in order to generate likelihood predictions.

Table 6 – Phase 2 Qualitative ecological effects table Lake Nagambie – Goulburn Weir

Parameter	Risk (Probability)	Uncertainty
Increased FRP (x4)	M	H
Increased Temperature (+ 4°C)	L	H
Decreased turbidity (0 NTU)	L	L
Decreased flow (halved)	L	H

Table 7 - – Phase 2 Qualitative ecological effects table Lower Goulburn River – Rodney Main Drain to River Murray

Parameter	Risk (Probability)	Uncertainty
Increased FRP (x5)	L	H
Increased Temperature (+ 4°C)	L	H
Decreased turbidity (halved)	L	H
Decreased flow (not modelled)	L	H
Increased salinity (not modelled)	L	H

13.5.3 Comparison with Phase 1 Ecological Effects Table

In Phase 1 of this project a qualitative ecological effects table was developed (Table 8). The Tables above are a substantial advance on the Phase 1 Table.

Table 8: Example ecological effects ranking matrix table – Phase 1

	Relative importance in catchment* (priority)		Impact of irrigation	Risk (probability)	Knowledge#
Ecological Consequence	Local	Broad			
Algal Blooms	M	H	M	M	M
Fish Kills	M	L	L	L, M, H	L
Invasion of Pest Plant and Animals	H	H	M	M	M
Degradation of Floodplain and Wetland Vegetation	H	H	H	H	M

*based on consideration of impact of irrigation and probability of the impact occurring.
identify level of knowledge in area from existing and past projects. Document proposed research projects.

13.6 Rankings of each of the risk factors

The ranking of risk factors is included in the ecological effects tables above.

13.7 Relationships between key risk factors and identified risk quantified

Develop ecological models to quantify the relationships between risk factors and the identified risk

13.7.1 Fish component

For the fish component of the project the original intention was to develop a series of curves of the form conceptualized by Cottingham et al 2000. For example, the diagram below (Figure 5) could describe the relationship between fish survival and changes in habitat.

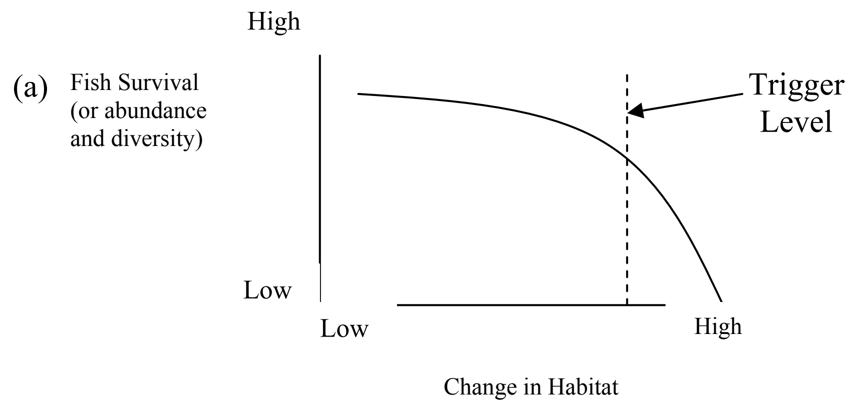


Figure 5 – Conceptualised relationship between fish survival and changes in habitat.

The project utilized detailed multivariate statistical techniques to describe the fish communities in the catchment, but the models produced were not predictive. It was also established that the data available on native fish communities in general, let alone the Goulburn Broken catchment, was not suitable to establish empirical relationships between parameters.

For this reason, the graphical modelling technique, Bayesian networks, was used to further describe risk factors, and to predict responses in native fish abundance and diversity in current environmental conditions and pre and post management interventions. The structure of the BN model is shown in Fig 2 and a generic BN model is shown in Fig 3. The Bayesian approach utilized probabilistic estimations to derive the relationships between habitat variables and native fish abundance and diversity, and therefore mathematical functions were not utilized to describe relationships (refer to Attachment 1 for further detail). In order to quantify the relationships between variables, conditional probabilities were utilised. Conditional probability distributions can be obtained three ways; they can be judged directly from experts; from the literature; or obtained by fitting a network to a set of observed cases (Henrion *et al.* 1996). In this study, all information sources were utilised and probability distributions were ascertained over two iterations.

- *Iteration One*

As stated earlier, the BN developed in this study is composed of 5 sub-models. Parent variables for each sub-network feed into mediating descriptor variables, whose outcomes are calculated by conditional probability relationships.

The conditional probabilities of the descriptor variables for physical data variables (‘Water Quality Descriptor’ ‘Hydraulic Habitat Descriptor’ ‘Structural Habitat Descriptor’) are based on an additive model calculated from raw data. This approach is similar to that used in the Index for Stream Condition (http://www.vicwaterdata.net/; accessed January 2004). Fuzziness was generated within descriptor variables to represent uncertainties in parameter measurements.

The conditional probability relationships of the descriptor variable for the biological data variables ‘Biological Potential Descriptor’, and the model endpoint variables ‘Future Abundance’ and ‘Future Diversity’ are based on expert opinion and relationships detailed in the literature. These parameter estimates incorporate uncertainty. Sources of uncertainty taken into consideration by experts included subjective judgments, inherent variability in the study system and knowledge gaps. Explicit incorporation of uncertainty acknowledges that the final BN model can only be regarded as a simplification of reality. For expert elicitation of conditional probability tables, a similar approach to Marcot *et al.* (2001) was used.

- *Iteration Two*

To introduce the frequency information embodied in the spatially specific physical and biological monitoring records, conditional probabilities of data variables, non-data descriptor variables and the endpoint variables were updated from the data using the data learning process, the EM (Expectation Maximisation) algorithm.

The EM algorithm is useful for parameterising a model when there is missing data problems. It is an iterative computation, maximising the probability of the data given the BN. Thus, conditional probability estimations in iteration one was used for establishing initial parameter estimates and relationships contained in monitoring data were used to refine these. The data learning process was supervised, by applying an equivalent sample size weighting to conditional probability distributions ascertained in iteration 1. Several trials were conducted to refine conditional probabilities, each time assessing whether the degree of changes between expert probabilities and EM-derived probabilities were acceptable. The shifts in probability distributions between model iterations were measured using Battacharyya distance, as detailed in Woodberry *et al*. (submitted). This process also enabled the robustness of the expert elicitation process versus the automated learning process to be tested.

Data was incorporated into the model as set of cases that represented system states observed. The frequency of values in the sampling data for a site determines how certain the site dependent probability distributions were.

13.7.2 Blue green algae

The blue green algal component of the study took a different approach by utilizing a deterministic model developed for the Darling River and modifying it for application in the Goulburn Broken catchment. The structure of this model is shown in Figure 4.

A model originally developed for the weir pool at Bourke, N.S.W. (Webb, Linacre & Grace, submitted) was applied to the case study and analogue sites. In its original application, this model successfully recreated all the blooms that occurred in Bourke Weir over a 10-year period. It also falsely predicted one other bloom. Thus, we had an a priori expectation that this model would provide a conservative estimate of the conditions likely to lead to bloom formation in the Goulburn-Broken sites. Some modifications were carried out compared to the model described in Webb et al. (submitted). The model is described below.

The model was developed for the bloom-forming cyanobacterium *Anabaena sp*. *Anabaena* is the most common bloom forming cyanobacterium in Australian inland waters (Jones & Orr, 2000), and members of the genus are common throughout the world. This genus is also common in blooms within the Goulburn Broken catchment. The cells form filaments that can control their buoyancy (Oliver & Ganf, 2000), and can thus float into well-lit surface waters during periods of reduced water circulation. Anabaena species also have the ability to fix atmospheric nitrogen (Oliver & Ganf, 2000). The model was re-parameterised for Lake Mokoan, as *Microcystis aeruginosa* is the most common bloom forming taxon within that system.

The two systems being modelled do not generally experience high algal populations. We tested various scenarios by altering data input values to the models (i.e. higher FRP, higher temperature, lower turbidity, lower flow) to see how far parameters could be altered before the model started to project elevated cell numbers.

Conceptual model
The numeric model is based on the conceptual model pictured in Figure 4. In the model, either light or phosphorus limitation, together with the effect of water temperature, regulate the daily rate of algal reproduction. Mortality reduces population numbers, as does a component representing the net number of cells washed from the weir each day. Day length combines with turbidity to determine the extent of light limitation on population growth. The amount of dissolved reactive phosphorus determines the extent of phosphorus limitation on cell production.

Information on the model is provided above and in the attachments.

13.8 Summarising Results Against Objectives

13.8.1 Overall Objective

The purpose of this project is to implement Phase 2 of the project "Assessment of ecological risk associated with irrigation systems in the Goulburn Broken catchment." This will assist development of a generic framework for the Ecological Risk Assessment (ERA) of irrigated agriculture in a catchment context.

In an overall sense this objective has been met. Implementation of the project has been undertaken and reported upon. The project outputs should fed into Phase 3, the development of a generic framework.

However, the project did not produce the anticipated outcomes due to

- Lack of data in both the fish and blue green algal components
- Lack of clearly quantifiable or agreed relationships between identified risk factors in the fish component.

Despite these limitations the project has produced excellent outcomes from a management perspective. For native fish clear management directions are indicated for activities and actions that should be undertaken to address native fish issues. From a blue green algal management perspective the likely risks of blooms in the Goulburn River system are now much better documented and understood.

13.8.2 Specific objectives:

Complete the ecological effects semi quantitative ranking table prepared in Phase 1

Tables have been completed – see Section 13.4 above. These Tables are a substantial advance over the Table presented in the Phase 1 report.

Undertake limited research to gather missing information and further quantify key relationships

This objective was met by the undertaking of a number of small research projects, development and application of non standard techniques and modification of existing models. These are briefly described below.

Fish component

Bayesian tools

In collaboration with the Computer Science and Software Engineering (CSSE) group at Monash University, windows-based programs to conduct both sensitivity to findings and sensitivity to parameters have been developed as support tools for constructing Bayesian networks. A conceptual diagram and decision tree to guide future development of

Bayesian networks, informed by the experience of building the native fish Bayesian network, are being developed to assist future modelling studies.

Other software tools

Application of a tool being developed by the CSSE group (Causal Minimum Message Length - CaMML) as part of their own research agenda. This uses data mining techniques to establish the causal relationships between variables in a dataset. Using the technique 'Minimum Message Length' (MML) the simplest model structure to predict fish communities in the catchment, as embodied in the physical, chemical and biological case data, was identified (Figure 18).

The CaMML modelling program identified the presence or absence of a barrier being the primary driver of fish abundance in the catchment. The CaMML model for fish abundance as embodied in the data, is shown in Figure 6. From an academic perspective, this relationship is of great interest. From a management perspective, barrier removal is unlikely to be a viable solution and the range of manageable variables in the catchment need to be investigated.

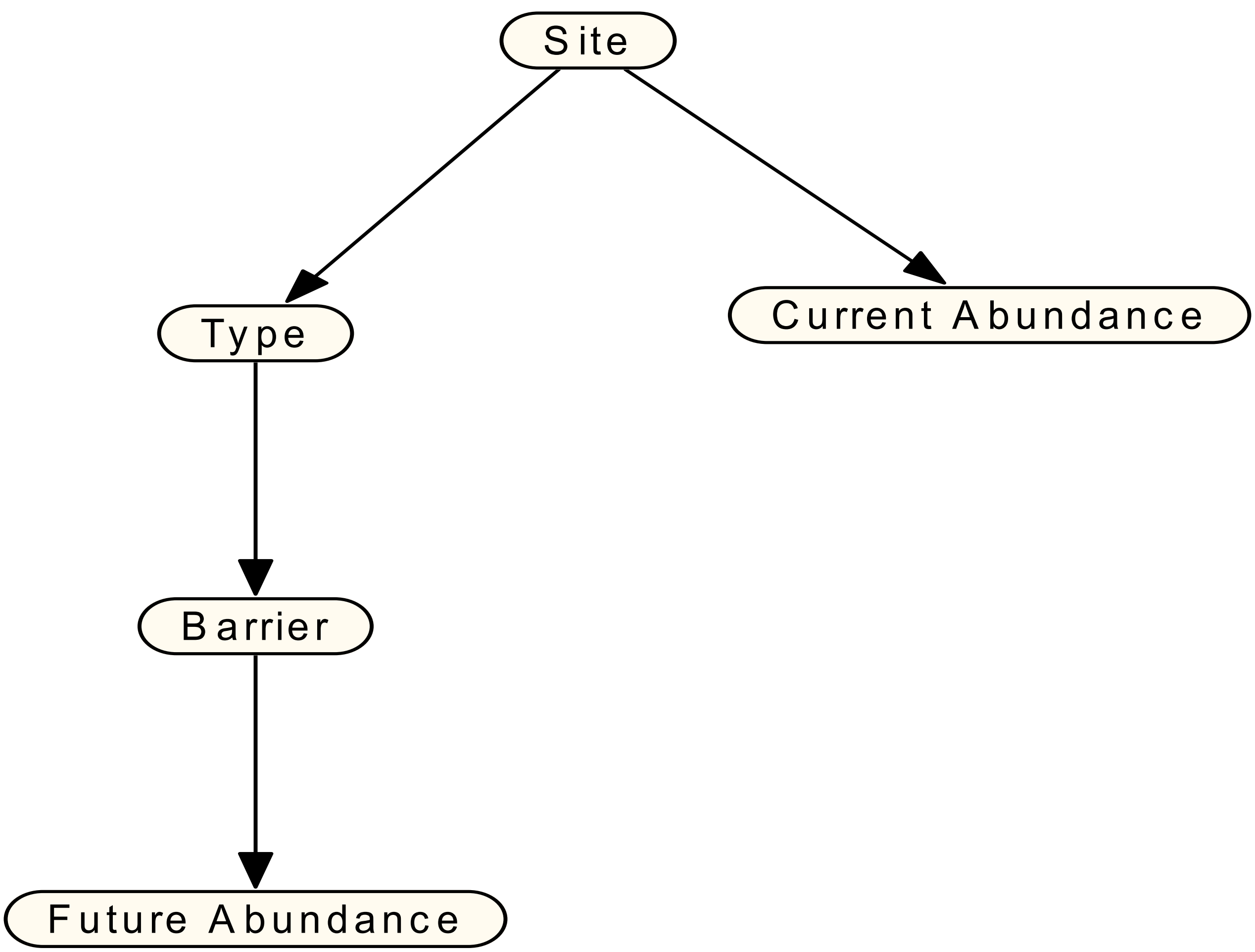


Figure 6: CaMML structure, a data mining technique describing fish communities in the Goulburn Broken Catchment.

Blue green algal component

Light attenuation

The relationship between turbidity and specific light attenuation depends upon the types of sediments suspended in the water column. For the original application of the model, an empirical relationship developed for the waters of Bourke Weir (Oliver *et al.*, 1999) was used. For this project, we undertook similar investigations.

Model modification

A model originally developed for the weir pool at Bourke, N.S.W. (Webb, Linacre & Grace, submitted) was applied to the case study and analogue sites. Some modifications were carried to the model for it to be used in this project.

Analogue sites

Neither of the case study sites has a documented history of algal blooms. This lack of blooms means that it is not possible to validate bloom models using monitoring data for the sites. Moreover, to our knowledge, there have been no attempts in the past to model cyanobacterial populations at either of the two sites. In order to give an indication of how well models were working for the case study sites, the cyanobacterial model was applied to data from two nearby systems that have a history of cyanobacterial blooms. Lake Mokoan has been well studied and is the subject of several detailed models of cyanobacterial population dynamics. The East Goulburn Main Channel has not been studied in the past. These two sites provided rough analogues of the Lake Nagambie, and lower Goulburn river sites respectively.

Re-parameterisation of model for Lake Mokoan

The model was developed for the bloom-forming cyanobacterium *Anabaena* sp. *Anabaena* is the most common bloom forming cyanobacterium in Australian inland waters (Jones & Orr, 2000), and members of the genus are common throughout the world. This genus is also common in blooms within the Goulburn Broken catchment.

The dominant bloom forming taxon in Lake Mokoan is *Microcystis aeruginosa*, and so several parameters in the model specific to *Anabaena* sp. had to be changed. These parameters were the cell quota of phosphorus (P_{cell}), the half saturation rate of phosphorus uptake (K_S), the temperature-growth multiplier (Q_{10}), and the basal growth rate (r_{20}). Unlike *Anabaena*, *Microcystis aeruginosa* cannot fix atmospheric nitrogen. Strictly speaking, the model for Lake Mokoan should have included an opportunity for Nitrogen limitation. However, the additional effort entailed in such modelling was not justified, given that Lake Mokoan is designated as an analogous site with which we can test the model developed for Lake Nagambie.

Provide input to the ERA linkage project that is to develop a generic framework for applying the ERA approach to assess the ecological risks from irrigation systems at the catchment level.

This objective was met via the participation of the team in the 2 linkage workshops held in August 2003 and June 2002. and this final report.

14 Future R&D needs

14.1 Fish component

In order to satisfy the requirements of an ecological risk assessment, an important attribute of models is they need to be iterative. Compared to other model types, Bayesian networks can be updated relatively easily. Both the structural and quantitative components of a model can be improved as new knowledge becomes available. This is particularly valid in a management context. As management actions are undertaken in the Goulburn Broken Catchment, the model can be updated to reflect pre- and post- fish community responses.

In workshop 1, stakeholders identified successful recruitment as a desirable endpoint for the native fish model. This was not considered achievable in this study given the paucity of data available. On the request of expert stakeholders in workshop 2, recruitment was made explicit in the model. An important area of research in the CRCFE is the investigation of factors contributing to successful recruitment. As the knowledge of conditions required for successful recruitment by native fish improves, the recruitment section of the BN could be expanded. Integration of information from the MDFRC into this model would be particularly beneficial. In the BN model, the level of successful recruitment was identified as an important variable in sensitivity analyses.

Another key information gap identified in the model was the effect turbidity is having on native fish communities, particularly in the mid and lower sections of the catchment. Once again, relevant study findings should be incorporated into the model as they become available. This is also relevant for other important factors, including temperature changes and flow. One such study being undertaken by the EPA Victoria and Monash University may partly fulfill this information need. Turbidity monitoring data is also required throughout the catchment."

A desire of expert stakeholders in workshop 2 was that the model be species specific. At this stage the fisheries data available in the catchment is not comprehensive enough to be divided into species groups. In order for this to be done, a comprehensive fisheries survey in the catchment is required. Additionally, the knowledge of environmental factors influencing native fish species in the catchment is poorly understood, with expert knowledge and data being poor.

As stated earlier, the Broken catchment data was incorporated into the model simply for better quantification of the relationship between variables. There is the potential to expand the model to other lowland river systems, particularly in areas that have healthy native fish communities. The model in its current iteration has not had much experience with systems with healthy fish communities.

The BN produced is not a dynamic model. The model is static representations of fish abundance and diversity over both 1 year and 5 year time periods. In order to have a more dynamic representation of the system, an ecosystem model would be more appropriate. Bayesian dynamic networks require rich information sources, or a comprehensive expert understanding of how system component interacts with one another. One way of achieving this is to use deterministic physical and chemical models to inform the Bayesian network.

In the current iteration of the BN, only discrete probabilities are used to describe relationships between interacting variables. Future iterations could investigate using continuous probability distributions. At the present time, the data available is not strong enough to develop a full understanding of these distributions. The use of distributions also limits the capacity of the model relationships to be updated using the EM algorithm, the learning technique used to update the model in this study. The model would also become more generic for systems, rather than specific for areas as it is now.

Recommendations for future monitoring

In order for the BN model produced in this study to be applicable to the Catchment in the long term, it needs to be updated regularly. To improve the value of fisheries data for use in modelling, a series of recommendations can be made to those collecting data:

- Record date, site (Longitude/Latitude or Northing/Easting) and fish sampling technique(s);
- Use uniform methodologies (eg. electrofishing, large and small fyke nets) for sampling;
- Indicate the proportion of fish that are larvae, juveniles and adults;
- Incorporate basic water quality measurements in routine monitoring (eg. pH, dissolved oxygen, temperature, salinity, turbidity) and document methodologies;
- Include measurements of flow;
- Conduct physical habitat assessments (eg. snags, aquatic vegetation, evidence of sand slugs causing channel infilling, riffles or pools);
- Quantify all fish collected, not just target species or species of interest;
- If possible, conduct a rapid assessment of the health of microfauna populations;
- Enter information into a common database.

Improvements in the design of monitoring protocols will assist in validating model predictions and enabling better quantification of relationships between variables.

14.2 Blue Green algal component

- For the lower Goulburn River, basic information on the river channel, and the physico-chemical conditions within the river stretch would improve our confidence in the modelled results, or direct us to modify the model appropriately
- In order to proceed from this qualitative risk assessment to a fully quantified risk assessment, further research is required into the processes governing algal dynamics within the case study systems. In particular, further development of the phosphorus limitation routine within the cyanobacterial population model is likely to lead to improved simulations of cyanobacterial populations. Once confidence in the output of the deterministic models has been improved, introducing stochastic elements to the models will allow a quantitative estimate of the likelihood of bloom occurrence.

A decision as to whether to proceed with the above work should be made in light of the low algal abundances in the system, and the low apparent risks of blooms under various perturbation scenarios that have been identified in this report

15 Refinement of this Ecological Risk Assessment

As noted in Section 13.1 the ecological risk assessment process should ideally be carried out iteratively, allowing new information to be incorporated into the risk assessment as it becomes available. In an ideal world with abundant funding, tractable research problems and long term management commitment, refinement of an ERA would be a considered to be a component of an adaptive management cycle (or a continuous improvement cycle).

In reality, funding is limited, there are difficult and competing research questions, managers are distracted by competing priorities, it is difficult to see how an ERA can continuously be updated. In this environment the best that can be hoped for is that the outcomes of various phases of the ERA can be incorporated in various management strategies (for example for this ERA the CMA's River Health Strategy). If these strategies are regularly updated (say on a 5 yearly cycle) then the opportunity exists to update the ERA.

Another way continuous review might be achieved is via specific investigations triggered by this project. For example, if further investigations were deemed warranted into provision of a fish way at Goulburn Weir, then it could be expected that substantial resources and funding would be directed to firming up the outcomes of this project by undertaking a number of targeted investigations which should ultimately lead to an updating the Phase 2 ERA. The recommendations outlined in Section 14.1 would provide a good basis for the required investigations.

16 References

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17 Attachments

1. Ecological Risk Associated with Irrigation in the Goulburn-Broken Catchment – Phase 2 - Adverse changes to the abundance and diversity of native fish – Milestone 5 report prepared by Carmel Pollino

2. Ecological risk Associated with Irrigation Systems in the Goulburn-Broken Catchment – Phase 2: Priority Risk – blue Green Algal Blooms – Final Report prepared by J.A. Webb and T.U. Chan

3. Fish communities and habitat changes in the highly modified Goulburn Catchment, Victoria, Australia. Carmel A Pollino, Pat Feehan, Michael R Grace, Barry T Hart. (submitted). *Marine and Freshwater Research.*

4. Management-oriented modelling of blue green algal blooms: and example from the Bourke Weir, NSW. Webb J.A., Linacre N.A. & Grace M.R. (submitted). *Ecological Modelling*