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NPSI Project UMO45
Delivering Sustainability through Risk Management

Ecological Risk Assessment Case Study for the Lower Loddon Catchment: *Bayesian decision network model for predicting macroinvertebrate community diversity in the Lower Loddon River*

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The National Program for Sustainable Irrigation focuses research on the development and adoption of sustainable irrigation practices in Australian agriculture.
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Executive Summary

This report - *Ecological Risk Assessment Case Study for the Lower Loddon Catchment: Bayesian decision network model for predicting macroinvertebrate community diversity in the Lower Loddon River* - is the third in a series of five produced by NPSI project UMO45 *Delivering Sustainability through Risk Management*.

Ecological Risk Assessment (ERA) is a formal process for determining the risk posed by hazards (stressors, threats) to the health of ecosystems. ERA evolved from the need to develop processes that better deal with the complexity of aquatic ecosystems. That is, the difficulties in assessing multiple stressors for a wide range of species within inherently variable ecosystems. Such assessments provide an explicit and transparent process for making management decisions for complex ecosystems that may not always be fully understood.

The ERA conducted in this study was focused on the assessment of the health of the Lower Loddon River. The aim of the risk assessment is to provide local resource managers with a better understanding of risks to the Lower Loddon River and the effectiveness of different management actions in protecting and rehabilitating the River. This primarily involved the development of a Bayesian network to assess the health of the macroinvertebrate community in the Lower Loddon catchment.

A Bayesian decision network model for predicting macroinvertebrate community diversity in the Lower Loddon River was developed and full details are provided in the report.

Sensitivity analysis showed that habitat variables (e.g. in-stream habitat, food availability, in-stream vegetation, turbidity, sedimentation, riparian vegetation, woody debris and roots, bank erosion) had the greatest influence on the predicted macroinvertebrate community diversity.

The Bayesian network predicted that the macroinvertebrate community diversity in all six ISC reaches in the Lower Loddon River would be poor. This certainly agrees with the small amount of field data available.

The Bayesian network has also been used to predict the effect on the macroinvertebrate communities of three levels of stock access (low, moderate, high) to the riparian zone and the channel. Reducing stock access significantly improved the macroinvertebrate community diversity in good to very good condition from 21% for high access to around 80% for low access.

These results support the current Loddon catchment management plan, where major on-ground fencing works are being implemented to reduce stock access to the riparian zone and the river.

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1. Introduction

The National Program for Sustainable Irrigation (NPSI) is committed to improving the sustainability of current and proposed irrigation schemes throughout Australia.

In support of this aim, NPSI has funded project UMO45 *Delivering Sustainability through Risk Management*, which is designed to raise awareness of the Australian irrigation industry in adopting risk-based environmental management approaches. The adoption of risk-based approaches is considered to be vital if the industry is to achieve its goal of long-term sustainability. This project is a logical extension of an earlier NPSI project (UMO40) that developed an Ecological Risk Assessment framework for the Australian irrigation industry (Hart et al., 2005).

This *Delivering Sustainability through Risk Management* project aims to achieve an improved level of adoption of risk assessment and risk management approaches in environmental management and a greater capacity to use such approaches, within both the irrigation industry and regulatory authorities in Australia.

The project has three components:

- to undertake a series of *regional awareness workshops* aimed at explaining the objectives of this project, as well as the ways in which risk management might be adopted by the irrigation industry and how this will assist them to achieve the ultimate aim of long-term sustainability of the industry,
- to establish ***case study partnerships*** involving the irrigation industry and appropriate State irrigation regulators, and to work with these partnerships to develop capacity within the individual organizations to use risk assessment and risk management procedures to improve the ecological sustainability of the irrigation region, and
- to work with *selected Sustainable Irrigation projects* (and their key stakeholders) in trialling different methods and approaches for adopting risk management procedures into their projects.

Five reports have been produced by this project:

- Summary Report - *Delivering Sustainability through Risk Management* (Hart et al., 2006).
- Report 1 – *Prospects for Adoption of Ecological Risk Assessment in the Australian Irrigation Industry* (Walshe et al., 2006).
- Report 2 – *Ecological Risk Assessment Case Study for the Murray Irrigation Region* (Pollino et al., 2006).
- Report 3 - *Ecological Risk Assessment Case Study for the Lower Loddon Catchment - Bayesian decision network model for predicting macroinvertebrate community diversity in the Lower Loddon River* (Westbury et al., 2006).
- Report 4 - *Ecological Risk Assessment Case Study for the Lower Loddon Catchment - Bayesian decision network model for predicting grey-crowned babbler population abundance in the Lower Loddon catchment* (Chan & Hart, 2006).

These reports are all available at www.sci.monash.edu.au/wsc.

This document is Report 3 of the series. It reports the case study undertaken in the Lower Loddon catchment downstream of Bridgewater in northern Victoria.

The Lower Loddon catchment ecological risk assessment was a collaborative project involving staff from EPA Victoria, Water Studies Centre Monash University, North Central Catchment Management Authority (NCCMA) and Goulburn-Murray Water (G-MW). The project was assisted by funding from the National Action Plan for Salinity and Water Quality and the National Program for Sustainable Irrigation (NPSI). Figure 1 provides a summary of the project approach and Figure 2 contains a map of the project area.

The aim of the project was to provide information and decision support tools to assist NCCMA, G-MW and Department of Primary Industries (DPI) in targeting on-ground management actions and monitoring programs, for rehabilitation of the lower Loddon catchment. The focus and scope of the risk assessment was developed during the Problem Formulation phase of the project in collaboration with stakeholders with an interest in the Lower Loddon area (see Westbury et al., 2005). The stakeholder group involved had considerable knowledge and experience in the management of the Lower Loddon Region, and included natural resource managers, landholders, regulators, local government and water authorities.

During the Problem Formulation phase, stakeholders identified two ecological values potentially at risk to be the focus of a quantitative risk analysis; these were the *ecological health of the Lower Loddon River* and *farmland ecological values*. This report discusses the development of a Bayesian Decision Network (BDN) model to predict macroinvertebrate community diversity as an indicator of the ecological health of the Lower Loddon River.

Stakeholders defined the area to be covered by the Lower Loddon River risk assessment as the Loddon River main channel downstream of Bridgewater (Figure 2). The risk analysis focused on providing information at both an overall catchment scale and also separately at an individual Index of Stream Condition (ISC) reach scale (ISC reaches 1-6, Figure 2).

An appropriate method for measuring river health must be selected if the risks, and the outcomes of management actions, are to be assessed for the Lower Loddon River. A measurement endpoint is a characteristic of the value that is predictable and measurable, indicates the biological health of the value and is representative of management goals. Macroinvertebrate community diversity was chosen as the endpoint for assessing the health of the Lower Loddon River. Macroinvertebrates include aquatic animals such as insects, snails, worms and shrimps. They provide a direct biological measure of an important part of the river fauna, are relatively easy to monitor and are a part of current and future monitoring programs in the Loddon catchment. The standard measures chosen for measuring macroinvertebrate community diversity are the indices AUSRIVAS, SiGNAL and Number of Families.

The risk analysis involved the development of a BDN model for macroinvertebrate community diversity in the Lower Loddon River. Bayesian Networks are ideally suited to assist in natural resource management decision-making, where problems are complex and data often scarce and uncertain. Bayesian networks are able to bring together and incorporate all available types of data, knowledge and information. This is all combined in the network to provide predictions of the overall risk posed to ecological values, and the likely outcomes under different management scenarios. The models can be easily updated when more information becomes available, increasing the understanding of catchment processes over time. Most importantly, they provide quantitative predictions that explicitly state where the uncertainties are in the information.

The information from the Bayesian network will provide the NCCMA, G-MW, DPI and landowners with a better understanding of risks to the Lower Loddon River and the effectiveness of different management actions for its protection and rehabilitation. This information is to be used in conjunction with, and to support, existing catchment processes.

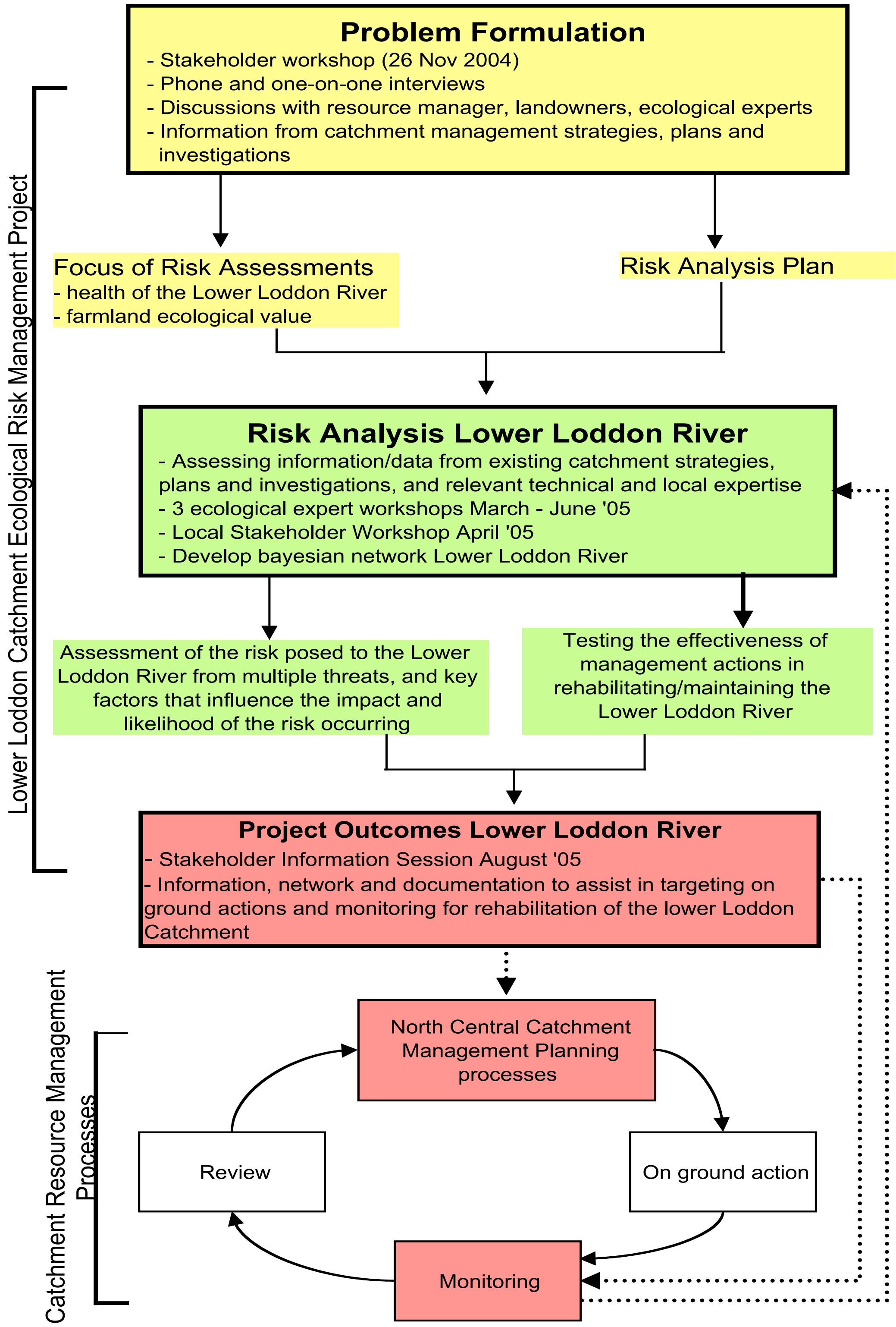

Figure 1: Summary of the Lower Loddon Catchment Ecological Risk Management Project, and linkage to North Central Catchment Management Processes

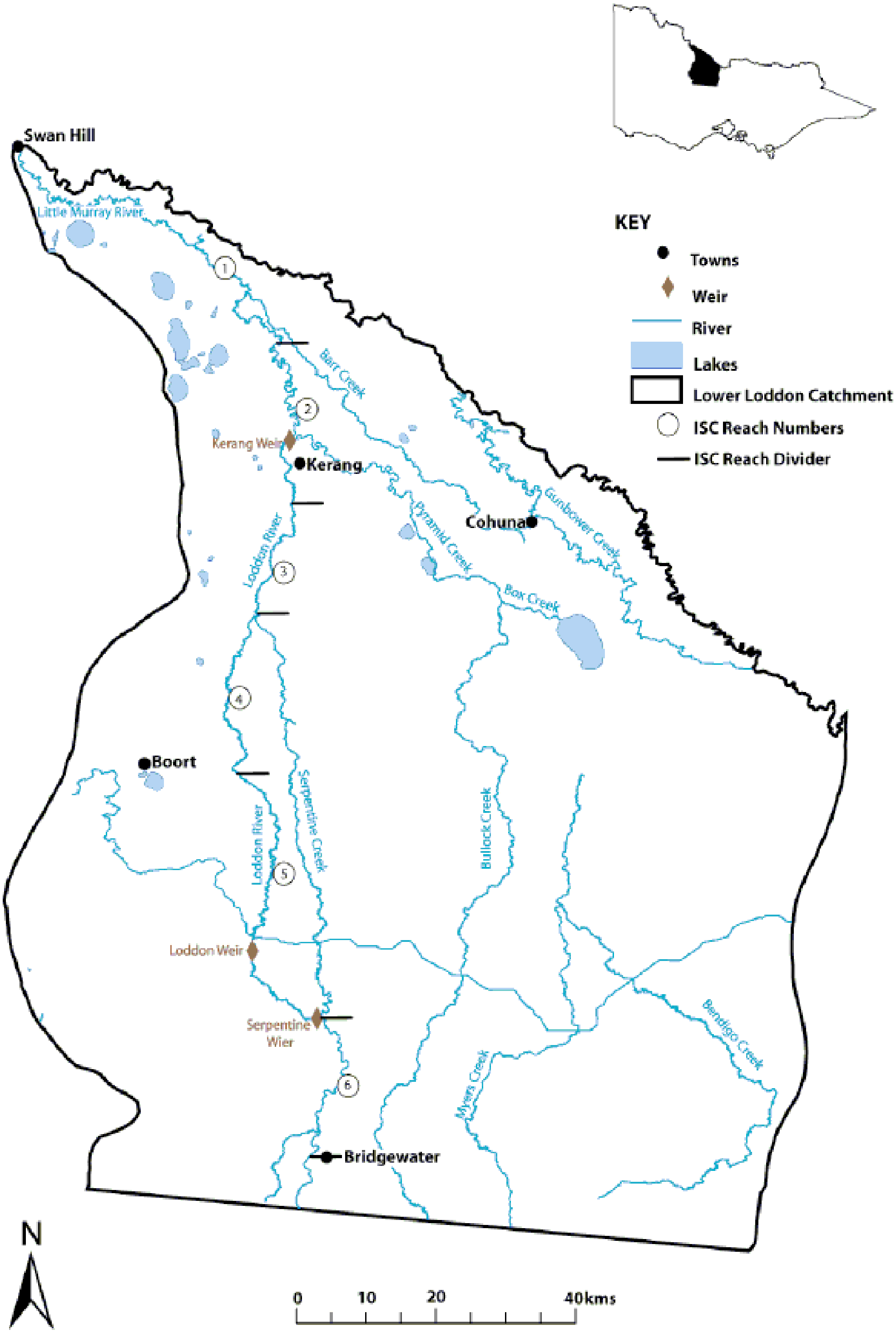

Figure 2: Map of the Lower Loddon Catchment

2. Macroinvertebrate Bayesian decision network

2.1 Overview

The three main tasks in developing a Bayesian network model are first the construction of the graphical structure, second population of the node states and the conditional probability tables (CPT's) using data or expert opinion, and third testing of the sensitivity and validation of the model outputs.

Developing the graphical structure involves the formal and systematic identification of the system variables and the interactions (linkages) between them. In almost all cases, the initial network is overly complicated and well-founded decisions need to be made on what variables to omit from the network.

For the macroinvertebrate Bayesian network, the key variables and the nature of their dependencies were identified and refined through:

- the stakeholder workshop process when a conceptual model was constructed and key hazards and threats were identified;
- a comprehensive survey of the relevant literature; and
- consultations with river managers and experts in macroinvertebrate ecology.

Since the main purpose of this model was the prediction of macroinvertebrate community diversity to inform management decisions, it was important that the model should not be overly detailed (Reckhow, 1999). The guiding principle therefore was to include only those variables and relationships that contribute to the ability to predict ecosystem attributes of management relevance (Borsuk *et al*., 2004). Each node in drafts of the graphical Bayesian network model was systematically reviewed to determine if the variable it represented was either (a) controllable, (b) predictable, or (c) observable at the scale of the management problem.

To formalize the graphical model as a Bayesian network model, variables had to be clearly defined, be observable and testable. The definition of model variables, the states included and the placement of break-points (in the case of continuous variables) was established using the relevant literature and in consultation with technical experts.

Probabilities for CPTs of the various model variables were specified using a combination of empirical data, functional relationships and expert judgements.

The Bayesian network modelling was carried out using the software Netica (Norsys Software Corp. 1997-2003). Netica uses junction tree algorithms to perform probabilistic inference (Norsys, 1997). Details on the computation and algorithms used in Netica are available in Neapolitan (1990) and Spiegelhalter *et al*. (1993). Appendix A provides further discussion on Bayesian Networks and Bayes Theorem.

2.2 Stakeholder involvement in developing the Bayesian network

To be successful an ERA must involve all relevant and interested stakeholders. This ensures that the issues investigated and the outcomes of the assessment are useful and appropriate for local management needs. The focus for the Lower Loddon ERA and the type of management information needed was identified with input from a range of local stakeholders with an interest in the catchment. This was achieved through stakeholder workshops, phone and one-on-one interviews, meetings and local tours with resource managers and community members and information gathered from regional management strategies, plans and investigations. The stakeholder group involved in the project have considerable knowledge and experience in catchment management of the lower Loddon Region. A list of the local stakeholders involved in the risk assessment is given in Table 1.

Table 1: Lower Loddon ERA stakeholder participants

Representation	Participants
North Central Catchment Management Authority	Jo Haw, Rohan Hogan, Angela Gladman, Jon Leevers, Tim Shanahan.
Goulburn-Murray Water	David Douglas, Anne Graesser, Lester Haw, Dale McGraw, Ross Stanton, Daniel Irwin.
Landowners Including committee representatives for: Loddon/Campaspe Irrigation Implementation Committee, Torrumbarry Water Services Committee, Loddon Murray Forum, Boort Western Loddon Salinity Management Plan Committee, Kerang-Swan Hill Future Land Use Pilot Project, Victorian Field and Game.	Stan Archard, Barry Barnes, John Baulch, Brian Drummond, Neville Goulding, Paul Haw, Bradley Haw, Ken Hooper, Tom Lowe, Colin Myers, John McNeil, Stuart Simms, Rod Stringer, Bill Twigg, Geoff Williams, Anne Teese.
Department of Primary Industries	Rob O'Brien, Matt Hawkins
Environment Protection Authority, Victoria	Dean Edwards, John Williamson.
Parks Victoria	Bruce Wehrner
Lower Murray Water	Kate Maddy
Loddon Shire	Trevor Barker
Gannawarra Shire	Des Bilske

2.2.1 Stakeholder consultation in the Problem Formulation phase

Initial discussions were held with the NCCMA (Tim Shanahan) and G-MW (Anne Graesser) project representatives. The local information they provided was invaluable for identifying the relevant stakeholders and for advice as to how the consultation would best be targeted. A stakeholder mapping exercise was conducted with them before making direct contact with the local resource managers and community members.

Stakeholders were initially contacted by phone to inform them about the project and to ascertain their willingness to be involved. A follow-up project fact sheet was sent to all interested stakeholders. The first stakeholder workshop was held on the 26th November 2004. There were 32 participants from a range of agencies and the community. For those who wanted to contribute but could not make the first stakeholder workshop, personal interviews were conducted and their input incorporated and reflected in the wider stakeholder consultation.

A number of stakeholder regional planning processes in the Lower Loddon catchment have already identified ecological values of high management priority. These include the North Central Regional Catchment Strategy (NCRCS), North Central River Health Strategy

(NCRHS), Loddon Murray Land and Water Management Strategy, the Bulk Water Entitlement (BE) conversion process and the Kerang-Swan Hill Future Land Use Pilot Project.

A list of the values from these previous processes was compiled and presented to the stakeholders for comment, clarification and possible expansion. Using this compiled list as a basis for further discussion meant that stakeholders who had been involved in previous projects did not feel the risk assessors were starting from scratch and had taken notice of the substantial information gathered from previous work. Stakeholders added to this list, discussed the values identified, and selected the ecological values on which to conduct risk assessments. These were the *ecological health of the Lower Loddon River* and *Farmland Ecological Values*.

Stakeholders then discussed threats and hazards to the two key values. In a similar way to the value identification exercise, a list of the threats identified from previous processes was compiled, and workshop participants added to this. Using the list of threats stakeholders mapped their knowledge of the threats and factors that may influence the likelihood of risks occurring to the ecological values. These discussions were summarised by stakeholders in conceptual models developed in groups of 4 to 6 people. Stakeholders also identified that it was important for the risk assessment to incorporate and build on the useful work and projects undertaken in the catchment to date, and to link this project directly to on ground management actions.

After the first stakeholder workshop, a meeting was held with key stakeholder representatives (G-MW, NCCMA, community members) to establish the assessment and measurement endpoints. The meeting included two community members to ensure the views of the community were taken into account and that the broader community felt that agency staff were not solely making the crucial decisions. Background information and a summary table of suggested endpoints and the strengths and weaknesses of each were presented to assist in the decision making.

The key stakeholder representatives selected *macroinvertebrate community diversity* as the endpoint for assessing the Lower Loddon River, to be measured using the indices AUSRIVAS, SIGNAL and Number of Families. Stakeholders defined the area to be covered by the risk assessment as the Loddon River main channel downstream of Bridgewater. The spatial scale for outputs from the Bayesian Networks was determined as both the overall lower Loddon catchment scale and also separately at an individual ISC reach scale (ISC reaches 1-6). Specific Loddon catchment projects that contain information and data, which needed to be incorporated into the risk analysis modelling, were also identified.

Following this key stakeholder representative meeting, feedback in the form of a newsletter was provided to all stakeholders. This outlined the outcomes of the problem formulation phase, including outcomes of the stakeholder workshop and key stakeholder representatives meeting.

2.2.2 Stakeholder consultation in the Risk Analysis phase

The Lower Loddon River Bayesian Network structure developed by the risk assessor and ecological expert panel (Table 2) was reviewed by a broad group of stakeholders at a workshop held in April 2005. The workshop was attended by 14 stakeholders, including natural resource managers (NCCMA, DPI, G-MW) and local landowners. Prior to the workshop, fact sheets on Bayesian Networks and the Lower Loddon River Network were sent to workshop participants to provide background information. At the workshop specific feedback was gathered on whether the network:

- realistically represented the Lower Loddon system;
- assessed the interactions between key threats impacting the Lower Loddon River and management actions to deal with these; and
- provided information to assist in answering key catchment management questions.

Table 2: Summary of Ecological Expert Panel Members

Name	Expertise
Stephen Adamthwaite (Freshwater Sciences, EPA Victoria)	Key area of expertise: macroinvertebrates Other areas of expertise: local knowledge of river, catchment and landuses
Leon Metzeling (Freshwater Sciences, EPA Victoria)	Key area of expertise: macroinvertebrates Other areas of expertise: general river health processes, water quality
Clare Putt (Freshwater Sciences, EPA Victoria)	Key area of expertise: macrophytes Other areas of expertise: water quality
David Robinson (Freshwater Sciences, EPA Victoria)	Key area of expertise: water quality Other areas of expertise: macroinvertebrates, general river health processes
David Tiller (Freshwater Sciences, EPA Victoria)	Key area of expertise: river health processes Other areas of expertise: Water quality, macroinvertebrates

At the workshop, stakeholders discussed and provided input into the key management information needs from the modelling, and alterations/improvements required in the Network structure. Written feedback from the second stakeholder workshop was circulated to all stakeholders, including updates to the networks.

The quantification of the Bayesian Network conditional probability tables (CPTs) was done in consultation with ecological and local experts and is detailed for the individual CPTs in Appendix B. Two further expert ecological workshops were held (Table 2) in June 2005. Local stakeholder input was obtained from resource managers and landowners through ongoing phone discussions and a two-day field trip along the Lower Loddon River. The field trip was organized by Rob O'Brien (DPI) to give the risk assessors a detailed look at the river and surrounding catchment. The trip included several local guides (landowners, DPI and NCCMA staff) that had extensive knowledge of various sections of the Loddon River. The knowledge and data gained from that trip was invaluable for carrying out the risk analysis.

2.2.3 Consultation on project outcomes

A stakeholder information session was held on 12 August 2005, which presented and discussed the results of the risk assessment and information from the Bayesian network. The workshop was attended by 16 stakeholders, including natural resource managers (NCCMA, DPI, G-MW) and local landowners. At the workshop, stakeholders expressed support for the Bayesian network and urged that it be used by Loddon catchment resource managers (NCCMA, G-MW, DPI, landowners).

Methods for incorporating the Bayesian network into local resource management processes were identified by stakeholders and included: nominating key people to receive extensive technical documentation, catchment decision-making processes to be targeted (e.g. Loddon Implementation Committees, Stressed Rivers Project), the need for an additional 'farmer friendly flyer', and involvement of local resource managers in further monitoring identified for the Bayesian network.

Written feedback on the project was also sought from stakeholders on the day. Some 95% of participants thought the risk assessment was good to very good in improving understanding of catchment risks and knowledge gaps, and providing information for assisting management of the Lower Loddon River.

2.3 Graphical structure of the network

The Bayesian network focused on the main channel of the Loddon River downstream of Bridgewater, and was developed to provide outputs at both an overall lower Loddon catchment scale and also separately at an individual ISC reach scale (ISC reaches 1-6). The network assessment endpoint was macroinvertebrate community diversity, which is measured using the standard indices AUSRIVAS, SiGNAL and Number of Families developed for Victorian lowland rivers and streams. Macroinvertebrates include aquatic animals such as insects, snails, worms and shrimps, and are an important part of the river fauna.

The Bayesian network structure was based on the conceptual models initially developed during the first stakeholder workshop (Figure 3), and on information in catchment reports and the scientific literature. The first iteration of the Network was reviewed and updated by a panel of five expert aquatic ecologists (Table D.1) at a workshop held in March 2005. The Bayesian network structure was then reviewed by a broader group of stakeholders at a workshop held in April 2005, which included local resource managers (DPI, NCCMA, G-MW) and landowners.

The full graphical Bayesian probability network for macroinvertebrate community diversity in the Lower Loddon River is shown in Figure 4 and a summary of the network variable definitions, metrics and states is given in Table 3.

The network structure (Figure 4) represents the key cause-effect relationships determining macroinvertebrate health in the Lower Loddon River. These are discussed in Appendix B, and can be summarised into the following categories:

- ***Habitat availability*** - the important habitats for macroinvertebrates in the lower Loddon River are instream vegetation and woody debris. The key factors influencing the quality and abundance of these habitats, either directly or indirectly, are sedimentation, turbidity, riparian vegetation, flow regime, bank erosion, stock access and salinity.
- ***Food availability*** – the important sources of food for macroinvertebrates in the lower Loddon River are instream vegetation and litter from riparian vegetation.
- ***Water quality*** **–** the key water quality influences on macroinvertebrates in the lower Loddon River are turbidity, dissolved oxygen and salinity levels.

The initial Bayesian Network structure included catchment landuse variables and their relationship to catchment runoff and tailwater drainage (Figure 3). However, these have been omitted from the current Bayesian Network, as the data, information and understanding required to adequately include them is currently not available. And given the very high uncertainty surrounding these variables, it would not be possible to generate any meaningful information from the network with their inclusion. Information on these variables and their relationships have been included in Table 2 and Appendix B, to provide a starting point for their future inclusion when more information and data allows.

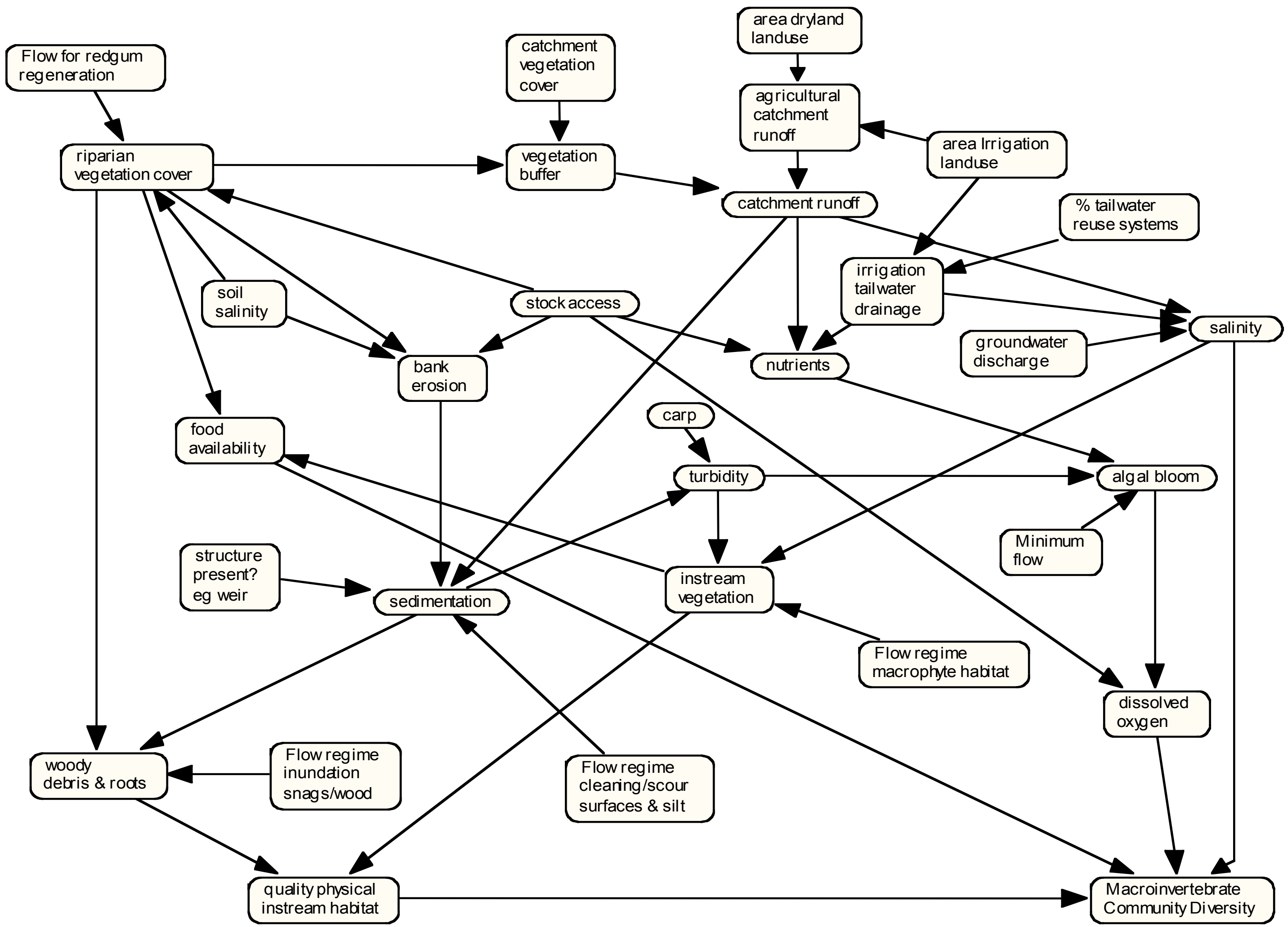

Figure 3: Conceptual model of the factors that influence macroinvertebrate communities in the lower Loddon River. This includes landuse variables not in the current network

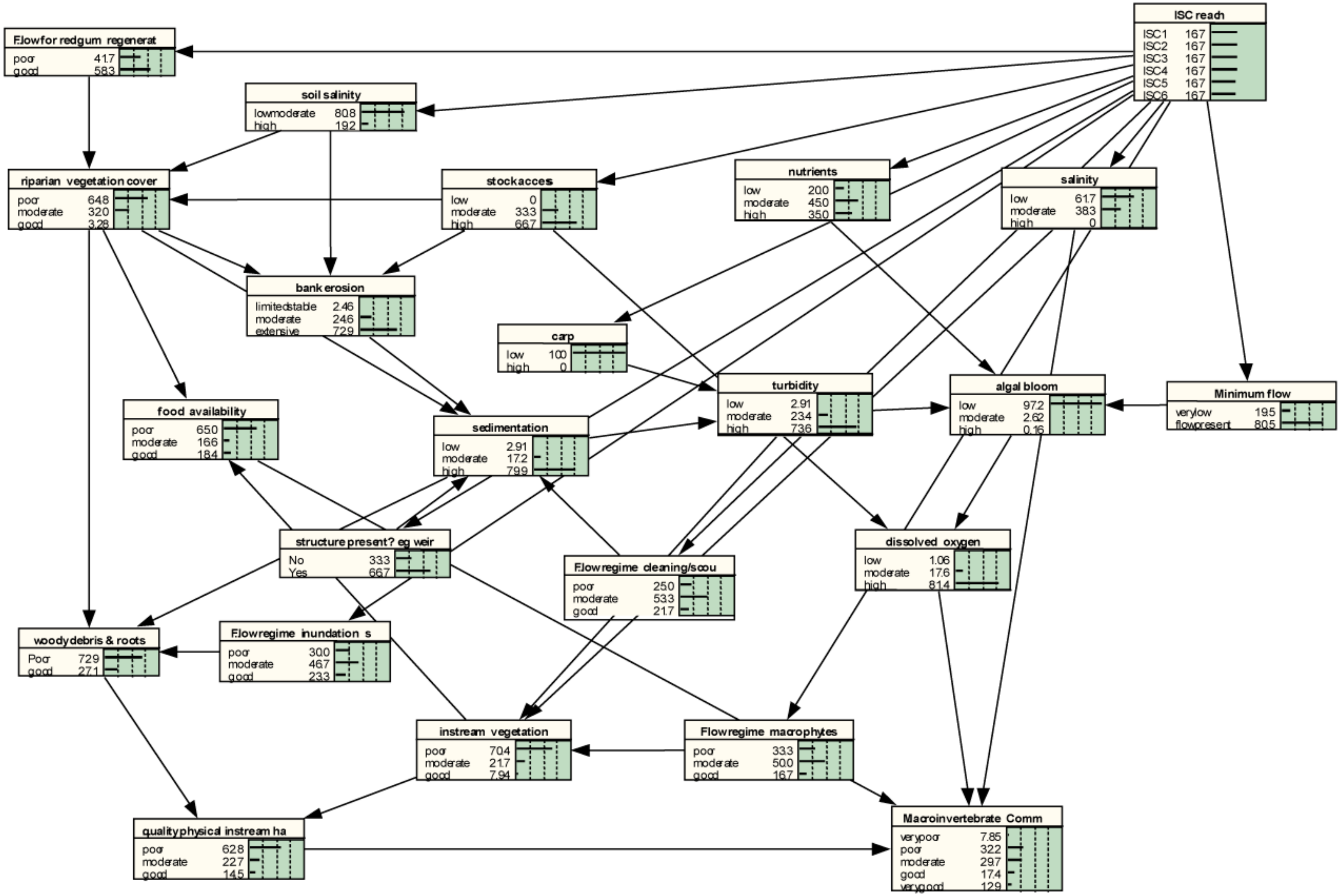

Figure 4: Bayesian Network for predicting the condition of macroinvertebrate communities in the Lower Loddon River

Table 3. Summary Table of Lower Loddon River Bayesian Network Variables

Variable	States	Rationale	Parents	Data/Information sources
Macroinvertebrate community diversity	Very poor - Extreme modification from reference state Poor - Major modification from reference state Moderate - Moderate modification from reference state Good - Acceptable Reference state Very good - High quality Reference state	States according to Victorian Environment Protection Authority (Vic EPA) Index of Stream Condition (ISC) preliminary report for calculation of ISC scores using State Environment Protection Policy (Waters of Victoria) (SEPP WoV) biological indices (AUSRIVAS, SIGNAL, Number of Families).	Instream physical habitat, DO%, salinity, food availability	EPA macroinvertebrate monitoring program Expert opinion (ecological expert panel)
Quality physical instream habitat	Poor Moderate Good	Integrative variable (i.e. a variable that integrates the information of the parent variables into one variable, in order to simplify the network so that it is more computationally efficient), states determined by expert opinion (Vic EPA) given states of instream vegetation and woody debris and roots, which provides a poor, moderate and good habitat for macroinvertebrate communities.	Instream vegetation, woody debris and roots	Determined by data on instream vegetation and woody debris: ISC Data EPA woody debris/macrophyte data: Macroinvertebrate monitoring program Loddon 2 day tour 2005 Loddon River Environmental Flows Scientific Panel, 2002b Expert opinion (ecological expert panel)
Instream vegetation	Structure types (emergent, floating, submerged) and cover of macrophytes: Poor: 1 structure present or 2-3 structures present with 1 structure dominating >95%, with < 10% or >90% cover 2 structures with <10% cover 3 structures with <1% cover Moderate: 1 structure/2-3 structures & 1 structure dominating >95% with 10 – 90% cover 2 structures with 10–35 % cover 3 structures with 1-10% cover or	States determined by expert opinion (Vic EPA) based on the diversity of structure types present (submerged, emergent and floating) and % coverage of macrophytes that provides a poor, moderate and good habitat for macroinvertebrate communities.	Turbidity, salinity, flow regime macrophyte habitat	EPA macrophyte data: Macroinvertebrate monitoring program Loddon 2 day tour 2005 Loddon River Environmental Flows Scientific Panel, 2002b Expert opinion (ecological expert panel, Kimberley James)

Variable	States	Rationale	Parents	Data/Information sources
	>90% cover Good: 2 structures with 35-90 % cover 3 structures with 10-90% cover			
Snags, woody debris and roots	Cover of large woody debris (>10cm in diameter) Poor = <5% cover & ISC 0-1 Good = >5% cover & ISC 2-4	States determined by expert opinion (Vic EPA) based on the coverage of woody debris that provides a poor, moderate and good habitat for macroinvertebrate communities.	Riparian vegetation, flow, regime inundation snags/wood	ISC Data EPA woody debris data: Macroinvertebrate monitoring program Loddon 2 day tour 2005 Loddon River Environmental Flows Scientific Panel, 2002b Jansen and Robertson, 2001; Stewardson et al., 2004. Expert opinion (ecological expert panel)
Food availability	Poor Moderate Good	Integrative variable, states determined by expert opinion (Vic EPA) given states of instream vegetation and riparian vegetation that provides a poor, moderate and good food source for macroinvertebrate communities.	Instream vegetation, riparian vegetation	Determined by data on riparian vegetation and instream vegetation: Landstat information ISC Data EPA field sheet data Loddon River Environmental Flows Scientific Panel, 2002b Expert opinion (local riparian revegetation experts) Expert opinion (ecological expert panel)
Salinity	EC 75th percentile of monthly annual data Low – <1500 EC Moderate – 1500 – 5000 EC High - > 5000 EC	States determined by expert opinion (Vic EPA) based on the EC levels that have been shown in studies to have no impact on macroinvertebrates and macrophytes, moderate impact on more sensitive species of macroinvertebrates and macrophytes and an impact on a majority of macroinvertebrates and macrophytes species.	None	VWQMN sites: 407229 – Loddon River @ Serpentine Weir 407202 – Loddon River @ Kerang weir Waterwatch Site: LOD 525 – Loddon River @ Salisbury West EPA EC data: Macroinvertebrate monitoring program Loddon 2 day tour 2005 Hart et al., 1991; James & Hart 1993; James et al.2003.

Variable	States	Rationale	Parents	Data/Information sources
				Expert opinion (ecological expert panel)
Dissolved oxygen (DO)	DO % saturation 25th percentile of monthly annual monitoring data Low = < 50% sat Moderate = 50 – 80% sat High = > 80% sat	States determined by expert opinion (Vic EPA) based on those shown to have no impact on macroinvertebrate community diversity, shown to moderately reduce macroinvertebrate community diversity and greatly reduce macroinvertebrate community diversity.	Algal bloom, stock access	VWQMN sites: 407229 – Loddon River @ Serpentine Weir 407202 – Loddon River @ Kerang weir EPA DO data: Macroinvertebrate monitoring program Loddon 2 day tour 2005 Expert opinion (ecological expert panel)
Riparian vegetation	ISC streamside zone indexes Poor – 0 - 3 Moderate – 4 - 6 Good – 7 –10	States determined by expert opinion (Vic EPA) based on the key interactions of riparian vegetation with macroinvertebrates (food source, habitat (woody debris, root zone), filtering of runoff entering river).	Stock access, flow for Redgum regeneration, soil salinity	Landstat information ISC Data EPA field sheet data Loddon River Environmental Flows Scientific Panel, 2002b Expert opinion (local riparian revegetation experts) Lovett and Price, 1999a; Lovett and Price, 1999b; Robertson and Rowling, 2000; Jansen and Robertson, 2001; Cramer and Hobbs 2002; Wilson, et al., 2003. Expert opinion (ecological expert panel, local riparian experts)
Stock access	ISC 1999 Stock access yes/no Low – <10% reach Moderate – 10 – 30% reach High - > 30% reach ISC 2004 Low – no stock access Moderate – stock access with minor impact (s) High – stock access with major impact (s)	States determined by expert opinion (Vic EPA) based on study results showing stock access levels impacting riparian vegetation and bank erosion.	None	ISC Data Loddon River Environmental Flows Scientific Panel, 2002b Expert opinion (DPI)
Nutrients	Total Phosphorus 75th percentile of monthly annual monitoring data	States determined by expert opinion (Vic EPA) based on levels influencing potential for algal blooms	None	VWQMN sites: 407229 – Loddon River @ Serpentine Weir

Variable	States	Rationale	Parents	Data/Information sources
	Low – <45 ug/L Moderate – 45-100 ug/L High – >100 ug/L			407202 – Loddon River @ Kerang weir Waterwatch Site: LOD 525 – Loddon River @ Salisbury West EPA nutrient data: Macroinvertebrate monitoring program Expert opinion (ecological expert panel)
Algal bloom	Low - < 1000 cells/ML Moderate – 1000-30,000 cells/ML High - >30,000 cells/ML	States determined by expert opinion (Vic EPA), given the level of bloom shown to have no impact on DO levels, begin to depress DO levels and greatly depress DO levels.	Nutrients, turbidity, minimum flow	NCCMA, 2003, G-MW reports of algal blooms Expert opinion (ecological expert panel)
Turbidity	75th percentile of monthly annual monitoring data Low = <30 NTU Moderate = 30 - 80 NTU High = > 80 NTU	States determined by expert opinion (Vic EPA), as those at Victorian lowland reference sites, determined to begin limiting instream vegetation and determined to greatly limit instream vegetation.	Sedimentation, carp	VWQMN sites: 407229 – Loddon River @ Serpentine Weir 407202 – Loddon River @ Kerang weir Waterwatch Site: LOD 525 – Loddon River @ Salisbury West EPA turbidity data: Macroinvertebrate monitoring program Loddon 2 day tour 2005 King et al. 1997 Expert opinion (ecological expert panel)
Carp	Low - < 1000 kg/ha High – > 1000 kg/ha	States determined by expert opinion (Vic EPA), based on King et al.1997 for the carp density showing significant difference in turbidity and explaining high % turbidity variation.	None	King et al.1997
Bank erosion	ISC: Extreme/extensive erosion = 0-1 Moderate erosion = 2 Limited/stable erosion = 3-4 EPA field sheets: Bare erosional ground: Extensive erosion = >30% Moderate erosion = 5 - 30%	States based on ISC categories and determined by expert opinion (Vic EPA) as those contributing to low, moderate and high sedimentation.	Stock access, riparian vegetation, soil salinity	ISC Data EPA bank erosion/stability data: Macroinvertebrate monitoring program Loddon 2 day tour 2005 Loddon River Environmental Flows Scientific Panel, 2002b Lovett and Price, 1999a; Lovett and Price 1999b; Robertson and Rowing, 2000; Jansen and Robertson, 2001; Stewardson, et al., 2004.

Variable	States	Rationale	Parents	Data/Information sources
	Limited/stable erosion = <5% Bank Stability: Extensive erosion = 0-4 poor Moderate erosion = 5-7 marginal Limited/stable = 8-10 optimal			Expert opinion (ecological expert panel, DPI)
Structure present? eg weir	Yes No	Local experts determined as key factor increasing sedimentation, due to reductions in flow, and thus power for flushing sediment.	None	Loddon River Environmental Flows Scientific Panel, 2002b
Sedimentation	EPA field sheets: Loose silt on substrate: High = >50% Moderate = 10 – 50% Low = <10% Sediment deposition: High = 1-8 Moderate = 9-14 Low = 15-20	States determined by expert opinion (Vic EPA) based on those shown to have no impact on available substrate habitat, shown to moderately reduce available substrate habitat and greatly reduce available substrate habitat.	Bank erosion, riparian vegetation, flow regime cleaning/scour surfaces and silt, structure present? eg weir	EPA sedimentation data: Macroinvertebrate monitoring program Loddon 2 day tour 2005 Loddon River Environmental Flows Scientific Panel, 2002b Lovett and Price, 1999a; Lovett and Price, 1999b; Stewardson, et al., 2004. Expert opinion (ecological expert panel, DPI)
Soil Salinity	Low/moderate = Soil classes A, B, C (EC <8.6 dS/m) High = Soil class D (EC > 8.6 dS/m)	States determined by expert opinion (Vic EPA) based on estimated salinity ranges for native vegetation using DPI plant salinity indicator list for the Loddon Murray.	None	Sinclair Knight Merz. 2000 Expert opinion (DPI)
Flow regime macrophytes	Poor Moderate Good	States determined by expert opinion (Vic EPA) from Environmental Flow Determination of the Loddon River Catchment (2002): flows for restoring and maintaining mosaic of macrophytes. Poor - < 25% flow objectives reached Moderate - 25 - 80% flow objectives reached Good - >80% flows objectives reached ISC Reach 1: variable min flow 7-12ML/day Nov-Apr, >50ML/d once for 14 days Jan-Feb; >400ML/day 2 times/yr for 7 days btw July-Oct ISC Reach 2: top to Kerang weir: variable min	None	VWQMN sites: 407229 – Loddon River @ Serpentine Weir 407202 – Loddon River @ Kerang weir Loddon River Environmental Flows Scientific Panel, 2002a Loddon River Environmental Flows Scientific Panel, 2002b.

Variable	States	Rationale	Parents	Data/Information sources
		7-12 ML/day Nov-Apr, >50ML/d once for 14 days Jan-Feb; Kerang Weir to bottom reach: variable min flow 7-12ML/day Nov-Apr, >50ML/d once for 14 days Jan-Feb; >400ML/day 2 times/yr for 7 days btw July-Oct. ISC Reach 3: variable min 7-12 ML/day Nov-Apr, >50ML/d once for 14 days Jan-Feb. ISC Reach 4: variable min 7-12 ML/day Nov-Apr, >50ML/d once for 14 days Jan-Feb. Serpentine to Loddon weir: 19ML/day Nov-April with>61ML/d min 3 times/season for min 11 days in Nov-Apr. Loddon weir to end reach: variable min 7-12 ML/day Nov-Apr, >50ML/d once for 14 days Jan-Feb. ISC Reach 6: min 15ML/day Nov-Apr.		
Flow regime cleaning/scour surfaces & silt	Poor Moderate Good	States determined by expert opinion (Vic EPA) from Environmental Flow Determination of the Loddon River Catchment (2002) for cleaning bed surfaces and scouring silt: Poor - < 25% flow objectives reached Moderate - 25 - 80% flow objectives reached Good - >80% flows objectives reached ISC Reach 1: >50ML/d once for 14 days Jan-Feb. ISC Reach 2: Start reach to Kerang Weir: >50ML/d once for 14 days Jan-Feb. Kerang weir to end reach: >50ML/d once for 14 days Jan-Feb. ISC Reach 3: >50ML/d once for 14 days Jan-Feb. ISC Reach 4: >50ML/d once for 14 days Jan-Feb. ISC Reach 5: Serpentine to Loddon weir: >61ML/d min 3 times/season for min 11 days in Nov-Apr. >400 ML/d, 2 times/yr, min 7days, in July-Oct. >2,000 ML/d, 2 times/yr, min 6 days, in Aug-Oct Loddon weir to end	None	VWQMN sites: 407229 – Loddon River @ Serpentine Weir 407202 – Loddon River @ Kerang weir Loddon River Environmental Flows Scientific Panel, 2002a Loddon River Environmental Flows Scientific Panel, 2002b.

Variable	States	Rationale	Parents	Data/Information sources
		reach: >50ML/d once for 14 days Jan-Feb. ISC Reach 6: > 52ML/d, min 3 times/ season for min 13 days in Nov-Apr. >900 ML/d, 2 times/yr for 9days in Jun-Oct; >7,300 ML/d, once every 2 yrs (peak for 1 day) in Jun-Oct		
Flow regime inundation of wood debris and roots	Poor Moderate Good	States determined by expert opinion (Vic EPA) from Environmental Flow Determination of the Loddon River Catchment (2002): Flow regime for restoring and maintaining invertebrate woody debris and root habitat: Poor - < 50% flow objectives reached Good - >50% flows objectives reached ISC Reach 1: variable min flow 7-12ML/day Nov-Apr, >50ML/d once for 14 days Jan-Feb. ISC Reach 2: variable min 7-12 ML/day Nov-Apr, >50ML/d once for 14 days Jan-Feb. ISC Reach 3: variable min 7-12 ML/day Nov-Apr, >50ML/d once for 14 days Jan-Feb. ISC Reach 4: variable min 7-12 ML/day Nov-Apr, >50ML/d once for 14 days Jan-Feb. ISC Reach 5: Serpentine to Loddon weir: 19ML/day Nov-April with>61ML/d min 3 times/season for min 11 days in Nov-Apr. Loddon weir to end reach: variable min 7-12 ML/day Nov-Apr, >50ML/d once for 14 days Jan-Feb. ISC Reach 6: min 15ML/day Nov-Apr, > 52ML/d, min 3 times/ season for min 13 days in Nov-Apr.	None	VWQMN sites: 407229 – Loddon River @ Serpentine Weir 407202 – Loddon River @ Kerang weir Loddon River Environmental Flows Scientific Panel, 2002a Loddon River Environmental Flows Scientific Panel, 2002b.
Flow for riparian vegetation	Poor Good	States determined by expert opinion (Vic EPA) from Environmental Flow Determination of the Loddon River Catchment (2002): Overbank flows for maintaining red gum regeneration. Poor - < 25% flow objectives reached	None	VWQMN sites: 407229 – Loddon River @ Serpentine Weir 407202 – Loddon River @ Kerang weir Loddon River Environmental Flows Scientific Panel, 2002a Loddon River Environmental Flows Scientific

Variable	States	Rationale	Parents	Data/Information sources
		Moderate - 25 - 80% flow objectives reached Good - >80% flows objectives reached ISC Reach 1: >1,200 ML/d, 2 times/yr, min 7days, in July-Oct. ISC Reach 2: Kerang weir to end reach: >1,200 ML/d, 2 times/yr, min 7days, in July-Oct. Start reach to Kerang weir: overbank >400 ML/d, 2 times/yr, min 7days, in July-Oct. ISC Reach 3: overbank >400 ML/d, 2 times/yr, min 7days, in July-Oct. ISC Reach 4: overbank >400 ML/d, 2 times/yr, min 7days, in July-Oct. ISC Reach 5: Serpentine weir to Loddon weir: >13,000 ML/d, once every 3yrs, peak for 2 days, Jun-Oct. Loddon to end reach: overbank >400 ML/d, 2 times/yr, min 7days, in July-Oct. ISC Reach 6: None		Panel, 2002b.
Minimum flow	Very Low – Reach 1: <250 ML/day, for 28 days. Reaches 2-6: <50 ML/day, for 28 days. Flow present - Reach 1: >250 for 28 days ML/day. Reaches 2-6: >50 ML/day, for 28 days	States determined by expert opinion (Vic EPA) based on discharge levels that will or will not cause turbulence in river. These states need to be refined when more data is collected as part of the EPA biological monitoring 2005/6	None	VWQMN sites: 407229 – Loddon River @ Serpentine Weir 407202 – Loddon River @ Kerang weir Loddon River Environmental Flows Scientific Panel, 2002a Loddon River Environmental Flows Scientific Panel, 2002b.
Groundwater discharge	Low – <10,000 EC Moderate – 10,000 – 30,000 EC High - > 30,000 EC	States determined by expert opinion (Vic EPA) based on groundwater monitoring levels in catchment.	None	Sinclair Knight Merz, 2003; NCCMA, 2004.
ISC Reach	ISC Reaches 1 - 6	States determined by NCCMA as spatial scale for Bayesian Network.	None	NCCMA GIS data
Area irrigation landuse[a]	Low - <50km^2 Moderate – 50-100 km^2 High - > 100 km^2	States determined by expert opinion (Vic EPA) based on landuse areas in ISC reaches.	None	2001 GIS information

Variable	States	Rationale	Parents	Data/Information sources
% tailwater reuse systems[a]	Low High	States to be determined by expert opinion (DPI), when more data/information is available.	None	DPI information
Irrigation tailwater drainage[a]	Low Moderate high	Synthetic variable, states determined by expert opinion (Vic EPA) given states of area irrigation landuse and % tailwater reuse systems.	Area irrigation landuse, % onfarm drainage reuse	G-MW, DPI information
Area dryland landuse[a]	Low - <50km^2 Moderate – 50-100 km^2 High - > 100 km^2	States determined by expert opinion (Vic EPA) based on landuse areas in ISC reaches.	None	2001 GIS information
Catchment vegetation cover[a]	Poor - < 10% Moderate – 10 – 50% Good - >50%	States determined by expert opinion (Vic EPA) based on buffering capacity to reduce runoff.	None	2001 GIS information
Agricultural catchment runoff[a]	Low Moderate high	Integrative variable, states determined by expert opinion (Vic EPA) given states of irrigation runoff and dryland runoff.	Irrigation runoff, dryland runoff	TEOLWG, 1995; NCCMA, 2003; NCCMA, 2004.
Vegetation buffer[a]	Poor Moderate Good	Integrative variable, states determined by expert opinion (Vic EPA) given states of riparian vegetation and catchment vegetation cover.	Riparian vegetation, catchment vegetation cover	2001 GIS information
Catchment runoff[a]	Low Moderate high	Integrative variable, states determined by expert opinion (Vic EPA) given states of agricultural catchment runoff and vegetation buffer.	Agricultural catchment runoff, vegetation buffer.	TEOLWG, 1995; Lovett and Price, 1999a; Robertson and Rowing, 2000; Sinclair Knight Merz, 2003; NCCMA, 2003; NCCMA, 2004.

[a] Not included in current Lower Loddon River Bayesian Network as the data, information and understanding required to adequately include them is currently not available.

2.4 Population of the node states and the conditional probability tables (CPT's)

The Bayesian Network node states and CPTs were populated using information from catchment reports and studies, the scientific literature, assessment of catchment data and expert opinion from freshwater ecologists and local catchment resource managers. The information and data sources for each node are summarized in Table 3. Full details on the population of the individual node states and construction of their CPTs are provided in Appendix B.

As part of the expert consultation, three workshops were held with a panel of five aquatic ecologists (Table 2) in March to June 2005. These were followed up by several discussions with the appropriate ecological experts for individual CPTs. Input from local resource managers was obtained through ongoing phone discussions and a two-day field trip along the Lower Loddon River. The field trip included several local guides (landowners and DPI/NCCMA staff) that had extensive knowledge of various sections of the Loddon River.

2.5 Sensitivity analysis

Previous studies have indicated that macroinvertebrate communities in the Lower Loddon River are in poor condition (McGuckin & Doeg, 2000; Loddon River Environmental Flows Scientific Panel, 2002b). A sensitivity analysis was conducted on the Bayesian Network to assess the variables having the most influence on macroinvertebrate community diversity being predicted as 'poor'. These variables can represent key hazards and gaining a thorough understanding of these interactions and management of these is a key priority. The results are presented in Figure 5.

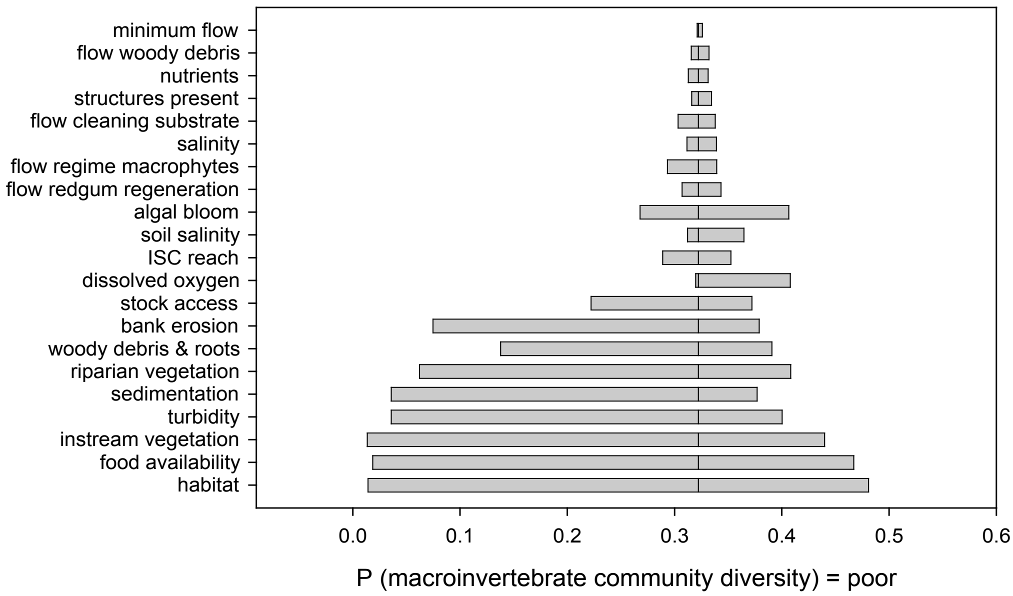

Figure 5: Sensitivity Analysis Results - the influence of network variables on "macroinvertebrate community diversity" being in a 'poor' state.

The software (Netica) conducts the sensitivity analysis by systematically varying the values of the individual network variables, to determine how much the mean belief of the 'macroinvertebrate community diversity' node being 'poor', can be influenced by a single finding at each variable. This is done by plotting the variation in the node of concern, when parent nodes are altered over probability ranges 0 to 1. The results given are the range of lowest to highest that the expected values of 'macroinvertebrate community diversity' can have, due to the range of findings at each variable (Wooldridge & Done, 2003; Norsys Software Corp., 2003).

Figure 5 shows the relative level of influence of each of the network variables in determining the probability of macroinvertebrate community diversity being 'poor'. The variables at the bottom of the graph (represented with the widest bars) have the greatest influence on macroinvertebrate community diversity, with decreasing influence as one moves up the graph (and the bar size decreases).

Thus, the macroinvertebrate community diversity is most sensitive to changes in physical in-stream habitat, food availability, in-stream vegetation, turbidity, sedimentation, riparian vegetation, woody debris and roots, bank erosion and stock access. Noticeably all the sensitive variables are related to habitat and food, or variables directly related to these.

The in-stream physical habitat (e.g. snags, roots, macrophytes) had the greatest influence on macroinvertebrate community diversity, with in-stream vegetation (e.g. macrophytes) being the most influential component of this variable. The next two most influential variables were turbidity and sedimentation. These findings are in accord with the opinion of the project ecological expert panel (Table 2) and Dr Kimberley James (Appendix B, Section 3). The experts who helped to develop this Bayesian network considered poor habitat to be the key factor adversely impacting on the macroinvertebrate communities in the Lower Loddon River. In particular, high turbidity and sedimentation caused a reduction in the in-stream vegetation through the lack of light.

Apart from food availability, all the other variables assessed as having a high influence on macroinvertebrate community diversity are also related to habitat. Sedimentation is related to high turbidity which in turn reduces the growth of in-stream vegetation in the river. The condition of the riparian vegetation, bank erosion and stock access all influence the level of sedimentation. Riparian vegetation also directly influences the amount of woody debris and roots habitat, and also food availability (the second highest influence).

This analysis indicates that management actions to reduce sedimentation/turbidity levels, such as reducing stock access and improving riparian vegetation protection of the streamside zone and banks, are a key priority to improving instream habitat and the condition of the macroinvertebrate community.

2.6 Network predictions

The macroinvertebrate Bayesian Network was run for each ISC reach in the Lower Loddon River, and the networks are shown in Figures 6-11.

The network predicts high probability of poor to moderate macroinvertebrate community diversity in all six of the ISC reaches. These results appear to be driven more by poor habitat than by poor water quality (as indicated in the sensitivity analysis). In these reaches, all the habitat variables (quality physical in-stream habitat, in-stream vegetation and woody debris and roots) are degraded. Additionally, the factors driving habitat (i.e. turbidity, sedimentation, bank erosion, riparian vegetation) are also degraded in this lower region of the Loddon River. The most important water quality variables (salinity and dissolved oxygen) are reasonably good in this lower section of the river and have less effect on the macroinvertebrate communities.

2.7 Validation of the Bayesian network

The predictive accuracy of the Bayesian Network can be tested by comparing the predicted outcomes of the network to measured data, and calculating the frequency with which the network predictions are correct. Unfortunately, there is currently not enough data and information available to validate this Bayesian Network, and for this reason, the predictive accuracy of the network cannot be quantitatively calculated at this stage.

However, EPA Victoria are planning a study to collect macroinvertebrate, habitat and water quality data over 2005/2006 in the Lower Loddon catchment that will assist in updating and validating the current Bayesian model. This study will focus on macroinvertebrates, and the key habitat and habitat–related variables identified in the sensitivity analysis (e.g. physical in-stream habitat, food availability, in-stream vegetation, turbidity, sedimentation, riparian vegetation, woody debris and roots, bank erosion and stock access). The data will be used to update the network (using a data learning technique), and also validate the predictions of the network. This will help to reduce the uncertainty and improve the robustness of the network, and provide a better understanding of the Lower Loddon system.

Although there is currently not sufficient data to validate the network, some of the variable predictions were compared to general field observations made by the analyst and local experts. It should be noted that these field observations were not included as data in the running of the network, and are therefore independent. The field observations indicated in-stream vegetation and woody debris to be poor for most of the Lower Loddon River, with woody debris being better in the upper than the lower reaches; sedimentation and turbidity to be high for most of the Lower Loddon; and, riparian vegetation to be poor to moderate in all reaches, with reaches 3-6 being in better condition than reaches 1-2. These observations are reflected in current network predictions.

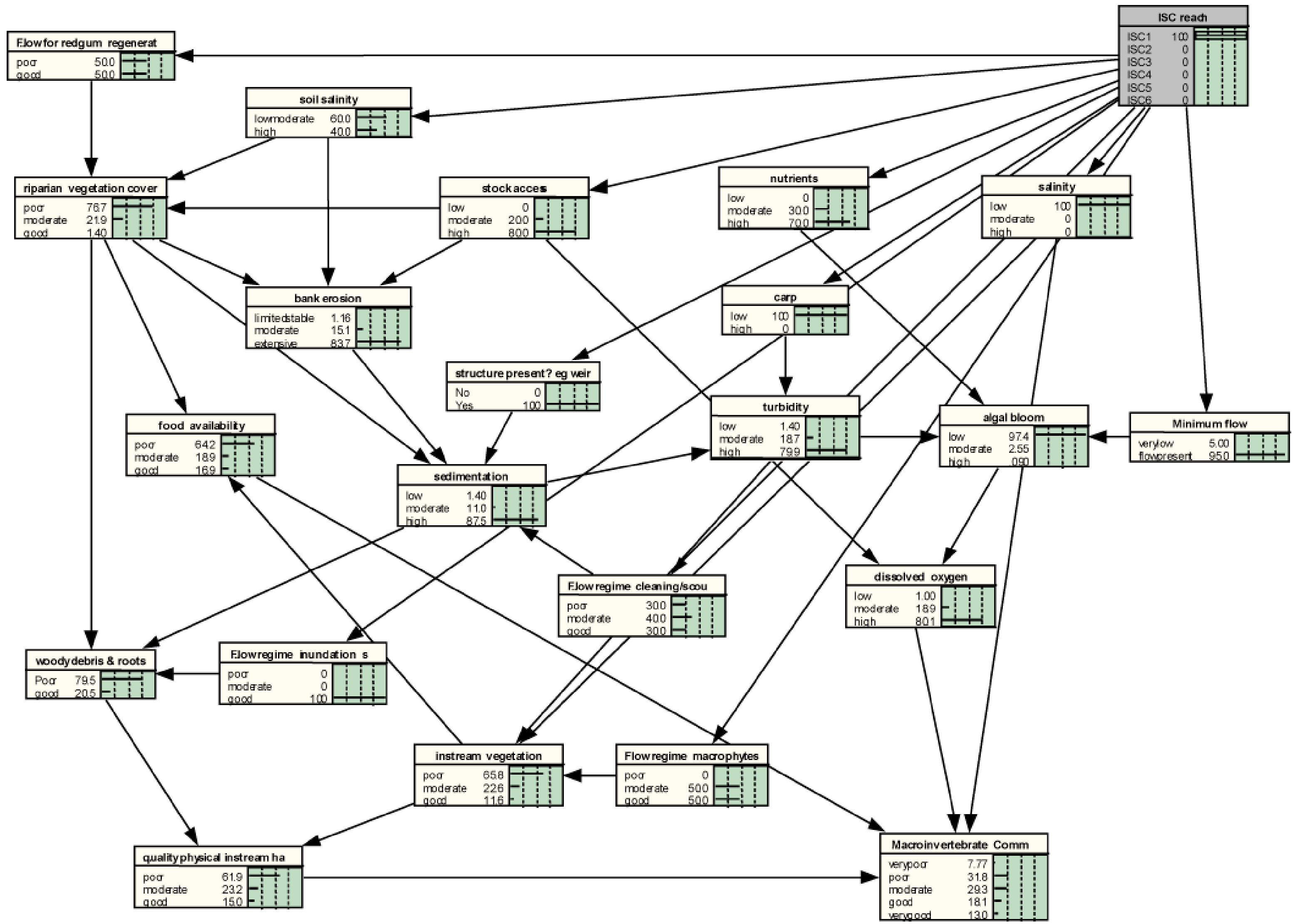

Figure 6: Lower Loddon River Bayesian Network Output for ISC Reach 1

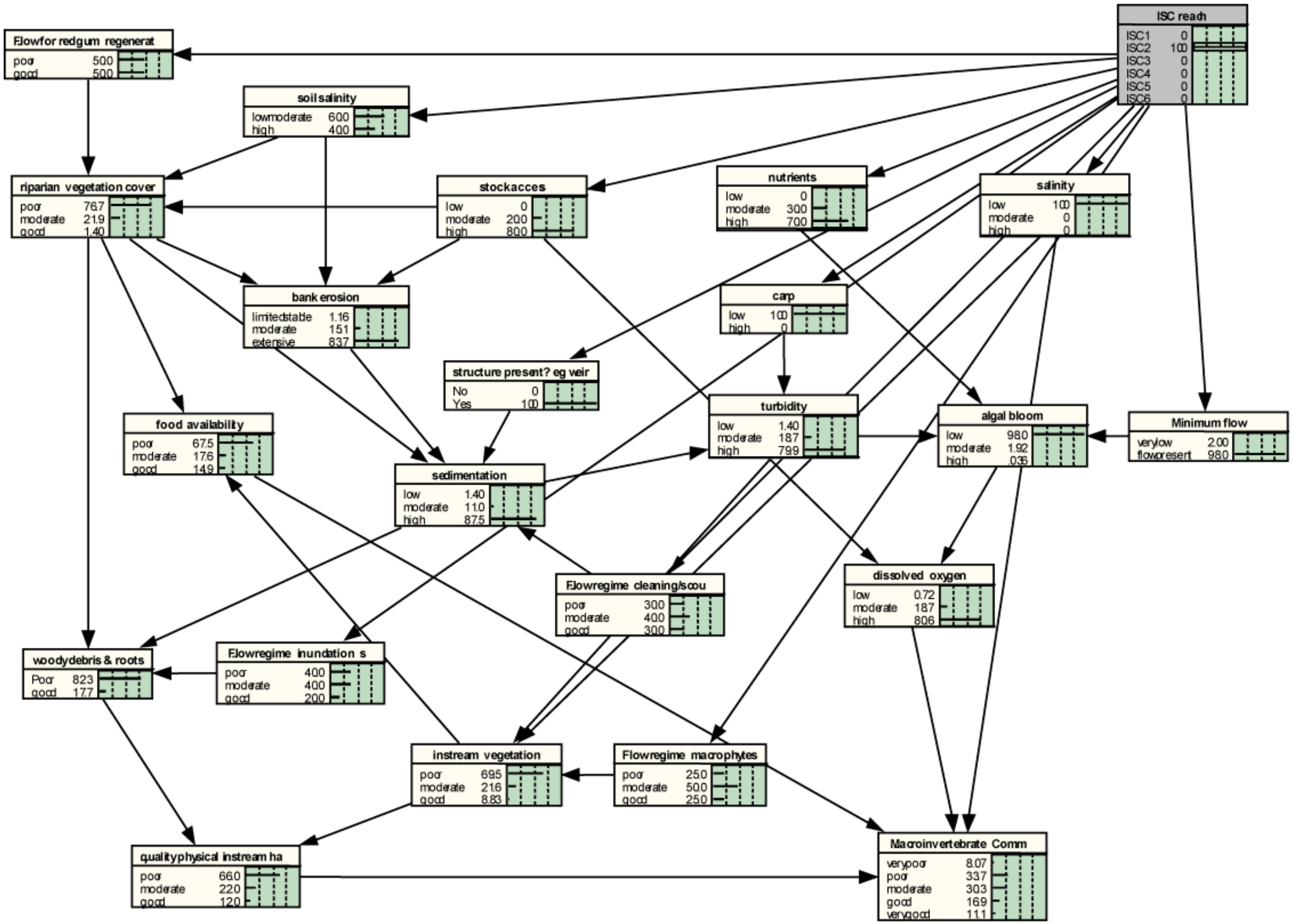

Figure 7: Lower Loddon River Bayesian Network Output for ISC Reach 2

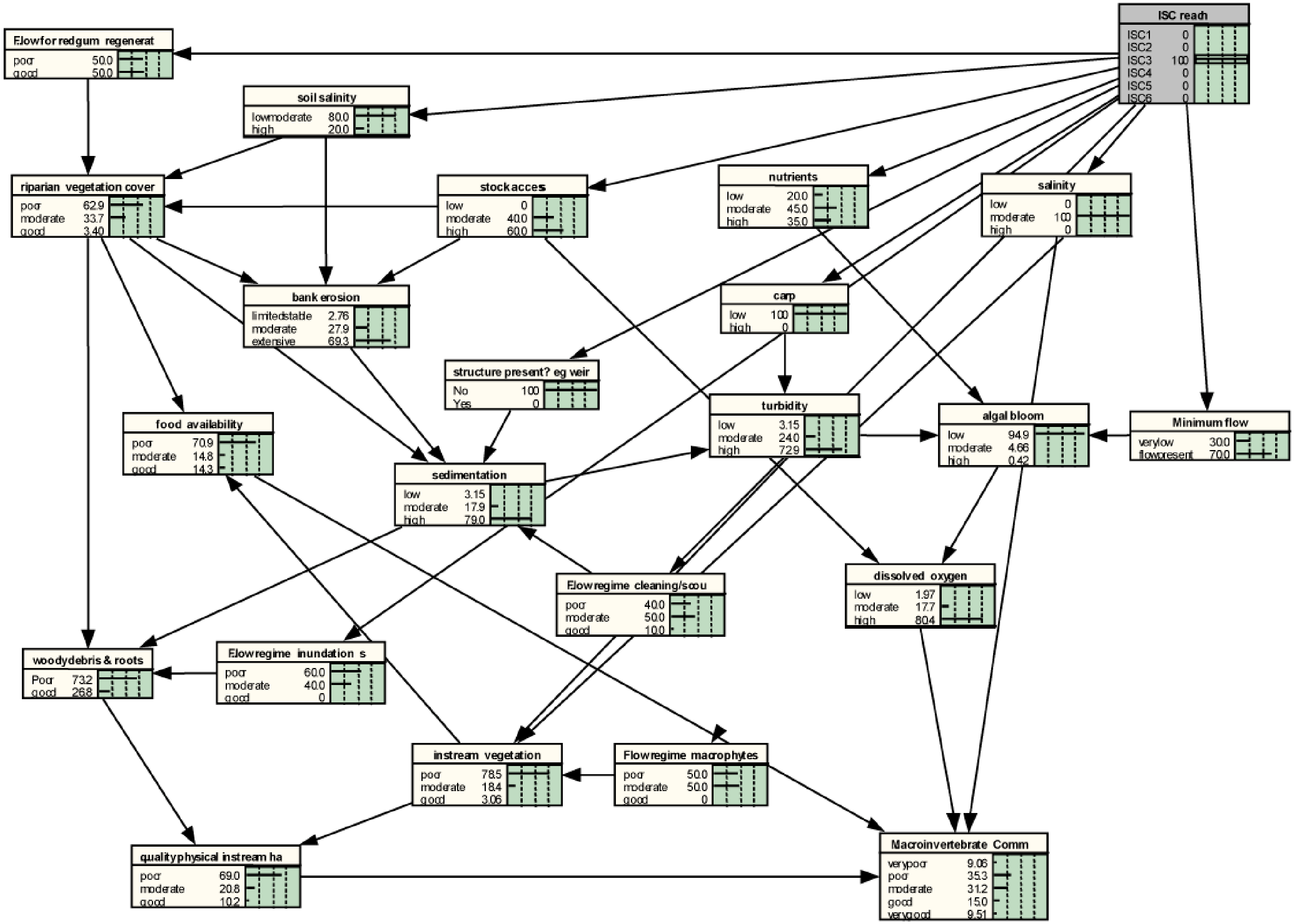

Figure 8: Lower Loddon River Bayesian Network Output for ISC Reach 3

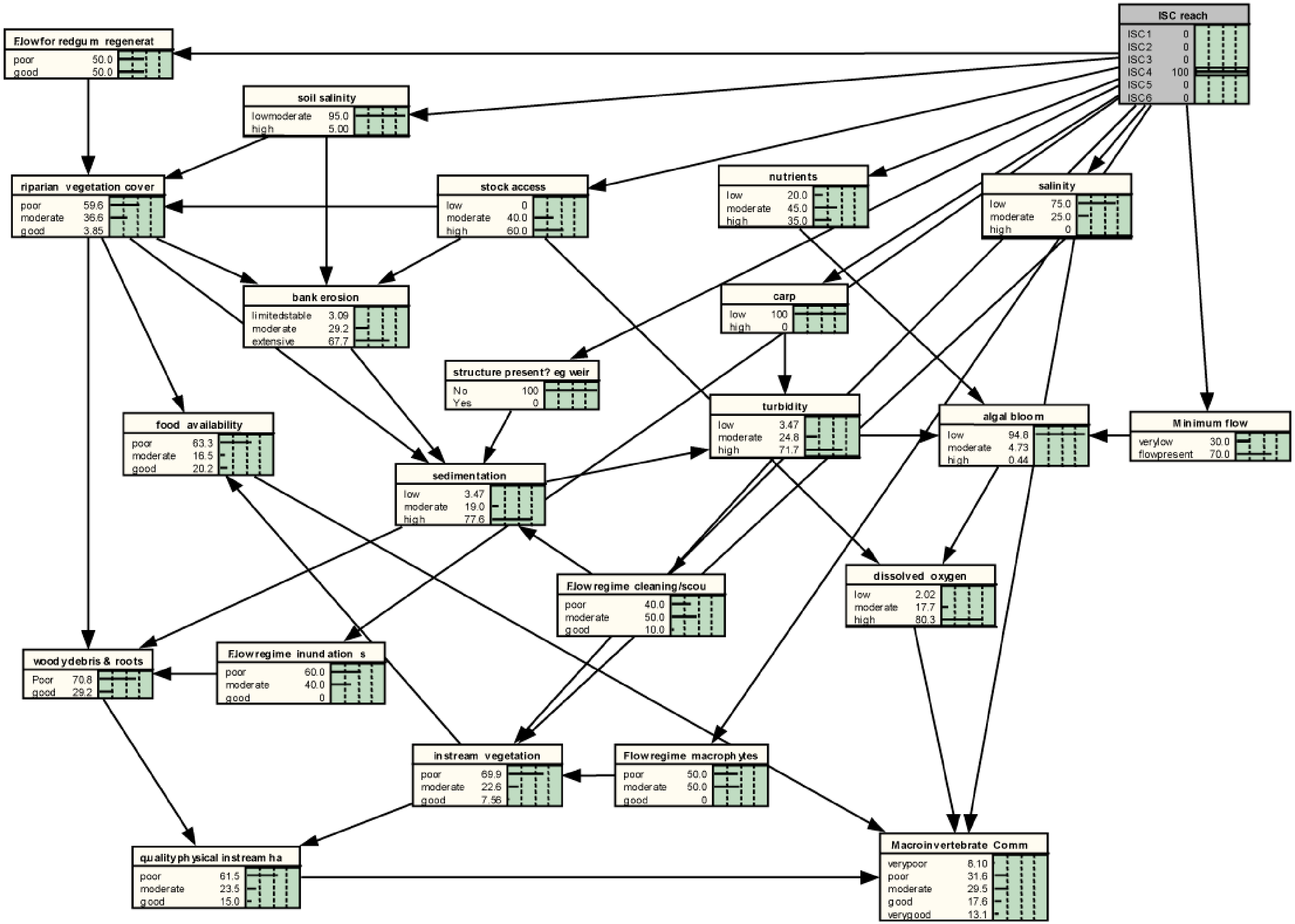

Figure 9: Lower Loddon River Bayesian Network Output for ISC Reach 4

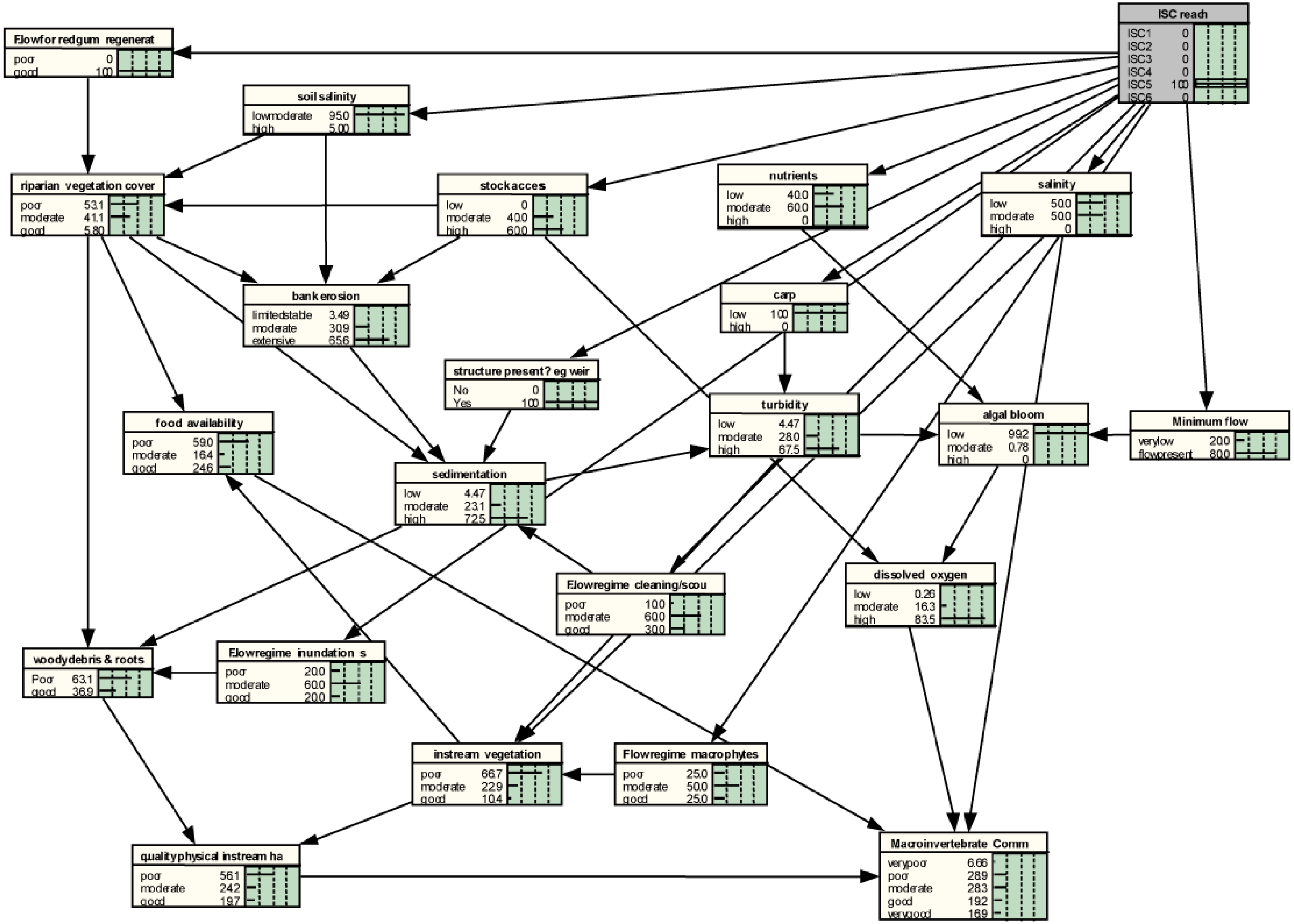

Figure 10: Lower Loddon River Bayesian Network Output for ISC Reach 5

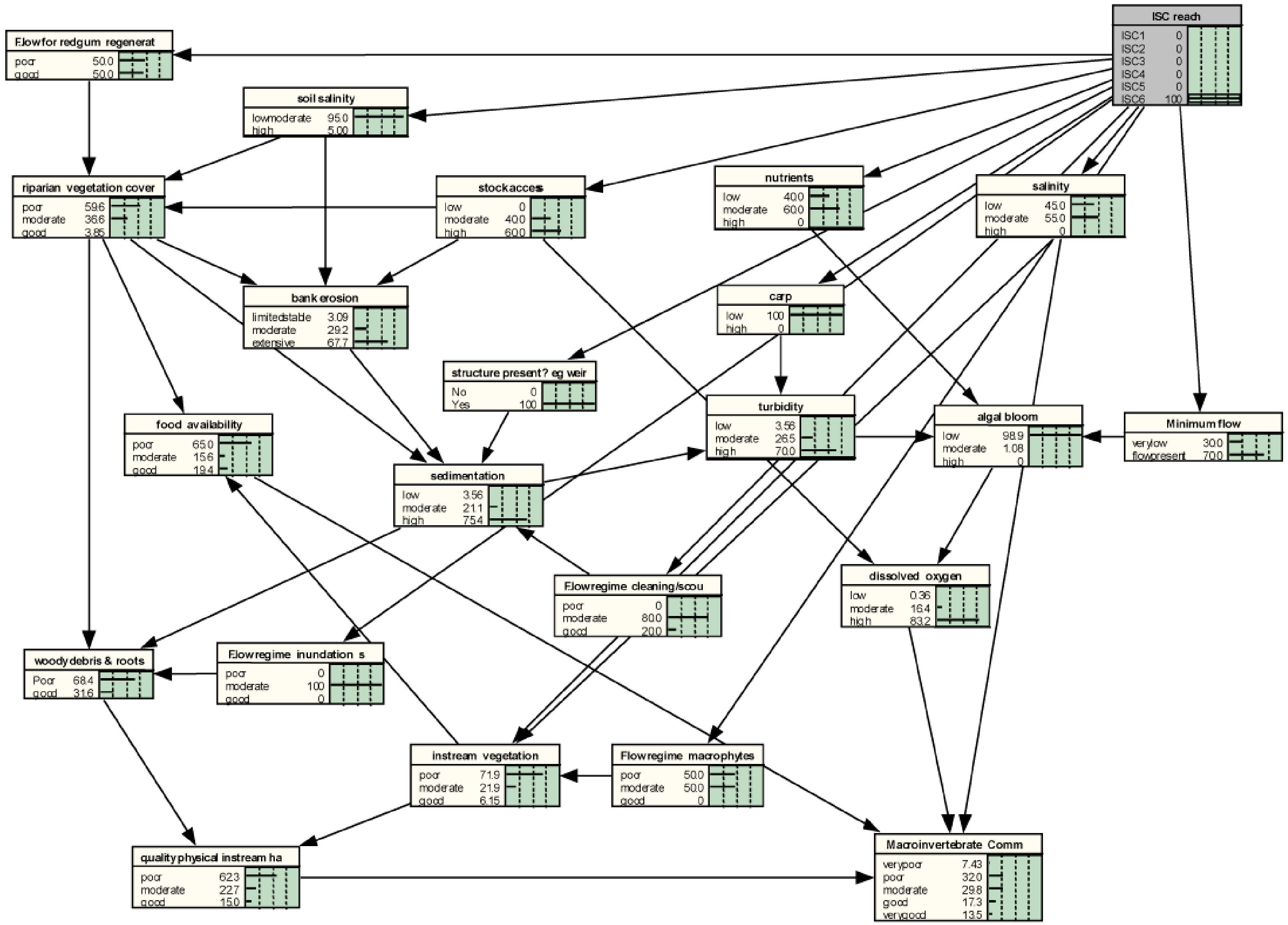

Figure 11: Lower Loddon River Bayesian Network Output for ISC Reach 6

3. Management scenario testing

An important application of Bayesian Networks is their ability to provide information on various management scenarios. Variables in the network can be updated to reflect certain management actions, and the network run to ascertain the probabilities of improvement in the selected endpoints. In this way, various management actions can be tested for their relative effectiveness and predicted outcomes.

This section provides the results of model predictions for one important management action – removal or reduction of stock access to the river.

Stock have been allowed to access most of the Lower Loddon River over a long period of time, although natural resource managers (NCCMA, DPI) and landowners have recently begun major on-ground fencing works to reduce stock access to the riparian zone and the river channel (Rob O'Brien, pers. comm.). It is planned to continue these management actions into the future. Stock access was identified in the sensitivity analysis as having a major influence on macroinvertebrate community diversity. This effect was induced predominately through stock degrading riparian vegetation and increasing bank erosion, thereby increasing in-stream sedimentation and turbidity, and reducing in-stream woody debris.

The management scenario tested was to increase the amount of fencing along the Lower Loddon River so that stock access was reduced. The network was run for three levels of stock access - low, moderate and high[1]. The results are summarised in Figure 12 (full details of these calculations are presented in Appendix C).

Reducing stock access was shown to significantly improve macroinvertebrate community diversity, instream habitat and the riparian zone (Figure 12). For example, the macroinvertebrate community diversity in good to very good condition improved from 21% for high access, to 48% for moderate access, to around 80% for low access. These results support the current Loddon catchment management plan of fencing to reduce stock access.

4. Conclusions

The Bayesian network predicted that the macroinvertebrate community diversity in all six ISC reaches in the Lower Loddon River would be poor. The sensitivity analysis showed that it is the habitat variables (e.g. in-stream habitat, food availability, in-stream vegetation, turbidity, sedimentation, riparian vegetation, woody debris and roots, bank erosion) that are having the greatest influence on macroinvertebrate community diversity being in a poor state.

There is currently not enough data and information available to update or validate the Bayesian network. EPA Victoria will be conducting monitoring in the Lower Loddon catchment over 2005/2006, which will focus on macroinvertebrates and the key influential habitat variables identified in the sensitivity analysis. This data will be used to update the Bayesian network using a data learning technique, and to validate the network. This will reduce the uncertainty and improve the robustness of the network, and provide a better understanding of the Lower Loddon system.

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1 Stock access is assessed as *Low* if stock are associated with <10% of the reach, *Moderate access* if stock have access to10-30% of the reach, and *High access* if >30% of the reach (Table 1).

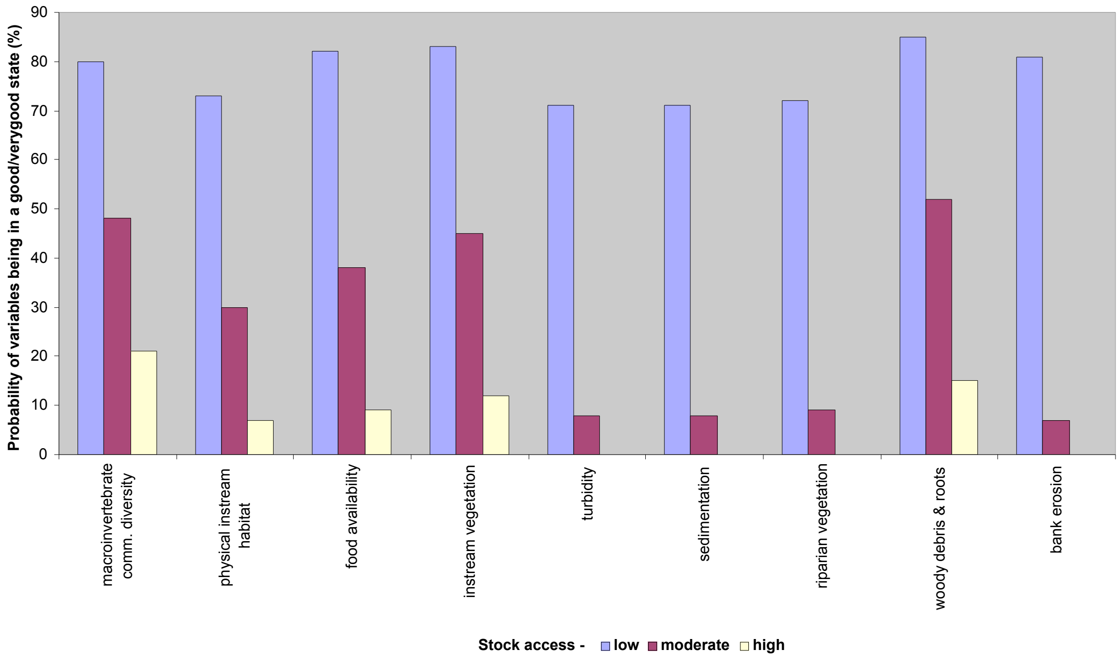

Figure 12: Results for Fencing/Stock Access Management Scenario for the Lower Loddon River - Probability of Key Bayesian Network variables being in a good/very good state

Local resource managers (NCCMA, G-MW, DPI) and landowners expressed support for the use and uptake of the Bayesian network in the Lower Loddon catchment. NCCMA, G-MW and DPI staff will be working with EPA to incorporate the networks into local catchment processes (e.g. Loddon Implementation Committees, Stressed Rivers Project). Local resource managers will also be involved in further monitoring and information updates planned for the Bayesian network.

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Appendix A: Discussion of Bayesian Networks and Bayes Theorem

What are Bayesian Networks?
Bayesian Networks are a tool for representing the interactions that control real world systems (such as aquatic ecosystems, irrigation systems and forests). They are built using measured data, where available, and also expert understanding of the likely relationships between factors where data is not available.

A Bayesian Network is essentially a diagram that shows the cause and effect relationships about particular systems and includes information on how much and in what way one part of the system affects another. These networks attempt to give a useful estimate of a predicted outcome (for example, the occurrence of an algal bloom given certain nutrient conditions) even if apparently key pieces of information are poorly known.

Bayesian networks get their name from Reverend Thomas Bayes who developed a mathematical formula for calculating probabilities (published posthumously in 1763) amongst related variables for which the relationships are not known (see the "Infobox: Bayes Theorem" for more details). Bayesian networks have only recently become practical with the development of computer hardware and software that can handle these Bayesian relationships among a useful number of variables. As an example, Microsoft Office now uses Bayesian Networks to decide how to offer users help, based on past experience with the user. Bayesian Networks are now increasingly being applied to situations in medicine, engineering and the environment.

Why Use Bayesian Networks?
Bayesian Networks are useful tools for understanding how natural systems work, and how particular management decisions can affect the system. They are particularly useful where there are many possible management actions, and many criteria on which to base decisions about which are the best management actions. They can also be used to increase our understanding of the relationships between components making up an ecosystem.

The basis of the network is a diagram representing various aspects of the system being considered (e.g. see the Example). Because they are graphical, they can improve communication about our current understanding of the system, and allow input from people less familiar with computer modelling, but with a good understanding of the system.

Bayesian Networks are particularly useful where a relationship between variables is thought to be important but where our understanding of that relationship is incomplete. In such situations we need to describe the probability that particular relationships will occur, based on our observations of the variables.

One of the most important features of Bayesian Networks is the fact that they can account for uncertainty. This is particularly important given the complexity of the natural world and the difficulty in making exact predictions of the effects of management actions. Managers need to balance the desirability of an outcome against the chance that particular management actions may not lead to the expected outcome.

Additionally, Bayesian networks are easy to adapt and change as our understanding of the system develops, if new factors come into play, or when new data is collected. The network can "learn" from additional data and become better at predicting outcomes.

How does a Bayesian Network work?
A Bayesian Network is a set of system variables, also known as "nodes", which may be factors such as nutrient levels, salinity, or algal concentrations if a network is looking at water quality. Links between the nodes represent the relationships between the nodes (for example, a link between nutrient levels and algal concentrations). The relationship between nodes is quantified with a set of probabilities (so-called "Conditional Probability Tables") specifying the belief that a node will be in a particular state given the states of the nodes that affect it.

Thus the value (or "state") of a node is a result of the states of the nodes linked to it. The network can then be "trained" with data. The more evidence there is on how the system has behaved in the past, the more certain we can be that it will behave in a similar way in the future.

Inputs to a Bayesian Network can include and combine data from regular monitoring (e.g. for water quality, weather stations), from specific studies or surveys (e.g. once-off fauna surveys). Sometimes no data is available for a certain node/relationship because it is complicated or expensive to collect, or because the region under consideration is remote. If no data is available, consultation with experts to obtain their opinion on nodes/relationships can be used until data can be collected, with predictions based on this having a higher uncertainty than those predictions based on measured data.

The output from a Bayesian Network can be a prediction on the state of the measurement endpoint, for example "good", "moderate" or "poor" abundance of a certain focal species. This can be defined within the final node as, for example, an abundance of more than 10 individuals of the focal species per hectare being "good", between 3 and 10 individuals being "moderate", and less than 5 individuals being "poor". This output can be compared for different management actions to assist in deciding whether an action is worth taking, or which action is most likely to give the best result.

Further information
For more information on Bayesian networks, these sources may be useful:

General/popular articles:

- "Adding art to the rigor of statistical science", by David Leonhardt, New York Times, April 28, 2001: http://www.nytimes.com/2001/04/28/arts/28BAYE.html
- "The ghost in the machine", by Jane Black, Business Week, July 31, 2001: http://www.businessweek.com/bwdaily/dnflash/jul2001/nf20010731_509.htm

More detailed articles:

- "A brief introduction to graphical models and Bayesian networks", by Kevin Murphy 1998: http://www.cs.ubc.ca/~murphyk/Bayes/bayes.html
- "An Introduction to Bayesian Networks and their Contemporary Applications", by Daryle Niedermayer: http://www.niedermayer.ca/papers/bayesian/index.html
- "Netica, Bayesian Network Software & Tutorial": http://www.norsys.com/tutorials/netica/nt_toc_A.htm

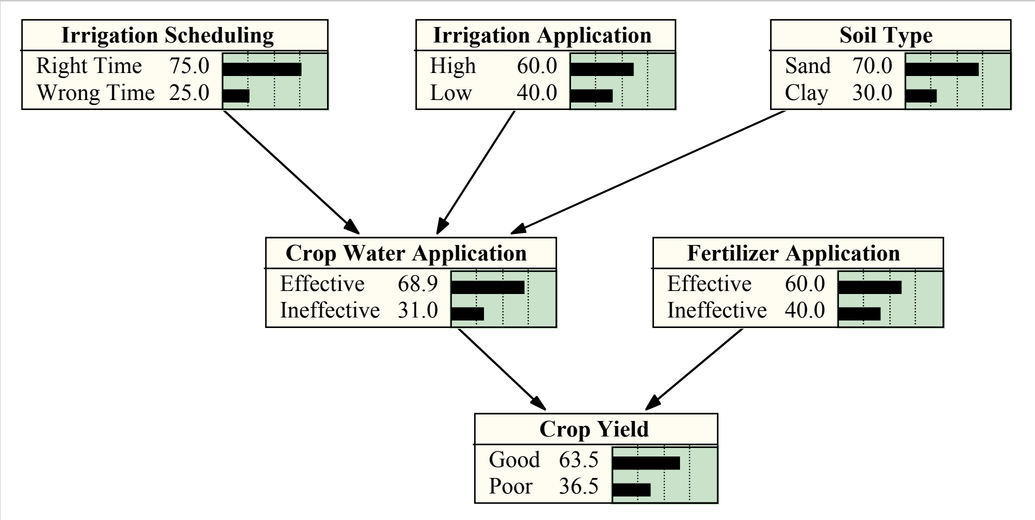
Infobox: Bayes Theorem

The networks essentially rely on a relationship developed by Bayes. In probability notation, for two events A and B:

$p(A|B) = p(B|A) \times p(A) / p(B)$

Essentially, this says that if we had a high degree of belief in the likelihood of event A occurring based on past experience (i.e. the probability of A ($p(A)$) is high), and we now observe data (Event B, and the probability of B, p(B)) that would be likely to occur if Event A occurs (the probability of B given the we have observed event A, $p(B|A)$), then our "after the evidence confidence" (i.e. probability of A given the probability of B, $p(A|B)$) in Event A should be strengthened. This is "inference", which allows us to determine which "cause" can "explain" observed data better.

Example: A simple Bayesian network for "crop yield" based on a two primary variables, water application and fertilizer application



Using just the lower three nodes, this BN predicts that given a high probability (69%) of an "effective" crop water application, and a 60% probability of an "effective" fertilizer application, (unsurprisingly) the probability of a "good" yield is quite high (63.5%). The states of "effective" application and "good" crop yield would be defined within each node**.**

Appendix B: Conditional Probability Tables for Bayesian Network

B.1 Macroinvertebrate Community Diversity

Macroinvertebrate community diversity was chosen as the assessment endpoint for the Lower Loddon River Bayesian Network. Macroinvertebrates include aquatic animals such as insects, snails, worms and shrimps. They provide a direct biological measure of a critical part of the river fauna, are relatively easy to monitor and are a part of current and future monitoring programs in the Loddon catchment. The value in assessing the biological community is that it responds to all types of disturbances, and reflects the net effect of all environmental factors, including impacts of stresses over a period of weeks, months or years.

The "macroinvertebrate community diversity" node characterises the health of the macroinvertebrate community in the Loddon River. Put quite simply, the more diverse the community, the healthier it is. The five states for "macroinvertebrate community diversity" determined by the expert panel are very poor, poor, moderate, good and very good. These states were selected as they are well established thresholds defined using the standard indices AUSRIVAS, SIGNAL and Number of Families, according to the method detailed in EPA (2004). The states are presented in Table B.1.

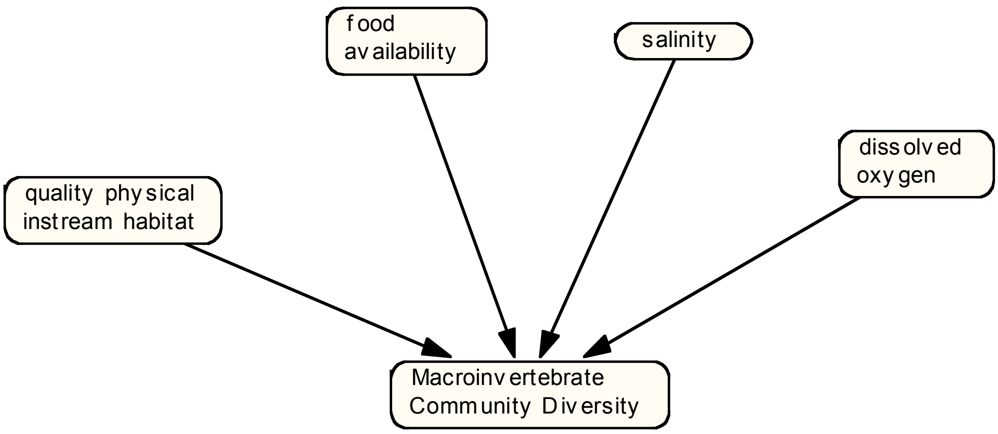


Figure B.1. Graphical submodel for "Macroinvertebrate Community Diversity"

The panel of ecological experts identified "physical habitat", "dissolved oxygen", "food availability" and "salinity" as the key variables directly influencing "macroinvertebrate community diversity" in the Loddon River (Figure B.1). The conditional probabilities for "macroinvertebrate community diversity" were determined by the panel of ecological experts and are presented in Table B.1. The conditional probabilities are the mean of the expert responses. The individual responses of the ecological expert panel are presented in Table D2 in Appendix D.

The ecological expert panel had high certainty in estimating the overall relative influence of the four variables determining macroinvertebrate diversity. They were able to base this judgement on a substantial amount of information from previous studies and personal observations in the field. This translated to a moderate confidence in the detail of the individual probability estimates for these relationships, given the detail required.

Table B.1 Conditional Probabilities for "Macroinvertebrate Community Diversity"

Physical Habitat	DO%	Food Availability	Salinity	Macroinvertebrate Community Diversity				
				Very Poor	Poor	Moderate	Good	Very Good
Poor	Low	Poor	Low	80	20	0	0	0
Poor	Low	Poor	Moderate	90	10	0	0	0
Poor	Low	Poor	High	95	5	0	0	0
Poor	Low	Moderate	Low	75	20	5	0	0
Poor	Low	Moderate	Moderate	80	15	5	0	0
Poor	Low	Moderate	High	90	10	0	0	0
Poor	Low	Good	Low	60	30	10	0	0
Poor	Low	Good	Moderate	80	20	0	0	0
Poor	Low	Good	High	90	10	0	0	0
Poor	Moderate	Poor	Low	20	50	30	0	0
Poor	Moderate	Poor	Moderate	40	40	20	0	0
Poor	Moderate	Poor	High	60	40	0	0	0
Poor	Moderate	Moderate	Low	0	30	65	5	0
Poor	Moderate	Moderate	Moderate	10	50	35	5	0
Poor	Moderate	Moderate	High	45	50	5	0	0
Poor	Moderate	Good	Low	5	20	55	20	0
Poor	Moderate	Good	Moderate	10	30	50	10	0
Poor	Moderate	Good	High	50	40	10	0	0
Poor	High	Poor	Low	10	50	35	5	0
Poor	High	Poor	Moderate	15	55	30	0	0
Poor	High	Poor	High	50	45	5	0	0
Poor	High	Moderate	Low	5	30	45	20	0
Poor	High	Moderate	Moderate	5	50	45	0	0
Poor	High	Moderate	High	45	50	5	0	0
Poor	High	Good	Low	5	25	45	25	0
Poor	High	Good	Moderate	5	40	45	10	0
Poor	High	Good	High	35	45	20	0	0
Moderate	Low	Poor	Low	35	65	0	0	0
Moderate	Low	Poor	Moderate	45	55	0	0	0
Moderate	Low	Poor	High	90	10	0	0	0
Moderate	Low	Moderate	Low	35	60	5	0	0
Moderate	Low	Moderate	Moderate	40	60	0	0	0
Moderate	Low	Moderate	High	45	40	10	5	0
Moderate	Low	Good	Low	25	55	20	0	0
Moderate	Low	Good	Moderate	40	50	10	0	0
Moderate	Low	Good	High	65	35	0	0	0
Moderate	Moderate	Poor	Low	5	15	60	20	2
Moderate	Moderate	Poor	Moderate	0	45	45	10	0

Physical Habitat	DO%	Food Availability	Salinity	Macroinvertebrate Community Diversity				
				Very Poor	Poor	Moderate	Good	Very Good
Moderate	Moderate	Poor	High	30	40	25	5	0
Moderate	Moderate	Moderate	Low	0	0	35	45	20
Moderate	Moderate	Moderate	Moderate	0	0	55	35	10
Moderate	Moderate	Moderate	High	15	35	40	10	0
Moderate	Moderate	Good	Low	0	0	40	50	10
Moderate	Moderate	Good	Moderate	0	10	45	40	5
Moderate	Moderate	Good	High	25	30	40	5	0
Moderate	High	Poor	Low	5	25	40	20	10
Moderate	High	Poor	Moderate	10	35	45	10	0
Moderate	High	Poor	High	35	35	25	5	0
Moderate	High	Moderate	Low	0	0	25	55	20
Moderate	High	Moderate	Moderate	0	5	50	35	10
Moderate	High	Moderate	High	20	35	35	10	0
Moderate	High	Good	Low	0	0	25	50	25
Moderate	High	Good	Moderate	0	5	45	35	15
Moderate	High	Good	High	15	30	45	5	5
Good	Low	Poor	Low	40	35	25	0	0
Good	Low	Poor	Moderate	45	40	15	0	0
Good	Low	Poor	High	70	25	5	0	0
Good	Low	Moderate	Low	20	45	25	5	5
Good	Low	Moderate	Moderate	45	40	15	0	0
Good	Low	Moderate	High	65	30	5	0	0
Good	Low	Good	Low	20	50	30	0	0
Good	Low	Good	Moderate	35	45	20	0	0
Good	Low	Good	High	50	40	10	0	0
Good	Moderate	Poor	Low	5	25	40	20	10
Good	Moderate	Poor	Moderate	5	35	45	10	5
Good	Moderate	Poor	High	30	40	25	5	0
Good	Moderate	Moderate	Low	0	0	15	70	15
Good	Moderate	Moderate	Moderate	0	5	30	50	15
Good	Moderate	Moderate	High	25	30	30	15	0
Good	Moderate	Good	Low	0	0	10	60	30
Good	Moderate	Good	Moderate	0	0	25	65	10
Good	Moderate	Good	High	15	25	40	20	0
Good	High	Poor	Low	0	5	35	45	15
Good	High	Poor	Moderate	0	15	55	25	5
Good	High	Poor	High	30	35	30	5	0
Good	High	Moderate	Low	0	0	5	55	40
Good	High	Moderate	Moderate	0	5	15	55	25
Good	High	Moderate	High	25	30	30	15	0
Good	High	Good	Low	0	0	0	25	75
Good	High	Good	Moderate	0	5	10	50	35

Physical Habitat	**DO%**	**Food Availability**	**Salinity**	**Macroinvertebrate Community Diversity**				
				Very Poor	Poor	Moderate	Good	Very Good
Good	High	Good	High	15	30	35	20	0

B.2 Instream Physical Habitat

The “instream physical habitat” node is a synthetic variable characterising the overall availability of habitat for macroinvertebrates. The three states defined for “instream physical habitat”, poor, moderate and good, are dependant on the given states of “instream vegetation” and “woody debris and roots” (Figure B.2).

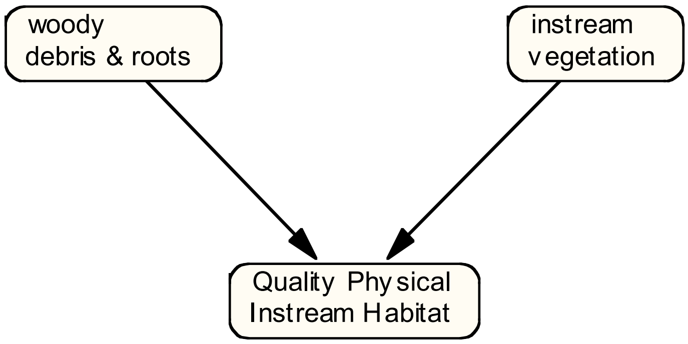


Figure B.2. Graphical submodel for “Instream Physical Habitat”

The network structure and conditional probabilities (Table B.2) for “instream physical habitat” were determined by the panel of ecological experts. The conditional probabilities are the mean of the expert responses. The individual responses of the ecological expert panel are presented in Table D3 in Appendix D. They identified “Instream vegetation” and “woody debris and roots” as the two key habitats for macroinvertebrates in lowland rivers, in particular for highly sedimented rivers such as the Loddon, which lack a stable bed habitat. “Instream vegetation” was considered to be a more important habitat for a wider range of macroinvertebrates than woody debris and roots, and as such has a proportionally greater effect on the “instream physical habitat” variable.

The ecological expert panel had high certainty in the probability estimates for this relationship, as they were able to base their estimates on a relatively substantial amount of information from previous studies and field observations.

Table B.2. Conditional Probabilities for “Instream Physical Habitat”

Woody Debris and Roots	Instream Vegetation	Instream Physical Habitat		
		Poor	Moderate	Good
Poor	Poor	100	0	0
Poor	Moderate	15	85	0
Poor	Good	0	30	70
Good	Poor	35	60	0
Good	Moderate	0	40	60
Good	Good	0	0	100

B.3 Instream Vegetation

The "instream vegetation" node characterises the abundance and structural diversity of instream vegetation as a habitat for macroinvertebrates. The three states for "instream vegetation" are poor, moderate and good. These states were defined by the ecological expert panel according to % coverage of macrophytes and the structure types present (submerged, emergent and floating) and are presented in Table B.3. The panel of ecological experts identified "turbidity", "salinity" and "flow regime" as the key factors influencing instream vegetation in the Loddon River (Figure B.3).

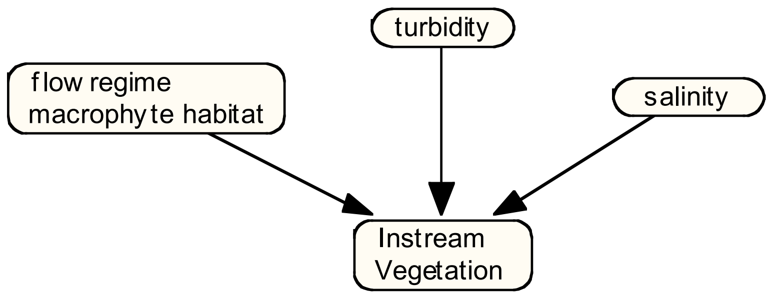


Figure B.3. Graphical submodel for "Instream Vegetation"

The conditional probabilities (Table B.3) for "instream vegetation" were determined by the panel of ecological experts. The conditional probabilities are the mean of the expert responses. The individual responses of the ecological expert panel are presented in Table D5 in Appendix D. Turbidity was identified as having the greatest influence on the amount and type of instream vegetation present in the Loddon. This was confirmed by Dr Kimberley James (aquatic plant expert who has conducted and supervised macroinvertebrate and macrophyte studies in the Loddon region), who identified high turbidity levels as the main cause of reduced instream vegetation (pers comm.). There is currently little data available on the exact turbidity levels that impact various aquatic macrophytes, although these are known in a general sense from field observation. The states set for turbidity by the ecological expert panel are those that they identified as have varying impacts on macrophytes given the moderate data and information available. As turbidity was identified as having the greatest influence in reducing instream vegetation in the Lower Loddon River, a key habitat for macroinvertebrates, there is scope to considerably improve the network with more research into this relationship for the River.

The ecological expert panel had moderate certainty in the probability estimates for this relationship, as they were able to base their estimates on an adequate amount of information from previous studies and field observations.

Table B.3. Conditional Probabilities for "Instream Vegetation"

Turbidity	Salinity	Flow Regime macrophytes	Instream Vegetation		
			Poor	Moderate	Good
Low	Low	Poor	10	40	50
Low	Low	Moderate	0	25	75
Low	Low	Good	0	0	100
Low	Moderate	Poor	20	70	10
Low	Moderate	Moderate	0	30	70
Low	Moderate	Good	0	30	70
Low	High	Poor	30	70	0
Low	High	Moderate	10	70	20
Low	High	Good	0	20	80
Moderate	Low	Poor	25	65	10
Moderate	Low	Moderate	10	45	45
Moderate	Low	Good	10	45	45
Moderate	Moderate	Poor	45	50	5
Moderate	Moderate	Moderate	30	60	10
Moderate	Moderate	Good	30	50	20
Moderate	High	Poor	65	35	0
Moderate	High	Moderate	55	45	0
Moderate	High	Good	50	50	0
High	Low	Poor	90	10	0
High	Low	Moderate	85	15	0
High	Low	Good	75	20	5
High	Moderate	Poor	95	5	0
High	Moderate	Moderate	95	5	0
High	Moderate	Good	90	5	5
High	High	Poor	100	0	0
High	High	Moderate	95	5	0
High	High	Good	95	5	0

B.4 Woody Debris and Roots

The "woody debris and roots" node characterises the level of woody habitat available for macroinvertebrates. The two states for "woody debris and roots" are poor and good. These states were defined by the ecological expert panel according to the cover of large woody debris (>10cm in diameter) and are presented in Table B.4. EPA field data is collected on large and small woody debris, however the ISC data collected only includes large woody debris. It is due to data availability that the expert panel chose large woody debris only as the measure for this variable, which they identified as being able to provide a good indicator of all woody debris and riparian root habitat available.

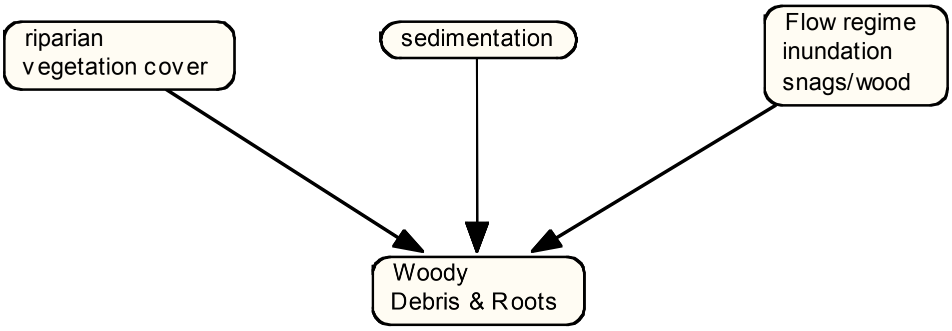


Figure B.4 Graphical submodel for "Woody Debris and Roots"

The panel of ecological experts identified "riparian vegetation", "sedimentation" and "Flow regime inundation of wood debris and roots" as the key variables influencing "woody debris" in the Loddon River (Figure B.4). Information on the relative influences of these variables and their relationship to "woody debris and roots" was assessed using: EPA field data collected in the Loddon catchment on riparian condition, loose silt lying on substrate and woody debris cover; previous studies (Jansen & Robertson 2001, Loddon River Environmental Flows Scientific Panel 2002) and expert judgement from members of the ecological expert panel. The conditional probabilities determined from the information and data are presented in Table B.4.

The EPA field data and study by Jansen & Robertson (2001) both showed that moderate to good riparian vegetation will both provide a good cover of woody debris and root habitat at the majority of sites, and poor riparian vegetation provides a poor cover of woody debris. This information was supported by field observations from the ecological expert panel. Stewardson (2004) estimated that the increase in instream woody debris from improved riparian vegetation was a longterm response (> 10 years) over a small spatial scale. The expert panel identified that low and moderate sedimentation levels should have relatively similar impacts on the available woody debris and high sediment levels would have a much higher influence.

Table B.4: Conditional Probabilities for "Woody Debris and Roots"

Riparian Vegetation	Sedimentation	Flow regime inundation of wood debris and roots	Woody Debris And Roots	
			Poor	Good
Poor	Low	Poor	100	0
Poor	Low	Moderate	100	0
Poor	Low	Good	90	10
Poor	Moderate	Poor	100	0
Poor	Moderate	Moderate	100	0
Poor	Moderate	Good	90	10
Poor	High	Poor	100	0
Poor	High	Moderate	100	0
Poor	High	Good	100	0
Moderate	Low	Poor	20	80
Moderate	Low	Moderate	10	90
Moderate	Low	Good	10	90
Moderate	Moderate	Poor	40	60
Moderate	Moderate	Moderate	30	70
Moderate	Moderate	Good	20	80
Moderate	High	Poor	30	70
Moderate	High	Moderate	20	80
Moderate	High	Good	10	90
Good	Low	Poor	10	90
Good	Low	Moderate	0	100
Good	Low	Good	0	100
Good	Moderate	Poor	20	80
Good	Moderate	Moderate	0	100
Good	Moderate	Good	0	100
Good	High	Poor	30	70
Good	High	Moderate	20	80
Good	High	Good	10	90

The flow relationship was identified from the Loddon River Environmental Flows Scientific Panel (2002) study. These were the flows calculated to restore and maintain invertebrate woody debris and root habitat, by inundating the available habitat and flushing sediment from substrate. There is high certainty in the probability estimates for woody debris and roots as these were able to be based on a relatively substantial amount of data and information from previous studies and field observations by the expert panel.

B.5 Food Availability

The "food availability" node is an integrative variable (i.e. a variable that integrates the information of the parent variables into one variable, in order to simplify the network so that it is more computationally efficient) characterising available food sources for macroinvertebrates. The three states defined for "food availability", poor, moderate and good, are dependant on the given states of "riparian vegetation" and "instream vegetation" (Figure B.5).

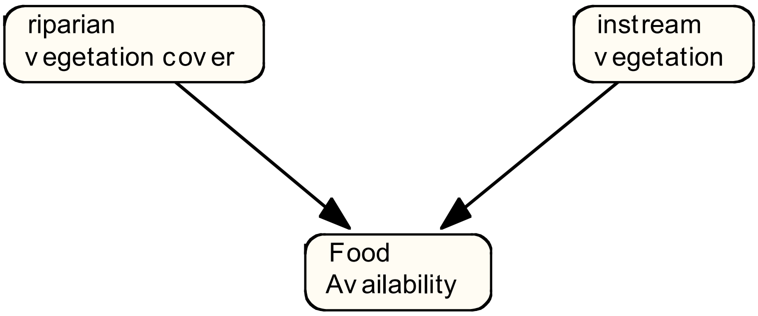


Figure B.5: Graphical submodel for "Food Availability"

The network structure and conditional probabilities (Table B.5) for "food availability" were determined by the panel of ecological experts. The conditional probabilities are the mean of the expert responses. The individual responses of the expert panel are presented Table D.4 in Appendix D. They identified "riparian vegetation" and "instream vegetation" as two key food sources for macroinvertebrates in lowland rivers. Another key food sources for macroinvertebrates is algae biofilms, however this food source has no available data, and would be difficult to include in any routine monitoring programs. As algae biofilms are most prevalent on instream vegetation and woody debris, the expert panel felt that these two network variables would provide a good indication of the available algae biofilm as well. Particularly instream vegetation, which has similar requirements (e.g. light availability, nutrients) to algae biofilms.

The experts considered "Instream vegetation" to be a more important food source for macroinvertebrates than "riparian vegetation". The ecological expert panel had high certainty in the probability estimates for this relationship, as they were able to base their estimates on a relatively substantial amount of information from previous studies and field observations.

Table B.5. Conditional Probabilities for "Food Availability"

Riparian Vegetation	Instream Vegetation	Food Availability		
		Poor	Moderate	Good
Poor	Poor	100	0	0
Poor	Moderate	15	80	5
Poor	Good	0	35	65
Moderate	Poor	65	35	0
Moderate	Moderate	0	0	100
Moderate	Good	0	0	100
Good	Poor	30	60	10
Good	Moderate	0	0	100
Good	Good	0	0	100

B.6 Dissolved Oxygen % Saturation

The "dissolved oxygen" node is defined as the % saturation of dissolved oxygen (DO % saturation) in the water column. The three states for "dissolved oxygen" are low, moderate and high. These states were determined by the ecological expert panel according to the DO % saturation levels that have been shown to greatly reduce, moderately reduce and have no impact on macroinvertebrate community diversity, and are presented in Table B.6. The panel of ecological experts identified "algal blooms" and "stock access" as the key factors influencing "dissolved oxygen" levels in the Loddon River (Figure B.6).

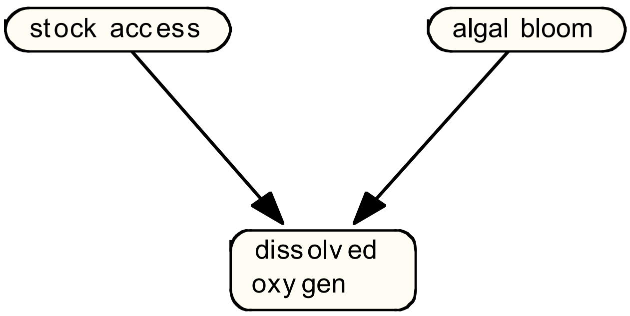


Figure B.6. Graphical submodel for "Dissolved Oxygen"

The conditional probabilities were determined by the analyst and a member of the expert ecological panel (David Tiller) and are presented in Table B.6. The presence of a high level algal bloom was identified as having a much greater influence in reducing dissolved oxygen levels than high stock access.

There is low certainty associated with the probability estimates for this relationship in the Loddon system, as there is a limited amount of data available on DO % saturation levels. There is considerable scope for research in the Lower Loddon system to improve the conditional probability estimates in this sub-network, in particular by conducting diurnal monitoring of DO % saturation levels. However, dissolved oxygen levels in the Lower Loddon Catchment currently don't appear to be at levels posing a high risk to the ecosystem, and study efforts may be better directed elsewhere.

Table B.6. Conditional Probabilities for "Dissolved Oxygen %Saturation"

Algal Bloom	Stock Access	DO		
		Low	Moderate	High
Low	None	0	10	90
Low	Moderate	0	10	90
Low	High	0	20	80
Moderate	None	30	50	20
Moderate	Moderate	30	50	20
Moderate	High	40	50	10
High	None	80	20	0
High	Moderate	80	20	0
High	High	90	10	0

B.7 Riparian Vegetation

The "riparian vegetation" node characterises the longitudinal continuity, structural coverage (groundcover, shrub and tree layers) and indigenous coverage of riparian vegetation. The three states for "riparian vegetation" are poor, moderate and good. These states were defined by the ecological expert panel according to the ISC streamside zone scores and are presented in Table B.7.

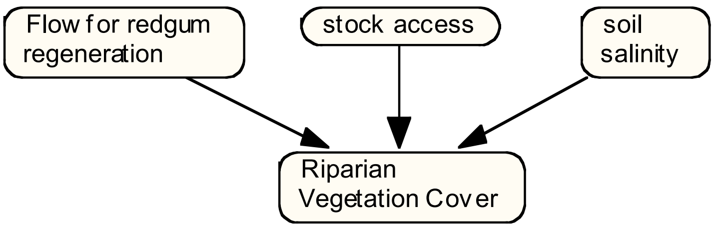


Figure B.7. Graphical submodel for "Riparian Vegetation"

The network structure (Figure B.7) for "riparian vegetation" was determined by the analyst and panel of ecological experts. They identified "stock access", "soil salinity" and "Flow for Redgum regeneration " as the key factors influencing "riparian vegetation" in the Loddon River. Information on the relative influences of these variables and their relationship to "riparian vegetation" was researched from the literature and discussions with local and ecological experts.

Stock access has been shown to greatly reduce riparian vegetation condition (e.g. Lovett and Price, 1999a; Lovett and Price, 1999b; Robertson and Rowing, 2000; Jansen and Robertson, 2001; Wilson et al., 2003). Studies of lowland river systems in south-eastern Australia (Robertson and Rowing, 2000; Jansen and Robertson, 2001; Wilson et al., 2003) showed a strong significant relationship between stock access and riparian vegetation condition. With stock access having the greatest influence on riparian vegetation condition. High stock access areas were in the worst riparian condition, moderately grazed areas were in an intermediate riparian condition and areas with no stock access had the best riparian vegetation condition.

Moderate stock access if managed well (e.g. crash grazing after native grasses go to seed) will have an even lesser impact on riparian vegetation condition (Paul Haw & Bradley Haw pers. comm.). Robertson and Rowing (2000) identified improvements in riparian condition within five years of livestock exclusion, with the improvement in riparian vegetation condition being most pronounced at sites where the riparian zone has been excluded from stock for more than 50 years. Robertson and Rowing (2000) surmised that the impacts of livestock may override any beneficial impact of environmental flow allocations.

Local experts also identified flow regime and soil salinity as having a lesser influence on riparian condition than stock access (Rob O'Brien (DPI), Matt Hawkins (DPI), Paul Haw & Bradley Haw pers. comm.). In localised spots where soil salinity is very high, it appears to override all other factors and prohibit any reasonable riparian vegetation (Rob O'Brien (DPI), pers. comm.).

Using the above data and information the conditional probabilities were determined by the analyst and a member of the expert ecological panel (David Tiller) and are presented in Table B.7. There is moderate certainty in the probability estimates for "riparian vegetation". Although there was substantial data and information available for the stock access variable, there was less information available on the quantitative impacts of the "flow for Redgum regeneration" and "soil salinity" variables.

Table B.7. Conditional Probabilities for "Riparian Vegetation"

Stock Access	Soil Salinity	Flow for Redgum regeneration	Riparian Vegetation		
			Poor	Moderate	Good
Low	Low	Poor	0	30	70
Low	Low	Good	0	0	100
Low	High	Poor	45	55	0
Low	High	Good	30	60	10
Moderate	Low	Poor	35	60	5
Moderate	Low	Good	25	60	15
Moderate	High	Poor	65	35	0
Moderate	High	Good	40	55	5
High	Low	Poor	85	15	0
High	Low	Good	70	30	0
High	High	Poor	100	0	0
High	High	Good	98	2	0

B.8 Algal Bloom

The "algal bloom" node is defined as the number of algal cells/ML. The three states for "algal bloom" are low, moderate and high. These states were determined by expert opinion (Vic EPA), given the level of bloom previously shown to have no impact on DO levels, begin to depress DO levels and greatly depress DO levels. The states are presented in Table B.8.

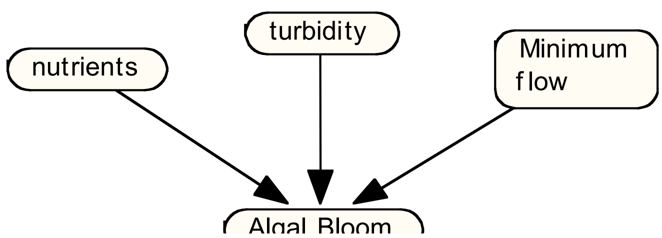


Figure B.8. Graphical submodel for "Algal Bloom"

Based on information from the literature (e.g. ANZECC, 2000), the analyst and a member of the ecological expert panel (David Tiller) identified "nutrients", "turbidity", and "minimum flow" as the key factors influencing the potential of an algal bloom occurring in the Lower Loddon River (Figure B.8). Conditional probabilities for this relationship were determined by a member of the expert ecological panel (David Tiller), and are presented in Table B.8. It was identified that a high algal bloom is only likely to occur when nutrients are high, turbidity is low or moderate, and there has been no turbulence in the water column for a minimum of four weeks (i.e. allowing algal cell populations time to build up without flushing).

There is low certainty associated with the probability estimates for this relationship in the Loddon system. Given the limited amount of data available to develop a relationship for the Loddon River, there is considerable scope for research to improve the conditional probability estimates in this sub-network. However, given there is currently a low risk of major algal blooms occurring in the Lower Loddon River, which would deplete dissolved oxygen to critical levels, study efforts may be better directed elsewhere.

Table B.8. Conditional Probabilities for "Algal Bloom"

Turbidity	Nutrients	Minimum Flow	Algal Bloom		
			Low	Moderate	High
Low	Low	Very Low	100	0	0
Low	Low	Flow Present	100	0	0
Low	Moderate	Very Low	80	20	0
Low	Moderate	Flow Present	100	0	0
Low	High	Very Low	10	40	50
Low	High	Flow Present	80	20	0
Moderate	Low	Very Low	100	0	0
Moderate	Low	Flow Present	100	0	0
Moderate	Moderate	Very Low	80	20	0
Moderate	Moderate	Flow Present	100	0	0
Moderate	High	Very Low	60	30	10
Moderate	High	Flow Present	90	10	0
High	Low	Very Low	100	0	0
High	Low	Flow Present	100	0	0
High	Moderate	Very Low	100	0	0
High	Moderate	Flow Present	100	0	0
High	High	Very Low	70	30	0
High	High	Flow Present	100	0	0

B.9 Turbidity

The "turbidity" node is an indicator of the clarity of the water (i.e. the 'muddiness'), and is measured by the nephelometric turbidity units (NTU) level in the water column. The three states for "turbidity" are low, moderate and high. These states were determined by the ecological expert panel according to the NTU levels they thought may have a low, moderate and high impact in reducing instream vegetation, and are presented in Table B.9.

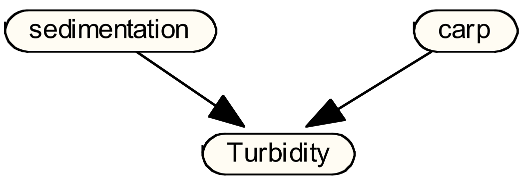


Figure B.9. Graphical submodel for "turbidity"

The panel of ecological experts and local experts identified "sedimentation" and "carp" as the key factors influencing "turbidity" levels in the Loddon River (Figure B.9). Sedimentation was identified as the biggest influence on turbidity levels, as turbidity is directly related to the amount of sediment suspended in the water column.

Studies on Australian systems show that the influence of carp on turbidity levels is greater in lentic (still) than in lotic (flowing) systems, and high densities of carp are required to have a significant impact on turbidity levels in lotic systems (King et al., 1997). Subsequently, the high state for carp was set at a high density level, based on that shown in King et al. (1997) to result in a significant difference in turbidity levels.

The conditional probabilities were determined by the analyst and a member of the expert ecological panel (David Tiller) and are presented in Table B.9. There is moderate certainty in the probability estimates for "turbidity". The sensitivity analysis identified turbidity as having a major influence on macroinvertebrate community diversity. Turbidity has been identified as the major factor in reducing instream vegetation, an important habitat and food source. Turbidity is a direct consequence of the amount of sedimentation in the River. Further research into this relationship and management actions directed at reducing sedimentation would therefore be a high priority for the Loddon River.

Table B.9. Conditional Probabilities for "Turbidity"

Sedimentation	Carp	Turbidity		
		Low	Moderate	High
Low	Low	100	0	0
Low	High	90	10	0
Moderate	Low	0	90	10
Moderate	High	0	80	20
High	Low	0	10	90
High	High	0	0	100

B.10 Bank Erosion

The "bank erosion" node characterises the level of erosion of the bank, which is a potential source of sediment inputs to the River. The three states for "bank erosion" are extensive, moderate and limited/stable. These states were defined by the ecological expert panel using ISC data and EPA field data and are presented in Table B.10.

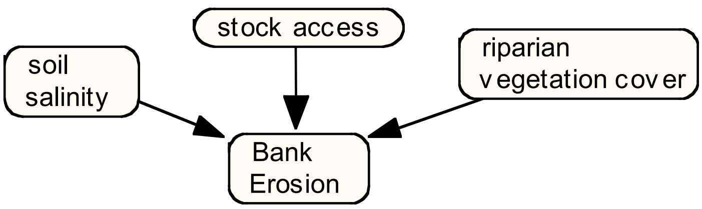


Figure B.10. Graphical submodel for "Bank Erosion"

The network structure (Figure B.10) for "bank erosion" was determined by the analyst and panel of ecological experts. They identified "stock access", "soil salinity" and "riparian vegetation" as the key factors influencing "bank erosion" in the Loddon River.

Information on the relative influences of these variables and their relationship to bank erosion was researched from the literature and discussions with local and ecological experts. Studies of lowland river systems in south-eastern Australia (Robertson and Rowing 2000, Jansen and Robertson 2001, Lovett and Price 1999a, Lovett and Price 1999b) showed a strong significant relationship between stock access and riparian vegetation condition to bank stability, with stock access having a greater influence on bank stability than riparian vegetation. Stewardson et al., (2004) estimated that the reduction in bank erosion from the removal of stock access was a short-term response (approx 2 years), with a longer-term response (> 10 years) in the reduction of erosion rate from associated bank revegetation. These processes operate over a small spatial scale. Soil structure was also shown to have an influence on bank erosion, but to a lesser degree than the other two variables. This is reflected through the soil salinity variable, with saline soils having poor structure. The above information was supported by discussions with DPI Kerang staff (Rob O'Brien and Matt Hawkins) and members of the ecological expert panel of field observations.

Using the above data and information the conditional probabilities were determined by the analyst and a member of the expert ecological panel (David Tiller) and are presented in and are presented in Table B.10. There is moderate certainty in the probability estimates for "bank erosion", which are based on a small number of quantitative studies and a substantial amount of field observation.

Table B.10. Conditional Probabilities for "Bank Erosion"

Stock Access	Soil Salinity	Riparian Vegetation	Bank Erosion		
			Extensive	Moderate	Limited/Stable
Low	Low	Poor	35	60	5
Low	Low	Moderate	0	20	80
Low	Low	Good	0	0	100
Low	High	Poor	50	50	0
Low	High	Moderate	10	80	10
Low	High	Good	0	40	60
Moderate	Low	Poor	50	50	0
Moderate	Low	Moderate	20	70	10
Moderate	Low	Good	10	70	20
Moderate	High	Poor	60	40	0
Moderate	High	Moderate	30	65	5
Moderate	High	Good	20	70	10
High	Low	Poor	100	0	0
High	Low	Moderate	70	30	0
High	Low	Good	60	40	0
High	High	Poor	100	0	0
High	High	Moderate	80	20	0
High	High	Good	70	30	0

B.11 Sedimentation

The "sedimentation" node characterises the level of sediment deposited on the stream bed and other substrate (e.g. woody debris), and into the streambed itself. The three states for "sedimentation" are low, moderate and high. These states were defined by the ecological expert panel based on sedimentation levels shown to have no impact on available substrate habitat, shown to moderately reduce available substrate habitat and greatly reduce available substrate habitat. The states are presented in Table B.11.

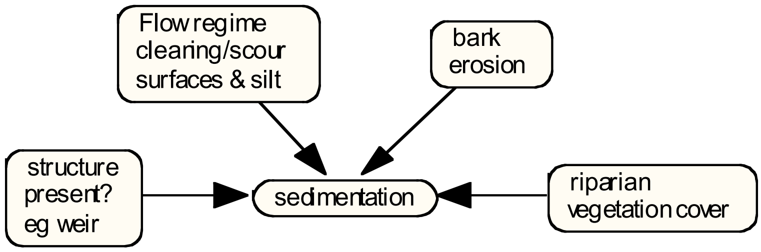


Figure B.11. Graphical submodel for "Sedimentation"

The network structure (Figure B.11) for "sedimentation" was determined by the analyst, panel of ecological experts and Rob O'Brien (DPI). "Bank erosion", "riparian vegetation", "structures present" and "flow regime cleaning/scour surfaces & silt" were identified as the key factors influencing "sedimentation" in the Loddon River. It should be noted that catchment runoff was identified as one of the key sources of sedimentation to the Loddon River. However, due to a lack of data and information, catchment runoff could not be directly included in the current Bayesian Network. Riparian vegetation has been shown to greatly influence the amount of catchment runoff entering rivers, with good riparian vegetation substantially reducing sediment entering rivers from catchment runoff (Lovett and Price. 1999a; Lovett and Price, 1999b). The variable "riparian vegetation" was therefore included in the relationship for "sedimentation", as the key factor reducing sediment inputs from catchment runoff into the Loddon River.

Lovett and Price (1999a and 1999b) identify bank erosion as leading to the delivery of more sediment to rivers than catchment runoff, particularly in Australian systems. This was supported by ecological and local experts for the Loddon River, with bank erosion being identified as having the major influence on sedimentation. Riparian vegetation (i.e. its ability to reduce catchment runoff), and flow regime were identified as being the next most influential variables on sedimentation levels in the Loddon River. Structures such as weirs were identified as having a major localised impact on sedimentation, but the least influence on a reach scale. With the provision of a good scouring flow regime identified as greatly reducing the impact of such structures.

Using the available information and expert opinion the conditional probabilities were determined by the analyst and a member of the expert ecological panel (David Tiller) and are presented in Table A.11. There is moderate certainty in the probability estimates for "sedimentation". The sensitivity analysis identified sedimentation as having a major influence on macroinvertebrate community diversity. Further research into this relationship and management actions directed at reducing sedimentation would therefore be a high priority for the Loddon River.

Table B.11. Conditional Probabilities for "Sedimentation"

Structures Present	Bank Erosion	Riparian Vegetation	Flow regime Cleaning/ Scour Surfaces & silt	Sedimentation		
				Low	Moderate	High
Absent	Limited/Stable	Poor	Poor	0	70	30
Absent	Limited/Stable	Poor	Moderate	0	80	20
Absent	Limited/Stable	Poor	Good	10	80	10
Absent	Limited/Stable	Moderate	Poor	20	80	0
Absent	Limited/Stable	Moderate	Moderate	30	70	0
Absent	Limited/Stable	Moderate	Good	40	60	0
Absent	Limited/Stable	Good	Poor	90	10	0
Absent	Limited/Stable	Good	Moderate	100	0	0
Absent	Limited/Stable	Good	Good	100	0	0
Absent	Moderate	Poor	Poor	0	20	80
Absent	Moderate	Poor	Moderate	0	40	60
Absent	Moderate	Poor	Good	10	50	40
Absent	Moderate	Moderate	Poor	0	50	50
Absent	Moderate	Moderate	Moderate	10	60	30
Absent	Moderate	Moderate	Good	20	70	10
Absent	Moderate	Good	Poor	10	80	10
Absent	Moderate	Good	Moderate	30	70	0
Absent	Moderate	Good	Good	40	60	0
Absent	Extensive	Poor	Poor	0	0	100
Absent	Extensive	Poor	Moderate	0	0	100
Absent	Extensive	Poor	Good	0	10	90
Absent	Extensive	Moderate	Poor	0	0	100
Absent	Extensive	Moderate	Moderate	0	10	90
Absent	Extensive	Moderate	Good	0	20	80
Absent	Extensive	Good	Poor	0	20	80
Absent	Extensive	Good	Moderate	0	40	60
Absent	Extensive	Good	Good	0	50	50
Present	Limited/Stable	Poor	Poor	0	65	35
Present	Limited/Stable	Poor	Moderate	0	75	25
Present	Limited/Stable	Poor	Good	5	85	10
Present	Limited/Stable	Moderate	Poor	15	85	0
Present	Limited/Stable	Moderate	Moderate	25	75	0
Present	Limited/Stable	Moderate	Good	45	55	0
Present	Limited/Stable	Good	Poor	85	15	0
Present	Limited/Stable	Good	Moderate	95	5	0
Present	Limited/Stable	Good	Good	95	5	0
Present	Moderate	Poor	Poor	0	25	75
Present	Moderate	Poor	Moderate	0	30	70
Present	Moderate	Poor	Good	0	50	50

Structures Present	Bank Erosion	Riparian Vegetation	Flow regime Cleaning/ Scour Surfaces & silt	Sedimentation		
				Low	Moderate	High
Present	Moderate	Moderate	Poor	0	45	55
Present	Moderate	Moderate	Moderate	5	65	30
Present	Moderate	Moderate	Good	15	75	10
Present	Moderate	Good	Poor	5	85	10
Present	Moderate	Good	Moderate	25	75	0
Present	Moderate	Good	Good	35	65	0
Present	Extensive	Poor	Poor	0	0	100
Present	Extensive	Poor	Moderate	0	0	100
Present	Extensive	Poor	Good	0	5	95
Present	Extensive	Moderate	Poor	0	0	100
Present	Extensive	Moderate	Moderate	0	5	95
Present	Extensive	Moderate	Good	0	15	85
Present	Extensive	Good	Poor	0	15	85
Present	Extensive	Good	Moderate	0	35	65
Present	Extensive	Good	Good	0	45	55

B.12 Nutrients [2]

The "nutrients" node is defined as the amount of total phosphorus in the water column. The three states for "nutrients" are low, moderate and high. These states were determined by the ecological expert panel according to the phosphorus levels estimated to present a low, moderate and high risk of a major algal bloom occurring in a lowland river, and are presented in Table B.12. "Catchment runoff", "stock access", and "tailwater drainage" were identified as the key contributors to phosphorus levels in the Lower Loddon River (Figure B.12). This was determined by the analyst and a member of the ecological expert panel, based on catchment reports (Sinclair Knight Merz, 2003; NCCMA, 2003; NCCMA, 2004) and discussions with G-MW and DPI Kerang staff.

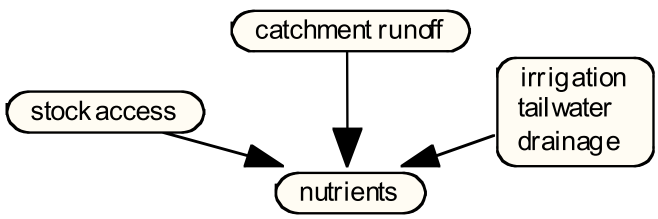


Figure B.12. Graphical submodel for "Nutrients"

Information on the relative inputs of these variables was researched from the literature and discussions with local and ecological experts. Stock access is indicated as a major source of

[2] This conditional probability table is not included in the current Lower Loddon River Bayesian Network, as the data, information and understanding required to adequately include the landuse parent variables is currently not available. The nutrients node is currently populated with water quality monitoring data.

nutrients, both as a direct source of nutrients from manure and their major contribution to bank erosion. Studies of Australian systems indicate that the associated bank erosion contributions may be a greater source of nutrients to rivers than catchment runoff (Lovett and Price 1999a). Calculations of the phosphorus concentrations in catchment runoff for different landuses have been done for the Torrumbarry East of Loddon area (TEOLWG, 1995). Estimations of the possible nutrient concentrations in irrigation drains in the Lower Loddon area have also been done (Sinclair Knight Merz, 2003). There was not enough information and data, on quantities and concentrations of the variables to directly quantify the phosphorus inputs to the Loddon River from these sources. Nor was there enough information on all the variables to quantify the relative phosphorus contributions of "catchment runoff" "stock access" and "tailwater drainage" to the Loddon River.

Conditional probabilities were estimated by the analyst and a member of the expert ecological panel (David Tiller), based on the limited information available, and are presented in Table B.12. "Stock access" and "tailwater drainage" were identified as potentially having the greatest influence on instream phosphorus levels, and "catchment runoff" as having a lower influence.

Table B.12. Conditional Probabilities for "Nutrients"

Catchment Runoff	Stock Access	Irrigation Tailwater Drainage	Nutrients		
			Low	Moderate	High
Low	Low	Low	90	10	0
Low	Low	High	0	40	60
Low	Moderate	Low	40	60	0
Low	Moderate	High	0	30	70
Low	High	Low	10	50	40
Low	High	High	0	20	80
Moderate	Low	Low	50	50	0
Moderate	Low	High	0	30	70
Moderate	Moderate	Low	10	80	10
Moderate	Moderate	High	0	20	80
Moderate	High	Low	0	50	50
Moderate	High	High	0	10	90
High	Low	Low	10	80	10
High	Low	High	0	20	80
High	Moderate	Low	0	40	60
High	Moderate	High	0	10	90
High	High	Low	0	10	90
High	High	High	0	0	100

There is very low certainty associated with the probability estimates of the relationship between "catchment runoff" "stock access" and "tailwater drainage", and instream phosphorus levels. Given the limited amount of data and information on which these probabilities were determined, there is considerable scope for research to improve the conditional probability estimates in this sub-network. However, given the current risk of major algal blooms occurring in the Lower Loddon River being predominately low, study efforts may be better directed elsewhere.

B.13 Salinity [3]

The "salinity" node is defined as the electrical conductivity (EC) level in the water column. The three states for "salinity" are low, moderate and high. These states were determined by the ecological expert panel according to the EC levels that have been shown in studies to have no impact on macroinvertebrates and macrophytes, moderate impact on more sensitive species of macroinvertebrates and macrophytes and an impact on a majority of macroinvertebrates and macrophytes species (Hart et al., 1991; Metzeling et al., 1995; James et al., 2003; James & Hart 1993). The states are presented in Table B.13. "Groundwater discharge", "catchment runoff" and "tailwater drainage" were identified as the key contributors to salinity levels in the Lower Loddon River. This was determined by the analyst based on catchment reports (Sinclair Knight Merz, 2003; NCCMA, 2004) and discussions with G-MW and DPI Kerang staff.

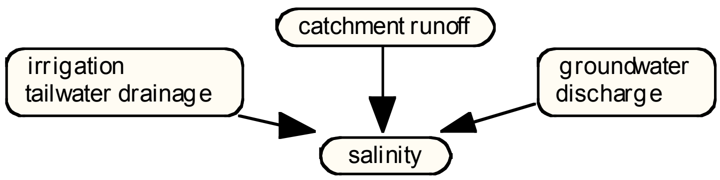


Figure B.13. Graphical submodel for "Salinity"

Information on the relative inputs of these variables was researched from the literature and discussions with local and ecological experts. No information was found that quantifies "groundwater discharge", "catchment runoff" or "tailwater drainage" to the Loddon River, or how these relate to salinity levels in the Loddon River in anything but a very general sense. It was also advised that there is not a known constant relationship of the relative contributions of these variables to salinity levels in rivers that can be used, and that analysis of an adequate set of monitoring data for all variables would be required to estimate the relative contributions with any reasonable degree of certainty (Bruce Gill, pers. comm.). Such data does not currently exist for the Loddon Catchment.

The conditional probabilities were estimated by the analyst and a member of the expert ecological panel (David Tiller), based on the limited information available, and are presented in Table B.13. "Groundwater discharge" and "tailwater drainage" were identified as having the greatest influence on instream salinity levels, and "catchment runoff" as having the lowest influence. Given the limited amount of data and information on which these probabilities were determined, there is considerable scope for research to improve the conditional probability estimates in this sub-network. However, salinity levels in the Lower Loddon Catchment currently don't appear to be at levels posing a high risk to the ecosystem, and study efforts may be better directed elsewhere.

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[3] This conditional probability table is not included in the current Lower Loddon River Bayesian Network, as the data, information and understanding required to adequately include the landuse parent variables is currently not available. The salinity node is currently populated with water quality monitoring data.

There is very low certainty associated with the probability estimates of the relationship between "groundwater discharge", "catchment runoff" and "tailwater drainage", and instream salinity levels, due to a lack of data and information.

Table B.13. Conditional Probabilities for "Salinity"

Groundwater Discharge	Catchment Runoff	Tailwater Drainage	Salinity		
			Low	Moderate	High
Low	Low	Low	100	0	0
Low	Low	High	10	90	0
Low	Moderate	Low	80	20	0
Low	Moderate	High	10	80	10
Low	High	Low	40	60	0
Low	High	High	10	70	20
Moderate	Low	Low	50	50	0
Moderate	Low	High	0	60	40
Moderate	Moderate	Low	50	50	0
Moderate	Moderate	High	0	50	50
Moderate	High	Low	40	60	0
Moderate	High	High	0	40	60
High	Low	Low	10	90	0
High	Low	High	0	10	90
High	Moderate	Low	10	80	10
High	Moderate	High	0	10	90
High	High	Low	10	70	20
High	High	High	0	0	100

B.14 Irrigation Tailwater Drainage [4]

The "irrigation tailwater drainage" node is an integrative variable characterising the amount of tailwater draining to the Loddon River. The three states defined for "irrigation tailwater drainage", low, moderate and high, are dependant on the given states of "area irrigation landuse" and "% tailwater reuse systems" (Figure B.14).

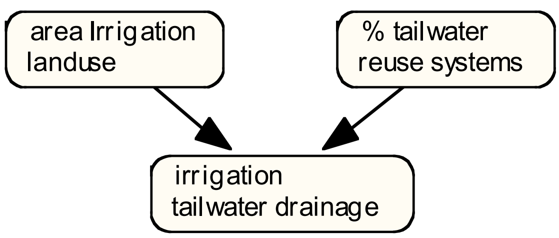

Figure B.14. Graphical submodel for "Irrigation Tailwater Drainage"

[4] This variable is not included in current Lower Loddon River Bayesian Network, as the data, information and understanding required to adequately include it is currently not available

The network structure and conditional probabilities (Table B.14) for "irrigation tailwater drainage" were estimated by the analyst, based on discussions with G-MW and DPI Kerang staff. Whilst reuse systems are known to have a positive influence in reducing the amount of tailwater drainage, the relationship between quantity of reuse systems and level of reduction in tailwater drainage to the Loddon are currently not well known. There is therefore a very low certainty associated with the probability estimates for "irrigation tailwater drainage".

Table B.14. Conditional Probabilities for "Irrigation Tailwater Drainage"

Area Irrigation Landuse	% Irrigation Reuse Systems	Irrigation Tailwater Drainage		
		Low	Moderate	High
Low	Low	100	0	0
Low	High	100	0	0
Moderate	Low	0	100	0
Moderate	High	40	60	0
High	Low	0	0	100
High	High	20	80	0

B.15 Agricultural Catchment Runoff [5]

The "agricultural catchment runoff" node is an integrative variable characterising the amount of agricultural catchment runoff to the Loddon River. The three states defined for "agricultural catchment runoff", low, moderate and high, are dependant on the given states of "area irrigation landuse" and "area dryland landuse" (Figure B.15).

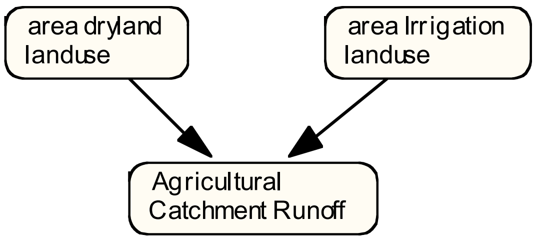

Figure B.15. Graphical submodel for "Agricultural Catchment Runoff"

There isn't a known constant relationship for landuse and catchment runoff. It is a very complex relationship and would require a substantial amount of local data and information on factors such as rainfall, slope, landuse type, crop type/time of year in cropping, to quantify this relationship for the Lower Loddon Catchment (Bruce Gill (DPI) pers. comm.). Research done in the Lower Loddon Catchment does however identify that the nutrient runoff contribution from irrigation landuse is considerably higher than that for dryland landuses (TEOLWG, 1995; Sinclair Knight Merz, 2003).

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[5] This variable is not included in current Lower Loddon River Bayesian Network, as the data, information and understanding required to adequately include it is currently not available

The conditional probabilities (Table B.15) for "agricultural catchment runoff" were estimated by the analyst and a member of the expert ecological panel (David Tiller). Based on the above information, "area irrigation landuse" was determined to have a greater influence on "agricultural catchment runoff" than "area dryland landuse". Given the limited amount of data and information available a very low certainty is associated with the probability estimates for "agricultural catchment runoff".

Table B.15. Conditional Probabilities for "Agricultural Catchment Runoff"

Area Irrigation Landuse	Area Dryland Landuse	Agricultural Catchment Runoff		
		Low	Moderate	High
Low	Low	100	0	0
Low	Moderate	70	30	0
Low	High	40	60	0
Moderate	Low	20	80	0
Moderate	Moderate	0	100	0
Moderate	High	0	80	20
High	Low	0	20	80
High	Moderate	0	10	90
High	High	0	0	100

B.16 Vegetation Buffer [6]

The "vegetation buffer" node is an integrative variable characterising the potential for catchment and riparian vegetation to reduce catchment runoff to the Loddon River. The three states defined for "vegetation buffer", low, moderate and high, are dependant on the given states of "riparian vegetation" and "catchment vegetation cover" (Figure B.16).

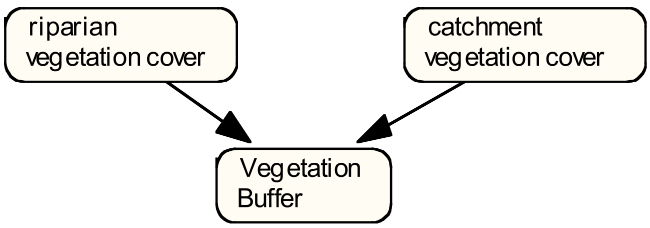

Figure B.16. Graphical submodel for "Vegetation Buffer"

The conditional probabilities (Table B.16) for "vegetation buffer" were estimated by the analyst and a member of the expert ecological panel (David Tiller). "Riparian vegetation" was determined to have a greater influence on "vegetation buffer" than "catchment vegetation cover". That is, riparian vegetation was identified as having a greater capacity to reduce catchment runoff entering the Loddon River than catchment vegetation. No data or

[6] This variable is not included in current Lower Loddon River Bayesian Network, as the data, information and understanding required to adequately include it is currently not available

information was available to quantify the reductions in catchment runoff from riparian and catchment vegetation. There is therefore a very low certainty associated with the probability estimates for "vegetation buffer".

Table B.16. Conditional Probabilities for "Vegetation Buffer"

Riparian Vegetation	Catchment Vegetation Cover	Vegetation Buffer		
		Poor	Moderate	Good
Poor	Poor	100	0	0
Poor	Moderate	80	20	0
Poor	Good	50	50	0
Moderate	Poor	20	80	0
Moderate	Moderate	0	90	10
Moderate	Good	0	60	40
Good	Poor	0	50	50
Good	Moderate	0	10	90
Good	Good	0	0	100

B.17 Catchment Runoff [7]

The "catchment runoff" node is an integrative variable characterising the amount of catchment runoff entering the Loddon River. The three states defined for "catchment runoff", low, moderate and high, are dependant on the given states of "vegetation buffer" and "agricultural catchment runoff" (Figure B.17).

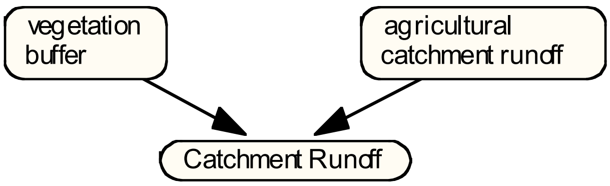

Figure B.17. Graphical submodel for "Catchment Runoff"

The conditional probabilities (Table B.17) for "catchment runoff" were estimated by the analyst and a member of the expert ecological panel (David Tiller), based on expert opinion. No data or information was available to estimate the amount of catchment runoff entering the Loddon River. There is therefore a very low certainty associated with the probability estimates for "catchment runoff".

[7] This variable is not included in current Lower Loddon River Bayesian Network, as the data, information and understanding required to adequately include it is currently not available

Table B.17. Conditional Probabilities for "Catchment Runoff"

Vegetation Buffer	Agricultural Catchment Runoff	Catchment Runoff		
		Low	Moderate	High
Poor	Low	100	0	0
Poor	Moderate	0	100	0
Poor	High	0	0	100
Moderate	Low	100	0	0
Moderate	Moderate	30	70	0
Moderate	High	0	30	70
Good	Low	100	0	0
Good	Moderate	40	60	0
Good	High	10	80	10

Appendix C: Management scenario for the Lower Loddon River - Fencing to reduce stock access

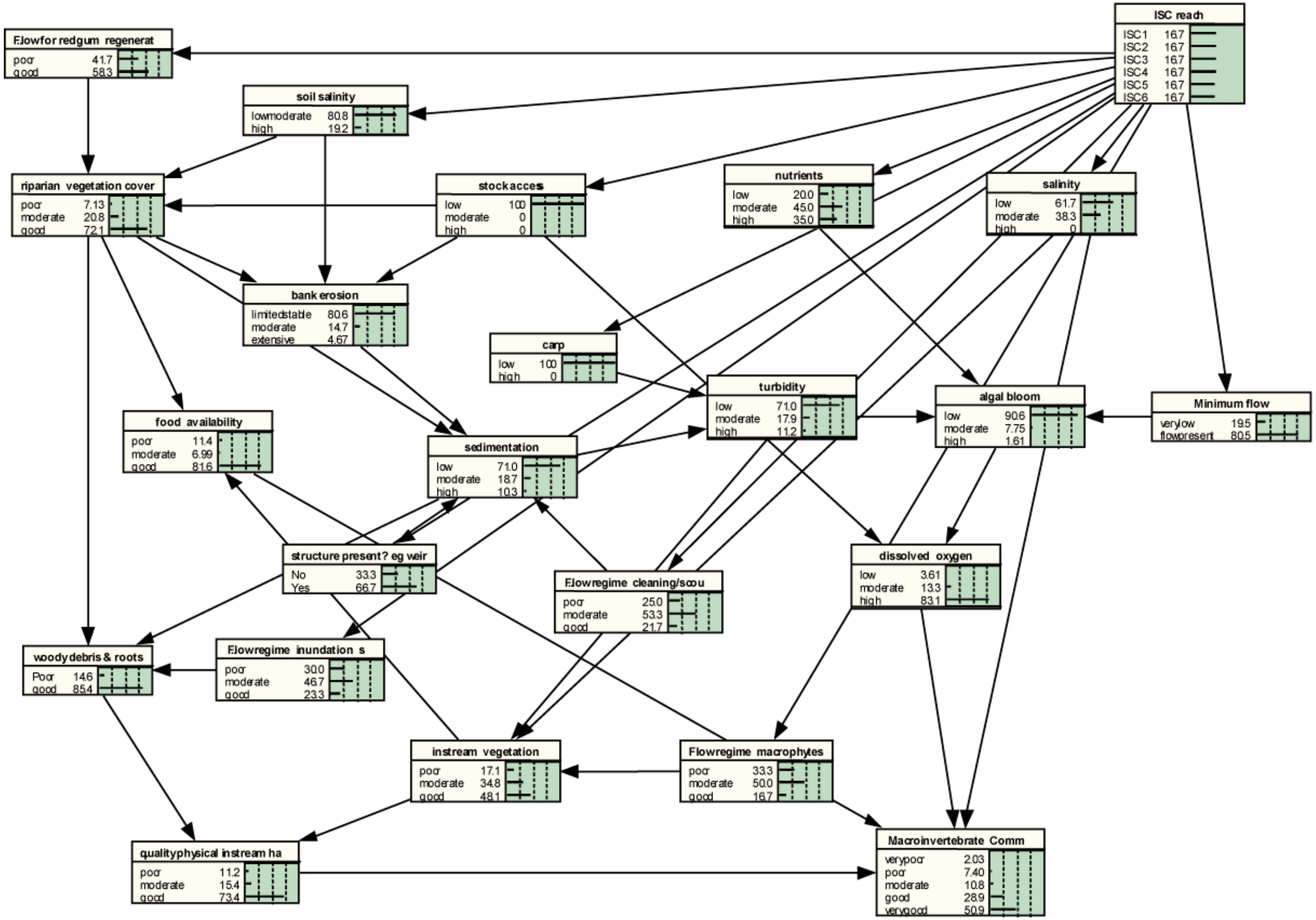

Figure C.1. Stock Fencing Management Scenarios - LOW STOCK ACCESS for Entire Lower Loddon Catchment

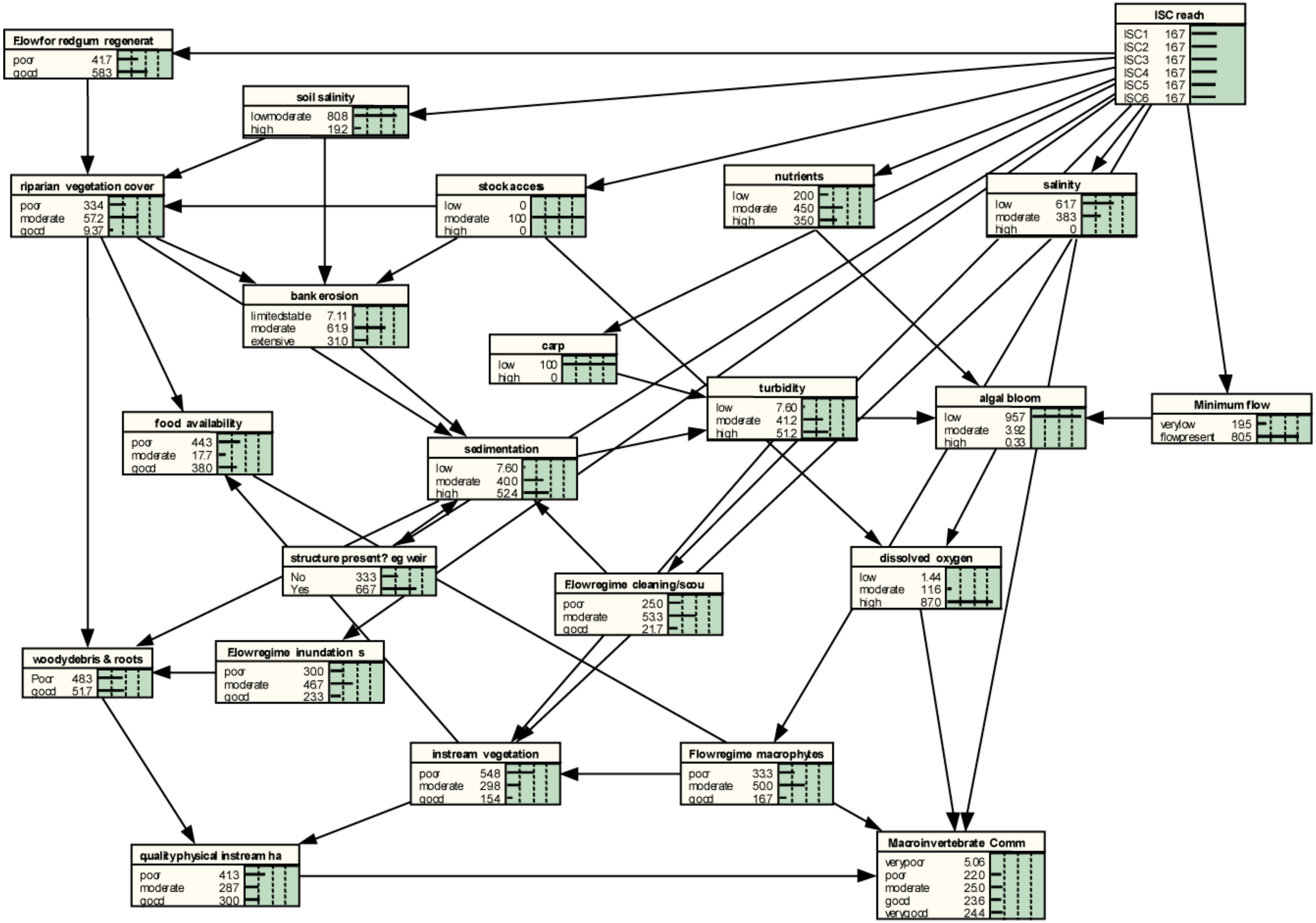

Figure C.2. Stock Fencing Management Scenarios - MODERATE STOCK ACCESS for Entire Lower Loddon Catchment

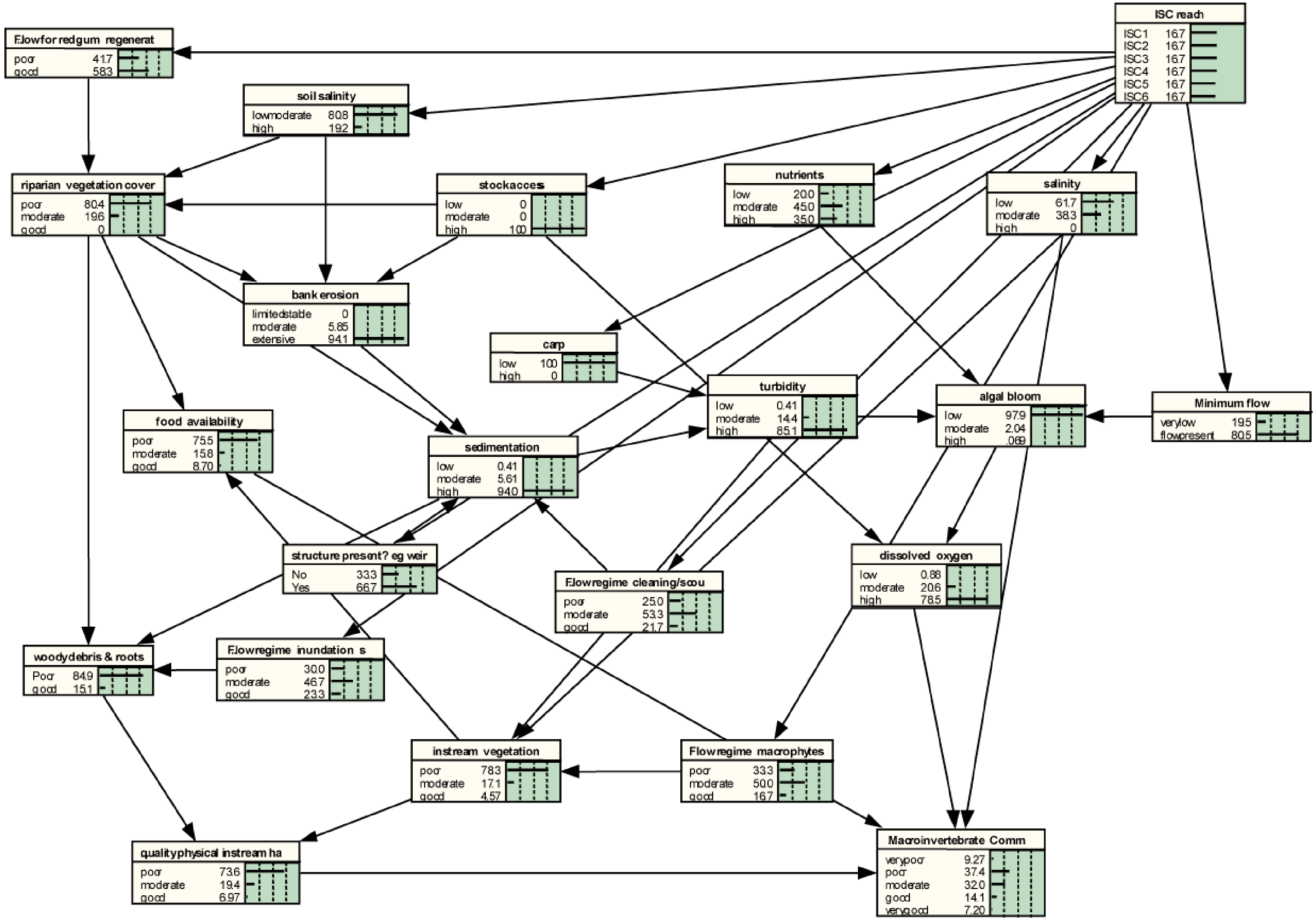

Figure C.3. Stock Fencing Management Scenarios - HIGH STOCK ACCESS for Entire Lower Loddon Catchment

Appendix D: Ecological Expert Panel Summary and Responses

Table D1: Summary of Ecological Expert Panel Members

Name	Expertise
Stephen Adamthwaite (Freshwater Sciences, EPA Victoria)	Key area of expertise: macroinvertebrates Other areas of expertise: local knowledge of river, catchment and landuses
Leon Metzeling (Freshwater Sciences, EPA Victoria)	Key area of expertise: macroinvertebrates Other areas of expertise: general river health processes, water quality
Clare Putt (Freshwater Sciences, EPA Victoria)	Key area of expertise: macrophytes Other areas of expertise: water quality
David Robinson (Freshwater Sciences, EPA Victoria)	Key area of expertise: water quality Other areas of expertise: macroinvertebrates, general river health processes
David Tiller (Freshwater Sciences, EPA Victoria)	Key area of expertise: river health processes Other areas of expertise: Water quality, macroinvertebrates

Table D2. Ecological Expert Panel Responses for "Macroinvertebrate Community Diversity" CPT

Physical Habitat	DO%	Food Availability	Salinity	Macroinvertebrate Community Diversity																								
				Very Poor					Poor					Moderate					Good					Very Good				
				CP	DR	DT	LM	SA	CP	DR	DT	LM	SA	CP	DR	DT	L M	SA	CP	DR	DT	LM	SA	CP	DR	DT	LM	SA
Poor	Low	Poor	Low	80	80	80	70	80	20	20	10	30	20	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0
Poor	Low	Poor	Moderate		100	90	80	80		0	10	20	20		0	0	0	0		0	0	0	0		0	0	0	0
Poor	Low	Poor	High	90	100	90	100	100	10	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poor	Low	Moderate	Low		80	80	70	60		10	10	30	40		10	10	0	0		0	0	0	0		0	0	0	0
Poor	Low	Moderate	Moderate		80	90	80	70		10	10	20	30		10	0	0	0		0	0	0	0		0	0	0	0
Poor	Low	Moderate	High	90	80	90	80	100	10	20	10	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Poor	Low	Good	Low			70	60	60			20	30	40			10	10	0			0	0	0			0	0	0
Poor	Low	Good	Moderate			80	80	70			20	20	30			0	0	0			0	0	0			0	0	0
Poor	Low	Good	High			90	90	90			10	10	10			0	0	0			0	0	0			0	0	0
Poor	Moderate	Poor	Low	10	40	10	10	20	70	60	40	40	60	20	0	50	50	20	0	0	0	0	0	0	0	0	0	0
Poor	Moderate	Poor	Moderate			40	60	30			30	20	60			30	20	10			0	0	0			0	0	0
Poor	Moderate	Poor	High			60	80	50			40	20	50			0	0	0			0	0	0			0	0	0
Poor	Moderate	Moderate	Low	0	0	0	0	0	20	20	20	40	40	80	80	60	60	50	0	0	20	0	10	0	0	0	0	0
Poor	Moderate	Moderate	Moderate		20	0	30	5		60	20	50	60		20	70	20	30		0	10	0	5		0	0	0	0
Poor	Moderate	Moderate	High		20	60	80	20		80	30	20	70		0	10	0	10		0	0	0	0		0	0	0	0
Poor	Moderate	Good	Low			0	20	0			10	30	20			60	40	60			30	10	20			0	0	0
Poor	Moderate	Good	Moderate			0	40	0			20	40	30			60	20	60			20	0	10			0	0	0
Poor	Moderate	Good	High			60	70	20			30	20	70			10	10	10			0	0	0			0	0	0
Poor	High	Poor	Low			10	0	20			60	30	60			20	60	20			10	10	0			0	0	0
Poor	High	Poor	Moderate			10	0	30			70	40	60			20	60	10			0	0	0			0	0	0
Poor	High	Poor	High			60	50	50			30	50	50			10	0	0			0	0	0			0	0	0
Poor	High	Moderate	Low			10	0	0			50	20	20			30	50	60			10	30	20			0	0	0
Poor	High	Moderate	Moderate			10	0	5			50	40	60			40	60	30			0	0	5			0	0	0
Poor	High	Moderate	High			60	50	30			40	40	60			0	10	10			0	0	0			0	0	0
Poor	High	Good	Low			10	0	0			50	20	10			30	40	60			10	40	30			0	0	0
Poor	High	Good	Moderate			10	0	5			50	40	30			40	40	50			0	20	15			0	0	0
Poor	High	Good	High			60	30	15			40	50	45			0	20	40			0	0	0			0	0	0
Moderate	Low	Poor	Low			20	60	25			80	40	70			0	0	5			0	0	0			0	0	0
Moderate	Low	Poor	Moderate			20	70	40			80	30	60			0	0	0			0	0	0			0	0	0
Moderate	Low	Poor	High			90	100	80			10	0	20			0	0	0			0	0	0			0	0	0

Physical Habitat	DO%	Food Availability	Salinity	Macroinvertebrate Community Diversity																								
				Very Poor					Poor					Moderate					Good					Very Good				
				CP	DR	DT	LM	SA	CP	DR	DT	LM	SA	CP	DR	DT	LM	SA	CP	DR	DT	LM	SA	CP	DR	DT	LM	SA
Moderate	Low	Moderate	Low			20	60	20			70	40	70			10	0	10			0	0	0			0	0	0
Moderate	Low	Moderate	Moderate			20	70	30			80	30	70			0	0	0			0	0	0			0	0	0
Moderate	Low	Moderate	High	10	50	40	70	50	20	50	60	30	50	50	0	0	0	0	10	0	0	0	0	0	0	0	0	0
Moderate	Low	Good	Low			30	30	10			60	40	70			10	30	15			0	0	5			0	0	0
Moderate	Low	Good	Moderate			40	60	20			50	30	70			10	10	10			0	0	0			0	0	0
Moderate	Low	Good	High			60	90	40			40	10	60			0	0	0			0	0	0			0	0	0
Moderate	Moderate	Poor	Low			0	0	5			30	10	10			60	50	65			10	40	15			0	0	5
Moderate	Moderate	Poor	Moderate	0	0	0	0	5	50	80	40	20	20	40	20	50	60	65	10	0	10	20	10	0	0	0	0	0
Moderate	Moderate	Poor	High			40	50	10			50	40	25			10	10	60			0	0	5			0	0	0
Moderate	Moderate	Moderate	Low			0	0	0			0	0	0			40	30	40			50	40	50			10	30	10
Moderate	Moderate	Moderate	Moderate	0	0	0	0	0	0	0	0	0	0	50	60	50	60	60	40	30	40	30	30	10	10	10	10	10
Moderate	Moderate	Moderate	High			30	10	5			50	50	10			20	40	65			0	0	20			0	0	0
Moderate	Moderate	Good	Low			0	0	0			0	0	0			30	60	30			60	30	60			10	10	10
Moderate	Moderate	Good	Moderate			0	0	0			0	30	0			30	50	50			60	20	40			10	0	10
Moderate	Moderate	Good	High			30	40	5			50	30	5			20	30	70			0	0	20			0	0	0
Moderate	High	Poor	Low			20	0	0			60	0	10			20	40	60			0	40	25			0	20	5
Moderate	High	Poor	Moderate			20	0	5			60	20	20			20	60	60			0	20	15			0	0	0
Moderate	High	Poor	High			60	30	10			30	30	50			10	30	30			0	10	10			0	0	0
Moderate	High	Moderate	Low			0	0	0			0	0	0			30	30	15			60	40	60			10	30	25
Moderate	High	Moderate	Moderate	0	0	0	0	0	0	0	0	20	0	50	60	50	60	40	40	30	40	20	40	10	10	10	0	20
Moderate	High	Moderate	High			30	30	0			50	40	20			20	30	60			0	0	20			0	0	0
Moderate	High	Good	Low			0	0	0			0	0	0			30	20	20			50	50	50			20	30	30
Moderate	High	Good	Moderate			0	0	0			0	20	0			50	40	50			40	30	30			10	10	20
Moderate	High	Good	High			30	20	5			50	40	5			20	40	70			0	0	15			0	0	5
Good	Low	Poor	Low			70	30	20			20	30	50			10	30	30			0	10	0			0	0	0
Good	Low	Poor	Moderate			70	30	30			30	40	50			0	30	20			0	0	0			0	0	0
Good	Low	Poor	High			80	70	60			20	20	30			0	10	10			0	0	0			0	0	0
Good	Low	Moderate	Low	20	10	40	20	10	20	80	50	30	50	20	10	10	40	40	20	0	0	10	0	20	0	0	0	0
Good	Low	Moderate	Moderate			70	40	20			20	40	60			10	20	20			0	0	0			0	0	0
Good	Low	Moderate	High			80	70	50			20	20	45			0	10	5			0	0	0			0	0	0
Good	Low	Good	Low			30	20	5			60	40	45			10	40	40			0	0	10			0	0	0
Good	Low	Good	Moderate			40	50	15			50	30	60			10	20	25			0	0	0			0	0	0

Physical Habitat	DO%	Food Availability	Salinity	Macroinvertebrate Community Diversity																								
				Very Poor					Poor					Moderate					Good					Very Good				
				CP	DR	DT	LM	SA	CP	DR	DT	LM	SA	CP	DR	DT	LM	SA	CP	DR	DT	LM	SA	CP	DR	DT	LM	SA
Good	Low	Good	High	40	40	50	70	50	50	60	40	20	40	10	0	10	10	10	0	0	0	0	0	0	0	0	0	0
Good	Moderate	Poor	Low			10	0	5			50	10	20			30	20	65			10	40	10			0	30	0
Good	Moderate	Poor	Moderate			10	0	5			50	20	30			40	30	60			0	30	5			0	10	0
Good	Moderate	Poor	High			40	40	20			50	30	40			10	20	40			0	10	0			0	0	0
Good	Moderate	Moderate	Low	0	0	0	0	0	0	0	0	0	0	20	0	30	20	0	60	80	60	60	80	20	20	10	20	20
Good	Moderate	Moderate	Moderate			0	0	0			10	10	0			40	40	10			40	40	70			10	10	20
Good	Moderate	Moderate	High			30	40	0			40	30	20			20	20	50			10	10	25			0	0	5
Good	Moderate	Good	Low	0	0	0	0	0	0	0	0	0	0	20	0	10	10	0	50	75	70	60	50	30	25	20	30	50
Good	Moderate	Good	Moderate			0	0	0			0	0	0			20	40	10			70	50	70			10	10	20
Good	Moderate	Good	High	10	25	10	30	0	30	25	20	30	20	50	25	50	30	50	10	25	20	10	25	0	0	0	0	5
Good	High	Poor	Low			0	0	0			0	0	10			40	20	40			40	50	45			20	30	5
Good	High	Poor	Moderate			0	0	0			20	20	10			60	40	70			20	40	15			0	0	5
Good	High	Poor	High			40	40	5			50	30	20			10	30	55			0	0	20			0	0	0
Good	High	Moderate	Low			0	0	0			0	0	0			10	10	0			70	50	40			20	40	60
Good	High	Moderate	Moderate			0	0	0			0	10	0			10	20	10			70	40	60			20	30	30
Good	High	Moderate	High			40	30	0			50	40	5			10	20	60			0	10	30			0	0	5
Good	High	Good	Low	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	20	10	10	50	30	80	90	90	40	70
Good	High	Good	Moderate		0	0	0	0		5	0	10	0		15	0	20	10		60	20	50	60		20	80	20	30
Good	High	Good	High		25	10	20	5		25	70	30	5		25	10	40	60		25	10	10	25		0	0	0	5

CP – Clare Putt, DR – David Robinson, DT – David Tiller, LM – Leon Metzeling, SA – Stephen Adamthwaite

Table D3. Ecological Expert Panel Responses for "Instream Physical Habitat"

Snags, Woody Debris	Instream Vegetation	Instream Physical Habitat														
		Poor					Moderate					Good				
		CP	DR	DT	LM	SA	CP	DR	DT	LM	SA	CP	DR	DT	LM	SA
Poor	Poor	100	100	100	100	100	0	0	0	0	0	0	0	0	0	0
Poor	Moderate	20	0	10	20	20	80	100	90	80	80	0	0	0	0	0
Poor	Good	0	0	0	0	0	40	20	40	20	40	60	80	60	80	60
Good	Poor	50	10	40	40	30	50	80	60	40	70	0	10	0	20	0
Good	Moderate	0	0	0	0	0	20	0	0	40	20	80	100	100	60	80
Good	Good	0	0	0	0	0	0	0	0	0	0	100	100	100	100	100

CP – Clare Putt, DR – David Robinson, DT – David Tiller, LM – Leon Metzeling, SA – Stephen Adamthwaite

Table D4. Ecological Expert Panel Responses for "Food availability"

Riparian Vegetation	Instream Vegetation	Food Availability														
		Poor					Moderate					Good				
		CP	DR	DT	LM	SA	CP	DR	DT	LM	SA	CP	DR	DT	LM	SA
Poor	Poor	100	100	100	100	100	0	0	0	0	0	0	0	0	0	0
Poor	Moderate	20	0	10	20	20	80	80	70	80	80	0	20	20	0	0
Poor	Good	0	0	0	0	0	50	20	30	50	30	50	80	70	50	70
Moderate	Poor	60	50	80	50	80	40	50	20	50	20	0	0	0	0	0
Moderate	Moderate	0	0	0	0	0	0	0	0	0	20	100	100	100	100	80
Moderate	Good	0	0	0	0	0	0	0	0	0	0	100	100	100	100	100
Good	Poor	10	10	80	10	50	80	80	10	60	50	10	10	10	30	0
Good	Moderate	0	0	0	0	0	0	0	0	0	0	100	100	100	100	100
Good	Good	0	0	0	0	0	0	0	0	0	0	100	100	100	100	100

CP – Clare Putt, DR – David Robinson, DT – David Tiller, LM – Leon Metzeling, SA – Stephen Adamthwaite

Table D5: Ecological Expert Panel Responses for "Instream Vegetation"

Turbidity	Salinity	Flow Regime Macrophytes	Instream Vegetation														
			Poor					Moderate					Good				
			CP	DR	DT	LM	SA	CP	DR	DT	LM	SA	CP	DR	DT	LM	SA
Low	Low	Poor	35	0	0	20	0	60	30	30	20	60	5	70	70	60	40
Low	Low	Moderate	0	0	0	0	0	20	20	20	20	40	80	80	80	80	60
Low	Low	Good	0				0	0				0	100				100
Low	Moderate	Poor	20					70					10				
Low	Moderate	Moderate	0					30					70				
Low	Moderate	Good	0	0	0	0	0	20	50	10	40	20	80	50	90	60	80
Low	High	Poor	30					70					0				
Low	High	Moderate	10					70					20				
Low	High	Good	0					20					80				
Moderate	Low	Poor	10	50	10	40	20	80	50	70	40	80	10	0	20	20	0
Moderate	Low	Moderate	0	40	0			20	40	70			80	20	30		
Moderate	Low	Good	0	40	0			20	40	80			80	20	20		
Moderate	Moderate	Poor	40	80	20	40	50	60	20	60	60	50	0	0	20	0	0
Moderate	Moderate	Moderate	10	80	20	30	10	80	20	70	60	80	10	0	10	10	10
Moderate	Moderate	Good	50	80	0	20	10	40	10	80	60	60	10	10	20	20	30
Moderate	High	Poor	60		70			40		30			0		0		
Moderate	High	Moderate	40		70			60		30			0		0		

Moderate	High	Good	10		60			80		40			10		0		
High	Low	Poor	70	100	100			30	0	0			0	0	0		
High	Low	Moderate	60	100	90			40	0	10			0	0	0		
High	Low	Good	50	80	90	80	80	30	20	10	20	20	20	0	0	0	0
High	Moderate	Poor	90	100	90	90	100	10	0	10	10	0	0	0	0	0	0
High	Moderate	Moderate	80	100	90	90	100	10	0	10	10	0	10	0	0	0	0
High	Moderate	Good	70	100	80	90	100	10	0	20	10	0	20	0	0	0	0
High	High	Poor	100	100	100	100		0	0	0	0		0	0	0	0	
High	High	Moderate	90	100	100	100	100	10	0	0	0	0	0	0	0	0	0
High	High	Good	90	100	100	100		10	0	0	0		0	0	0	0	

CP – Clare Putt, DR – David Robinson, DT – David Tiller, LM – Leon Metzeling, SA – Stephen Adamthwaite