ENVIRONMENT REPORT

AN ECOLOGICAL RISK ASSESSMENT OF THE LOWER WIMMERA RIVER

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Small, disconnected, saline pool at the site: Wimmera River u/s Ellis Crossing, Spring 2007

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EXECUTIVE SUMMARY

Ecological risk assessment (ERA) is a formal process for determining the risk posed by one or more threats (stressors, hazards) to the health of ecosystems. It addresses the difficulties in assessing multiple threats for a range of species within naturally variable ecosystems. Such assessments provide an explicit and transparent process to inform management decisions in ecosystems where processes may not always be fully understood.

The ERA conducted in this study focused on the ecological health of the lower Wimmera River, a highly stressed system in the north west of Victoria. The river experiences saline groundwater intrusion and long periods where there is little or no flow. As a consequence, the salinity of the river can reach levels that are harmful to many plants and animals, and, in some sections, the salinity is up to twice that of seawater. Increased salinity and low flows also result in low dissolved oxygen problems.

The Wimmera Catchment Management Authority (WCMA) identified the lower Wimmera River as a priority reach for environmental flow release management. The aims of this risk assessment were to provide a better understanding of risks to river health and evaluate the effectiveness of different environmental flow management options in reducing these risks.

A Bayesian decision network was developed to assess key water quality parameters, macrophytes, habitat quality and macroinvertebrate community diversity. Sensitivity analysis showed that salinity had the greatest influence and that flow, in particular the delivery of freshes, was the key driver of salinity levels in the river.

The WCMA receive an annual environmental flow allocation under the Bulk Entitlement Conversion Process. The network can be used to determine the optimal flow delivery regime of any given allocation volume for river health improvement. The network can predict water quality levels, macrophyte health and macroinvertebrate community diversity under a range of climatic conditions.

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ACRONYMS

WCMA	Wimmera Catchment Management Authority
ERA	Ecological risk assessment
WMSDS	Wimmera Mallee Stock and Domestic Supply
ISC	Index of stream condition
VWQMN	Victorian Water Quality Monitoring Network
EPA	Environment Protection Authority (EPA Victoria)
SEPP (WoV)	*State Environment Protection Policy (Waters of Victoria)*
MBI	Macroinvertebrate Biotic Index
AUSRIVAS	Australian River Assessment System
SIGNAL	Stream Invertebrate Grade Number Average Level
EPT	Ephemeroptera Plecoptera and Trichoptera
RBA	Rapid BioAssessment

1. INTRODUCTION

The Wimmera Catchment Management Authority (WCMA) recognises the value of the Wimmera River. They have identified the lower Wimmera River as a priority reach for management, as it is of high ecological value, yet is highly stressed and regarded as degraded (WCMA, 2005; WCMA, 2007). Of particular concern are the pools which act as refuges for fish populations and other aquatic animals, macrophytes and water birds. These values are currently threatened by low flows, deteriorating water quality (mainly increasing salinity), and loss of habitat (WCMA, 2007). Environmental flow management is believed to be central to restoring water quality and ecological health in the river (SKM, 2002; WCMA, 2006).

Environmental flow recommendations for the Wimmera catchment were determined through the Stressed Rivers project and Bulk Entitlement Conversion Process (SKM, 2002; Victorian Government, 2004). Environmental flow objectives were established to facilitate the restoration of biological, chemical and physical functions in the lower Wimmera River. The WCMA is now responsible for managing these deliveries under the Wimmera-Mallee Bulk Entitlement arrangements (Victorian Government, 2004).

Environmental flows have the potential to: increase connectivity between pools, improve water quality within pools (reducing salinity and improving dissolved oxygen), cover low lying bars and woody debris, which provides instream habitat, and provide for the growth of aquatic plants (WCMA, 2005). The volume of water the WCMA receives for environmental flows depends on the total volume available in the Grampians Wimmera Mallee Water storages. When storages are not at full capacity, they receive a reduced allocation, relative to the amount available. To date, they have not received a full annual allocation for environmental flows. This trend is expected to continue with climate change and drought conditions continuing to decrease water availability. Therefore, the challenge for the WCMA is selecting the optimum flow scenario, for the volume of water available, that will result in the greatest environmental gain.

EPA Victoria in collaboration with the WCMA conducted an ecological risk assessment (ERA) of the lower Wimmera River. The aim of this ERA was to identify risks to the river and to provide information and tools to assist in managing these risks with environmental releases. The large pool of existing information and targeted monitoring data collected as part of this project was used to build a quantitative tool: a Bayesian Network (see Section 3). This predictive tool will aid in decision-making for management of environmental flow allocations to protect the lower Wimmera River ecosystems.

1.1 The study area

The Wimmera River is situated in the semi-arid, north-western part of Victoria and has a total catchment area of 2,401,130 ha. It is Victoria's largest endoreic river and one of its most variable rivers with regard to annual discharge (Anderson and Morison, 1989).

The Wimmera River has been regulated since the 1840's, resulting in considerably reduced stream flow and an altered flow regime (Anderson and Morison, 1989). Even so, in the past the system has been a reliable source of surface water. However, with the introduction of the Wimmera-Mallee Stock and Domestic Supply (WMSDS) for the purpose of water distribution in the area, natural flow regimes have been substantially altered (Anderson and Morison, 1989; Lind, 2004). Some of the open channels of this supply network have recently been replaced with more efficient underground pipelines in an effort to save water. However, since 1997 the catchment has experienced below average rainfall and periods of severe drought (Bureau of Meteorology, 2008), which have further exacerbated alterations to natural flow regimes (see Figure 1).

The combination of these factors has had a dramatic effect on the volume of water within streams in this catchment, resulting in greatly reduced flows (Butcher, 2007; EPA 2008) and increase water quality impacts. Twenty years of ecological monitoring has shown that flow and water quality issues are critical factors affecting the health of the lower Wimmera River ecosystems (Anderson and Morrison, 1989; EPA Victoria, 1993; WCMA, 2006).

The lower Wimmera River is defined as the section of river downstream from Horsham to Lake Hindmarsh (see Figure 2). It is of high environmental value and contains many sections of relatively intact riparian and instream vegetation, a Heritage River section (proclaimed under the *Heritage Rivers Act 1992*) and many threatened fauna species (WCMA, 2006).

According to the *Index of Stream Condition* (ISC) report (DSE, 2005), the lower Wimmera River between Horsham and Dimboola is in moderate condition. This reach is characterised by sections of relatively intact riparian vegetation. Downstream of Dimboola the river is generally in poor condition, with both poor water quality and clearing of native riparian vegetation identified as the greatest causes of degradation (DSE, 2005).

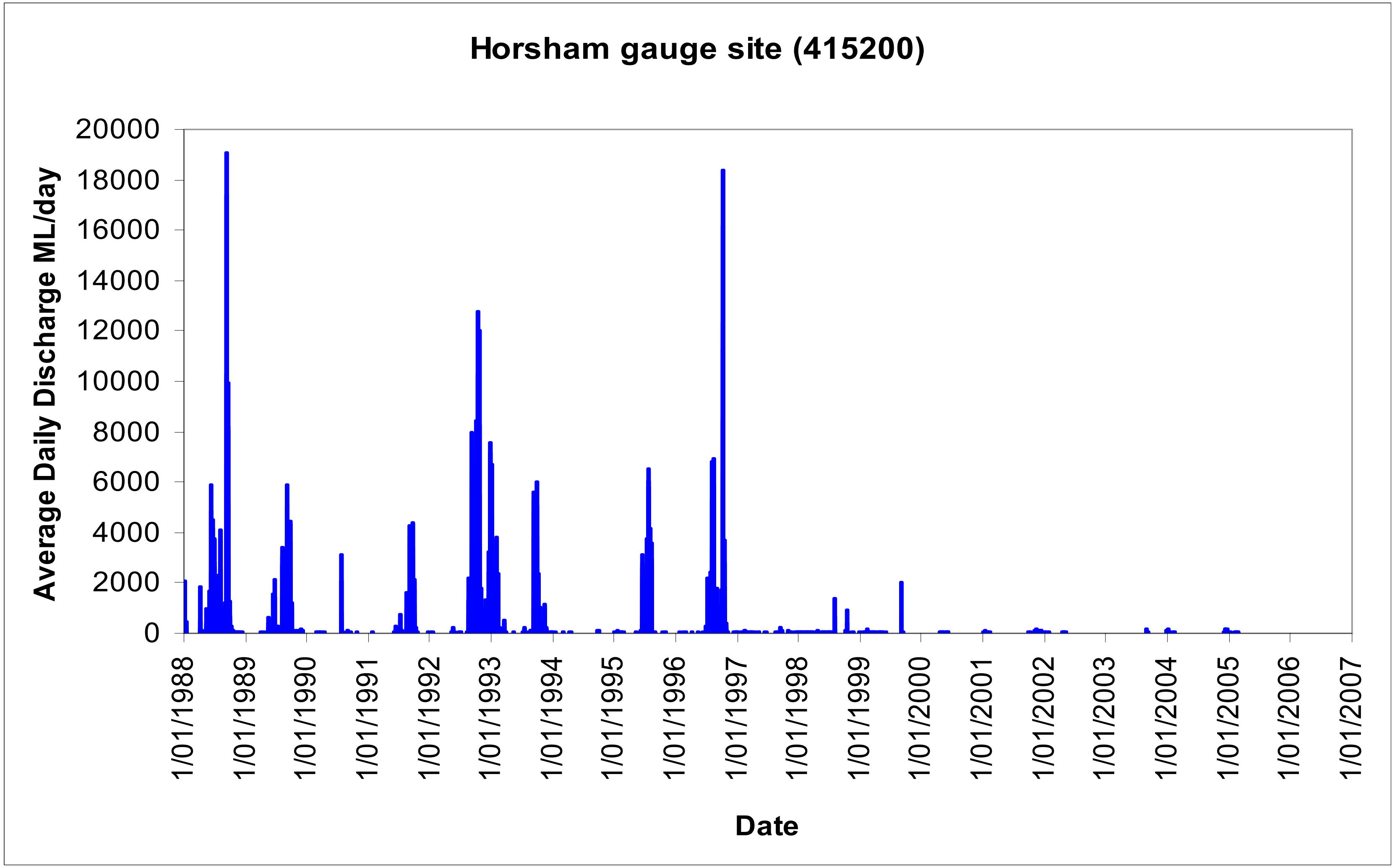

Figure 1: Average daily discharge (ML/day) at Horsham gauge from 01/01/1988 to 03/01/2007(VWQMN Site 415200)

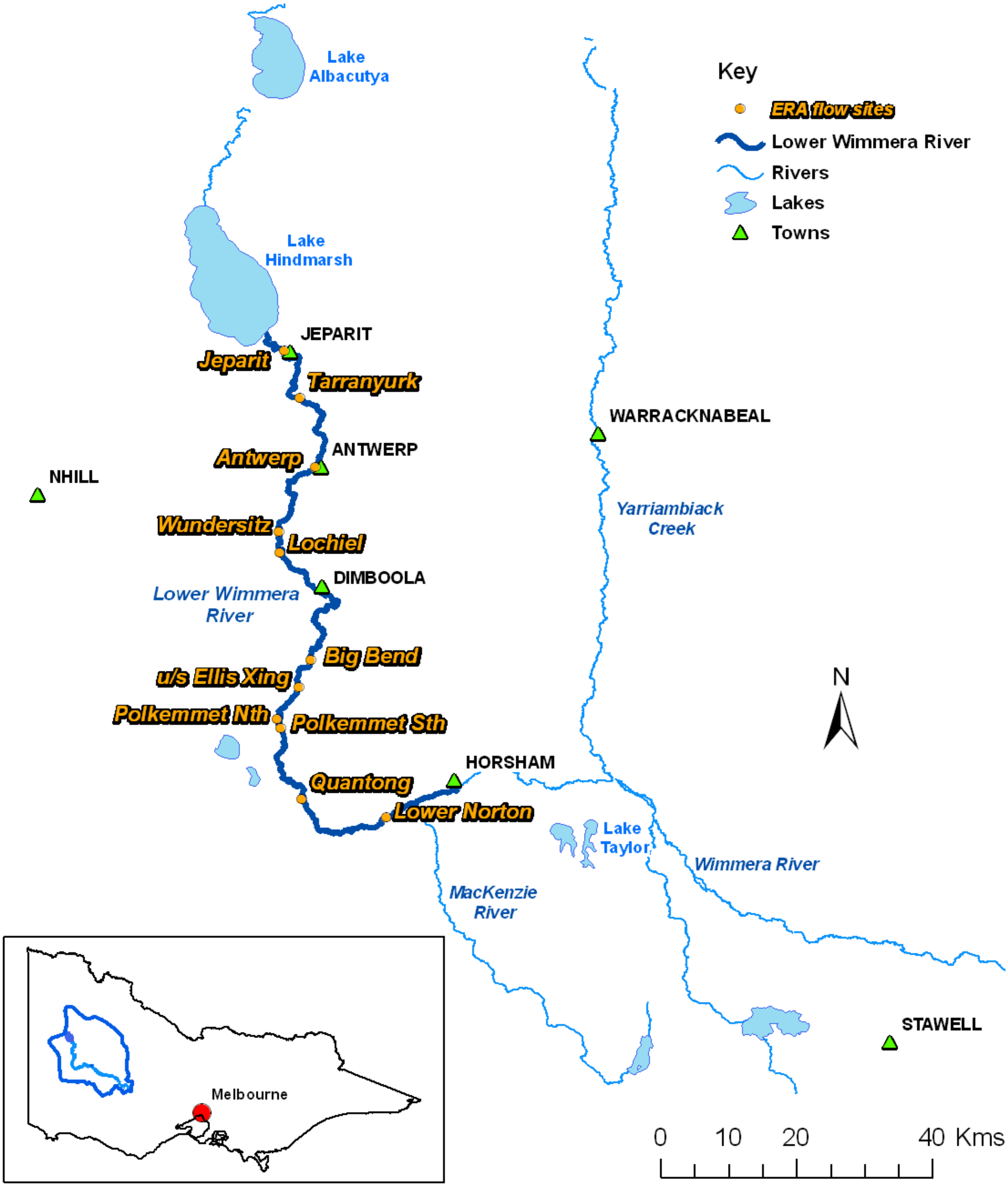

Figure 2: Map of the lower Wimmera River downstream of Horsham and the location of ERA flow sites, with an inset of the Wimmera catchment and the Wimmera River in the context of Victoria.

1.2 The ecological risk assessment (ERA) process

ERA is a formal process for determining the risk posed by one or more threats (stressors, hazards) to the health of ecosystems (USEPA, 2001). It provides an explicit and transparent way to deal with the complexity of assessing and making management decisions for aquatic systems.

The three phases of an ERA are:

- **problem formulation** (Section 2), which involves identifying values and threats, the relationships between these and developing a risk analysis plan
- **risk analysis** (Section 3), which assesses the likelihood that a threat(s) will impact an ecosystem and the effects of such an impact
- **risk characterisation** (Section 4), which is the evaluation and reporting of the problem formulation and risk analysis results, providing the information needed for decision-making and risk management.

The ERA approach systematically organises and evaluates data, information, assumptions and uncertainties to assess risks. It identifies key knowledge gaps and can be used to assess the effectiveness of various management actions in reducing risks.

Figure 3 shows the framework and activities conducted for the lower Wimmera River ERA. The activities directly link with the decision-making processes associated with catchment management. This framework is based on current nationally, and internationally, accepted risk assessment frameworks (Suter, 1993; USEPA, 1998; ANZECC and ARMCANZ, 2000; USEPA, 2001; Hart et al., 2005; Burgman, 2005, USEPA, 2008).

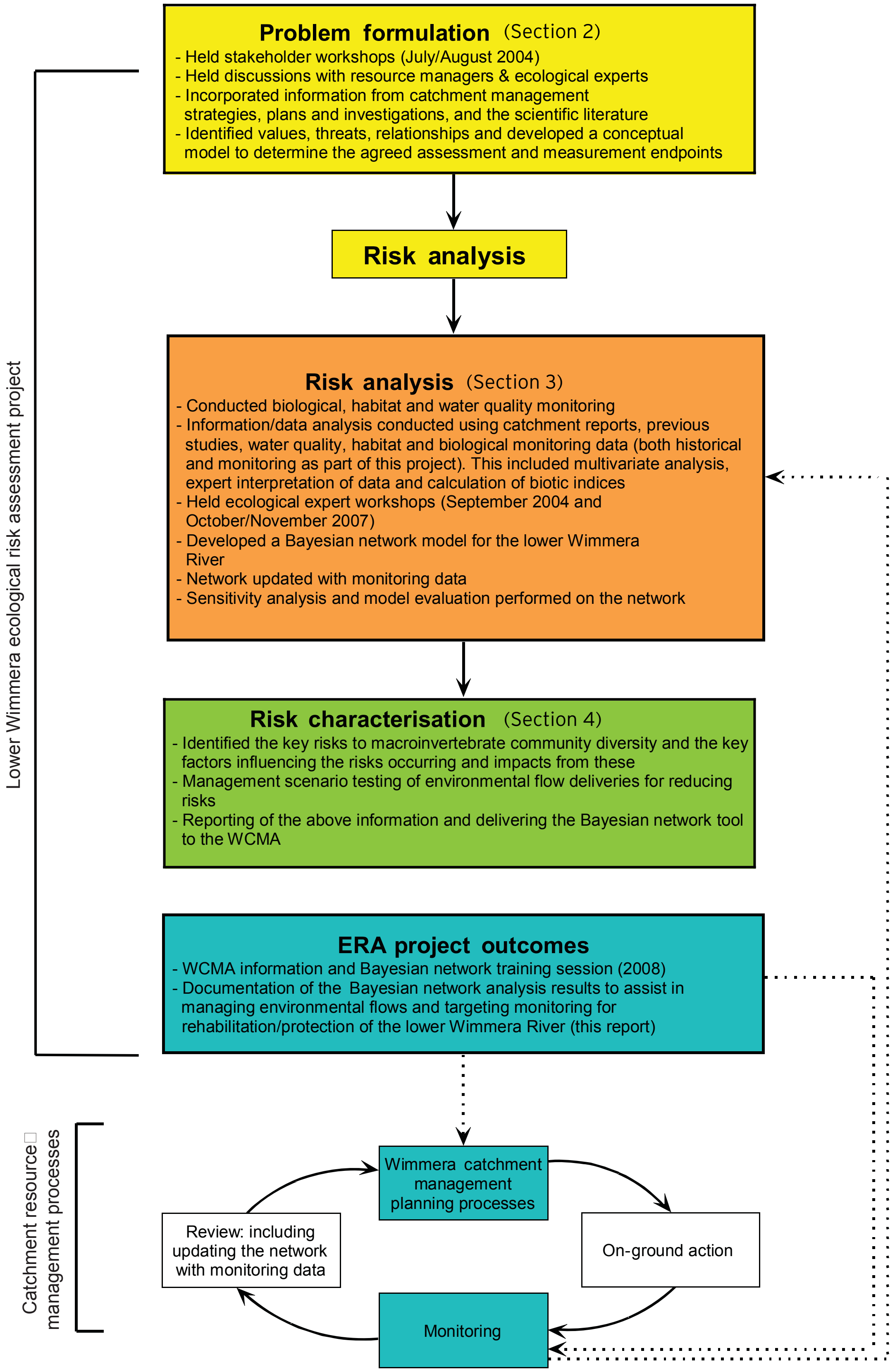

Figure 3: Summary of the lower Wimmera ecological risk assessment project, and linkage to Wimmera catchment management processes

2. PROBLEM FORMULATION

Problem formulation determines the focus and scope of the risk assessment and the type of management information required. In the ERA this involved:

- identification and engagement of relevant stakeholders and experts
- collation and integration of available information and data from previous studies and catchment reports
- development of the scope of the ERA
- identification of the priority ecological values to protect, maintain and/or rehabilitate with environmental flow allocations
- selection of the key values on which to conduct the risk assessment
- identification of the main threats (hazards, stressors) to these key values
- development of a conceptual model of the relationships between values and threats
- selection of assessment and measurement end points for the key values;
- identification of catchment management information needs
- development of a risk analysis plan.

During this phase, stakeholder and ecological expert workshops were held, along with ongoing discussions with WCMA staff and ecological experts, and an extensive review of catchment and scientific reports and studies. This process was interactive and iterative as more information became available. The participants in the stakeholder workshops are given in Appendix A.

2.1 Scope

Stakeholders defined the spatial scope of the ERA as the Wimmera River downstream of Horsham (see Figure 2). This is the area of the river that is influenced by environmental flows released from Taylors Lake and the MacKenzie River. The temporal scope of the ERA was identified as drought and non-drought conditions.

2.2 Identification of ecological values

During the stakeholder workshops, a range of ecological values were identified for protection, maintenance or rehabilitation with environmental flow allocations. A full list of these values is presented in Appendix B. They were largely based around values previously identified in the *Wimmera Regional Catchment Strategy* and the *Stressed Rivers Report* (WCMA, 2003; SKM, 2002).

Following initial discussions, stakeholders determined the key values that formed the basis of the risk assessment. These were biodiversity and good water quality for biota.

These values were chosen by stakeholders to encompass the range of values listed in Appendix B.

2.3 Identification of threats to ecological values

Stakeholders discussed the main threats to biodiversity and good water quality. A list of these threats is presented in Appendix C. The factors that influence the likelihood of the risks occurring were also considered. For example, high salinity is a threat to biodiversity. The factors that may influence an increase in salinity include a reduction in flow volume and the presence of saline groundwater intrusion.

Stakeholders identified the priority threats to biodiversity as:

- low flows
- reduced habitat availability
- deteriorating water quality, in particular increasing salinity levels and decreased dissolved oxygen.

Stakeholder discussions regarding the threats to ecological values, the relationships between them, and potential management scenarios, facilitated the construction of a conceptual model.

2.4 Conceptual model

A conceptual model is a visual representation of the predicted relationships between values, threats and the factors influencing the likelihood of risk(s) occurring.

Conceptual models are useful in representing the current knowledge of the ecosystem or parts of the system (Hart et al., 2005). They are particularly useful when there are multiple threats that need to be considered and they can be used to help develop hypotheses for potential cause-effect relationships (Ferenc and Foran, 2000).

The conceptual model built by the stakeholders is given in Figure 4. It represents the workshop participants' understanding of the key threats to biodiversity and good water quality for biota in the lower Wimmera River, and the relationships between these parameters. It also incorporates factors that can influence the likelihood of risk to the ecosystem, e.g. reduced flow volume and the allocation of environmental flows.

It should be noted that good water quality for biota is not represented in the conceptual model by a single parameter. Instead, it is separated into the key water quality parameters that are deemed important for maintaining biodiversity in the Wimmera River. For example, water quality with suitable salinity and dissolved oxygen levels is a requisite for a healthy ecosystem. Importantly, water quality can be considered primarily as a value to be protected (i.e. good water quality for biota) as well as a threat (e.g. toxic salinity levels).

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2.5 Assessment and measurement end points

End points are selected to measure/monitor the key values being assessed. Assessment end points are explicit expressions of the values to be protected. Measurement end points are a definable measure of assessment end points. End points differ from management goals by their neutrality and specificity. That is, they do not represent a desired state or goal; they are defined by specific measurable components, and provide a means of measuring stress-response relationships (Suter, 1993; USEPA, 1998).

The end point for this risk assessment needed to be sensitive to the effects of environmental flow delivery. In addition, it had to be predictable and measurable, unambiguously defined, responsive to the priority threats and biologically relevant to the values identified.

The assessment end point selected by the stakeholders to assess biodiversity and good water quality for biota was **macroinvertebrate community diversity** (macroinvertebrates include aquatic animals such as insects, snails, worms and shrimps). The assessment end point was selected because:

- macroinvertebrates are an important component of river fauna
- there is in-depth knowledge of how macroinvertebrate community diversity relates to key aspects of river health (e.g. water quality)
- there are standard methods for measuring community diversity such as the biological indices Australian River Assessment System (AUSRIVAS), Stream Invertebrate Grade Number Average Level (SIGNAL) and Number of Families
- macroinvertebrates are relatively easy to sample and they are part of current and future river health monitoring in the Wimmera catchment.

The measurement end point for assessing macroinvertebrate community diversity was determined by macroinvertebrate experts at EPA Victoria. They chose the macroinvertebrate biotic index (MBI) as the measurement end point, as it is a measure that aggregates all the standard macroinvertebrate indices into one score (EPA Victoria, unpublished). The MBI is calculated in the same manner as the Aquatic Life score in the ISC (Ladson and White, 1999); however it incorporates all available macroinvertebrate indices (AUSRIVAS /Key families, SIGNAL, Number of Families and Ephemeroptera Plecoptera and Trichoptera [EPT]). The EPT index was not used in the MBI score since these fauna are not common to the Murray and Western Plains areas of Victoria.

The aggregated MBI score is a single value between 0 and 10. MBI scores are translated using categories for ease of interpretation. The categories are: 0-2 very poor; 3-4 poor; 5-6 moderate; 7-8 good; and 9-10 very good.

In addition to the macroinvertebrate community diversity end point, the stakeholders identified sustainable populations of freshwater catfish (listed in the *Flora and Fauna Guarantee Act 1988*) as another end point. This was measured using the abundance of breeding populations and recruitment of juvenile catfish. The University of Melbourne completed the risk analysis for this end point and the analysis is not addressed in this report. For more information please refer to the published report by Chee et al., (2005).

2.6 Risk analysis plan

The risk analysis plan summarises the problem formulation phase and details the design for the risk analysis phase. The plan was developed from the conceptual model and information and data collected during problem formulation. The aims of the risk analysis were to:

- quantitatively assess the level of risk posed to the two key ecological values (as measured by the end point)
- provide a better understanding of the factors influencing the consequences and likelihood of risks occurring
- assess the effectiveness of environmental flow management scenarios for mitigating these risks.

The risk analysis plan involved three stages. These were:

- construction of a targeted sampling program to aid the development of a Bayesian network (section 2.6.1)
- data analysis: interpretation of data, use of a range of multivariate statistics, calculation of biotic indices and incorporation of other information and expert opinion (section 2.6.2)
- donstruction of a Bayesian network (section 2.6.3).

2.6.1 Construction of a targeted sampling program to aid the development of a Bayesian network

The sampling program is given in Table 1. Monitoring of water quality during the 2004-05 environmental flow releases was conducted at 20 sites along the lower Wimmera River by the WCMA. Some of the 20 sites corresponded with Victorian Water Quality Monitoring Network (VWQMN) gauging sites, which are a source of historical flow and water quality data. A sub-set of 11 sites were selected for biological monitoring (macroinvertebrates, water quality and habitat data) by the EPA. These sites were chosen to cover the variety of habitats, depths, saline stratification, salinities and area of the lower Wimmera River. Three of the 11 sites also corresponded with VWQMN gauging sites.

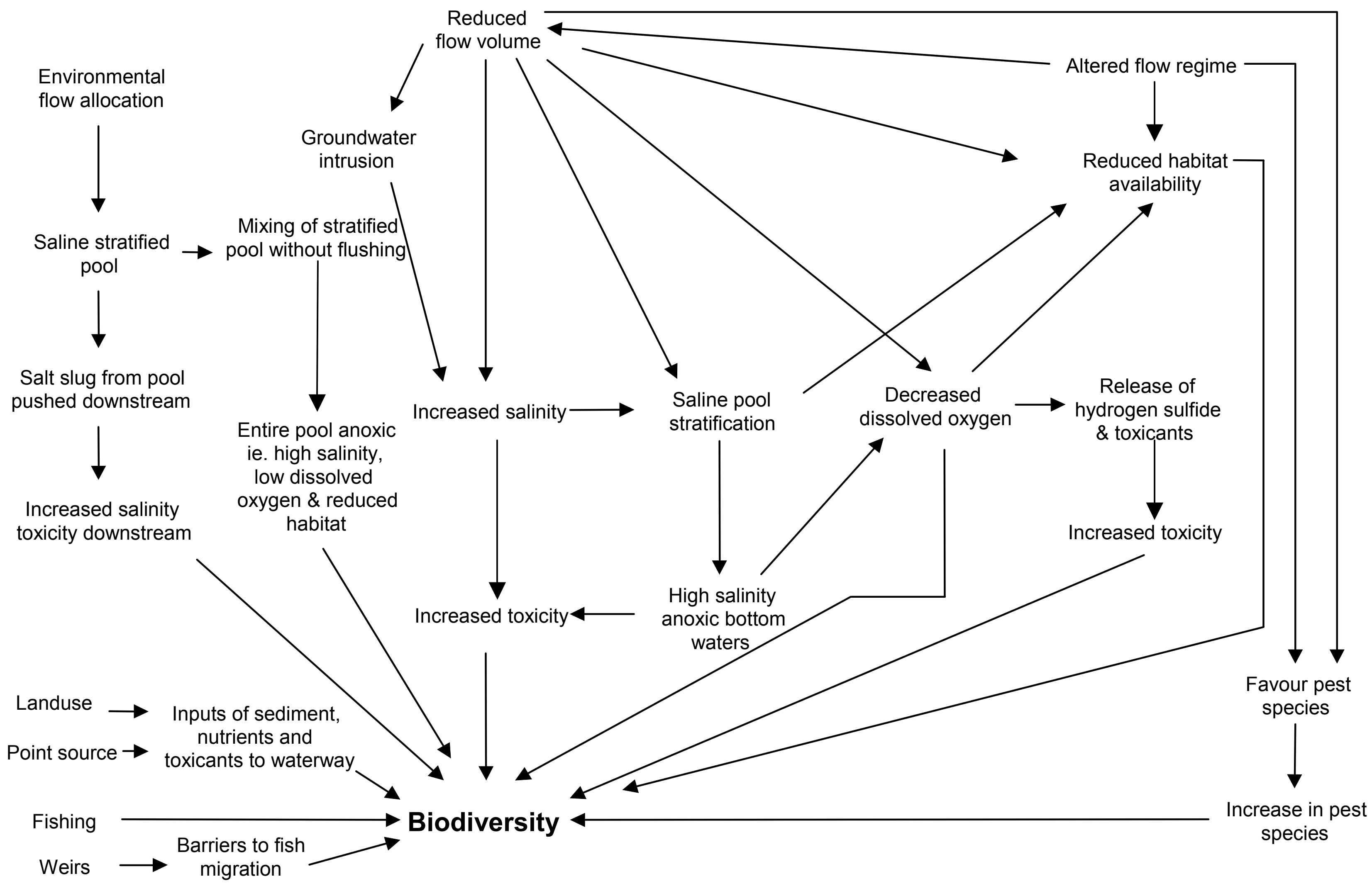

Figure 4: Stakeholders' understanding of the key hazard/threats to 'biodiversity' and 'good water quality for biota' in the lower Wimmera River and the relationships between these

These sites were monitored in spring and autumn from November 2004 to November 2007. This provided data pre and post the 2004-05 environmental flow release, and through an extended period of no flows (2006-07) in the study area. A small environmental flow was released in spring 2007. However, as the volume of the release was inadequate to wet and fill the largely dry river channel, the flow only reached two of the 11 sites, having little impact on most of the lower Wimmera River.

As part of an Australian Research Council linkage project with the University of Sydney, University of Tasmania and Griffith University, a three-dimensional flow model for saline pools in the river was to be developed. Continuous water quality and depth profile sampling was planned for the scheduled spring 2006 environmental flows. However, this delivery was postponed due to water shortages and data could not be collected. Sampling will occur when the next environmental flow is delivered and this will provide information that will complement the Bayesian network.

2.6.2 Data analysis

All existing flow, water quality and macroinvertebrate data, and the data collected for this ERA, were analysed using a variety of methods.

These were:

- multivariate analyses, including MDS, SIMPER analysis and BEST analysis, which was used to investigate flow, water quality, habitat and macroinvertebrate community diversity relationships
- graphing and expert interpretation of flow and water quality relationships
- expert interpretation of macrophyte data;
- AUSRIVAS, SIGNAL, number of families and MBI calculations
- incorporation of relevant scientific literature and expert opinion gained from discussions and workshops.

2.6.3 Construction of a Bayesian network

A Bayesian network was developed based on the data analyses, information from previous studies in the Wimmera catchment, scientific literature and expert knowledge. This is discussed in Section 3.1.

Table 1: EPA Victoria and Wimmera CMA sampling program for the macroinvertebrate Bayesian Network and Wimmera environmental flow releases.

Sample type	Sampling regime	Number of sites	Source
Macroinvertebrates (rapid bioassessment)	2004–2007: biannual in spring/autumn	11	EPA biological monitoring program
Habitat field data (rapid bioassessment)	2004–2007: biannual in spring/autumn	11	EPA biological monitoring program
Water quality (electrical conductivity, dissolved oxygen, temperature, pH, phosphorus, nitrogen, turbidity)	2004–2007: biannual in spring/autumn	11	EPA biological monitoring program
Water quality depth profiles (electrical conductivity, dissolved oxygen, temperature, pH)	2005: three sampling runs – 1) pre-environmental flow release, 2) during environmental flow release, 3) end of environmental flow release	20	WCMA contractors
Continuous water quality depth profiles (electrical conductivity, temperature)	Continuous water quality profile measurements taken over a 7–14 day period during the initial environmental flow release. This will be undertaken during the next environmental flow releases to the Wimmera.	2	ARC linkage project

3. RISK ANALYSIS

Risk analysis is the determination of the probability and magnitude of an adverse effect with specific consequences occurring to the values within a certain time frame (Suter, 1993, Hart et al., 2005). The risk analysis phase for this ERA involved the development of a Bayesian network.

Bayesian networks are a useful tool for assessing cause and effect relationships in complex systems. They are built using measured data where available, and expert understanding of the likely relationships between factors where data is not available.

These networks form a graphical model that represents the variables in a system, which are linked by a set of arrows that represent the direct dependencies between variables (Korb and Nicholson, 2004). A set of probabilities exists for each variable, specifying the belief that a variable will be in a particular state given the states of those variables that affect it directly (Cain, 2001). Appendix D provides further discussion on Bayesian networks and Bayes Theorem.

Bayesian networks can:

- improve understanding of how complex natural systems work
- use and combine all types of data and expert knowledge
- provide predictions of the risk posed to an ecosystem from a number of different threats all operating at the same time and in different ways
- assess which factors have the main influence on the health of an ecosystem
- address uncertainty explicitly
- make predictions about the likely outcomes in improving the health of an ecosystem under different management scenarios
- be easily updated as new data and information becomes available, to provide more certainty and understanding.

3.1 Development of the Bayesian network

The five main tasks in developing a Bayesian network model[1] are:

- development of the structure;
- definition of the variables and their states
- population of the conditional probability tables (CPTs)
- sensitivity analysis
- evaluation of model predictions.

These steps are outlined below.

1 The Bayesian network software used was Netica (Norsys Software Corp. 1997; 1997-2008).

3.1.1 Development of the structure

Development of the graphical structure involved the formal and systematic identification of the key variables influencing the end point and the interactions (linkages) between them. The conceptual model developed during problem formulation provided a starting point for the network structure.

The structure of the Lower Wimmera Bayesian network was finalised through:

- focus on the key values and threats identified in the problem formulation workshops
- results from data analyses
- consultation with ecological experts and the WCMA.

Multivariate analysis showed salinity, dissolved oxygen, macrophytes and flow as the key variables affecting macroinvertebrate community diversity. These findings were supported by previous studies (Anderson and Morison, 1989; EPA, 1993 and 1995; WCMA, 2006) and expert opinion.

Other factors originally identified as potential key influences were shown to have no significant impact on the end point. For example, nutrient levels in the lower Wimmera River, particularly total phosphorus, were historically a major issue given the discharge from the Horsham Sewerage Authority Treatment Plant (EPA, 1993). However, discharges ceased in 1988 significantly reducing nutrient inputs. Multivariate analyses showed that current nutrient levels have a non-significant impact on the end point and, as such, nutrients were omitted as a variable from the final structure.

The final structure of the network is given in Figure 5. The key cause-effect relationships are discussed in Appendix E. The different categories within the network are colour coded and are as follows:

- **Flow regime** – The blue nodes represent the flow variables. 'Freshes per year' (small peak flow events), 'high flow' (bank-full flows) and 'baseflow' are the variables that can be manipulated to test different flow management options. 'Previous river level' provides an indication of the amount of water within the channel, reflecting drought and non-drought conditions.
- **Habitat availability** – The green nodes represent the habitat variables. The important habitats for macroinvertebrates in the lower Wimmera River are 'macrophytes' and 'leaf packs and woody debris'. 'Water for habitat' is also essential, as there needs to be enough water within the channel to cover a range of habitats and provide for the growth of macrophytes.
- **Water quality** – The yellow nodes represent the water quality variables most important in the river. The multivariate data analysis and previous studies showed salinity to be the key water quality variable

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influencing the end point and 'dissolved oxygen' to be the second largest water quality influence. 'Salinity surface' is the variable representing the salinity levels predicted in the river in response to flow management scenarios set in the model. The salinity levels are also influenced by the presence of saline groundwater intrusions and the surface salinity levels prior to delivery of flow. These influences are represented in the network by the variables 'presence of groundwater intrusion' and 'previous salinity surface'.

- **End point** – The red node denotes the 'macroinvertebrate community diversity' end point (Section 2.5).

The flow components of this model can be manipulated to investigate the effects of different environmental flow release options on water quality, available habitat and macroinvertebrate community diversity. This identifies the ideal delivery option for different allocation volumes under drought and non-drought conditions.

3.1.2 Definition of the variables and their states

The definitions and measures of variables and their states were determined using the relevant literature, data analysis, and consultation with ecological experts and the WCMA (see Table 2). The finalised network and variable states is given in Figure 6. The network also contains the integrative variables: 'flow regime for water quality improvement', 'water for habitat' and 'quality instream habitat'. These variables are not directly observable or measurable. Their purpose is to reduce the number of linkages to a particular variable, which simplifies the structure and complexity of CPTs for expert elicitation.

The states of the integrative variables were more difficult to define, as they are qualitative expressions of condition, such as a good or poor flow regime for water quality improvement. Discussion around the ecological meaning of the states of these variables was crucial, to align expert's understanding before assigning probabilities to the CPTs.

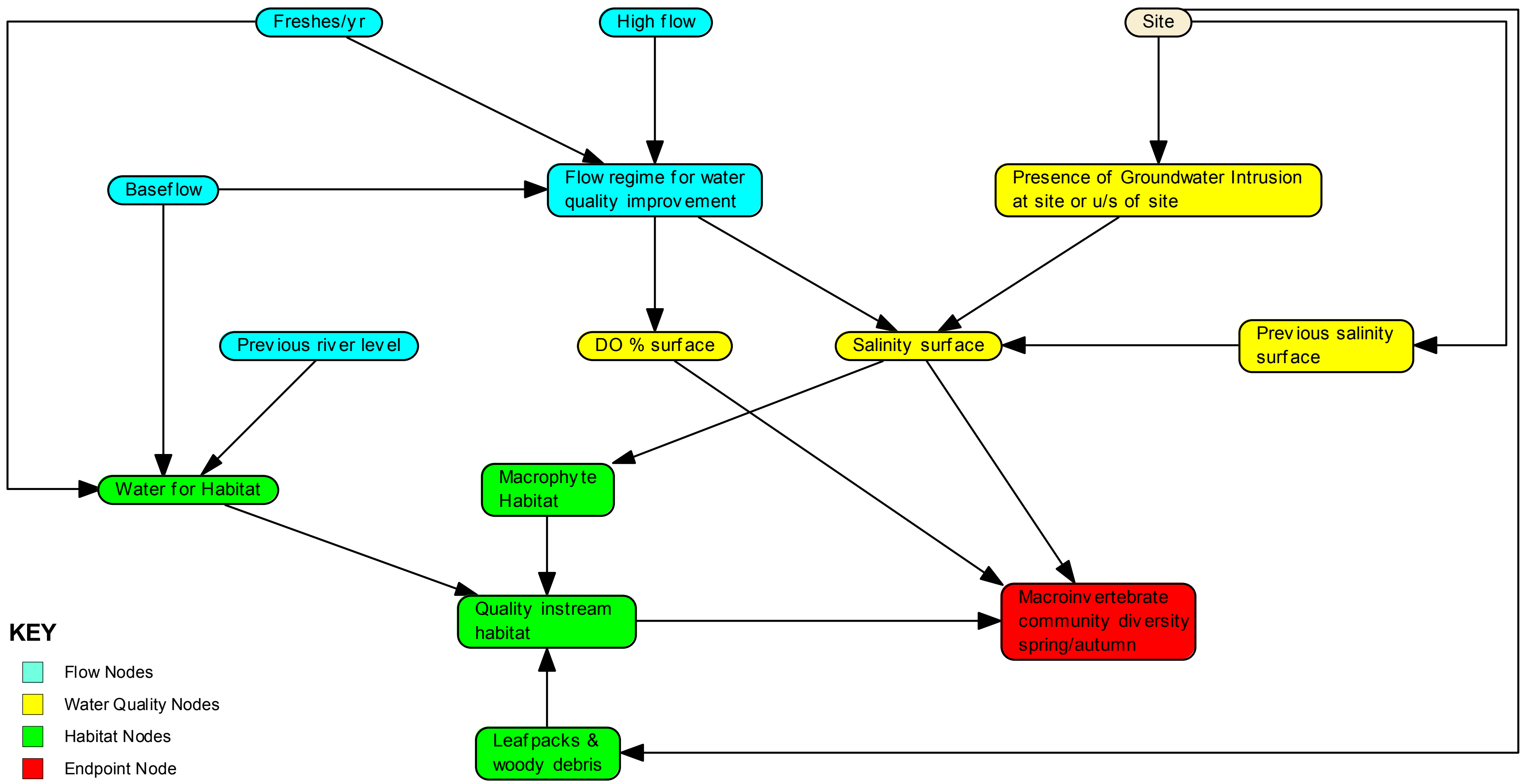

Figure 5: Final Bayesian network structure

Table 2: Definitions of variables, their states and the data used for this process

Variable (nodes)	Parent nodes (variables)	States	Method for defining variables, states and calculating prior probabilities in CPT	Data Source
Site	None	Lower Norton Quantong Polkemmet South Polkemmet North Upstream Ellis Crossing Big Bend Lochiel Wundersitz Antwerp Tarranyurk Jeparit	Sites assessed by the model were those that were being sampled for the ERA. They were chosen to represent the varying water quality, habitat and channel characteristics of the lower Wimmera River.	
Baseflow	None	Low: <100 days Moderate: 100-200days High: ≥200 days	Base flow is defined as release from Taylors Lake and additional natural flows recorded at Horsham gauge 415200. States were defined using Horsham gauge data, based on baseflow values for Dec–May and June–Nov, which were formed using information from the Stressed Rivers Report. Dec–May baseflow = >5ML/day and June–Nov baseflow =>35 ML/day.	WCMA environmental flow release rate data. Daily discharge data from Horsham gauge 415200. *Stressed Rivers Report*, SKM (2002)
Freshes/year	None	Low: 0 Moderate: 1–2 High: ≥3	Freshes are defined as the volume recorded at Horsham gauge 415200. A fresh must be 150% of the baseflow, which is the average daily flow over either the Dec–May or June–Nov period, and must be at least 40 ML/day for the defined period. A fresh must last for at least 7 to 14 days. If the fresh lasts for 30 days, this is recorded as two freshes (volume divided by 14). Values are rounded down to the whole number. This pattern continues up until a three month cut-off (90 days).	WCMA environmental flow release rate data. Daily discharge and EC data from Horsham gauge 415200. *Stressed Rivers Report*, SKM (2002)
High flow	None	Yes: >3000 ML/day for a minimum of two days No: all other times	High flow defined as > 3000ML/day for a minimum of two days released from Taylors Lake (Stressed Rivers Report). This is in addition to other natural flow recorded at Horsham gauge 415200.	WCMA environmental flow release rate data. Daily discharge data from Horsham gauge 415200. *Stressed Rivers Report*, SKM (2002)

Variable (nodes)	Parent nodes (variables)	States	Method for defining variables, states and calculating prior probabilities in CPT	Data Source
Previous river level	None	Measured as gauge height Low: <0.23 metres Moderate: 0.23–0.55 metres High: ≥0.55 metres	States were defined by the WCMA based on the discharge rating table data at Horsham gauge 415200. Low, moderate and high states are represented as gauge height levels in metres at Horsham.	Discharge rating tables at the Horsham gauge 415200.
Flow regime for water quality improvement	Baseflow Freshes/year High flow	Good Poor	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 easier to populate CPTs. States were determined by expert opinion (EPA Victoria) given the states of baseflow, freshes and high flow that provide a good or poor flow regime for water quality improvement. The CPT was completed using expert elicitation based on their previous knowledge and results of the data analysis	Expert opinion (Ecological expert panel) Daily discharge and EC data from Horsham gauge 415200.
Presence of groundwater intrusion at site	Site	Yes No	The WCMA advised which sites experience groundwater intrusion and which do not. The CPT was set automatically in the network.	WCMA
Salinity surface	Previous salinity surface Flow regime for water quality improvement Presence of groundwater intrusion at site	Low: <3000 µS/cm Moderate: 3000–10,000 µS/cm High: 10,001–40,000 µS/cm Very High: ≥40,000 µS/cm	Continuous variable. This is a spot surface measurement taken in µS/cm at the time of macroinvertebrate sampling. States were set at ecologically significant levels for macroinvertebrates in the lower Wimmera River, eg healthy, moderate effects, lethal/large effects. The states were set around decreases in community diversity drawing on results from various multivariate statistics and graphical representations of the macroinvertebrate/salinity relationships. The CPT was completed using expert elicitation.	WCMA contractor water quality monitoring VWQMN gauging stations: 415247 (Tarranyurk) 415246 (Lochiel) 415256 (u/s Dimboola) 415200 (d/s Horsham) EPA Rapid Bio Assessment (RBA) monitoring water quality data
Previous salinity surface	Site	Low: <3000 µS/cm Moderate: 3000–10,000 µS/cm High: 10,001–40,000 µS/cm Very High: ≥40,000 µS/cm	Continuous variable. Previous surface salinity (µS/cm) was defined as the three month average one year prior to the sampling date. For example, if a sample was taken on 4/4/2006, the previous surface salinity would be the 3 month average of January, February and March 2005. States were set using the same method for salinity surface.	WCMA contractor water quality monitoring VWQMN gauging stations: 415247 (Tarranyurk) 415247 (Lochiel) 415256 (u/s Dimboola) 415200 (d/s Horsham) EPA RBA monitoring water quality data

Variable (nodes)	Parent nodes (variables)	States	Method for defining variables, states and calculating prior probabilities in CPT	Data Source
DO% surface	Flow regime for water quality maintenance	Poor: <30 or >150% saturation Sufficient: 30–150% saturation	States were determined by expert opinion (EPA Victoria). The CPT was completed using historical and current water quality data.	Expert opinion (Ecological expert panel) EPA RBA water quality data WCMA water quality monitoring
Water for Habitat	Previous river level Freshes/year Baseflow	Poor Good	Integrative variable. States determined by expert opinion (EPA Victoria) given the states of baseflow, freshes and previous river level that provide a good or poor amount of water for habitat. The CPT was completed using expert elicitation based on their previous knowledge and results of the data analysis	Expert opinion (Ecological expert panel) Stressed Rivers Report
Macrophyte Habitat	Salinity surface	Poor: ≤2 macrophyte sub-structures Good: ≥3 macrophyte sub-structures	States were defined using EPA RBA monitoring data. The data was split by EC (poor >10000 and good <10000). States were defined using the majority number of macrophyte substructures (e.g., emergent reed-like, submerged feather-like, etc) occurring in these 2 groups. This data was also used to populate the CPTs.	EPA RBA monitoring data
Leaf packs and woody debris	Site	Good: >5% cover of large woody debris (LWD) and/or coarse particulate organic matter (CPOM) in the reach Poor: <5% cover of LWD and/or CPOM in the reach	States were defined using expert opinion.	EPA RBA monitoring data
Quality physical instream habitat	Macrophyte habitat Leaf packs and woody debris Flow for habitat	Poor Moderate Good	Integrative variable. States determined by expert opinion (EPA Victoria) given the states of macrophyte habitat, leaf packs and woody debris and flow for habitat that provide good, moderate and poor physical instream habitat. The CPT was completed using expert elicitation based on their previous knowledge and results of the data analysis	Expert opinion (Ecological expert panel) EPA RBA monitoring data
Macroinvertebrate community diversity	Salinity surface DO% surface Quality physical habitat	Very good Good Moderate Poor Very poor	States were defined using MBI score definitions. The CPT was completed using expert elicitation.	MBI – Aquatic life score information

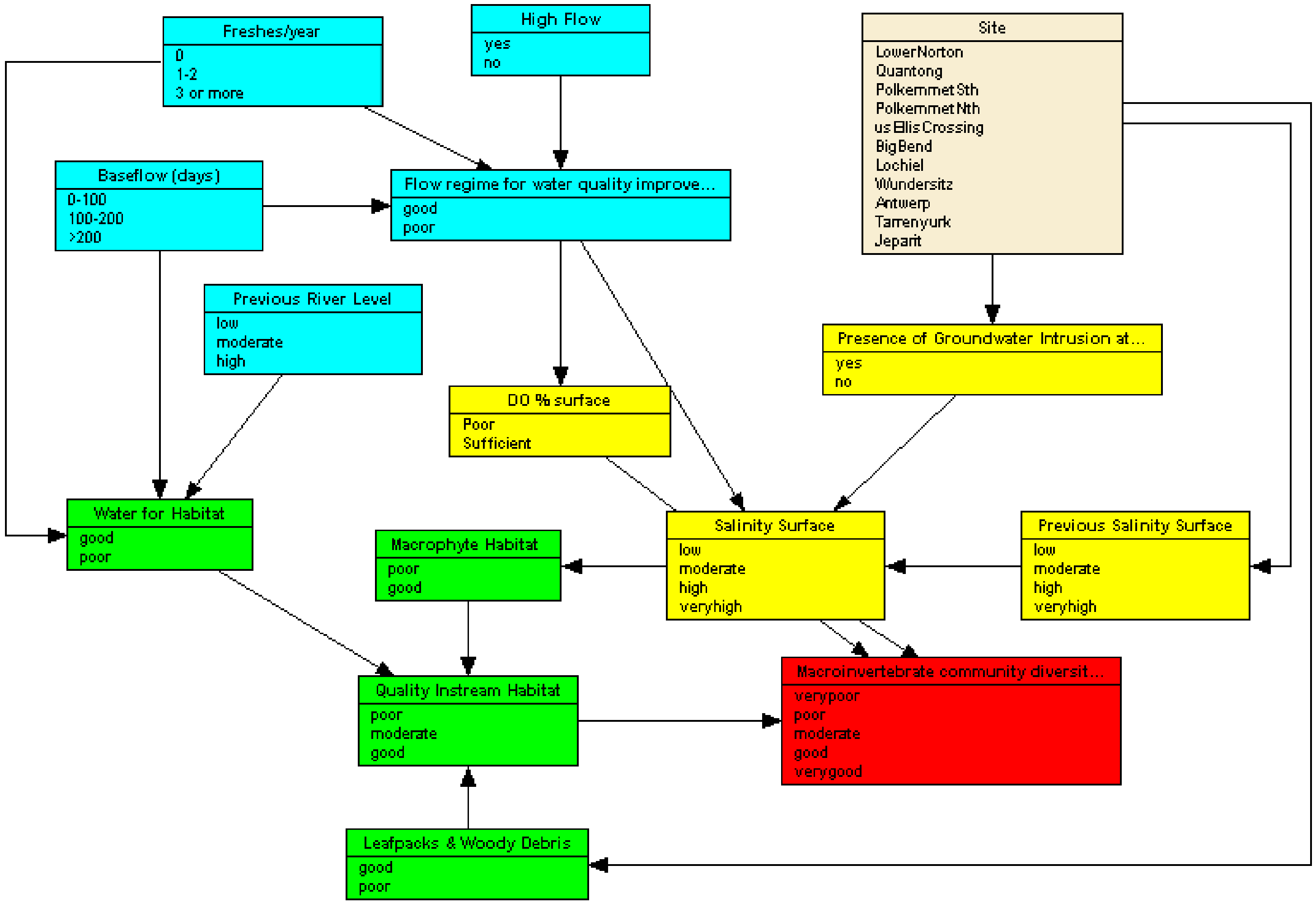

Figure 6: Finalised Bayesian network for the lower Wimmera River, showing variable states

3.1.3 Population of the conditional probability tables (CPTs)

The relationships between variables are quantified in CPTs. Parent variables lead into child variables (see Figure 7), and the outcomes of child variables are conditional on the states of the parent variables. These relationships are defined by assigning probabilities for each possible scenario in the corresponding CPT. This can be achieved by using data, outputs from other models, results from other analyses and/or expert opinion. Table 3 provides an example of the CPT for the 'quality instream habitat' variable relationships in Figure 7. This defines the probability of habitat condition being 'poor' 'moderate' or 'good' given the different potential scenarios for 'macrophyte habitat', 'leaf packs and woody debris' and 'water for habitat'.

The network CPTs were initially populated using expert opinion. The experts determined probabilities for all scenarios based on information from the ERA, data analysis and previous studies conducted by these experts and others. Expert elicitation was conducted in three workshops held in September 2004 and October and November 2008. A list of the experts in attendance is given in Appendix F.

Each expert individually completed the probabilities for each CPT. These responses were averaged and the average was used to populate the CPTs in the network (see Appendix G).

The probabilities in the CPTs were then updated using available data. The majority of update data (75%) was collected post 2004 as part of the ERA under drier climate conditions. The remaining 25% was historical data collected during 1993 to 2004 as part of the statewide biological monitoring program, providing information under wetter conditions.

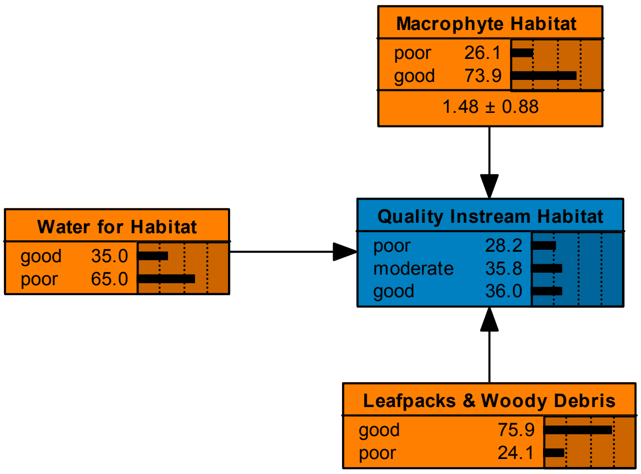

Figure 7: An example of parent variables (orange) linked to a child variable (blue)

Table 3: The CPT for the variable 'quality instream habitat'

Macrophyte habitat	Leaf packs & woody debris	Water for habitat	Habitat condition: Poor	Habitat condition: Moderate	Habitat condition: Good
Poor	Good	Good	21.25	32.5	46.25
Poor	Good	Poor	88.75	6.25	5
Poor	Poor	Good	40	30	30
Poor	Poor	Poor	98.75	1.249	0.001
Good	Good	Good	0.001	1.249	98.75
Good	Good	Poor	47.5	40	12.5
Good	Poor	Good	0.001	11.249	88.75
Good	Poor	Poor	57.5	32.5	10

3.2 Sensitivity analysis

Sensitivity analysis was performed to determine the variables that have the most influence on the condition of macroinvertebrate community diversity and surface salinity, i.e., the variables of greatest management interest. In this case, the sensitivity measure for macroinvertebrate community diversity (discrete variable) is mutual information or entropy reduction, and for surface salinity (continuous variable) the measure is variance reduction (variance of beliefs). For more information on sensitivity measures, refer to Pearl (1988).

The results from this analysis assist in prioritising the:

- threats to macroinvertebrate community diversity
- best actions to reduce salinity
- important knowledge gaps to be filled by further research and monitoring.

The results from the sensitivity analyses conducted for macroinvertebrate community diversity and surface salinity are presented in Tables 4 and 5, respectively. In these tables, only the network variables that are directly measurable are included. The sensitivity values presented indicate the relative level of influence each variable has over the variables of management interest. The higher the sensitivity value, the greater the relative influence is. Interpretations need to consider that the closer a variable is in the network structure to the subject of the sensitivity analysis, the more likely the analysis will show it as having a greater influence (Cain 2001).

Table 4 indicates that salinity has the greatest influence on macroinvertebrate community diversity. The next most influential variable is macrophyte habitat, followed by the presence of saline groundwater intrusion and low levels of dissolved oxygen. The component of environmental flow deliveries showing the greatest influence on macroinvertebrate community diversity is the delivery of freshes. The flow variables are structurally furthest from the end point, and therefore have relatively lower mutual information values. However, it is the delivery of freshes as part of environmental flows that has the most influence on the salinity levels, as shown in Table 5.

These findings are consistent with the literature. EPA (1993) indicated that macroinvertebrate communities were driven by flow and salinity levels. More specifically, freshes were found to be the key component to restoring water quality (Anderson and Morison, 1989, EPA, 1993, and SKM, 2002). High structural diversity of macrophytes is also essential for providing a variety of habitats for a wide range of macroinvertebrates.

The results indicate that freshes are key to management of salinity and improving macroinvertebrate community diversity. A range of flow management scenarios are analysed in Section 4.2.

The sensitivity analysis results also highlight knowledge gaps. While information exists about the positive effects of environmental flow delivery on water quality (e.g. freshes to decrease salinity levels and increase dissolved oxygen levels), more information and data on the negative effects (e.g. mixing in stratified pools or salt slugs downstream of stratified pools at flow delivery) would also be beneficial. This knowledge gap will be addressed by the University of Sydney in the saline pool flow model which will be completed when more data is collected during the next environmental flow release.

Table 4: Sensitivity analysis of macroinvertebrate community diversity in order of most to least influential variables

Variable	Mutual info – entropy reduction
Salinity surface	0.44346
Previous salinity surface	0.16858
Macrophyte habitat	0.14719
Presence of groundwater intrusion	0.0772
DO% surface	0.07240
Freshes/year	0.05902
Leak packs and woody debris	0.01368
Previous river level	0.0094
Baseflow	0.0033
High flow	0.00025

Table 5: Sensitivity analysis of surface salinity in order of most to least influential variables

Variable	Variance of beliefs
Previous salinity surface	0.0724
Presence of groundwater intrusion	0.06211
Freshes/year	0.0042
Baseflow	0.00051
High flow	0.0000391
Previous river level	0

3.3 Evaluation of the Bayesian network

Evaluation of the Bayesian network assesses the predictive accuracy of the network. It compares the predicted states of network variables with actual sampling data, calculating the frequency with which the network provides correct predictions.

Evaluation requires complete datasets (cases) containing data that was not used to update the CPTs. Complete cases in this instance require a measurement for each variable in the network except the integrative variables. Twenty per cent (14 cases) of the complete cases were used for model evaluation (See Appendix I), with most of this data being from drier periods. The other 80 per cent of complete cases were used in the prior CPT update. Fourteen cases is a small sample size and more data from a range of flow scenarios and prior conditions is required for model validation.

The Netica[1] function, test with cases, was used to evaluate the accuracy of network predictions for:

- macroinvertebrate community diversity
- salinity surface
- DO per cent surface
- macrophyte habitat.

The predictive error rate from this analysis is scored out of 100 per cent. The lower the percentage, the better the network is predicting for a particular variable.

The predictive error rates for the above variables are as follows:

- macroinvertebrate community diversity = 14.29%
- salinity surface = 21.43%
- DO per cent surface = 7.14%
- macrophyte habitat = 21.43%

Based on results from other Bayesian network studies (e.g., Pollino et al., 2006), these findings indicate that the predicted and actual values were generally consistent with each other. This is especially the case for DO per cent surface and macroinvertebrate community diversity, as the error rates for these variables are comparably low. However, these results should be used as a guide only, as more data is required to formally validate the model's predictions.

Further investigation compared the observed and predicted results for the above variables, case by case (see Appendix J). This showed the predictive accuracy of the network to be very high. For 96.5 per cent of the time, the observed state was either the highest or second highest predicted state by the network, with a difference between these of no greater than 10 per cent. When the model is predicting two states closely like this, these predictions provide a good indication of the most likely outcomes of the variable of interest under certain flow scenarios and prior conditions. For example, if the observed state for macroinvertebrate community diversity was good, and the model predicted a 48 per cent chance of moderate and a 42 per cent chance of good, then this still provides a good indication of the potential diversity for that management scenario.

Updating the model with more data, particularly from non-drought times, would increase the robustness and predictive accuracy of the network.

1 The Bayesian network software used was Netica (Norsys Software Corp. 1997; 1997-2008).

4. RISK CHARACTERISATION

Risk characterisation is the evaluation and reporting of the problem formulation and risk analysis results to provide information for decision-making and risk management.

4.1 Key risks

The ERA showed **high salinity** to be the key direct threat to macroinvertebrate community diversity in the Lower Wimmera River. **Low dissolved oxygen** can also potentially have a significant influence on macroinvertebrates under extended low flow conditions.

The key influences on the risk of high salinity concentrations are:

- saline groundwater intrusion
- low flows.

There are several sections of the river downstream of Quantong that have **saline groundwater intrusions**. The Parilla Sands is the main aquifer underlying much of the study area. It is highly saline with salinities exceeding 33,333 μS/cm. The aquifer intersects with the streambed in places, particularly downstream of Polkemmet (see Figure 2), resulting in very high salinities and the formation of stratified saline pools in some places (Anderson and Morison 1989). Where saline groundwater intrusion is present at a site, the salinity can increase substantially depending on the size and depth of the pool. Increased evaporation rates during summer and ongoing **low flows** can reduce pool size and depth, concentrating salts, which increases salinity levels further. In some of these pools, especially those furthest downstream, salinities can equal seawater (58,700 μS/cm) and in some instances have been twice that of seawater (>110,000 μS/cm). The State Environment Protection Policy (Waters of Victoria) (SEPP [WoV]) objective for salinity in the Wimmera is ≤1500 μS/cm.

The data collected as part of this study clearly shows the effect of **saline groundwater intrusion** and **low flows** on salinity concentrations at the 11 study sites. Table 6 illustrates this effect by comparing salinity data after the 2004–05 environmental flows and salinity data after an extended period of low to no flows. The salinities of Lower Norton and Quantong, sites with no groundwater intrusion, only slightly increased in response to the low flow period. All other sites, which have groundwater intrusions, show a significant increase in salinities over this time, with very high salinities being recorded.

Low flows are considered to be the main threat in the lower Wimmera River. It is the reduced flow that is driving poor water quality, in particular high salinity concentrations. Elevated salinity levels have a direct toxic effect on aquatic biota, cause changes in chemical processes, and result in a loss of instream habitat, riparian zones and adjacent floodplains (James, et al., 2003). Low flows also affect the amount of habitat available for macroinvertebrates. Figures 8 to 13 show selected sites after the 2004–05 environmental flows and after an extended period of low to no flows. These figures illustrate the impact of reduced flow on available habitat, quality of macrophyte communities and water quality.

Low dissolved oxygen events may also occur as a result of organic matter build up in dry sections of riverbed, during cease to flow periods. If only small flows return to these dry sections, there is potential for decay of this material that can cause dissolved oxygen levels to drop to very low levels. This is known as a 'black water' event. These events can best be avoided by the initial delivery of larger 'flush' (fresh) flows.

Flow can be used to manage deteriorating water quality. The effects of different flow release options on salinity levels and ultimately the macroinvertebrate community diversity are discussed in Section 4.2 below.

Figure 8: Lower Norton after the 2004/05 environmental flows (Autumn 2005)

Figure 9: Lower Norton (Autumn 2007) after an extended period of low to no flows

Figure 10: Upstream of Ellis Crossing after the 2004/05 environmental flows (Autumn 2005)

Figure 11: Upstream of Ellis Crossing (Autumn 2007) after an extended period of low to no flows

Figure 12: Jeparit after the 2004/05 environmental flows (Autumn 2005)

Figure 13: Jeparit (Autumn 2007) after an extended period of low to no flows

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Table 6: Salinities recorded at ERA sites in the lower Wimmera River, post 2004–05 flows and after a period of extended low flows.

Site	Reach Position	Saline Groundwater Intrusion	Salinity (μS/cm) after the 2004-05 environmental flows	Salinity (μS/cm) after an extended period of low flows (Spring 2007)
Lower Norton	Upstream	No	1500	1577
Quantong	Upstream	No	1548	2996
Polkemmet South	Middle	Yes	1967	18252
Polkemmet North	Middle	Yes	1923	18250
Upstream Ellis Crossing	Middle	Yes	2206	64,417
Big Bend	Middle	Yes	2671	18,016
Lochiel	Middle to downstream	Yes	3492	21,740
Wundersitz	Middle to downstream	Yes	3671	10,843
Antwerp	Middle to downstream	Yes	5670	35,370
Tarranyurk	Furthest Downstream	Yes	29,930	51,697
Jeparit	Furthest Downstream	Yes	34,400	110,374

4.2 Management scenario testing

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

This section provides the results of model predictions for a range of flow management scenarios under drought and non-drought conditions. Four of the 11 sites were chosen for presentation here. These sites are in order of upstream to downstream:

- Lower Norton
- Polkemmet South
- Upstream of Ellis Crossing
- Tarranyurk.

The sites were selected to represent the range of salinities and habitats that occur in the lower Wimmera River. In addition, these sites have the most existing data, which was used to develop and update the model.

4.2.1 Drought conditions

Drought conditions represent periods of extended low or no flows. The Wimmera River is currently experiencing drought conditions.

For each flow management scenario, states for ‘previous river level’ and ‘previous surface salinity’ were entered to reflect drought conditions. As the region is in drought, selection of previous salinity states for each site was based on the site’s current salinity range. The ‘previous river level’ variable was set to ‘low’ for all scenarios, as this is the current river level. ‘High flow’ was set to ‘no’ for each flow management scenario.

The flow management scenarios investigated were:

- none, one to two and three or more freshes with none to 100 days of baseflow
- none, one to two and three or more freshes with 100 to 200 days of baseflow
- none, one to two and three or more freshes with more than 200 days of baseflow.

Overall the results (Appendix K) suggest that delivering 100 to 200 days of baseflow and three or more freshes under drought conditions, has the highest likelihood of producing moderate to very good macroinvertebrate community diversity, throughout the entire lower Wimmera River. (See Table 7).

Releasing none to 100 days of baseflow with one to two freshes will still achieve very good macroinvertebrate community diversity for the upstream reaches of the river (e.g., Lower Norton), but not in the lower reaches which are predicted as being moderate to poor (e.g., Tarranyurk). However, if the amount of water available for environmental flows was small, this management scenario could be employed to

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protect important refuges in the upstream sections of the river.

The possible outcomes if no environmental flows occur under drought conditions were also investigated. Overall the condition of the river would deteriorate, with a greater likelihood of high salinity levels and moderate to very poor macroinvertebrate community diversity throughout the entire lower Wimmera River. (See Table 8).

4.2.2 Moderate conditions

The early 1990's can be considered a period of relatively moderate weather conditions for the Wimmera: not too dry or too wet. Analysis of flow data for 1994 supports this, and salinity data for the four sites were generally as follows:

- Lower Norton – low.
- Polkemmet South – low to moderate.
- Upstream of Ellis Crossing – low to moderate.
- Tarranyurk – moderate to high.

Under moderate conditions, the previous river level variable was set to moderate and the previous surface salinity variable was adjusted accordingly. The same, flow management scenarios were then run under moderate conditions.

Considering the entire study area, the best flow management option would be delivery of 100 to 200 days of baseflow and one to two freshes, resulting in moderate to very good macroinvertebrate diversity. (See Table 9).

The results, presented in Appendix L, indicate Lower Norton to have a high likelihood of maintaining very good macroinvertebrate community diversity under all flow scenarios.

If no environmental flows occurred, the overall end point would have a greater likelihood of being moderate to poor condition. (See Table 10).

Results from this ERA indicate different sections of the river may require different flow delivery regimes to achieve an improvement in macroinvertebrate community diversity, water quality and available habitat. Therefore it is imperative to work out the most effective environmental flow delivery regime, based on the volume of water allocated and what the WCMA are able to protect with this.

4.3 Limitations

As with any model there are limitations. The limitations of the lower Wimmera River Bayesian network are:

- an uneven spread of data from the 11 sites used to update the model, potentially skewing predicted probabilities in the model
- a lack of data from wet times to update the model and provide better predictions under these times
- the exclusion of the saline pool modelling sub-network to assess the effects of salt slugs and mixing of saline pools, due to postponement of the 2006 environmental flows.

Although there are limitations, the network's predictions were shown to be reasonably accurate. Continued monitoring and collection of data, especially from wetter times and from a range of sites, would be the priority for updating the network, to increase its predictive accuracy.

4.4 Future use

This network was produced to assist the WCMA in decision-making for management of environmental flow allocations. The EPA provided training in model use for the WCMA in May 2008, enabling incorporation of the model into their environmental flow strategies. The WCMA are planning a continued monitoring program, collecting data to update the model and test its predictive accuracy over time.

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EPA would like to thank all those who assisted with the lower Wimmera River ERA. In particular, we would like to thank the WCMA for their enthusiasm and continuous support to EPA staff throughout this project. They provided local knowledge and expertise that was integral to the success of this ERA. Extensive local knowledge and expertise was also provided by Leon Metzeling (EPA Victoria) and David Tiller (Karoo Consulting). EPA would also like to thank Dr Carmel Pollino (Australian National University) who provided expert advice and guidance for the use of Bayesian networks.

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6. FURTHER INFORMATION

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Table 7: Predicted outcome for salinity and macroinvertebrate community diversity in the case of 100–200 days of baseflow and three or more freshes under drought conditions (low previous river level)

Site	Previoussalinity	Most likely outcome(s) for EC	Most likely outcome(s) for macroinvertebrate community diversity as predicted by the network
Lower Norton	Low	Low 95%	Very Good 53.4%
Polkemmet South	Moderate	Moderate 58.4%	Very Good 32.7% & Moderate 28.2% & Good 23.9%
Polkemmet South	High	Moderate 45.8%	Moderate 28.8% Poor 25.9%
U/S Ellis Crossing	Moderate	Moderate 58.4%	Very Good 31.9% & Moderate 28.5% & Good 24.1%
U/S Ellis Crossing	High	Moderate 45.8%	Moderate 29.1% & Poor 25.7%
Tarranyurk	High	Moderate 45.8%	Moderate 30.2% & Poor 25%
Tarranyurk	Very High	Moderate 44.4%	Poor 28.2% & Moderate 26% & Very Poor 18.7%

Table 8: Predicted outcome for salinity and macroinvertebrate community diversity in the case of no environmental flow delivery (<100 days of baseflow and no freshes) under drought conditions (low previous river level)

Site	Previous salinity	Most likely outcome(s) for EC	Most likely outcome(s) for macroinvertebrate community diversity as predicted by the network
Lower Norton	Low	Low 73.6%	Good 32.2% & Moderate 31.4%
Polkemmet South	Moderate	Moderate 50.1% & High 44.5%	Moderate 34.6% & Poor 28.9%
Polkemmet South	High	High 56.1%	Poor 37% & Very Poor 30.2%
U/S Ellis Crossing	Moderate	Moderate 50.1% & High 44.5%	Moderate 34.5% & Poor 29.1%
U/S Ellis Crossing	High	High 56.1%	Poor 37% & Very Poor 30.2%
Tarranyurk	High	High 56.1%	Poor 36.9% & Very Poor 30.1%
Tarranyurk	Very High	Very High 98%	Very Poor 61.1%

Table 9: Predicted outcome for salinity and macroinvertebrate community diversity in the case of 100–200 days of baseflow and three or more freshes under moderate conditions (moderate previous river level)

Site	Previous Salinity	Most likely outcome(s) for EC	Most likely outcome(s) for macroinvertebrate community diversity as predicted by the network
Lower Norton	Low	Low 95%	Very Good 75.2%
Polkemmet South	Low	Low 67.1%	Very Good 62.3%
Polkemmet South	Moderate	Moderate 58.4%	Very Good 45.3%
U/S Ellis Crossing	Low	Low 67.1%	Very Good 60.7%
U/S Ellis Crossing	Moderate	Moderate 58.4%	Very Good 44.3%
Tarranyurk	Moderate	Moderate 58.4%	Very Good 40.3%
Tarranyurk	High	Moderate 45.8%	Moderate 27.5% & Poor 25.2% & Very Good 22.7%

Table 10: Predicted outcome for salinity and macroinvertebrate community diversity in the case of no environmental flow delivery (<100 days of baseflow and no freshes) under moderate conditions (moderate river level)

Site	Previous Salinity	Most likely outcome(s) for EC	Most likely outcome(s) for macroinvertebrate community diversity as predicted by the network
Lower Norton	Low	Low 73.6%	Very Good 40.5%
Polkemmet South	Low	Moderate 53.9%	Moderate 29% & Very Good 26.6%
Polkemmet South	Moderate	Moderate 50.1% & High 44.5%	Poor 32.1% & Moderate 31%
U/S Ellis Crossing	Low	Moderate 53.9%	Moderate 29.2% & Very Good 26%
U/S Ellis Crossing	Moderate	Moderate 50.1% & High 44.5%	Poor 31.8% & Moderate 31.2%
Tarranyurk	Moderate	Moderate 50.1% & High 44.5%	Moderate 32.1% & Poor 30.9%
Tarranyurk	High	High 56.1%	Poor 40.1% & Very Poor 31.4%

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APPENDIX A: PROBLEM FORMULATION STAKEHOLDER WORKSHOP PARTICIPANTS

Table A1: Lower Wimmera ERA problem formulation stakeholder workshop participants

Organisation	Participants
Wimmera Catchment Management Authority	Paul Fennell, Rochelle Carter, Elyse Reithmuller, Greg Barber, Dean Robertson
Fisheries Victoria	Murray Burns, Simon McBeth, Craig Murdoch
EPA Victoria	Leon Metzeling, David Tiller, Clare Marsh, Paul Leahy, Anne-Maree Westbury, Naren Narenthiran
University of Melbourne	Yung En Chee, Jan Carey, Mark Burgman, Andrew Western, Terry Walshe
CSIRO	Shaun Meredith
Mallee Catchment Management Authority	Clare Mason
Glenelg Hopkins Catchment Management Authority	Kylie Waller
Monash University	Carmel Pollino

APPENDIX B: ECOLOGICAL VALUES IDENTIFIED BY WIMMERA STAKEHOLDERS

Table 1: Ecological Values identified by Wimmera stakeholders to be protected by environmental flow allocations.

The values are grouped into general themes identified by stakeholders. It is recognised that there is overlap between the themes and some values could be considered under more than one theme.

Biodiversity	Water quality	Aquatic biota	Flow/physical characteristics
Overall biodiversity[2]	Maintenance of good water quality in pools for biota[2,3]	Diverse macroinvertebrate community	Natural flow regime
Natural endemic species	Fresh water in the saline pools	Diverse phytoplankton community	Flow volume
Ecological vegetation classes (EVCs)	Low salinity	Diverse macrophyte community	Maintenance of Wimmera River terminal lakes system
Riparian vegetation	High dissolved oxygen levels in the water column and sediments	Diverse benthic community[3]	Connectivity
Ducks and native waterbirds (including listed species)	Low turbidity and nutrient concentrations	Recreational non-endemic native fish species (e.g., Golden perch, Freshwater catfish)	Diverse and natural geomorphological function
Water dependant mammals	Natural temperature regime	Endemic native fish species (e.g. Australian Smelt, Western carp gudgeon)	Diversity in channel form[3]
Recruitment of Redgums	Low concentrations of toxic chemicals, particularly hydrogen sulfide and ammonia	Diversity of biofilms	Wetting and drying phases
Threatened species, protected species		Diversity of frogs	Available habitat for biota
Sustainable Redgum communities[3]		Self sustaining populations of Murray Cod[3]	Diversity of instream habitat
		Self sustaining populations of Macquarie Perch[3]	
		Self sustaining populations of Freshwater Catfish[3]	

[2] Key priority values stakeholders chose to focus the ERA on.
[3] Values come from Table 7-3 'Environmental flow recommendations for the Wimmera River Reach 4/5 between McKenzie River and Lake Hindmarsh', in SKM (2002) Stressed Rivers Project – Environmental Flow Study, Wimmera River System. Sinclair Knight Merz.

APPENDIX C: THREATS TO ECOLOGICAL VALUES IDENTIFIED BY WIMMERA STAKEHOLDERS

Table 1: Potential threats to the lower Wimmera River identified by stakeholders

Flow related	Water Quality related	Other
Reduced flow	Low dissolved oxygen in pools	Fire
Alteration of seasonal regime	Groundwater quality of saline intrusions	Some grey areas in management roles and responsibilities of contributing organisations
Increased groundwater intrusion	Decreased dissolved oxygen	The threat of doing nothing
Weir management for recreational activities	Increased salinity	Community perception and expectations
Water extraction and abstraction (timing and volume)	Secondary salinisation and stratification	Climate variability
Unnatural flow regime	Quality of water released from storages	Government decisions
Continuing drought	Saline slug	
Potential for environmental flows to be preferential for invasive species. For example *Phragmites*, algal blooms and Carp	Excessive plant productivity	
Operational constraints	Water quality affects downstream	
Losses in evaporation, transmission and weather conditions	Blackwater events	
Inappropriate flow regimes could affect the carbon drivers	Algal blooms	
Water availability	Low pH in pools	
Lack of rainfall	Arsenic toxicity (leaching from rock bleaching)	
Potential hazards from the environmental flow: timing of the release (e.g., seasonal implications); frequency of the specific flow events; flows that mix saline pools, causing anoxic conditions in the entire pool; and flows that send salt slugs downstream of saline pools	Contaminants/toxicants in sediments in river channel	

APPENDIX D: 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 'Info box: 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 that make up an ecosystem.

The basis of the network is a diagram representing various aspects of the system being considered (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.

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 ('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 opinion 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 end point, 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 ten individuals of the focal species per hectare being 'good', between three and ten individuals being 'moderate', and less than five 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.

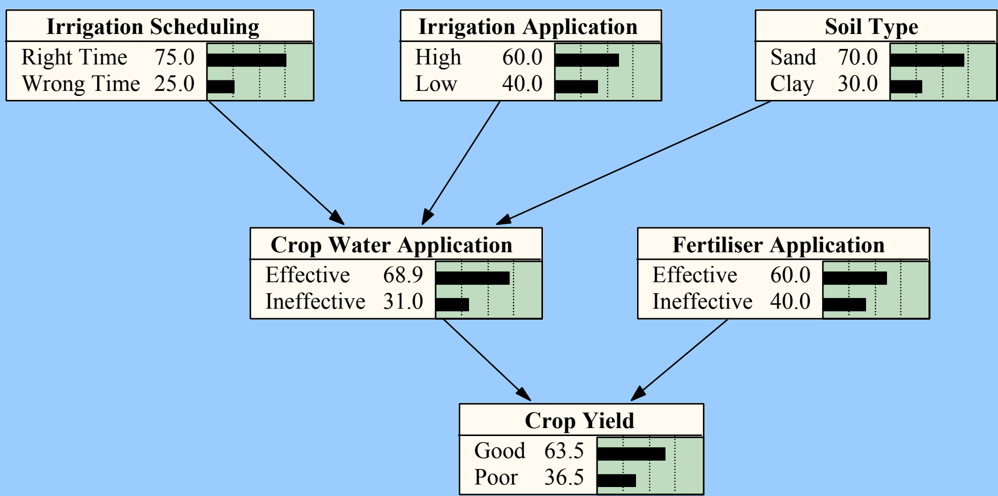
Info box: Bayes Theorem

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 that 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 fertiliser application.



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

Further information

For more information on Bayesian networks:

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: www.cs.ubc.ca/~murphyk/Bayes/bayes.htm
- 'An Introduction to Bayesian Networks and their Contemporary Applications', by Daryle Niedermayer: www.niedermayer.ca/papers/bayesian/index.html
- 'Netica, Bayesian Network Software and Tutorial': www.norsys.com/tutorials/netica/nt_toc_A.htm

APPENDIX E: CONDITIONAL PROBABILITY TABLES OF THE BAYESIAN NETWORK

E1: macroinvertebrate community diversity

Macroinvertebrate community diversity was chosen as the assessment end point for the Lower Wimmera 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 Wimmera 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' variable characterises the health of the macroinvertebrate community in the lower Wimmera 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 MBI score which is based on the standard indices AUSRIVAS, SIGNAL and Number of Families, according to the method detailed in EPA (unpublished).

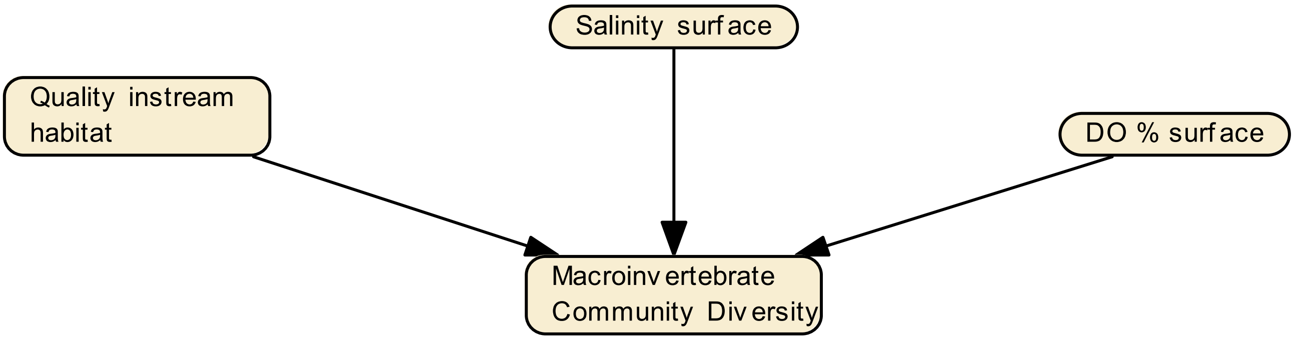


Figure E1: Graphical submodel for 'macroinvertebrate community diversity'

The panel of ecological experts identified 'quality instream habitat', 'DO per cent surface' and 'surface salinity' as the key variables directly influencing 'macroinvertebrate community diversity' in the lower Wimmera River (see Figure E1). They each determined the conditional probabilities for the end point and these responses are given in Appendix E. The average of these responses was entered into the CPT for 'macroinvertebrate community diversity' (see Table E1).

The ecological expert panel identified salinity surface as having the greatest influence on the end point. This was based on a substantial amount of information from previous studies, personal observations in the field and extensive knowledge of the area. Quality instream habitat was considered the second most influential factor, with DO per cent saturation having the least influence on the end point.

The panel had high certainty in estimating the overall relative influence of the three variables determining macroinvertebrate diversity, based on the wealth of information and personal experience in the area. This translated to a moderate confidence in the detail of the individual probability estimates for these relationships, given the detail required.

Table E1: Conditional probabilities for 'macroinvertebrate community diversity'

			Macroinvertebrate community diversity condition				
Quality instream Habitat	**Salinity surface**	**DO% surface**	**Very poor**	**Poor**	**Moderate**	**Good**	**Very good**
Poor	Low	Poor	21	56	22.998	0.001	0.001
Poor	Low	Sufficient	1.25	12.5	32.5	36.25	17.5
Poor	Moderate	Poor	25	60	14.998	0.001	0.001
Poor	Moderate	Sufficient	2.5	42.25	42.25	12.999	0.001
Poor	High	Poor	43.748	46.25	10	0.001	0.001
Poor	High	Sufficient	31.25	41.25	26.25	1.249	0.001
Poor	Very High	Poor	91.25	8.747	0.001	0.001	0.001
Poor	Very High	Sufficient	81.25	16.25	2.498	0.001	0.001
Moderate	Low	Poor	7.499	32.5	50	10	0.001
Moderate	Low	Sufficient	0.001	0.001	17.498	47.5	35
Moderate	Moderate	Poor	22.5	42.5	32.5	2.499	0.001
Moderate	Moderate	Sufficient	0.001	11.249	46.25	35	7.5
Moderate	High	Poor	37.5	46.25	16.248	0.001	0.001
Moderate	High	Sufficient	20	52.5	22.5	4.999	0.001
Moderate	Very High	Poor	88.75	8.75	2.498	0.001	0.001
Moderate	Very High	Sufficient	81.25	15	3.748	0.001	0.001
Good	Low	Poor	7.5	42.5	30	15	5
Good	Low	Sufficient	0.001	0.001	1.248	33.75	65
Good	Moderate	Poor	21.25	36.25	37.5	4.999	0.001
Good	Moderate	Sufficient	0.001	1.249	30	40	28.75
Good	High	Poor	28.75	50	18.75	2.499	0.001
Good	High	Sufficient	19.75	45.25	30	4.999	0.001
Good	Very High	Poor	83.75	16.247	0.001	0.001	0.001
Good	Very High	Sufficient	81.25	15	3.748	0.001	0.001

E2: Surface salinity

The 'surface salinity' variable is defined as the electrical conductivity (EC) level in the water column, measured in µS/cm. The four states for 'salinity surface' are low, moderate, high and very high. These states were determined through analysis of data using multivariate statistics and represent levels at which macroinvertebrate community diversity significantly decreases. The ecological expert panel confirmed these states. 'Flow regime for water quality improvement', 'groundwater intrusion present at site or upstream of site' and 'previous surface salinity' were identified by the ecological experts as the key contributors to salinity levels in the lower Wimmera River (see Figure E2). This was based on previous studies and catchment reports (Anderson and Morison, 1989; EPA, 1993 and 1995; SKM, 2002, WCMA 2005 and 2006) and discussions with WCMA staff.

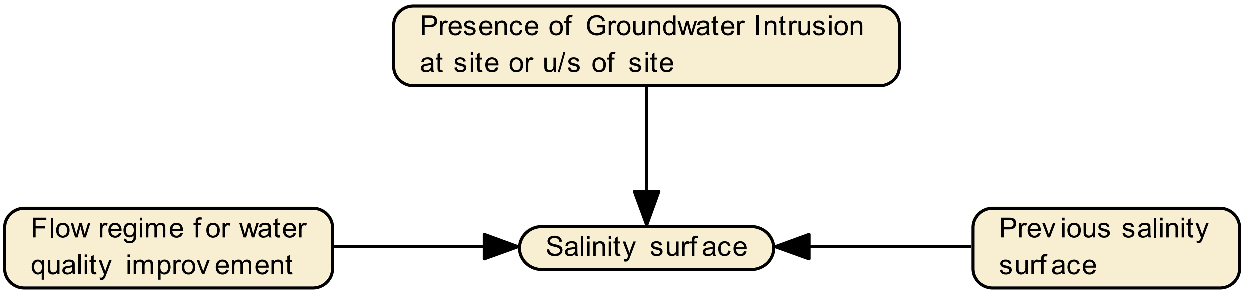


Figure E2: Graphical submodel for 'salinity surface'

The panel of ecological experts determined the conditional probabilities for 'salinity surface' individually and these responses are given in Appendix F. The average of these responses was entered into the CPT (see Table E2).

Table E2: Final prior probabilities for the Salinity Surface CPT.
The prior probabilities are an average of the four ecological experts' responses.

			Salinity surface condition			
Flow regime for water quality improvement	**Groundwater intrusion present at site or upstream of site**	**Previous surface salinity**	**Low <3000**	**Moderate 3000–10,000**	**High 10,000–40,000**	**Very high >40,000**
Good	Yes	Low	51	41.25	7.5	0.25
Good	Yes	Moderate	28.75	53.75	15.75	1.75
Good	Yes	High	7	53	37	3
Good	Yes	Very High	3	32.25	47.5	17.25
Good	No	Low	93.25	6.5	0.249	0.001
Good	No	Moderate	78.75	21	0.249	0.001
Good	No	High	34	47.5	17.5	1
Good	No	Very High	15.25	27	47.75	10
Poor	Yes	Low	21.25	50	25	3.75
Poor	Yes	Moderate	0.25	37.25	50	12.5
Poor	Yes	High	0.001	4	63.749	32.25
Poor	Yes	Very High	0.001	0.249	8.5	91.25
Poor	No	Low	46.25	40	11.25	2.5
Poor	No	Moderate	4	50	43.25	2.75
Poor	No	High	0.001	6.499	67.25	26.25
Poor	No	Very High	0.001	0.249	22.75	77

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

E3: Flow regime for water quality improvement

The 'flow regime for water quality improvement' variable is an integrative variable characterising the flow regime that will improve water quality in the lower Wimmera River. The two states defined for this variable were good and poor and are dependent on the given states of ' freshes/year', 'baseflow' and 'high flow' (see figure E3).

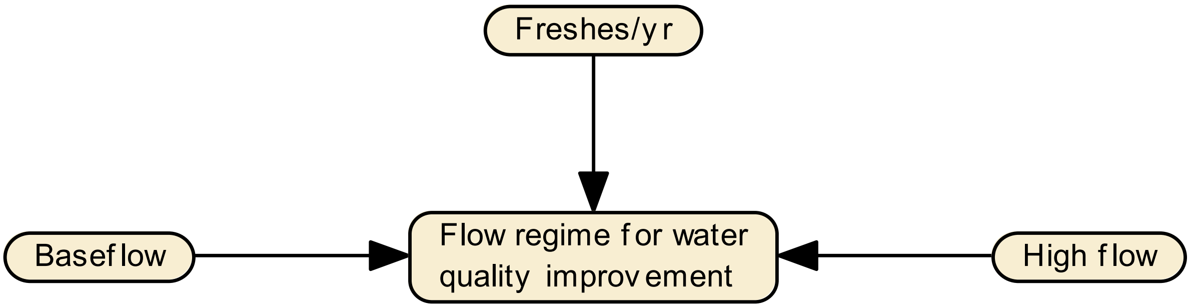


Figure E3: Graphical submodel for 'flow regime for water quality improvement'

The panel of ecological experts determined the conditional probabilities for 'flow regime for water quality improvement' individually and these responses are given in Appendix F. The average of these responses was entered into the CPT (see Table E3).

The panel identified freshes as having the greatest influence on the 'flow regime for water quality improvement' in the lower Wimmera River. Baseflow was deemed the second most influential factor. The experts' rationale was based on historical flow and salinity data from relevant VWQMN gauging sites and previous studies that investigated the effects of different flow delivery methods on water quality. High flow played the least important role in improving water quality in the river.

Table E3: Final prior probabilities for the flow regime for water quality improvement CPT. The prior probabilities are an average of the four ecological experts' responses.

			Flow regime condition	
Freshes/year	Base flow	High Flow	Good	Poor
Low	Low	Yes	30	70
Low	Low	No	2.3	97.7
Low	Moderate	Yes	50	50
Low	Moderate	No	18.75	81.25
Low	High	Yes	65	35
Low	High	No	35	65
Moderate	Low	Yes	66.25	33.75
Moderate	Low	No	25	75
Moderate	Moderate	Yes	85	15
Moderate	Moderate	No	61.25	38.75
Moderate	High	Yes	91.25	8.75
Moderate	High	No	73.75	26.25
High	Low	Yes	73.75	26.25
High	Low	No	58.75	41.25
High	Moderate	Yes	92.5	7.5
High	Moderate	No	76.25	23.75
High	High	Yes	99	1
High	High	No	86.25	13.75

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, knowledge of the area and field observations.

E4: Quality instream habitat

The 'quality instream habitat' variable is an integrative variable characterising the overall availability of habitat for macroinvertebrates. The three states defined for 'quality instream habitat', poor moderate and good, are dependent on the given states of 'macrophyte habitat', 'water for habitat' and 'leaf packs and woody debris' (see Figure E2).

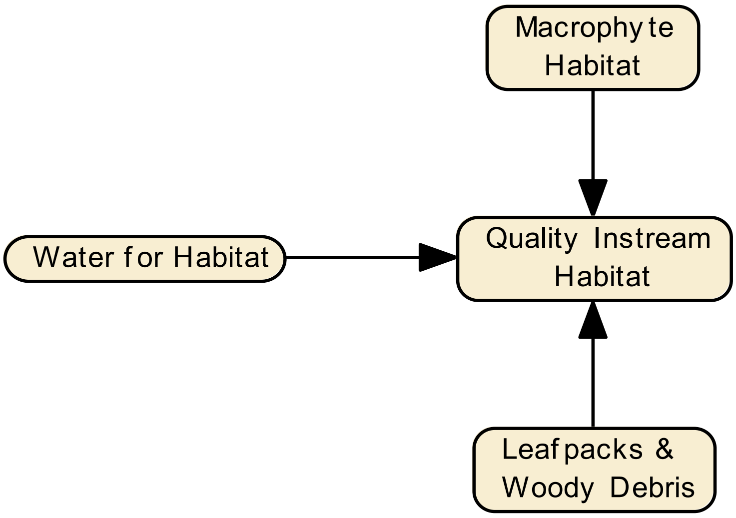


Figure E4: Graphical submodel for 'quality instream habitat'

The panel of ecological experts determined the conditional probabilities for 'quality instream habitat' individually and these responses are given in Appendix F. The average of these responses was entered into the CPT (see Table E4).

Table E4: Conditional probabilities for 'quality instream habitat'

			Instream habitat condition		
Macrophyte habitat	Leaf packs and woody debris	Flow for habitat	Poor	Moderate	Good
Poor	Good	Good	21.25	32.5	46.25
Poor	Good	Poor	88.75	6.25	5
Poor	Poor	Good	40	30	30
Poor	Poor	Poor	98.75	1.249	0.001
Good	Good	Good	0.001	1.249	98.75
Good	Good	Poor	47.5	40	12.5
Good	Poor	Good	0.001	11.249	88.75
Good	Poor	Poor	57.5	32.5	10

The panel identified 'water for habitat' as having the greatest influence on the amount of instream vegetation present in the lower Wimmera River. 'Macrophyte habitat' was deemed the second most influential factor. The experts rationale was that water is required to provide instream habitat, such as submerged logs and macrophytes, and that macrophytes play an important role in providing a diversity of habitats for a range of macroinvertebrates. Leaf packs and woody debris were deemed the least influential habitat in 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, knowledge of the area and field observations.

E5: Water for habitat

The 'water for habitat' variable is an integrative variable characterising the amount of water available for habitat. The two states defined for 'water for habitat', poor and good, are dependant on the given states of 'freshes/year', 'baseflow' and 'previous river level' (see Figure E5).

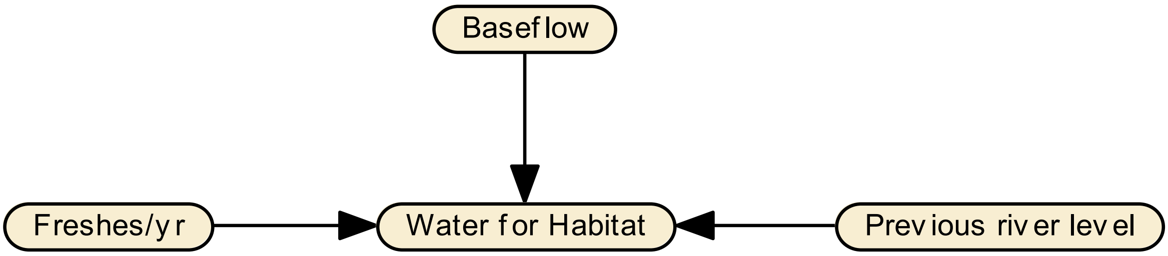


Figure E5: Graphical submodel for 'water for habitat'

The panel of ecological experts determined the conditional probabilities for 'water for habitat' individually and these responses are given in Appendix F. The average of these responses was entered into the CPT (see Table E5).

**Table E5: Final prior probabilities for the Water for Habitat CPT.
The prior probabilities are an average of the four ecological experts' responses.**

			Water for habitat condition	
Previous river level	Freshes/year	Baseflow	Good	Poor
Low	Low	Low	0.3	99.7
Low	Low	Moderate	8.3	91.7
Low	Low	High	15.0	85.0
Low	Moderate	Low	6.0	94.0
Low	Moderate	Moderate	18.3	81.7
Low	Moderate	High	26.7	73.3
Low	High	Low	14.3	85.7
Low	High	Moderate	24.3	75.7
Low	High	High	35.0	65.0
Medium	Low	Low	46.7	53.3
Medium	Low	Moderate	60.7	39.3
Medium	Low	High	70.0	30.0
Medium	Moderate	Low	62.7	37.3
Medium	Moderate	Moderate	76.7	23.3
Medium	Moderate	High	84.0	16.0
Medium	High	Low	73.3	26.7
Medium	High	Moderate	85.0	15.0
Medium	High	High	90.0	10.0
High	Low	Low	84.0	16.0
High	Low	Moderate	87.7	12.3
High	Low	High	91.7	8.3
High	Moderate	Low	90.7	9.3
High	Moderate	Moderate	91.7	8.3
High	Moderate	High	96.0	4.0
High	High	Low	91.7	8.3
High	High	Moderate	96.7	3.3
High	High	High	97.0	3.0

The panel identified 'previous river level' as having the greatest influence on the amount of water available for habitat in the lower Wimmera River. 'Freshes' was the second most influential factor determining quality instream habitat, followed by 'baseflow'. The experts rationale for this was that the higher the river the greater the likelihood that there will be more instream habitat. Freshes were deemed as having a greater influence than baseflow, as freshes have been shown to improve water quality, which is important for macrophytes.

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, knowledge of the area and field observations.

E6: Macrophyte habitat

The 'macrophyte habitat' variable is defined as the number of substructures present instream (e.g. emergent rush-like, submerged feather-like, etc). The measure for this variable was determined through multivariate analysis that showed substructure (e.g., not number of taxa present) to have the most influence over macroinvertebrate community diversity. The two states for 'macrophyte habitat' are good and poor. These states were determined through analysis of data collected as part of this ERA and represent levels at which the end point significantly decreases. The ecological expert panel then confirmed the states. The experts identified 'salinity surface' as the key influence over macrophyte establishment and growth in the lower Wimmera River (see Figure E6). This was based on previous studies and catchment reports (Anderson and Morison, 1989; EPA, 1993 and 1995; SKM, 2002, WCMA 2005 and 2006) and discussions with WCMA staff and ecological experts.

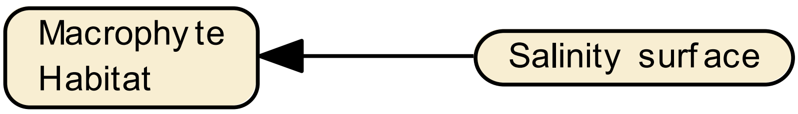


Figure E6: Graphical submodel for 'macrophyte habitat'

The conditional probabilities for 'macrophyte habitat' were determined by analysing data collected as part of this ERA. These probabilities are given in Table E6.

Table E6: Final prior probabilities for the Macrophyte Habitat CPT. The prior probabilities were based on existing data.

	Macrophyte habitat condition	
Salinity surface	**Poor**	**Good**
Low	6.25	93.75
Moderate	12.5	87.5
High	60	40
Very High	99.999	0.001

E7: DO% surface

The 'dissolved oxygen' variable is defined as the per cent saturation of the surface water. The two states for 'dissolved oxygen' are sufficient and poor. The term 'sufficient' is used as the range of values within this state are definitive of good to sufficient dissolved oxygen levels. These states were defined by ecological experts through analysis of data collected as part of this ERA and WCMA sampling. These states represent levels at which macroinvertebrate community diversity significantly decreases. The experts identified 'flow regime for water quality improvement' as the key influence over dissolved oxygen levels in the lower Wimmera River (see Figure E6). This was based on previous studies and catchment reports (Anderson and Morison, 1989; EPA, 1993 and 1995; SKM, 2002, WCMA 2005 and 2006).

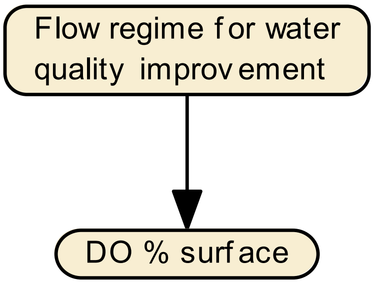


Figure E7: Graphical submodel for 'DO% surface'

The conditional probabilities for 'dissolved oxygen' were determined by analysing data collected as part of this ERA. These probabilities are given in Table E6.

Table E7: Final prior probabilities for the DO per cent surface CPT. The prior probabilities were based on existing data.

	DO% surface condition	
Flow regime for water quality improvement	**Poor**	**Sufficient**
Good	5	95
Poor	30	70

APPENDIX F: EXPERT ELICITATION WORKSHOP PARTICIPANTS

Table F1: Ecological experts in attendance for the lower Wimmera River expert elicitation workshops in September 2004 and October and November 2008.

Name	Key area of expertise	Other areas of expertise
Stephen Adamthwaite (Freshwater Sciences, EPA Victoria)	Macroinvertebrates	Written a report assessing the health of rivers and streams in the Wimmera catchment.
Leon Metzeling (Freshwater Sciences, EPA Victoria)	Macroinvertebrates and water quality	Has been working in the Wimmera region for over 20 years and has published various reports concerning macroinvertebrate communities in the Wimmera. Has extensive experience and knowledge of salinity tolerances of aquatic biota in freshwater systems.
David Tiller (Karoo Consulting)	River health processes and water quality	Macroinvertebrates and water quality. Has been working in the Wimmera region for more than 20 years.
Anne Maree Westbury (Freshwater Sciences, EPA Victoria)	River health processes Exo-toxicology ERA	Water Quality. Involved in the ERA from beginning to end. Involvement in other ERAs.

APPENDIX G: INDIVIDUAL ECOLOGICAL EXPERTS' PRIOR PROBABILITIES AND THE AVERAGE RESPONSE FOR FIVE CPTS IN THE LOWER WIMMERA BAYESIAN NETWORK

NB: The CPTs for 'DO% surface' and 'Macrophyte Habitat' were completed using the analysis of historical and ERA data. These CPTs do not appear in this appendix, please refer to Appendix D. The Key for ecological experts for all following tables is: SA = Stephen Adamthwaite, DT = David Tiller, LM = Leon Metzeling, AW = Anne-Maree Westbury and AV = Average

Table G1: Final prior probabilities for the macroinvertebrate community diversity CPT for each individual ecological expert

Quality instream habitat	Salinity surface	DO% surface	Very poor					Poor					Moderate					Good					Very good				
			SA	DT	LM	AW	AV	SA	DT	LM	AW	AV	SA	DT	LM	AW	AV	SA	DT	LM	AW	AV	SA	DT	LM	AW	AV
Poor	Low	Poor	20	20	10	30	**21**	70	60	50	40	**56**	10	20	30	30	**22.5**	0	0	0	0	**0**	0	0	0	0	**0**
Poor	Low	Sufficient	5	0	0	0	**1.25**	30	10	0	10	**12.5**	55	20	20	35	**32.5**	10	40	60	35	**36.25**	0	30	20	20	**17.5**
Poor	Moderate	Poor	25	20	20	35	**25**	70	60	60	50	**60**	5	20	20	15	**15**	0	0	0	0	**0**	0	0	0	0	**0**
Poor	Moderate	Sufficient	10	0	0	0	**2.5**	70	20	30	45	**42.5**	20	60	40	45	**42.5**	0	20	20	10	**12.5**	0	0	0	0	**0**
Poor	High	Poor	50	20	60	45	**43.75**	50	50	40	45	**46.25**	0	30	0	10	**10**	0	0	0	0	**0**	0	0	0	0	**0**
Poor	High	Sufficient	40	5	40	40	**31.25**	50	30	30	55	**41.25**	10	60	30	5	**26.25**	0	5	0	0	**1.25**	0	0	0	0	
Poor	Very high	Poor	100	95	100	70	**91.25**	0	5	0	30	**8.75**	0	0	0	0	**0**	0	0	0	0	**0**	0	0	0	0	**0**
Poor	Very high	Sufficient	100	95	70	60	**81.25**	0	5	20	40	**16.25**	0	0	10	0	**2.5**	0	0	0	0	**0**	0	0	0	0	**0**
Moderate	Low	Poor	10	10	0	10	**7.5**	20	50	20	40	**32.5**	60	40	60	40	**50**	10	0	20	10	**10**	0	0	0	0	**0**
Moderate	Low	Sufficient	0	0	0	0	**0**	0	0	0	0	**0**	20	20	10	20	**17.5**	60	40	30	60	**47.5**	20	40	60	20	**35**
Moderate	Moderate	Poor	20	20	10	40	**22.5**	40	60	30	40	**42.5**	40	20	50	20	**32.5**	0	0	10	0	**2.5**	0	0	0	0	**0**
Moderate	Moderate	Sufficient	0	0	0	0	**0**	10	10	20	5	**11.25**	70	30	40	45	**46.25**	20	40	40	40	**35**	0	20	0	10	**7.5**
Moderate	High	Poor	30	40	20	60	**37.5**	60	50	40	35	**46.25**	10	10	40	5	**16.25**	0	0	0	0	**0**	0	0	0	0	**0**
Moderate	High	Sufficient	10	30	10	30	**20**	80	50	40	40	**52.5**	10	10	40	30	**22.5**	0	10	10	0	**5**	0	0	0	0	**0**
Moderate	Very high	Poor	100	95	80	80	**88.75**	0	5	10	20	**8.75**	0	0	10	0	**2.5**	0	0	0	0	**0**	0	0	0	0	**0**
Moderate	Very high	Sufficient	95	95	70	65	**81.25**	5	5	20	30	**15**	0	0	10	5	**3.75**	0	0	0	0	**0**	0	0	0	0	**0**
Good	Low	Poor	5	20	0	5	**7.5**	40	60	10	60	**42.5**	50	20	20	30	**30**	5	0	50	0	**15**	0	0	20	0	**5**
Good	Low	Sufficient	0	0	0	0	**0**	0	0	0	0	**0**	0	5	0	0	**1.25**	40	15	40	40	**33.75**	60	80	60	60	**65**
Good	Moderate	Poor	20	30	0	35	**21.25**	40	40	30	35	**36.25**	40	30	50	30	**37.5**	0	0	20	0	**5**	0	0	0	0	**0**
Good	Moderate	Sufficient	0	0	0	0	**0**	5	0	0	0	**1.25**	60	10	30	20	**30**	30	50	40	40	**40**	5	40	30	40	**28.75**
Good	High	Poor	10	30	20	55	**28.75**	70	50	40	40	**50**	20	20	30	5	**18.75**	0	0	10	0	**2.5**	0	0	0	0	**0**
Good	High	Sufficient	5	20	30	20	**18.75**	60	30	40	45	**43.75**	30	40	20	30	**30**	5	10	0	5	**5**	0	0	0	0	**0**
Good	Very high	Poor	95	95	80	65	**83.75**	5	5	20	35	**16.25**	0	0	0	0	**0**	0	0	0	0	**0**	0	0	0	0	**0**
Good	Very high	Sufficient	90	95	80	60	**81.25**	10	5	10	35	**15**	0	0	10	5	**3.75**	0	0	0	0	**0**	0	0	0	0	**0**

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Table G2: Final prior probabilities for the quality instream habitat CPT for each individual ecological expert

Macrophyte habitat	Leaf packs and woody debris	Flow for habitat	Poor					Moderate					Good				
			SA	DT	LM	AW	AV	SA	DT	LM	AW	AV	SA	DT	LM	AW	AV
Good	Good	Good	0	0	0	0	**0**	0	5	0	0	**1.25**	100	95	100	100	**98.75**
Good	Good	Poor	50	70	50	20	**47.5**	50	20	30	60	**40**	0	10	20	20	**12.5**
Good	Poor	Good	0	0	0	0	**0**	10	10	10	15	**11.25**	90	90	90	85	**88.75**
Good	Poor	Poor	80	80	50	20	**57.5**	20	20	40	50	**32.5**	0	0	10	30	**10**
Poor	Good	Good	0	10	20	55	**21.25**	50	20	20	40	**32.5**	50	70	60	5	**46.25**
Poor	Good	Poor	100	80	80	95	**88.75**	0	0	20	5	**6.25**	0	20	0	0	**5**
Poor	Poor	Good	40	20	20	80	**40**	40	30	30	20	**30**	20	50	50	0	**30**
Poor	Poor	Poor	100	95	100	100	**98.75**	0	5	0	0	**1.25**	0	0	0	0	**0**

Table G3: Final prior probabilities for the flow regime for water quality improvement CPT for each individual ecological expert

Freshes/year	Baseflow	High Flow	Good					Poor				
			SA	DT	LM	AW	AV	SA	DT	LM	AW	AV
0	<100 days	Yes	30	30	30	30	**30**	70	70	70	70	**70**
0	<100 days	No	1	-	1	5	**2.33**	99	-	99	95	**97.66**
0	100-200 days	Yes	50	50	50	50	**50**	50	50	50	50	**50**
0	100-200 days	No	10	25	20	20	**18.75**	90	75	80	80	**81.25**
0	>200 days	Yes	60	50	70	80	**65**	40	50	30	20	**35**
0	>200 days	No	20	40	40	40	**35**	80	60	60	60	**65**
1-2	<100 days	Yes	60	75	80	50	**66.25**	40	25	20	50	**33.75**
1-2	<100 days	No	15	-	30	30	**25**	85	-	70	70	**75**
1-2	100-200 days	Yes	80	90	90	80	**85**	20	10	10	20	**15**
1-2	100-200 days	No	40	65	70	70	**61.25**	60	35	30	30	**38.75**
1-2	>200 days	Yes	85	95	95	90	**91.25**	15	5	5	10	**8.75**
1-2	>200 days	No	60	75	80	80	**73.75**	40	25	20	20	**26.25**
≥3	<100 days	Yes	85	80	70	60	**73.75**	15	20	30	40	**26.25**
≥3	<100 days	No	50	75	60	50	**58.75**	50	25	40	50	**41.25**
≥3	100-200 days	Yes	95	95	90	90	**92.5**	5	5	10	10	**7.5**
≥3	100-200 days	No	60	80	80	85	76.25	40	20	20	15	23.75
≥3	>200 days	Yes	99	99	99	99	99	1	1	1	1	1
≥3	>200 days	No	70	90	90	95	86.25	30	10	10	5	13.75

Table G4: Final prior probabilities for the surface salinity CPT for each individual ecological expert.

Flow regime for water quality improvement	Presence of ground water intrusion	Previous surface salinity	<3000 EC					3000–10,000 EC					10,000–40,000 EC					>40,000 EC				
			SA	DT	LM	AW	AV	SA	DT	LM	AW	AV	SA	DT	LM	AW	AV	SA	DT	LM	AW	AV
Good	Yes	Low	50	40	70	44	51	40	55	20	50	41.25	10	5	10	5	7.5	0	0	0	1	0.25
Good	Yes	Moderate	20	30	30	35	28.75	50	60	60	45	53.75	28	10	10	15	15.75	2	0	0	5	1.75
Good	Yes	High	2	20	1	5	7	43	60	55	55	53.25	50	20	43	35	37	5	5	1	5	4
Good	Yes	Very high	0	10	1	1	3	10	60	29	30	32.25	50	20	60	60	47.5	40	10	10	9	17.25
Good	No	Low	99	90	90	94	93.25	1	10	10	5	6.5	0	0	0	1	0.25	0	0	0	0	0
Good	No	Moderate	80	80	80	75	78.75	20	20	20	24	21	0	0	0	1	0.25	0	0	0	0	0
Good	No	High	20	60	30	30	35	60	20	60	50	47.5	20	15	10	25	17.5	0	5	0	0	1.25
Good	No	Very high	2	40	20	1	15.75	10	30	30	30	27	70	20	40	65	48.75	10	10	10	14	11
Poor	Yes	Low	20	15	30	20	21.25	60	50	40	50	50	18	30	25	27	25	2	5	5	3	3.75
Poor	Yes	Moderate	1	0	0	0	0.25	39	30	40	40	37.25	50	60	40	50	50	10	10	20	10	12.5
Poor	Yes	High	0	0	0	0	0	1	5	0	10	4	50	70	70	65	63.75	49	25	30	25	32.25
Poor	Yes	Very high	0	0	0	0	0	0	0	0	1	0.25	0	5	10	19	8.725	100	95	90	80	91.25
Poor	No	Low	50	20	80	35	46.25	40	40	20	60	40	10	30	0	5	11.25	0	10	0	0	2.5
Poor	No	Moderate	1	0	10	5	4	50	40	60	50	50	48	50	30	45	43.25	1	10	0	0	2.75
Poor	No	High	0	0	0	0	0	1	10	10	5	6.5	69	60	80	60	67.25	30	30	10	35	26.25
Poor	No	Very high	0	0	0	0	0	0	0	0	1	0.25	1	20	30	40	22.75	99	80	70	59	77

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Table G5: Final prior probabilities for the water for habitat CPT for each individual ecological expert.

Previous river level	Freshes/year	Baseflow	Good				Poor			
			SA	LM	AW	AV	SA	LM	AMW	AV
Low	0	<100 days	0	1	0	**0.33**	100	99	100	**99.66**
Low	0	100–200 days	5	10	10	**8.33**	95	90	90	**91.66**
Low	0	>200 days	10	20	15	**15**	90	80	85	**85**
Low	1-2	<100 days	3	5	10	**6**	97	95	90	**94**
Low	1-2	100–200 days	15	20	20	**18.33**	85	80	80	**81.66**
Low	1-2	>200 days	25	30	25	**26.66**	75	70	75	**73.33**
Low	≥3	<100 days	8	20	15	**14.33**	92	80	85	**85.66**
Low	≥3	100–200 days	18	30	25	**24.33**	82	70	75	**75.66**
Low	≥3	>200 days	30	40	35	**35**	70	60	65	**65**
Moderate	0	<100 days	60	50	30	**46.66**	40	50	70	**53.33**
Moderate	0	100–200 days	72	60	50	**60.66**	28	40	50	**39.33**
Moderate	0	>200 days	80	70	60	**70**	20	30	40	**30**
Moderate	1-2	<100 days	68	60	60	**62.66**	32	40	40	**37.33**
Moderate	1-2	100–200 days	75	75	80	**76.66**	25	25	20	**23.33**
Moderate	1-2	>200 days	82	80	90	**84**	18	20	10	**16**
Moderate	≥3	<100 days	70	75	75	**73.33**	30	25	25	**26.66**
Moderate	≥3	100–200 days	80	85	90	**85**	20	15	10	**15**
Moderate	≥3	>200 days	85	90	95	**90**	15	10	5	**10**
High	0	<100 days	82	80	90	**84**	18	20	10	**16**
High	0	100–200 days	85	85	93	**87.66**	15	15	7	**12.33**
High	0	>200 days	90	90	95	**91.66**	10	10	5	**8.33**
High	1-2	<100 days	87	90	95	**90.66**	13	10	5	**9.33**
High	1-2	100–200 days	90	90	95	**91.66**	10	10	5	**8.33**
High	1-2	>200 days	93	95	100	**96**	7	5	0	**4**
High	≥3	<100 days	90	90	95	**91.66**	10	10	5	**8.33**
High	≥3	100–200 days	93	98	99	**96.66**	7	2	1	**3.33**
High	≥3	>200 days	95	98	97	**97**	5	2	2	**3**

APPENDIX H: COMPLETE AND INCOMPLETE DATA SETS USED FOR UPDATING THE CPTS

Table H1: Raw data used to update the Bayesian CPTs. Bold indicates the sampling season after the 20–2005 environmental flows. * represents missing data (data that was unavailable)

ID number	Date	Site	Groundwater intrusion	Previous salinity surface	Previous river level	Freshes/ year	High flow	Baseflow	Salinity surface	DO% surface	Macrophyte habitat	Leaf packs and woody debris	Macroinverterbrate community diversity
1	5/05/1999	Antwerp	Yes	*	Moderate	High	No	High	2147	Sufficient	Good	Good	Good
2	11/11/1999	Antwerp	Yes	*	Low	Moderate	No	Moderate	2558	Sufficient	Good	Good	Moderate
3	11/11/2004	Antwerp	Yes	*	Low	Low	No	Low	8000	Sufficient	Good	Poor	Poor
4	**27/04/2005**	**Antwerp**	**Yes**	*****	**Low**	**Moderate**	**No**	**Low**	**5670**	**Sufficient**	**Good**	**Good**	**Moderate**
5	24/11/2005	Antwerp	Yes	8000	Low	Moderate	No	Low	8233	Sufficient	Good	Good	Poor
6	4/04/2006	Antwerp	Yes	5670	Low	Low	No	Low	10903	Sufficient	Poor	Good	Poor
7	29/03/2007	Antwerp	Yes	10903	Low	Low	No	Low	23980	Sufficient	Poor	Poor	Poor
8	10/11/2004	Big Bend	Yes	*	Low	Low	No	Low	5950	Sufficient	Good	Poor	Moderate
9	**26/04/2005**	**Big Bend**	**Yes**	*****	**Low**	**Moderate**	**No**	**Low**	**2671**	**Sufficient**	**Good**	**Poor**	**Very good**
10	23/11/2005	Big Bend	Yes	5950	Low	Moderate	No	Low	5863	Sufficient	Good	Good	Very good
11	4/04/2006	Big Bend	Yes	2671	Low	Low	No	Low	8247	Sufficient	Good	Good	Good
12	14/11/2006	Big Bend	Yes	5863	Low	Low	No	Low	10218	Sufficient	Good	Poor	Moderate
13	26/03/2007	Big Bend	Yes	8247	Low	Low	No	Low	13167	Sufficient	Good	Good	Poor
14	27/11/2007	Big Bend	Yes	10218	Low	Low	No	Low	18016	Sufficient	Good	Poor	Moderate
15	17/04/1997	Jeparit	Yes	*	Moderate	High	Yes	High	4083	Sufficient	Poor	Good	Poor
16	19/11/1997	Jeparit	Yes	*	Moderate	High	No	High	4543	Sufficient	Good	Good	Moderate
17	9/11/2004	Jeparit	Yes	*	Low	Low	No	Low	43400	Sufficient	Poor	Good	Poor
18	**28/04/2005**	**Jeparit**	**Yes**	*****	**Low**	**Moderate**	**No**	**Low**	**34400**	**Sufficient**	**Poor**	**Good**	**Poor**
19	24/11/2005	Jeparit	Yes	43400	Low	Moderate	No	Low	48980	Sufficient	Poor	Good	Poor
20	4/04/2006	Jeparit	Yes	34400	Low	Low	No	Low	85168	Poor	Poor	Good	Poor
21	15/11/2006	Jeparit	Yes	48980	Low	Low	No	Low	83567	Sufficient	Poor	Poor	Very poor
22	28/03/2007	Jeparit	Yes	73237	Low	Low	No	Low	110374	Poor	Poor	Good	Very poor
23	27/11/2007	Jeparit	Yes	83567	Low	Low	No	Low	86350	Sufficient	Poor	Poor	Very poor
24	**27/04/2005**	**Lochiel**	**Yes**	**3190**	**Low**	**Moderate**	**No**	**Low**	**3492**	**Sufficient**	**Good**	**Poor**	**Good**
25	23/11/2005	Lochiel	Yes	3657	Low	Moderate	No	Low	4131	Sufficient	Good	Poor	Moderate
26	5/04/2006	Lochiel	Yes	3492	Low	Low	No	Low	4493	Sufficient	Good	Poor	Good
27	14/11/2006	Lochiel	Yes	8400	Low	Low	No	Low	8400	Sufficient	Good	Poor	Good
28	27/03/2007	Lochiel	Yes	5859	Low	Low	No	Low	15520	Sufficient	Good	Good	Moderate
29	8/12/1993	Lower Norton	No	550	High	High	Yes	High	634	Sufficient	*	*	Very good

ID number	Date	Site	Groundwater intrusion	Previous salinity surface	Previous river level	Freshes/ year	High flow	Baseflow	Salinity surface	DO% surface	Macrophyte habitat	Leaf packs and woody debris	Macroinverterbrate community diversity
30	1/03/1994	Lower Norton	No	617	High	High	Yes	High	1080	Sufficient	*	*	Very good
31	20/10/1994	Lower Norton	No	939	High	Moderate	No	High	714	Sufficient	*	*	Very good
32	5/04/1995	Lower Norton	No	1162	High	Moderate	No	Moderate	623	Sufficient	*	*	Good
33	18/11/1997	Lower Norton	No	693	Moderate	High	No	High	2090	Sufficient	*	Good	Very good
34	6/05/1998	Lower Norton	No	1280	Moderate	Moderate	No	High	943	Sufficient	*	Good	Very good
35	9/11/1998	Lower Norton	No	2005	Moderate	High	No	High	1961	Sufficient	Poor	Good	Good
36	4/05/1999	Lower Norton	No	1076	Moderate	High	No	High	943	Sufficient	Poor	Good	Moderate
37	10/11/1999	Lower Norton	No	2264	Low	Moderate	No	Moderate	838	Sufficient	Poor	Good	Good
38	14/03/2001	Lower Norton	No	798	Low	High	No	Moderate	2009	Sufficient	Good	Good	Very good
39	30/10/2001	Lower Norton	No	823	Low	Moderate	No	Low	2009	Sufficient	*	Good	Very good
40	12/03/2002	Lower Norton	No	1727	Low	Moderate	No	Moderate	1614	Sufficient	Good	*	Very good
41	12/11/2002	Lower Norton	No	1285	Low	Moderate	No	Moderate	1317	Sufficient	Good	Good	Very good
42	17/11/2003	Lower Norton	No	1257	Low	Low	No	Low	2940	Sufficient	Good	Good	Very good
43	**27/04/2004**	**Lower Norton**	**No**	**1657**	**Low**	**Moderate**	**No**	**Low**	**1654**	**Sufficient**	**Good**	**Good**	**Good**
44	28/04/2005	Lower Norton	No	1467	Low	Moderate	No	Low	1500	Sufficient	Good	Good	Very good
45	3/04/2006	Lower Norton	No	1500	Low	Low	No	Low	1291	Sufficient	Good	Good	Good
46	15/11/2006	Lower Norton	No	619	Low	Low	No	Low	1274	Sufficient	Good	Good	Good
47	26/11/2007	Lower Norton	No	1274	Low	Low	No	Low	1577	Sufficient	Poor	Good	Moderate
48	10/11/2004	Polkemmet Nth	Yes	*	Low	Low	No	Low	2670	Sufficient	Good	Good	Good
49	**26/04/2005**	**Polkemmet Nth**	**Yes**	*****	**Low**	**Moderate**	**No**	**Low**	**1923**	**Sufficient**	**Good**	**Poor**	**Very good**
50	22/11/2005	Polkemmet Nth	Yes	2670	Low	Moderate	No	Low	3025	Sufficient	Good	Good	Very good
51	14/11/2006	Polkemmet Nth	Yes	3025	Low	Low	No	Low	6742	Sufficient	Good	Poor	Moderate
52	27/03/2007	Polkemmet Nth	Yes	3877	Low	Low	No	Low	11898	Sufficient	Poor	Good	Good
53	28/11/2007	Polkemmet Nth	Yes	6742	Low	Low	No	Low	18250	Poor	Poor	Good	Good
54	10/11/2004	Polkemmet Sth	Yes	*	Low	Low	No	Low	2690	Sufficient	Good	Good	Poor
55	**26/04/2005**	**Polkemmet Sth**	**Yes**	*****	**Low**	**Moderate**	**No**	**Low**	**1967**	**Sufficient**	**Good**	**Good**	**Very good**
56	22/11/2005	Polkemmet Sth	Yes	2690	Low	Moderate	No	Low	2929	Sufficient	Good	Good	Moderate
57	5/04/2006	Polkemmet Sth	Yes	1967	Low	Low	No	Low	4510	Sufficient	Good	Good	Good
58	13/11/2006	Polkemmet Sth	Yes	2929	Low	Low	No	Low	6981	Sufficient	Poor	Good	Moderate
59	27/03/2007	Polkemmet Sth	Yes	4510	Low	Low	No	Low	12032	Sufficient	Poor	Good	Moderate
60	28/11/2007	Polkemmet Sth	Yes	6981	Low	Low	No	Low	18252	Poor	Poor	Good	Moderate
61	6/05/1998	Quantong	No	*	Moderate	Moderate	No	High	1090	Sufficient	Poor	*	Very good
62	10/11/1998	Quantong	No	*	Moderate	High	No	High	522	Sufficient	Poor	*	Moderate

ID number	Date	Site	Groundwater intrusion	Previous salinity surface	Previous river level	Freshes/ year	High flow	Baseflow	Salinity surface	DO% surface	Macrophyte habitat	Leaf packs and woody debris	Macroinverterbrate community diversity
63	10/11/2004	Quantong	No	*	Low	Low	No	Low	1024	Sufficient	Good	Good	Very good
64	**28/04/2005**	**Quantong**	**No**	*****	**Low**	**Moderate**	**No**	**Low**	**1548**	**Sufficient**	**Poor**	**Good**	**Very good**
65	23/11/2005	Quantong	No	1024	Low	Moderate	No	Low	2040	Sufficient	Good	Good	Good
66	13/11/2006	Quantong	No	2040	Low	Low	No	Low	3323	Sufficient	Good	Poor	Very good
67	29/03/2007	Quantong	No	2560	Low	Low	No	Low	4823	Sufficient	Poor	Good	Poor
68	26/11/2007	Quantong	No	3323	Low	Low	No	Low	2996	Sufficient	Good	Good	Moderate
69	9/11/2004	Tarranyurk	Yes	35052	Low	Low	No	Low	38580	Poor	Poor	Poor	Poor
70	**28/04/2005**	**Tarranyurk**	**Yes**	**17797**	**Low**	**Moderate**	**No**	**Low**	**29930**	**Poor**	**Poor**	**Poor**	**Good**
71	24/11/2005	Tarranyurk	Yes	38580	Low	Moderate	No	Low	38700	Poor	Poor	Poor	Poor
72	4/04/2006	Tarranyurk	Yes	29930	Low	Low	No	Low	52617	Sufficient	Poor	Good	Very poor
73	27/03/2007	Tarranyurk	Yes	38809	Low	Low	No	Low	55601	Sufficient	Poor	Poor	Poor
74	10/11/2004	U/S Ellis Crossing	Yes	*	Low	Low	No	Low	3875	Sufficient	Good	Good	Moderate
75	**26/04/2005**	**U/S Ellis Crossing**	**Yes**	**3020**	**Low**	**Moderate**	**No**	**Low**	**2206**	**Sufficient**	**Good**	**Good**	**Very good**
76	22/11/2005	U/S Ellis Crossing	Yes	3875	Low	Moderate	No	Low	8599	Sufficient	Good	Good	Good
77	4/04/2006	U/S Ellis Crossing	Yes	2206	Low	Low	No	Low	28717	Sufficient	Poor	Good	Good
78	14/11/2006	U/S Ellis Crossing	Yes	8599	Low	Low	No	Low	50221	Poor	Poor	Poor	Poor
79	28/03/2007	U/S Ellis Crossing	Yes	28717	Low	Low	No	Low	58080	Sufficient	Poor	Good	Very poor
80	11/11/2004	Wundersitz	Yes	*	Low	Low	No	Low	3461	Sufficient	Good	Good	Moderate
81	**27/04/2005**	**Wundersitz**	**Yes**	*****	**Low**	**Moderate**	**No**	**Low**	**3671**	**Sufficient**	**Good**	**Good**	**Very good**
82	23/11/2005	Wundersitz	Yes	3461	Low	Moderate	No	Low	4109	Sufficient	Good	Good	Moderate
83	5/04/2006	Wundersitz	Yes	3671	Low	Low	No	Low	4668	Sufficient	Good	Good	Very good
84	15/11/2006	Wundersitz	Yes	4109	Low	Low	No	Low	6436	Sufficient	Poor	Poor	Good
85	27/11/2007	Wundersitz	Yes	6436	Low	Low	No	Low	10843	Sufficient	Poor	Good	Moderate

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APPENDIX I: DATA USED FOR EVALUATING THE NETWORK

Table I1: Raw complete data sets used to evaluate the Bayesian network.

ID number	Date	Site	Groundwater intrusion	Previous salinity surface	Previous river level	Freshes/ year	High flow	Baseflow	Salinity surface	DO% surface	Macrophyte habitat	Leaf packs and woody debris	Macroinverterbrate community diversity
1	15/11/2006	Antwerp	Yes	8233	Low	0	No	0	19115	Sufficient	Poor	Poor	Poor
2	27/11/2007	Antwerp	Yes	19115	Low	0	No	0	35370	Sufficient	Poor	Good	Poor
3	11/11/2004	Lochiel	Yes	2856	Low	0	No	59	3657	Sufficient	Good	Poor	Moderate
4	27/11/2007	Lochiel	Yes	8400	Low	0	No	0	21740	Sufficient	Poor	Poor	Moderate
5	5/4/2000	Lower Norton	No	1092	Low	2	No	93	422	Poor	Good	Good	Very good
6	19/3/2003	Lower Norton	No	1539	Low	1	No	46	1691	Sufficient	Good	Good	Very good
7	9/11/2004	Lower Norton	No	2321	Low	0	No	59	1618	Sufficient	Good	Good	Good
8	23/11/2005	Lower Norton	No	1618	Low	2	No	93	619	Sufficient	Good	Good	Very good
9	5/4/2006	Polkemmet Nth	Yes	1923	Low	0	No	0	3877	Sufficient	Good	Good	Good
10	5/4/2006	Quantong	No	1548	Low	0	No	0	2594	Sufficient	Good	Good	Good
11	15/11/2006	Tarranyurk	Yes	38700	Low	0	No	0	49962	Sufficient	Poor	Poor	Poor
12	27/11/2007	Tarranyurk	Yes	49962	Low	0	No	0	51697	Sufficient	Poor	Poor	Very poor
13	28/11/2007	U/S Ellis Crossing	Yes	50221	Low	0	No	0	64417	Sufficient	Poor	Poor	Very poor
14	29/3/2007	Wundersitz	Yes	5234	Low	0	No	0	9040	Sufficient	Poor	Good	Moderate

APPENDIX J: MODEL PREDICTIONS OF THE EVALUATION DATA

Table 1: Network predictions for surface salinity, DO% surface, macrophyte habitat and macroinvertebrate community diversity for 14 cases in the lower Wimmera River. Bold font represents a correct prediction.

ID number	Site	Salinity surface	Predicted salinity surface	DO% surface	Predicted DO% surface	Macrophyte habitat	Predicted macrophyte habitat	Macroinverterbrate community diversity	Predicted macroinvert. community diversity	Percentages
1	Lower Norton	low	**low 73.6** moderate 25 high 1.17 very high 0.26	sufficient	**sufficient 84.3** poor 15.7	good	**good 77** poor 23	good	**good**	very good 20.1 **good 32.2** mod 31.4 poor 13.7 very poor 2.65
2	Quantong	low	**low 73.6** moderate 25 high 1.17 very high 0.26	sufficient	**sufficient 84.3** poor 15.7	good	**good 77** poor 23	good	**good**	very good 19.6 **good 32.3** mod 31.6 poor 13.8 very poor 2.67
3	Polkemmet Nth	moderate	low 30.8 **moderate 53.9** high 14.8 very high 0.44	sufficient	**sufficient 84.3** poor 15.7	good	**good 72.5** poor 27.5	good	moderate	very good 13 good 28.1 mod 34.4 poor 20.8 very poor 3.77
4	Wundersitz	moderate	low 0.11 **moderate 50.1** high 44.5 very high 5.28	sufficient	**sufficient 84.3** poor 15.7	poor	good 53.7 poor 46.3	moderate	**moderate**	very good 5.94 good 22.8 **mod 34.5** poor 29.1 very poor 7.67
5	Lochiel	moderate	low 30.8 **moderate 53.9** high 14.8 very high 0.44	sufficient	**sufficient 84.3** poor 15.7	good	**good 72.5** poor 27.5	moderate	**moderate**	very good 11.7 good 28.1 **mod 34.6** poor 21.8 very poor 3.8
6	Lochiel	high	low 0.11 moderate 50.1 high 44.5 very high 5.28	sufficient	**sufficient 84.3** poor 15.7	poor	good 53.7 poor 46.3	moderate	**moderate**	very good 5.22 good 22.9 **mod 34.0** poor 30.2 very poor 7.62

ID number	Site	Salinity surface	Predicted salinity surface	DO% surface	Predicted DO% surface	Macrophyte habitat	Predicted macrophyte habitat	Macroinverterbrate community diversity	Predicted macroinvert. community diversity	Percentages
7	Antwerp	high	low 0.11 moderate 50.1 high 44.5 very high 5.28	sufficient	**sufficient 84.3** poor 15.	poor	good 53.7 poor 46.3	poor	moderate	very good 5.22 good 22.9 mod 34.0 poor 30.2 very poor 7.62
8	Antwerp	high	low 0.031 moderate 0.58 **high 56.1** very high 43.3	sufficient	**sufficient 84.3** poor 15.7	poor	good 15 **poor 85**	poor	**poor**	very good 0.081 good 12.1 mod 20.6 **poor 37** very poor 30.2
9	Tarranyurk	very high	low 0.031 moderate 0.58 high 56.1 very high 43.3	sufficient	**sufficient 84.3** poor 15.7	poor	good 15 **poor 85**	poor	**poor**	very good 0.07 good 12.5 mod 20.5 **poor 36.9** very poor 30.1
10	Lower Norton	low	**low 91.5** moderate 8.04 high 0.37 very high 0.081	poor	sufficient 94.9 poor 5.08	good	**good 76.1** poor 23.9	very good	**very good**	**very good 57.5** good 21.5 mod 15.2 poor 5.07 very poor 0.75
11	Lower Norton	low	**low 91.5** moderate 8.04 high 0.37 very high 0.081	sufficient	**sufficient 94.9** poor 5.08	good	**good 76.1** poor 23.9	very good	**very good**	**very good 57.5** good 21.5 mod 15.2 poor 5.07 very poor 0.75
12	Lower Norton	low	**low 91.5** moderate 8.04 high 0.37 very high 0.081	sufficient	**sufficient 94.9** poor 5.08	good	**good 76.1** poor 23.9	very good	**very good**	**very good 57.5** good 21.5 mod 15.2 poor 5.07 very poor 0.75
13	U/S Ellis Crossing	very high	low 0.002 moderate 0.17 high 1.82 **very high 98**	sufficient	**sufficient 84.3** poor 15.7	poor	**poor 99.4** good 0.61	very poor	**very poor**	very good 0.02 good 0.45 moderate 1.02 poor 37.4 **very poor 61**
14	Tarranyurk	very high	low 0.002 moderate 0.17 high 1.82 **very high 98**	sufficient	**sufficient 84.3** poor 15.7	poor	**poor 99.4** good 0.61	very poor	**very poor**	very good 0.02 good 0.45 moderate 1.02 poor 37.4 **very poor 61**

APPENDIX K: MANAGEMENT SCENARIO TESTING UNDER DROUGHT CONDITIONS

Table K1: Management scenario testing results under drought conditions for four sites: Lower Norton, Polkemmet South, Upstream Ellis Crossing, and Tarranyurk

Site	Previous salinity	Baseflow	Freshes/year	Predicted EC	Predicted macroinvertebrate community diversity
Lower Norton	Low	Low	Low	Low 76.9%	Good 32.4% and Moderate 31.1%
Lower Norton	Low	**Low**	**Moderate**	**Low 92.2%**	**Very Good 57%**
Lower Norton	Low	Low	High	Low 90.2%	Good 32.8% and Very Good 32.3% and Moderate 25.9%
Lower Norton	Low	Moderate	Low	Low 81.2%	Good 31.9% and Moderate 28.8% and Very Good 25.7%
Lower Norton	Low	Moderate	Moderate	Low 96.9%	Very Good 40.9% and Good 31.7%
Lower Norton	Low	**Moderate**	**High**	**Low 95.5%**	**Very Good 53.6%**
Lower Norton	Low	High	Low	Low 84.8%	Good 31.3% and Very Good 30.5% and Moderate 26.8%
Lower Norton	Low	High	Moderate	Low 96.6%	Very Good 42.2%
Lower Norton	Low	High	High	Low 98.9%	Very Good 48.3%
Polkemmet South	Moderate	Low	Low	Moderate 50.6% and High 44.1%	Moderate 34.5% and Poor 29.2%
Polkemmet South	Moderate	**Low**	**Moderate**	**Moderate 56.1%**	**Very Good 32.2% and Moderate 27.3%**
Polkemmet South	Moderate	Low	High	Moderate 55.4%	Moderate 32.7% and Good 27.1%
Polkemmet South	Moderate	Moderate	Low	Moderate 52.1%	Moderate 33.7% and Poor 26.3% and Good 23.7
Polkemmet South	Moderate	Moderate	Moderate	Moderate 57.9%	Moderate 30.9% and Good 28.5% and Very Good 26.4%
Polkemmet South	Moderate	**Moderate**	**High**	**Moderate 57.3%**	**Very Good 33% and Moderate 28% and Good 23.8%**
Polkemmet South	Moderate	High	Low	Moderate 53.4%	Moderate 32.9% and Good 24.6% and Poor 23.5%
Polkemmet South	Moderate	High	Moderate	Moderate 57.7%	Moderate 30.6% and Good 27.9% and Very Good 27%
Polkemmet South	Moderate	**High**	**High**	**Moderate 58.6%**	**Very Good 32.3% and Moderate 29.2% and Good 27.3%**
Polkemmet South	High	Low	Low	High 57.3%	Poor 39.2%

Site	Previous salinity	Baseflow	Freshes/year	Predicted EC	Predicted macroinvertebrate community diversity
Polkemmet South	High	Low	Moderate	Moderate 46.2%	Poor 29.4% and Moderate 27.4%
Polkemmet South	High	Low	High	Moderate 40.2% and High 38.7%	Moderate 29.6% and Poor 29.3%
Polkemmet South	High	Moderate	Low	High 51.4%	Poor 36.6%
Polkemmet South	High	**Moderate**	**Moderate**	**Moderate 60.2%**	**Moderate 33.5% and Poor 23.7%**
Polkemmet South	High	Moderate	High	Moderate 55.9%	Moderate 30.4% Poor 25.7%
Polkemmet South	High	High	Low	High 46.2%	Poor 34% and Moderate 25.7%
Polkemmet South	High	High	Moderate	Moderate 59.1%	Moderate 33% and poor 24.1%
Polkemmet South	High	**High**	**High**	**Moderate 66%**	**Moderate 33.9%**
U/S Ellis Crossing	Moderate	Low	Low	Moderate 50.6% and High 44.1%	Moderate 34.4% and Poor 29.4%
U/S Ellis Crossing	Moderate	**Low**	**Moderate**	**Moderate 56.1%**	**Very Good 31.5% and Moderate 27.6%**
U/S Ellis Crossing	Moderate	Low	High	Moderate 55.4%	Moderate 32.8% and Good 27.2%
U/S Ellis Crossing	Moderate	Moderate	Low	Moderate 52.1%	Moderate 33.7% and Poor 26.5% and Good 23.8%
U/S Ellis Crossing	Moderate	Moderate	Moderate	Moderate 57.9%	Moderate 31.1% and Good 28.6% and Very Good 25.8%
U/S Ellis Crossing	Moderate	**Moderate**	**High**	**Moderate 57.3%**	**Very Good 32.3% and Moderate 28.3% and Good 24.1%**
U/S Ellis Crossing	Moderate	High	Low	Moderate 53.4%	Moderate 33% and Good 24.7% and Poor 23.7%
U/S Ellis Crossing	Moderate	High	Moderate	Moderate 57.7%	Moderate 30.8%, Good 28% and Very Good 26.4%
U/S Ellis Crossing	Moderate	**High**	**High**	**Moderate 58.6%**	**Very Good 31.5%, Moderate 29.5% and Good 27.5%**
U/S Ellis Crossing	High	Low	Low	High 57.3%	Poor 39.2%
U/S Ellis Crossing	High	Low	Moderate	Moderate 46.2%	Poor 29.1% and Moderate 27.7%
U/S Ellis Crossing	High	Low	High	Moderate 40.2% and High 38.7%	Moderate 29.7% and Poor 29.3% and Good 20.1%
U/S Ellis Crossing	High	Moderate	Low	High 51.4%	Poor 36.5%
U/S Ellis Crossing	High	**Moderate**	**Moderate**	**Moderate 60.2%**	**Moderate 33.6% and Poor 23.8% and Good 23.4%**
U/S Ellis Crossing	High	Moderate	High	Moderate 55.9%	Moderate 30.6% and Poor 25.6%

Site	Previous salinity	Baseflow	Freshes/year	Predicted EC	Predicted macroinvertebrate community diversity
U/S Ellis Crossing	High	High	Low	High 46.2%	Poor 33.9% and Moderate 25.8%
U/S Ellis Crossing	High	High	Moderate	Moderate 59.1%	Moderate 33.1% and Poor 24.2%
U/S Ellis Crossing	High	**High**	**High**	**Moderate 66%**	**Moderate 34%**
Tarranyurk	High	Low	Low	High 57.3%	Poor 39.1%
Tarranyurk	High	Low	Moderate	Moderate 46.2%	Moderate 28.8% and Poor 28.2%
Tarranyurk	High	Low	High	Moderate 40.2% and High 38.7%	Moderate 29.8% and Poor 29.6%
Tarranyurk	High	Moderate	Low	High 51.4%	Poor 36.4%
Tarranyurk	High	**Moderate**	**Moderate**	**Moderate 60.2%**	**Moderate 33.9% and Good 23.9%**
Tarranyurk	High	Moderate	High	Moderate 55.9%	Moderate 31.5% and Poor 25.3%
Tarranyurk	High	High	Low	High 46.2%	Poor 33.8% and Moderate 26%
Tarranyurk	High	High	Moderate	Moderate 59.1%	Moderate 33.5% and Poor 24.5%
Tarranyurk	High	**High**	**High**	**Moderate 66%**	**Moderate 34.5%**
Tarranyurk	Very High	Low	Low	Very High 97.7%	Very Poor 55.9%
Tarranyurk	Very High	Low	Moderate	Very High 44.3%	Poor 32.2% and Very Poor 28.2%
Tarranyurk	Very High	Low	High	Very High 51.2%	Poor 34% and Very Poor 30.8%
Tarranyurk	Very High	Moderate	Low	Very High 83%	Very Poor 48.2% and Poor 39.4%
Tarranyurk	Very High	**Moderate**	**Moderate**	**Moderate 40.1% and High 31.1%**	**Poor 30.2% and Moderate 26.7%**
Tarranyurk	Very High	Moderate	High	Moderate 37.2% and Very High 32.9% and High 29%	Poor 30.9% and Moderate 24% and Very Poor 21.4%
Tarranyurk	Very High	High	Low	Very High 70.1%	Very Poor 41.4% and Poor 37%
Tarranyurk	Very High	High	Moderate	Moderate 39.3% and High 30.6%	Poor 30.4% and Moderate 26.1%
Tarranyurk	Very High	**High**	**High**	**Moderate 44.1% and High 34%**	**Poor 29.2% and Moderate 28.7%**

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APPENDIX L: MANAGEMENT SCENARIO TESTING UNDER NON-DROUGHT CONDITIONS

Table L1: Management Scenario Testing results under moderate conditions under moderate previous river level, for four sites: Lower Norton, Polkemmet South, Upstream Ellis Crossing, and Tarranyurk

Site	Previous Salinity	Baseflow	Freshes/year	Predicted EC	Predicted Macroinvertebrate Community Diversity
Lower Norton	Low	Low	Low	Low 76.9%	Very Good 41.4%
Lower Norton	Low	Low	Moderate	Low 92.2%	Very Good 60.1%
Lower Norton	Low	Low	High	Low 90.2%	Very Good 64.3%
Lower Norton	Low	Moderate	Low	Low 81.2%	Very Good 50.8%
Lower Norton	Low	Moderate	Moderate	Low 96.9%	Very Good 71.9%
Lower Norton	Low	**Moderate**	**High**	**Low 95.5%**	**Very Good 75.4%**
Lower Norton	Low	High	Low	Low 84.8%	Very Good 58.2%
Lower Norton	Low	**High**	**Moderate**	**Low 96.6%**	**Very Good 81.6%**
Lower Norton	Low	High	High	Low 98.9%	Very Good 41.7% and Good 32.1%
Polkemmet South	Low	Low	Low	Moderate 53.4%	Moderate 28.9% and Very Good 26.7% and Good 21.1%
Polkemmet South	Low	Low	Moderate	Low 60.8%	Very Good 48.1%
Polkemmet South	Low	Low	High	Moderate 57%	Very Good 50.4%
Polkemmet South	Low	Moderate	Low	Moderate 47.8% and Low 39.4%	Very Good 35.2% and Moderate 25.5%
Polkemmet South	Low	Moderate	Moderate	Low 69.9%	Very Good 60.2%
Polkemmet South	Low	**Moderate**	**High**	**Low 67.1%**	**Very Good 62.3%**
Polkemmet South	Low	High	Low	Low 46.5% and Moderate 42.8%	Very Good 42.6%
Polkemmet South	Low	**High**	**Moderate**	**Low 69.2%**	**Very Good 68.1%**
Polkemmet South	Low	High	High	Low 73.7%	Very Good 35.8% and Good 30.9%
Polkemmet South	Moderate	Low	Low	Moderate 50.6% and High 44.1%	Poor 32% and Moderate 31%

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Site	Previous Salinity	Baseflow	Freshes/year	Predicted EC	Predicted Macroinvertebrate Community Diversity
Polkemmet South	Moderate	Low	Moderate	Moderate 56.1%	Very Good 33.8% and Moderate 26.6%
Polkemmet South	Moderate	Low	High	Moderate 55.4%	Very Good 34% and Moderate 25.8%
Polkemmet South	Moderate	Moderate	Low	Moderate 52.1%	Moderate 29.1% and Poor 28.3%
Polkemmet South	Moderate	**Moderate**	**Moderate**	**Moderate 57.9%**	**Very Good 45.3%**
Polkemmet South	Moderate	**Moderate**	**High**	**Moderate 57.3%**	**Very Good 45.8%**
Polkemmet South	Moderate	High	Low	Moderate 53.4%	Moderate 27.4% and Very Good 25.3% and Poor 24.5%
Polkemmet South	Moderate	**High**	**Moderate**	**Moderate 57.7%**	**Very Good 50.7%**
Polkemmet South	Moderate	High	High	Moderate 58.6%	Moderate 30.8% and Good 29.3% and Very Good 28.1%
U/S Ellis Crossing	Low	Low	Low	Moderate 53.4%	Moderate 29.2% and Very Good 26.1% and Good 21.3%
U/S Ellis Crossing	Low	Low	Moderate	Low 60.8%	Very Good 47%
U/S Ellis Crossing	Low	Low	High	Low 57%	Very Good 49.1%
U/S Ellis Crossing	Low	Moderate	Low	Moderate 47.8% and Low 39.4%	Very Good 34.4% and Moderate 25.9%
U/S Ellis Crossing	Low	Moderate	Moderate	Low 69.9%	Very good 58.7%
U/S Ellis Crossing	Low	**Moderate**	**High**	**Low 67.1%**	**Very Good 60.8%**
U/S Ellis Crossing	Low	High	Low	Low 46.5% and Moderate 42.8%	Very Good 41.6%
U/S Ellis Crossing	Low	**High**	**Moderate**	**Low 69.2%**	**Very good 66.4%**
U/S Ellis Crossing	Low	High	High	Low 73.7%	Very Good 35%, and Good 31.1% and Moderate 26%
U/S Ellis Crossing	Moderate	Low	Low	Moderate 50.6% and High 44.1%	Poor 31.8% and Moderate 31.2%
U/S Ellis Crossing	Moderate	Low	Moderate	Moderate 56.1%	Very Good 33.1% and Moderate 27%
U/S Ellis Crossing	Moderate	Low	High	Moderate 55.4%	Very Good 33.3% and Moderate 26.2%
U/S Ellis Crossing	Moderate	Moderate	Low	Moderate 52.1%	Moderate 29.4% and Poor 28.1%
U/S Ellis Crossing	Moderate	**Moderate**	**Moderate**	**Moderate 57.9%**	**Very Good 44.2%**
U/S Ellis Crossing	Moderate	**Moderate**	**High**	**Moderate 57.3%**	**Very Good 44.8%**

Site	Previous Salinity	Baseflow	Freshes/year	Predicted EC	Predicted Macroinvertebrate Community Diversity
U/S Ellis Crossing	Moderate	High	Low	Moderate 53.4%	Moderate 27.8% and Very Good 24.7% and Poor 24.3%
U/S Ellis Crossing	Moderate	**High**	**Moderate**	**Moderate 57.7%**	**Very Good 49.6%**
U/S Ellis Crossing	Moderate	High	High	Moderate 58.6%	Moderate 31% and Good 29.5% and Very Good 27.4%
Tarranyurk	Moderate	Low	Low	High 57.3%	Poor 38%
Tarranyurk	Moderate	Low	Moderate	Moderate 45.9% and High 36%	Poor 29.2% and Moderate 28.1%
Tarranyurk	Moderate	Low	High	Moderate 40.2% and High 38.6%	Moderate 30.7% and Poor 29.7%
Tarranyurk	Moderate	Moderate	Low	High 51.4%	Poor 35.8%
Tarranyurk	Moderate	**Moderate**	**Moderate**	**Moderate 60.1%**	**Moderate 35.1%**
Tarranyurk	Moderate	Moderate	High	Moderate 55.8%	Moderate 32.3% and Poor 26%
Tarranyurk	Moderate	High	Low	High 46.2%	Poor 33.5% and Moderate 26.5%
Tarranyurk	Moderate	High	Moderate	Moderate 59%	Moderate 34.5% and Poor 25.2%
Tarranyurk	Moderate	**High**	**High**	**Moderate 66%**	**Moderate 35.5%**
Tarranyurk	High	Low	Low	High 57.3%	Poor 41.6%
Tarranyurk	High	Low	Moderate	Moderate 46.2%	Moderate 28.5% and Poor 28.2%
Tarranyurk	High	Low	High	Moderate 40.2% and High 38.7%	Poor 30.1% and Moderate 26.7%
Tarranyurk	High	Moderate	Low	High 51.4%	Poor 38.4%
Tarranyurk	High	**Moderate**	**Moderate**	**Moderate 60.2%**	**Moderate 30.6% Poor 23.6%**
Tarranyurk	High	Moderate	High	Moderate 55.9%	Moderate 29.2% and Poor 25%
Tarranyurk	High	High	Low	High 46.2%	Poor 35.2%
Tarranyurk	High	High	Moderate	Moderate 59.1%	Moderate 29.3% and Poor 23.8% and Very Good 23.8%
Tarranyurk	High	**High**	**High**	**Moderate 66%**	**Moderate 35.3% and Good 25.3%**

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