Report No 2

NPSI Project UMO45: Delivering Sustainability through Risk Management

Ecological Risk Assessment Case Study for the Murray Irrigation Region

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

This report - *Ecological Risk Assessment Case Study for the Murray Irrigation Region* - is the second in a series of five produced by NPSI project UMO45 *Delivering Sustainability through Risk Management*.

An ecological risk assessment (ERA) was undertaken in the Murray irrigation region in southern NSW to assess the risks to the ecological values (or assets) from irrigation and other agricultural activities. This case study was part of a larger National Program for Sustainable Irrigation (NPSI) funded project (*UMO45 - Delivering Sustainability through Risk Management*), which aimed to achieve an improved level of adoption of risk-based approaches in environmental management and a greater capacity to use such approaches within both the Australian irrigation industry and regulatory authorities.

The Murray irrigation region case study sought to work in partnership with the irrigation industry (Murray Irrigation Ltd - MIL) and appropriate State irrigation regulators (the NSW Department of Environment & Conservation) to develop capacity within the individual organizations to use risk-based approaches to improve the ecological sustainability of the Murray irrigation region. An underlying expectation was that the use of ERA procedures would reduce the chance for conflicts between the industry and the government regulators.

The process

The Murray irrigation region case study was undertaken in two stages.

- The *problem formulation* stage focused on training key personal in risk assessment procedures, and undertaking a qualitative assessment of the key risks to environmental values in the Murray irrigation region. This report provides a brief summary of what was done and the outcomes.
- The *risk analysis* stage involved the development of quantitative Bayesian decision network (BDN) models for the two environmental assets assessed as being at high risk from irrigation - the Black Box (*Eucalyptus largiflorens*) wetlands and native fish communities (river health).

Black Box (*Eucalyptus largiflorens*) model

This BDN model predicts the following variables (endpoints):

- Black Box condition (as measured by percent canopy foliage), and
- Success of Black Box regeneration.

The model assumes these endpoints are influenced by five major factors: land management, surface water condition, soil condition, groundwater condition and wetting regime.

Sensitivity analysis of the model showed that altered wetting regime is the priority risk to maintaining the condition of Black Box trees and for successful regeneration. Fencing and grazing are also important factors in regeneration of these trees. In comparison, other factors (soil, groundwater and surface water salinity) only have a minor impact on tree health and regeneration.

Two management scenarios were tested to demonstrate application of the model in predicting the condition and regeneration of Black Box trees.

- *Scenario A (No fencing, river is regulated, no artificial wetland watering (irrigation or environmental))* - the model predicted a 39% probability that Black Box condition would be intermediate to good, and a 56% probability that condition would be poor to very poor.

The model also predicted a low (22%) probability that Black Box regeneration would occur.

- *Scenario B (Area is fenced, river is regulated, wetland receives environmental water, but not irrigation water)* - the model predicted an improvement in both condition and regeneration of the Black Box trees. For example, there was a slightly higher (42%) probability that the condition of Black Box trees would be intermediate to good, and a much lower (40%) probability that condition would be poor to very poor. However, this management scenario had greatest effect on the Black Box regeneration, increasing the probability of successful regeneration from 22% to almost 50%.

The results of a sensitivity analysis were used to simplify the complex model structure. This simple model is focused mainly on the wetting regime and fencing & grazing impacts. The simplified model performed more poorly than the complex model in all tests undertaken, but is still probably accurate enough for initial testing of different management scenarios.

The BDN model prediction supports the management actions (fencing and wetland watering) being promoted by Murray Irrigation Ltd, and promoted and implemented by Murray Wetland Working Group, on private lands as having a positive impact on the health of Black Box trees. A watering frequency of between one in five years and one in ten years was found to be optimal in maintaining tree health and promoting regeneration.

Fish Habitat Bayesian decision network model

During the Problem Formulation phase of the study, stakeholders assessed the degradation of 'river health' as a key risk from irrigation activities in the Murray irrigation region. However, there was disagreement between the groups on whether native fish communities in the region are under threat.

A Fish Habitat BDN model was developed to assist MIL, and potentially the Murray Catchment Management Authority (CMA), in managing irrigation and other activities that could threaten native fish communities and their habitat. This model is a sub-set of the much larger model that would be required to predict the effect of irrigation and other activities on 'river health'.

The Fish Habitat BDN model was based on the conceptual model developed in collaboration with key stakeholders, a previous Fish BDN developed for the Goulburn River in Victoria, and information adapted from the fish habitat condition model within the Murray Flow Assessment Tool (MFAT). MFAT contains the most up to date knowledge regarding fish communities in the Murray Darling Basin.

The current Fish BDN model is spatially limited to the section of the River Murray from Yarrawonga Weir to Wakool Junction, and to the Edward River. Preference curves relevant for this river section were set up as conditional probability tables in the BDN. Fish groups considered were flood spawners, freshwater catfish, main channel specialists and low flow specialists.

The Fish Habitat BDN model is still in the early stages of development with a number of components yet to be completed. However, even in this early stage the BDN model has a number of advantages compared with the MFAT fish module. These include: the capacity to *integrate model outcomes* for individual or groups of fish species, at one or more locations, and over broader spatial scales, easier testing of *management actions or system changes*, the BDN model is more *transparent*, *uncertainties* are built into the outputs (probabilistic distributions), and the model is easily updated as new data and information becomes available, making it compatible with *adaptive management* processes.

Lessons from this project

Clear definition of the objectives and scope of the project

Some stakeholders questioned the validity of the study once it became clear that the assessment would be limited to ecological values and would not address all issues of sustainability in the region. Despite the fact that it was never intended that this study would cover social and economic factors, the fact that this was not made absolutely clear from the start meant that stakeholder engagement (in itself an intensive process) in the project was poorly maintained. A problem with the Murray irrigation region case study from the outset was the poorly defined and amorphous objective of the assessment, the unclear and confused objectives of the project among stakeholders, and the lack of cohesiveness within the project team.

Values or threats?

Additionally, the project team did not spend enough time in defining the risk assessment language, e.g. there was confusion amongst stakeholders with the meaning of terms such as environmental or ecological value, environmental or ecological asset, threats and hazards, and risks. The objective of stakeholder interviews was to clearly define the ecological values (or assets) in the Murray irrigation region, and what the threats (or hazards) are to that value. It is crucial from the outset to define the distinction between these terms (although there can be cross over between terms), and to work through this with stakeholders.

Scales of interest

The different scale of interest between stakeholder groups was quite apparent during the Problem Formulation phase. Environmental and indigenous groups focussed on broad scales that are long-term and span entire systems (e.g. focus on entire river systems and homelands), whereas landholders focused on short-term scales, which span the size of a landholding (e.g. soil integrity, vegetation loss). These conflicting scales of interest contributed to some landholders failing to see how the activities on their landholding impact broader ecological scales.

Commitment of project partners

There was a notable difference in the level of commitment by industry partners in this ERA case study compared with two other ERA studies we have undertaken (Goulburn River study with Goulburn Murray Water (Pollino, 2003) and Lower Loddon study with Vic EPA, North Central CMA and GMW (Westbury - NPSI Report 3)). The differences may be linked to attitudes of industry staff, and to the resources available to undertake the study.

Adoption of risk-based approaches

It is clear that legislative incentives are a key driver for adoption of risk-based approaches by the irrigation (and other) industry in Australia. Currently, such incentives do exist in Victoria, but not in NSW. It is difficult to see irrigation companies going beyond a minimal Environmental Management System (EMS) to adopt risk-based approaches without some further legislative incentives.

The role of BDN models in decision making

When constructing models for an ecological risk assessment, uncertainties can arise as a result of incomplete datasets for model parameterisation, subjective assessments from expert indecision or lack of consensus amongst experts. The representation of uncertainty in risk assessment is critical in assisting system managers faced with making decisions to minimise or eliminate risks.

The BDN modelling approach is increasingly being used for predictive modelling of ecological systems with poor data and high uncertainties. The BDN models developed in this study, when used with other tools, will assist future decision-making in the Murray irrigation region. These BDN models are capable of being improved a new data and knowledge becomes available, making them an integral part of the adaptive management process.

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1. Introduction

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

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

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

The project has three components:

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

Five reports have been produced by this project:

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

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

This document is Report 2 of the series. It reports the case study undertaken in the Murray irrigation region in southern NSW. The Murray irrigation region project was undertaken in two phases:

- Phase 1 (Oct 2003 – June 2004) focused on training key personal in risk assessment procedures, and undertaking a qualitative assessment of the key risks to environmental values in the Murray irrigation region. This report contains only a brief summary of what was done and the outcomes. Full details are available in Pollino (2004).
- Phase 2 (July 2004 – Aug 2005) involved the development of quantitative Bayesian decision network (BDN) models for the two environmental assets assessed as being at high risk from irrigation - the Black box wetlands and fish habitat (river health).

The initial project partners for this case study were Murray Irrigation Ltd (MIL), NSW EPA (Department of Environment & Conservation) and the NPSI Risk Management project team (from Monash and Melbourne Universities).

2. The Murray irrigation region

The Murray irrigation district is located in southern NSW and stretches from Mulwala in the east, to Moulamein in the west, and covers over 748,000 hectares of farmland north of the Murray River (Figure 1).

It is believed that Aboriginal people have occupied the Murray-Darling Basin for at least 40,000 years. Several large Aboriginal communities lived in the Murray area, including the Banggarang, Yorta-Yorta, Baraba-Baraba, Wamba-Wamba, Wadi-Wadi and the Dadi-Dadi (Eardley, 1999).

The area was central to the Aboriginal way of life, providing a rich concentration of food resources. Communities that lived along the rivers would have controlled access to the water and its resources, the rights to this occupation being handed down from ancestors (Eardley, 1999).

Between 1835 and 1839, pastoral runs of between twenty and forty thousand hectares were established along the Murray and Murrumbidgee Rivers, as far west as Hay. In 1915 the River Murray Waters Agreement provided for the construction of 26 dams and the supply of water for irrigation became the main river focus (Eardley, 1999).

2.1 Murray Irrigation Limited (MIL)

MIL is a private irrigation company formed in 1995 under the Irrigation Corporations Act (1994) when the State Government of New South Wales transferred ownership of the Berriquin, Denimein, Deniboota, Wakool, and Tullakool irrigation areas and districts to irrigators. Ownership in MIL shares is held in proportion to the water entitlements owned by each irrigator.

MIL provides irrigation and drainage services for its shareholder irrigators across 748,000 ha of farmland, which stretches from Mulwala in the east to Moulamein in the west. The system is composed of 2,952 km of eastern supply channels and 1,222 km of stormwater escape channels. There are 19,000 structures in the supply and drainage system with a replacement value of $500 million.

MIL operations are licensed by the NSW Department of Infrastructure, Planning and Natural Resources (DIPNR) for the diversion and delivery of irrigation water (Irrigation Corporation Water Management Works License) to Murray irrigation shareholders. The NSW Department of Environment and Conservation (formerly Environmental Protection Authority) issues a license for the discharge of waters from the MIL area of operation.

Since the company's inception in 1995, MIL has sought to address the environmental issues of salinity, water quality and biodiversity (MIL, 2003). MIL focuses on environmental issues associated with operations at a broad scale and at a farm scale via the Murray Land and Water Management Plans (LWMPs). LWMPs are in operation at the Berriquin, Cadell, Denimein and Wakool districts (Figure 1). Within these districts, a total of 49% of the land has been developed for dryland farming and 51% for irrigation (MIL, 2003), although this varies each year according to water availability.

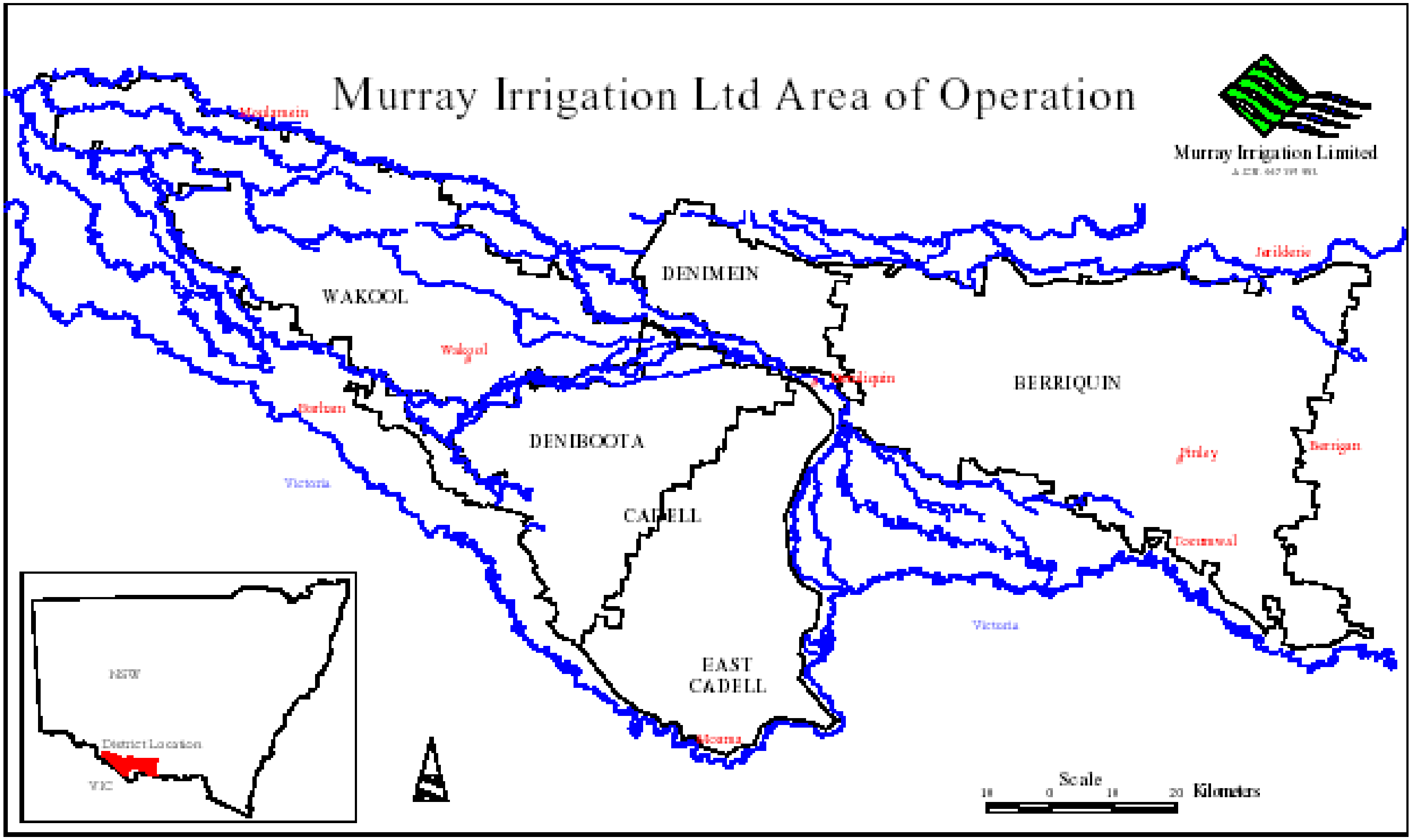


Figure 1: MIL area of operation (MIL, 2003). Streams are in blue and district boundaries are in black.

2.2 Land and Water Management Plan Areas

LWMPs are integrated catchment management plans developed by the local community with support by Local, State and Federal governments. The plans are a mixture of on-farm management initiatives and regional scale programs which seek to address the full spectrum of land and water sustainability issues including irrigation supply, on-farm irrigation, best farm management practices and district drainage.

The LWMP timeframes are 30 years with government and landholders expecting to invest $473 million. Government funding for the plans were secured for 15 years. The plans form the basis for environmental management on private land. Each LWMP district is characterised by its own landscape, with different farming activities and intensities of farming. Farming activities also change from year to year, given different circumstances.

Spatially explicit information was obtained for each of the 4 regions for the stakeholder consultation phase. Often the issues were common to each region, although the extent of the problem could changed according to the area examined.

Cadell LWMP: An estimated 14,800 people live in the Cadell district, of which the rural population is 4,750 (Cadell LWMP Working Group, 2001). The district covers 299,090 ha with 996 landholdings (MIL, 2003). In the district, rice is the dominant industry, followed by wool, wheat, prime lambs and beef cattle (Cadell LWMP Working Group, 2001). In 1994 the total production generated by the major enterprises was estimated at $40 million.

Wakool LWMP: The Wakool district has a population of only 880 people, of which 350 live in the township of Wakool and 500 in Moulamein (Wakool LWMP Working Group, 2001). The district covers 210,694 ha with 381 landholdings (MIL, 2003). In the district rice, wool, meat, cereals and milk are the main industries (Wakool LWMP Working Group, 2001).

***Denimein LWMP**:* The Denimein district has a population of over 350 people, of which 15% of Denimein landholders live in the township of Deniliquin (Denimein LWMP Working Group, 2001). The district covers 53,809 ha with 190 landholdings (MIL, 2003). Approximately 80% of landholders have been directly involved in an LWMP incentive. In the district rice is the dominant industry, followed by grazing, vegetables, dairy and piggeries (Denimein LWMP Working Group, 2001). There are also a large number of hobby farms.

***Berriquin LWMP**:* The Berriquin district has a population of 19,445 (Berriquin LWMP Working Group, 2001). The district covers 341,546 ha with 1,490 landholdings (MIL, 2003). The gross value for production in Berriquin was $144 million in 1991/1992. The main contributors were rice, milk, wool, vegetables, hay and cattle.

2.3 Existing catchment targets and plans

The biodiversity catchment target in the Murray Catchment Blueprint (Murray Catchment Management Board, 2003) predominantly focuses on vegetation:

> *"No net loss of all broad vegetation types (as mapped in 2001) and by 2012 restore 52,000 ha of under-represented broad vegetation types with the goal of achieving a minimum of 30% of their original extent and composition type by the year 2052."*

The target aims to protect and effectively manage existing remnant vegetation and to undertake long-term restoration of depleted 'ecosystems' (Murray Catchment Management Board, 2003).

The target also aims to have environmental, social and economic benefits:

- Environmental: support greater variety of plants and animals; improve ecosystem services (greenhouse gases reduction, prevent land degradation, improve soil health and water quality, control of runoff).
- Social: landscape aesthetics; opportunities for recreation, tourism, research, education; cultural identity and spirituality; protection of Aboriginal sites.
- Economic: control of land degradation; increased productivity; increased income sources.

Across the Murray irrigation region, vegetation cover is at approximately 10%, although cover varies considerably between the LWMP regions (e.g. approximately 6% vegetation cover remains in the Berriquin area versus approximately 17% in the Wakool area).

Other targets address improvements to the extent and quality of habitat for fish and aquatic species, recovery of at least 10 threatened species, and the maintenance of populations of threatened birds, mammals, reptiles and aquatic species.

2.4 Environmental specifics of the region

The availability of water and the highly fertile nature of the soils of the riverine floodplain make the area productive for plant growth. These factors have influenced human activities and land use in the region. The impact of land use has been an extensive modification of the natural distribution and condition of vegetation cover (Eardley, 1999).

Access to water for irrigation allowed for intensive agricultural production on lands adjacent to the Murray River, which has resulted in a complete modification and fragmentation of the landscape. In turn, the modification of the river systems to support intensive agriculture has resulted in altered hydrological regimes, water logging, salinity, land degradation, vegetation decline and fragmentation which has directly impacted upon and continues to threaten biodiversity (Eardley, 1999).

2.4.1 Soil quality

Soil acidity is a key indicator of soil condition. There is anecdotal evidence suggesting that the pH of soil has changed over time, with a trend toward increasing acidity.

2.4.2 Watertables and salinity

According to the MIL (2003), the most serious threat to the environment in the region is rising watertables. Given that the groundwater in much of the MIL region is naturally saline, the increased height of watertables causes waterlogging and mobilises salt through soils. High watertables and associated increases in soil salinity can adversely affect agricultural production, biodiversity, river health and infrastructure. Biodiversity impacts include the loss of species, the simplification of vegetation composition and change in vegetation structure. During the 2002/2003 period, salinity levels within the stormwater escape system varied between 45 EC and 139,000 EC, with median levels between 62 and 4,220 EC (MIL, 2003).

High watertables were reported in the western areas of the region during the 1950s and again in the 1970's. Over the past few years, there has been a general decline in the area affected by high watertables. Lower than average rainfalls, reduced water allocation, and LWMPs have potentially contributed to this fall. There are some areas in the region that continue to rise, particularly in the far east.

2.4.3 Quality of surface water

The MIL system has a stormwater drainage network, and to ensure that license requirements are being met, the system is routinely monitored for salinity, nutrients, turbidity and pesticides. Trends of discharge surface water quality in 2002/2003 indicate that parameters are trending in the right direction (MIL, 2003). However, this may be partially the result of reduced irrigation activities in the region given that there was a drought during the 2002 - 2003 season.

2.4.4 Nutrients and algal blooms

Previously, it has been stated that, given the high nutrient irrigation wastewater discharged from MIL, algal blooms are likely to occur (NSW EPA, 2002). Blue-green algal levels reached high alert levels in March and April 2003 in the Berriquin, Deinmein and Deniboota districts (MIL, 2003) but, it appears the bloom originated in the Hume Dam, and was transported through the MIL region via the Mulwala Canal. The bloom was a first for the supply system.

2.4.5 Pesticides

MIL operates a chemical contingency plan to prevent unacceptable levels of agricultural chemicals reaching receiving waters through the company's stormwater escape system. Escapes are monitored during October to December. Action is taken by MIL if unacceptable levels of chemicals are detected. During the 2002/2003 monitoring period, with drainage flows at a minimum, there were no detectable levels of chemicals in the stormwater escapes.

2.4.6 Changes to wetland and floodplain flora

River regulation, while providing a reliable and constant source of water for growing crops, has altered the delicate balance of the natural wetting and drying cycle and extent and duration of flooding. These changes have affected native flora and fauna habitat. Water regulation has promoted a compositional change of riverine vegetation by the expansion of some communities to the exclusion of others (Eardley, 1999).

Water regulation and altered hydrological regimes have impacted on wetland habitats and in particular waterbird breeding cycles. Australia wetlands have a natural process of drying and refilling to which native flora and fauna have adapted. The increase in water flow during dry periods stops the natural drying of rivers and breaks the wet/dry cycle favoured by fauna for breeding while the reduced height, frequency and duration of inundation of low to medium floods have in turn reduced waterbird breeding opportunities (Eardley, 1999).

River regulation and associated high summer river levels have led to the development of semi-permanent wetlands in some low-lying areas. While this provides habitat for waterbirds during dry seasons it results in the death of River Red Gum (*Eucalyptus camaldulensis*) (Smith and Smith, 1990), Black Box (*E. largiflorens*) and Lignum (*Muehlenbeckia florulenta*) which require periodic drying events and are used by fauna as habitat for breeding (Eardley, 1999).

The flooding requirements of the River Red Gum community means its distribution is restricted to the floodplains of the main river systems and their tributaries. The River Red Gum understorey is largely herbaceous comprising perennials, annuals and post flooding ephemerals (Eardley, 1999).

Adjacent to the River Red Gum on the higher, more saline heavy grey and brown clays of the outer parts of the floodplain is Black Box Woodland (*Eucalyptus largiflorens*). The Black

Box understorey comprises salt tolerant grasses, daisies and saltbushes. The common understorey shrubs include Lignum (*Muehlenbeckia florulenta*) and Nitre Goosefoot (*Chenopodium nitrariaceum),* Old Man Saltbush (*Atriplex nummularia*) and Bladder Saltbush (*Atriplex vesicaria*). It is a community that has been extensively cleared for cropping (Eardley, 1999).

Throughout the MIL region, there are 4 wetlands listed in the Directory of Important Wetlands in Australia on the Environment Australia website (http://www.ea.gov.au). These are located in the Werai Forest, the Millewa Forest, the Kondrook and Perricoota Forests, and the Wakool-Tullakool Evaporation Basins.

Vegetation mapping and bird surveys have been conducted in the MIL region as part of the Wetland Watering Program (a joint initiative between the NSW Wetlands Working Group, MIL and private landholders). Wetland watering trials commenced in the MIL region in 2001. The trials are focussed on providing water to wetlands, Black Box depressions and creek and stream runners (MIL, 2003; Nias *et al*., 2003) and are aimed at improving biodiversity in the region. Water birds and regeneration of native vegetation have been observed at wetland sites.

2.4.7 Changes to terrestrial vegetation

Remnant vegetation has been lost throughout much of the region, and is still declining in some parts. In NSW, native vegetation clearance is the single greatest threat to terrestrial biodiversity (EPA, 2000). Vegetation clearing and grazing reduce or modify natural habitat. Grazing in the MIL area has modified the saltbush plains. Apart from the impacts of clearing, cropping practices cause substantial changes in soil structure.

Many bird species that utilise the vegetation as habitat are listed as threatened. It is not only habitat loss from clearing that has caused the decline in bird populations, but also the fragmentation of habitat. Fragmentation results in the fauna increasingly relying on smaller patches of habitat for survival, and may lead to habitat simplification and habitat degradation. Those species which can compete successfully for reduced nesting sites, adapt to more open conditions, and co-exist with feral predators tend to survive (Eardley, 1999).

The native grasslands of the Riverina are of national importance because the lowland grasslands of south-eastern Australia are among the most threatened and poorly conserved ecosystems (Eardley, 1999).

2.4.8 Changes to fauna

The riverine forests form a relatively narrow strip of wetland habitat along the river system, and are particularly important habitat features in a landscape largely lacking tree cover. The Riverine Forest provides habitat for those species dependent upon trees for food, cover and nesting sites. Significant species known to inhabit the riverine forests include the Superb Parrot (*Polytelis swainsonii*), Sugar Glider (*Petaurus breviceps*), Feathertail Glider (*Acrobates pygmaeus*), Squirrel Glider (*Petaurus norfolcensis*), Brush-tailed Phascogale (*Phascogale tapoatafa*), Koala (*Phascolarctos cinereus*), Carpet Python (*Morelia spilota*), Freckled Duck (*Stictonetta naevosa*) and Peregrine Falcon (*Falco peregrinus*) (Eardley, 1999).

Wetlands support a diversity of waterbirds many of which are migratory, and several which are listed as vulnerable under the *NSW Threatened Species Conservation Act, 1995* such as the Australasian Bittern (*Botaurus poiciloptilus*), Freckled Duck and Painted Snipe (*Rostratula benghalensis*) (Eardley, 1999).

Black Box Woodlands provide important habitat for a variety of birds such as the Bush Thickknee (*Burhinus magnirostris*) and the Superb Parrot. The Superb Parrot is a threatened species and only nests in River Red Gum that are within 10 km of Box Woodland (Eardley, 1999). Grasslands and shrublands provide food and shelter habitat for a number of species, including the threatened Plains-wanderer (*Pedionomus torquatus*) (Eardley, 1999).

3 Problem formulation phase

3.1 Objectives

The Murray irrigation region case study sought to work in partnership with the irrigation industry (MIL) and appropriate State irrigation regulators (the NSW EPA) to develop capacity within the individual organizations to use risk assessment and risk management procedures to improve the ecological sustainability of the irrigation region. An underlying expectation was that the use of ERA procedures would reduce the chance for conflicts between the industry and the government regulators.

The first phase – problem formulation – is reported in this section. Only a brief summary of what was done and the outcomes is provided here. A more detailed report has been prepared by Pollino (2004).

3.2 What is an Environmental Risk Assessment?

Environmental risk assessment is a process for determining the level of risk posed by stressors, such as salinity, pesticides, nutrients, land clearing, to the health of ecosystems. Risk-based approaches evolved from the need to develop processes that better deal with the complexity of aquatic ecosystems, particularly when taking into account difficulties in assessing multiple stressors for a wide range of species within inherently variable ecosystems. The risk assessment process not only incorporates complexity and uncertainty into the decision making process, but also avoids ambiguity as it is transparent and clearly defines the problem and desired outcomes.

Risk-based approaches are increasingly being adopted by industries, environmental agencies and research bodies for evaluating adverse ecological effects. The level and method of investigation of risk is dependant on consideration of a number of factors, including: the perceived level of risk posed to the ecosystem, conservation issues, available resources, cost-benefit analysis and community concern.

The initial phase of a risk assessment is ***problem formulation***, which involves *identifying the environmental values (or assets) to be protected or managed, and the associated (existing and potential) threats or hazards to these values or assets* as a result of the irrigation activities. This normally involves undertaking the following:

- gathering and integrating available information from key stakeholders (e.g. community groups, irrigators, conservation groups, system managers, government agencies),
- developing a conceptual model of the issue(s), and
- developing a plan for the next stage of the assessment, being the risk analysis stage.

In the ***risk analysis*** stage, the priority hazards or threats are analysed further by investigating the likelihood (probability) of the adverse effect occurring and the consequences if such an event did occur. The outcomes of the risk analysis are used to inform the environmental management processes of regulatory bodies and the irrigation industry.

3.3 Approach - Identification of values and threats and priority risks

The problem formulation phase of this study was undertaken via short phone interviews, pre-workshop one-on-one interviews, a stakeholder workshop and post-workshop one-on-one interviews. Pollino (2004) has provided a full report on what was done and the outputs. A brief summary is provided in this section.

3.3.1 Phone interviews

An initial list of potential stakeholders was provided by MIL and this was expanded through a snowball sampling method, where stakeholders were asked to identify other individuals or organisations that they regarded as important. From that exercise, 19 groups/organisations were identified as important stakeholders. Sixteen of these were contacted by phone and given a short phone interview. The remaining stakeholders were contacted by email. Using information from these initial conversations a stakeholder map was produced.

Stakeholders were sent a letter of invitation to the workshop, background information about the MIL area of operation and a fact sheet containing background information about Ecological Risk Assessment and the project.

3.3.2 One-on-one interviews

Following the initial conversations, 8 one-on-one interviews were held. In these interviews stakeholders were asked to:

- Identify the aspects of the environment in the system under review that they regard as being of value/threatened/unsustainable,
- Identify the threats or hazards to the key values, and
- Consider whether they thought current land and water use practices in the region were sustainable.

The interviews also attempted to engage the interviewee in a conversation to elicit conceptual models (including information of the spatial and temporal scales to be considered).

3.3.3 Stakeholder workshop

A workshop was held on 31 March 2004 in Deniliquin, with the following objectives:

- Introduce the participants to the process of subjective risk ranking, the first stage of a complete ecological risk assessment,
- Demonstrate the importance of language, context and motivation in determining judgments of risk,
- Elicit a reasonably comprehensive set of hazards, defined as threats to things that the participants valued,
- Identify the most important issues from among the full list,
- Draft one or two conceptual models, to demonstrate the direction that an ERA may take.

The outcomes of the workshop are available on request.

3.3.4 Further stakeholder interviews

Following the workshop it was agreed that more discussion with stakeholders was required before the project could proceed to Phase 2. It was decided that additional in-depth individual stakeholder interviews were needed. Stakeholders from a number of groups were interviewed (Table 1) using the same format described above. Note that the categories of stakeholder groups in Table 1 (Environment, Irrigator etc) may not be that clearly distinct in practice.

Table 1: Target groups interviewed

Group	Organisation
Conservation	Riverina Environment Council Nature Conservation Working Group Nature Conservation Council Environment Victoria Murray Wetlands Working Group
Indigenous	Deniliquin Aboriginal Land Council Friends of the Earth Yorta Yorta Nations Aboriginal Corporation
Irrigator	Southern Riverina District Council Berriquin LWMP Cadell LWMP Denimein LWMP Wakool LWMP Groundwater Users Assoc.
Industry	MIL
Regulatory	NSW EPA NSW Fisheries DIPNR NSW Dept. of Agriculture NSW State Forests Murray CMA
Scientific	CSIRO

The outcome of the environmental value elicitation process from interviews are summarised in Table 2.

Table 2: Summary of elicitation of values from stakeholders, including number of references by stakeholders

Value	**No. of references**
Environmental / Ecological	
Good Land Management	1
Viable Environment	4
Barmah (incl Barmah lakes one also mention of Pericotta)	4
Terrestrial Vegetation (includes flora and fauna, grasslands, native veg and remnants)	17
• Fauna (birds: Barking Owl, Plains Wanderer [T], Superb Parrot [T]) Marsupial: Brush-tailed Phascogale)	4
Wetlands (Black Box depressions)	13
River Health (In stream Health)	7
• Fish	3
• Fishing	2
• River Redgums/ Floodplain forests	7
• Surface Water Quality	6
Soil Quality/ Health/ Productivity	6
Groundwater Quality	2
Air Quality	1
Whole Ecosystem	1
Economic*	
Sustainable Farming / Good Land Management	4
Productivity of Region	7
• Crop Production	2
Water Availability	1
Irrigation Industry	1
Social/Community*	
Public Perceptions of Farming	1
Cultural Integrity (Aboriginal)	1
Cultural Landscape (Aboriginal)	1
Sustainability of Region (services etc)	4

*** Questions asked during interviews were targeted towards Environmental/Ecological values ONLY. This study does not demonstrate the true reflection of Economic or Social /Community values.**

3.4 Key outcomes

The following environmental values (assets) featured prominently during problem formulation phase:

- Terrestrial vegetation and fauna,
- Wetland vegetation and fauna, and
- River 'health' (including floodplain).

For each issue, conceptual diagrams were constructed. These were based on information obtained from stakeholder interviews.

Model endpoints were further refined after consultation with representatives of MIL, the NSW EPA, the Murray CMA and the Murray Wetlands Working Group (MWWG).

The two options selected for further investigation were:

- *To develop a decision support tool for management of Black Box wetland communities,*
- *To investigate the relationship between 'river health' indicators (riparian, water quality, flows) and aquatic biota (macrophytes, fish, macroinvertebrates).*

It was anticipated that there would be major gaps in both data and knowledge to develop these two quantitative decision support tools. As recognised by Eardley (1999), conservation and biodiversity assessments of the Riverina bioregion have suffered from the lack of primary biological data, the inconsistency and quality of data, and the inaccessibility of some of the existing data sets.

4 Risk analysis phase

4.1 Objectives

Environmental Risk Assessment (ERA) is a formal process for improving the robustness of environmental management processes. The risk analysis phase of an ERA involves quantitatively assessing the relationships between the hazards/threats and environmental values/assets identified in the problem formulation phase. The outcomes of the risk analysis stage are used to develop tools to inform decision-making in environmental management.

The specific objectives of this phase were:

- To develop decision-support tools (quantitative models) linking hazards/threats and environmental values/assets identified in Phase 1,
- To assess and prioritise the key risks to environmental values in the Murray irrigation region, and
- To assist in developing a risk management plan to minimise the identified risks.

Further it was decided to develop two Bayesian decision networks to quantify the risks to:

- *Black Box* (Eucalyptus largiflorens) *wetland communities,* and
- *River health, specifically native fish and their habitat.*

It was anticipated that the models would be used to test the outcomes of alternative management scenarios, prioritise the risks to be managed, identify key knowledge gaps, and recommend where existing monitoring programs can be improved or where monitoring programs need to be implemented.

For the models to have an extended lifespan, they need to be updated using new data and information as it becomes available, particularly after management actions have been undertaken in the catchment. We believe it best if the model users (the resource managers) maintain the models. The predictive accuracy of Bayesian models improves as new data and information is incorporated, since these models can 'learn' to better represent existing relationships or new relationships.

4.2 Decision support tools

4.2.1 What are decision support tools?

A decision support tool should ideally set up an analytical framework exploring system variables and processes, and their interactions, with a set of environmental values acting as endpoints. The decision support tool to be used in this case study is a *quantitative model*.

Where possible, management actions and decisions should be underpinned by scientifically credible and pragmatic environmental decision support tools (Turner et al., 2003). To be robust, such tools should explicitly identify the processes used and the assumptions made by the decision-maker in decision-making (i.e. the process is tractable).

4.2.2 What are the advantages of using quantitative models compared with the decision processes currently used?

Traditionally in environmental management, although decisions have dealt with probabilities, rarely have they been quantified and decisions have largely been based on expert judgements. By using quantitative probabilistic models, decisions can be based on a combination of both data and expert judgements. Threats to a value are not looked at in isolation, but in association with one another. Importantly, unlike traditional approaches to decision-making, the probabilistic models produced in this case study will also explicitly quantify the uncertainties associated with decisions.

Using quantitative models, management scenarios or system changes can also be investigated to inform decision-making. Consequently, threats to environmental values can be prioritised and key data and knowledge gaps identified, thus identifying areas where further research and/or monitoring data is required.

By using a formal quantitative approach to decision-making, it is anticipated that a greater understanding of the decision processes and how these decisions relate to our environmental value will be achieved, and the decisions made will be more robust, defensible and tractable.

4.2.3 What if the data and understanding of the threats and the processes influencing the environmental value are poor?

Uncertainties are going to exist irrespective of whether a model exists. The models proposed in this case study are intended to document the data and knowledge that does exist, bring together disparate information held by the various groups, and develop a set of recommendations regarding the monitoring data and/or research studies that are required to better inform decisions in the future.

4.2.4 Who will use the models?

On completion, models will be made publicly available. The intended users of any tools produced are those engaged in the management of the environmental values/assets, those engaged in the management of activities which impact on environmental values/assets, and/or those engaged in activities that directly impact on the value/asset. By engaging all groups in the process of developing the quantitative models, it is hoped that an improved and shared understanding of the environmental value/asset and threats to conditions will be achieved.

4.2.5 Will the model unrealistically heighten the expectations of model users or landholders?

No. The models produce probabilistic outcomes over defined time periods, and associated with this prediction is a measure of uncertainty (e.g. over a 10 year period, the abundance of native fish community A has *x* probability of increasing given management actions *y* and *z* in the reach between Yarrawonga and Tocumwal). The models will not produce absolute numbers.

4.2.6 What if the model is wrong?

Models undergo a rigorous validation/verification process described in the latter part of this report. If the model is not robust, it will not be recommended for use in decision-making. Final models should be peer reviewed to ensure they are scientifically credible.

4.2.7 Will the models lead to a devolved responsibility by managers (who may take the easy way out by letting the model make decisions)?

Quantitative models should always be used in collaboration with other existing tools and management/decision-making processes. Models are not intended for use in isolation and decisions should not be made based on risk analysis alone.

4.2.8 Where will the model 'sit' and how will it be updated?

The models will be available for use by any group or person who expresses an interest, particularly as the models will potentially contain information from multiple groups. As the models are intended to promote integrative decision-making, hopefully those who adopt the final product will use and update it in a coordinated manner.

The models are not 'owned' by any group. This project is funded to improve environmental management, and all products will be available as a 'public good'.

Other questions often asked are: how will the model be updated? by whom? how regularly? And how will quality control be ensured?

If the models produced are adopted for use in a decision-support capacity, it is hoped that interested parties can work in a coordinated fashion. Programming interfaces can be put onto the model for updating and quality control purposes. This will be the responsibility of future model users.

On completion of the model development it is unlikely that the Water Studies Centre will be in a position to maintain it. We would hope that through the NPSI project we will train enough people with BDN skills to be able to keep these models going in the future.

4.3 Bayesian decision networks

4.3.1 What are Bayesian Networks?

Bayesian networks are graphical models used in a variety of applications to establish a causal relationship between key factors and final outcomes. They maintain clarity by making causal assumptions explicit (Stow and Borsuk 2003) and are often used for modelling when relationships to be described are not easily expressed using mathematical notation (Pearl 2000). Probabilities are used to represent linkages and these can be developed using expert knowledge or empirical data (Marcot *et al.* 2001; Rieman *et al.* 2001). Bayesian networks readily incorporate uncertain information (Reckhow 2002), with uncertainties being reflected in the conditional probabilities defined for linkages (Rieman *et al.* 2001).

In ecology, the modelling of processes using Bayesian networks is particularly ideal as Bayesian inference updates scientific knowledge as new information is made available (Reckhow 2002). This type of iterative improvement of models enables better accuracy in model prediction and fits into the ecological risk assessment paradigm.

4.3.2 How do they work?

Bayesian networks are made up of a collection of nodes that represent important environmental variables. Arrows represent causal dependencies between nodes. A probability distribution is used to describe the relative likelihood of the state of each variable, conditional on every possible combination of states of parent variables. If a node has no parents, it can be described probabilistically by a marginal probability distribution.

Bayesian networks exploit the distributional simplifications of the network structure by calculating how probable certain events are, and how these probabilities can change given subsequent observations, or predict change given external interventions (Korb and Nicholson 2004). A prior (unconditional) probability represents the likelihood that an input parameter will be in a particular state; the conditional probability calculates the likelihood of the state of a parameter given the states of input parameters affecting it; and the posterior probability is the likelihood that parameter will be in a particular state, given the input parameters, the conditional probabilities, and the rules governing how the probabilities combine. The network is solved when nodes have been updated using Bayes' Rule:

$$P(A|B) = \frac{P(B|A)\,P(A)}{P(B)}$$

where P(A) is the prior distribution of parameter, A. After collection of data B, P(A|B) represents the posterior distribution, given the new knowledge. P(B) is the marginal distribution of B (a normalising constant).

To determine how probabilities change in response to external interventions, such as management actions, the simplest intervention is to enter evidence by assigning a fixed distribution to the parameter of interest. Thus, the original function is assigned a new function that specifies a value, with other variables being kept the same (Borsuk et al. 2004). The new model represents the system's behaviour under the intervention and can be solved for the other variables to determine the net effect of the specified intervention.

The modelling shell Netica (www.norsys.com) is being used to construct Bayesian networks.

4.3.3 Constructing Bayesian decision networks

Developing Bayesian decision network models is an iterative process as shown in Figure 2 and discussed in Woodberry *et al*. (accepted).

Model structure

The first step in constructing a Bayesian network is to use the conceptual model for each endpoint to develop a causal structure, with relevant variables (nodes) and dependencies. Important criteria for deciding whether variables should be included in the BDN are - is the variable manageable, predictable, or observable at the scale of the management problem. Any processes or factors not included become part of the uncertainty of the network, forming the predictive uncertainty described in probability distributions.

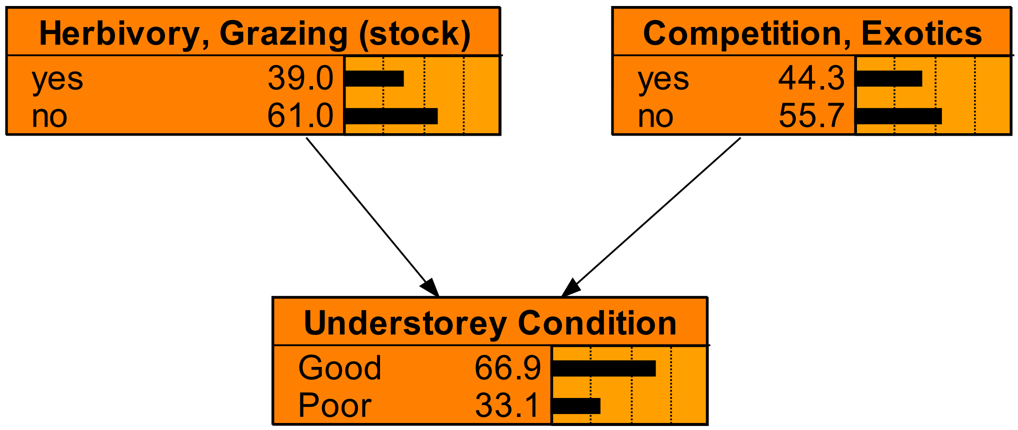
Discretisation of Nodes: Assigning States

States can be categorical, continuous or discrete. In order to represent continuous relationships in a Bayesian network, a continuous variable must be divided or discretised into states. The states of a variable can be numerical ranges (≤ 3, >3) or expressions (that can also represent data if appropriate, e.g. acceptable ≤ 3, unacceptable >3). Nodes can be discretised according to guidelines, existing classifications or percentiles of data (for examples of this, see Table 4).

An example of a continuous variable divided into discrete states (represented by numerical ranges) is shown in Figure 3.

Specification of prior probabilities

After defining node states, the linkages between nodes need to be described. Parent nodes lead into child nodes, and the outcomes of child nodes are conditional on how the parent variables combine. This is relationship is defined using conditional probability tables (CPTs). The following shows an example of CPT for the Black Box network, showing how the states of parent nodes combine to describe the outcome of the node 'Understorey Condition'.



		Understorey Condition	
Herbivory, Grazing	**Competition, Exotics**	**Good**	**Poor**
Yes	Yes	0.01	0.99
Yes	No	0.64	0.36
No	Yes	0.70	0.30
No	No	0.99	0.01

In the networks, sub-networks are used to describe physical or chemical processes relevant to the spatial scale specified. The impacts of these on the final outcome node, which often represents a biological/ecological process, are combined in the CPTs. For this reason, Bayesian networks are often described as being integrative models.

CPTs can be derived via one or a combination of methods:

- Direct elicitation of scenarios from expert,
- Parameterisation from datasets,
- Equations that describe relationships between variables.

It should be noted that the more complex the interactions are in a Bayesian network, the more conditional probabilities there are to specify.

Calculating posterior probabilities

Data or new knowledge can be incorporated into BNs and used to calculate posterior probabilities. Data sources can be entered into the network as a series of 'cases'. Cases can represent data collected during a monitoring exercise, undertaken as part of a research study, and so on.

Testing Management Alternatives

Management alternatives can be tested by entering new information into the network as evidence, directly changing the distribution of probabilities on the node itself.

Knowledge gaps and priority risks

Having established the structure of the model, and the relationships used to drive the model, the key knowledge gaps in our understanding and priority risks can be identified. To do this, sensitivity analysis is used.

Model validation

To test model accuracy, four tests are usually employed:

- Model predictions versus real data,
- Stakeholder review of the model,
- Sensitivity analysis,
- Predictive accuracy tests.

The first two tests are qualitative. Where possible, model predictions showing relationships between existing land uses, existing environmental conditions and ecological endpoints are plotted against existing data. The second test is a model review, which is conducted with key stakeholders. Stakeholder feedback is then used to test if the model output is reasonable, and where further effort is required to improve the model quantitatively and qualitatively.

The last two tests are quantitative. Two types of sensitivity analysis can be used to identify sensitive parameters - *sensitivity to findings* and *sensitivity to parameters*. Both are used to identify potential errors in the quantitative and qualitative components of the model.

The sensitivity to findings results are used to identify and rank risks to model endpoints. Sensitivity to parameters analysis provides a ranking of the importance of each variable, relative to the variable of interest (usually the endpoint). These results can be used to decide where better quantification in the network should be investigated.

The predictive accuracy test is conducted by splitting the dataset so that 80% will be used to train the model and 20% of the data set will be used to test model predictions.

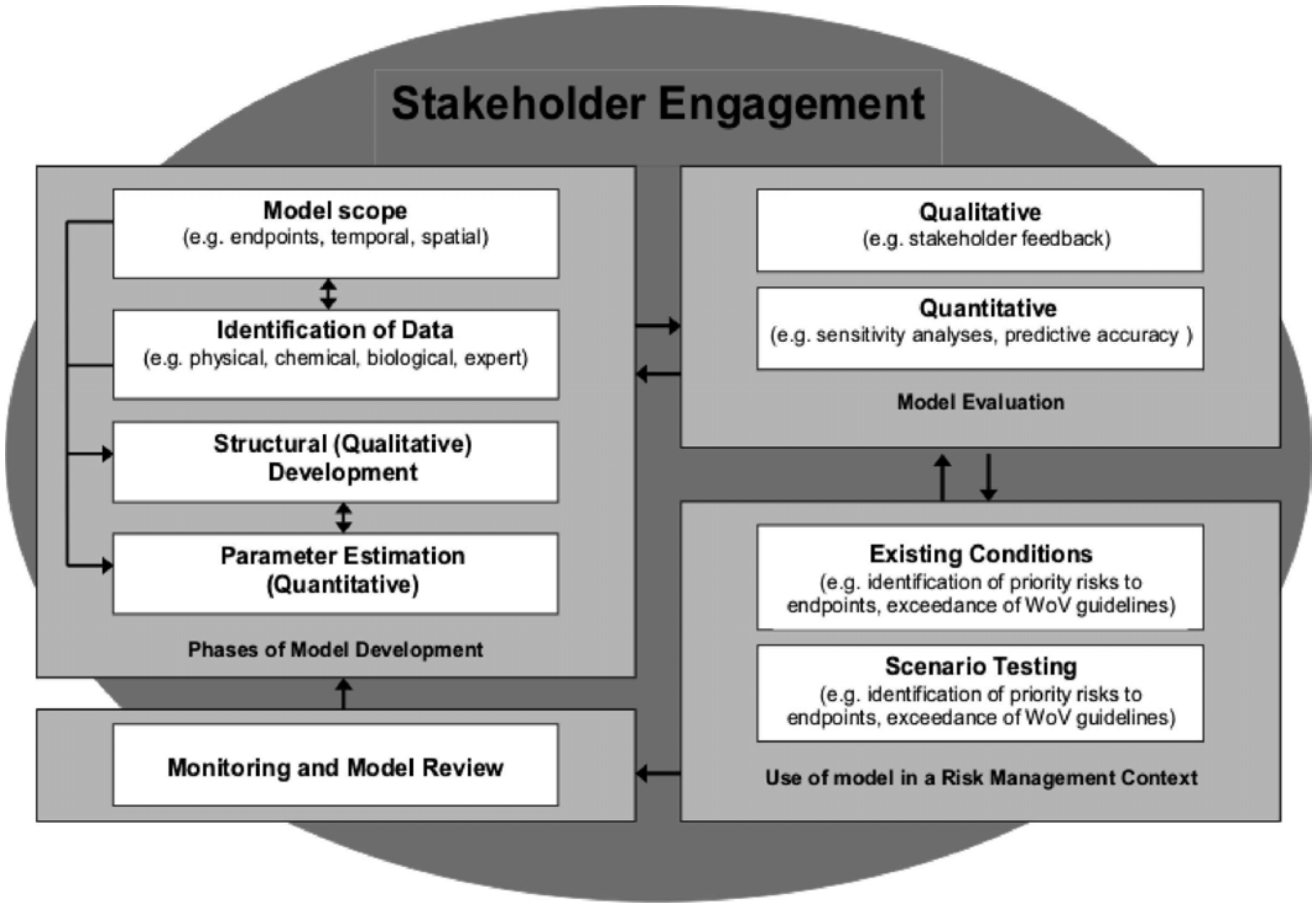


Figure 2: Major steps in the development and use of a Bayesian decision network model

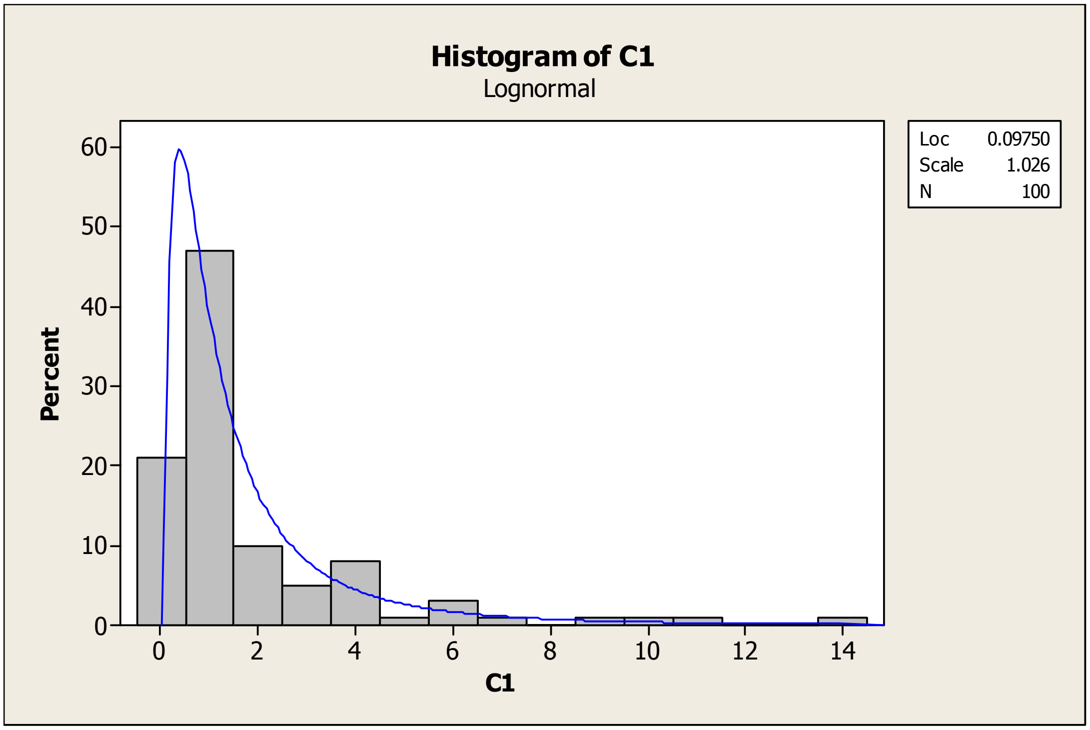


Figure 3: Example of how a continuous variable can be discretised.

5 Bayesian decision network for Black Box wetland communities

5.1 Background

The objective here was to develop a BDN model that could act as a decision support tool to potentially aid the MWWG, MIL and Murray CMA in management of activities that threaten the sustainability of Black Box (*Eucalyptus largiflorens*) depression communities.

Initial stakeholder discussions identified the following ways the BDN could assist managers (where possible, utilising knowledge already available):

- Further demonstrate that certain regimes for watering (how often? time of year? duration?) are more optimal than others for regeneration of Black Box and maintenance of Black Box depression communities (acknowledging that variability exists in watering and ecological response, and the importance in maintaining such variability);
- Further demonstrate how certain landholder activities (use as storage? unmanaged grazing? laser levelling? aerial spraying?) affect the ecological integrity of wetlands;
- Scenario test alternative management strategies for wetlands (eg. watering? grazing? fencing?):
    - Probabilistically predict the outcomes of alternative management regimes (e.g. by flooding a depression in the Wakool area *x* times over a 10 year period, there is a *x* probability of achieving regeneration);
    - Identify high risk activities and communicate those risks to stakeholders;
    - Quantify the uncertainty associated with predictions;
- Assist in prioritising watering of wetlands by demonstrating that the environmental conditions of certain Black Box wetland areas (soil type? groundwater height? proximity to drains? soil salinity?) are more optimal for watering than others (MIL);
- Assist in strategically selecting and targeting Black Box depressions on private land for watering (MIL) (include landholder attitude?);
- Develop a shared understanding of the factors influencing Black Box depressions amongst different stakeholder groups;
- Bring together past and present datasets (physical, chemical and ecological), and disparate datasets (e.g. MWWG, MDFRC, MIL, DIPNR);
- If relevant, connect existing NRM models (eg. hydro and water quality models) with ecological outcomes;
- Identify key knowledge gaps and make recommendations for improved monitoring and targeted research.

One of the MWWG selection criteria (after landholder applications have been screened by MIL) for selecting a wetland for watering on private land is ‘landholder attitude and motivation’ (Nias *et al.* 2003). The current BDN does not incorporate these ‘landholder attitude’ measures, but could do so in the future.

From all the possible benefits of the BDN models to both MWWG and MIL, the more likely benefits are listed in Table 3.

Table 3: Potential benefits of the BDN model to MWWG and MIL

Group	Benefits
Murray Wetland Working Group	• Further assist in determining the likelihood of an improved wetland biodiversity outcome • Further demonstrate the existence of knowledge and data gaps in the processes underpinning wetland management • Assist in directing where more rigorous data collection and research studies are required • Identify where the MWWG may wish to invest in gaining improved knowledge (knowledge generation) • Document community attitudes towards wetland watering • Use as an educational tool
Murray Irrigation Ltd	• Assist in screening landholder applications for wetland watering • Enable strategic approaches for selecting wetlands for watering • Explore how irrigation activities impact on wetlands • Improve ecological understanding of wetlands and wetland management • Use as an educational tool

5.2 The complex model

5.2.1 Stakeholder interactions

Stakeholder groups (NSW Murray Wetland Working Group, MIL, DIPNR, MDBC and MDFRC) were consulted during the development of this BDN to obtain information/advice about:

- the model scope (including endpoints),
- development and refinement of the model structure, and
- obtaining data.

At present, Black Box depressions in the Murray irrigation region are actively managed by the NSW Murray Wetlands Working Group (MWWG), under the Wetland Watering Program. This program is a joint initiative between the MWWG, MIL and private landholders. The MWWG membership is comprised of independent landholders and representatives of community groups, local councils, non-Government and Government agencies. MWWG activities include vegetation mapping and bird surveys. Given the important role of the MWWG in managing wetlands, they were consulted at the commencement of this project, and a cooperative working relationship was established.

The MWWG is working to rehabilitate degraded wetlands and improve the management of wetlands in the River Murray and Lower Darling catchments of New South Wales. The group seeks to develop and implement well researched, technically sound and community endorsed management programs for specific wetlands. The MWWG commenced wetland watering trials in the Murray irrigation region in 2001. The trials focus on providing water to wetlands, black box depressions and creek and stream runners, and are aimed at improving biodiversity in the region. Water birds and regeneration of native vegetation have been observed at wetland sites.

At the commencement of the study, a concern raised by the MWWG was the current lack of knowledge and data about Black Box depressions. The BDN model developed in this case study was intended to identify and compile the data and knowledge that does exist about Black box wetlands. The model has the potential to be used to make recommendations for future monitoring activities and/or research studies that are required to better understand linkages between key model variables. Given that the models are iterative, it is recommended that they be updated as new information/data is gained. As such, BDN models are ideal for promoting and enabling adaptive approaches to environmental management.

The model produced can also be used as an educational tool. As the majority of Black Box depressions are found on private lands, it is hoped that the model can further advocate the actions that can be undertaken by individual irrigators and the MWWG, and promoted by MIL to maintain and restore Black box depression sites. By using the model, it is hoped that a greater understanding of how irrigation and other landholder activities impact on depressions will be achieved, thus improving management actions in the future.

The model is to be used in collaboration with other tools and management/decision-making processes. Models are not intended for use in isolation and decisions should not be made based on risk analysis alone.

5.2.2 Threats/hazards

The following processes are thought to have resulted in the decline of the Black Box wetlands (according to the NSW Murray Wetlands Working Group, July 2005):

- *Changes to Natural Hydrology* - Many wetlands in the Murray Darling Basin area have been impacted by changes in the seasonality, duration, extent and frequency of flooding and drying. Some wetlands have been deprived of their natural flooding, while others have been degraded by permanent or near-permanent inundation due to river regulation.
- *Changes to Water Quality* - Water quality changes have been caused by disposal of waste water and poor management of surrounding land. These changes disturb the ecological processes within wetlands and lead to the loss of aquatic plants and habitat.
- *Salinisation* - In many areas, river regulation, irrigation practices and vegetation clearing are bringing saline groundwater closer to the surface. Wetlands, the lowest areas of the landscape, are usually the first areas affected by shallow watertables. Salinisation brings drastic changes to the vegetation and habitat of a wetland and restricts the options for managing flood inflows and recession.
- *Agricultural Use* - Development of wetland areas for agricultural production, such as lake bed cropping, irrigation or water storage, disturbs natural processes and may remove native vegetation. Excessive stock grazing of wetland vegetation may alter the mix of plant species and change the habitat for native fauna. Stock may also trample plants and disturb sediments and the invertebrates that those sediments support.

- *Surrounding Land Use* - The management of surrounding areas affects the condition of a wetland. Erosion from these areas causes excessive sedimentation and may carry nutrients and agricultural chemicals to the wetland. The fringe of native vegetation protects a wetland from such disturbances and is also an integral part of the wetland ecosystem. This fringing vegetation must be protected to maintain the diversity of habitats for native fauna and to minimise the impacts of surrounding activities.

5.2.3 Data and knowledge sources

The model was constructed using both quantitative and qualitative information obtained largely from MWWG and the scientific literature. Given the paucity of data relevant for the Murray irrigation region, the model incorporated data and knowledge from other areas within New South Wales (Murrumbidgee and Chowilla floodplain) and from South Australia (Chowilla floodplain). (Roberts *et al.* 2000) was used as a guide for the Black Box case study.

5.2.4 Model details

Variables

The BDN model predicts the following (endpoint) variables:

- Black Box maintenance/condition (as measured by percent canopy foliage), and
- Success of Black Box regeneration.

These endpoints are influenced by 5 major factors: Land management, Surface water condition, Soil condition, Groundwater condition and Wetting regime.

Model scale

The endpoints, which represent biological/ecological processes, were assumed to be site independent. Therefore, regardless of where Black Box occurred, the response to physical/chemical conditions would not change. There is no evidence in the literature surveyed to suggest that this assumption is incorrect.

However, a number of the driving variables are known to vary from region to region. To allow for this, the BDN model recognises several spatially distinct regions, namely: Denimein (MIL), Wakool (MIL), Cadell (MIL), Berriquin (MIL), Murrumbidgee, SA Chowilla and NSW Chowilla (no data at this stage).

It was also necessary to identify several temporal scales to account for the wetting regime. Inundation frequencies considered in the model were:

- No inundation
- One period of inundation in one year
- One period of inundation in five years
- One period of inundation in ten years
- One period of inundation in twenty years

Seasonal relationships were also explored in the model where possible (i.e. where there was data or knowledge).

Model structure

The first phase of model building was to construct a conceptual model for Black Box, looking at the variables that are important in regulating both condition and regeneration of *Eucalyptus largiflorens*. The conceptual model developed during the Problem Formulation phase was used as a starting point, and this was supplemented with additional variables and interactions after consulting the scientific literature and experts. The final model structure that was parameterised is shown in Figure 4.

Using the approach of (Borsuk *et al.* 2004), the important criteria for inclusion of variables in the Bayesian network were: is the variable either manageable, predictable, or observable at the scale of the management problem? If the variable from the conceptual model did not meet one of these criteria, it was not included. In the final model, the variables represent the key factors that are recognised in the scientific literature and by stakeholders as being important in determining the condition and regeneration of *Eucalyptus largiflorens*.

The model structure is highly complex, with many variables and interactions between variables. Such complexity is a product of stakeholders wishing to see a range of stressors represented in the model.

Many studies have been conducted looking at the impact of river regulation on Black Box. In order to show the relevant variables and the spatial scale of these studies, it is possible to select the 'Information Source' in the model, and the relevant probability distributions will be shown.

Model states

In order to represent continuous distributions in the BN, nodes were discretised into sub-ranges. Where possible, nodes are discretised according to existing guidelines and classifications or on classifications used in the scientific literature (see Table 4).

As stated previously, model parameters were estimated using quantitative and qualitative information. Information sources are documented in Table 4. Data is incorporated into the model in case format, and is represented in the network as probability bars (Figure 5). In the absence of monitoring data, probabilities are equally distributed.

In this study, a range of data and information sources were utilized. Qualitative and quantitative information was set up as a set of cases. The data file consisted of 529 cases. Probability distributions in the model were updated using the EM algorithm function of Netica (Woodberry et al. 2004), or specified using equations.

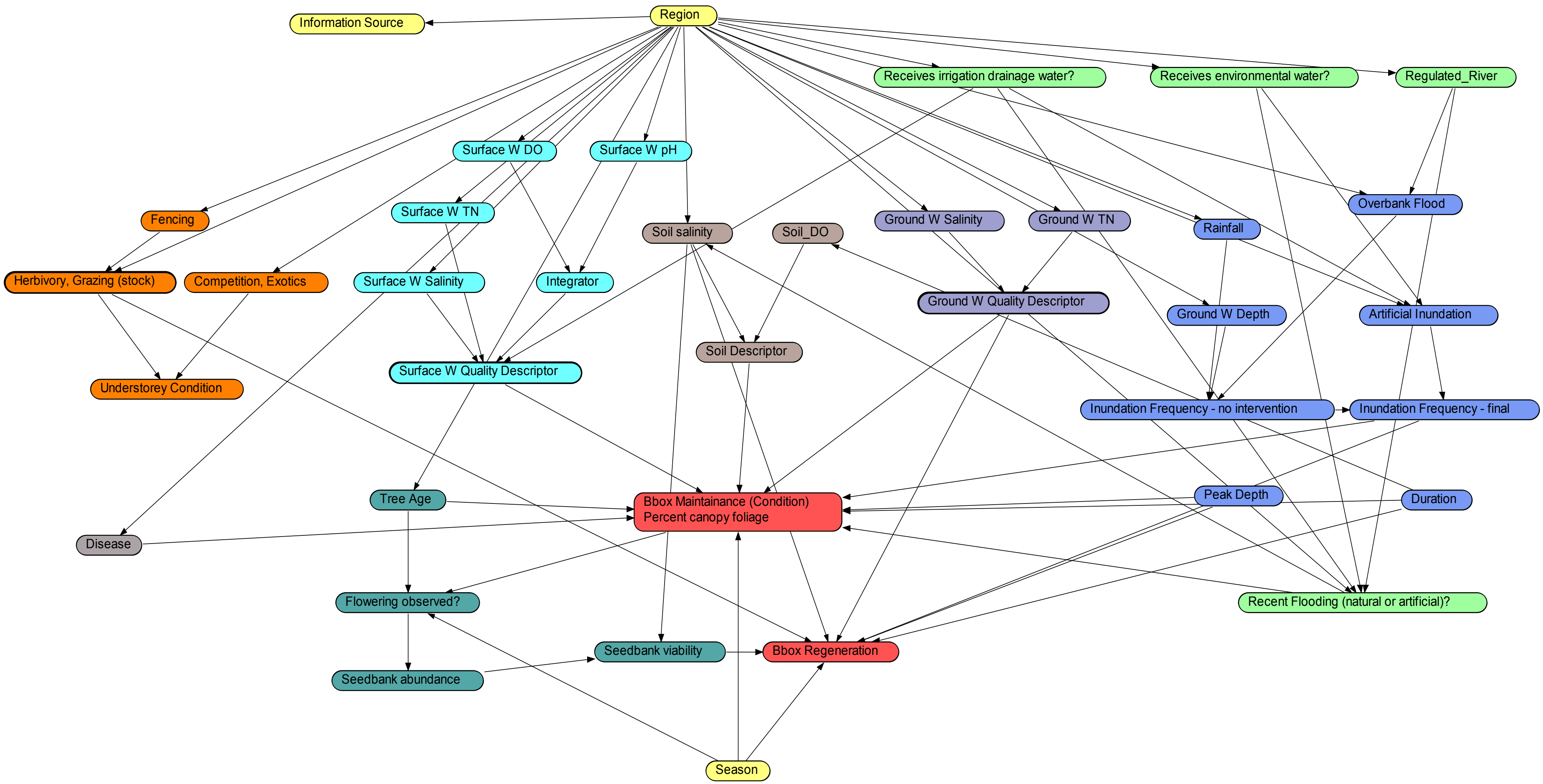


Figure 4: Model structure used for the complex BDN for Black Box (*Eucalyptus largiflorens*).

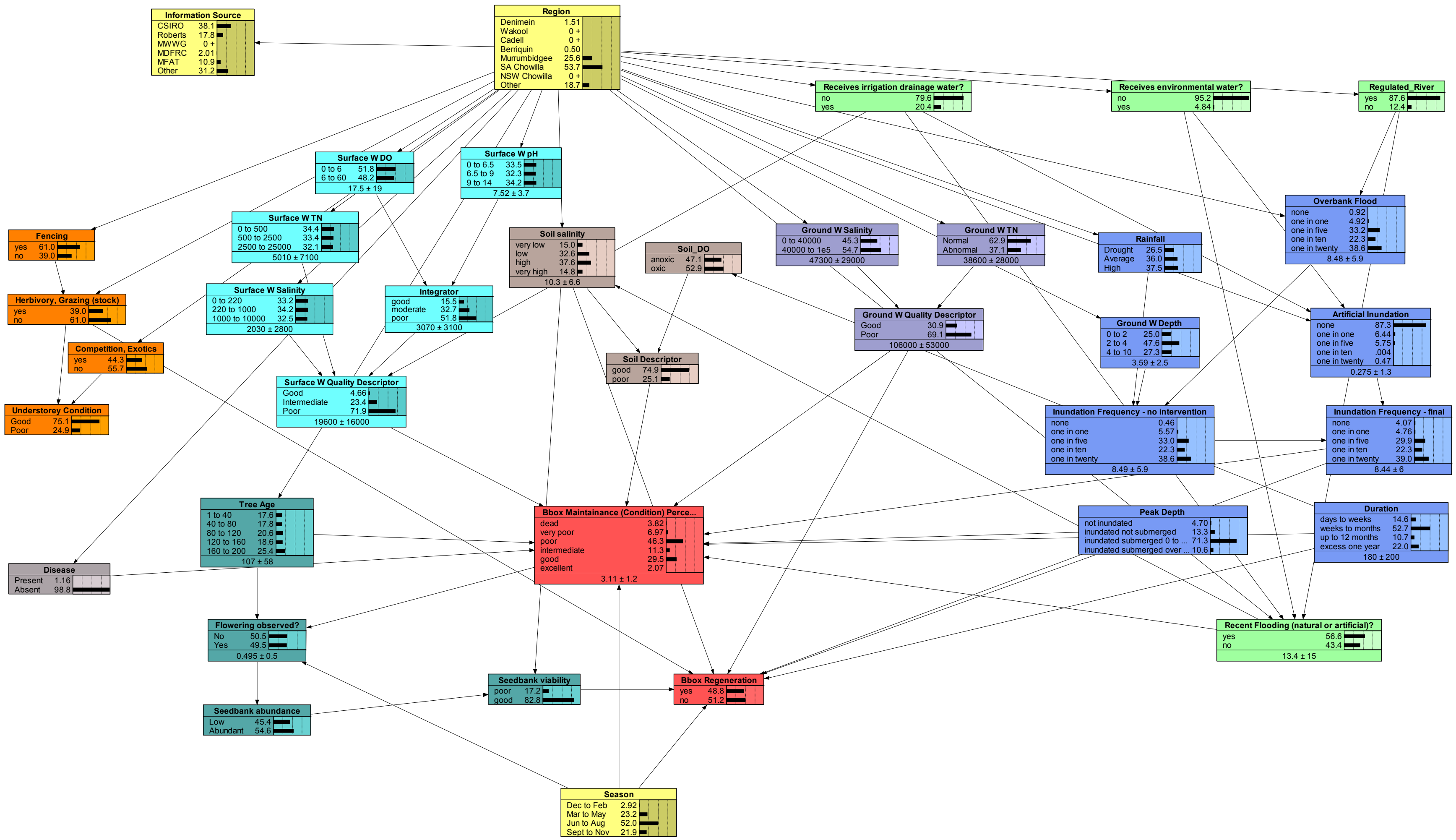


Figure 5: Complex BN for Black box (*Eucalyptus largiflorens*), showing model states.

Table 4: Definitions and sources of information used to parameterize conditional probability tables

Sub-network	Node name	Description	States Names	State Ranges	Equation or CPT?	Reference (States)	Reference (information source in model)
Information source	Information source	Source of data / literature / expert opinion	CSIRO Roberts MWWG MDFRC MFAT Others	-	CPT – specified from dataset	-	
Spatial scale	Region	Survey area	Denemein Wakool Cadell Berriquin Murrumbidgee NSW – Chowilla SA - Chowilla	-	CPT – specified from dataset		
Wetting Regime	Receives Irrigation Water?	Receives Irrigation Water?	No Yes		CPT		(Akeroyd *et al.* 1998; George *et al.* 2005; Jolly *et al.* 1993; Palmer and Roberts 1996; Roberts *et al.* 2000; Shepheard 1992; Taylor *et al.* 1996; Zukowski *et al.* 2003)
	Receives environmental water?	Receives environmental water (MWWG or otherwise)?	No Yes		CPT		
	Regulated River	Regulated River	No Yes		CPT		
	Recent flooding (natural or artificial)?	Recent flooding (natural or artificial)?	No Yes		CPT		
	Artificial Inundation	Watering by MWWG or private landholder	none one in one one in five one in ten one in fifty	0 - 0 0 - 1 1 - 5 5 - 10 10 - 50	CPT – specified from dataset	Literature	
	Overbank Flood	Natural flooding - position on floodplain relative to river. Based on current regime (weirs, levees, etc.)	none one in one one in five one in ten one in fifty	0 - 0 0 - 1 1 - 5 5 - 10 10 - 50	CPT – specified from dataset	Literature	
	Ground water depth	Height of groundwater from surface. Changes include effects of pumping.	0 – 2 m 2 – 4 m 4 – 10 m		CPT – specified from dataset	[Palmer, 1996 #258; Taylor, 1996 #442]	
	Rainfall	Rainfall	Drought Average High		CPT – specified from dataset		

Sub-network	Node name	Description	States Names	State Ranges	Equation or CPT?	Reference (States)	Reference (information source in model)
	Inundation Frequency - no intervention	Frequency of inundation of wetland without intervention	none one in one one in five one in ten one in fifty	0 1 5 10 50	CPT – specified from dataset		
	Inundation Frequency - final	Inundation of wetland with intervention	none one in one one in five one in ten one in fifty	0 - 0 0 - 1 1 - 5 5 - 10 10 - 50	CPT calculated frequency of inundation given intervention and no intervention scenarios	Literature	
	Peak depth	Peak inundation depth	not inundated inundated not submerged inundated submerged 0 to 20 cm inundated submerged over 20 cm		CPT – specified from dataset	Literature	
	Duration	Duration of inundation	Days to weeks Weeks to months Up to 12 months Excess one year		CPT – specified from dataset	Literature	
	Season	Season important variable for floristics and regeneration	Dec to Feb Mar to May Jun to Aug Sep to Nov		CPT – specified from dataset	Literature	
Groundwater Quality	Groundwater TN	Enrichment of total nitrogen in groundwater	Normal High		CPT – specified from dataset		(Eldridge *et al.* 1993; Jolly and Walker 1996; Palmer and Roberts 1996; Taylor *et al.* 1996)
	Groundwater Salinity	Salinity levels in groundwater	-	0 – 40000 uS/cm 40000 - 10000	CPT – specified from dataset	[Taylor, 1996 #442]	
	Groundwater quality Descriptor	Description of groundwater condition (Integrator)	Poor Intermediate Good		Ground_W_Quality (Ground_W_TN, Ground_W_Salinity) = Ground_W_TN + Ground_W_Salinity		
Soil Quality	Soil salinity	Soil salinity	Very low Low High Very high	2 – 4 4 – 8 8 – 16 16 - 30	CPT – specified from dataset	RIRDIC, Trees, Water and Salt	(Akeroyd *et al.* 1998; George *et al.* 2005; Jolly and Walker 1996; Miller *et al.* 2003)
	DO (soil water)		Anoxic Oxic		CPT – specified from dataset	Literature	
	Soil environment descriptor	Description of soil condition	Good Poor		Soil_Descriptor (Soil_salinity, DO) = Soil_salinity + 4*DO		

Sub-network	Node name	Description	States Names	State Ranges	Equation or CPT?	Reference (States)	Reference (information source in model)
Surface water Quality	Surface water pH		0 – 6.5 6.5 – 9 9 - 14	0 – 6.5 6.5 – 9 9 - 14	CPT – specified from dataset	ANZECC	(Zukowski et al. 2003)
	Surface water DO		Low Normal	0 – 6 mg/L 6 – 60 mg/L	CPT – specified from dataset	ANZECC	
	Surface water TN	Enrichment of total nitrogen in surface water	Normal High	0 – 500 ugN/L 500 - 5000	CPT – specified from dataset	ANZECC	
	Surface water salinity	Salinity levels in surface water		0 – 220 uS/cm 220 – 1000 1000 - 10000	CPT – specified from dataset	Zurkowski et al 2003 ANZECC	
	Integrator		Good Moderate Poor		CPT -		
	Surface water quality Descriptor	Description of surface water condition (Integrator)	Poor Intermediate Good		Surface_W_Quality (Surface_W_TN, Surface_W_Salinity, Integrator) = 0.5*Surface_W_TN + Surface_W_Salinity + Integrator		
Dry flora/ Management	Fencing	Fencing off of wetland from grazing	Yes No		CPT – specified from dataset	Literature	(George *et al.* 2005; Hart *et al.* 2003; Jolly *et al.* 1993; Roberts 2003; Roberts and Marston 2000; Shepheard 1992; Siebentritt *et al.* 2004; Taylor *et al.* 1996; Young *et al.* 2003)
	Herbivory, grazing	Stock, rabbits	None Some Intense		CPT – specified from dataset	Literature	
	Competition, exotics	Indication of spread	None Some Intense		CPT – specified from dataset	Literature	
	Understorey Condition	Condition of native understorey – indication of grazing	Poor: Bare dirt/ dominated by exotics Good: Healthy, abundant native veg		CPT – specified from dataset	Literature	
Black box	Disease	Indication of disease that may effect the health of the tree	Present Absent		CPT – specified from dataset	Literature	(Miller et al. 2003)
	Tree Age	Approximate age of trees – life span of trees?	1 to 10 10 to 20 20 to 50 50 to 100	1 to 10 10 to 20 20 to 50 50 to 100	CPT – specified from dataset	Literature	

Sub-network	Node name	Description	States Names	State Ranges	Equation or CPT?	Reference (States)	Reference (information source in model)
	Black box Maintenance / Condition	Percentage of canopy with foliage	very poor (1 to 25) poor (25 to 65) intermediate (65 to 85) good (85 to 95) excellent (95 to 100)	1 2 3 4 5	CPT – specified from dataset	Grimes Index (Roberts 2003)	(Akeroyd *et al.* 1998; Eldridge *et al.* 1993; Jolly and Walker 1996; Palmer and Roberts 1996; Sharley and Huggan 1995)
	Flowering observer?	Major Flowering: Dec, Jan Minor Flowering: Nov, Feb Incidental Flowering: Mar - Oct	No Yes		CPT – specified from dataset	Literature	(Siebentritt *et al.* 2004; Young *et al.* 2003)
	Seedback Abundance	Seedback Abundance	Low Abundant		CPT – specified from dataset	Literature	
	Seedbank Viability	Seedbank Viability	Poor Good		CPT – specified from dataset	Literature	
	Black box Regeneration	Ensures periodic establishment or re-establishment of plants, whether from seed or from other propagules.	Yes No		CPT – specified from dataset	Literature	(George *et al.* 2005; Roberts 2003; Sharley and Huggan 1995; Shepheard 1992; Siebentritt *et al.* 2004; Young *et al.* 2003)

The EM algorithm searches over Bayes net CPTs in an attempt to maximize the probability of the data given the Bayes net (i.e. minimize negative log likelihood) (Norsys 2005) and uses the Bayesian learning method of (Spiegelhalter *et al.* 1993). Netica assumes that the conditional probabilities are independent.[1] The updated model, including model states, is shown in Figure 5.

5.2.5 Model outcomes and validation

Sensitivity analysis

Sensitivity analysis was carried out in order to determine the variables that have the most influence on the condition of Black box. Sensitivity analysis results can be represented using metrics such as mutual information (Das, 2000; Korb and Nicholson, 2004) or by plotting variation in a target node, when parent nodes are altered over probability ranges 0 to 1. Outcomes can be used as a guide as to the most influential variables of tree condition. Subsequently, these are the variables should be given greater attention. These variables can represent key hazards, and parameters need to be determined accurately. In a management context, it is these variables that may represent key management actions.

Model findings consistently show that altered wetting regime is the priority risk to maintaining the condition of Black Box depressions, and for successfully achieving regeneration. Fencing and grazing are also important factors in regeneration. In comparison, other factors (soil, groundwater, surface water) only have a minor impact on tree health and regeneration.

Priority risks: Sensitivity analysis

Sensitivity analysis of mathematical models can be used to investigate the uncertainties and inaccuracies in model structure, relationships and outputs (Coupé et al., 2000), and subsequently identify where priority knowledge and data gaps exist. And, based on the results, recommendations can be made for targeted monitoring and investigations.

Condition of Black Box

Sensitivity results (Figure 6) show that Black Box condition is most sensitive to the wetting regime. ‘Good’ tree condition is maintained when the inundation frequency is between one in five and one in ten years. Optimal duration of wetting is weeks to months.

Response to poor soil condition is minimal. Black Box are frequently found in saline soils (e.g. Chowilla floodplain, SA), with little impact on the health of trees.

Regeneration of Black Box

Sensitivity analysis indicates seedbank viability is important in achieving regeneration of Black Box (Figure 7). Black Box regeneration is also impacted by grazing, so that fencing of depression areas is highly important in encouraging tree regeneration. Optimal regeneration occurs when depressions are wetted between one in five and one in ten year intervals.

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[1] This refers to the CPT table only, not the causal structure. This simplifying assumption is necessary to allow the parameterisation (learning) algorithms of BNs to operate efficiently. In reality, it is unlikely that this assumption is true for all relationships; however experience suggests that for elicited variables, expert intuitively consider parameters as conditionally dependent. For learning algorithms, the assignment of states is generally robust to this assumption. The sensitivity of the network (and parameters) to this assumption has not been assessed for the networks in this report.

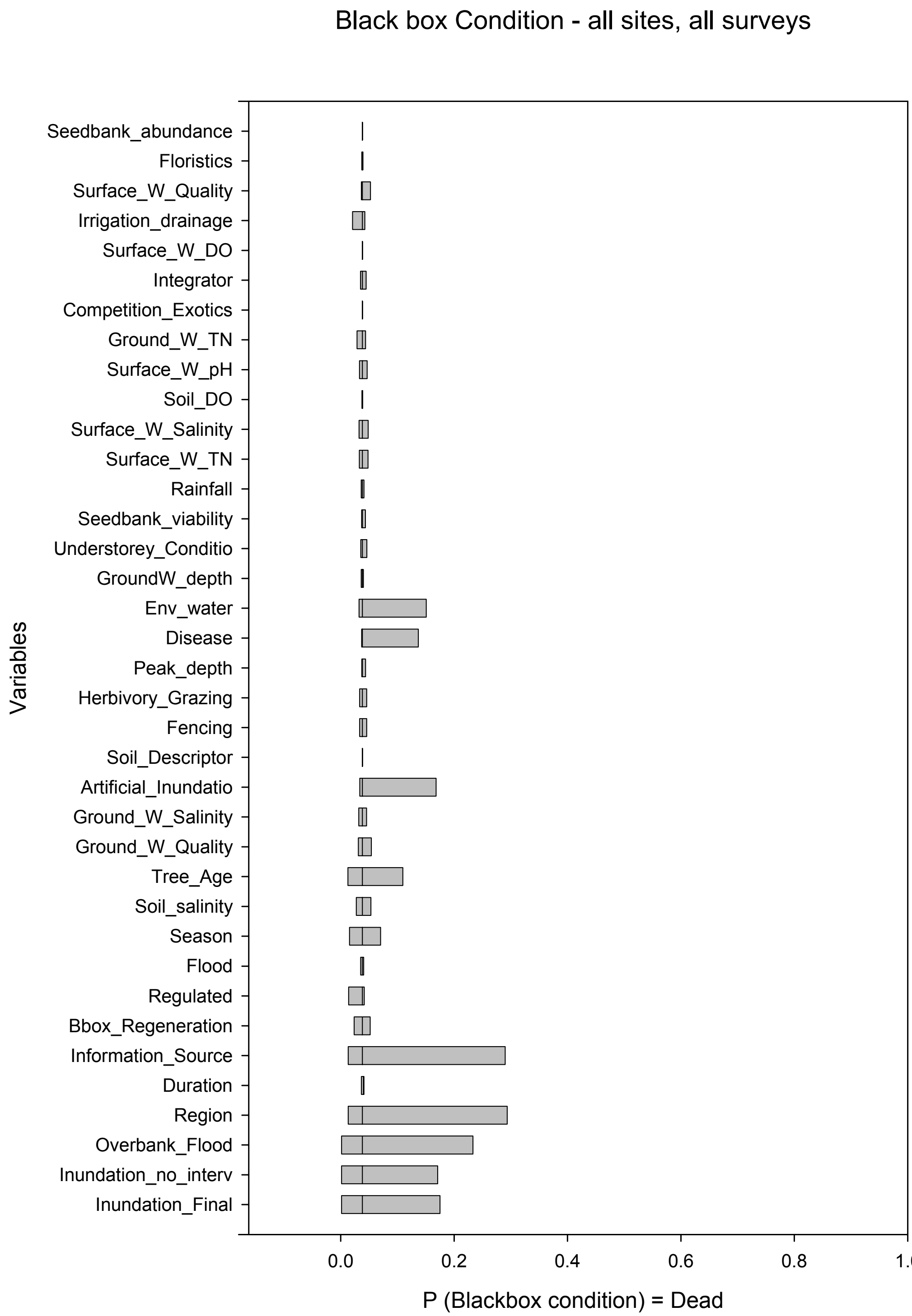

Figure 6: Sensitivity analysis results for the complex Black Box BDN (relevant for the endpoint 'Condition'), relevant for all regions and all studies

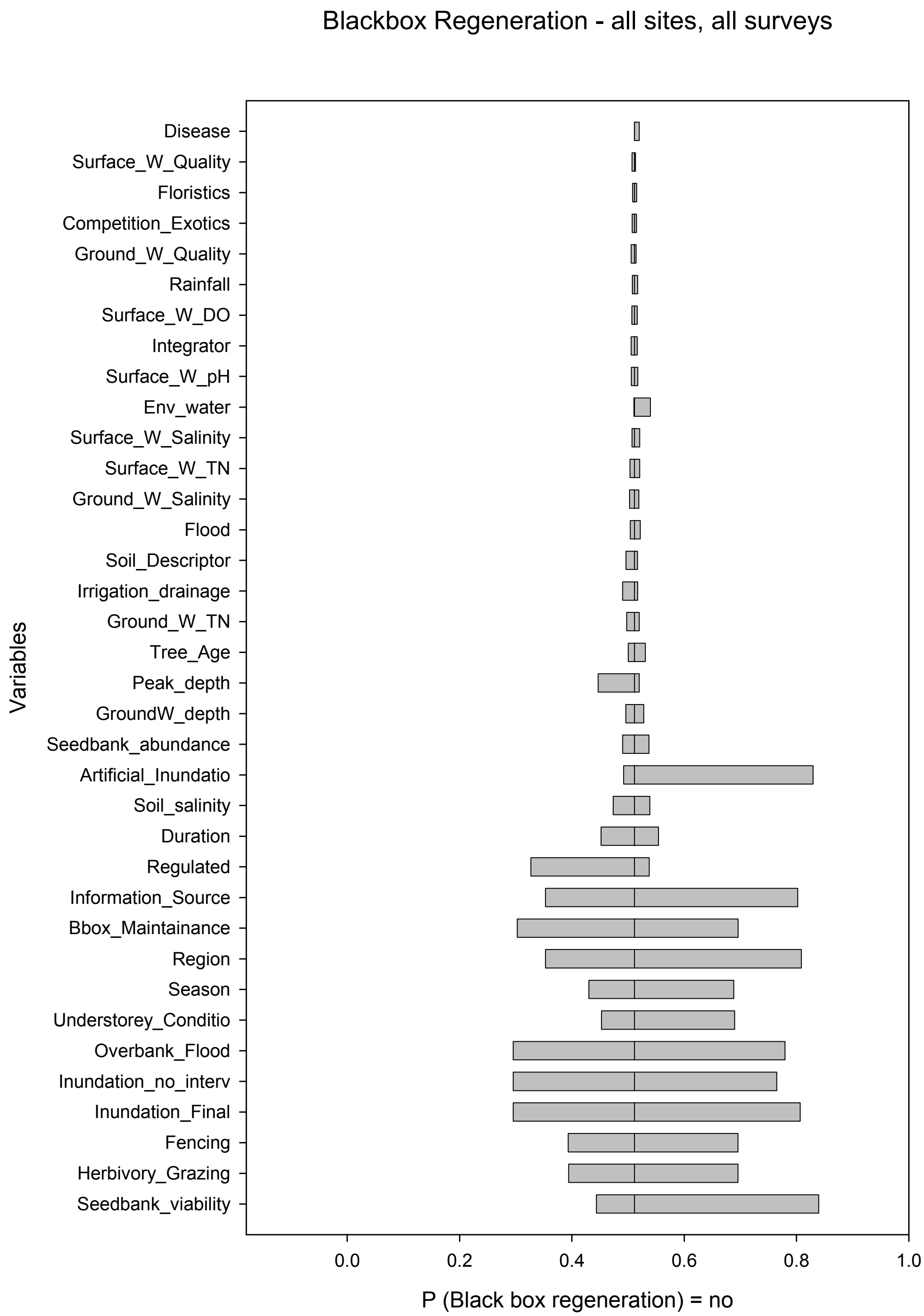

Figure 7: Sensitivity analysis results for complex Black box BDN (relevant for the endpoint 'Regeneration'), relevant for all regions and all studies.

Predictive Accuracy Tests

To test the predictive accuracy of the BDN model, case data was split, with 80% of the data used for training and 20% used for testing. The 80/20 split of case data was random.

Results indicate that the predicted and actual values from the test cases were not always consistent. The accuracy of model predictions is only fair. Further data and or knowledge are required to improve the model accuracy.

Predictive Accuracy

Predictive accuracy records the frequency with which a model gets its prediction right, and is a widely used technique for model evaluation.

The error rates of the two endpoints (condition and regeneration) were:

Condition error rate = 33%

Regeneration error rate = 16%

Scoring Rules

Probability assessments can be evaluated using scoring rules.[2] When using a set of cases for evaluation, scoring rules calculate the difference between actual outcomes and the assessed probability (Morgan and Henrion 1990).

Interpretation of these scoring rules is as follows (Norsys, 2005):

- Logarithmic loss values are between 0 and infinity inclusive, with zero indicating the best performance,
- Quadratic loss (also known as the Brier score) is between 0 and 2, with 0 being best,
- Spherical payoff is between 0 and 1, with 1 being best.

The scoring rule results were:

- *Condition* (for 80/20 data split): Logarithmic loss = 0.91; Quadratic loss = 0.50; Spherical payoff = 0.71
- *Regeneration* were (for 80/20 data split): Logarithmic loss = 0.59; Quadratic loss = 0.26; Spherical payoff = 0.86

5.2.6 Management scenarios

Two management scenarios were tested to demonstrate how the model can be used. The endpoint of interest is Black box condition and regeneration.

Scenario A: No fencing, river is regulated, no artificial wetland watering (irrigation or environmental

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[2] Scoring rule equations (Norsys. 2005. Netica: www.norsys.com.):

Logarithmic loss = MOAC [- log (Pc)]

Quadratic loss = MOAC [1 - 2 * Pc + sum[j=1 to n] (Pj ^ 2)]

Spherical payoff = MOAC [Pc / sqrt (sum[j=1 to n] (Pj ^ 2))]

where Pc is the probability predicted for the correct state, Pj is the probability predicted for state j, n is the number of states, and MOAC stands for the mean (average) over all cases (i.e. all cases for which the case file provides a value for the node in question).

For this scenario, the BDN model predicted (Figure 8) a 39% probability that the Black Box condition would be intermediate to good, and a 56% probability that condition would be poor to very poor. The model also predicted a low (22%) probability that Black Box regeneration would occur.

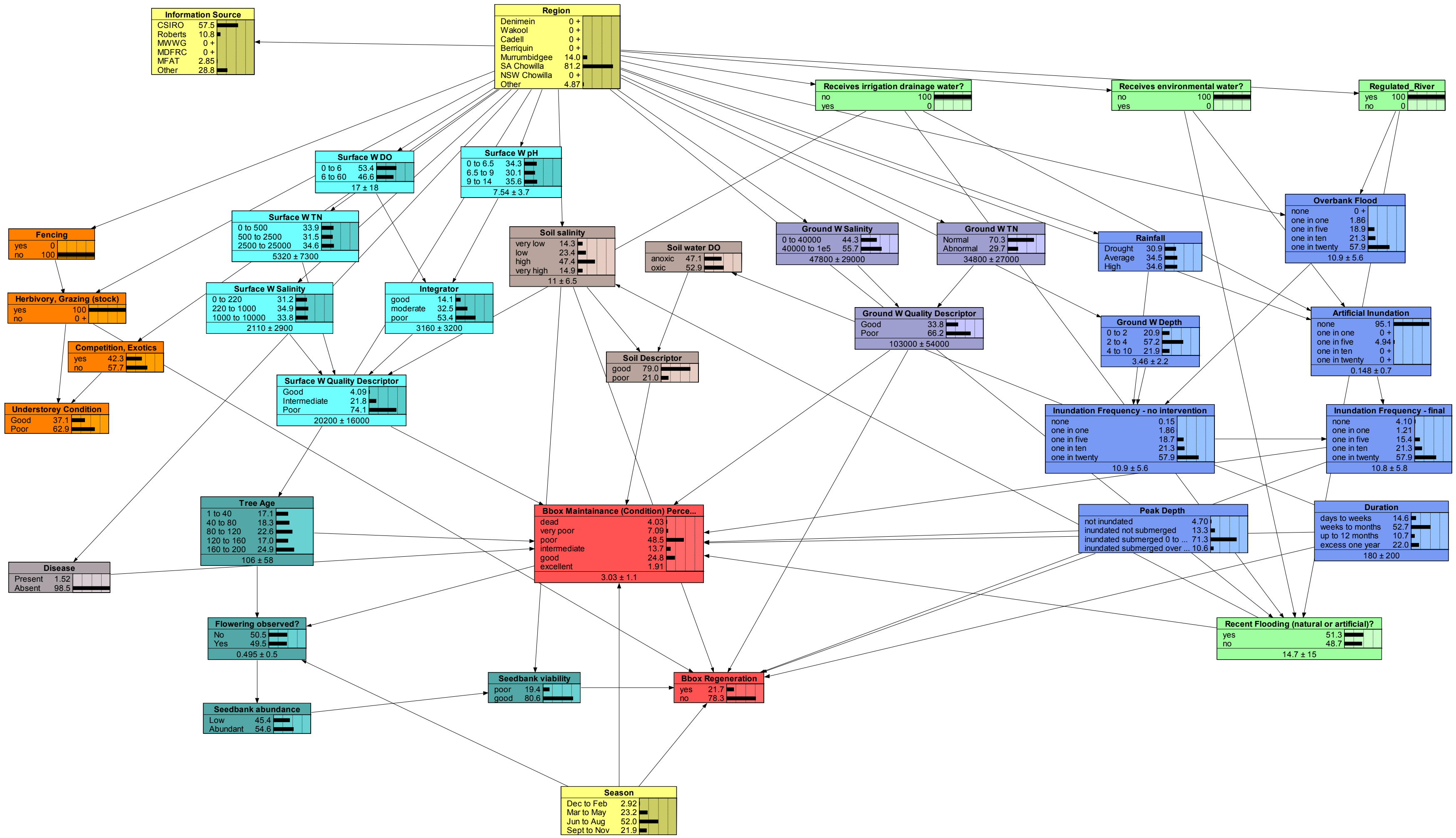

Figure 8: Complex BDN for Black Box (*Eucalyptus largiflorens*), showing interventions (scenario A)

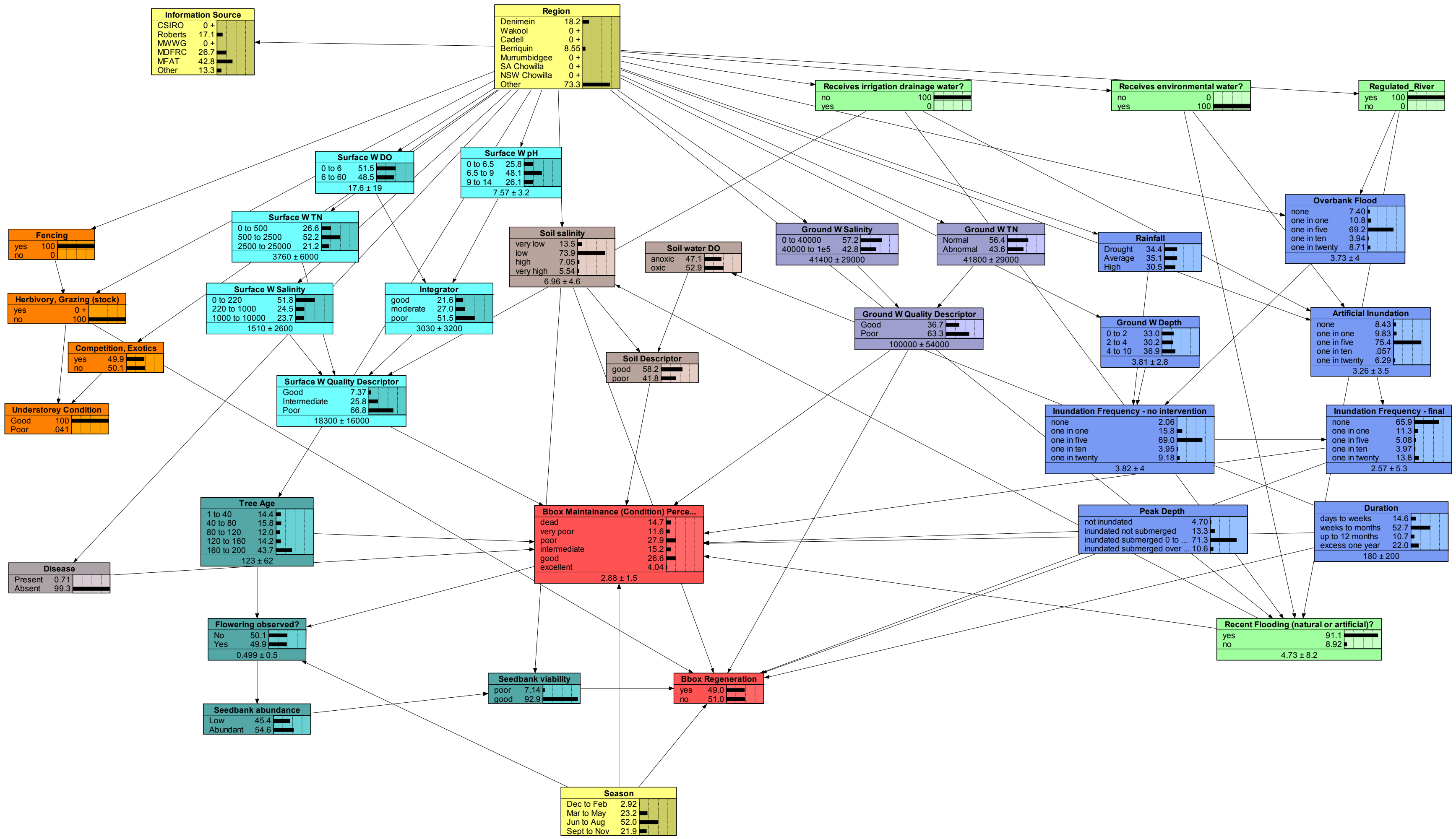

Figure 9: Complex BDN for Black Box (*Eucalyptus largiflorens*), showing interventions (scenario B)

Scenario B: Fencing, river is regulated, wetland receives environmental water, but not irrigation water

For this scenario, the BDN model predicted an improvement in both condition and regeneration of the Black Box trees (Figure 9). For example, there was a slightly higher (42%) probability that the Black Box condition would be intermediate to good, and a much lower (40%) probability that condition would be poor to very poor. However, this management scenario had greatest effect on the Black box regeneration, increasing the probability of successful regeneration from 22% to almost 50%.

5.3 The simple model

One of the advantages of Bayesian decision network models over other modeling approaches is their simplicity. They are able to describe inherently complex relationships (Stow *et al.* 2003), while avoiding the over representation of irrelevant mechanistic detail (Borsuk et al., 2004).

It is always useful to test a BDN to see if it can be made simpler, since simple models are easier to comprehend (Iwasa *et al.* 1987), and make it easier to communicate results to stakeholders. For these reasons a simplified version of the Black Box BDN was developed to investigate whether a simpler model could do the same (or a better) job.

5.3.1 Model structure

The results of the sensitivity analysis were used to simplify the complex model structure shown in Figure 5. The most sensitive variables were selected from the finding of the sensitivity analysis.

The simple model (Figure 10) is composed of the wetting regime and fencing/grazing impacts. But, because it is widely perceived that salinity can also impact on Black Box trees, soil salinity and groundwater salinity variables were also retained in this model. The spatial scale and report origin were also kept in the model structure.

5.3.2 Model parameterisation

Model parameterisation followed the methods described above.

5.3.3 Model outcomes and validation

Priority Risks: Sensitivity Analysis

Sensitivity analysis confirmed the importance of wetting regime for the maintenance or tree condition (Figure 10) and for regeneration (Figure 12). The importance of fencing and grazing was also reaffirmed.

Predictive accuracy tests

To test the predictive accuracy of the BDN model, case data was split, with 80% of the data was used for training, and 20% used for testing. The 80/20 split of case data was random.

As with the more complex model, the results indicated that the predicted and actual values from the test cases were not always consistent and that the accuracy of model predictions was poor.

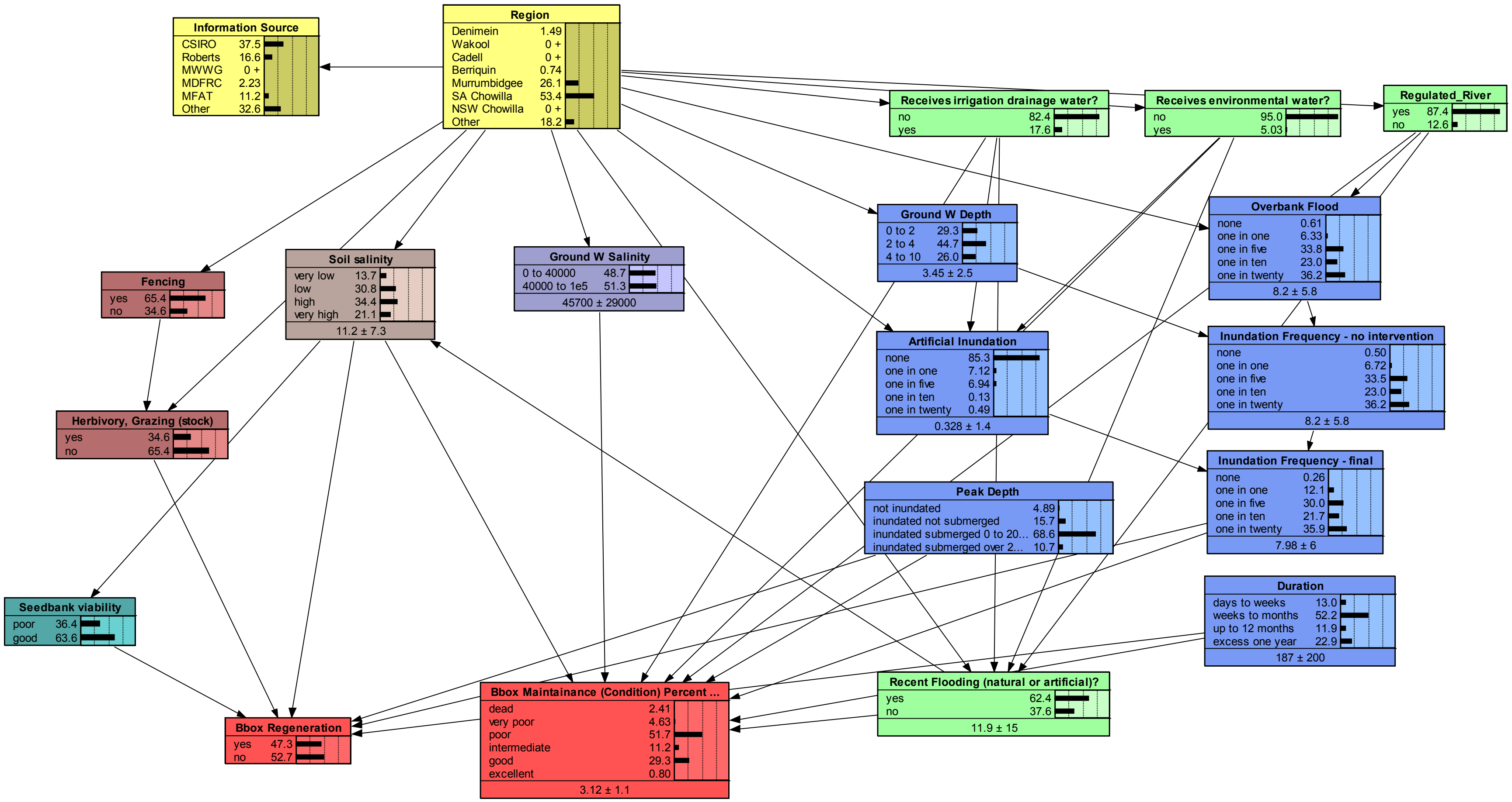

Figure 10: Simplified BDN for Black box (*Eucalyptus largiflorens*), showing model states

Predictive Accuracy

The error rates of the two endpoints (condition and regeneration) were:

Condition error rate = 43%

Regeneration error rate = 32%

Scoring Rules

An assessment of the probability predictions of this simple model was also done using the scoring rules outlined above. The scoring rule results were slightly worse than those for the more complex model:

- *Condition* (for 80/20 data split): Logarithmic loss = 1.4; Quadratic loss = 0.63; Spherical payoff = 0.62
- *Regeneration* were (for 80/20 data split): Logarithmic loss = 1.4; Quadratic loss = 0.52; Spherical payoff = 0.70

5.3.4 Complex vs. Simple BDN Model

In all tests, the simplified model performed more poorly than the complex model. Although all variables in the complex model do not have a dominant influence on the network, they do improve the accuracy of this model's predictions.

Generally, an increase in the number of interacting variables decreases the possibility of predicting future behaviour (Boero *et al.* 2004). However, in this example, the opposite is true. Simplicity came at the expense of accuracy. Indeed, increases in model complexity are often necessary to yield more meaningful results (Loehle 2004).

5.4 Summary

5.4.1 Model Findings

The model findings reinforce that management actions (fencing and wetland watering) being promoted by MIL, and promoted and implemented by MWWG, on private lands are having a positive impact on the health of Black Box trees. A watering frequency of between one in five years and one in ten years was found to be optimal in maintaining tree health and promoting regeneration. This finding will assist future decision making.

5.4.2 Model limitations and knowledge gaps

The Black Box BDN model has a number of limitations, the most important being:

- The temporal component of the model is crude. Given that wetting regime is of high importance, the inundation component of the model requires further development. This can partly be achieved by linking the Black Box BDN to a hydrological model.
- Although spatial scale is considered in this study, the difference between processes (and Black Box responses) within the Murray irrigation region and between this and other regions, was not thoroughly explored given the paucity of data relevant to the Murray irrigation region.
- Little data was available relating surface water quality to the health of Black Box trees.

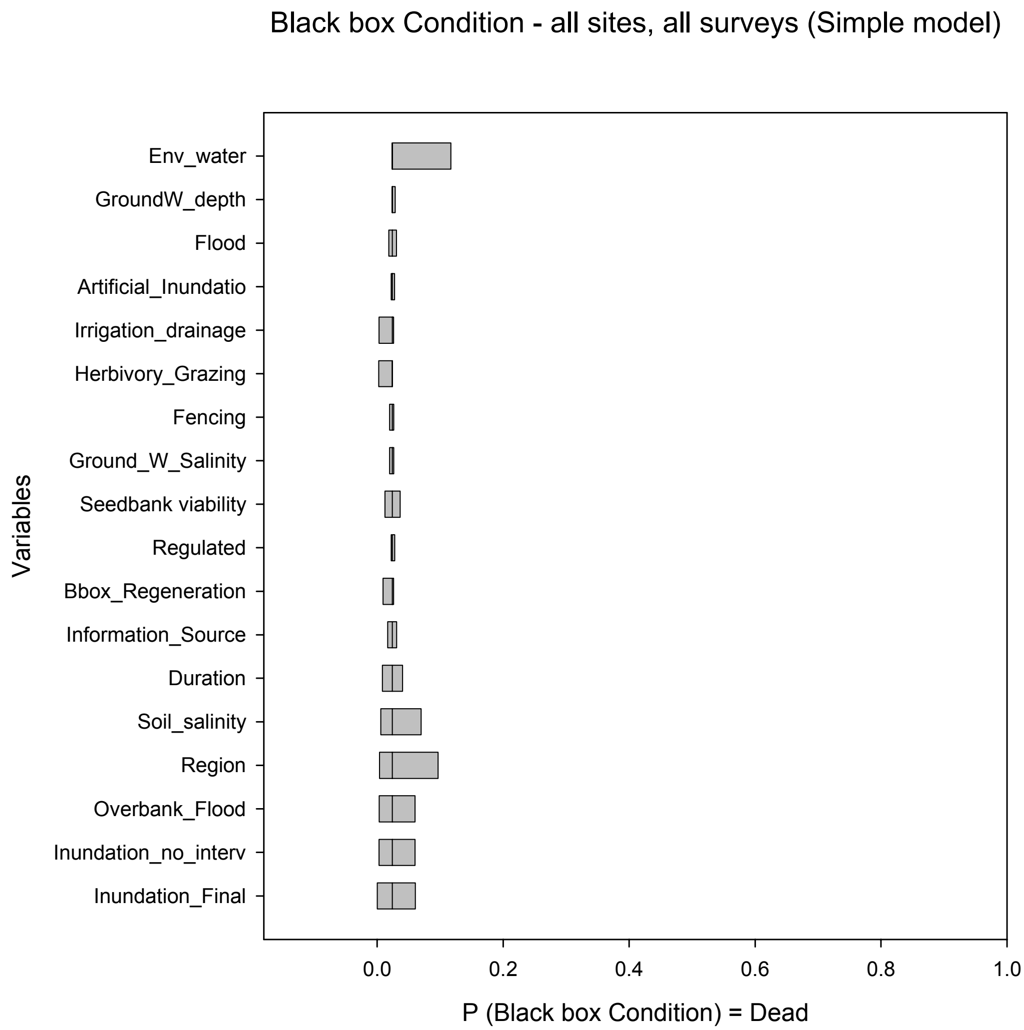

Figure 11: Sensitivity analysis results for simple Black box BN (relevant for the endpoint 'Condition'), relevant for all regions and all studies.

- Little data was available relating ground water quality to the health of Black Box trees.
- Little data was available relating soil quality to the health of Black Box trees.
- Little data was available investigating the occurrence and impact of disease on the health of Black Box trees.
- Little data was available looking at seed bank abundance and viability, and how this impacts on regeneration.
- Little data that was relevant to the Murray irrigation region was available.

In order to address these limitations, the BDN model requires further updating with relevant data as it becomes available. Such data can only be obtained by undertaking additional research and improving existing monitoring programs.

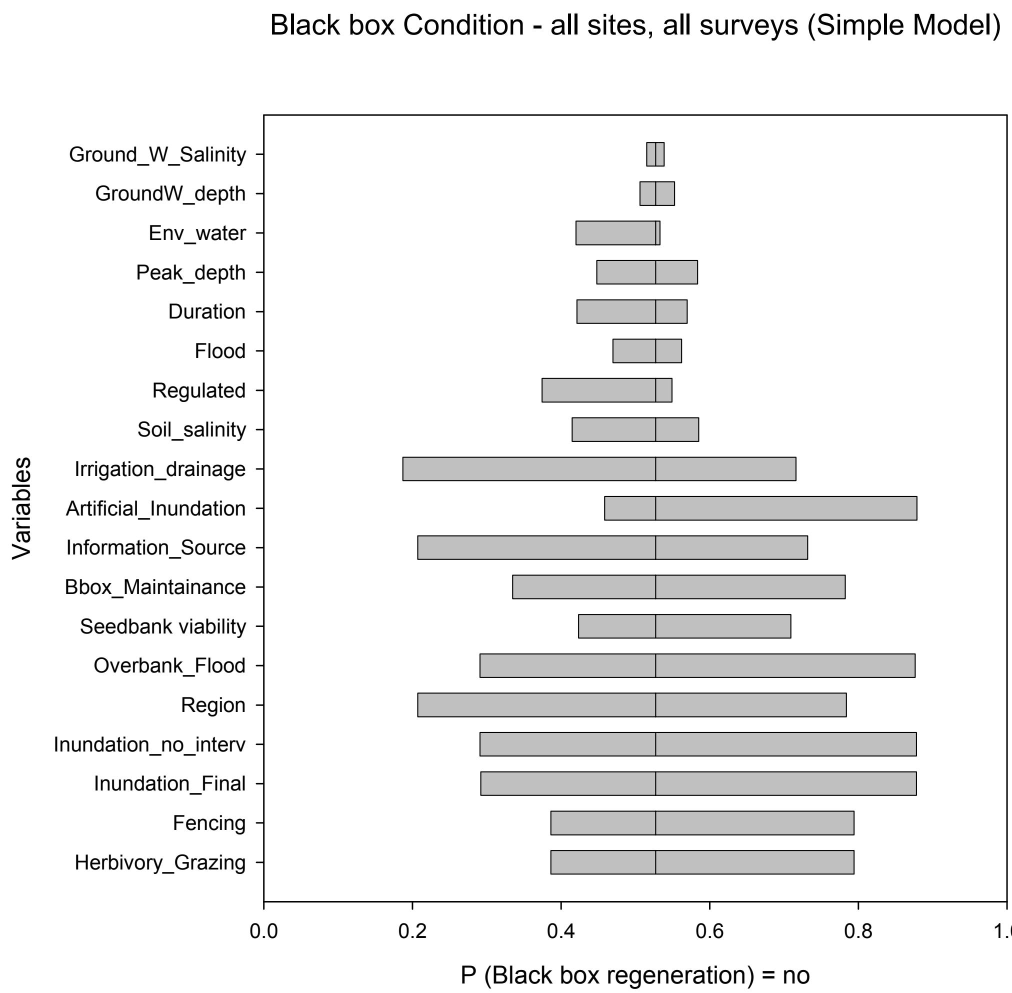

Figure 12: Sensitivity analysis results for simple Black Box BDN (relevant for the endpoint 'Regeneration'), relevant for all regions and all studies.

BDN models are ideal for fitting into an adaptive management context. Adaptive management involves learning from management actions, and using that learning to improve the next stage of management. BDNs models can incorporate new data and knowledge, assisting in the model learning/model parameterisation process.

5.4.3 Stakeholder perceptions of the model

Two major concerns were expressed by stakeholders at the initiation of the study, these being:

- there is a lack of data available to construct the model,
- Black Box responses are highly variable, and knowledge about these is poor.

These points are addressed below.

Lack of data

At the initiation of the modelling, stakeholders widely believed that not enough information existed to construct a model. Upon reviewing the literature, it became clear that little relevant data exists for the area within the Murray irrigation region. Unfortunately, very little relevant monitoring data from the Murray irrigation region was also available for this modeling exercise. For this reason, data and information from other regions was incorporated into the models. Model findings can act as guidance to both future monitoring, research and management activities.

A CSIRO model, investigating transpiration rates in waterlogged and saline soils of the Chowilla floodplain of South Australia (Eldridge *et al.* 1993; Jolly *et al.* 2002; Jolly and Walker 1996; Jolly *et al.* 1993; McEwan *et al.* 1995; Palmer and Roberts 1996; Slavich *et al.* 1999a; Slavich *et al.* 1999b; Zukowski *et al.* 2003), was used to guide parameterization of the BDN (note: the focus and scale of the CSIRO model and BDN model are quite different). Using this information, along with other surveys of Black Box on the Murray-Darling floodplain, a BDN model was constructed. The BDN model explicitly acknowledges the different data sources and their associated spatial scales.

This study clearly demonstrates that lack of information in a specific area should not preclude the development of a BDN model. However, it is important to note that future monitoring and research is essential to improve the robustness of the current model. Indeed, monitoring activities and basic research cannot be supplanted by a model, and are critical in improving the understanding of the impact of stressors on Black Box, leading to improved management actions.

Uncertainties

Another concern expressed by stakeholders at the commencement of this study was the importance of portraying variability, and the existence of uncertainties in the response of Black Box trees to environmental changes. Part of this concern was due to the belief by a number of the stakeholders that models must be process-based or empirical (which require lots of data) and have deterministic outcomes. The outputs from BDN models are not deterministic, but rather are expressed as probability distributions, with the shape of the distribution reflecting the level of uncertainty in both the model and the input data.

6 BDN for river health

6.1 Background

It is widely recognised throughout the Murray Darling Basin that in an effort to increase the security of water supply to irrigators, the creation of uniform flow conditions in river systems has had a profound effect on the health and long-term sustainability of our natural values (Maher et al. 2002). And in order to address the degradation of river health, scientists have been called upon to recommend alternative river management strategies. Unfortunately, scientific knowledge for determining the volume and cycle of flows that are required to rehabilitate degraded river systems is still poor.

The lack of certainty in scientific knowledge and predictions has been poorly communicated to the community. Landholders feel threatened by the prospect of the introduction of environmental flows, calling for clear scientific proof for the harms of irrigation. However, science by its nature cannot provide absolute proof. The debate has been further exacerbated by scientists using elaborate, and often impenetrable, forms of statistical analyses (often with many implicit assumptions), which are impervious to landholder groups (Schofield *et al.* 2003).[3] These factors, along with scientists being inherently poor communicators, have lead to the belief that scientists are not impartial in the debate over environmental flows.

During the Problem Formulation phase of this project, stakeholder interviews clearly showed that farming groups in the Murray irrigation region felt threatened by policies and by scientists advocating increases in environmental flows. As residents of the region, they also felt that river health was not being affected by farming activities. In contrast, non-community stakeholders felt that river health was under threat as a result of landholder activities in the region. It was also expressed that landholders often fail to recognise the impact of farming practices on areas dislocated from their own land.

Although these conflicts were not specifically addressed during this study, the work reported in this section aimed to show how an existing decision support tool can be modified so that it is more transparent, better used to communicate uncertainties, and can be applied in an adaptive management context.[4] These attributes are all extremely important as is briefly discussed below.

Model Transparency - enables stakeholders to understand how a system is represented within a model and the assumptions that have been made in setting up the model. Model transparency enables a models capabilities and limitations to be assessed. As a result, the associated assumptions and limitations in decision-making are more open and honest.

Model Uncertainty - Communicating uncertainties, representing our lack of knowledge of complex systems and the variability of ecological systems, is essential when analysing risk. When applying model predictions over broad ecological scales, predictions are inherently linked with indeterminacy. The longer the timescale and the more dynamic an ecosystem, the greater the uncertainty will be in predictions. The generally poor understanding of the workings of ecological systems leads to even greater model uncertainties. Such uncertainties need to be communicated to stakeholders (including decision-makers) to provide an

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[3] At present, the Murray Flow Assessment Tool is used to guide decision making for environmental flows.

[4] The credibility and robustness of the existing DSS is not questioned or doubted.

understanding of the risks associated with management options. Uncertainties in decision-making can be addressed in policy by the use of the principles of adaptive management.

Models and Adaptive Management - The appeal of adaptive management is driven by three factors - our rudimentary knowledge of natural systems, these ecological systems being dynamic and variable, and community goals and management expectations always being in flux (Pagan and Crase 2004). Despite the fact that policies for water allocations promote the implementation of environmental flows in an adaptive management context, the currently available tools are inadequate to meet this need.

6.2 Objectives

During the Problem Formulation phase of the study, stakeholders assessed the degradation of 'river health' as a key risk from irrigation activities in the Murray irrigation region. However, there was disagreement between the groups as to whether or not native fish communities in the region are under threat.

It was decided to develop a BDN model to assist MIL, and potentially the Murray CMA, in managing irrigation and other activities that could threaten native fish communities and their habitat. This model is a sub-set of the much larger model that would be required to predict the effect of irrigation and other activities on 'river health'.

It was proposed that the BDN model would cover the major threats to fish communities upstream and downstream of the MIL area of operation and within the area. The model should assist MIL in recognising and managing the threats to native fish in their area. The model will also consider those activities that are beyond the management control of MIL.

Given that there already exists two tools that address the management of native fish communities in the Murray Darling Basin (Murray Flow Assessment Tool (MFAT) and Native Fish Strategy (NFS)), we sought to use the quantitative relationships and expert knowledge utilised in MFAT and the NFS in developing the Fish BDN.

6.3 Murray Flow Assessment Tool (MFAT)

MFAT is a decision support system that relates river flow to potential habitat condition for river and floodplain environments. MFAT can help governments and communities make informed decisions on environmental flows for the River Murray system (MDBC accessed July 2005).

MFAT (MDBC accessed July 2005):

- uses the best available scientific information,
- provides consistent and repeatable assessment,
- integrates assessments from river zones to the whole river system,
- documents the source and confidence of supporting ecological evidence,
- is based on the prototype Environmental Flows Decision Support System (EFDSS) developed by CSIRO Land and Water and Environment Canberra.

It works by providing a score of the potential condition of habitat for floodplain and wetland vegetation, waterbirds and native fish for any given flow pattern. Scores for habitat conditions range from 0 (unsuitable) to 1 (ideal).

MFAT uses ecological models to assess habitat condition based on modelled daily river flows. Some ecological models use daily river flow data directly, while others use the floodplain hydrology model to generate the required flow data. The models are driven by ecological information from selected localities along the river. Results for localities are then grouped to provide habitat condition scores for river zones and the whole river system.

Native fish module in MFAT

The native fish habitat condition model assesses the effects of given flow scenarios on groups of species that live in similar types of habitat. Fish found in more than one type of habitat appear in more than one group. Assessments are made for adult fish (spawning and non-spawning) and larval-juvenile fish. Seven fish groups are assessed: Flood spawners, Macquarie perch, Wetland specialists, Freshwater catfish, Main channel generalists, Main channel specialists and Low-flow specialists.

The following description of the fish module in MFAT has been modified from (Young *et al.* 2003):

Model Description

The fish habitat model in MFAT enables simulation of the likely condition of native fish habitat (primarily flow-related habitat) in the River Murray system under different river flow scenarios. The model is run for 'river sections' for which the hydrology can reasonably be described by time series data from a single location. The primary input data are simulated daily river flow volumes.

Other input data include:

- A stage-discharge relationship,
- Several habitat preference curves that relate aspects of habitat condition to hydrologic or hydraulic variables,
- Qualitative time-invariant descriptions of other aspects of habitat such as woody debris, thermal pollution, riparian condition, channel condition.

Habitat condition is represented by a dimensionless 'unit' index that ranges from 0 (intolerable) to 1 (ideal). Ideal is not considered equivalent to natural, the latter usually being less than ideal for the long-term average. Explicit consideration is made of adult, spawning, and larval-juvenile habitat preferences, with habitat condition indices calculated for each life stage. Separate assessments are made either for individual species, or for groups of species with similar habitat preferences, with species found in more than one habitat type appearing in more than one group.

Native fish groups

Separate assessments of habitat condition are made for seven (7) groupings of native fish:

Flood spawners - Golden perch, Silver perch: Spawn and recruit following flow rises. Major spawning occurs during periods of floodplain inundation.)

Macquarie perch: Require clean gravel substrate. Floodplain inundation not required, but spawning probably enhanced by rising flows.

Wetland specialists - Australian smelt, Bony herring, Carp gudgeons, Southern pygmy perch, Hardyheads, *Galaxias rostratus:*Spawn and recruit in floodplain wetlands (and lakes, anabranches and billabongs) during in-channel flows.

Freshwater catfish: Spawn in coarse sediment beds (usually sand or gravel) during any flow conditions.

Main channel generalists - Australian smelt, Bony herring, Flathead gudgeons: Spawn and recruit in high or low flow in the main channel.

Main channel specialists - Murray Cod, Trout cod, River blackfish, Two-spined blackfish: Spawn and recruit under high or low flow in the main channel. Woody debris important habitat attribute.

Low-flow specialists - Crimson-spotted rainbow fish, Carp gudgeons: Only spawn and recruit during low flow (channel or floodplain habitats.

6.4 Fish BDN model

The Fish BDN model (Figure 13) was based on the fish conceptual model developed in collaboration with key stakeholders (Figure 14), with information adapted from the fish habitat condition model within MFAT (Figure 15). The MFAT modelling frame was used for the BDN as little value was seen in 'reinventing the wheel'. MFAT contains the most up to date knowledge and type of knowledge available with respect to fish communities in the Murray Darling Basin.

A series of equations were used in MFAT (Young *et al.* 2003) to describe interactions between model variables. These equations were rewritten in the programming language C (Table 5). Select equations are specific for fish groups.

Preference curves were used in the MFAT fish model to describe the response of a particular biotic group to environmental conditions. As described by Young et al. (2003), a preference curve has as its x axis (or input) a variable that is usually a function of the flow regime (a hydrologic or hydraulic variable) or a function of time (such as calendar month, or time duration – usually days or months). Preference curves are specific for particular groups, and may also vary between localities. For the fish model, preference curve relationships were elicited from fish ecologists (see Young et al., 2003).

The current Fish BDN model is spatially limited to 'Section C' of the Murray River (Yarrawonga Weir to Wakool Junction) and to the Edward River. Preference curves relevant for Section C of the Murray River were set up as conditional probability tables in the BDN. Fish groups considered were flood spawners, freshwater catfish, main channel specialists and low flow specialists.

6.4.1 Model details

Scope

The model used the existing Goulburn River Fish Bayesian Network as a starting point (Pollino et al., in review). The model incorporates data relevant to regions upstream and downstream of the Murray irrigation region as well as within the region. The model has endpoints for the four recognized types of native fish communities in the Murray Darling Basin (as in MFAT), as opposed to the single endpoint for abundance and diversity in the existing model.

The model incorporates knowledge and data from the following systems and reaches:

- River Murray
    - Hume Dam to Yarrawonga Weir
    - Yarrawonga to Tocumwal
    - Tocumwal to Edward offtake (Picnic Point)
    - Edward offtake (Picnic Point) to Barmah
    - Barmah to Torrumbarry Weir
    - Torrumbarry Weir to Narrung
- Edward River
    - Edward offtake (Picnic Point) to Stevens Weir

  - Stevens Weir to Murray confluence
- Wakool River
- Tuppal Creek

The predictive time frames can fit in with the Murray Catchment Blueprint (2003) targets, being 1 year (now), 10 year, and 50 year.

Data sources

Data was obtained from MDFRC, MIL, DIPNR and NSW Fisheries.

The detailed consultation of experts documented in MFAT and the NFS circumvented the need to consult more widely with fisheries experts, although it will not do away with this process in entirety (will need to consult to verify the model).

The MDBC will soon be commencing a study investigating improving fish habitat between Hume Dam and Yarrawonga Weir (under the NFS banner) (Barrett 2004).

Parametarisation

An unfortunate aspect of BDN models is the need to discretise continuous variables. This presents a problem in flow models, where data is continuous. After parameterising the Fish BDN, sensitivity analysis will be used to identify key flow variables for each fish group in each focus reach, and if necessary, the number of sub-categories for these variables will be given finer definition.

For conditional probability tables specified by equations (Table 5), sub-ranges were specified so that they were manageable (≤5 ranges). Increasing the number of sub-ranges exponentially increases the number of conditional probabilities that need to be specified, and at present an increase in complexity is not warranted (particularly as estimates are dimensionless units not 'real' values). If the Fish BDN model is to be developed further, a greater breakdown in sub-categories could be explored.

Single categorical values matching qualitative descriptions of habitat (woody debris, fish passage, water temperature) were used in the MFAT fish model (Young *et al.* 2003) and are shown in Table 6.

Flow relationships were used in the MFAT fish model to specify channel condition, where relative changes of test and reference S80 flows[5] were examined. To do this, look up tables are used (Young *et al.* 2003). Four reduction factors were also applied to index values. These are shown in Table 7.

[5] Difference between the 10th and 90th percentiles divided by the 50^{th}

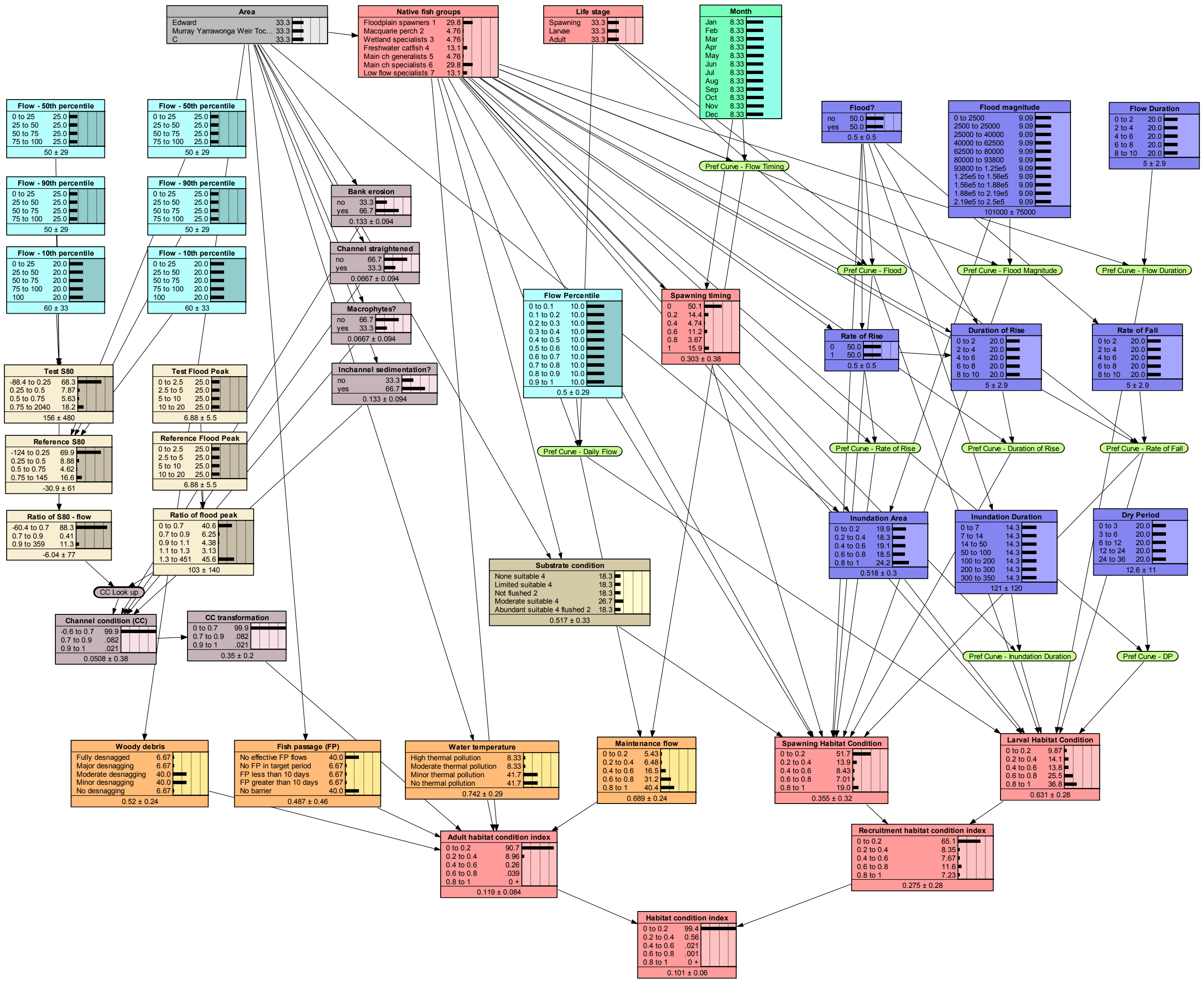

Figure 13: BN for Fish Habitat Condition showing model states

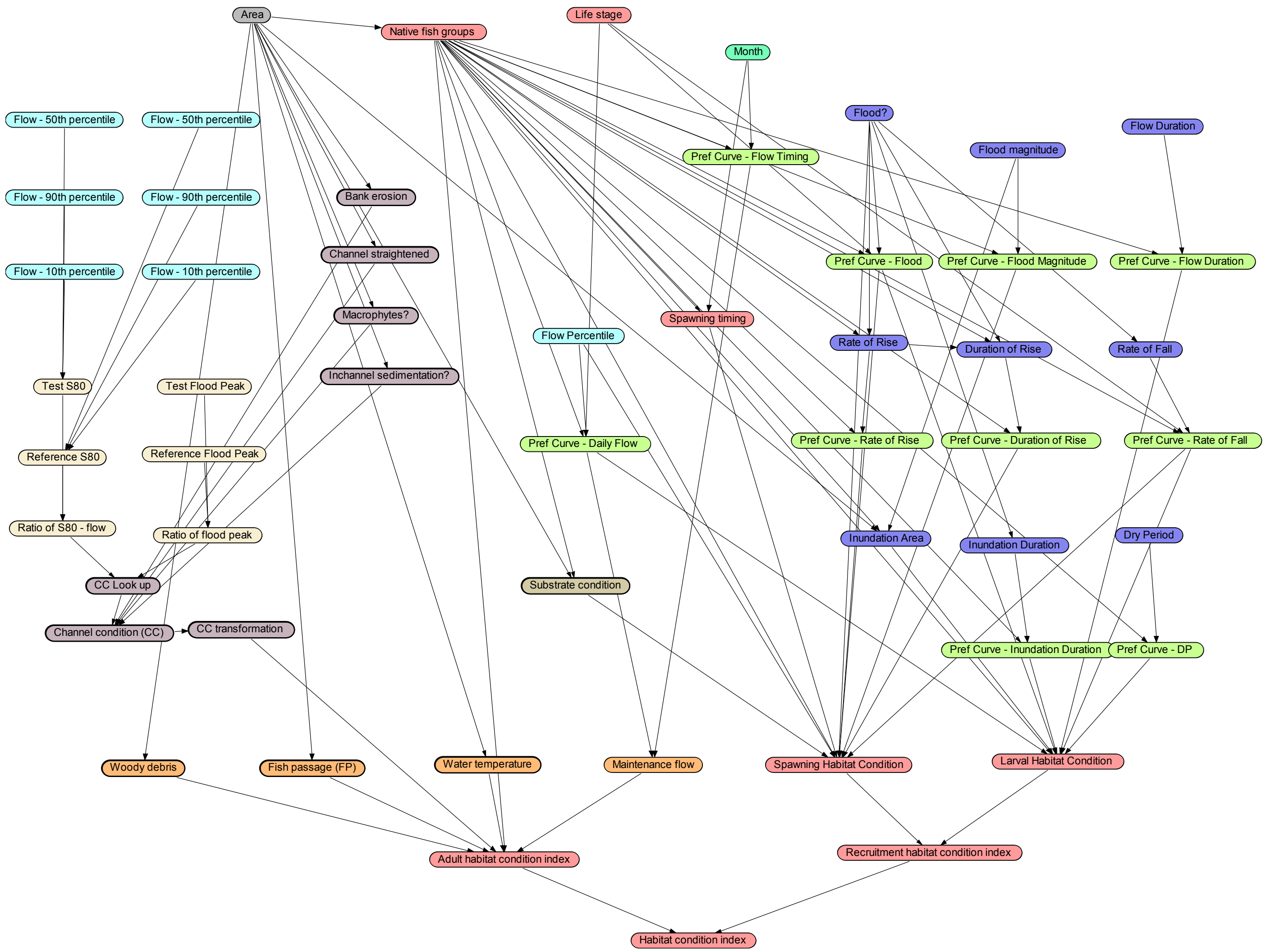

Figure 14: Conceptual model of Fish Habitat Condition

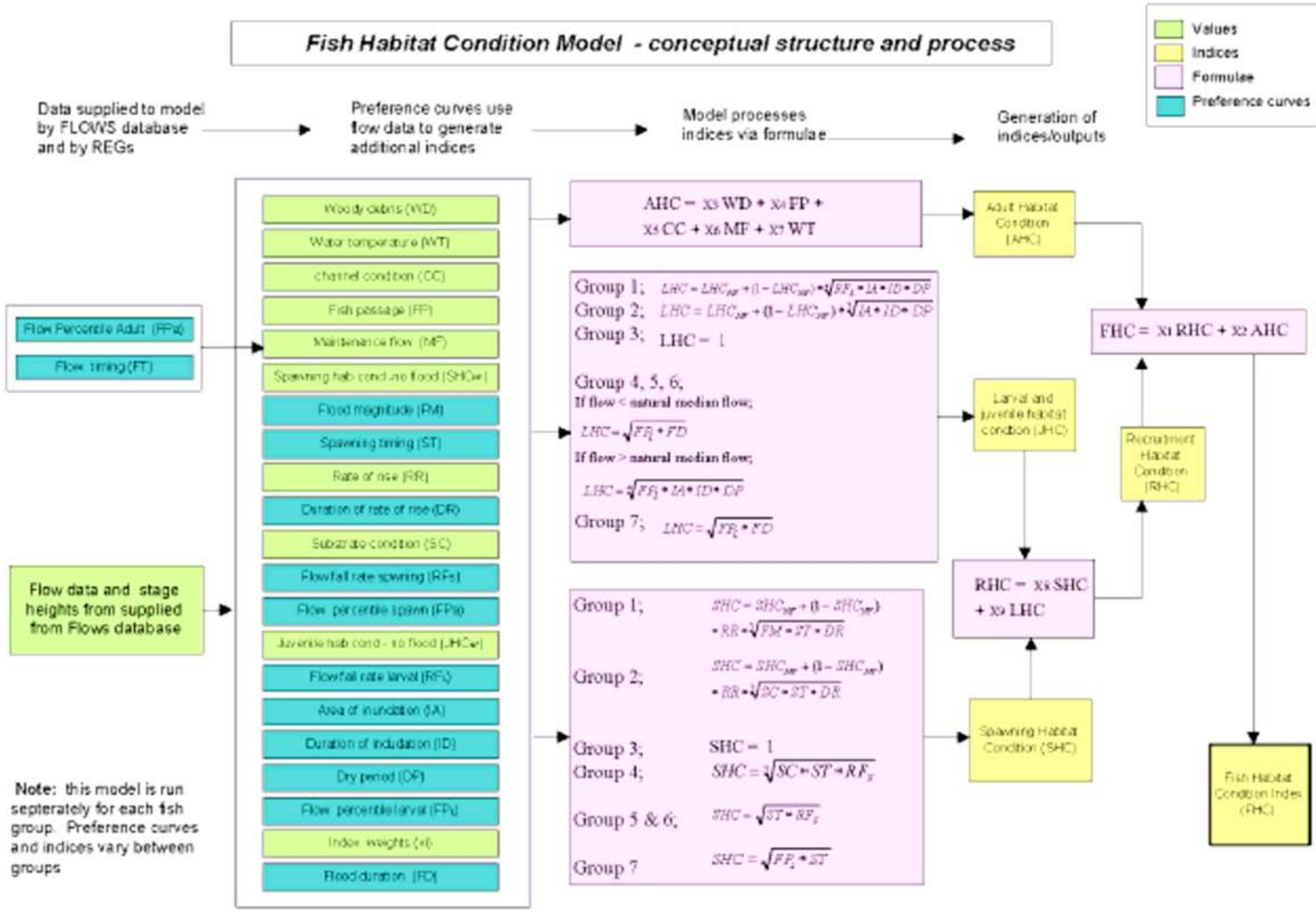

Figure 15: Structure of Fish Habitat Condition Model within MFAT

Table 5: Equations used to parameterise select nodes of the Fish BDN

Node	**Equation**
Test S80	Test_S80 (Flow_50th_P, Flow_90th_P, Flow_10th_P) = (Flow_90th_P-Flow_10th_P)/Flow_50th_P
Reference S80	Reference_S80 (Flow_50th_P1, Flow_90th_P1, Flow_10th_P1) = (Flow_90th_P1-Flow_10th_P1)/Flow_50th_P1
Ratio of S80 flows	Ratio_Flow (Test_S80, Reference_S80) = Test_S80/Reference_S80
Test Flood peak	Test (Flow_50th_P, Flow_90th_P, Flow_10th_P) = (Flow_90th_P-Flow_10th_P)/Flow_50th_P
Ratio of Flood peak	Ratio_Flood (Test_fp, Reference_fp) = Test_fp/Reference_fp
Maintenance Flow	Flow (PC_Daily_Flow, PC_Daily_FlowT) = sqrt (PC_Daily_Flow*PC_Daily_FlowT)
Channel Condition	Channel (Channel_straightened, Inchannel_sedimentation, Macrophytes, Bank_erosion, CC_Look_up) = CC_Look_up-Channel_straightened-Inchannel_sedimentation-Macrophytes-Bank_erosion
Spawning Habitat Cond	Spawning_HC (PC_Daily_FloodM, Spawning_timing, PC_Daily_RR, PC_Daily_DR, Substrate_condition, PC_RF, Flow_Percentile, Fish_Grp, PC_Flood) = Fish_Grp==Floodplain_spawners_1? PC_Flood+(1- PC_Flood)* PC_Daily_RR*((PC_Daily_FloodM*Spawning_timing* PC_Daily_DR)^1/3): Fish_Grp==Macquarie_perch_2? PC_Flood+(1- PC_Flood)* PC_Daily_RR*((Substrate_condition*Spawning_timing* PC_Daily_DR)^1/3): Fish_Grp==Wetland_specialists_3? 1.0:

Node	Equation
	Fish_Grp==Freshwater_catfish_4? ((Substrate_condition*Spawning_timing* PC_RF)^1/3): Fish_Grp==Main_ch_generalists_5? (sqrt(Spawning_timing* PC_RF)): Fish_Grp==Main_ch_specialists_6? (sqrt(Spawning_timing* PC_RF)): Fish_Grp==Low_flow_specialists_7? (sqrt(Flow_Percentile*Spawning_timing)):0
Larval Habitat Condition	Larval_HC (Fish_Grp, PC_Flood, PC_RF, Inundation_Area, PC_ID, PC_DP, PC_Daily_Flow, PC_FD) = Fish_Grp==Floodplain_spawners_1? PC_Flood+(1- PC_Flood)* ((PC_RF *Inundation_Area* PC_ID* PC_DP)^1/4): Fish_Grp==Macquarie_perch_2? PC_Flood +(1- PC_Flood)* ((Inundation_Area* PC_ID* PC_DP)^1/3): Fish_Grp==Wetland_specialists_3? 1.0: Fish_Grp==Freshwater_catfish_4? (sqrt(PC_Daily_Flow* PC_FD)): Fish_Grp==Main_ch_generalists_5? (sqrt(PC_Daily_Flow* PC_FD)): Fish_Grp==Main_ch_specialists_6? (sqrt(PC_Daily_Flow* PC_FD)): Fish_Grp==Low_flow_specialists_7? (sqrt(PC_Daily_Flow* PC_FD)):0
Recruitment Habitat Condition	Recruit (Spawning_HC, Larval_HC) = Spawning_HC*Larval_HC
Adult Habitat Condition	Adult_hab (Woody_debris, Fish_passage, Water_temperature, CC_non_neg, Flow, Fish_Grp) = Fish_Grp==Floodplain_spawners_1? Woody_debris*Fish_passage*Water_temperature* CC_non_neg: Fish_Grp==Macquarie_perch_2? Woody_debris*Fish_passage*Water_temperature* CC_non_neg: Fish_Grp==Wetland_specialists_3? Woody_debris*Fish_passage*Water_temperature* CC_non_neg*Flow: Fish_Grp==Freshwater_catfish_4? Woody_debris*Fish_passage*Water_temperature* CC_non_neg: Fish_Grp==Main_ch_generalists_5? Woody_debris*Fish_passage*Water_temperature* CC_non_neg: Fish_Grp==Main_ch_specialists_6? Woody_debris*Fish_passage*Water_temperature* CC_non_neg: Fish_Grp==Low_flow_specialists_7? Woody_debris*Fish_passage*Water_temperature* CC_non_neg:0
Habitat condition index	Habitat (Adult_hab, Recruit) = Adult_hab*Recruit

Table 6: Default index values associated with different habitat types (Young *et al.* 2003)

Habitat type	Class	Default value
Woody debris	No woody debris - fully desnagged	0.0
	Few woody debris - major desnagging	0.2
	Moderate level of woody debris - moderate desnagging	0.4
	Numerous woody debris - minor desnagging	0.7
	Woody debris at natural levels - no desnagging	1.0
Fish passage	Flows never provided effective fish passage past the worst barrie in this river section during this year (ie flow < 'threshold' for entire year)	0.0
	Flows provided effective fish passage past the worst barrier in this river section in this year but not during target period	0.2
	Flows provided effective fish passage past the worst barrier in this river section in this year during target period but for < 10 days	0.4
	Flows provided effective fish passage past the worst barrier in this river section for > 10 days during target period this year	0.7
	There are no barriers to fish passage in this river section	1.0
Water temperature	High thermal pollution due to upstream dam	0.0
	Moderate thermal pollution due to upstream dam	0.4
	Minor thermal pollution due to upstream dam	0.7
	No thermal pollution - natural thermal regime	1.0
Channel condition	Channel straightened	0.2
	Bank erosion	0.2
	Inchannel sedimentation	0.2
	Absence of Macrophyte beds (for Group 4 – catfish)	0.2

Table 7: Look-up table of Channel Condition (CC) default index values (Young *et al.* 2003).

	Ratio of S80 values for test condition/natural conditions		
Ratio of 1.58 year return flood peak values test condition/natural condition	<0.7	0.7-0.9	>0.9
<0.7	0.2	0.3	0.4
0.7-0.9	0.3	0.5	0.7
0.9-1.1	0.4	0.7	1.0
1.1-1.3	0.3	0.5	0.7
>1.3	0.2	0.3	0.4

6.4.2 Current status of the Fish BDN model

The prototype fish BDN is shown in Figure 13.

A number of components of the model have yet to be completed:

- It is not possible to validate the model using predictive accuracy tests because the endpoints are surrogates of fish habitat and not real measures,
- Sensitivity analysis will be undertaken when the model has been parameterised with flow data,
- The fish model still needs to be linked to a hydrological model in order to specify flow percentiles at each reach under consideration, and
- The BDN model does not incorporate the weighings[6] for select variables that are contained in the MFAT fish module. Such weighting are highly subjective and there was little justification in including them in the BDN model.

6.5 Comparison between the fish BDN and the MFAT fish module

The fish BDN has the following advantages when compared with the MFAT fish module:

- The MFAT fish model requires location and fish group to be specified for each model run. The fish BDN has the capacity to *integrate model outcomes* for individual or groups of fish species, at one or more locations, and over broader spatial scales. There is no need to have separate models for different spatial areas or different fish species.
- Within a BDN, *management actions or system changes* can be readily tested by calculating how probable events are and how these probabilities can change given subsequent observations, or predict change given external interventions (Korb and Nicholson, 2004). Flow scenarios or habitat changes can be tested in the model using interventions.
- Model *uncertainties* are readily communicated with outcomes presented as probabilistic distributions.
- Model *transparency* is encouraged. As the model is graphical, the processes in the model are transparent, enabling decision-making processes to be more open. This aspect also augments communication and educational processes.
- Bayesian statistics encourages the learning process by formalising a sequential approach to probabilistic updating. This property suits *adaptive management* processes. Bayesian networks can incorporate new information as it becomes available, allowing model parameters to be continually adapted and refined, enabling innovative responses to novel situations, and assisting in the learning process.

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6 Three sets of weights can be set for each locality (Young et al., 2003):

- weighting to each fish group, of adult and recruitment stages
- weighting to each fish group, of influence of woody debris, fish passage, thermal pollution,
- and maintenance flow on adult habitat condition
- weighting to each fish group, of spawning and larval stages within the recruitment stage.

Default values are provided, together with the evidence or justification of these values. These values can be changed if there is reasonable evidence to do so. The evidence should be documented in the **Evidence** forms. The weights control the relative importance of the different indices to the overall fish habitat condition (FHC). The weights can be different for each fish group (Young et al., 2003).

In order to meet the needs of decision-makers, the BDN tool has the ability to be improved with relative ease. Such improvements could include:

- The use of experts to specify quantitative relationships in the MFAT native fish module is clearly stated. By adjusting (or adding) measurable endpoints (abundance, biomass or CPUE), the BDN has the potential to validate and update these relationships using field *data*. This could be achieved by using data obtained as part of the Native Fish Strategy (Barrett 2004).
- *Other stressors* (e.g. water quality, fishing pressure, introduced fish) could be integrated into the framework.
- Outputs of the Fish BDN could be linked to *GIS* (improving spatial representation and communication of model outputs).
- The *temporal* component of the model could be improved, and potentially linked to fish life histories of each group.

Negative aspects of the Fish BDN are:

- The temporal component of the model is poor (as with MFAT),
- The focus of model is predominantly on flow (as with MFAT),
- The model endpoint is not measurable (i.e. not linked to actual numbers of fish) which complicates validation of the model (as with MFAT),
- The model is highly complex (there are over 68 million conditional probabilities) and is slow to run,
- The Fish BDN must be linked to a hydrology model (or to historical flow database) to be operational (unlike MFAT).

7 Conclusions

7.1 Risk analysis outcomes in the Murray irrigation region

The power of both the Fish and Black Box BDN models lies in their ability to readily simulate alternative management actions and system changes. Thus, the impact of changes in the system on model endpoints can be determined. Such simulations can be regarded as virtual experiments, which are designed to help us understand and manage ecosystems (Green and Sadedin 2005). Real large-scale experiments are often impossible, are costly, and the consequences can be negligible or disastrous or simply met with public opposition (Green and Sadedin 2005). A BDN cannot substitute the value gained from such experiments, but can help guide such experiments, and the framework established allows lessons to be learnt from real world experiments.

Black Box depression areas are ideal candidates for experimentation. However, if these experiments are to be done it is important that rigorous monitoring to measure the outcomes of actions is undertaken. Likewise, implementation of the Native Fish Strategy (Barrett 2004) and the Living Murray initiatives provide ideal opportunities to monitor responses of fish communities, testing the assumptions contained in MFAT and the Fish BDN, and improving our understanding of the ecological impacts of river regulation.

In order to satisfy the requirements of an ecological risk assessment, an important attribute of models is they need to be iterative. Thus, it is important that the Fish BDN model is updated as new data and knowledge from the Murray irrigation region is obtained. Both the structural and quantitative components of models can be improved as new knowledge becomes available.

7.2 Lessons from this project

In undertaking this project, several lessons were learned. These are explored below.

7.2.1 Clear definition of the objectives and scope of the project

In this project, adoption of ecological risk assessment was promoted as a process that could elucidate how ‘sustainability’ could be achieved within a region. But ‘sustainability’ is a very broad statement with no clear operational definition, and consequently, it is not readily measurable. In order to decide whether sustainability is being achieved, the term must first be defined (this can be specific for a region), and this definition must include social and economic factors as well as ecological and environmental factors.

ERAs were not originally conceptualised as a vehicle by which sustainability issues could be explored. It is primarily a tool for improving the management of ecological risks. By definition, sustainability encompasses three components: environmental, social and economic factors. ERA is a highly reductionist methodology that only explores one aspect of sustainability (ecological), and only a measurable indicator for a subset of the entire ecological system (in this study – Black Box and Fish). Ecological risks assessors need to acknowledge this and be explicit from the start to avoid undue expectations of stakeholders.

In the Murray irrigation region study, as it became clearer to stakeholders (and project partners) that the assessment was limited to ecological values, the validity of the study was questioned because it was not seen to adequately address all issues of sustainability in the region.

Given the resources and limited time of this study and the skills of the project team, an integrative investigation of all factors relevant to sustainability (e.g. economic and/or social) would have been problematic. However, as a result of the scope of the study not being made clear from the outset, stakeholder engagement (in itself an intensive process) in the project was poorly maintained.

A clear problem with the Murray irrigation region study from the outset was the poorly defined and amorphous objective of the assessment, the unclear and confused objectives of the project among stakeholders, and the lack of cohesiveness in the project team.[7]

7.2.2 Problem formulation: Values or threats?

Problem Formulation is the first major step in the ERA process. The objective of stakeholder interviews was to clearly define the ecological values (or assets) in the Murray irrigation region, and what the threats are in the context of that value. Problem formulation took the form of asking questions, such as: What ecological values in this region do you want to attain/retain? What ecological values in this region do you believe are threatened? What are the threats to these values?

By not defining regional values from the outset, the list of threats has the potential to become endless and could be somewhat generic across areas. Defining values prior to eliciting the hazards or threats also facilitates the development of conceptual models. Focussing the elicitation process on values rather than hazards also promotes the investigation of multiple stressor/hazards issues, which is a major benefit of an ERA over other management processes.

As is often the case during the Problem Formulation phase, threats and values, and ecological[8] and environmental[9] values were frequently confused by stakeholders[10]. The latter are often perceived by stakeholders as being one and the same. It is crucial from the outset to define the distinction between these terms (although there can be cross over between terms), and to work through this with stakeholders.

7.2.3 Scales

The different scale of focus between stakeholder groups was quite apparent during the Problem Formulation phase. Environmental and Indigenous groups often focussed on broad scales that are long-term and span entire systems (e.g. focus on entire river systems and home lands), whereas landholders often focus on short-term scales, which span the size of a landholding (e.g. soil integrity, vegetation loss). These conflicting scales of interest can be regarded as a symptom of landholders often failing to see how the activities on their landholding impact broader ecological scales and the difference between individual versus collective responsibilities.

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7 The failure of the workshop to fulfil 'Problem Formulation' objectives (as a result of differing objectives and poor communication amongst project team members) lead to a general loss of credibility in the project amongst stakeholders, with select stakeholders refusing to further take part in the study and others being disillusioned by the process. The lack of engagement of some project partners was also problematic.

8 E.g. Remnant vegetation, such as black box depressions

9 E.g. Maintain soil integrity for farming purposes

10 This was exacerbated by the workshop which did not clearly define the distinction between threats and values, or ecological and environmental values.

7.2.4 Project partners

When comparing this ERA study (MIL) with a previous ERA study (GMW),[11] there was a notable difference between the level of commitment by industry partners (both in the ERA process and as part of the project team). This difference may be linked to attitudes of company directors and company boards.

7.2.5 Adoption

At present, in NSW there are no legislative incentives to undertake risk-based approaches in environmental management. Accordingly, there is little incentive for an irrigation company, such as MIL, to go beyond the routine monitoring and reporting requirements of state agencies.[12] Therefore, adoption of rigorous risk assessment protocols in decision-making processes is an unlikely prospect.

In NSW, there are obvious incentives for industry to gain accreditation with an Environmental Management System (EMS).[13] EMSs are widely used by corporations as a sign that they are responsible corporate citizens, and, from a legislative perspective, accreditation with an EMS has been used successfully several times as a mitigating factor to demonstrate compliance and due diligence. Given the legislative incentives (NSW and SA) and the minimal commitment needed to develop an EMS (compared with an ERA), industry has little incentive to adopt ERA procedures into environmental management.

In its current form, it is difficult to envisage ERA processes being adopted into the irrigation industry. Reasons for this include irrigation bodies having:

- little to no corporate responsibility for maintaining and rehabilitating ecological values;
- no legislative requirements to adopt risk-based approaches;
- no accreditation of companies who have undertaken a risk assessment;
- little regard for broader stakeholder involvement;
- little regard for uncertainties in decision-making;
- few incentives or opportunities for companies to implement ERA / adaptive management processes into practice (particularly as they are costly processes that require long-term planning);
- limited funding, difficult and competing research questions, and competing priorities of companies (see Hart et al., 2005; Walshe et al., 2005).

If rigorous risk assessment protocols are to be promoted to the irrigation industry, future risk assessments should seek to be more encompassing of and relevant to issues of sustainability in irrigation areas/catchments. This may be achieved by exploring integration of environmental, social and economic factors into assessment. This is particularly important in

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[11] Pollino C.A. 2003. Ecological risk associated with irrigation in the Goulburn-Broken catchment - Phase 2 - Adverse changes to abundance and diversity of native fish. Melbourne: Monash University.

[12] e.g. the NSW Department of Environment and Conservation and the NSW Department of Infrastructure Planning and Natural Resources

[13] Such as ISO14000

irrigation areas such as MIL, where agricultural/irrigation activities are important in maintaining community viability.

Nonetheless, for adoption of risk-based approaches to be guaranteed, legislative provisions will remain the major incentive mechanisms for industry.

7.2.6 BDNs and decision making

When constructing models for an ecological risk assessment, uncertainties can arise as a result of incomplete datasets for model parameterisation, subjective assessments from expert indecision, or lack of consensus amongst experts. The representation of uncertainty in risk assessment is critical for assisting system managers faced with making decisions to decrease or eliminate risks.

The BDN modelling approach is increasingly being used for modelling systems with poor data and high uncertainties. The BDN models developed in this study, when used with other tools, have the potential to support future decision making in the Murray irrigation region. However, as outlined previously, BDN models need regular updating to have an expanded life span.

The potential use of BDNs in advocating more rigorous decision making is summarised in Table 8 (where the objectives of better decision making were modified from (van Noordwijk et al. 2001)).

Although BDNs have many advantages, their negative aspects should also be acknowledged:

- Poor representation of temporal relationships (not dynamic);
- Continuous variables requiring discretisation;
- Limitations in model complexity (particularly if conditional probability tables are being elicited);
- Potential to be abused due to their user-friendly nature.

Table 8: Potential role of BDNs in decision-making

Objectives of improved decision-making	**Role of a BDN**
Improve the conceptual/mental models models of all stakeholders	BNs can be used to facilitate and support the process of communication among stakeholders, particularly in defining the conceptual model, which forms the graphical structure of the BN. If different conceptual models exist, the BN can be used to quantitatively test internal consistencies, and identify strong causal links
Make better use of both the conceptual/mental and quantitative models for planning how to obtain objectives;	BNs can be used to better understand the drivers of an existing system, and be used to inform scenario planning / management actions
Identify clearer, more realistic, and/or more encompassing objectives in the maintenance and rehabilitation of ecological values,	Assessors are forced to clearly define realistic and quantifiable objectives as BNs are based on measurable objectives / endpoints
Construct better performance indicators that reflect the way these objectives are met;	Success of management objectives can be assessed against measurable endpoints
Improve the understanding and evaluate the current state of a system via an integrative process	The impact on an endpoint often integrates a range of processes, forcing decision-makers to treat systems holistically.
Facilitate and encourage learning on understanding how the real world responds to change;	As stated earlier, BDNs can incorporate new information as it becomes available, allowing model parameters to be continually adapted and refined, enabling innovative responses to novel situations, and assisting in the learning process.
Improve the implementation of management plans and scenarios based on these learnings	BDNs are ideal for use in an adaptive management context

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