Exploring the utility of risk management as an integrating framework for the development and application of water resource planning tools

SM Cuddy[a] and **CA Pollino**[a]
[a] *CSIRO Land and Water, Canberra, Australia*

Abstract: Impacts from overallocation and drought have caused a widespread decline in the ecological health of river systems within Australia and elsewhere. Within the Murray-Darling Basin of Australia, a whole-of-Basin Plan, as described in the Australian Government's *Water Act 2007*, is being developed to redress issues of overallocation of water resources. The Act requires an identification of the risks to the condition, or continued availability, of the water resources within the Basin; and strategies to be adopted to manage, or address, these risks.

This legal requirement to consider risk, while adding another dimension to what is already a very complex multi-layered process, provides us with the opportunity to explore its use as an overarching framework for water resource planning itself, and for the development and delivery of modelling and other decision support tools to support the planning process. Aspects that are of particular interest are – how does risk 'scale up'; how does risk fit with public policy processes?; how do we quantify and communicate risk such that it improves, rather than confuses, decision processes? how do we measure different levels of risk? how do we develop tools that incorporate risk (and associated uncertainty) that are relevant to water resource planners? This paper explores some of these issues in its investigation of the utility of risk management frameworks to provide cohesion within the water planning sphere. While much of this exploration is theoretical in nature, the paper includes a case study of a set of Bayesian network tools developed to assess risks to water resources in the Murray-Darling Basin, as defined in the Act.

Keywords: Risk management; water resource planning; water allocation planning

1   INTRODUCTION

1.1   Water resource planning

Water resource planning is a highly political, and contextually sensitive exercise, in all parts of the world where agriculture and/or urban development require sufficient and reliable access to potable water. Within Australia, as with other countries which share a highly variable climate encompassing long periods of drought, this access has historically come at the expense of declining condition of the environment, particularly of its inland, freshwater systems. This decline in condition has been recognised by governments and citizens, and in Australia is being addressed through a National Water Initiative agreement between the Commonwealth government and states of Australia (COAG, 2004), aimed to achieve sustainable water management. Of particular interest is the Murray-Darling Basin which is home to the largest percentage of Australians who do not live along the coastline, has highly effective and high-earning agricultural (irrigated and

dryland) sectors, and contains many iconic Australian inland rivers. Within this Basin, a whole-of-Basin Plan, as described in the Australian Government's *Water Act 2007*, is being developed to redress issues of overallocation of water resources and return water to the environment. The Act requires an identification of the risks to the condition, or continued availability, of the water resources within the Basin; and strategies to be adopted to manage, or address, these risks. Aligned with this, is the requirement to develop clear and open processes whereby water allocation planning is conducted. This requires clarity around the setting of policy goals and objectives, and the consequent development of strategic and operational plans to realise these goals (if they are in fact achievable).

1.2   Risk in the context of water resource planning

Through the National Water Initiative (COAG, 2004), jurisdictions have agreed to a set of key elements within their water planning frameworks, covering stakeholder engagement, full consideration of all water sources, adaptive management to meet productive, environmental and other public benefit outcomes. Risk in the context of the National Water Initiative mainly refers to the assignment of risk arising from any future reductions in the availability of water for consumptive use. However, risks from the 'impact of natural events such as climate change and land use change, or limitations to the state of knowledge underpinning estimates of the resource' are to be explicitly addressed (COAG, 2004, Schedule E, Clause 1 (iii)).

All jurisdictions have responded positively to the imperative for reform, implementing a range of approaches to assess available water resources, competing demands, while responding to social and environmental values. They (e.g. DOW, 2011) have established guidelines and processes for developing water allocation plans and the consequent plans are assessed against an agreed set of national metrics (NWC, 2011). To date, these guidelines and processses, most of which state that they follow a risk-based approach, do not incorporate the ISO 31000:2009 definition of risk (ISO, 2009), nor do they include guidelines on how to deal explicitly with uncertainty.

1.3   Defining risk and related vocabulary

Definitions of, and processes associated with, risk management in this paper are those provided by ISO (2009) and used in the International Standard AS/NZS ISO 31000:2009 Risk management—principles and guidelines (Standards Australia, 2009). Risk is 'the effect of uncertainty on objectives'; with effect being 'a deviation from the expected'; and uncertainty 'the state, even partial, of deficiency of information related to, understanding or knowledge of an event, its consequence, or likelihood'.This contemporary definition shifts the emphasis from the 'event' to the 'effect'. Purdy (2009) describes this as the difference between considering risk as the chance of the share market crashing to the chance that a crash will disrupt or affect objectives. This leads to a fundamental change in how risk is characterised – by the consequences of an event and the likelihood of those consequences, rather than by the probability of the event itself (Purdy, 2009). Thus the consequence of a risk occurring may be negative (hazard risks), positive (opportunity risks) or may result in greater uncertainty (AIRMIC, Alarm and IRM, 2010).

The ISO 31000:2009 standard sets out 11 principles and a 7-step process (Figure 1). In this paper we follow the Standard's distinction between risk management, being the architecture (principles, framework and process) and managing risk, being the application of that architecture to particular risks (Standards Australia, 2009, p. v).
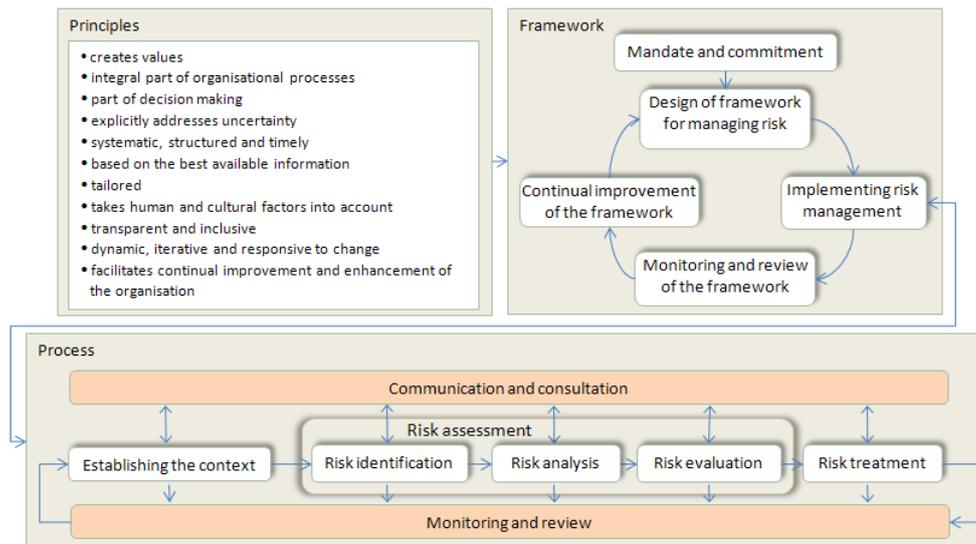
Figure 1. The risk management architecture (principles, framework and process), adapted from Figure 1, Standards Australia, 2009)

The espoused principles align well with current attitudes to community involvement in science and planning, with early engagement of stakeholders in shaping the context (including the setting of values), and adaptive management. While we are most directly involved in the Implementing risk management component of the framework (through our interest in risk assessment tools), the case study review made later in this paper demonstrates the need for risk assessment to be conducted within a mandated risk management framework.

1.4 Water planning tools

Research support for water allocation planning has traditionally focussed on development and delivery of models and decision support systems for scenario analysis, i.e. tools that support investigation of a range of alternative planning options, with results presented in a fashion that is appropriate to the model (but not necessarily useful for the intended user). These include complex biophysical models, decision support systems that integrate the social, environmental and economic dimensions, and decision science tools that attempt to capture the decision-making process itself. In the main, these have not been designed from a risk perspective, though there are exceptions such as that described in the case study used in this paper (Pollino et al., 2010). One of our core motivations in researching for this paper is in understanding what needs to change in our approach to modelling and building planning tools to ensure their relevance within an organisations' risk management framework and their usefulness in undertaking water resource planning within that framework.

1.5 Scope of this paper

Having described the approach to risk management that we intend to pursue, Section 2 poses a set of criteria for evaluating the utility of risk management for integrating, or at least underpinning, the development of water planning tools. Section 3 then describes our case study and evaluates it against these criteria. This is a rather theoretical assessment as the evaluation criteria are untested and selected for the purposes of exploring the stated benefits of adopting a risk management framework approach. The paper concludes with a short discussion and next steps.

2   SETTING EVALUATION OF UTILITY CRITERIA

Evaluation criteria must be developed with stakeholders to ensure that the criteria reflect their values, priorities and ambitions, and assist in determining whether the framework had assisted in meeting and managing planning and policy goals. A comprehensive technical evaluation would include criteria to support comparison across, and between, a range of alternative approaches. As this has been a scoping study, we have not yet engaged with stakeholders, nor have we undertaken an in-depth investigation of alternative, or complementary, approaches such as weight of evidence frameworks (e.g. Pollard et al., 2008) or alternative assessment frameworks (e.g. Rossi et al., 2006). On the need to engage with stakeholders, this is a given; and on the latter, bringing in new learnings is embedded in the ISO 31000:2009 principles of being well-informed, being responsive to change, and seeking continual improvement.

For the purposes of this paper, without the input of stakeholders, we have chosen a set of criteria that we consider capture the ISO 31000:2009 approach to risk management and demonstrate its utility as an integrating framework for the development of tools. These criteria are:

(1)   incorporates a clear articulation of objectives
(2)   improves the identification of opportunity risks and threat/hazard risks
(3)   caters to a range of risk tolerances (i.e. is sufficiently flexible to be usable by low- and high-risk takers)
(4)   creates uniform risk criteria and evaluation metrics
(5)   explicitly incorporates uncertainty together with how that uncertainty impacts on meeting objectives.

3   CASE STUDY

Section 22(1)3 of the Water Act 2007 requires an identification of the risks to the condition, or continued availability, of the water resources within the Basin. In response, a basin scale risk assessment was undertaken, to identify the key threats to the continued availability of the water resource. This risk assessment is used here as a case study to investigate the utility of risk management as a framework for developing tools. It is in contrast to the more traditional approach of developing matrices of likelihood and consequence. The tool was developed in line with ISO/IEC 31010 Risk management —risk assessment techniques (IEC/ISO, 2009).

Given the multidimensional nature of the assessment required to meet the terms of the Water Act 2007, and the lack of a good dataset, Bayesian networks were trialled as a risk analysis tool. Bayesian networks are model-based decision support tools that are ideal for environments where considerable uncertainty exists, and for diverse problems of varying size and complexity, where disparate issues require consideration. The models are graphical, where the structure is used to describe the causal or correlative relationships between key factors and final outcomes. They maintain clarity by making causal assumptions explicit (Stow and Borsuk, 2003) and are often used to model relationships not easily expressed using mathematical notation (Pearl, 2000). Being graphical, Bayesian networks are made up of a collection of variables (or nodes), which represent the relevant variables for analysis. Arrows (or arcs) describe relationships between variables. 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).

The use of Bayesian networks for the case study sought to address the following needs within the risk assessment:

- Integration: Bayesian networks are able to integrate a range of data types and existing models. Where data do not exist, qualitative information can be used. When this evidence is assembled in concert, the overall weight from individual threads of evidence can be assessed.
- Prioritisation: Ranking of risks to water resources can be determined through analysis of Bayesian network models.
- Flexibility: Models can be modified to suit the context in which they are applied. Models can also be updated as new knowledge is obtained.
- Adaptability: Bayesian networks can be updated over time and extended (e.g. to incorporate risk management scenario planning) if required.
- Transparency and repeatability: Bayesian networks offer a transparent and repeatable mechanism for analysis.

To focus the assessment, three risk 'endpoints' were defined – (1) risks to water availability, (2) risks to water quality, and (3) risks of declining health of water dependent ecosystems. Using influence diagrams (see Figure 2), the hazards posed to each of these endpoints were identified. This formed the causal structure of the models, and the level of risk of the hazards to the endpoints was quantified using probabilities. Hazards were characterised as institutional, compliance and biophysical attributes (relating to the knowledge-base to characterise attributes or the processes associated with attributes). These attributes included climate variability, groundwater and surface water data availability and model quality, species data antecedent condition, and knowledge for quantifying environmental water requirements (Pollino et al., 2010). Probabilities were used to capture uncertainty in knowledge, as well as variability in the information source. Where possible, data were used to characterise interactions between hazards and risk; with expert opinion used where data were not available. Where possible, hazards were represented at a regional scale, and aggregated to a basin scale.
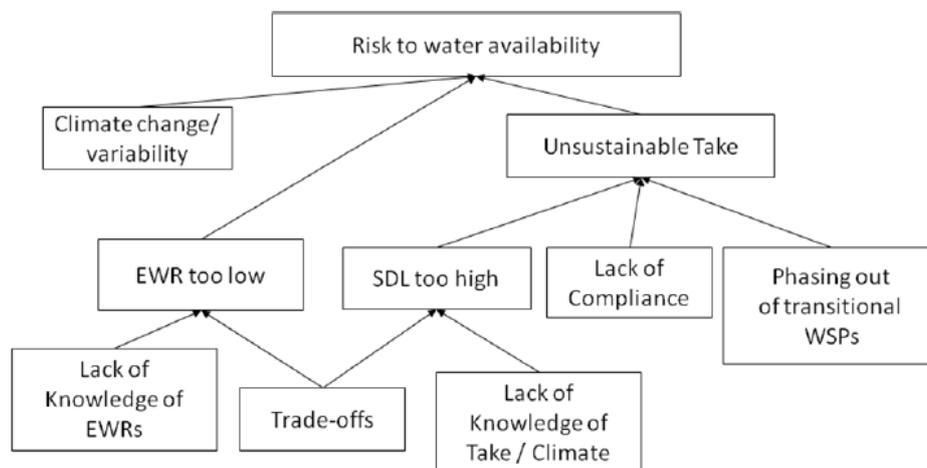

Figure 2. Influence diagram implemented as a Bayesian network model, showing the factors that pose a risk to water availability in the Basin, where EWR is environmental water requirement, SDL is sustainable diversion limit (on consumptive use), and WSP is Water Sharing Plan.

Sensitivity analysis of the risk analysis models was used to determine the most influential hazards in estimating risk to each of the endpoints (Pollino et al., 2007). Models outcomes for risks to water availability indicated that the quality of knowledge for determining environmental watering requirements was generally quite poor, representing a significant knowledge gap in determining the quantity of water required to protect environmental assets of the Basin. Uncertainties also arose regarding the data and models available to quantify water availability in the

Basin, where the quality of the model baseline, simplifications of river system representation and quality of the groundwater modelling generally contributed to the risk. Another potential risk to quantifying availability of the water resource was the variable quality of water accounting, particularly as related to the fraction of the catchments that are ungauged. The poor knowledge of floodplain harvesting was also a significant source of uncertainty in estimating interceptions of runoff in the Basin.

Each of the hazards identified as highly influential and controllable became the focus of development of a risk management strategy (Pollino and Glendining, 2010). Such hazards included knowledge for defining hydrological requirements for ecological wetlands, compliance arrangements for water access at a local scale, gauge coverage in selected regions in accurately quantifying the available resource and lack of water quality models to assist in planning. It is worth noting that influential hazards varied by region across the Basin.

An independent evaluation of the models and outcomes during the case study identified the following limitations:
- communicating complex model outcomes in a succinct and transparent manner
- a lack of 'trust' in the methodology and model outputs
- difficulty in interpreting probabilistic outcomes and
- a lack of commitment in updating and improving model as both the policy environment and the knowledge base improved.

3.1 Evaluation against criteria

In this sub-section, we evaluate the case study against the risk management utility criteria established in Section 2.

(1) Incorporates clearly articulated objectives
The tool was based on a conceptual model formulated by the client, and this conceptual model captured their objectives. The complicating factor throughout the model development process was the changing objectives of the client, reflecting the political realities of the process of water resource planning.

(2) Improves the identification of opportunity risks and threat/hazard risks
The tool was designed to identify hazard risks. Opportunities were expressed as treatments to reduce those risks, i.e. the management strategies that were available to mitigate risk.

(3) Caters to a range of risk tolerances (i.e. is sufficiently flexible to be relevant to low- and high-risk takers
The Water Act 2007 aims to minimise (hazard) risk to water resources. Through sensitivity analysis, controllable risks were identified. It was then a decision of the client as to whether they were going to adopt a high or low risk attitude to mitigation through investment to manage the controllable risks.

(4) Creates uniform risk criteria and evaluation metrics
Bayesian networks are based on probabilities, where all drivers and endpoints are transformed to be represented as probability distributions, thus providing a uniform representation of risk and consequences. We believe that this is a key strength of Bayesian networks, and makes them highly suitable for use in a risk management context.

(5) Explicitly incorporates uncertainty together with how it impacts on achievement of stated objectives
The representation of drivers and endpoints as probabilities allows the representation of multiple sources of uncertainty, including variability and lack of knowledge. However it did not distinguish between these in the assessment – it

was only in the interpretation of outcomes that these uncertainties could be distinguished.

Based on these criteria, the case study tool scores well. Although the case study fulfills these criteria, the limitations noted in the previous section resulted in no update of the model in the subsequent planning for water resources in the Basin.

4   DISCUSSION AND CONCLUSIONS

The adoption of ISO standard 31000:2009 as an integrating framework is in line with sound business practice, and meets the directive of the National Water Initiative. It has not been possible within the limited scope of this paper and the selection of a pre-existing case study to fully assess its utility for the development of water resource planning tools. However the contemporary definitions of risk and its consequences provide enormous scope to use the principles and vocabulary of risk management to refocus our tools to better support the questions that need to be answered before making decisions.

The central role of uncertainty in the risk management framework is challenging at all steps in the risk management process. There is evidence that explicit reporting of uncertainty encourages conservative behaviour, resulting in missed opportunities (see Brown and Baroang (2011) for a good description of the relationship between risk and opportunity.) By inference, the elimination of uncertainty eliminates risk. Risk is linked to objectives; the clearer the objectives are stated, the easier it is to identify, assess and evaluate risk.

The development of evaluation criteria that contribute to the learning cycle of adaptive management is also a maturing science. Yet it is a critical factor in demonstrating return on investment in reform of water management, as mandated in Australia under the National Water Initiative and the Water Act 2007. The adoption of international standards in risk management and risk assessment within the water resource planning and R&D industries, is one large step in implementation of best practice.

The next step is to trial the utility by building a case study from scratch and assess how our current modelling approaches align with risk management principles. It may be that the models themselves require little modification, and effort needs to be focussed on how objectives and options (scenarios) are described, and in the presentation and interpretation of likely outcomes against objectives.

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