Development of an Interdisciplinary Bayesian Network Tool for Catchment Management in the Solomon Islands

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Keywords: *Water, ecological risk assessment, catchment management, participatory approaches*

EXTENDED ABSTRACT

This paper presents the first phase of an interdisciplinary study for the management of Kongulai catchment, a primary water source providing up to 60% of the water supply for Honiara, the capital of the Solomon Islands. There are complex economic, social and ecological factors involved, including multiple uses for both water and catchment and many potential threats to the water supply, including logging, agriculture, pathogens, unstable geology and the institutional arrangements. In such cases a risk-based approach is widely recommended (Rothstein *et al*. 2006, Slater and Jones 1999).

The approach used here is based on catchment-based Ecological Risk Assessment (e.g. Hart *et al.* 2003, Hart *et al.* 2006), and was used to guide development of a model to quantitatively assess threats and hazards to water in the catchment.

There are widespread and ingenious applications of modelling to a variety of real-world situations, but transfer of modelling technologies to managers and real-world application of these models to improve management remains a challenge (e.g. McIntosh *et al*. 2005, Matthews *et al*. 2006). Increased involvement of stakeholders, both the managers and the communities who are part of or live in the system being modelled, has been widely suggested as a key requirement for closing the gap between model development and use (Jakeman *et al*. 2003).

For this study, participatory approaches were used from the initial problem formulation phase and involved local water managers, a number of government departments and other stakeholders including customary landowners and non-governmental organisations. This process has been emphasized in constructing models intended for use in management decision-making (van Delden and Engelen 2006).

There is a need for a quantitative tool to integrate the complex factors involved and prioritise management actions. Because of the sparse data, high uncertainty and incomplete understanding of the system, and because of its intuitive graphical basis (Bromley et al. 2005, Welp et al. 2006), Bayesian techniques were considered appropriate and a Bayesian network model is being developed.

An additional consideration is that the development context of the Pacific region requires care to ensure any model-based tool is appropriate. There is a lack of data and restricted human and financial resources.

Conceptual maps of the primary factors affecting the key water value were elicited from stakeholders and used to discuss water resource issues. This is also being used as the basis for a quantitative model. Ongoing consultation with the managers aims to display underlying assumptions and keep model construction transparent.

Although the managers are receptive to the potential benefits of the model, the extent to which it will be applied is not yet clear. At minimum, outcomes from the model will enable application to the government or aid agencies for resources to quantify important risks to the system. Additional benefits would derive from ongoing model use by managers to indicate where limited resources would best be applied. The primary barriers to uptake are resource scarcity for training in the use and updating of the model, and institutional inertia.

Additionally, building a relationship with the stakeholders as well as facilitating the relationship between stakeholder groups will be required for successful management.

1. INTRODUCTION

Water resources are of increasing concern to governments and environmental managers. Many of the problems associated with environmental management, such as complexity and variability, environmental degradation, and lack of data on which to base management decisions, are exacerbated in developing countries. The authors initiated a case study to develop techniques to assist in water resource management in this context in the Solomon Islands.

Considerations of access and data availability, as well as of potential human impact, narrowed possible study sites to those near the capital of Honiara. Consultation with local water managers indicated that Kongulai catchment, just west of Honiara was an appropriate site, as it has a number of current issues needing study. As there are multiple and conflicting uses for the water resource and for its catchment, as well as multiple potentially serious hazards, and because managers need to evaluate, prioritise and find solutions to these problems, a risk-based approach was deemed appropriate (e.g. Rothstein *et al*. 2006, Slater and Jones 1999, Bartell 1998).

A Risk Assessment approach has been used increasingly over the past few years by resource managers, environmental agencies and research bodies, to assist in the protection and management of ecosystems (e.g. Slater and Jones 1999, Hart *et al.* 2003, Hart *et al.* 2006). Ecological Risk Assessment (ERA) is a process for predicting the level of risk posed by hazards (i.e. stressors, threats) to the health of ecosystems. Risk is the likelihood that potential hazards will have a damaging effect on an ecosystem, multiplied by the consequences of this to the ecosystem.

ERA aims to provide an open and transparent process for coming to terms with the need to make management decisions for complex ecosystems that may not always be fully understood. The level and method of investigation of risk is dependent on a number of factors, including: the perceived level of risk posed to the ecosystem, conservation issues, community concern and available resources.

This paper describes the first phase in the ERA process, which attempts to ensure usability of modelling outcomes.

In developing country contexts such as the Solomon Islands however, it should be noted that the environment as it relates to human health, livelihoods and safety take precedence.

2. METHOD

The approach for undertaking an ERA can be seen as comprising of two main phases, the Problem Formulation phase and the Risk Analysis and Characterisation phase, as illustrated in Figure 1.

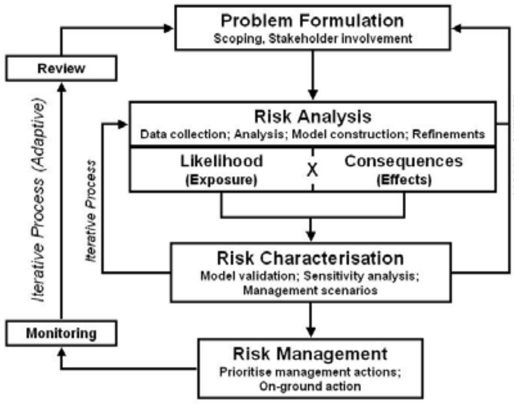

Figure 1. The ERA process.

This paper focuses on the Problem Formulation phase and how this feeds into the proposed modelling and helps ensure a useful tool for the on-ground managers. It should also be noted that adjustments were made for the developing and foreign context, in particular, that any environmental focus came secondary to human health issues.

2.1. Problem Formulation

The Problem Formulation phase determines the scope of the risk investigation and the type of management information it needs to provide. For the Kongulai case study, the relevant literature was reviewed, particularly local studies and reports, to prevent repetition of effort, and to provide an idea of the issues and a basis for discussion with stakeholders. This review also provided a first step in identification and mapping of the stakeholder groups and possible representatives. Consultations with stakeholders and formal consultations (workshops) provided an understanding of the risk assessment process and encouraged their input to provide a basis for ownership of the project and its outcomes.

This phase also encourages stakeholders to explicitly think about the issues involved and provides an avenue for discussion and exchange of views and concerns between stakeholders and examination of alternative conceptual models of the same system. Because of current tensions between stakeholder groups, three separate sets of consultations were performed for this phase, firstly with community and landholder representatives, secondly with government and water management stakeholders, and finally with non-governmental organisations. A later stage is intended to combine the groups and allow a mediated exchange of views.

Stakeholder engagement

Stakeholder mapping identified interest groups within government and resource management, non-governmental organisations (NGOs), and the community. Potential stakeholder representatives were gathered from initial contact points in the Australian Agency for International Development (AusAID) and the Solomon Islands Government, particularly the Water Authority and the Division for Water Resources, and further contacts were made through these networks. This "snowballing" of contacts was an important way of identifying the most appropriate representatives in different groups, and was also important for culturally sensitive initiation of contact. This exploratory process also identified a skilled and widely respected government employee who, as a member of a related landholder clan, was able to facilitate our contact and interactions with this group and act as translator where necessary.

Personal invitations to be involved in the consultations were sent to these groups and to specific representatives, via a local contact (the Director of the Water Resources Division for government and NGOs groups, and the community facilitator for the community stakeholders). Consultations were set up with two community landholder groups living in the catchment, government organisations, and NGOs.

As there has been some tension between the groups, the consultations were held separately to encourage participants to speak freely, and to manage tangential and possibly confrontational discussions. The possibility of a later meeting with all stakeholders was also introduced.

Community consultations

Two initial community consultations (of 30-35 people) were held with the two sub-clans of the catchment landholders. These were open to all. We were introduced by the local facilitator, and then introduced the project, setting out our ethics procedures, our aims in identifying how to improve management of the catchment, how it might help them, and how it might be generally useful. We were also careful to be very clear that we didn't have any say over international funding or further projects and that we weren't working on the behalf of the local authorities with whom they normally dealt with on land and resource issues. A number of issues were aired at these meetings, in particular the current tension between landholders and the government. After questions and a general discussion, the groups were asked to select representatives for smaller separate meetings for men and women.

On subsequent days four smaller community meetings (6-9 people each) were based around discussion of a large map of the catchment. Where there were lulls in discussion, questions were used to elicit further information about catchment features, the water cycle, spatial, temporal and historical variations, rivers, springs, sinkholes, runoff; flows, rainfall, seasonality, personal water collection and use, other local uses for water, landuses, threats to water; and causal links between factors discussed.

Government and NGOs

An all day workshop was held for the 19 government representatives, and a separate workshop for the 16 NGO representatives. Government stakeholders included representatives from the Solomon Islands Water Authority, the Water Resources Division, the Department of Mines and Energy, the Ministry for Agriculture and Livestock, Environmental Health, Ministry of Health, the Honiara City Council, the Ministry of Planning and the Meteorological Service. NGO stakeholders included representatives from the Solomon Islands Development Trust, Oxfam, Greenpeace, Live and Learn, the Community Support Program, Vois Blong Mere Solomon, the Environmental Concerns Action Network of the Solomon Islands, the World Wildlife Fund, the Nature Conservancy and World Vision. The workshops were more structured than the community consultations, and after the project introductions, ethics clearances and catchment map discussions, discussion of values was followed by a formal (blind) vote to identify the priority value.

Brainstorming and discussion of threats to water in the Kongulai was followed by discussion of known or suspected sources of data for any factors mentioned thus far. Finally, the groups were divided into smaller groups to construct causal diagrams of how the stakeholders understood the catchment to work, based around the priority value and including those threats they thought were significant, as well as any additional factors they considered important. These were then presented to the larger stakeholder group for comparison and discussion.

2.2. Risk Analysis and Characterisation

The Problem Formulation feeds into the Risk Analysis and Characterisation phase, which is currently underway. This phase aims to quantitatively assess risks to the key value/s identified in the Problem Formulation phase based on the refined conceptual diagrams of the stakeholders. Additional existing quantitative data relevant to the major threats/hazards or any other important factors with an affect on the key value are identified, sourced and collated. Quantitative estimates for likelihood and consequence are then combined in the model to obtain an assessment of risk for potential threats/hazards (and allowing them to be ranked). An analysis of sensitivity and of the consequences to the key values, and the likely outcomes under different management scenarios is then intended to provide practical information and tools to assist resource managers in prioritising solutions to management of the threatened values.

2.3. Data

There is little regularly collected data available. The data used in this study was collated from a number of sources. The Solomon Islands Water Authority (SIWA) collects water quality data, with a primary focus on variables with a direct impact on human health such as coliforms and heavy metals. The Water Resources Division in the Department of Mines and Energy collects some flow data, but only from limited sites, none of which were within the study site. The Japan International Cooperation Agency (JICA) has done a number of projects in the region and has collected relevant bore data and additional flow and water quality data from within Kongulai catchment. Collating and formatting the many sources of data into a common database is used for the quantitative modelling (see below), and also provides something of direct use to managers.

2.4. Proposed modelling methods

In the context of this project, with sparse data and limited understanding of many of the processes involved, and resulting uncertainty in many areas, Bayesian methods are particularly suitable. A Bayesian Network (BN) is based on a diagram that depicts and organizes the knowledge about a particular system. It includes probabilistic information on how much and in what way one part of the system affects another. BNs attempt to give a useful estimate of a predicted outcome even if apparently key pieces of information are missing. BNs explicitly account for uncertainty. This is particularly important where the complexity and variability of the natural world means exact predictions of the effects of management actions are rarely possible. Managers can then balance the desirability of an outcome against the chance that management actions to produce the outcome may not work as expected. BNs are particularly useful where there are many possible management decisions, and many criteria on which to base management decisions. Because BNs are graphically based, they also allow input from people less familiar with computer modelling, but with a good understanding of the system and can improve communication about our current understanding of the system by providing a basis for a common mental model as recommended by Kolkmann and van der Veen (2006) and others. A more detailed description of the background and application of BNs can be found in Korb and Nicholson 2004.

Importantly for adaptive management (Parma 1998), BNs are relatively easy to adapt and change if our understanding of the system develops as new factors come into play, or when new data are collected. The networks “learn” from additional data and become better at predicting outcomes.

3. RESULTS

3.1. Problem formulation

The development context of this study meant that environmental considerations were secondary to human survival concerns. All stakeholder consultations resulted in the selection of the key value of “water for human survival” as being the primary concern amongst all groups. However, a number of environmental issues came up in all discussions, and there was high stakeholder awareness of the impact of threats such as logging and other human activities, as well as population growth on this value. Other common factors that were discussed are listed in Table 1, with the number of smaller sub-groups (of the total four community subgroups, three government sub-groups and two NGO sub-groups) discussing each factor or including it in their conceptual diagram listed (individual prioritising votes for the “values” in the table are listed in brackets).

The key outcomes of the stakeholder consultation were identification of, and consensus about:

- Values in the selected areas that are of key concern to stakeholders and considered a priority for the focus of the investigation,
- Potential threats or hazards to these key values,
- Stakeholder conceptual maps relating their understanding of the catchment and causal impacts of important threats and other factors on values (see Figure 2 and Figure 3), and a number of similarities

and differences between stakeholder groups (see Table 1),

- The type of information and tools that resource managers would need to practically manage the potential risks, and
- Information and knowledge sources for the selected regions and values, threats and other factors.

Table 1. Common water factors considered important by community (4 groups), government (38 total votes) and NGO (32 total votes) stakeholders. 'X' indicates discussed, not voted for; '0' indicates not included in conceptual diagram; '-' indicates not discussed.

Values	Community	Government	NGOs
For human survival	4/4	3/3 (15)	2/2 (17)
For flora/fauna	-	3/3 (8)	1/2 (4)
Quality	4/4	3/3 (12)	2/2 (X)
Quantity	X	3/3 (5)	2/2 (X)
Commercial uses	-	0/3 (2)	0/2 (2)
Reliability	3/4	1/3 (X)	0/2 (X)
Sustainability	3/4	1/3 (8)	-
Income to landholders and govt	-	0/3 (5)	0/3 (3)
Access (e.g. distance)	3/4	3/3 (-)	2/2 (0)
Domestic uses	2/4	0/3 (X)	0/2 (X)
Agriculture/farming	2/4	3/3 (X)	2/2 (3)
Social/cultural	1/4	0/3 (X)	0/2 (2)
Ecosystem health	-	0/3 (X)	2/2 (1)
Removal of wastes	3/4	-	0/2 (2)
Food source	-	-	0/2 (2)

Threats	Community	Government	NGOs
Geological change (e.g. earthquakes)	3/4	3/3	2/2
Floods	1/4	2/3	1/2
Ethnic tensions	2/4	0/3	0/3
Logging	3/4	3/3	2/2
Agriculture	0/4	3/3	2/2
Pollution	4/4	3/3	2/2
Population growth	3/4	3/3	2/2
Erosion and sedimentation	4/4	0/3	0/2
Poor relationship between water authority/govt and landowners	3/4	3/3	2/2
Landowners (e.g. blocking spring deliberately)	3/4	3/3	2/2
Climate change	0/4	3/3	0/2

It should also be noted that community stakeholders were very appreciative at being consulted at such an early stage of the project, and had a number of anecdotes relating that this was not usually the case.

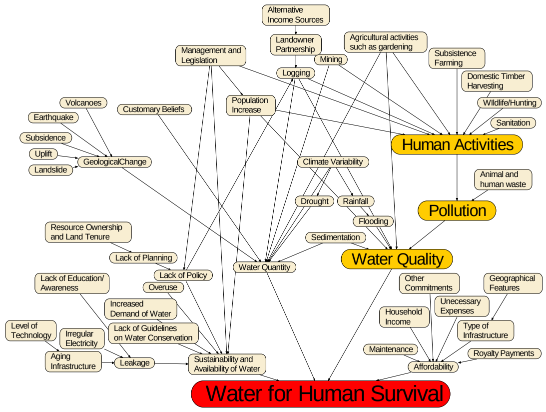

Figure 3. Government conceptual diagram.

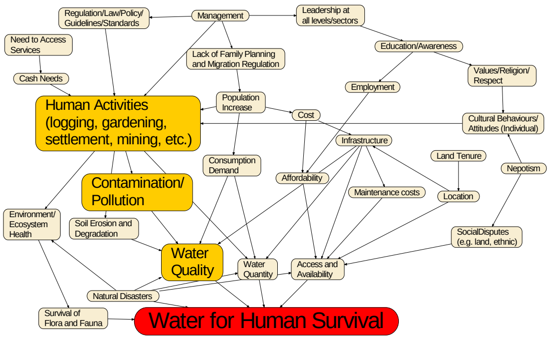

Figure 2. NGO conceptual diagram.

3.2. Preliminary Risk Analysis

The conceptual diagrams are currently being merged, refined and parameterised. Common branches such as that indicated by the yellow nodes in Figures 2 and 3 will be retained and can be parameterised as in the example in Figure 4.

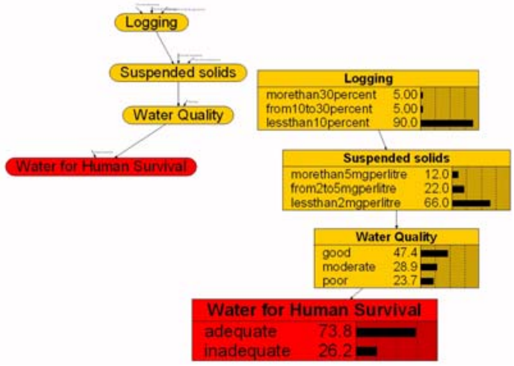

Figure 4. Model refinement, "Logging" branch.

Nodes and linkages will be further retained, pared, and merged according to their concurrence in the conceptual diagrams and according to the literature. Initial conditional probability tables will be assigned from the literature and expert elicitation where available. The network will then be trained with the available data, reserving part of the dataset for error analysis.

4. DISCUSSION AND FURTHER WORK

As has been found in many previous studies (e.g. Castelletti and Soncini-Sessa 2007), involvement of stakeholders is vital to ensuring the relevance of a project and prevents it from being a purely academic or technically driven exercise, as well as increasing the legitimacy of the project and the acceptability of the outcomes. Local knowledge of the system under consideration is also an important facet of this process. It was unfortunate that due to complications of language, inaccessibility of meeting places, and time restrictions, community consultations could not replicate the structure of the government and NGO workshops. However, it was evident that there was common ground in the views of all groups. This included the priority value, water quality and quantity, issues of sustainability/reliability, the importance of geology (karst) and geological change, and threats from pollution, agriculture, logging and poor sanitation. As illustrated in Figure 3, parts of the different conceptual diagrams had a very similar structure.

However, it was interesting to note that the government stakeholders focused on biophysical and infrastructure aspects of the catchment and included much detail that was not considered by the NGOs. Conversely, the NGOs were concerned primarily with cultural and socio-economic factors, although all stakeholders indicated awareness of the importance of: a) the poor relationship between the landholders and government, b) policy/legislation, and c) community attitudes. These differences appear to dovetail for a more holistic view of the system.

This study is currently continuing and model development is underway. There is extensive refinement of the conceptual maps required with ongoing consultation with locals and experts for parameterisation of the model, and ongoing data mining from disparate past studies and organisations.

Although there are currently electronic and phone conversations with the resource manager stakeholders, an additional trip is planned for in-person presentation to the wider stakeholder group, involving discussion and comparison of the conceptual maps, the commonalities and differences, and details of conversion to a quantitative model. This is intended to facilitate the exchange of views between stakeholders and continue to build the relationship between resource managers and community. The consultation will also allow further feedback on the model and the risk analysis and characterisation, for a further iteration of model development.

Stakeholder involvement from the beginning and throughout the ERA process is essential. The process needs to be transparent and understood by stakeholders and trust between model-builder and end-users needs to be developed. The resource managers and other stakeholders should believe that the model is a reasonable representation of reality for the model to be used and/or for uptake of model results.

Obstacles to the uptake of a model or of any new management processes include the current tension and conflict between community landholders (partly a result of poor integration between government departments and institutions such as Department of Lands, Division of Water Resources, Finance and the Water Authority), and time and resource constraints for the managers to implement any new procedures. The government/managers and stakeholders will need to start viewing the maintenance of their relationship as necessary work (Guizol and Pularmo 2005, McAllister et al 2005). Facilitation of this relationship may be necessary.

5. CONCLUSION

As noted previously, the Ecological Risk Assessment process is ideally iterative, feeding into a continuing adaptive management decision-making process to develop a risk management plan. This would include a monitoring program to provide information on the success or otherwise of any management actions, and a review process to ensure the management plan is adapted or upgraded as knowledge improves and priorities change along with changes in the region or in stakeholder views.

Unfortunately, even in developed countries, it is rare that monitoring programs are implemented that definitively indicate whether management actions are having the desired impact over a reasonable time period. Thus, where there is sparse and uncertain evidence available (e.g. from specific short-term studies, landholder observation), application of Bayesian techniques (e.g. updating Bayesian Networks) are likely to be one method by which managers can update management plans and support decisions to switch or maintain management strategies.

Tool design and usability must be done in conjunction with the end-user. However, even if this is successfully completed, there is no avoiding the reality that new problems and new management alternatives will appear and another iteration for model and management improvement will be required.

6. ACKNOWLEDGMENTS

This research was funded by the Australian Agency for International Development. A great deal of in-country help was provided to the researchers by the Director of the Division of Water Resources, Charlie Bepapa, and Isaac Lekelalu. John Waki, the General Manager of the Solomon Islands Water Authority, and Jacob Houtarau are also gratefully acknowledged. The researchers also thank local liaisons Gabriel Vaga and Donald Marahare for their assistance, as well as all stakeholders who participated in the research.

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