DRAWING LINES UNDER AND RINGS AROUND LYNGBYA: AN INTEGRATED BAYESIAN NETWORK SOLUTION

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Introduction

Although blooms of marine weeds, such as the cyanobacteria *Lyngbya,* have occurred to varying degrees for decades around the world, it is only more recently that the toxicity of such weeds and their increased biomass have become substantial environmental and health issues. Therefore an understanding of the scientific and management factors impacting on their initiation, bloom, maintenance and decay is imperative.

This paper is a summary of a substantive project undertaken by QUT as part of the contracted research for the Healthy Waterways 2005-2007 *Lyngbya* Research and Management Programme. See Hamilton *et al* (2005) and Hamilton *et al* (2007) for details and corresponding literature review. The project aimed to integrate available scientific and management knowledge about *Lyngbya* blooms in Deception Bay, near Brisbane, Australia. Comprising about 1.8 million people, Brisbane is Australia's third largest city, so the pressure on marine waterways and the possible environmental health risks arising from the invasion of this weed, are substantial.

The project aim was achieved by developing an Integrated Bayesian Network (IBN) approach comprising a series of Bayesian Networks (BN) designed to conceptualise and quantify the major factors and their pathways leading the initiation of *Lyngbya*. This was achieved in close collaboration with a *Lyngbya* Science Working Group (LSWG) drawn from diverse disciplines and a *Lyngbya* Management Working Group (LMWG) drawn from local and state government and private organisations.

A Bayesian Network (BN) is a graphical framework overlying a conditional probability network. Each environmental factor is represented by a node which is connected to at least one other node. Underlying each of the nodes is a probability table that is determined by the state of the node and of the nodes that influence it. The Network provides a probability of the outcome of interest, given the factors influencing it, their interactions and their individual conditional probabilities.

Methods

We describe here the IBN for the probability of initiation of *Lyngbya*. This network comprising two primary BNs, a Management and a Science Network, integrated with a catchment water simulation model, E2 that was concurrently being developed under the *Lyngbya* Programme. The IBN is conceived as a series of steps, in which the Management Network informs about nutrient discharge into the Deception Bay catchment, the E2 model simulates the movement of these nutrients to the *Lyngbya* site in the Bay, and the Science model then integrates this nutrient information with other factors to determine the probability of initiation of *Lyngbya.*

The Management Network focused on management inputs that potentially influence the delivery of nutrients to the Bay. In two meetings of the LWMG, participants defined and located point sources, agreed on the nutrients discharged, identified management options for each source (existing, committed, best practice) and identified a contact person and relevant sources of information. The Network was then quantified by asking, 'what is the probability of low/high nutrient discharge for each source under each management option?'.

The Science Network focused on nutrient and physical factors that were agreed to be important for the initiation (and later growth, duration, biomass and decay) of *Lyngbya.* A conceptual model of these factors (represented as nodes) and the way in which they interacted (represented as a series of pathways or links) was constructed. For each node, a conditional probability table was formed, based on the factors that affected that node. For example, the probability of low or high turbidity was determined for different levels of land run-off load (high or low) and bottom current climate (high or low). The Science Network was interrogated to identify factors that have most impact on the probability of initiation of *Lyngbya* and investigate the sensitivity of this probability to changes in the factors.

The models were developed using a variety of software modelling tools. The conceptual Management Network was visually represented using the BN package Netica® and then interfaced with the hydrological flow and nutrient load model created in the simulation package, E2, in order to identify nutrient loads reaching the *Lyngbya* site. The Science Network was developed entirely in the BN software Netica® and later in Hugin®.

In collaboration with the management committee, a series of scenarios was proposed that exemplified management actions in the catchment that would impact on nutrient delivery to the *Lyngbya* site. Scenarios included: upgrading a point source from existing to best practice (eg, eliminating potassium output from sewage treatment plants across the catchment), changing a land use (eg, converting forest to horticulture in a subcatchment area), describing a climate event (eg, a severe summer storm or last year's summer).

The IBN may then be used for scenario modelling in the following manner. First, a scenario is proposed that represents a change to the nutrient sources in the Management model or to the factors affecting the initiation of *Lyngbya* in the Science model. If nutrient sources are changed, the impact on nutrient outputs across the catchment arising from the management scenario is spatially quantified via the Management Network. The effect of the management scenario on the nutrient flow to the *Lyngbya* site in Deception Bay is then simulated through the E2 model. The Science Network is then updated to reflect these nutrient loads and other changes related to the proposed scenario. The Network is then activated to provide the probability of initiation of a *Lyngbya* bloom under this scenario.

Results

Figure 1 depicts the Integrated Bayesian Network for the initiation of *Lyngbya*. As described above, the Management Network feeds into the E2 catchment model which informs the Science Network.

The Science Network for initiation of *Lyngbya* is depicted in Figure 2. The following factors were identified as impacting on the initiation of *Lyngbya*: available nutrient pool (dissolved), dissolved organics, dissolved N concentration, dissolved P concentration, dissolved Fe concentration, particulates, point sources, air, number of previous dry days, rainfall-present, ground water amount, land run-off load, tide, wind direction, wind speed, bottom current climate, sediment nutrient climate, turbidity, light quality, light quantity, light climate and temperature.

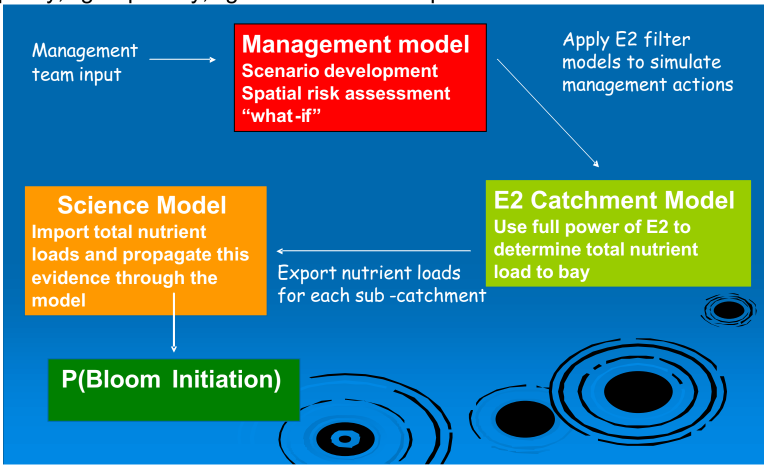

Figure 1: Proposed Lyngbya Network.

The seven most influential factors in the Science Network were identified to be (in decreasing order of influence): available nutrient pool, bottom current climate, sediment nutrients, dissolved iron, dissolved phosphorous, light and temperature. Sensitivity assessment and scenario modelling consistently identified available nutrient pool as the factor that most heavily influences the probability of initiation of a bloom.

The following scenarios indicate the sensitivity of the probability of initiation of *Lyngbya* to various factors in the Network. In a 'typical' year (defined by the LMWG), the probability of a bloom is 23%; this doubles if attention is focused on the high-risk two month in which blooms usually occur. If temperature is high, light climate is optimal and available nutrient pool (dissolved) is adequate, the probability of a bloom is 100%. With high rain and adequate light, the probability of a bloom is 46%. Changing nutrient availability alone changes the probability of a bloom initiation from 1% (inadequate nutrients) to 67%. Changing iron availability alone changes the probability of a bloom initiation from 16% to 30%. Changing organics availability alone changes the probability of a bloom initiation from 20% 25%.

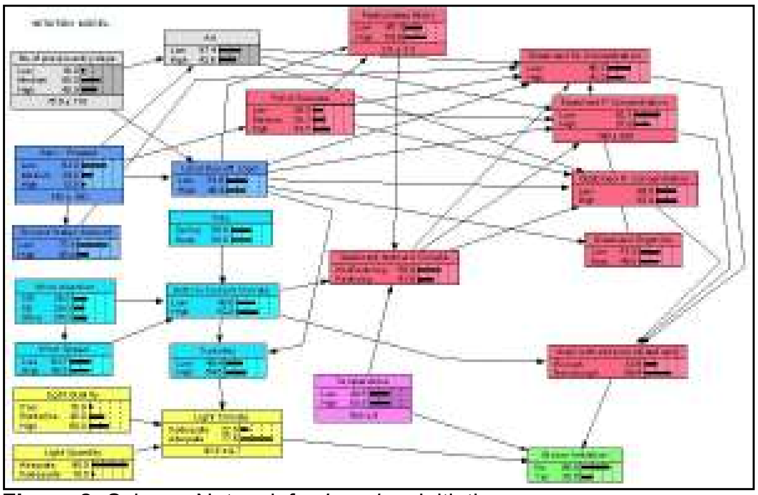

Figure 2. Science Network for *Lyngbya* initiation

The point and diffuse nutrient sources contributing to the Management Network for *Lyngbya* initiation included: aquaculture, composting, on site sewage, poultry, waste disposal, waste water treatment plant, agriculture, artificial development, development and clearing, extractive industries, forestry, grazing, natural vegetation and stormwater.

An extract of the Management Network is shown in Figure 3. The complete Management Network is shown in Figure 4.

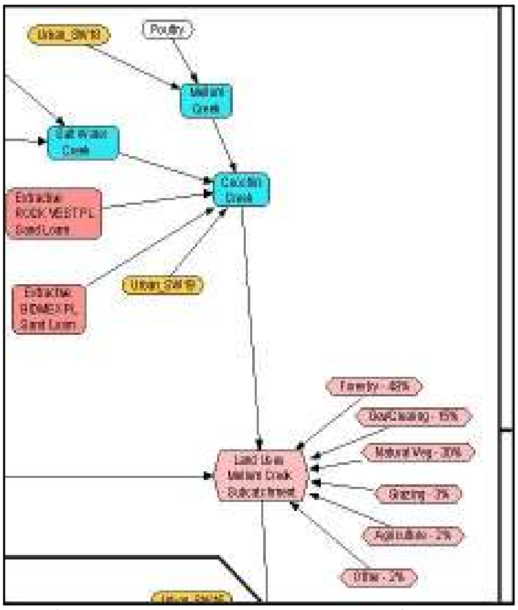

Figure 3. Extract of the Management Network identifying and locating point and diffuse sources of nutrients in the Deception Bay catchment.

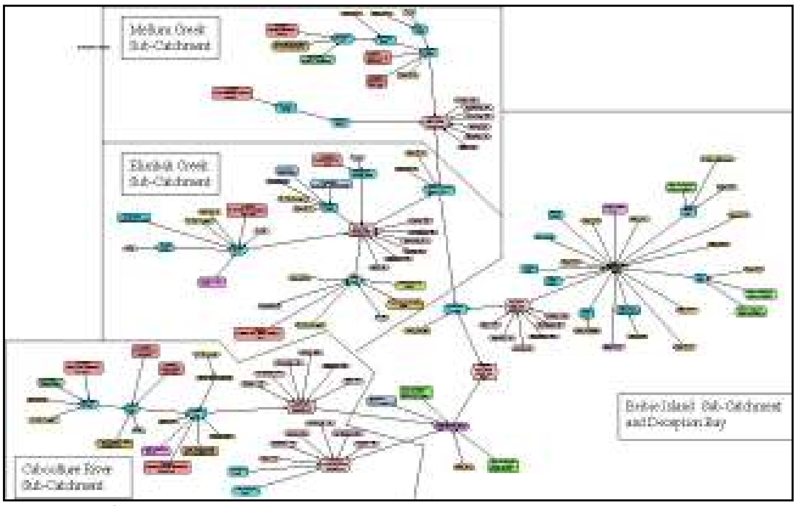

Figure 4. Complete Management Network

Discussion

Two important concurrent activities of the project were the commencement of documentation of meta-data for this wealth of information, and the identification of knowledge gaps. Information relating to complex environmental problems such as these is very diverse in content, type and accessibility. It is essential for auditability of the Networks, as well as for longer term management and research of this and related problems, that the information is well documented. The level of documentation and integration may depend on the project, but at least the meta-data on each information source should be compiled.

The identification of knowledge gaps is as informative and important as the identification of knowledge itself in problems such as the one considered here. In particular, it allows appropriate acknowledgement of the uncertainty of the affected nodes in Network outcomes, and informs about future data collection and research direction. In the *Lyngbya* project, knowledge gaps relating to nutrient loads by some sources, light quality and intensity, turbidity, iron, organics, sediments and biomass were identified.

The Integrated Bayesian Network approach described in Section 2 is not confined to the initiation of *Lyngbya*, but can also be used for investigating other features of this organism, such as growth, biomass and decay, through appropriate changes to the Science Network. These are currently being developed. The Integrated Network approach is also conceptually suitable for investigating other outcomes of interest that are impacted by nutrient outputs and water systems in a catchment.

More broadly, the general approach proposed in this paper is applicable to problems that involve both scientific and management considerations. Information arising from expert knowledge, data and research can be formally conceptualised and quantified through Science and Management Networks, and combined into an Integrated Network. Such an approach involves definition of the problem of interest, agreement about important factors and pathways that impact on the problem, and identification and integration of information that allow quantification of these factors and impacts. The benefits of such an approach include a much greater awareness of the problem, buy-in from diverse stakeholders, consolidation and formalisation of information, an audit trail for decision-making, and quantitative outcomes in the form of probability statements about the outcome of interest.

Acknowledgements

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References

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