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DEVELOPMENT OF A DECISION SUPPORT SYSTEM FOR WATER QUALITY MANAGERS: CONCEPTS AND STRUCTURE

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ABSTRACT

Water quality scientists in Australia are responding to the need from managers and politicians to predict the future of estuarine and marine systems. However, poor communication between scientists and managers can hinder understanding of each other's needs. This can lead to inappropriate and ineffective use of monitoring and predictive tools in the decision making process. Furthermore, scientists involved in this process generally have expertise in only one area: monitoring or modeling.

This Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management (Coastal CRC) project aims to develop a tool to educate and direct decision making on monitoring and modeling. The PC-based education tool will be a knowledge-driven decision support system (DSS) that will hold a series of knowledge bases (a collection of facts, rules, and procedures) including: basic concepts and definitions, classification of models, types of monitoring, data requirements for modeling and information on linking water quality models to catchment information. The tool will be designed in the first case to assist a specific management issue, the licensing and regulation of wastewater treatment plants, and will be trialed with a target user group. This paper will present an overview of the project concept, the support tool structure, and examples of knowledge base content.

1 INTRODUCTION

This project aims to develop a water quality decision support system (WQDSS) for decision makers. The idea for the WQDSS evolved from the concept that management, modeling and monitoring in coastal waters can be better integrated in Australia. Initial examination of the links between management, modeling and monitoring revealed that one of the weakest links appears to be in the area of modeling, despite an increasing management need to better predict outcomes. The use of modeling appears to be largely ad-hoc, opportunistic and under-utilized. The area of modeling can be highly technical and modeling expertise can be scarce or perhaps limited to particular software or model types. Furthermore, communication between decision makers and modelers is often poor.

Although similar issues are relevant for water quality monitoring, more monitoring does occur and there are arguably large bodies of information available on water quality monitoring. However, it can be difficult for decision makers to interpret and use this information in relation to their specific management needs given their limited resources. In many situations, monitoring work could be better targeted to management needs and better communicated, or tailored specifically for inputs into models.

The major aim of developing the WQDSS is to help to professionals understand and be able to make decisions about monitoring and/or predictive modeling options. The DSS tool will provide an interactive computer-based system to guide the user in a consistent and transparent way to making a decision.

This paper begins by outlining the scope of the tool related to the audience and potential links to other DSS. The proposed methodology to be used to develop the tool (including software and knowledge base development), will then be discussed. Finally, the modules and the help system of the WQDSS will be described and the project plan summarized.

2 THE SCOPE OF THE EDUCATION SUPPORT TOOL

As part of the development of the DSS, the project team will build a knowledge base of information targeted at Government decision makers rather than technical specialists. This knowledge base will provide introductory information and concepts about monitoring and modeling while encouraging users to follow an advised procedure of environmental assessment. For the more involved user, the DSS will provide an outline of: the types of models/monitoring, the typical uses, the type of expertise involved, data requirements, advised procedures, quality assurance considerations and the implications of different options and links to further information (Table 1).

In general, the project will not focus on developing new technical information, although it is planned to undertake some technically based research with regard to computationally linking models and review of software options and issues.

Table 1: Scope of the WQDSS project

Scope Issue	WQDSS Focus
Water types	Predominantly coastal rivers and bays but some freshwater/estuarine environments may be included.
Environmental stressors	Nutrients, biodegradable organics, sediment, toxicants, pathogens, ecological health, flow.
Models	Water quality models: approaches, types and quality assurance guidelines. Links to catchment information (including catchment & activity/process models) will also be examined.
Monitoring	Will include exploration of ambient and event-based (in-situ) water quality monitoring, remote sensing (ex-situ), biological indicators and tools for monitoring flows.

2.1 Waterbody types and management activities

The WQDSS framework is designed to be generic so as to be suitable for various management issues across different waterbody types and spatial scales. The waterbody types considered initially in this project will be coastal rivers and bays.

There are two management activities that have received strong support from our project partners: a) water flow and water resource planning and b) licensing of point source discharges. These management activities have been chosen as a starting point to demonstrate the integration (of management, modeling and monitoring) framework. Detailed consideration of other management issues is outside the scope of this project at this stage. However, the knowledge bases developed may also be relevant for a much broader range of issues such as catchment management, stormwater management, environmental value setting and 'State of the Environment' reporting (QEPA 2003).

2.2 Links with other DSS

The WQDSS will be designed to link with a few key DSS being created in Coastal CRC and Government projects. The Queensland Environmental Protection Agency (QEPA), with NSW and Victorian and Federal Government support, has developed a DSS for the process of licensing point source discharges under Environmental Protection legislation (Licensing Discharges DSS). This DSS follows an assessment process and includes access to information on treatment technology, hazard assessment and interpretation of water quality guidelines (ANZECC & ARMCANZ 2000) (McKenny et.al. 2004).

The WQDSS will provide another level of support to officers (and licensees such as local government) by offering guidance and education about predicting outcomes (modeling) and monitoring options for supporting this modeling or compliance. The WQDSS will focus primarily on water quality modeling and monitoring of natural aquatic environments rather than the activity itself (such as the sewage treatment process). However, in most cases, monitoring and modeling of the activity also needs to be considered and inputted to natural system models.

Other relevant DSS include one being developed by the Department of Infrastructure, Planning and Natural Resources (NSW), Coastal CRC and EPA Victoria to aid in the assessment of sustainability of coastal lakes (Rissik et.al 2004). The Vulnerability-Pressure-State-Risk-Response (VPSRR) approach could provide a useful overarching structure where links are made to the WQDSS.

3 METHODOLOGY

The WQDSS can be described as a knowledge-driven expert shell DSS where expert knowledge is provided to managers after being processed by a rule set manager (part of the DSS that holds the recommendations or directives expressed as “if”-“then” conclusions) and an inference engine (part of the DSS capable of interpreting these rules).

The development of the WQDSS, within the 1.5 year timeframe, will involve numerous stages of stakeholder consultation, expert elicitation (gathering of expert knowledge), formulation of decision trees, synthesis of knowledge bases, collation of the help system and technical engineering of the DSS software. The WQDSS does not include modeling simulations that can be run by the user. Guidance about decisions will be both structured and unstructured depending on the availability and level of certainty of the knowledge. Specialists working to provide advice about monitoring and predictive modeling options to managers have all supported the underlying concept of this project.

The WQDSS will be circulated initially amongst users in partner organizations for testing in mid-2005. Once the testing is complete and the final version (within this project) of the tool is produced, it is hoped that the WQDSS will be made available to other interested organizations. The generic framework for the DSS and some knowledge bases will still be published on the internet. Some components (if not all) will be available through the internet via the OzCoast website (of the Coastal CRC). This can be found at: <www.coastal.crc.org.au/ozcoast>.

3.1 How can a DSS help water quality managers?

DSSs are interactive computer-based systems intended to help decision makers utilize data (and/or models) to identify and solve problems and make decisions. DSS can aid the decision maker in solving unstructured problems through the organization of expert knowledge, relevant information or documents and decision checklists and heuristics (rules of good judgment). “They support, rather than replace, managerial judgment and their objective is to improve the effectiveness of the decisions” (Power 1999). From a Government agency’s point of view, having a DSS available at all times so people can access relevant and expert knowledge within short regulatory timeframes, is more efficient than repeatedly calling on the experts to provide this basic information.

3.2 Development of knowledge bases and expert elicitation

Expert knowledge will be elicited from experts in the form of professional opinion as well as documented resources to set up a knowledge base that will underpin the DSS. Heuristics will then be formulated from the expert elicitation to inform the decision process modules. In the tool’s simplest form, the knowledge base tables will be presented as a stand-alone help system, able to be viewed by the user.

Eliciting knowledge from experts is a very complex process. The project team is currently working with modeling and monitoring experts to assemble some of the knowledge bases for this DSS, through workshops and the employment of a facilitator. The best modeling experts in Australasia will be consulted to complete a framework for categorization of models and to then populate this framework. A peer review committee will also be established to evaluate the knowledge bases.

Expert knowledge will be sourced from scientists and managers working in organizations such as the Coastal CRC, the Queensland Department of Natural Resources and Mines (QNRM), the Environmental Protection Agencies (or equivalent) of Australia, the Australian Government Department of Environment and Heritage, the Cooperative Research Centre for Catchment Hydrology and relevant university research centers.

The next step will be to organize the knowledge bases in a logical way that can easily be used by stakeholders. For example, decision trees (hierarchical, tree-like drawings representing alternative sequential decisions and the possible outcomes from these decisions) are a common way to organize the questions and choices within the DSS. Decision trees provide a clear structure to describe decision options and investigate the possible outcomes (benefits, risks and data requirements highlighted by the experts) of choosing between the different options.

Gaps in knowledge will be identified by the team prior to DSS release to ensure that if the user navigates to a region in the WQDSS that has limited knowledge, they are advised on where to potentially access this information independently.

3.3 Software and engineering

Knowledge acquisition and representation of this knowledge in the DSS will be the major tasks in the WQDSS development process. A knowledge engineer will convert the expert knowledge into computer code so the significant objects and relations in the domain are organized into a system that will enable the DSS to make correct inferences and derive solutions.

There is a variety of commercial development and implementation tools available to construct DSS, ranging from high level programming languages, expert shells to toolkits containing domain-specific software. XpertRule® Knowledge Builder software developed by Attar Software in UK (Table 2) has been selected to develop the WQDSS prototype. This tool allows rapid development of the system and offers a number of different methods for knowledge representation and inferencing. User-friendly graphical user interfaces for entering required inputs, selection of options from the available list or access to stored information can be effectively designed using this tool. Report generation capabilities can be implemented using html format or standard Windows output. This tool also has capacity to link to databases, external programs and standard Microsoft Windows help systems.

Part of the knowledge acquired from experts and other information related to aquatic environments and water quality, will be stored electronically as a comprehensive help system. Storage of this information in HyperText Mark-up Language (html) is preferred so the information can be displayed by the user in any web browser program. At this stage, hypertext development kit (HDK) developed by Virtual Media (Republicorp Virtual Media 2004) software will be used to develop the help system the WQDSS links to. The help system software writes interactive cross-referencing in a document form to allow the user to jump from one section to another within the help system, which is a stand-alone program. HDK was used in the EPA's Licensing Discharges DSS but has since been superceded by XDK XML Development Kit (XDK) that supports additional web outputs: XHTML, XSLT, XML, HTML with SmarTOC for cross-browser support and Portable HTML.

Each page in the WQDSS will have a link to the help system so users can access relevant information and a glossary efficiently (Appendix, Figure 1). The help system will also provide guidance on running the DSS enabling users with minimal software training to access the tool.

Depending on the outcomes of consultation with stakeholders, software to convert the WQDSS to a web-based DSS may be applied, allowing users to work through the tool and generate results online.

Table 2: Details about XpertRule® software

Techniques:	Decision Trees, parallel Structured Query Language (SQL).
Platforms:	Win95, WinNT.
Import knowledge modules:	developed in XpertRule KBS or from XML files.
Knowledge deployment options-	PC standalone, COM+ Java Servlet or Java Applet, using XML for data exchange.
Vendor:	Attar Software, England. Website: <www.attar.com>.

4 DESCRIPTION OF MODULES AND HELP SYSTEM WITHIN THE WQDSS

The WQDSS DSS domain is a relatively large and complex system therefore it will be necessary to separate it into small units (modules) and develop several sub-systems to cover the whole system. The WQDSS will utilize an expert shell to step the user through these modules.

Although the specific decision trees and supporting knowledge bases have not yet been formulated, it is envisaged that each of the five modules will step the user through a generic decision process with access to associated knowledge bases and a help system that can be accessed at any time (Figure 1).

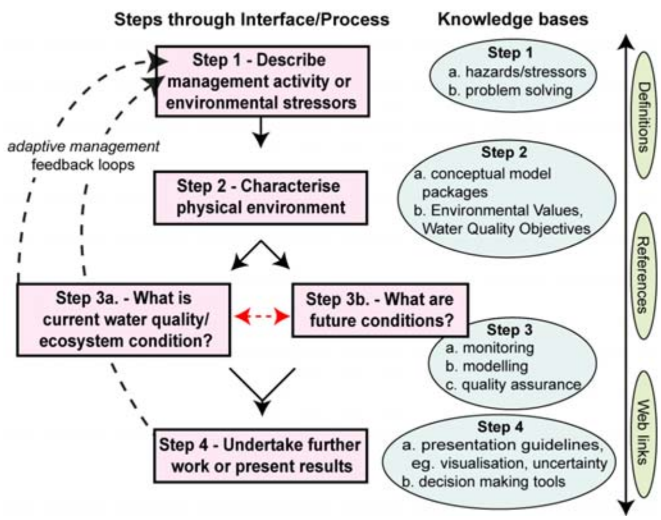

Figure 1: The interface process and associated knowledge bases for the WQDSS (rectangles represent the user interface questions, ovals, the specific knowledge bases and vertical oblongs, the help system).

As well as links to the expert knowledge and relevant resources, the WQDSS help system will include a clear and succinct glossary. Definitions for terms relevant to modeling and monitoring will be included, for example, in the modeling glossary: deterministic, stochastic, domain, grid, and Monte Carlo simulation. The information will range from introductory to more detailed, if the user desires to access this (Figure 2). Standard approaches or the 'ABC' of modeling/monitoring will also be described including how to apply models and correct use of monitoring data. This help system and glossary would essentially be a stand-alone resource but would also provide part of the knowledge base for the DSS.

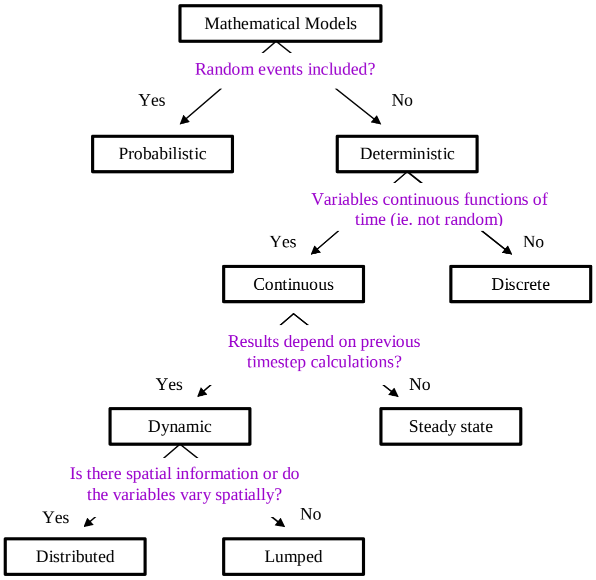

Figure 2: Break-down of mathematical models (adapted from Khandan 2002).

4.1 Step 1: Describe management activity or environmental stressors

The user will be able to choose from key management activities as either regulatory processes such as:

- Point source discharge
  - New license
  - Review of existing license
  - Management plan
- Water resource planning
  - New resource operations plan

or broad catchment and water quality stressors (based on Coastal CRC, 2004) such as:

- Sediments
- Bacteria/pathogens
- Freshwater flow regime (changed from natural)
- Hydrodynamics (changed from natural)
- Nutrients
- Organic matter
- Toxicants

The expert rule software will then use the selected criteria to select models and monitoring types that are suitable for the management activity. The user can also access background information about potential hazards and stressors to the waterbody (Appendix, Figure 2) as well as problem solving tools to help them to scope their management issues.

Example: An officer needs to assess an application to increase wastewater processing volumes at a wastewater treatment plant. According to the activity, nutrients, pathogens and sediment are default hazards that must be assessed. Progressing through the steps will provide them with information relevant to these issues.

4.2 Step 2: Characterize the physical environment

This step will encourage the user to summarize data such as:

- Waterbody type: lake, freshwater river reach, estuary, bay/ocean, whole catchment
- Location: within country/climatic region
- Other activities in the region: agricultural, industrial, point sources, catchment activities
- Ecosystem features: such as protected areas
- Specified environmental values or water quality objectives for the particular waterbodies

This information supports the user to view their particular management issue within the broader picture of the entire catchment or region. Collating this information will allow the WQDSS user to consider other stressors or factors (such as land-use activities) that may be impacting the waterbody in a broader context. This step is part of the general approach to educating about water quality management decision making but some of this information feeds into Step 3.

Example: The wastewater treatment plant discharge is located in an estuary. It is a highly modified estuary so the officer is encouraged to review objectives and consider whether regional catchment issues need to be considered. environmental values in the estuary may include: primary recreational and water for agricultural use, therefore this will determine what water quality assessments need to be carried out.

4.3 Step 3: Current and/or future conditions

Step 3 is a combination of two modules: 3a requires the user to consider existing data, while 3b encourages the user to think about the predictive questions they would like answered. Once 3a is completed, the user is stepped into 3b and the information is carried over and interrogated to provide guidance about modeling options and data needs. This module also encourages the user to assess their available timeframes and budget. The user can navigate between both the monitoring and modeling modules to change or review information.

4.3.1 Step 3a: What is the current water quality/ecosystem condition?

Available data on current conditions should be collated by the user at this point. The WQDSS will help the user determine whether the data is adequate or if more is required. This step will also help the user design a preliminary monitoring plan.

Example: Information about the water quality in the estuary is available through a regional ambient monitoring program that has been running monthly for 3 years. This program has monitored physico-chemical and nutrient pa-

rameters such as Dissolved Oxygen (DO), turbidity, salinity, temperature, total nitrogen, nitrate (NO_3), total phosphorous, filterable reactive phosphorus.

4.3.2 Step 3b: What are future conditions?

The user may need to predict impacts from their activity on the water quality in the surrounding discharge area. The tool will help the user to understand the possibilities for predictive modeling in their situation.

Example: The officer will be advised on different predictive modeling options applicable for their client's management issues and the waterbody type. For example, a multi-dimensional numerical model may be a better option than a simple model due to the highly variable discharge zone and a simple model's inability to model this accurately. If the officer has been provided with modeling results already, they can compare the procedure used and parameters modeled to the guidance provided through the WQDSS.

4.4 Step 4: Undertake further work or present results

Reports from working through the tool will be produced at this stage and guidelines will be produced on what further work should be considered. The user will be able to print out the reports or re-visit particular modules via a feedback loop, to change their choices, following an adaptive management framework.

Example: As the officer needs to know about potential impacts from waste on the recreational and agricultural environmental values, a local monitoring program (including mixing zone) should be implemented including pathogen measurements. Prediction of likely water quality following rainfall events should also be done and a numerical model with a daily time-step for these high rainfall times would be advised.

5 SUMMARY AND CONCLUSIONS

This paper has presented an overview of the Coastal CRC's Water Quality Decision Support System: the concepts for the project, the support tool structure, and examples of knowledge base application and content. The main goal of developing this tool is to enable users to quickly and effectively access expert knowledge on modelling and monitoring relevant to their particular management issue. Specific management issues chosen in the first instance, will be point source discharge regulation and water allocation but the WQDSS structure will be applicable to other management issues. Options for assessing and predicting the outcomes for aquatic systems will be provided primarily within the scope of coastal waters.

There are many choices available for DSS software but XpertRule® will be used to develop the WQDSS prototype. The DSS will comprise of approximately 5 modules, stepping through the process of describing the management activity and relevant waterbody, characterizing the environment, classifying current water quality condition and as a result of user inputs, advising on modeling alternatives and monitoring requirements. A feedback loop approach will encourage the user to obtain any additional information that is required before further progression through the tool. The WQDSS will link to a comprehensive help system that can operate and be distributed as a standalone program.

Using decision support software to produce this tool will result in increased consistency and transparency and having the tool as a PC-based application means that the user can have access to the information at any time. The WQDSS will be developed to complement other DSSs and technical software that is already seeking to provide decision makers with access to better water quality data and interpretation skills.

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APPENDIX:

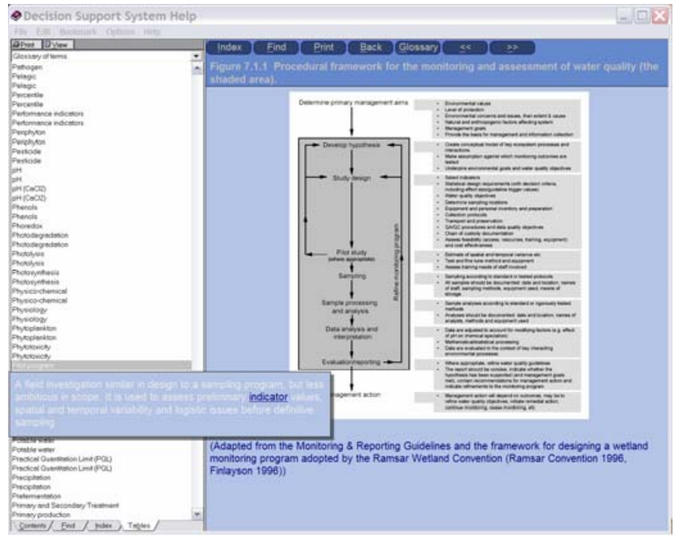

Figure 1: Screen grab from Help system associated with the QEPA's DSS for Licensing Discharges to Aquatic Environments (QEPA 2005).

Hazards Report

Typical Substances	Possible Sources
Alkanes	Heavy industry, Light industry, Medical and scientific
Ammonia	Heavy industry, Light industry, Commercial, Domestic
Aniline (Benzenamine)	Heavy industry, Light industry
Arsenic	Heavy industry, Light industry, Commercial
Barium	Heavy industry, Light industry, Medical and scientific
Cadmium	Heavy industry, Light industry, Cropping, Medical and scientific
Carbamate pesticides	Light industry, Commercial
Chromium	Heavy industry, Light industry, Medical and scientific
Copper	Light industry, Commercial, Cropping, Domestic
Cyanide	Heavy industry, Light industry, Cropping, Domestic
Herbicides and fungicides	Cropping
Lead	Heavy industry, Light industry, Domestic, Cropping
Mercury	Heavy industry, Light industry, Domestic, Cropping
Nitrogen	Light industry, Cropping, Poultry, Domestic
Oils & petroleum hydrocarbons	Heavy industry, Light industry, Domestic, Commercial
Organic alcohols	Commercial
Organic sulfur compounds	Heavy industry, Light industry, Commercial
Organochlorine pesticides	Cropping, Domestic
Phosphorous	Poultry, Cropping, Light industry
Polychlorinated biphenyls	Light industry
Polycyclic aromatic hydrocarbons	Heavy industry, Light industry, Domestic
Selenium	Commercial, Grazing, Poultry, Domestic

Figure 2: Hazards report. Typical substances (hazards) resulting from the user's trade wastes being treated. In this case: Cropping, Light Industrial and Commercial wastes result in nitrogen, mercury, lead, herbicides, copper, barium, organochlorine pesticides and phosphorous as default hazards to be investigated. (QEPA 2005.)