The Integrated Monitoring and Assessment System (IMAS): A Decision Support System for Water Quality Monitoring and Assessment Programs

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***Keyword**: Water quality, Monitoring designs, Decision support systems*

EXTENDED ABSTRACT

Millions of dollars are invested in water monitoring programmes across the country each year and a variety of organisations, groups and individuals are responsible for the design, collection and assessment of water management and water quality improvement programs. The capacity to undertake monitoring and assessment programs vary within these groups and assistance is often required to produce technically sound and economically feasible monitoring programs. The validity and the usefulness of the collected data/information is dependent on the statistical robustness, quality control and quality assurance procedures deployed in monitoring plans. Setting monitoring objectives, selecting appropriate key and supplementary indicators, proper representation of the aquatic population, and the use of correct instruments and methods are a few important aspects of any monitoring plan. Further, data management, data analysis, interpretation, uncertainty estimates and the quantification of decision errors are essential in the process of defensible decision making.

The Integrated Monitoring and Assessment System (IMAS) is a suite of tools that has been developed to support both new and existing programs in addressing the common concerns organisations face in planning and conducting water quality monitoring plans. A survey was conducted using more than 18 eWater Cooperative Research Centre partner organisations to investigate end-user requirements, existing tools, and available knowledge. Based on survey results, the IMAS product project and specifications for tools were formulated. The IMAS Decision Support System (DSS) has been designed using contemporary science and state of the art DSS technology, which includes interactive tools, databases, knowledge bases, statistical tools, web-links, templates, decision-making processes, a comprehensive collection of relevant information and help materials. Available materials, guidelines, technical reports and software tools were extensively reviewed in the process of designing IMAS products. A number of existing and modified tools (prototype/beta versions) have been tested and released through workshops held in Queensland and very positive responses were received from end-users. These tools include eGuide (electronic version of searchable water quality related documents), Monitoring Plan Tool, Water Quality Guideline setting Tool, Loads Estimation Tool and "Multiple Levels and Lines of Evidence" (MLLE) software as an assessment tool. Prototypes of monitoring objective setter, indicator selection tool and a sample optimisation tool are being developed. A common shell for water quality data processing and analysis including time series data management has been developed mainly to share common input data for calculating variety indices and evaluations.

The IMAS software package consists of monitoring plan designer, data processing and analysis tools, assessment and reporting guides together with an assortment of information for designing monitoring plans. The IMAS tools will facilitate the development of well targeted monitoring programs, coupled to key performance indicators for environmental management. They will assist community groups, catchments managers, natural resource managers and water quality monitoring groups with the interpretation and communication of results from monitoring and assessment. The DSS developed under IMAS will ensure the quality (accuracy, precision, repeatability, representative and comparability) of collected data. This will also guarantee the maximum return from investments made on water monitoring programs across the country.

1. INTRODUCTION

Increasing public debate on water quality issues such as altered flow regimes in rivers, nutrient and sediment export to estuaries have added extra pressure on the water quality monitoring and assessment process. Monitoring can generally be defined as the repetitive measurement of a specified set of variables at one or more locations over an extended period of time according to prearranged schedules in space and time (Vos *et al*. 1999). However, monitoring program must be more than just data collection and it involves other essential activities such as analysis and interpretation of data and communication of results using an appropriate format for intended users. Water quality monitoring can evaluate the physical, chemical, and biological characteristics of a water body (e.g. stream, river, lake, estuary, or ocean) in relation to human health, ecosystem conditions, protected assets or designated environmental values. These assessments are generally made against water quality guidelines, water quality objectives or water quality targets (ANZECC 2000a). Water quality information can also be used for many other purposes, such as to determine source(s) of pollution (establish cause-and-effect), regulatory purposes, to provide input for management tools such as models, and to support scientifically-based decisions for preserving or improving the quality of a water resource.

In recent times, a significant amount of resources have been allocated across Australia for water quality observation and management and a variety of stakeholders are involved in this process. This is mainly due to a detected threat to protected assets (e.g. Great Barrier Reef), deteriorated aquatic ecosystems or the legal requirements of monitoring and reporting. Further, recent drought has exacerbated the condition of aquatic environments and the realisation that better management of freshwater resource is vital for the existence of ecosystems. Monitoring and assessment is an essential part of adaptive water management system (Figure 1). Designing a water quality monitoring plan is not a trivial process due to enormous variations in types of monitoring and the reasons for collecting data. It is necessary to define requirements for collecting the data and make decisions on the type, quantity, and quality of data needed to support defensible decision making process. This requires a multidisciplinary effort to input experience and resources, different kinds of knowledge, and collective focus on achieving a successful project outputs.

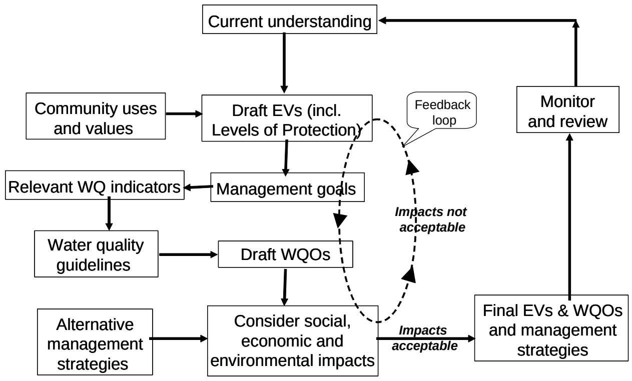

Figure 1. Adaptive water quality management strategy (EVs: environmental values, WQOs: water quality objectives).

The eWater Cooperative Research Centre (eWater CRC) is well placed to develop targeted tools through collaboration between a range of research partners and water managers. The Integrated Monitoring and Assessment System (IMAS) product project is responsible for designing and developing software tools for planning technically robust and economically feasible water quality monitoring designs. The major objective of this project is to collect existing tools, modify them to meet partner's requirements and design and develop new tools to fill the gaps in existing systems. This paper presents the methodology used in developing the IMAS software suite, a brief review of existing products and details of newly developed tools.

2. PROJECT PLANNING

Water quality monitoring design and/or data analysis and assessment are core business for many eWater CRC partners. As a preliminary study for IMAS product development, an extensive survey was conducted to document the water quality monitoring and assessments requirements of 18 different agencies. These agencies include Murray Darling Basin Commission, NSW Dept of Natural Resources, Sydney Catchment Authority, Queensland Natural Resources & Water, Queensland Environment Protection Agency (EPA), South Australia Dept of Water Land & Biodiversity Conservation, EPA South Australia, Victorian Dept of Primary Industries, Dept of Sustainability & Environment and EPA in Victoria. The outcome of this survey was used to provide the specifications for IMAS products. The survey also included the aspects of existing knowledge and available tools for designing and maintaining water quality monitoring programs. The reason for this exercise was to determine what knowledge/tools already exist, identify gaps and avoid duplications. A summary of the partners main requirements have been listed below.

- Scientifically robust product to develop monitoring objectives and indicators that are explicitly linked to natural resource management activities.
- Product that allows monitoring program designs to make transparent trade-offs between cost and statistical robustness.
- Flexible approach to design allowing for different types of input, from different types of systems and giving a variety of options for users to choose from.
- Innovative approaches to data analysis and reporting to allow for easier selection and application of appropriate techniques.
- Transparency in selection of data analysis tools – why they were chosen, why are they the most appropriate (currently many rely on expert advice).
- Flexibility in use of, and outputs from, products e.g. reporting guidelines that can cater to different audiences including those making management decisions.
- DSS/tools specifically targeting monitoring and assessment of estuarine environments and freshwater types.

The major tasks in IMAS project include the collection and collating available resources in monitoring and assessment, refinement of existing tools to better fulfil partner's needs and give access to a wider community. Available knowledge in the form of published materials (manuals, reports, books etc) will be transformed into interactive tools using decision support systems technology (Shim *et al*. 2002) and made available for end-users for efficient access. To supplement existing tools, a number of data analysis and assessment tools have been designed based on statistical theories and optimisation techniques.

3. MODULES OF IMAS SOFTWARE SUITE

Based on the end-user requirements, a list of products has been created under IMAS. A short description of each individual IMAS software tool is given below.

Objective setter: Setting clear objectives facilitates designing a sampling program to obtain the required quantity and quality of information. Monitoring objectives should be specific and precise, measurable, realistic and understandable. The development of meaningful objectives requires practice and experience. The proposed monitoring objective builder provides a structured approach to help users consider their management objectives and drivers to create specific monitoring objectives. The initial framework for objective builder was extracted from ANZECC guideline (ANZECC 2000b) and the Monitoring Plan Tool DSS developed by the National Action Plan for water quality and salinity program (Tennakoon and Cawley 2005). This online program prompts the user to address several key issues moving from the general to the specific for formulating study objectives and hypothesis. The monitoring objective builder will be linked to the indicator selection tool and the monitoring plan optimizer.

Conceptual model library: Conceptual models are well recognized as an important tool in the monitoring design process. eWater partners currently use conceptual models for a range of purposes, from developing system understanding, to communicating the rationale underpinning monitoring design (Wilkinson *et al*. 2007). A library of conceptual models will be compiled using existing resources. Users will be able to search and retrieve conceptual models from this library and modify them to suite their requirements.

Indicator selection tool: The indicator selection tool will assist users to select physical, chemical and biological indicators for monitoring and assessment programs based on their objectives and the particular context. This tool will allow users to check the usefulness of indicators currently in use.

Monitoring plan optimizer: The Monitoring plan optimizer will provide a transparent process for optimizing monitoring design for user-defined scenarios. This tool will be based on existing statistical tools and a new process/modelled based optimisation approach developed by eWater CRC research project. Both spatial (number of sites) and temporal (sampling frequency) aspects of the monitoring plan can be optimised considering available constraints and the level of accepted or required decision error.

Guide to techniques for combining data and information sources to infer causality: This tool will provide guidance and raises awareness about the potential for combining different forms of information to infer a causative link between management actions and ecosystem response. It will assist users to select from available techniques for combining different types of data and information, particularly using the Multiple Lines and Levels of Evidence approach.

Interpretation techniques and tools: This will be a utility software tool that will underpin other products and link to the user defined reporting guidelines. It would consist of a library of algorithms and plug-ins used in other eWater products that are available for user-defined issues. A library of visualization techniques (for example visualization of results showing associated uncertainty) will be created and linked to the reporting guidelines.

Guide for reporting of monitoring outputs: The reporting guide has been developed in conjunction with existing reporting templates (e.g. State of the Environment) to provide guidance on the necessary elements for good quality reporting (e.g. how to report the quality of data inputs). It includes a library of visualization and reporting protocols. The tool provides an overall quality standard, and greater transparency in the quality of supporting data and the rationale underpinning interpretation.

Common time-series data analysis techniques: This tool provides guidance on the selection and implementation of existing methods for common calculations based on time series data such as load calculation, trend detection or pattern recognition. Techniques included are those used in other eWater CRC products (e.g. River Analysis Package) and those in common usage by partners.

4. EXISITNG PRODCUTS

An extensive reviewing process was carried out to investigate the existing materials, knowledge, tools and other products currently available to be directly or indirectly used in water quality monitoring and assessment plans. Selected tools have been either tested as prototypes or modified to complement the specifications made in the IMAS product plan. The following section gives a brief description on few listed tools under IMAS software suite.

4.1. eGuide

eGuide is an electronic document which consists of a number of commonly referred to water quality guideline documents. The current version of eGuides contains the following documents.

- ANZECC/ARMCANZ 2000 Monitoring & Reporting Guidelines
- ANZECC/ARMCANZ 2000 Water Quality Guidelines
- NHMRC 2005 Recreational Guidelines
- Queensland Water Quality Guidelines
- Coastal CRC Users' Guide to Indicators for Monitoring

These documents have been compiled into a standard "HTML" version of Windows help systems (Figure 2) and able to install in any personal computer for easy and quick access to information. Users can select the document that they would like to manually browse, or select the 'search' tab to search all the guides for some key words. The searched items can be viewed, copied to another document or printed out for later references. The beta version of this tool has been released and available at (www.wqonline.info).

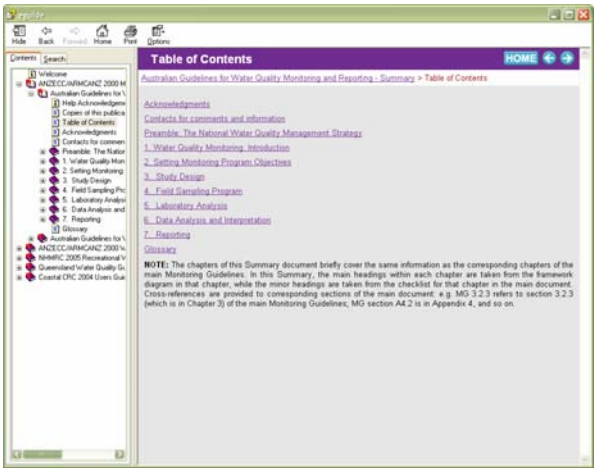

Figure 2. eGuide, an electronic documents

4.2. Monitoring Plan Tool

The National Action Plan (NAP) for Salinity and Water Quality Project has designed and developed user-friendly decision support software to assist community groups in designing a technically sound, rigorous and defensible monitoring plan that provides quality assurance as well as storage and communication capabilities. The prototype developed was based on the concept of water quality monitoring plans as developed and promoted by Waterwatch Australia (Waterwatch Australia 2002). The planning process comprises of eleven questions grouped under four major sections: defining objectives; method selection; monitoring design and data management. The system was designed to guide the user in a sequential order to collect and record the water quality monitoring plan information. The DSS was evaluated and tested using selected catchment groups in Queensland.

4.3. Indicator Selection Tool

Determining monitoring indicators will depend on the objectives, the intended use of the data, and the resources available for monitoring. However in aquatic systems, condition assessment indicators should be based on management activities (pressures) and drivers (stressors). Selection of appropriate indicators often requires experts' advice and better understanding of effects and causality. The Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management (Coastal CRC) has developed a tool to educate and support decision making on monitoring and modelling in estuarine systems (Ramsay *et al*. 2006). This Monitoring and Modelling Assessment DSS (MAMA) contains a component for selecting appropriate indicators. Based on management activity selected, the DSS will generate a list of key and potential hazards related to the activity. The user is required to input the information on environmental values and water quality objectives. A list of stressors and indicators will be generated and the details of these indicators can be accessed via the help system built into the DSS. A prototype of indicator selection tool (online version) has been developed based on the approach and techniques used in the MAMA DSS.

4.4. Water Quality Guideline Tool

Water quality Guideline Tool is statistical software developed to calculate locally relevant guideline values; store guideline values in a searchable database for later recall; and, test new datasets against guideline values to provide a statistical sound indication of the health of a site. The procedures used in this tool are based on the ANZECC 2000 methods. Both referential and biological approaches are available for setting up guidelines depending on type of available data. The tool can also assist in the development of water quality targets by providing a method to calculate proportional improvements in a measured variable. The system has been developed under The Invisible Modelling Environment (TIME) (Rahman *et al.* 2005) and the .NET framework to be compatible with other tools being produced be the eWater CRC. The Guideline Tool has been built with user friendly interface (Figure 3) for easy operations and the system comes with comprehensive help materials for operations as well as technical information used in deriving local water quality guideline values. The beta version of this tool has been released to some selected users in Queensland.

4.5. Loads Tool

The determination of constituent loads or loading rates from rivers and streams is not a trivial task. Due to the relatively sparse nature of concentration data and different sampling methods, special load estimation techniques should be applied to reduce estimation errors. There are more than 30 alternate load estimation methods available and these techniques have been developed based on some assumptions about the behaviour of pollutant concentrations in-stream during the times when the water quality was not sampled. The NAP for Salinity and Water Quality Program has developed a software tool for estimating loads in rivers or streams. This tool presents nine of the most common methods for long-term load calculation and four methods for estimating loads from storm events. A built-in function is available to calculate event mean concentration (EMC) values which are useful in catchment modelling exercises.

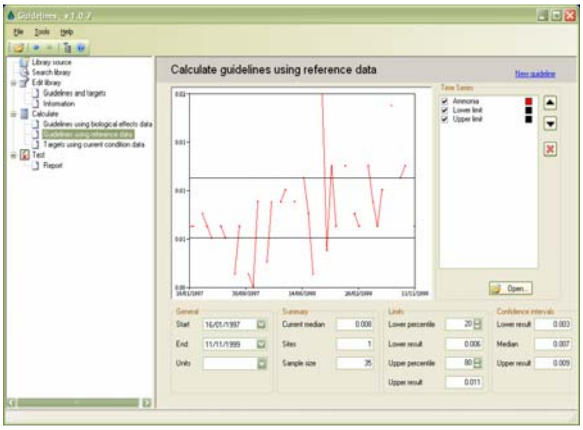

Figure 3. Water Quality Guideline Tool

4.6. MLLE (Multiple Levels and Lines of Evidence)

Assessing the ecological response of aquatic systems to management interventions is a complex process. Often limited opportunities for replication and randomisation makes the common impact assessment methods difficult and diminishes the reliability of conclusions made on causality. A Multiple Levels and Lines of Evidence (MLLE) schema is presented from which it is possible to examine evidence for causality between environmental stressors, management interventions and ecological outcomes. MLLE can be applied to studies collecting data at the site of interest and to evaluate relevant studies in the literature. Important steps involve in this process are to first determine the lines of evidence that will be comparable and relevant, second the weight that will be given to evidence in the studies based on the study design and the consistency of the results from many studies. Using this approach, evidence from many sources can be accumulated to confidently support the final conclusion. This method complements the approaches adopted by various jurisdictions including the Australian Water Quality Monitoring Guidelines. As a partner of eWater CRC University of Canberra has developed a software tool named “MLLE” for assessing the ecological outcomes of environmental impacts using multiple levels and lines of evidence (Norris *et al*. 2005). The beta version of this software is being developed and expected to be released in December 2007.

5. TESTING AND EVALUATION

eWater CRC has imposed a set of protocols for product development and stringent quality control and quality assurance procedures were implemented in developing or modifying IMAS tools. These tools were tested and verified to ensure that all of the algorithms were properly represented in computer codes and the knowledge is accurately captured and represented so that their outputs as intended. Some components of IMAS software suite has been released as beta versions (Table 1). A number of workshops across Queensland were conducted to demonstrate these tools and collected feedback from end-users. More than one hundred users have been trained to use these tools and very positive feedbacks were received. Further, IMAS workshops were conducted in New South Wales and Victoria and participants for these workshops included managers, scientists, environmental officers and information technology experts. These participants clearly expressed their requirements and willingness to use tools available in the IMAS software suite. Based on feedback, most popular module of IMAS software suite is water quality data analysis and assessment shell which contains water quality guidelines setting tool, load estimation tool and time series data analysis tools.

6. IMAS DELIVERY SYSTEM

IMAS is a collection of analytical tools, process based DSS, databases, electronic documents and frameworks designed to assist water quality monitoring and assessment programs. The end-users are able to access information, knowledge and analytical tools for various stages of water quality monitoring plan designs and management. Assistance is also provided for data processing, data analysis, assessment and reporting monitored data. The IMAS tools have been designed with user-friendly interfaces for efficient and easy access of information as well as simple analytical tools that can be operated with minimal computer knowledge. The IMAS software suite consists of both standalone software tools as well as few online programs. The product list, delivery mechanism, and the status of current version are given in Table 1. A web-based platform has been designed to host and deliver IMAS tools and the IMAS home page will be able to access through eWater CRC tool kit (www.toolkit.net.au) website.

Table 1. IMAS product list

Category	Tool	Delivery	Current version
Monitoring plan designs	Monitoring plan tool (MPT)	Standalone	Beta version
	Objective builder	Online	Prototype
	Conceptual model library	Online	Designing
	Indicator selection tool	Online	Prototype
	Sample optimisation tool	Standalone	Designing
Data management and analysis	Guideline tool	Standalone	Beta version
	Loads tool	Standalone	Beta version
	Time series data manager	Standalone	Prototype
	Time series data analyser	Standalone	Prototype
	Trend analysis tool	Standalone	Prototype
Assessment and reporting	MLLE	Standalone	Beta version
	Reporting guide	Online	Designing
	Reporting templates	Online	Designing
General support	eGuide	Standalone	Beta version
	Water quality database	Online	Designing
	Guideline database	Online	Designing
	Abstract database	Online	Prototype
	Reports and Manuals	Online	Prototype
	Web links	Online	Designing

7. CONCLUSIONS

IMAS is a suite of software tools to support both new and existing water quality monitoring and assessment programs. These tools have been designed using contemporary science and the state of the arts decision support systems technology. A variety of problem solving techniques were used in developing IMAS tools and these techniques include standard algorithms, heuristics, databases, knowledge-bases, related web-links and electronic documents. As components of IMAS, water quality Guideline Tool, Loads Tool, Monitoring Plan Tool and eGuide have been released as beta versions and currently available at www.wqonline.info website for download. A number of training and evaluation sessions were conducted in Queensland and very positive responses were received from users.

The procedures, information and tools available in the IMAS suite will assist a broad range of stakeholders in designing and maintaining cost effective and technically sound water quality monitoring program for estuarine and freshwater systems. The main group of targeted end-users are catchments authorities, regional body, community groups and some State Government agencies. IMAS will also assist natural resource managers and scientists with the interpretation and communication of results from monitoring and assessment programs. Further, materials and tools available in IMAS can be effectively used for quality control and quality assurances of water quality data and provide a framework for defensible decision making process.

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