

A Decision Support System for Licensing Sewage Discharges to Aquatic Environments: Development and Demonstration

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EXTENDED ABSTRACT

Licensing discharges to coastal waters can be complex and lengthy. It requires a substantial body of information to be prepared and assessed. Licensing officers and their technical advisors need to understand a broad range of biophysical, economic and social related issues in order to assess the quality, reliability and implications of this information when provided to them. There is also strict time frames legislated for the process and the expertise for the assessment may not always be available within the licensing agencies.

The technical aspects of the assessment can be particularly challenging, especially for new licensing officers not experienced with water quality issues. Therefore, the Queensland Environmental Protection Agency, in association with regulatory agencies from New South Wales and Victoria have developed a decision support system (DSS) to assist licensing of sewage discharges. Although the DSS was primarily developed for licensing officers, the information contained within the associated help system could also be useful to a wider audience including local government clients or their consultants.

The DSS focuses on the scientific and technical aspects of the licensing process and is underpinned by interpretation of the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000* for licensing discharges. In addition to these Guidelines, other knowledge bases were developed and used including sewer hazards, treatment technology and risk screening advice. The DSS does not provide prescriptive conditions but provides broad advice and a risk screening assessment of contaminants. It also takes into consideration the different policy and legislative requirements of each state. An added feature of the DSS is its comprehensive help system that contains

information on how to use the DSS and the contents of each knowledge base. This includes the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000*, which are present in an easy to use and searchable version.

The DSS for licensing of sewage discharges was structured so that the user steps through three modules. The modules include:

1. Characterise the activity - covering the sewer, the sewage treatment process and the qualities of the treated effluent,
2. Assess the receiving environment – covering waterbodies potentially effected by the discharge and their associated environmental values and water quality objectives, and
3. Results and recommendations – provides an interpretation of high and low risk contaminants and possible courses of action.

Each module is divided into a number of individual steps where the user is required to collect, check and record required information. The DSS was designed to answer questions mainly by choosing available options and inputting text information into the systems. At the end of the process, the user can generate a number of detailed reports of information entered by the user and generated by the DSS. The results include a risk assessment of each contaminant and recommendations for further action. A list of missing information and guidance on why this may be required is also produced.

The paper will describe how the DSS was developed and demonstrate key features of the DSS including a description of the knowledge bases and help system.

1. INTRODUCTION

Treated sewage is commonly discharged to coastal waters despite significant advances with water recycling. Licensing of these discharges can be a complex and lengthy process that requires a substantial body of information to be prepared and assessed. Licensing officers and their technical advisors need to understand a broad range of issues in order to assess the quality, reliability and implications of this information when provided to them.

The information supplied in the licensing process can cover topics such as latest treatment technologies, water recycling and most significantly, the possible impact of the discharge on the receiving waters. For the latter, officers need to apply the *Australian Water Quality Guidelines* (ANZECC & ARMCANZ, 2000). This document is large and complex with several volumes. The guidelines are not designed to provide prescriptive limits for licensing, but rather offer a risk assessment approach.

This project involved the collaboration of three state agencies from Queensland, New South Wales (NSW) and Victoria. The process for licensing discharges can vary quite significantly from state to state. This is due to differences in geography as well as differences in policy or legislation. For example, some states have mainly ocean outfalls while others have more discharges to estuaries. In regards to policy, some states use load-based licensing where economic penalties apply to the quantity of contaminant discharged. Others place emphasis on regulating contaminant concentrations. Nonetheless, the main commonality between each state is the use of the *Australian Water Quality Guidelines*.

The Queensland Environmental Protection Agency (QEPA) has developed a Decision Support System for Licensing Sewage Discharge (LSD DSS). It is designed to assist licensing officers assess the suitability of discharge proposals and enables easy access to relevant information. The DSS was also designed to support new licensing officers not experienced with water quality management. The system is knowledge driven in that it relies on elicited or documented expert knowledge on specific technical and scientific topics. One of the specific functions of the DSS is to screen contaminants of low and potentially high risk.

The knowledge bases are integrated into the decisions support system but are also contained in a stand-alone help system. This includes a fully

searchable version of the *Australian Water Quality Guidelines*. In addition, a few knowledge bases were specifically developed for the DSS. A wide audience including the local government and consultants who run the treatment plants and undertake the environmental impact assessments could use these knowledge bases and the help system.

The paper will describe how the DSS was developed and demonstrate key features of the DSS including a description of the knowledge bases and help system.

2. METHODOLOGY

2.1 Project Management

The project team involved in designing and developing this DSS included Queensland Environmental Protection Agency (EPA) project members and representatives from agencies in NSW and Victoria. The project commenced in 2003 and was funded by the National Heritage Trust. A series of workshops were conducted to bring together scientific and operational experts from Victoria, NSW and Queensland. The scope and detail of the DSS was continually refined at these workshops. One of the early decisions was to focus only on sewage treatment plant discharges, as the scope of the project originally included all types of point-source discharges.

A questionnaire was developed to ascertain the concerns and interests of major local government managers of sewage treatment plants across the three states. The questionnaire was used in association with interviews and resulted in several key recommendations from local governments in relation to this process. These included: improving consistency across industries; improving consistency across plants; greater transparency in decision making; better links between licence conditions and environmental impacts; more focus on loads rather than concentrations; and better differentiation between chronic and acute impacts.

After the consultation phase, the project team began developing decision trees that 'captured' the process of the assessment and helped select system knowledge. A major focus of this was the interpretation of the *Australian Water Quality Guidelines* for licensing. A prototype was then developed based on a portion of the DSS that related to recreational water quality assessment (as compared to the more difficult aquatic ecosystem protection) and is discussed in more detail by McKenny *et al.* (2004). The operations and scientific staff from each state evaluated the

prototype and identified possible improvements. The main focus was in the system inputs and outputs and the design (the 'look and feel').

A number of cycles were undertaken to refine and improve the functions and user interfaces in the DSS. Development of a DSS often requires a series of phases, each phase modifying and refining the work done in the previous phase (Walters and Nielsen 1988). Subsequently, substantial modifications were made to the prototype and a beta version of the DSS was developed. The beta version and associated help system was demonstrated to the representatives of the three state agencies in a series of workshops in February 2005. A user manual that contains all screen descriptions and knowledge base information was also provided. Information on the LSD DSS is available through the Water Quality Online Website (<http://www.wqonline.info>). The EPA will keep track of feedback and provide any modifications on the DSS where appropriate.

2.2 Experts Knowledge Acquisition

One of the main activities in the design of a knowledge-based DSS is the acquisition and formulation of 'domain' knowledge (knowledge used in the DSS). The quality and quantity of knowledge in the knowledge base is critical to DSS performance. In this DSS, both the process used by the experts in issuing licenses for effluent discharges together with the factual knowledge on water quality assessment were considered during system development. The factual or public knowledge was obtained from textbooks, journals and published water quality guidelines. The acquisition of un-written knowledge from experts was the most important and difficult task during the development of this DSS.

An expert in the field of DSSs can be described as someone who has devoted many years to studying and practising the problem 'domain' (Waterman 1986). A wastewater engineer with substantial expertise with sewage treatment plants was contracted to acquire the contemporary wastewater treatment technology knowledge. He also recommended further textbooks and other sources of information. Further extensive knowledge acquisition was carried out using experts available at the Queensland EPA to capture required knowledge on assessment of wastewater hazards, eco-toxicology, wastewater recycling etc. The project manager himself is an expert in this field and his knowledge and experience was extensively used during the designing of this DSS. The main source of documented (public) knowledge used in

designing this DSS was the *Australian Water Quality Guidelines*.

2.3 Computer Software and Hardware

Selecting suitable hardware and software is important in developing a DSS and the selection should be based on the available resources, problem type and objectives of the project. The end users have to be identified and the means of delivery defined (e.g. desktop or web-based). In this project, the end users are government operations officers and ultimately industry consultants.

It was decided that desktop delivery of the DSS was most suitable and that the most common operating system was the Microsoft Windows environment. Instead of building the DSS from first principles, it was decided to use 'of the shelf' expert shell software. Such software can make the development process considerably easier and more time efficient. An extensive search was carried out to select suitable software from the numerous development tools available for the Windows environment.

After evaluating a number of commercially available tools, XpertRule® Knowledge Builder software developed by Attar Software Limited (2004) in UK was selected to develop the DSS prototype. This tool allows rapid development of the system and offers a number of different methods for data entry, knowledge presentation and processing. For example, these include the ability to entering text strings, selecting options from a list or presenting stored information. Reporting can be done using html format or standard Windows output. This tool also allows links to databases, external programs and standard Microsoft Windows help systems.

A stand-alone Windows-based help system is used to store the knowledge acquired from experts and other information relevant to the DSS. The Hypertext Development Kit (HDK) developed by Virtual Media software was used. Information was in HyperText Mark-up Language (html) so that the user could display it in any web browser. The help system software allows interactive cross-referencing to enable the user to move from one section to another within the help system.

3. LSD DSS DESIGN AND OPERATION

The LSD DSS was structured so that the user steps through three modules as shown in Figure 1. The modules include: (i) Characterise the Activity; (ii)

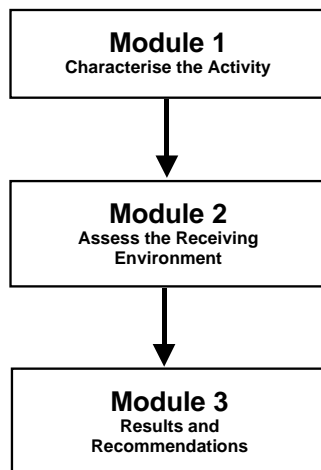


Figure 1. Module contained within the LSD DSS

Describe the Receiving Environment; and (iii) Results and Recommendations.

Each module uses its own body of knowledge, which includes databases and tables (e.g. guideline values for various environmental values), decision rules and tools. Tools are either technical (e.g. to help set acute to chronic toxicity ratios or to aid monitoring decisions) or conceptual (e.g. to help apply principles such as environmentally sustainable development). Help files are also associated with each module and these include further information and relevant case studies.

Each module is divided into a number of individual steps where the user is required to collect, check and record required information. The DSS was designed to answer questions mainly by choosing an available option or inputting text information into the systems. Once all modules are completed, the DSS compiles all the information captured in a number of detailed project reports. The following sections provide a brief description on each of the steps and the content of the DSS.

3.1 Characterise the Activity

The first module is an important one that involves identifying and characterising the pollutants, often called hazards, which might be released in the discharge. Each may need specific management actions to reduce their quantities in the discharge or specific environmental assessment to predict likely impacts. The major steps in Module 1 are discussed below.

Identify hazards: The potential hazards present in the discharge will depend on the source and treatment of the wastewater. The DSS requires the

user to enter information on the types of trade-waste that enter the treatment system. A report is later generated by the DSS based on these entries.

Waste reduction: Information on waste reduction is captured by the DSS as it should be considered prior to any management decision. Waste reduction could include reduction at the source (e.g. reducing sewer infiltration or stringent trade waste plans) and reuse schemes (e.g. use of the wastewater for industrial or domestic purposes).

Treatment technology: Wastewater treatment technology for five key pollutant groups (nitrogen, phosphorus, biodegradable carbon, toxicants and particulates) is considered in this DSS. The type of treatment technology used in a sewage treatment plant will affect the characteristics of the final effluent. Important information can include the typical performance and loading of the plant, practical considerations such as the characteristics of the influent and the local climate, environmental considerations such as the use of other chemicals and energy or the production of large amounts of waste or other by products. The DSS provides a report in key information based on the type of treatment technology used.

Effluent toxicants: The DSS requires the user to enter estimated toxicant concentrations in the discharge. These are used in the later modules to assess the potential impact on aquatic ecosystems or other relevant environmental values.

Effluent pathogens: The DSS requires the user to enter the indicators and concentrations of microbial pathogens in the proposed discharge. This information is used in later modules to assess the potential impact on recreation or other relevant environmental values.

Effluent loads: The DSS requires the user to enter information on changes in loads of each pollutant group: nitrogen, phosphorus, biodegradable organics and particulates. The changes in loads of these contaminants can be used to assess the potential impact of nutrients, sediments and biodegradable organics on the aquatic ecosystem.

3.2 Assess the Receiving Environment

The second module covers information on the receiving environment that is needed to assess the possible impacts of the proposed discharge on environmental values. In this module, the following steps are adopted.

Identify water bodies: The number and names of waterbodies potentially affected by the discharge

needs to be entered by the user. A waterbody should be a single water type, for example, an estuary or a bay. Identifying the geographical location of the discharge is also required to use the *Australian Water Quality Guidelines* trigger values. The DSS automatically presents physical chemical guidelines for south-east Australia and tropical Australia.

Water body information: This step captures detailed information on each water body listed by the user in the previous step. Firstly, water type must be entered and is required by the DSS to select guideline trigger values for physical and chemical stressors. The default water types provided include upland rivers, lowland rivers, estuaries and marine waters. Secondly, the number of zones must be entered where different environmental values exist. For examples, a dedicated swimming area could be a separate zone to where only visual recreation occurs. This step needs to be repeated for each water body.

Zone information: This step captures detailed information on each zone listed by the user in the previous step. This includes different levels of aquatic ecosystem protection, types of recreational values, types of primary industry values and locally specific values. Whether a zone receives the discharge directly is also important because this zone will generally have the highest risk of impacts due to the higher concentrations of contaminants. This step is repeated for each zone in the Waterbody.

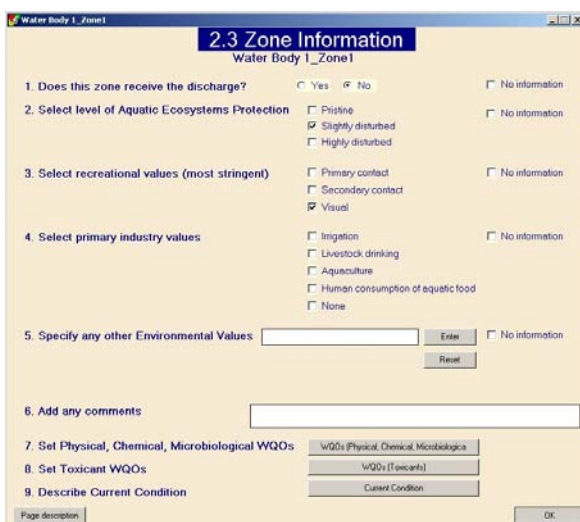


Figure 2. User interface for entering zone information in Module 2

Water Quality Objectives: Physical, chemical and microbiological: Information on water quality objectives for physical, chemical and

microbiological indicators is necessary to ensure the protection of environmental values. The DSS automatically generates default water quality objectives based on guideline trigger values. More relevant or locally specific water quality objectives can be entered manually.

Water quality objectives: Toxicants: Information on water quality objectives for toxicants is necessary to ensure protection of environmental values. The type of toxicants is dependent on the sources of effluent and was identified in Module 1. The DSS automatically generates default water quality objectives based on toxicant trigger values. These values can be modified if more relevant values are available.

Current condition: It is important to know the current condition of the waterbodies potentially affected by the proposal to help assess the environmental risks associated with the proposal. The current condition of the waterbodies should be measured according to standard methods outlined in the *Australian Water Quality Guidelines*. The DSS requires the user to enter information about the current condition of each water body based on compliance with water quality objectives for each indicator, i.e. comply or not comply.

3.3 Results and Recommendations

The third module presents a summary of results and recommendations for each of the three contaminants groups: toxicants, pathogens and loads. For toxicants and pathogens, the information on effluent concentrations (Module 1) is screened against the receiving environment information on water quality objectives (Module 2). For loads, the information on changes in loads (Module 1) is combined with information from Module 2 on current condition.

Contaminants that pose minimal risk to environmental values are clearly identified from the screening process. Those contaminants of high risk and potential significance are also highlighted. Recommendations are made for each contaminant based on its rating and include revising the proposal, further assessment, obtaining additional information or no further work

Finally, some key summary statistics are provided. These include the number of contaminants that were high risk, potentially significant, low risk or had insufficient information. The total number of 'no information' boxes ticked through the process is also presented.

3.4 Reporting

After completing the DSS modules, a series of reports can be generated, viewed and printed such as shown in Figure 3. This includes all of the user inputs such as the effluent characteristics, environmental values and current conditions and the generated information including potential hazards, treatment technology descriptions, water quality objectives and the screening results and recommendations. A 'missing information' report based on the ticked 'no information' boxes can also be generated. This provides an explanation on why this information might be required.

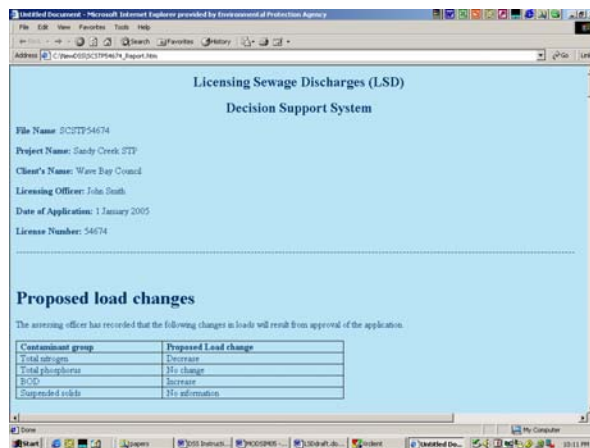


Figure 3. Typical report format generated by the DSS

3.5 Help system

A comprehensive help system has been developed and provides access to technical information used by the DSS and guidance for running the software. The help system contains descriptions of each screen and related information, decision rules, results and recommendations used by the system for screening, a peer-reviewed knowledge base on treatment technology, information on the possible hazards in sewage influent and the three volumes of the *Australian Water Quality Guidelines*. See Figure 4 for a typical help screen layout.

The help system can be activated in several ways. Firstly, it can be opened from the main menu. Secondly, each screen has a 'Page Description' button, linked to the part of the help system that describes the operation and context of the screen. Finally, some words on each screen of the DSS are linked to glossary terms or other parts of the help system. Both full-text and hierarchical searching/indexing functions are also available in this system.

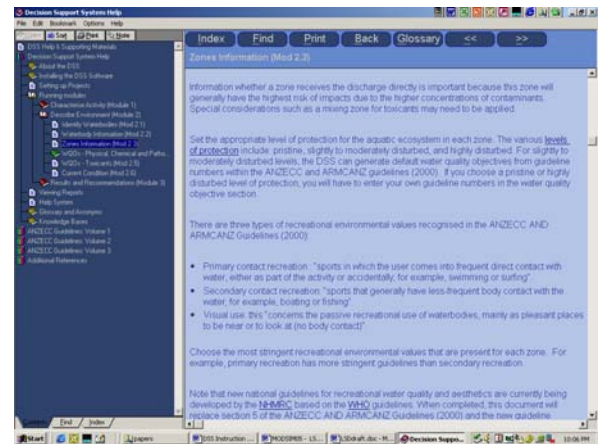


Figure 4. Typical view of a help screen page

Within the help system, the hazards knowledge base provides information on a wide range of organic carbon compounds, nutrients and toxicants. The treatment technology knowledge base provides substantial information on contemporary technologies used in wastewater treatments. It is divided into removal/reduction technology for major pollutant categories: biodegradable organics, solids, nutrients, toxicants and pathogen. Another knowledge base, developed for effluent screening in Module 3, includes a decision table and text on interpretation of results and recommendations for the numerous different possible combinations. Further detail about this knowledge base is available in the DSS user manual (QEPA 2005).

3.6 Evaluation of the DSS

The overall performance of the DSS was evaluated by a planned sequence of validation runs that included manual mathematical and visual checking. The validation process was repeated until all runs were successful. The final product is considered a beta version and still may contain some errors.

4. RESULTS AND DISCUSSION

The DSS was designed to be 'user-friendly' with easy navigation and minimal data entry. For example, the DSS uses a sequence of questions and answers with most answers selected from options. As the DSS is mainly a screening tool, the need for extensive data entry is limited. Most data is generated by the DSS although the user must enter contaminant concentrations in the proposed discharge. The user can modify generated data if required. As this may involve potential incorrect use, various pop-up warnings are programmed to appear.

The approach used to develop the LSD DSS should be broadly applicable to all Australian regions. The software provides aquatic ecosystem trigger values that are currently applied to the three states. However, for other states, the values can be obtained from the help system and entered into the DSS manually. Only minor modifications would be required to the tables in the DSS for the automatic generation of default guideline numbers for other states.

This version of the DSS has been developed only for sewage treatment plant discharges but is broadly applicable to other licensed activities. It is preferable that a separate DSS be developed for each major class of licensed activity so that knowledge bases and assessments can be tailored to those industries and the hazards present.

There were a number of issues that defined the scope of the final beta version. Firstly, due to the multitude of possible scenarios and the significant policy differences between agencies, the DSS was not able to provide prescriptive licence conditions as originally planned. It was agreed by the agencies involved that only broad advice including risk assessment should be provided. Due to time constraints, the DSS focus was limited to sewage treatment plants. This was largely due to the agencies' significant effort in dealing with these type of discharges. A further limitation of the DSS is that it does not provide detailed information on monitoring or modelling assessments. This was considered to be the scope of another DSS.

The verbal feedback on the LSD DSS from the final demonstration has been extremely positive. The general acceptance of the DSS and its ability to be suitable for use across three different states of Australia is a major outcome of the project, given the differences in organisations, policy and legislation. The acceptance and interest in the searchable electronic help system of the *Australian Water Quality Guidelines* is also a valuable outcome of the project.

It will now be up to individual state organisations to endorse the DSS and apply it to the broader environmental operations sections of their agencies. As there are potential limitations with the software tool used to produce the DSS, the DSS may be reproduced in the future using a standard programming language such as Visual Basic.Net. This could provide advantages such as improved reliability, reduced file and memory space and ease of installation.

5. CONCLUSIONS

The project has been successful in delivering a DSS for licensing discharges that is suitable for the three state agencies involved. It does not provide prescriptive conditions but broad advice and a risk screening assessment of contaminants. Other useful features are guidance on potential hazards and treatment technology. The DSS is easy to use and teaches the basic principles of assessing aquatic discharges and interpretation of the *Australian Water Quality Guidelines*. The help system that provides easy access to all the information contained in the DSS is accessed from the DSS or can be run as stand-alone software. The initial feedback from agency officers on the beta version DSS has been extremely positive.

6. ACKNOWLEDGMENTS

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