
EXECUTIVE SUMMARY

1. Introduction

Like many other countries in the world (Vollenweider, 1981), South Africa experiences serious water quality problems as a result of eutrophication. In South Africa management-oriented prediction of the consequences of eutrophication has gone through several phases. The first was a report reviewing eutrophication and providing tentative guidelines for its control in South Africa (Toerien, 1977). A second report provided guidelines for the control of eutrophication in South Africa (Walmsley and Butty, 1980). On the basis of these reports, the Department of Water Affairs decided to implement a special phosphorus (P) standard on effluents discharged in sensitive catchments. The special P standard was severely criticized and led to a third study in which available data and models were used to assess the impact of eutrophication control strategies on the trophic response of reservoirs in sensitive catchments (Grobler and Silberbauer, 1984). One of the conclusions of the study was that the highly variable hydrological conditions in South Africa required dynamic eutrophication models to be developed. During the fourth phase a dynamic Reservoir Eutrophication Model (REM) was developed for South African reservoirs (Grobler, 1985).

The development of a decision support system (DSS) for using the REM submodels as an aid to decision-making in implementing eutrophication control measures, represents the fifth phase in this research and is described in this report.

2. Objectives of the project

A joint project was initiated between the Division of Water Technology, Department of Water Affairs and the Water Research Commission. The primary goals of the project were (1) to develop the Reservoir Eutrophication Model (REM) further and (2) to implement this model by means of user-friendly software on a microcomputer to serve as a decision support system.

The objectives of each of these goals were:

1. Goal 1 - Further development of the REM submodels

- (a) Develop models for calculating P loads from flow and concentration records.
- (b) Refine the prediction of nonpoint source P loads.
- (c) Estimate the loss of point source P in rivers.
- (d) Refine the dynamic phosphate model by incorporating a reservoir water balance.
- (e) Refine the models for simulating the trophic response of reservoirs.
- (f) Develop an uncertainty analysis procedure.

2. Goal 2 - Development of a decision support system for eutrophication control.

- (a) Implement the REM submodels on a microcomputer.
- (b) Incorporate the REM submodels into a user friendly Decision Support System.
- (c) Write a comprehensive user's manual for the software which was to be developed.
- (d) Investigate ecological - economic - management decision models which could be used to include the quantifiable and unquantifiable consequences of eutrophication into the decision-making process.

3. Major results and conclusions of the project

3.1 Modelling the eutrophication process

In order to assess the impacts of different P control measures on water quality in receiving water bodies, the simulation of the three main components of the eutrophication process was required.

Subsystem 1 describes the relationship between P control measures in a catchment and the external P loads received by reservoirs. A statistical approach, i.e. a regression model, was developed to simulate nonpoint source P export as a function of runoff and catchment properties. Point source loads, where the discharge and concentration can be measured, were estimated as the product of the mean effluent discharge and the mean P concentration.

Subsystem 2 describes the relationship between external P load and P concentrations in a reservoir. The principle of conservation of mass was used to simulate the change in the mass of P in the reservoir with time. A water balance was carried out simultaneously with the phosphorus mass balance in order to calculate the ambient P concentration in the reservoir.

Subsystem 3 describes the relationship between in-lake P concentration and indicators of algal production, e.g. standing biomass (chlorophyll a concentration). A statistical approach, i.e. a regression model, was used to simulate temporal changes in algal biomass (as chlorophyll) as a function of the ambient P concentration (in clear water reservoirs) as well as a function of inorganic suspended sediments (in turbid reservoirs).

3.2 A decision support system for the REM models

The models which describe the eutrophication process were incorporated into a user friendly Decision Support System (DSS). The DSS consist of three components i.e. a model base, a data base and a computer program. The computer program links the model base and the data base and provides the interface with the user.

The model base contains the different REM submodels which describe the different subsystems of the eutrophication process. The data base contains the hydrological, point source, catchment and reservoir characteristic data of a specific reservoir. The DSS which was developed for REM, is a program which helps the user prepare the input data to the models, then runs the models and displays the simulation results in different formats. It is responsible for storing and retrieving data, organizing interim results and displaying results in a graphical from. The interface with the user is a dialogue system which uses menus which have to be completed by the user. The DSS furthermore checks for errors, corrects these if necessary and provides help facilities to new users.

The Dialogue system is the most important feature of the DSS because it characterizes the power, flexibility and usability of the DSS. In the past modellers were preoccupied with the structure of their models. Separate models were developed for each distinct part of the problem but were not integrated with each other. It was left to the manager as a manual and frustrating

process to establish the necessary communication between the relevant models. With the DSS this problem is solved by incorporating the models into a framework which performs the integration between the different models and the data as well as provide an interface with the user. The interface which was developed is largely menu driven and makes ample use of graphics to display numerical data.

An important feature in the development of the DSS was the iterative development process in collaboration with the users. The users were presented at the earliest opportunity with a prototype of the DSS. Through using the system, the user fed back information on shortcomings experienced and enhancements required. These were taken care of in subsequent versions of the DSS which, upon completion were passed back to the user for re-evaluation. The value of the user in this phase of the development cannot be overemphasized.

The program software (REMDSS) which was developed runs on a IBM compatible personal computer under the MS-DOS operating system. All the simulation results are displayed on screen and the user has the option of displaying results also on a printer or plotter. The program was developed with TURBO PASCAL (Borland International) and various third party supporting software. A comprehensive user's manual (Rossouw and Kelly, 1989) for the DSS was developed as part of the project.

3.3 Management decision models

The decision support system described so far provides decision makers only with information about the predicted physical, chemical and biological response of the reservoir to different eutrophication control measures. In the selection of appropriate control strategies, decision-makers are often faced with a multiplicity of conflicting objectives. The problem decision makers are faced with is how to integrate quantitative and qualitative information in the same decision framework. In this project the Analytical Hierarchy Process (AHP) developed by Saaty (1982) was used as decision model.

The AHP was applied with water resource managers from the Department of Water Affairs to select an optimum eutrophication control measure for Hartbeespoort Dam. The REMDSS was used to predict the impact of different control measures on water quality. After the actual control measure was selected for Hartbeespoort Dam, the AHP was retrospectively applied to analyze

the decision which resulted in the particular control measure being selected.

4. Statements about the objectives

All but two of the objectives set for the project was met to the satisfaction of the users of the DSS. In the initial phase of the project, it became clear that it would not be possible to meet the objective of refining various aspects of the nonpoint source export model in this project because of the amount of research required. A separate project with the WRC, entitled "The development of phosphate export models for catchments", was therefore initiated to fully investigate this aspect.

The second objective which was not met was the development of an uncertainty analysis procedure. There were two basic reasons for this. The first was that the project responded to user needs throughout the development phase of the DSS. For various reasons they did not require uncertainty analysis. The second reason was that problems were experienced with obtaining the services of an overseas expert to help with this phase. At the penultimate steering committee meeting it was decided that uncertainty analysis should only be done if the time allowed it.

5. Technology Transfer

The success of the project can also be measured in the acceptance of the decision support system by water resource managers. The decision support system for eutrophication control was used to assess the impact of the 1 mg P/l effluent standard on reservoirs in sensitive catchments. The project team were directly involved in applications which resulted in eight reports to the Department of Water Affairs. The following systems were investigated by the project team:

1. Crocodile River catchment - Hartbeespoort Dam and Rietvlei Dam.
2. Umgeni River system catchment - Midmar, Albert Falls, Nagle and Inanda dams.
3. Vaal River catchment - Vaal Dam and Bloemhof Dam and the middle Vaal River system.

The decision support system for eutrophication control was also used by the Department of Water Affairs for applications to the following reservoirs:

1. Roodeplaat Dam in the Pienaars River catchment.
2. Loskop Dam and Bronkhorstspruit Dam in the Olifants River catchment.
3. Shongweni Dam in the Umlaas River catchment.
4. Laing Dam and Bridle Drift Dam in the Buffalo River catchment.
5. Grootdraai Dam in the Vaal River catchment.

The decision support system was also used in the following studies:

1. An assessment of the impact of point and nonpoint source P pollution from Botshabelo, a high density low cost housing project in the eastern Free State, on reservoirs in the Modder River.
2. A M.Sc study to assess the economic impacts of eutrophication (Botha, 1989).

Two international publications (Grobler *et al.*, 1987; Grobler and Rossouw, 1989) were also produced during the course of the project and various concepts of the decision support system were introduced with six papers presented at national and international conferences.

6. Recommendations

At present, the DSS only simulates the transport and fate of P in catchment-river-reservoir systems. In the course of applications, four limitations in the DSS were identified. In order to develop realistic eutrophication control strategies, these shortcomings should be addressed in future development work on management orientated models.

- 6.1 **Nitrogen limited systems** - It was found that in some cases eutrophication related water quality in reservoirs were primarily regulated by the availability of nitrogen (e.g. Rietvlei Dam). Under these circumstances the export of N from a catchment, its fate in water bodies and the biological response to the ambient N and P concentrations should be simulated.
- 6.2 **Light limited systems** - In reservoirs where the growth of algae is limited by the availability of light as a result of high suspended sediment turbidity, much higher nutrient concentrations can be tolerated than in clear water systems. To simulate algal growth in

these systems turbidity should be incorporated into the models. This may also require that attention be given to characterizing the effects of salinity on turbidity.

- 6.3 **Spatial variability** - REMDSS assumes a completely mixed system. In some cases the water quality at specific abstraction points are of importance rather than the average water quality of the system. To meet these needs, methods to simulate spatial variability in management orientated models should be investigated.
- 6.4 **Sediment release processes** - Methods should be investigated to modify the sedimentation parameter to describe the increase in P losses which were observed after the sediment was exposed during a drought.

7. References

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