

## EXECUTIVE SUMMARY

### BACKGROUND

Eutrophication has been identified as a serious water quality problem in South Africa. Selection of the most appropriate management techniques to decrease the negative impact of eutrophication, as well as prediction of the effectiveness of possible treatment options, is difficult because the interactions between the processes that cause eutrophication are very complex. Also, as each impoundment is unique in the way it will react to the various factors that contribute to eutrophication, a management strategy that was effective at one impoundment may not be effective at another, i.e. each impoundment must be evaluated in its own right.

### AIMS OF STUDY

The aims of the project were as follows:

1. To validate the MINLAKE reservoir water quality model with regard to its ability to predict the trophic response of a reservoir to:
  - hydrological and climatic conditions different from those for which the model was calibrated
  - altered nutrient inputs.
2. To evaluate the confidence with which the MINLAKE model can be used by water managers to predict the results of management options.

### LEVEL OF STUDY

The study has been carried out at a low cost reconnaissance level.

## THE MODIFIED MINLAKE MODEL

Valuable information about the trophic behaviour of a particular impoundment can be obtained by simulating the hydrodynamic and water quality behaviour of the impoundment with the aid of a mathematical model. One such a model is the modified *MINLAKE* model. It is a *one-dimensional water quality model* that was originally developed at the University of Minnesota in the USA. The model has been extensively applied to various lakes and impoundments in the northern USA. However, the northern USA has a cold temperate climate, whereas the climate in South Africa is warm temperate to subtropical. Thus the original model had to be modified before it could simulate the water quality of a typical South African reservoir (Roodeplaat Dam near Pretoria). The modifications relate mostly to the climatic differences. For instance, the higher water temperature of dams situated in a warm temperate climate causes biological rates such as bacterial decomposition of organic matter to increase. This results in more rapid hypolimnetic oxygen depletion (and thus greater internal cycling of nutrients) than would be the case for a dam with a similar concentration of organic matter, but situated in a cooler region (Henderson-Sellers 1984). The aerobic/anaerobic state of the water therefore affects a great number of in-dam processes. In fact, according to Mortimer (1942) dams where the hypolimnion becomes anaerobic should be considered fundamentally different from dams where the hypolimnion does not become anaerobic. The original *MINLAKE* model did not make provision for the effect of the aerobic/anaerobic state of the water on process rates, probably because this affect was not considered important in the cold temperate climate where the model was developed. However, it was not possible to simulate the water quality behaviour of Roodeplaat Dam until the original *MINLAKE* model had been modified to take cognisance of the affect of the aerobic/anaerobic state of the water on process rates (Venter 1996).

The modified *MINLAKE* model not only provides for the effect of the aerobic/anaerobic state of the water on process rates, it also is the only one-dimensional water quality model that has been calibrated on a South African impoundment and that can simulate algal succession (Venter 1996). Hence it has the potential to be used as a tool in assessing the effectiveness of treatment options aimed at changing blue-green algal dominance to dominance by green algae. However, the model needed to be validated

before it could be used to predict future events. The need for validation stems from the following:

- Impoundments are not static and the complexity of the processes is such that if a model is formulated to mimic the dynamic state of an impoundment in detail, the resultant model must of necessity be complex. The greater the complexity of a model, the greater is the inherent uncertainty associated with the predictions (Jorgensen 1980). Thus the mathematical representation of some processes that are regarded as relatively static (or less dynamic) such as for instance, sediment nutrient release rate, are simplified by the use of constants and/or calibration coefficients. Though the simplified expression may mimic the process adequately over the short term, there may be long term changes in the process that may invalidate the simplified expression because of the constants that were used.
- There is an inherent uncertainty, or error, associated with the calibration coefficients that have to be specified during calibration of the model. If a calibrated model is used to predict future events, these uncertainties are propagated as a certain degree of error, or uncertainty in future predictions. There is thus no guarantee that the validity of a model extends beyond the data set against which it has been calibrated, until knowledge is obtained as to how errors of estimation of calibration coefficients affect the model predictions about the future behaviour of an impoundment.

## **SELECTION OF STUDY CATCHMENT**

Validation studies are often prohibited because of the time and money involved, as well as *scarcity of data*. An *ideal opportunity for validation of the MINLAKE model* was presented by the extensive data record that existed for Roodeplaat Dam. The record at this dam also provided a unique opportunity to evaluate the effect of the reduction in inflow phosphate load following the introduction of the 1 mg phosphate standard, and whether the model would have been able to predict the outcome of this particular management option correctly.

## **DATA COLLECTION AND PROCESSING**

The daily data required to run the modified MINLAKE model were collected and assessed. In some instances, the data base was surprisingly good. Minimum infilling of river inflow water quality data had to be done. Meteorological data presented the biggest problem. Although the required data were available, it was of poor quality and extensive infilling of meteorological data was required. The quality of in-dam data was good, as sampling was done on a regular basis in the epilimnion as well as the hypolimnion, thereby enabling comparison of simulated and observed results at various depths in the impoundment.

## **SELECTION OF VALIDATION PERIOD**

After assessment of the data it was decided that the most suitable validation period would be October 1988 to January 1990, a period of 15 months. The databases required by the model were constructed, and, where infilling of data was necessary, the methodology that was developed during calibration of the model was followed.

## **CONCLUSIONS**

The model simulated the hydrodynamic behaviour of Roodeplaat Dam during the validation period well. The validation results also showed that the model was able to predict the degree of change in phosphate concentration that occurred from the calibration to the validation period as a result of implementation of the 1 mg phosphate standard. Prediction of the degree of change in chlorophyll-a concentration, as well as ammonia and nitrate concentration, was less successful. This significantly decreases the potential use of the model to predict future trophic conditions in an impoundment.

The poor performance of the model in predicting the trophic response of the reservoir to the change in nutrient input rate is thought to be attributable to the simplistic modelling of sediment nutrient release rate. However, the possibility of an incorrect combination of coefficients selected for other model parameters cannot be ruled out. For instance, none of the coefficients relating to simulation of the nitrogen budget had been determined for Roodeplaat Dam, thus values from literature studies had to be

substituted. It is possible that these values are not the optimal values for Roodeplaat Dam.

## RECOMMENDATIONS

### Model applications

Although the model cannot be used to predict *future* trophic conditions, it still has many other uses. For instance, one of the greatest strengths of the modified MINLAKE model is its use to determine the relative importance of the various factors that may limit current algal growth in a particular impoundment (Venter 1996). This can assist the water manager to make an informed decision as to the treatment method that would be most appropriate and cost-effective. The model can also be used as an aid to determine the relative importance of the pollution loads that enter the impoundment, and to show to what extent the current water quality in the reservoir will be altered by changing loads from these sources. The possibility and effectiveness of improving water quality by switching between water sources, altering release patterns, or importing better quality raw water, as well as the best time to import raw water, can also be evaluated with the aid of a model such as the modified MINLAKE model.

The model can also be effective in assisting in the setting of water quality standards. Some reservoirs are able to tolerate a higher pollutant load than others, and thus the trophic response of a reservoir should serve as a measure for setting water quality guidelines for the inflowing rivers. The trophic response of a reservoir is best determined by using a model such as the modified MINLAKE model, which takes account of all the main factors that affect the trophic response of the reservoir.

Monitoring of water quality and meteorological data is very expensive. Hence the frequency of measurement should be reduced to the minimum necessary for the efficient operation of a reservoir. Monitoring programmes can be designed and optimised by the use of an appropriate water quality model. The relative importance of different water quality and meteorological variables can be determined with the aid of the model. For instance, during calibration of the MINLAKE model it was found that the effect of wind on the behaviour of the impoundments is much more significant than

the effect of radiation or humidity. The cost effectiveness of the monitoring programme can be further increased by using the model to determine the optimum monitoring frequency, and in the case of reservoir profile data, optimum depth of measurement.

From the above it can be concluded that, although the model cannot be used with confidence to predict the future behaviour of an impoundment, there still is significant scope for using a model such as the modified MINLAKE model for a multitude of practical applications.

### **Further research**

The following further research is recommended allow the Minlake model to be used with greater confidence.

1. Investigations are required to gain a better understanding of both the short and long term processes governing nutrient release and uptake by sediments under local conditions.
2. The constant rate sediment release algorithms used in the MINLAKE model need to be replaced by a more appropriate sub-model capable of simulating the dynamics of the processes involved.
3. Further work is required to better determine the most appropriate ranges and combinations for the host of model calibration values, especially the values relating to nitrogen simulation.