Chapter 4

CONCLUDING COMMENTS

The procedure described in Chapter 2 should be useful for lake trophic management planning because of the inclusion of uncertainty analysis and the carefully screened tables of export coefficients. Its value will be enhanced, however, if the analyst is mindful of the limitations of the methodology. Listed below are several items reflecting these limitations as well as guidelines for the interpretation and communication of the modeling/uncertainty analysis results.

1. The prediction of quantitative water quality impacts associated with changes in land use necessitates the use of a mathematical model. Projected or anticipated land use changes cannot be measured so information must be extrapolated from other points in space and/or time. Both the application of the mathematical model and the extrapolation of information imply prediction error. This error is therefore unavoidable, but when quantified, prediction uncertainty can be extremely useful in the planning process.
2. Prediction uncertainty is a measure of the information value contained in a prediction. If the uncertainty is small, the prediction is precise, and the predictive information is valuable. Alternatively, if the uncertainty is large, the prediction is imprecise, and the predictive information is less valuable. Prediction uncertainty is caused by natural

process variability, and bias and error in sampling, measurement, and modeling. Prediction uncertainty can be useful to the planner as long as it is reliably estimated. However, it is possible that unquantified supplemental uncertainty (Mosteller and Tukey, 1977) exists. This uncertainty term generally results from errors that are unknown to the analyst. For example, supplemental error may be introduced, but unquantified, because of poor choice of export coefficients. This hidden error may increase planning risks because the error is not included in the error analysis. Therefore the analyst must exercise care in the selection of the export coefficients and in the conduct of the modeling process.

3. The notion of supplemental uncertainty and hidden planning risks underscores the importance of selecting representative nutrient export coefficients. The watershed matching process described in Chapter 3 is central to this concern. The analyst must be aware of those watershed characteristics that are the major determinants of nutrient export. Then the appropriate export coefficients are selected according to a match between application lake watershed and export coefficient watershed, on the basis of these causal characteristics. This match leads to representative and reliable coefficients and diminishes supplemental uncertainty.

4. The discussion in Chapter 2 identifies the major limitations on the modeling/uncertainty analysis methodology. In fundamental terms, the limitations are generally associated with the fact that the model development data set for any particular model represents a subpopulation of lakes. Application

lakes that differ substantially from the model development subpopulation may not be modeled well (i.e., results may be biased). Any limnologic characteristic that is a causal determinant of lake phosphorus concentration is a candidate as a limiting, or constraint, variable. These include constraints on the model variables (e.g., all model development data set lakes have $P < .135$ mg/l), constraints on hydrology (e.g., there are no closed lakes in the model development data set), or constraints on climate (e.g., the model development data set contains only north temperate lakes).

5. The methodology described in Chapter 2 can be used to quantify the relationship between watershed land use and lake phosphorus concentration. Yet phosphorus by itself is not an objectionable water quality characteristic. The real quality variable of concern (i.e., the characteristic(s) that lend(s) value or human benefit to the water body, abbreviated "qvc") may be algal biomass, water clarity, dissolved oxygen levels, or fish populations (see Figure 1). Therefore the modeling methodology and the error analysis do not include all of the calculations necessary to link control variables (land use) with the qvc. This means that the relevant prediction error (on the qvc) is underestimated by the phosphorus model prediction error, and planning and management risks are inadequately specified. More useful methodologies are needed that quantitatively link control variables with the qvc for a particular application.
6. The error analysis procedure presented in Chapter 2 should provide a reasonable estimate of prediction uncertainty.

However, there are still problems in interpretation and application. For instance, the model error component was estimated from a least squares analysis on a multi-lake (cross-sectional) data set. This error is then applied to a single lake in a longitudinal sense. Thus, much of the model error term actually results from multi-lake variability, whereas when the model is applied to a single lake, the model error term <u>should</u> consist primarily of lack-of-fit bias and single lake variability. On the basis of present knowledge, it is not clear how a multi-lake-derived error relates to a single lake analysis.

7. A second issue associated with the error analysis concerns the subjective determinations of phosphorus loading and hence, loading estimation error. Statisticians and modelers generally prefer objective measures of uncertainty, such as calculated variability in a set of data. However both limited available data and the obviously unmeasurable nature of future impacts favor (or necessitate) subjective estimates. Given this subjectivity, and the inexperience of most planners and analysts with phosphorus loading estimation, there may be uncertainty in the uncertainty estimates. This is exacerbated by the potential for loading error "double counting" (see Reckhow, 1979d), although the procedure described in Chapter 2 is designed to reduce error double counting. It is likely that as analysts gain experience in loading and error estimation, this problem will be of less concern.

8. A third uncertainty analysis issue concerns the precise description of error terms presented in Chapter 2 to minimize

error double counting. It was noted in Chapter 2 that some variable error is already incorporated into the model standard error. The error analysis procedure proposed is designed to require additional application lake error only for those factors not already included in the model error. Therefore the analyst is urged to closely follow the guidelines in Chapter 2 for export coefficient selection and error estimation. The alternative may be a well-intentioned but inaccurate estimate of prediction uncertainty.

9. The simplicity of this technique necessarily limits its adaptability to certain situations that may occur within a watershed. This procedure may be flexible enough to accommodate some of these situations, but others may require more intensive study (than the procedure provides for). Therefore, it must be left to the judgment of the analyst as to whether or not this method is appropriate. Examples of events or characteristics that would alter the effectiveness of this procedure are:
    a) the input of phorphorus from sources not considered in the method presented. These sources might include a large number of resident water fowl in and around the lake or fertilizers applied to shoreline lawns;
    b) the trapping of phosphorus by mechanisms not considered. These phosphorus traps might include aquatic plants or an upstream lake within the watershed;
    c) the occurrence of an unnatural phenomenon that alters the lake ecosystem. These phenomena might include dredging, filling, and chemical treatment;

d) lake types not modeled well with this black box nutrient model. These types include closed lakes (lakes without well-defined outlets) and lakes with strong internal concentration gradients (i.e., lakes with significant local quality variations).

10. Water quality management planning and modeling incur a cost that is presumably justified in terms of the value of the information provided. The actual achievement of a water quality level often requires management and pollutant abatement costs but also carries with it various benefits. The analyst must be cognizant of the fundamental economic nature of environmental management, planning, and decision making. The acquisition of additional data or the conduct of additional modeling and planning studies should be justified in terms of information return for improved decision making.

11. Finally, the planner or analyst conducting a lake modeling study has as his/her primary goal the effective communication of the work carried out. This does not simply mean documentation of the calculations and presentation of the prediction and prediction uncertainty. Rather, effective communication requires consideration of the knowledge and concerns of the likely audience. The analyst must then describe his/her study so that the audience can comprehend the results, can understand the study's limitations, and can act (if necessary) in an informed manner. As a rule, this means that the analyst should completely describe procedural limitations and assumptions made in conducting the study.

Beyond that, the analyst should explain how the limitations and assumptions affect the interpretation of the results for planning. As a related issue, the analyst should justify his/her choice of export coefficients. A comprehensive discussion of the application of the modeling/uncertainty analysis methodology that meets the needs of the intended audience facilitates good water quality management planning.

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