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# VI. CONTROL OF CONVENTIONAL AND NON-CONVENTIONAL WATER RESOURCES

## THE SAINT JOHN RIVER SYSTEM MODELS: A CASE STUDY

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## INTRODUCTION

During the past decade or so, there has been increasing concern in Canada over environmental deterioration, especially with regard to air and water pollution. With increasing affluence, higher standard of living and higher levels of education, public perception of environmental problems, and their attitudes thereto, have significantly changed, and are also continually changing. Hence, the society as a whole no longer willy-nilly accepts the concept that the increase in economic indices line Gross National Product or per capita income, both in real terms, are the sole criteria of progress, and nor is it willing to accept the continuation of the use of economic analyses like benefit-cost ratio or cost-effectiveness as the only basis for project approval. The standard economic indices or analyses cannot handle intangible values which significantly contribute to the enrichment of our quality of life. The concern here is with all those components of environmental appreciation, entailing either observation or physical exploitation, which are not directly quantifiable, or if quantifiable, cannot be valued by market mechanism (Devine, 1966). The net social or 'psychic' income from resource use in this sense, extends beyond the concept of secondary benefits, and includes psychic and indirect monetary benefits to the user and ultimately to the society as a whole (Biswas and Coomber, 1973).

Normally, intangibles accrue from the aesthetic, scientific, educational, historical, or recreational aspects of the natural environment (Biswas, 1973a).

Thus, there is an increasing realization that with our past preoccupation with economic growth, we have not fully understood, realize or appreciated an equally important criterion for water resources management, that is, the quality of the environment we live in (Biswas and Durie, 1971). This increasing awareness of the necessity of improving our quality of life has been amply manifested in the water pollution field by increasing societal concern, and has precipitated the urgent necessity for developing new and better techniques to improve the quality of decisions being made in this area.

## MATHEMATICAL MODELLING

One of the newer and more promising techniques that is being increasingly considered during the recent years is the application of systems analysis techniques to water resources policy planning and decision-making. Admittedly, some of the fundamental and underlying concepts of systems analysis have undoubtedly been used in water resources management area for more than fifty years or so, but the real impetus to its use came in the early 1960's, primarily due to the relative success of systems analysis and operations research techniques in the defence and aerospace oriented industries during the post-1950 era (Biswas, Reynolds and Durie, 1972).

Development of mathematical models in water-oriented areas has become very fashionable during the last decade, and is undoubtedly the latest "in" thing to do. A cursory examination of the past issues of all water resources journals will confirm this fact. The proliferation of articles on systems analysis does not show any sign of abatement. The signs, if any, indicate an ever-increasing flow of articles. A sad fact, however, has been that most of these models are developed by the academia, and consequently very few of them have been actually used in our planning and management processes. There are several reasons for this rather sad state of affairs (Biswas, Pentland and Reynolds, 1972). The two major ones are that the models developed are not very practical to be used in actual planning processes, and the models developed are too complex, and hence beyond the comprehension of the average planner.

There is no doubt that the state-of-the-art in mathematical modelling has advanced sufficiently to be useful in water resources policy planning and decision-making. Admittedly, some of our current models in this field are rather crude, and somewhat dependent on the judgement and experience of the analyst, but the issue is very definitely on the side of having a model, even a crude one, against having no model at all (Biswas, 1972).

## MODELS OF THE SAINT JOHN RIVER SYSTEM

Right from the very beginning, when the terms of reference of this study was being conceived and developed by the writer, a major emphasis was to ensure that the models developed will be used for both decision-making and training purposes. To this end, considerable time and effort was devoted to involve all the Federal and Provincial Agencies that were to be associated with the planning of the Saint John River Basin. It was a time-consuming and often somewhat frustrating process, but looking back it was an essential part of the exercise which greatly contributed to the success of the study.

The main objective of the study was to develop a set of engineering-economic models to interrelate the benefits and costs to various water uses resulting from water quality control measures, and to determine the optimal plan for water quality management in any particular situation on the basis of socio-economic and physical considerations. The intention was to develop mathematical models specifically applicable to the Canadian conditions and which could lead on to broader framework studies of comprehensive socio-economic modelling. It was anticipated that once the current research effort developed the new techniques for a total systems approach to comprehensive river basin planning and management, and once the mathematical models so developed were tested and validated, the models would be used as planning tools by the Canada-New Brunswick Saint John River Basin Study Board.

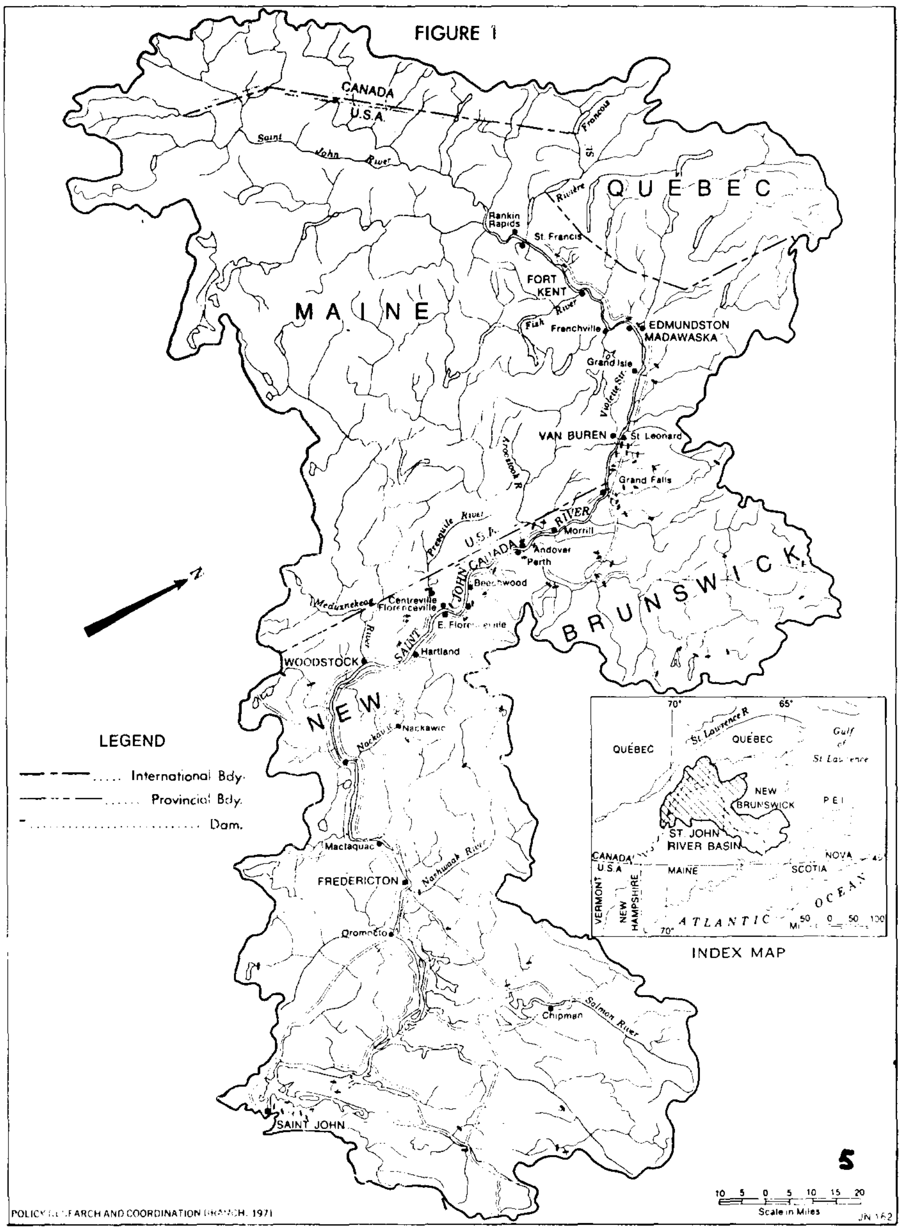
The study area - the Saint John is an international river, and flows through the State of Maine in the United States and the Province of Quebec and New Brunswick in Canada. Its length is approximately 700 km (435 miles) and has a drainage area of 54,934 $km^2$ (21,210 square miles). The comprehensive mathematical models that have been developed are only for the Canadian portion of the river (Figure 1).

The main industry in the Saint John River Basin has been the harvesting and processing of forest products. From water quality considerations, the major source of pollution has been the pulp and paper industry. The food processing industry, specially potato processing, also contributes significantly to the pollution load. In addition, the municipal pollution occurs throughout the length of the river. Fifty-nine significant sources of pollution have been identified between the headwaters and Oromocto during the process of development of the models.

The river has been used extensively for logging, and also serves as a transportation link. Its tributaries form the most significant spawning ground for the Atlantic salmon on the each of Canada, and, consequently, the Saint John System has been a vital element of the fishing industry for the Maritime Provinces. The river has always been used for recreational purposes, and the fish, wildlife and water fowl of the area depend on the river and its tributaries for survival. The river flow is partially regulated to develop hydroelectric power, having a current total installed capacity of 530 MW.

The Linear Programming Model - Different approaches have been used by various investigators to develop and validate mathematical models for specific conditions. In this exercise, it was decided to develop two complementary models: a linear programming (LP) or optimization model and a simulation model. The complementary usage of a relatively simple linear programming optimization model and a simulation model for the planing and management of complex river basins is not new. In

SAINT JOHN RIVER BASIN



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1969, Loucks suggested the use of programming models for the preliminary screening of alternative designs and operating to be followed by simulation models for more detailed analyses of select few designs and operating policies. A similar approach was used in the present study.

The model considers a series of quality sites and waste sources in the basin. For each waste source, cost functions were derived where the cost is assumed to be continuous function of the percent of BOD removal. While the usual modelling approach has been to characterize each effluent with one decay coefficient, it was decided that this simplistic approach will be inadequate for the Saint John River, as well as other major Canadian rivers, because of their typically long travel times. Thus, each waste was characterized by two components, each having its unique decay coefficient, representing carbonaceous and more slowly decaying nitrogenous portion of the effluent. The former represents the total decay behaviour of the waste during the first five days in the river, while the latter includes the decay behaviour of oxygen-consuming nitrogeneous compounds which take considerably longer than five days to become stabilized. Most waste inputs on the Saint John River have travel times considerably greater than five days before they flow out of the system.

Simulation Model - The simulation model evaluates the temporal effects on water quality of any single selected or optimal system over a prolonged period of varying hydrologic conditions.

Because of the lack of continuous long-term historical records of river flow, a statistical flow generating program was developed so that longer time periods of any desired length could be investigated. These river flows are generated based on the statistical characteristics of the existing flow records. In effect, these river flows, the physical characteristics of the river and the quantities of waste effluents after treatment provide the input data for the simulation model. The model routes the flow and the pollutants in a dual-routing algorithm and calculates oxygen profiles throughout the entire river. A daily time interval was used for this study, with

2-day and 3-day time intervals being available as option. Admittedly, a smaller time increment would have provided more detailed responses of water quality, but it would have been relatively more expensive in terms of development and usage.

The various segments of the simulation model are shown in Figure 2, and a brief description of the segments follow herein.

Synthetic flow generator - This segment generates the synthetic hydrology on a seasonal basis. River basin planning requires long-term records of river flow so that all the uncertainties associated with hydrometeorological conditions can be adequately considered.

Essentially the flow generator utilizes statistics of historical or actual data to "create" a river flow record of any duration that is "statistically similar" to the historical data. The sub-model used to generate the synthetic sequence of river flows provides long-term records of extreme conditions of low and high river flows which are not normally found in historical records and which are critical design periods for comprehensive river basin planning.

Hydrology Generator - The Synthetic Flow Generator provides flows on a seasonal basis at a number of gauging stations. The Hydrology Generator creates a synthetic daily flow record from this data for the season of interest in the form of inflows to the river at each waste and quality point. The daily flows generated include base flow in the river and interflows from surface runoff between node points. Typical storm events are generated in this sub-model to preserve as much of the natural hydrology of the river basin as possible.

The Routing Program - This segment of the simulation program uses flows from the hydrology generator and physical data from the Saint John River waste treatment system including waste loads after treatment, river geometry and desired water quality levels at specific points.

The Muskingum flow routing method is used to route the generated flows through the river system. Because changes in

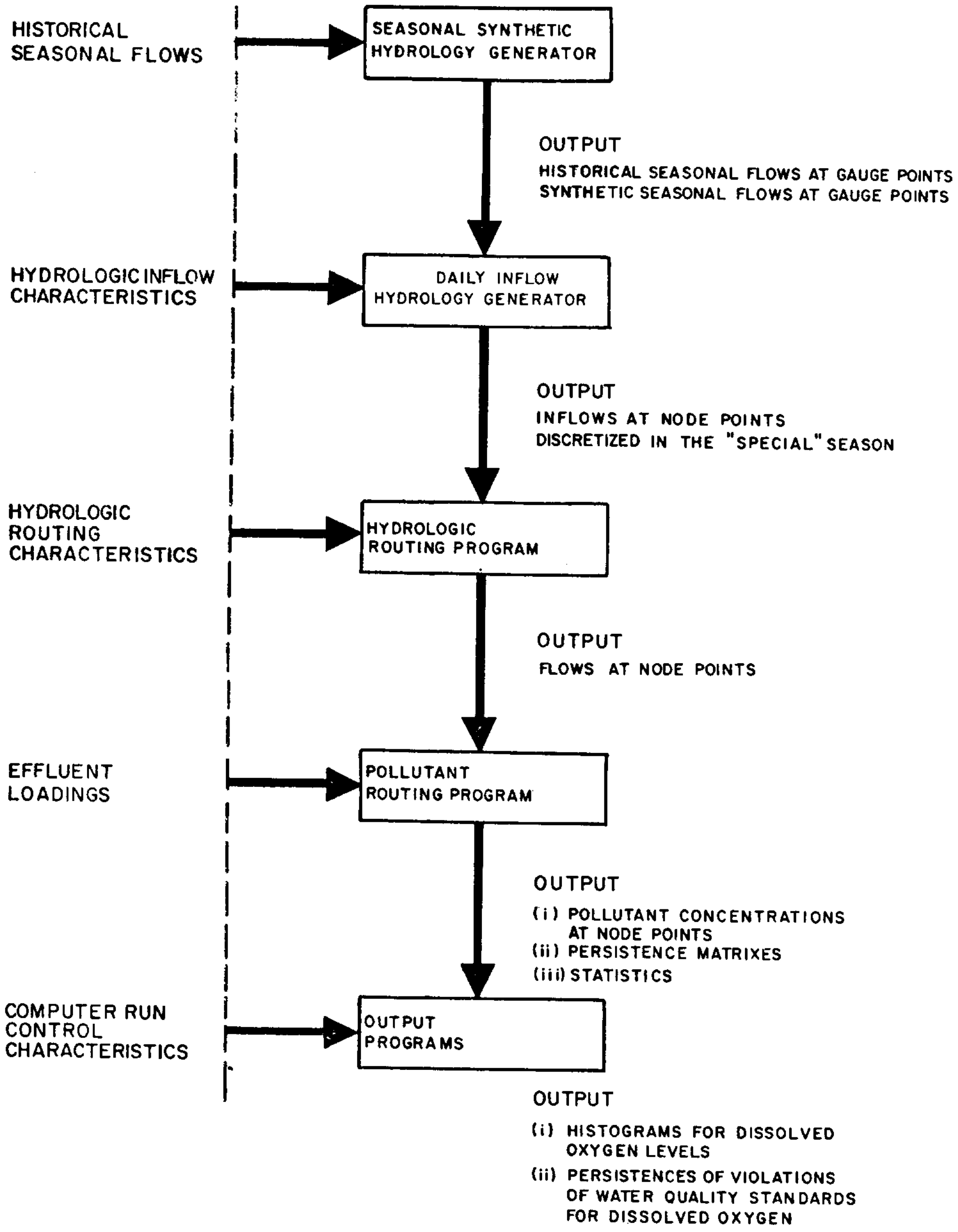

FIGURE 2. STRUCTURE OF SIMULATION MODEL

river flow move downstream with a speed equal to the wave celerity while changes in water quality concentration due to waste loads are propagated downstream at the average flow velocity, a separate routing algorithm for the pollutant is required. A rather complex "back-step" algorithm was developed to account for this difference in rate of river flow and pollutant flow.

Output - the main output of the simulation model is a description of the violation of various levels of water quality in terms of their frequency, magnitude and persistence. For selected biological species, near threshold levels, such information is vitally necessary to ensure their continuing survival. This information then can provide the rationale to establish water quality standards.

The LP model can be used to define required levels of treatment necessary at each of the effluent sources. This information serves as the basic input to the simulation model, which can then be run through a predetermined number of seasons of synthetic daily flows to evaluate detailed water quality responses to these loadings. The season selected for this study is the 3-month later summer-early fall period when flows and DO levels tend to be low, effluent loadings fairly high and bacterial decomposition is fairly rapid. From the large number of results obtained, DO levels at various points of the system were reduced to frequency plots. A typical result is shown in Figure 3.

From ecological considerations, it was decided to have spatial temporal representation of water quality as shown in Figure 4. It shows the DO levels for the worse 35-mile stretch of the river for one of the more 'severe' seasons. It indicates that certain species would be able to survive in this stretch of the river for certain period of time, in spite of consistently low water quality and low DO level.

A detailed report on the formulation of the model and the results of analyses is now available (Ecological Systems Branch, 1973).

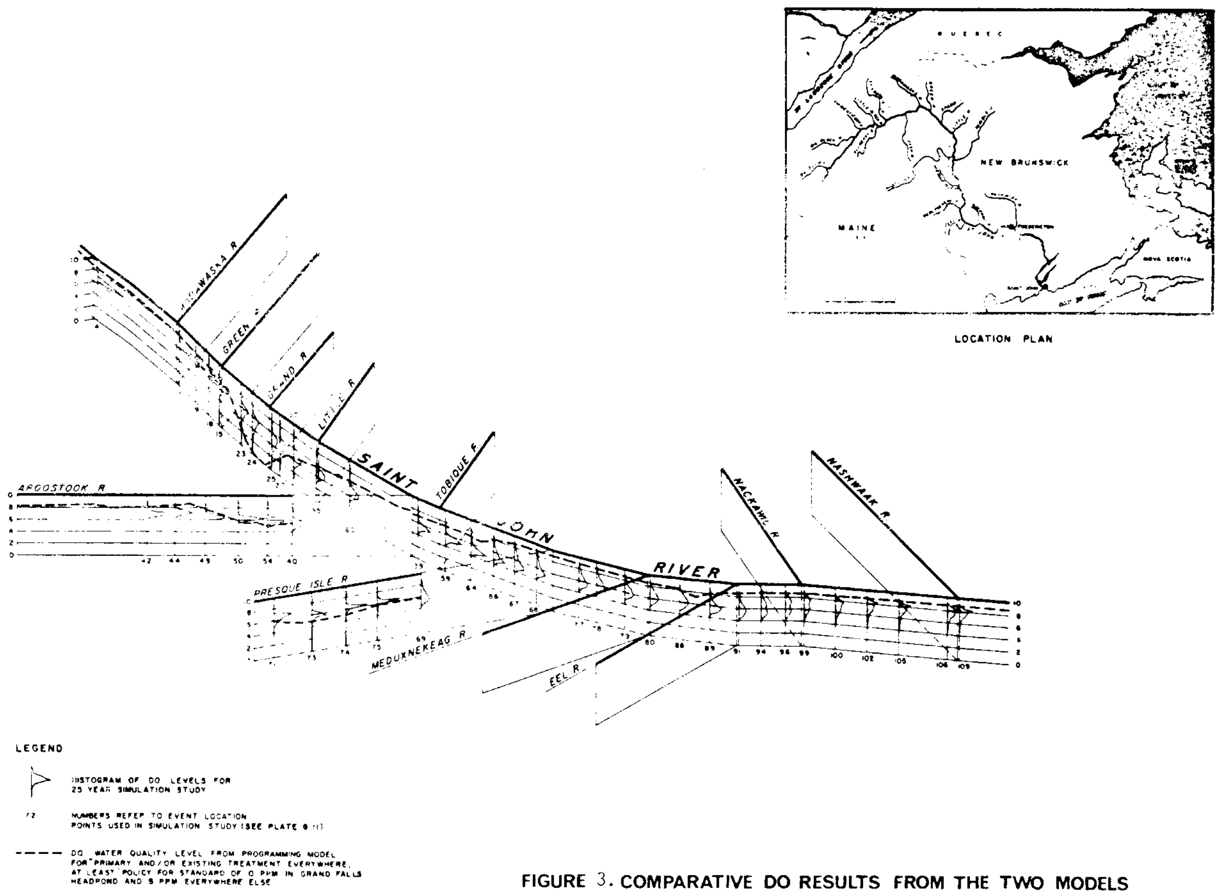

FIGURE 3. COMPARATIVE DO RESULTS FROM THE TWO MODELS

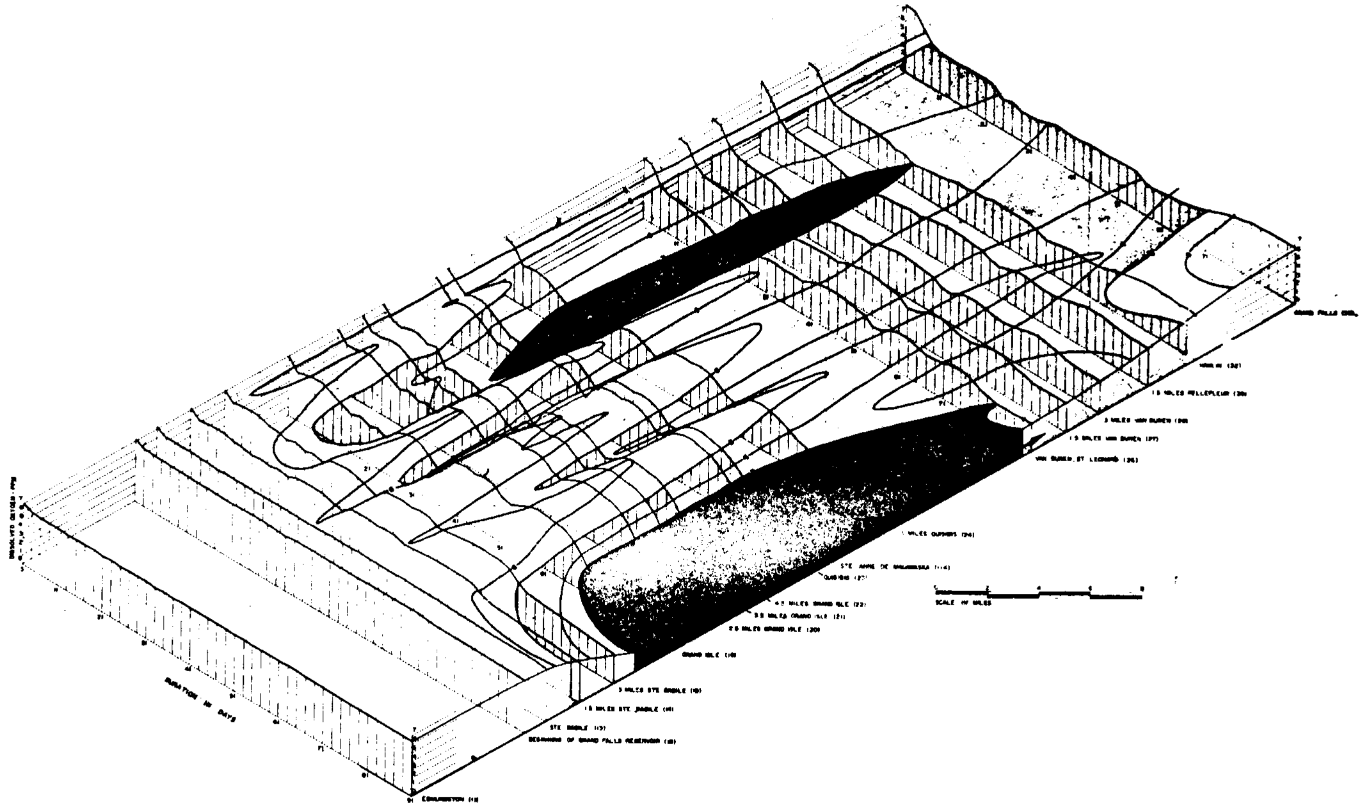

FIGURE 4. TEMPORAL AND SPATIAL VARIATION IN DO LEVELS

## CONCLUSION

Better understanding of the physical processes involved with water quality management and development of more powerful computer technology and better algorithms during the last decade or so have enabled us to analyse more complex systems by means of mathematical models. This, in turn, has provided another dimension to make better decisions. Generally, the more varied the manipulability of the models, the greater is their usefulness to policy planners and decision-makers in exploring the consequences of alternative policies. Decision-making in water quality management, like many other fields, is incremental rather than total, in the sense that the decision-maker proceeds through one stage at a time, comparing the consequences of different feasible policies. Thus, mathematical modelling can significantly aid the decision-makers to arrive at better decisions than otherwise possible by broadening his information base, by predicting the consequences of several alternative courses of action, or by selecting a suitable course of action which will accomplish a prescribed result. In addition, mathematical modelling is a dynamic process. That is, as we obtain more data on the various parameters and/or better information and understanding of the subsystems, the model is continually updated and refined.

It will be well to remember that one of the greatest possible pay-offs of these type of exercises generally come from the interaction between the model and the policy-makers. This is reflected by the improved quality of the decisions to be made. The main problem, however, is to actually get the policy-makers involved with the modelling exercises. Thus, the greatest possible pay-off in terms of improved quality of decisions, of these types of exercises may come from the interaction between the models and policy-makers (Biswas, 1973b).

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