Systems Analysis Applied to Water Management in Developing Countries: Problems and Prospects*

by

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INTRODUCTION

Water is a vitally important resource, but often its overall significance and total contributions to the economic development of countries are not fully realized, because its benefits are apt to be looked on sectorally by national governments. Thus often, for example, a Ministry of Health is concerned with the domestic water supply, a Ministry of Agriculture with irrigation development, a Ministry of Energy with hydroelectric power generation, a Ministry of Transport with navigation, a Ministry of Fisheries with aquacultural development, a Ministry of Industry with industrial water-use, and a Ministry of Environment with environmental implications. Unfortunately in most governments, relationships between the different ministries are not as good as they should be, due to years or even decades of rivalry over 'empire-building' and budget availability. Thus it is not unusual to find ministries which are reluctant to share with one another any data that are available and analyses that have been carried out, even though those are essential requirements for any water-management process.

Attempts to optimize total benefits that could accrue from an integrated water-development project thus become only partially successful. In certain countries the situation is still worse, as, even for a single objective such as irrigation development, there is often bureaucratic infighting between relevant ministries, such as those handling agriculture and irrigation. The existence of such a state of affairs is indeed unfortunate, as it is imperative to strive for optimal benefits from water development projects.

In most Third World countries, water needs to be used more effectively than elsewhere if it is to provide potable water for rural and urban populations, to produce more food, to generate more electricity, and to encourage other benefits to satisfy basic human needs to a much higher degree than they do at present. One possible way both to improve the existing water management process and to provide better communication between ministries, would be through the use of systems analysis.

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SYSTEMS ANALYSIS

Webster's *Dictionary for Everyday Use* (Allee, 1975) defines 'system' as 'assemblage of objects arranged after some distinct method, usually logical or scientific; whole scheme of created things regarded as forming one complete whole'. The word 'system' is derived from two Greek words 'syn' and 'histanai', meaning 'together' and 'to set', respectively. Thus, it can be said that literally the word 'system' means 'to set together'.

Elsewhere I have defined systems analysis as an explicit analytical study that assists a decision-maker to select a preferred course of action by identifying and examining the possible consequences of several feasible alternatives (Biswas, 1976). It is a logical and systematic approach wherein assumptions, objectives, and criteria, are enumerated. The technique, if used properly, can aid a decision-maker to arrive at better decisions, under uncertain conditions, than otherwise might have been possible—by better comprehension of the system and interlinkages of various subsystems, by broadening of the information base, by predicting the potential consequences of different alternative courses of action, by selecting an appropriate course of action which may accomplish a prescribed result, and by forcing people to approach the problem scientifically. It necessitates development of an overall framework for analysing the problem rather than an *ad hoc*, piecemeal approach such as is often prevalent.

While quantitative methods are preferred and extensively used in systems analysis, this does not mean that qualitative analysis or subjective views cannot be incorporated, if so desired. Computers are not mandatory for systems analysis, but they are often essential if the system to be analysed is complex and multidimensional. Furthermore, it should be noted that modelling and systems analysis are not identical, and consequently that these two terms cannot be used interchangeably. Modelling is a device which is often used within the framework of systems analysis in order to obtain answers to specific questions, and these answers often exemplify the approach of systems analysis.

Normally, within a systems analysis framework, an attempt is made to build a realistic replica of a real-world problem or situation, with the primary objective of experimenting with the replica to gain some insight into, or to obtain a better understanding of, the real-world problem. Commonly it is not possible to build an exact replica from the real world for a complex problem that needs to be analysed, but even in the few cases where this may be possible, it is neither easy nor cheap to develop such a model. Fortunately, for most cases encountered in water resources management, it is not essential that exact replicas from the real world should be developed: a close or reasonable approximation, to fulfil the objectives of the analysis, is often sufficient for the purpose.

It is also not possible to analyse all the alternatives that may be available. Even if analyses of all possible alternatives were feasible technically, economic considerations alone would militate against such a step. For example, if it is assumed that for a moderate-sized water development project some 50 design variables would have to be considered, and that each of these variables were assigned only three values—namely the most expected, and the 15% higher or lower than the most-expected values—then the number of designs to be analysed would become astronomical, totalling 3^{50} or several thousand million million designs. Such an analytical task, even with the latest generation of the most powerful computers, is not feasible, and even if it were technically possible, its cost alone would negate taking such a step. In other words, we have to be selective in choosing the number of alternatives to be explored.

It is imperative that the analysts have suitable experience and good judgement in order to identify the possible variants to be analysed. Accordingly, even though systems analysis has broadened the scope and breadth of analysis, the quality of the results obtained is to a great extent dependent on the skill of the analysts carrying out the study, and thus their limitations could become a severe constraint. In other words, systems analysis cannot replace experience, but it can augment it.

Systems analysis provides answers by methods and techniques which are available to everyone for critical analysis and examination. This, however, does not mean that the answers are unique and can be precisely duplicated by others having the necessary expertise and experience, which is a point that is often not realized.

The above discussion should not be construed as an unequivocal endorsement of the use of systems analysis for water management. It must be recognized that it is one—albeit an important one—of many techniques that are currently available for rational water management. Furthermore, there are some inherent limitations in building models of real-life problems. Such a device cannot guarantee development of optimal plans; nor is it easy to develop an analytical framework for water management that must consider multiple users, multiple purposes, and multiple objectives. Objectives are often not clear-cut, and are thus difficult to quantify for analytical purposes. This makes trade-offs between different objectives difficult. Also, different people within a decision-making process may have different objectives, depending on their own goals, values, and perspectives.

Furthermore, data available for analyses may not be sufficient or sufficiently reliable. The assumptions made to develop the models may then be incorrect, while future events can never be predicted with scientific precision. Moreover, qualitative factors affecting the process involved are difficult to handle. Admittedly, some of our existing models for water management are rather crude, and somewhat dependent on the experience and judgement of the analysts; but, in the final analysis, the issue is very definitely on the side of having a model—even a crude one—rather than on having no model at all.

SYSTEMS ANALYSIS IN DEVELOPING COUNTRIES

From my personal experiences as an adviser to international organizations—such as various agencies of the United Nations and the Organization for Economic Co-operation and Development (OECD)—and to several governments of developing countries, it is clear that, while use of systems analysis and computer technology is slowly increasing, there is no doubt that their potential in improving water resources planning and management processes has not yet been fully explored. There are many reasons for this lack of use, some of which are real and others imaginary, and only six major ones will be briefly discussed below.

Before discussing the reasons, it is important to make a qualification. There are many Third World countries, and as they are often at very different stages of development, it is not possible to make generalized statements that are equally applicable to all of these countries. Thus, what is valid for one country that is really developing may not be applicable to another which is not. Accordingly my comments will be applicable mainly to those countries which really are developing, which already have a trained pool of scientific and engineering personnel, and which possess the necessary infrastructure to carry out effectively the decisions that are taken. These are countries such as Egypt, India, and Venezuela. For such countries the following often appear to be the main problems, which could be real or imaginary:

1) Whereas it is said that systems analysis needs 'both hardware and software systems', which are so expensive that *'developing countries cannot afford them'*, this is incorrect. With technological developments, costs have declined significantly over the years. Thus, as the speed and capacity of computers have improved, the cost per unit operation has steadily declined. For example, in 1952 it cost US \$1.26 to carry out 100,000 multiplications; but despite chronic inflation, the unit cost has progressively declined—to \$0.26 in 1958, \$0.12 in 1964, \$0.05 in 1970, and to less than one cent at present.

Furthermore, the advent of mini-computers and sophisticated hand-held calculators has changed the situation drastically. The silicon-chip revolution has reduced the price of such instruments, and the costs of using them, quite dramatically. As a result, more than 90% of

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the problems faced by an average water resources agency in developing countries can be solved by equipment costing $35,000 or less.

2) Systems analysis cannot be carried out in developing countries owing to *'lack of trained personnel'*. This again is not a real problem, and it reminds me of the situation that was prevalent in water agencies of advanced industrialized countries such as Canada and Great Britain some decade-and-a-half ago, when similar objections were being raised. The problem was surmounted then, and there do not appear to be any reasons why this cannot be done again.

While there are not enough trained personnel to carry out systems analysis in nearly all the Third World countries, there is no reason to believe that people cannot be trained quickly—provided those who are in power are willing to see this done. In countries such as India, already many engineers and scientists are available who are knowledgeable on the application of systems analysis to water management, and a few universities have already started training, or are in a position to train, people if requested. If the directors of water agencies are willing to send and support some of their experienced water resources professionals for training, for periods ranging from 8 to 24 months, either at Indian universities or if necessary abroad, this problem can be solved quickly, and a large cadre of experienced professionals can thus be developed.

3) Use of systems analysis *requires a large quantity of reliable data*, and 'these are not available in developing countries'. While it is true that systems analysis requires data, two comments are appropriate here. First, it is possible to adapt the analysis to the limitations of data availability and, by using systems analysis in such cases, still obtain better results than would otherwise have been possible. Secondly, systems analysis can assist in the data collection and management processes. For example, sensitivity analyses can point out which variables are important for management, and hence such data should be collected. It could also point out the frequency with which such data should be collected. Moreover, through such means as assisting in data evaluation, sensitivity analysis may prevent the all-too-prevalent temptation to collect data on any variable relating to the project which could conceivably be relevant in the future.

For most situations in developing countries, it is likely that modelling and data collection processes will proceed in parallel fashion, with modelling often providing the better insight to the type of data that should be collected. Furthermore, the mere existence of data is not enough; their accessibility, accuracy, and usability, have to be considered.

4) Even though enough professionals can be trained to carry out systems analysis, the *top managers and decision-makers remain untrained*, and may not know how to utilize effectively the results of such studies. My personal experience in both developed and developing countries leads me to feel that this is probably the most difficult problem to overcome.

I must admit that we still have not found a good solution to this problem. It needs patience, and determined attempts have to be made to get the busy executives away from their daily routines for 2 to 4 weeks, so that they can be acquainted with the fundamentals of systems analysis through 'hands-on' workshops. Although this is not easy, we have had some limited success with such a programme, as will be discussed later.

5) Modelling is mainly an intellectual exercise, and *'no practical example can be shown where it has improved a water management process'*. There is no doubt a great deal of truth in this statement, but it is not exactly correct. Unfortunately there is no doubt that the vast amount of literature which has been published on modelling of water resources systems during the last decade is a product of academia, and its use to solve real-life problems is limited. While advancing the state of the art of modelling is a valid objective which should be encouraged, the fact remains that a far-too-high percentage of the models which are built remain mere academic exercises. Not enough proven models are easily available that can be successfully adopted for use in Third World countries.

In an attempt to improve this situation I recently wrote, with the support of the United Nations Environment Programme, a book entitled *'Models for Water Quality Management'* (Biswas, 1981), which provides details of important and usable models that have been developed latterly in Belgium, Canada, Denmark, West Germany, France, Great Britain, and the United States.

6) Another part-myth is that *'modelling is costly of time and money'*. Model developments do indeed take man-years of time, and computers are expensive to run. But then, physical hydraulic models of water development have been used for years in many countries, than which mathematical models are not more expensive and moreover are easy to interpret. Nevertheless one has to admit that systems analysts have often been not very successful in convincing those who have to pay the bills that all the promised goods can in fact be delivered—on time and on reasonable budgets!

CONSTRAINTS

The above statements should not be taken to construe that all is milk and honey with systems analysis. For example, Hoos (1972) has severely criticized the insensitive use of 'hard'* systems-analysis techniques in analysing public policy issues. Similarly, after reviewing a series of systems analysis studies carried out for the United States Department of Health, Education and Welfare, Drew (1967) summarized the results as follows:

> 'Some of the studies are more conscientious than are others about pointing out assumptions which are only guesses... Others at times reach levels of near unintelligibility... Some belabour the obvious, are super-

*Usually means relying on quantitative data.

repetitive (we shall discuss...we are discussing... we have just discussed), are littered with references to arcane studies, leave the reader to find the page which explains the chart, and serve up these vague euphemisms at which bureaucrats specialize... Finally, and most disconcertingly, some of the figures in the charts on benefit-cost ratios have been afflicted with typographical errors.'

There is no doubt that many systems-analysis studies are apt to be esoteric, full of technical jargon which non-specialists do not understand, and not easily digestible by the clients who are supposed to use them. Some consultants, in order to obtain a contract, 'promise the earth', and then later will write volumes to explain why their undertaking cannot be achieved. The costs and time required for studies are apt to be underestimated, and analysts often fail to realize the importance of social, environmental, institutional, and political, contexts within which decisions are usually made. In other words, there is a tendency to concentrate on tangible physical and economic factors which are quantifiable, while neglecting the unquantifiable factors. And yet, within a decision-making framework, 'soft'* information may be as important as, or even more important than, 'hard' data.

So far as developing countries are concerned, a major constraint in further utilization of systems analysis for water management is due to the training process that is employed, and especially to the type of people who are now being trained. The normal practice has been to train young people—some within the country concerned and others abroad—in order to develop a core group of capable technicians who can use systems analysis techniques. Several countries are now developing such indigenous expertise—mostly with assistance from international organizations.

There is no doubt that many programmes of this type have been successful in training a good many young people. For example, in the area of operational hydrology, such programmes have been very useful. Their success, however, has created another problem.

While at the working level in many developing countries there are now enough trained scientists and engineers who can use systems analysis techniques for water management, the knowledge unfortunately does not extend to the middle- and upper-management levels. When the results of the analyses come to the upper management levels for review and for the making of decisions towards which such analyses should be valuable inputs, they tend to pile up in offices and literally gather dust. As at the higher management levels there is not enough understanding of the techniques used, the tendency is not to consider the analyses very seriously—unless, naturally, the results are similar to a course of action which higher management would like to follow for political or other reasons! Ultimately the younger workers become frustrated, as no one appears to take their studies seriously.

*Namely, nonquantifiable information.

POSSIBLE SOLUTIONS

There is no doubt that one of the main reasons for this unfortunate state of affairs is the lack of proper communication between those who build the models and those who should use them. Therefore, high priority should be given to immediate means of improving communication (Frenkiel & Goodall, 1978). There are at least four attractive ways to improve communication and the 'image of modelling' in the eyes (and minds) of decision-makers, as follows:

A. *Define Concisely the Decision-maker's Problems and His Information Requirements:*—Modellers should know what information is required by water-resource managers, policy makers, and certain technologists at each hierarchical level of the decision-making process. The amount required, and the form of useful information, varies with each level, and we should devise the means to provide only what is required and can be successfully assimilated within the time-frame available for making decisions.

It is necessary to initiate programmes to define this scaling of information with the level of decision-making, starting with the highest level and working downwards. Such a programme would require the cooperation and personal attention of key administrators, and the active involvement of a few knowledgeable proponents of the art of modelling who can get to the heart of the communication problem. The task is not big, nor is it very expensive; but it is certainly the most important one in this particular context.

Equally necessary for the modellers is to keep a close watch on the changes in perception and understanding, on the part of the decision-makers, of the problems or set of problems that are being modelled. Model development takes time, and very often it takes more than a year from the time the decision to build a model is made to the time of its completion. As the real world is seldom static, even the restricted *milieu* of the decision-makers can change during the model-development phase. Their perception of the problem which is being modelled, its priority in terms of other problems that must be solved and hence of funds which need to be allocated, or even of other events that are beyond their control, could significantly affect the direction of the modelling process. Accordingly, it is not enough to decide, with the user, on the objective of the modelling at the beginning of the process: the modeller must know of any change in thinking on the part of the user, or of any chain of events that could affect the direction of model development, remembering always that models developed 'in a vacuum' would seldom be used.

B. *Conduct 'Hands-on' Workshops Using Simple but Practical Examples of How Decision-capability can be Enhanced by Considering a Host of Different Alternatives Within the Modelling Process:*—The management-gaming technique, with man–machine interaction to illustrate the power and fallibility of modelling, is a good way to initiate the layman. By carefully selecting a problem that has relevance to the user, and displaying the results immediately on CRT displays, the subjective prowess of the decision-maker actor can be tested. Many simple models of water-resources situations have been designed, or can be easily designed, for these types of workshops, where the primary aim is education and training. Indeed, this type of approach has already been tried in a few organizations.

What is necessary in this context is to provide short training courses for middle- and upper-level management officials. Past surveys of these types of officials indicate that it would be misguided to provide for them training courses of long duration: they prefer courses of from 1 to 2 weeks. The objective of such short courses should be to provide enough information on systems analysis to these decision-makers to ensure that they become familiar with the subject.

The objective of such courses should not be to make the participants experts, so that they could themselves carry out the actual analyses; this would be neither essential at such levels nor possible within the time available. But the short courses should point out advantages and disadvantages of using systems analysis, discuss case-studies of water management which are relevant for their purposes, suggest types of questions that should be asked of the analysts, provide realistic estimates of costs and times necessary, and so on. The present author, with the support of the United Nations Environment Programme, did direct such a 2-weeks' training course for middle- and upper-management officials from various water-related ministries of Egypt, Iran, Morocco, and Sudan, in 1979 (cf. Biswas *et al.*, 1980), and an independent ex-post analysis by the Ministry of Irrigation of Egypt indicated that it was 'a great success'. Currently, plans are well advanced towards his conducting another such 2-weeks' training workshop in New Delhi later in 1981, which will be attended by middle- and upper-level management officials from some 20 developing countries.

C. *Illustrate Some Real Cases in Straightforward and Understandable Terms:*—Three or four case-studies can be selected and addressed to problems that are of relevance to the agency concerned. These can be graphically illustrated by means of slides, filmstrips, or movies, to clarify the role of models in decision-making. The examples must be real—but need not be specifically identified—in the interest of conveying the general rather than the specific approach. Some examples in the area of water-resources management could be:

—Screening alternative strategies for pollution control in a river system or an estuary;

—Siting of a thermal or nuclear power-plant on a large lake, river, or estuary;

—Determining the main environmental and ecological effects of the construction and maintenance of a large dam;

—Assessing the ecological responses to the removal of nutrients; and

—Evaluating alternative strategies to contain an oil-spill.

D. *Develop Improved Methods for Displaying Model Results or Results of Model Applications:*—The capability currently exists of producing graphic displays directly from computers. An animated film-sequence of a simulation of a water-management problem would go far towards bridging the communication gap between modellers and decision-makers. To the best of my knowledge, no such demonstration of results is yet available, or has yet been attempted.

Consider, however, the possibility of showing, in a few minutes on a screen, such gradually-emerging realities as the intrusion of salinity into an estuary, the blooming of Algae in a lake, the effect of a pipeline or a canal on the migration patterns of wildlife, the routing of a flood through a river system, or the spreading of an oil-spill from a tanker on the high seas. The results of such 'impositions on Nature' could be made evident on video tapes produced from computer output, or on film prepared from CRT dispalys, or by means of graphic plotters. Such media for communication could be employed directly by technical personnel in the process of screening alternatives, or in presenting alternatives (after preliminary screening) to non-technical decision-makers.

It is evident that the development of economical means to 'animate' model results is important and indeed essential. Much of the necessary knowledge and technology are already available, and need only to be assembled and directed to the task. The cost of producing a 'pilot' to demonstrate the approach would be only a fraction of the investment needed to develop models. One could even visualize that the production of a 'computer graphic package' could be a standard part of model development in the future, in the manner of calibration or sensitivity analysis. At modest cost, we could thereby achieve much-improved understanding among all who are still in doubt about the practical future of mathematical modelling.

SUMMARY

During the last decade or so, the use of systems analysis and the application of computer technology for planning water resources development and management processes have increased significantly in many developed countries. The progress in most Third World countries, however, has not been commensurate and leaves much to be desired. Water management in recent years has become increasingly complex, and there is every indication that it will continue to do so in the future. Therefore, it is essential to utilize all the techniques which are available in order that the appropriate strategies and viable alternatives can be properly analysed, and the consequences of possible policy-decisions can be evaluated.

Systems analysis, if used properly, can significantly improve the management process; but whether, in spite of its great potential, it will actually be used for these purposes in Third-World countries, is another question, though it seems more likely to be adopted in those that are really developing than in the others.

Few models fail because technical expertise or state-of-the-art computer technology is inadequate, or because they are improperly implemented from a technical standpoint; they fail more often because too much concentration is placed on the technical issues and not enough on the managerial ones.

There seems no room for doubt that systems analysis has now advanced sufficiently to be of decisive use in water management for developing countries. This paper outlines the principal reasons as to why such a situation has developed, and what steps can be taken to increase the use of systems analysis for more rational and effective management of the often limited water resources that are available to Third World countries. Admittedly, some of our current models in this field are rather crude and liable to be dependent on the experience and judgement of the analysts; but in the final analysis, the issue is very definitely on the side of having a model—even a crude one—rather than on having no model at all.

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