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USE OF GEOGRAPHIC INFORMATION SYSTEMS (GIS) IN RIVER BASIN MANAGEMENT

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ABSTRACT

Geographic Information Systems (GIS) are shown to provide a number of capabilities which are of particular use to river basin operation and planning. GIS systems have the ability to display and graphically summarize both the input data for the analytical models and the results of application of management models using that data. The graphical display of input data can assist interpretation of conditions within the basin through depiction of spatial and temporal patterns in that data. GIS can also reduce the time required to enter data and improve the reliability of that data by reducing the errors in the data. The ability to display the results graphically improves the man-machine interaction which is generally accepted as being an integral part of multi-objective water resources analysis. Another important role for GIS is its use as an efficient interface between the data base and the operational computer models. It is asserted, however, that GIS should not be considered a means of providing final answers to complex water resources planning issues. It should be seen, rather, as an important component of Decision Support Systems by which information on the basin issues is transferred to the decision maker for his consideration. Specific aspects of the application of GIS are discussed in relation to a hypothetical river basin system used primarily for hydroelectric energy generation.

KEYWORDS

Data base; Geographic information system; Graphics, Multi-objective; River basin; Water resources.

INTRODUCTION

The growing need for integrated management of water resources on a basin-wide, or even a larger, scale has led to new requirements in the collection, storage, and display of data. The various objectives of a basin-wide management strategy require quite different levels and types of data. A comprehensive analysis of the water resources in a particular river basin will require consideration of all aspects of the water resource. These aspects will include the traditional physical characteristics of the water and related land resources such as quantity and spatial allocation of the water resources, quality parameters, land use, etc. However, in multi-objective analysis, the distribution of benefits and costs in both economic and environmental terms are equally important.

The huge data requirements associated with considering all the above items in a river basin planning study can actually complicate rather than clarify the issues by overwhelming the decision maker(s) with information. Part of this problem arises from the sheer power of the computers as shown by their capability to store, retrieve, and present data and the power of the computer models that can use this data.

It is important to note at this stage that operation of the computer models and direct interfacing with the data is normally performed by an analyst/engineer rather than a decision maker. Through multiple runs of computer models and repeated examination of the input data and results, the analyst learns a great deal about the river basin system and how it operates. This understanding is not directly attributable to a single run or perhaps a number of runs, but is the result of working with the system over a period of time.

Optimization is one type of computer model often used in river basin planning, and comprehensive river basin planning is obviously a public sector problem. Liebman (1976) asserts that the role of optimization in public sector planning is the development of insights and understanding rather than the provision of 'answers'. The role of the analyst under this philosophy is to transfer his understanding of and insights into the problem to the decision maker. In other words, the analyst/engineer must 'uncomplicate' the problem and present the essential facts, issues, trade-offs, etc.

Geographic Information Systems (GIS) are powerful tools in promoting and assisting in the 'insight transfer' process. In its most basic form, GIS is a graphically based system of storing and presenting input data and intermediate and final results. Such a graphical approach can summarize many of the critical conditions and issues, and present them in easily understandable form.

The following sections will review how the GIS approach can be used in river basin planning and management. Before proceeding with the specifics of how the approach is applied to water resources planning, the GIS approach itself will be reviewed and previous applications in water resources examined. It should be noted that the hardware and software aspects will not be examined in detail. The philosophy behind this paper is the role of the GIS in water resources, and in particular, river basin planning and management. It will be assumed that the appropriate software and hardware are available, and that the questions of importance here are: (1) Should GIS be used? and (2) If so, how should it be used?

GIS APPROACH

Dangermond (1983) has summarized the advantages of GIS. Some of these advantages are as follows:

(i) The system can store the data in a very compact form, i.e., magnetic disk (This ability is, of course, a feature of all computer data banks).
(ii) The data are then able to be updated and extracted at a low cost relative to other systems.
(iii) The data can be retrieved and presented more quickly.
(iv) Data which is normally handled in a graphical sense can be merged easily and effectively with data that is not normally thought of in a graphic sense.
(v) It is easy to run conceptual analytical models repeatedly and quickly and therefore to test a range of policy or management strategies. The speed issue here is related to the ease by which the results can be interpreted due to the graphical summaries of the outputs of the models.
(vi) Some forms of analysis can only be performed in a cost-effective manner on the GIS framework. In a river basin management situation, such examples are terrain analysis, slope calculation, and precipitation variations (spatial and temporal).
(vii) There is an overall improvement in the system operation due to an integration of the data, analytical analyses and decision maker response to the results.

Besides these computational aspects, the most valuable aspect of the GIS approach as applicable to water resources management is perhaps the capacity to define the parameters of interest by spatial and temporal location. This ability is particularly useful to water resource planning as the parameters of interest are often distributed spatially across the river basin and temporally through a season, a year, or a critical period.

It is important to note that GIS is a natural progression from the 'computer aided design' concept normally encountered in water resources planning and management. Computer models and data bases have long been considered essential components of a planning study. Where GIS differs is that the data base, computer models, and result presentation are all integrated into a more comprehensive and flexible system, as described above.

REVIEW OF GIS APPLICATION IN WATER RESOURCES PLANNING AND MANAGEMENT

The versatility of GIS makes it appropriate for a wide range of applications, involving spatial and temporal variation in the parameters (Dangermond, 1983). The work in water resources planning and management, in general, has not been identified as being GIS-based. Part of the reason for this is that GIS has grown more out of computer science, natural resource management, and scientific geography, than out of engineering. This fact has not, however, prevented water resources research and applications from using many of the aspects of GIS-based approaches.

French et al. (1980) reported on the use of computer graphics in water resources planning. In the introduction to their paper, French et al. claim that one of the obstacles to using the powerful analytical tools currently available for water resources planning and management is the difficulty in presenting and communicating the technical results to non-technical personnel such as project administrators or decision makers.

The problem is further compounded by the fact that many of the water resources planning and management problems are multi-objective in nature. Most of the effective multi-objective analysis techniques require some form of interaction between the analyst/mathematical model and the decision maker(s). This interaction generally takes the form of presenting a solution and asking the decision maker to respond to the conditions in that solution. The solution is then modified in light of the concerns of the decision maker(s), and the process is repeated until the solution is considered satisfactory. One of the best ways of presenting the result of each solution with its accompanying trade-offs, etc., is in a graphical mode which is one of the key features of a GIS system.

It is also interesting to note that French et al. (1980) also claim that the interactive graphics features reduce input errors while also reducing the time required to input the spatial data by several orders of magnitude. These features in themselves are valuable in any comprehensive river basin planning and management approach.

In a later paper, Loucks et al. (1982) discussed the role of interactive computer graphics in developing Decision Support Systems (DSS) for resource planning. In that paper, it was asserted that in order for the 'computer aided planning' to be effective, it must be able to mesh the two major aspects of any planning process, namely, the behavioural or judgemental, and the technical or structural aspects. Adaptation of the computer assistance to the style of the particular planning process was considered to be as important as ability to consider the essential components of the problem. Within this framework, GIS or any computer aided system should not be considered as a means of obtaining the answers, but more specifically as a means for identifying objectives or goals, constraints, etc. of a problem which is not well defined.

Loucks et al. (1982) also commented on two applications of the models developed at Cornell University to two actual governmental planning situations. It is interesting to note that reaction to the approaches was quite different. In one case, a problem in using the systems was associated with concerns about funding and in-house staff expertise. The response of Loucks et al. to these concerns is that expertise in the system is expected to become less of a problem if software improvements keep up with the hardware improvements. In the other case, the watershed planning agency was reported to have used the approach with considerable success in terms of time and general satisfaction, and were contemplating extending the use of the system across the United States. The success of the second case and concern of the first case being with the expertise required to use the process rather than the approach itself, suggests that GIS has a significant role to play in water resources planning and management.

Milton (1985) has proposed a GIS-based approach for problems related to the impacts of river bank erosion on the major rivers in Bangladesh. The interesting features of this proposal are that the GIS system would integrate a number of socio-economic parameters together with the more traditional physical or geographic characteristics of the region, such as erosion and deposition zones, soil type, current bank instability, etc. Another innovative component of the GIS in this application is the possibility of giving spatial and even temporal mappings of risk of erosion at points along the banks.

Other papers discussing various aspects of GIS in a water resources environment have been presented by Grayman (1985), who describes the technical aspects of GIS, and Berich (1985), who discusses micro-computer GIS systems which appear appropriate for use by small consulting firms and government agencies. Riley and Bernhard (1985) report on a GIS system developed for identification of conflicts, etc. for the Wasatach Front Total Water Management Study in Utah, U.S.A. This GIS system uses existing data bases, data from remote sensing, geographic data which can be purchased commercially, and unique data gathered in the field. The most important feature of this later paper is the ability to use existing data bases within the new GIS format. This issue is discussed in more detail in the following section.

The use of spreadsheet approaches in water resources such as that of Rossmiller (1985) is not discussed specifically in this paper. While such approaches do have a number of the features of GIS systems, they do not generally contain the *comprehensive* data base and resulting presentation features of GIS.

INTEGRATION OF GIS INTO WATER RESOURCES APPLICATIONS

One of the essential issues identified by French et al. (1980) and Loucks et al. (1982) is that computer aided planning (with the graphical display capability embedded) must be integrated with existing simulation and optimization models. The reasons for such a requirement are quite simple. Most, of not all, government river basin planning agencies and water resources consulting companies have existing computer models which their staff are comfortable in using, and in which they have confidence when interpreting the results. A primary role of GIS is to facilitate the whole process by upgrading data input (time, detail, and accuracy), improving data accessibility, easing interpretation of results.

Most government agencies and consulting firms which are likely to use GIS systems will also have their own data bases, or will access the existing data bases of the government agencies. The GIS must therefore be able to efficiently use the data bases as they exist. Most of these groups also have their own computer models, as discussed above. The GIS must therefore be able to be integrated into these existing computer models, as well as the existing data bases. In this way, the essential strengths of the existing systems are maintained. The GIS ability should, however, simplify the data preparation for the analytical models. A schematic description of the integration of the existing data bases and computer models in such a context is given in Figure 1.

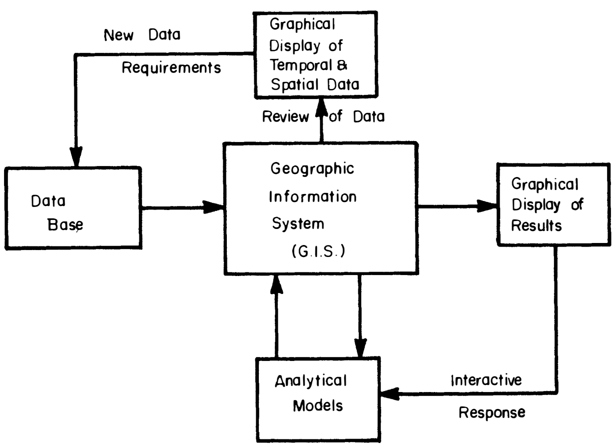

Figure 1. Schematic of GIS within a Decision Support System

Examination of Figure 1 shows that the GIS acts as an interface between data bases and models, and between model results and the analyst/decision maker. It is therefore apparent that one of the key features of GIS is an improvement in the way in which the computerized analysis of the system is performed. The whole computerized analysis is more of a unit than a series of discrete steps.

One feature of the GIS that may be of some concern is associated with problems for which there are not good data. In these cases, the time and money required to implement a GIS may not appear to be justified. Earlier in the paper it was stated that use of a GIS strategy can reduce input time and input errors. If the long-term benefits of being able to use a GIS in the analytical part of the planning process appear marginal, the benefits accruing from ease of data base development and improvement in data reliability should be seriously considered.

It should be apparent at this stage that GIS is really a component of an overall Decision Support System. It does not make decisions for the analyst, but is a key to helping make the decision in a more rational and knowledgeable fashion.

EXAMPLE OF A GIS APPLICATION TO RIVER BASIN MANAGEMENT

In this case, the river basin management problem is one of optimizing power production from a large hypothetical river system. The following conditions are assumed to apply to the basin. The basin has a number of existing hydroelectric power stations and potential for a number of additional stations. Environmental concerns arise from variations from natural flow conditions in the rivers, and flooding of land. The system has been in operation for some time, with existing computer models being used to predict flows and to optimize operation of the system.

The first role of GIS in this scenario is to be the interface between the existing data base and the current operating models. The next step in the process is to examine the needs of the 'existing' ('existing' now assumed to incorporate a GIS data management approach) to see what additional data would be useful and how GIS might be used in implementing the collection and use of that data. Such a case might be the examination of snow cover on a spatial basis to predict runoff conditions for the spring months. GIS can provide a good graphical representation of this type of data. GIS can also provide the same information for rainfall types of precipitation. The temporal capabilities of the GIS also permit it to be used on a real-time basis in these cases. The runoff predictions based on the available data can be depicted graphically to aid in the understanding of where and when the flows are occurring. This runoff prediction can then be processed through the GIS data management mode and passed to the operational models used to improve operation of the overall system.

If new data requirements are identified, and the data collection activity initiated, additional analytical computer models can be developed to utilize more fully the new information which will have become available in the modified data base.

However, in planning future development of the hydro-electric potential in the basin, it is often necessary to predict the level and extent of environmental disturbance as well as the optimal operation of the system. GIS is particularly appropriate for analysis of these environmental aspects. The levels and extent of flooding, the variation in flows from natural conditions are far more easily understandable when depicted graphically. Other parameters relevant to and affected by environmental disturbance are also easily understandable in graphical form. For example, the degree of flooding and soil types covered by flood give indications of the economic ramifications of particular development and operational policies. Predicted temporal and spatial changes in water quality caused by various development strategies can also be more easily understood when presented graphically. In this way, the tradeoffs between economic development and environmental protection can be examined in a more rational fashion.

When formulated in this context, the whole GIS becomes part of an improved support to the decision process for the agency. Improvement in the operation of the existing system can be quickly analyzed and interpreted using the readily accessible and comprehensive data base. Effects of various developmental strategies can be predicted and interpreted in much the same fashion. Improvements in the existing data are also easily implemented. A schematic description of how the GIS would fit into the DSS for the situation described above is given in Figure 2.

The hydroelectric system used in this example does not have the additional complexity of being designed for other objectives such as irrigation flood control or water supply. Inclusion of these objectives would complicate the operation and the development planning even further, thus making GIS even more valuable.

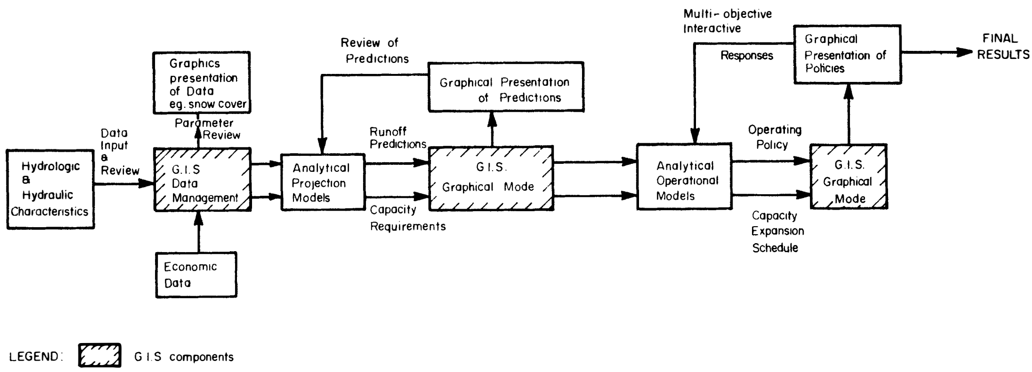

Figure 2. The place of GIS in a Decision Support System for operation and planning of a river basin hydro-electric generating system.

CONCLUSIONS

GIS represents a powerful methodology for improving the operations of water resources planning agencies and those consulting planners/engineers who work with them. A GIS data base can improve the use of operational models for river basin management by improving the efficiency of the data preparation for use by those models. The improved reliability of data bases obtained from implementation of the GIS can provide increased confidence in the results of the analysis. The spatial and temporal depiction of the data can also provide a better understanding of conditions in the basin. The graphical depiction capabilities implicit in a GIS provide a suitable environment for the man-machine (decision maker-computer model) interaction necessary for effective multi-objective planning.

It must be realized, however, that a GIS will not in itself produce answers, but is a major component in the decision support systems which can greatly enhance the ability of river basin agencies to make rational, informed, and optimal decisions.

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