THE POTENTIAL AND PRACTICALITY OF WATERSHED MODELS IN OPERATIONAL WATER MANAGEMENT

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In the recent past, research has produced an array of various modeling techniques related to water resource engineering. When these techniques are field tested with the intention of using the results in an operational mode, varying degrees of success are realized. Certainly this can be expected and possibly be attributed to differences between conditions under which a modeling technique was developed and conditions under which that same technique was applied. Generally speaking, however, research has provided the user with several watershed modeling approaches that can be used to develop and tailor a model that will go a long way in meeting a specific set of water management objectives; the critical proviso being that the user can supply the necessary data to adequately define his system. From an operational standpoint, the importance of this reality lies in the fact that watershed models can be of inestimable value to those responsible for timely water control decisions. What is proposed in this paper is first, to examine the characteristics a model must have in order for it to function as a decision-making aid within

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an operational framework and second, to evaluate what is required in the form of peripheral support to have an operational model function as an integral part of the total management system.

A precaution to engineers who contemplate embarking on development of an operational model is in order. Engineers are totally immersed in the design approach throughout their professional training. It is extremely difficult to avoid carrying this approach into model development. Operationally oriented models must give specific answers to very specific questions and circumstances, where design models must give the best general answers to the overall problem. If one is not careful, he will wind up with a model oriented toward only the catastrophic events, when in actuality, these are the rare cases. The model must give the proper response to the entire spectrum of events.

The mathematical framework of models in water management as well as other disciplines have been largely conceived from the classical methods of simulation and optimization. One type of model involves a compilation of mathematical expressions having similar properties or relationships with the natural or technological system under study (2). This approach has been properly defined as simulation and affords an investigator the opportunity to observe system response and behavior under a variety of input and controlled conditions. A second type involves the selection of a "best solution" from a range of feasible alternatives, while subject to constraints enforced by an objective function. This approach, which is usually a linear and/or dynamic programming problem, stresses the relative interrelations of a systems components or "activities" and is referred to as an optimization or programming model. Both techniques can be further described by the nature of its inputs and conceptual development. That is, its inputs may be statistically derived values inferring some measured degree of risk or may be known values derived from observed data. These are classically referred to as stochastic and deterministic, respectively. Also, concepts can be formulated from either an abstract mathematical fit or from relationships that are an attempt to parallel actual physical phenomena.

For a model to be of maximum value as an aid to water control managers in their day to day activities, certain unique characteristics are inherent that would give a strong predilection towards the deterministic approach. Pure stochastic inputs are principly used in planning and design functions that span broad temporal horizons and have comparatively little to contribute in making impending operational decisions due to an immediate event. This simply means that the sample size has reduced to one event and most statistical methods are not too well suited to this case. Similarly, optimization methods have been used extensively in the planning and design of water resource systems and in several investigations have been used specifically to develop operational rules or policies (1,3). These rules, however, were based on either synthetically generated or historical inputs and are designed to minimize risk in view of the entire spectrum of possible events; i.e., this is the best single answer if you must prejudge the case. They do not solve all the dilemmas of managing a complex system with limited storage. This is particularly true when, with the passage of time, some of the original assumptions become obsolete. While optimization methods are gainfully employed in allocating resources and stochastic inputs serve well in planning and design problems and future projections, they do not generate the most desired product for operational needs. This leaves as a favored solution, the simulation procedure using as many determined inputs as possible.

The choice as to whether relationships should be used that represent actual physical processes or a mathematical "fit" depends upon the person(s) or organization(s) developing the model. It is recognized that abstracting natural phenomena into functional relationships is a difficult task and all abstractions will be limited to some level of precision that is within the realm of present scientific inquiry. It is entirely possible to get better results from a pure fitting procedure than from a formal academic treatment simply due to the lack of data that is required to utilize the more formal technique. From a users point of view, it appears advantageous to capitalize on using those physical relationships already developed by researchers for which sufficient data is available to yield a satisfactory result. Tested empiricisms and fitting techniques could be used in solving any remaining problems. In any case, the application of either procedure is acceptable providing it produces the desired output.

There are two objectives that should be considered when developing a model to serve in an operational capacity. First, it must simulate a reasonably correct response of the contributing watershed areas to a rainfall event and secondly, it must simulate how the operator's control decisions will affect the managed area for all conditions of rainfall or its absence. At first glance, one would conclude that the potential of a particular modeling technique or models in general, can be gauged by how accurately it performs these two functions. Accuracy is obviously important because management must have enough confidence in the output to at least use it as an index for making their decisions. If not, the model is of no value in upgrading and assisting operational activities and therefore fails to be a profitable endeavor. However, it should be recognized that a "perfect" model is not the only final product that management will accept, use, and can afford. Without a model, management must resort to second-guessing a watershed and total project response based on (1) a limited number of calculations, (2) a tremendous amount of experience, and (3) a good "feel" for performance based on past observations. This method of operation works well as long as the number of decision points remain small and management objectives remain simple.

On the other hand, in a system where conflicting interests multiply, and accompanying social and political constraints require consideration of multi-purpose objectives, operation by experience and fixed rule becomes less effective and, in some cases, is accompanied by strong expressions of dissatisfaction from selected segments of the interested benefiaries. In these cases accuracy is not the only gauge one could use in evaluating the role of simulation models as an operational tool. Size and objectives of the system also have a great deal of impact in defining the potential of a model in that they become a near necessity in operating a complex system. While accuracy generates the confidence one has in simulated outputs, depending on size and objectives, necessity generates the potential a model has in assisting as an operational guide.

Models afford management the flexibility of pre-operating a system and evaluating several alternative schemes before making a final decision. Unfortunately, models are a necessary but not sufficient condition for performing such a task. To be properly utilized they must be supported by what is sometimes expensive and elaborate peripheral equipment. Actually, acquisition of these peripheral supports is more likely to be the determining factor in deciding whether it is economically practical to employ models in operational activities. An examination of a total system reveals that there are four major areas of support (Figure 1). First there is the sensing, recording, and transmission of field data to a central collection point; second is some form of processing these data into reduced parameters that drive the model; third is a method for outputing selected information in an easily digestible format; and fourth is to disseminate operational instructions. Cost, although not the only limiting factor, is probably the most influential consideration in determining the method by which these four peripheral functions will be handled. The question then arises concerning comparative costs for performing these functions and what makes them fluctuate.

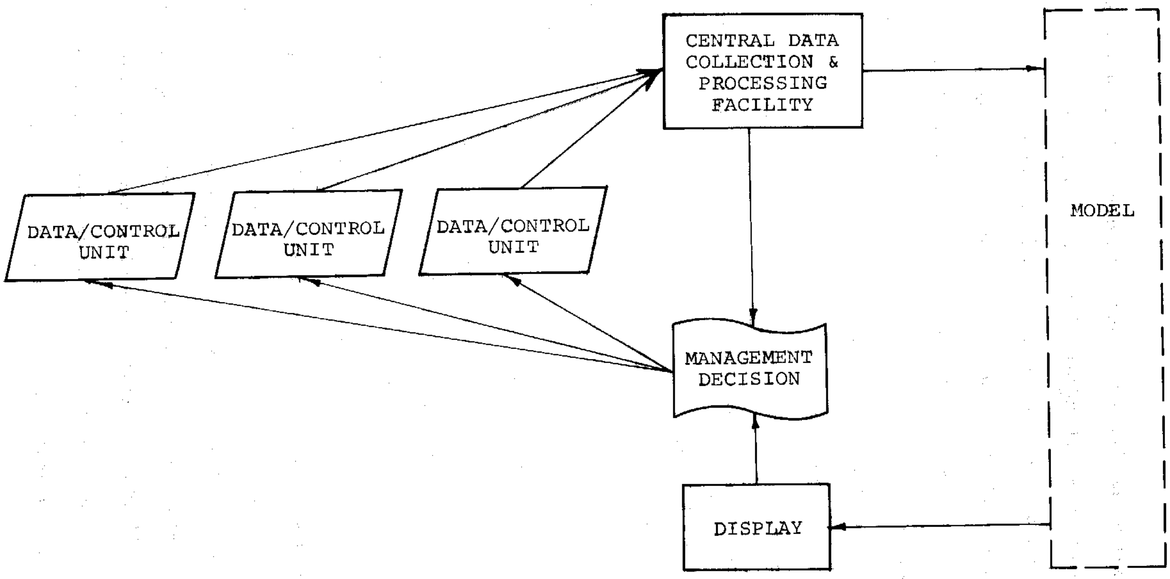
CENTRAL DATA COLLECTION & PROCESSING FACILITY
MODEL
DATA/CONTROL UNIT
DATA/CONTROL UNIT
DATA/CONTROL UNIT
MANAGEMENT DECISION
DISPLAY

FIG. I

system because the price tag is more palatable to management and changes in existing procedures will tend to be evolutionary rather than revolutionary. Yet, it still offers the opportunity of "getting into the business" of using models in establishing operational standards. The major disadvantage is the lag in reaction time for transforming recorded field events into usable outputs.

At the other end of the economic scale is a highly automated real-time system (Figure II). As visualized, all data is sensed, recorded, and transmitted at compact electro-mechanical field installations. These installations are interrogated on an optional manual/sequential monitoring schedule via a telemetry network which would, in turn, feed the collected data into a real-time process control computer. Pre-processing of data, storage and retrieval, and model execution is handled by the computer. Operating instructions are entered through I/O terminals interfaced with the computer. Selected outputs and alarms are transmitted to visual display aids for management's rapid digestion and evaluation of the pre-operative scheme. If the results are acceptable, operational commands would be sent back through the telemetry network to automated structures. If model outputs indicated that different operating strategies should be explored, the appropriate changes would be prescribed and re-testing of the new criteria would be executed. As is apparent, speedy reaction time is a major specification and objective of this type of system. To meet this specification it essentially requires the substantial removal of man-handling operations. To do this, a major investment must be made for purchasing hardware. The bulk of

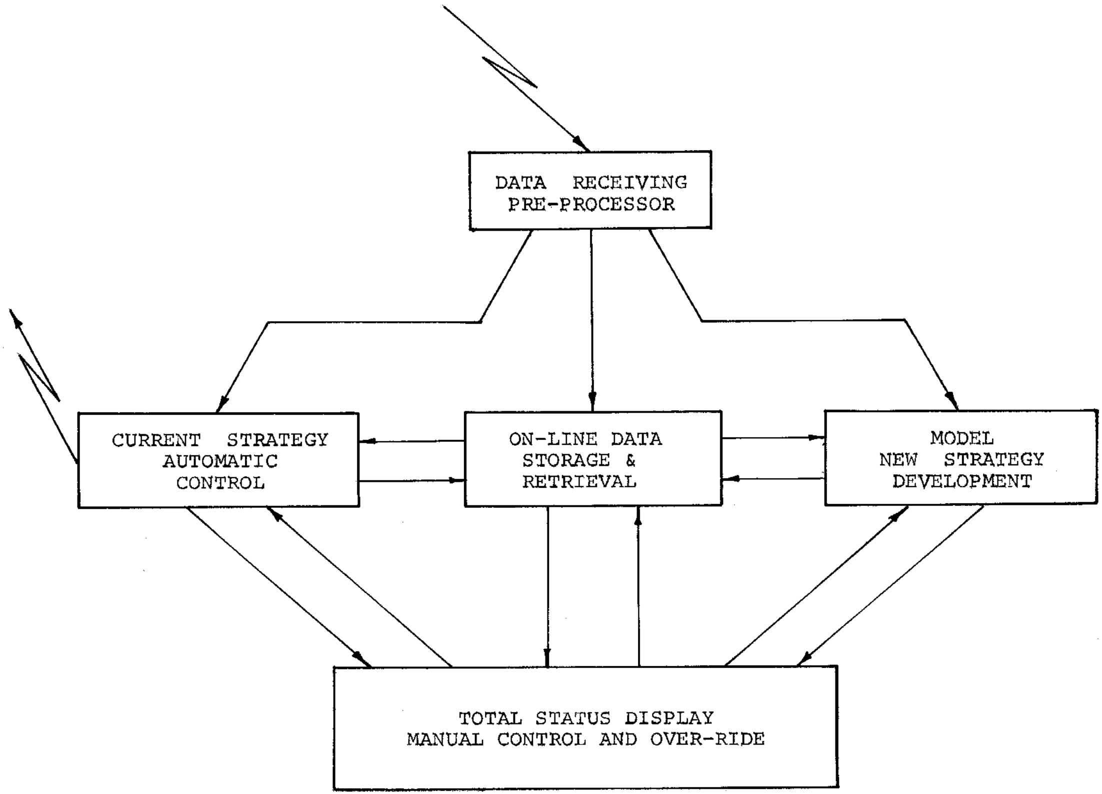
DATA RECEIVING
PRE-PROCESSOR
CURRENT STRATEGY
AUTOMATIC
CONTROL
ON-LINE DATA
STORAGE &
RETRIEVAL
MODEL
NEW STRATEGY
DEVELOPMENT
TOTAL STATUS DISPLAY
MANUAL CONTROL AND OVER-RIDE

FIG. II

this investment would be for field equipment used in data collection, a telemetry network, visual aids used in displaying output in an efficient manner, and fixed computer costs which would significantly increase over the basic requirement of the minimum system. These high initial costs or annual fixed costs are the biggest disadvantage to a highly automated, real-time system. There are, however, many advantages; the obvious being the job that would be done could not be performed with manpower alone. A second advantage is, as data needs grow, and as the number of operating structures increase, system components can be added with only slight increases in processing costs. This feature is also reflected in lower annual unit operating costs for the automated systems.

A comparison of cost relationships for the two types of systems is shown graphically in Figures III and IV. Figure III illustrates the general relationship between annual fixed costs and reaction time. As departure from real-time increases, the curve approaches a cost value that would support the previously described minimum configuration. When manpower begins to be traded off for automated field equipment and machine processing of data, then total fixed annual costs increase at an increasing rate.

High speed monitoring and processing of data at kilocycle rates as is done in the space industry, is not necessary for the successful and efficient application of similar concepts in water management. As a result, somewhat less sophisticated equipment can be used in the field, and computer process control requirements need not be as comprehensive. Because of this, fixed costs for real-time control can

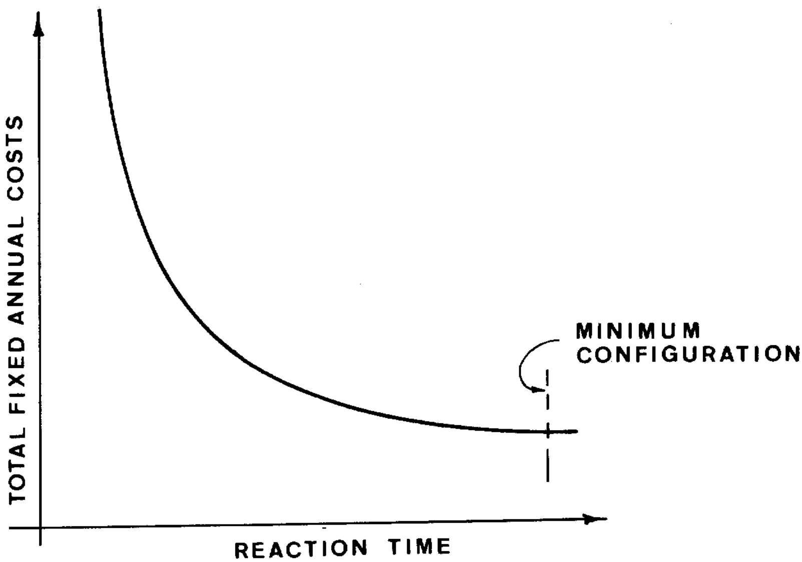
TOTAL FIXED ANNUAL COSTS
MINIMUM
CONFIGURATION
REACTION TIME

FIGURE III

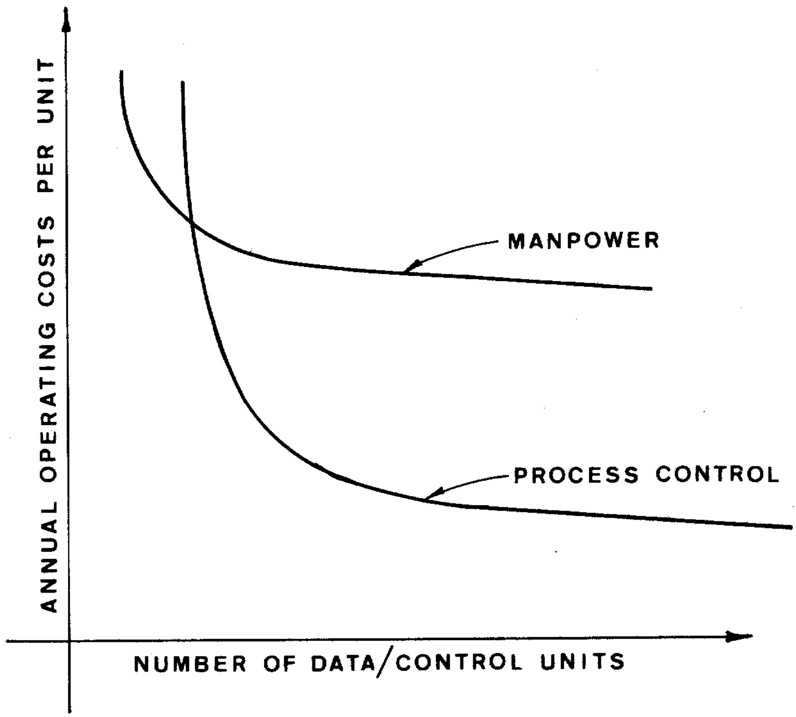
ANNUAL OPERATING COSTS PER UNIT
MANPOWER
PROCESS CONTROL
NUMBER OF DATA/CONTROL UNITS

FIGURE IV

avoid the rapidly increasing rates characteristic of the more rigorous systems.

Figure IV demonstrates the general relationships between annual operating costs per unit and number of operational units for the minimum and real-time configurations. Unit operating costs are substantially less for the real-time system, which brings forth an important and very real danger associated with model development. As results of a model begin to look promising and begin to be used in an advisory capacity for operational decisions, there is an incentive to upgrade accuracy of the model by, primarily, expanding and intensifying the existing data collection network. This sometimes unrecognized evolutionary process can grow to the point where manpower costs are excessive and perhaps would be better spent towards initiating a real-time system.

The authors have purposely refrained from placing costs on the graphs for several reasons. Product costs in the electronic and computer industry are changing at a rapid rate, and newer, more efficient instruments are being introduced almost daily. In order to display figures, it would require the pricing of a system based on a particular water management agency's size, objectives, and the author's choice of equipment. Such is not the purpose of this paper and would not be of any great value to another user because of the diverse criteria that defines different systems.

There is another economic factor that needs to be emphasized and seriously examined in evaluating whether a model based operational endeavor is economically feasible. The factor is simply this: extra benefits from a water resource project will be realized only if the project is operated in a manner that utilizes to a maximum degree a projects capabilities; wise operational decisions yield greater benefits. In addition, as user demands become greater and more complex, informed and versatile operational procedures may extend a projects performance beyond that which was originally anticipated in the design, without undertaking a major construction program. This benefit has not been given its proper recognition in the planning, design and funding of water resource projects. Operational "rules" based on design criteria and previously existing demands can fall short of generating maximum benefits when the complexion of land use, drainage, urbanization, pollution, industrialization, etc., within project boundaries change. For operations to be effective, they too must be responsive to changes in both long term public policy and short term emergency needs. The combined use of models and time saving peripheral supports offer management an excellent aid in exercising effective and responsive decisions and thereby yields greater benefits.

SUMMARY

As a result of intensified research on watershed models and recent reporting techniques, water management agencies have available to them an adequate portfolio of techniques for compiling and tailoring a model that can assist them in formulating operational policies. Of particular value are simulation models that reproduce project response to a set of alternative operational strategies. Useful results can vary in accuracies ranging from gross indices to very precise projections of project performance. To effectively use a model in an operational mode, funds must be available to provide support for peripheral functions. As a minimum, access to a computer with reasonably efficient I/O devices must be acquired. As confidence in model results is gained and accompanying benefits realized, an inherent expansion in model based operations can take place. This expansion usually involves the acquisition of additional field data, which means increased costs for collecting, reducing and storing information. The result is that cost for maintaining and using the model begin to soar and, from a financial standpoint, may become impractical to budget. From an academic viewpoint, operational models have a very real potential; but costs for satisfying their insatiable appetite for data may discourage utilizing this potential. For larger agencies and complex systems there are many benefits to be derived from automatically monitoring field data and testing operational alternatives. The magnitude of these benefits is largely a function of the variability of the political, social, and physical environments in which the agency must operate.

Once a model has been adopted by an agency as an operational tool, then a determination must be made concerning when, if at all, manpower should be traded for automated equipment. The two basic reasons for considering a trade are number of data/control points and reaction time. If, for the model to be significantly accurate, a large number of field installations must be operated and their data reduced, but time is not critical, then the trade can be based strictly on comparative costs for manpower vs automation. When reaction time is critical, then a decision can be based on expected extra benefits from continuously monitoring and controlling the water management system. Various combinations of automated field equipment, process control computers, and advanced data presentation systems are extremely attractive.

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