An Integrated Modular Watershed Planning Model Applied to the Upper South River Watershed, Waynesboro, Virginia

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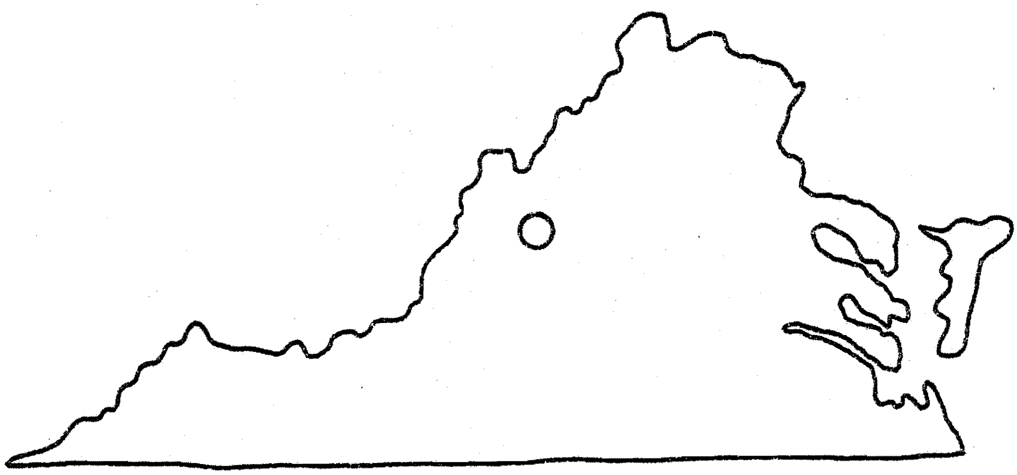


SOUTH RIVER WATERSHED
AUGUSTA COUNTY, VIRGINIA

INTEGRATED WATERSHED PLANNING MODEL

Introduction

The problems associated with rapid urbanization and its resultant effects on land development patterns, water pollution, and air quality are characteristic of the difficulties encountered in satisfying the nation's need to accommodate its growing population while at the same time maintaining the quality of life for present and future generations.

Problems of the environment have arisen because subsystem managers (households, industries, farms, and cities) do not consider their actions in terms of a broader perspective. The resolution of these problems can only be achieved if analysts and managers do not commit the error of focusing on too limited a context. On the other hand, environmental management must not consider systems in such great scope that the situation renders itself unworkable.

As the magnitude of the harm that humanity can do to the environment grows, it can no longer be assumed that natural systems will endure and absorb human actions and return to their original status. Increasingly, it becomes important to understand our environment as a complex of interrelated systems. The area of water resources as it relates to land use planning illustrates the need for a broadening of perspectives. It was at one time sufficient to be concerned with only a single tributary in order to be a responsible manager. The situation evolved to the point that the upstream effluent grew so large that no actions downstream could make the ambient water tolerable, and many communities used the nearest lake as a solution to their disposal problems so that the lake changed in character from unpleasant to toxic. It became apparent that in order to achieve a reasonable outcome the problem had to be viewed in a larger context. The first broadening in scope was physical. Management programs were realigned so that the domains of action became river systems and watersheds.(1)

In many areas of environmental management, an extension of the geographical breadth of understanding is not enough. Methods of analysis that were adequate to understanding a single reach of a stream could not be modified to be adequate to understand an estuary. Also, aggregation techniques were not enough to extend this comprehension to such areas as wetlands. It came to be perceived that marshlands have profound effects upon the surface waters and in turn are affected by them.

Ground water is greater in volume than surface water and exchanges between the two systems are continual and significant.(2) To conceive the problems in terms of surface waters alone was to neglect vital processes as well as additional indicators of the problem situation.

The example problem from the area of water resource management is not unique to any one area of environmental concern. The many and varied disciplines concerned with environmental management continue to search for integration and appropriate ranges of optimality.

Objectives

Given that there is a search for improving capabilities in environmental management, the questions which this study addresses are:

> Will continued emphasis on modeling contribute substantially to improving environmental management capabilities?
> and
> If modeling offers potential contributions, what form should the models take?

In response to these questions, the following study objectives have been identified:

1. To develop a modular program which considers land use, runoff, and water quality, and to connect them to a budgetary function.

2. To test the concept of this framework for modeling in the Upper South River Watershed by means of several alternative proposed development patterns.

3. To contribute to the field of modeling by outlining a framework which possesses the ability to evolve in response to a changing problem environment.

Hopefully, as a result of this undertaking the structure of the systems and their interrelationships will be more clearly understood.

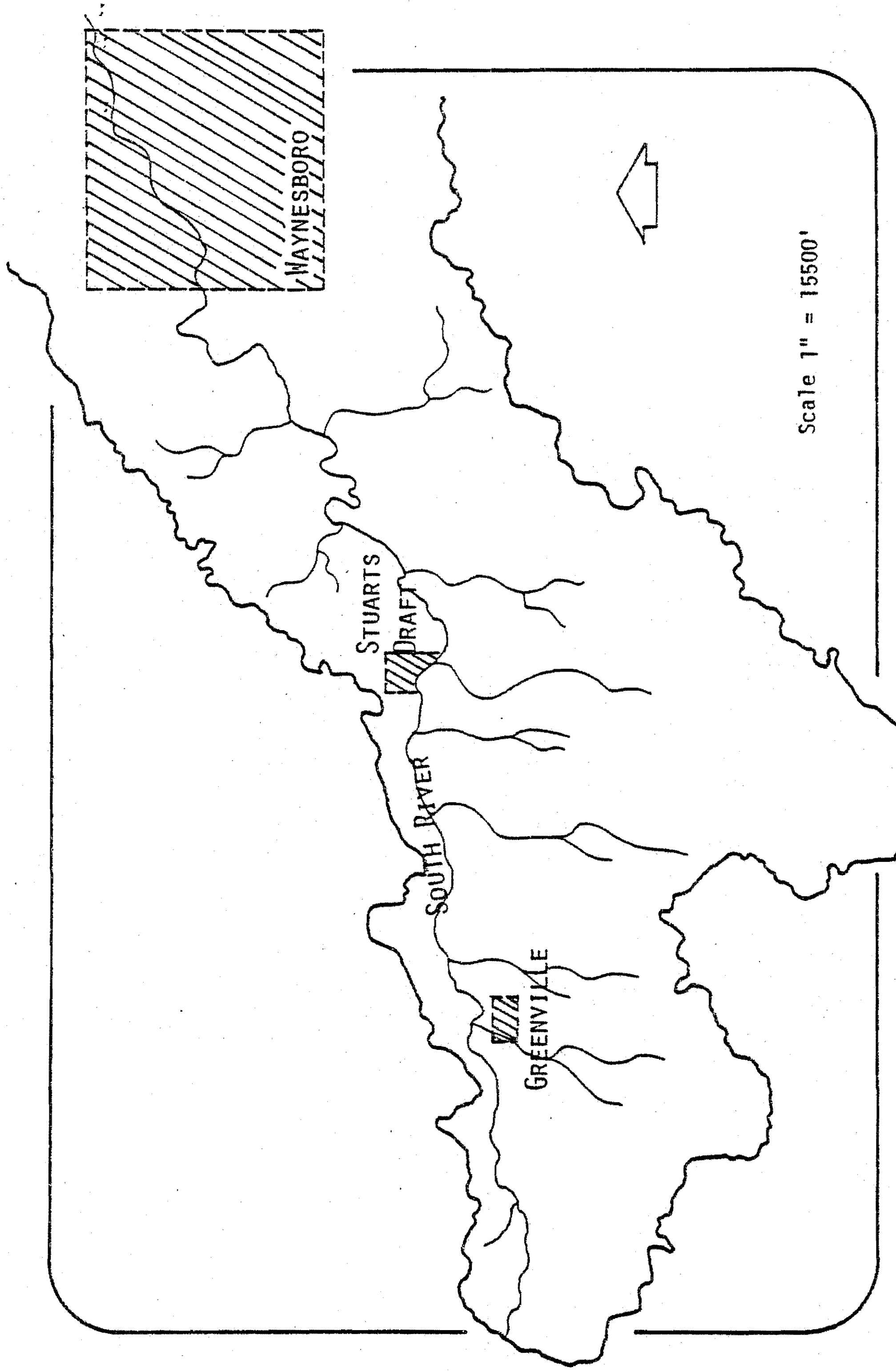


Fig. 1 South River Watershed

For example, consider the simple negative feedback model which describes the thermostat for a furnace. The goal of this system is controlled from outside the system; that is, the thermostat is set for the desired temperature. If, on the other hand, the organization of the system was not understood, one might resort to the tactic of lighting a match near the thermometer of the thermostat to lower the room temperature or placing ice on the thermostat to increase the room temperature to the desired level. Such is the case with our strategies for environmental planning and management systems.

Unless the structure and interrelationships are understood, it is unlikely that the appropriate action will be taken. Unless decision making tools can be substantially improved it is also unlikely that great progress toward this goal of understanding will be made. It appears that a major barrier to satisfying this search is the lack of simple environmental models which can aid the decision making process.

Fig. 2 outlines the basic organization of the study. In reading the following pages particular note should be given to the fact that the model is discussed at two points. In order to provide an overall understanding of the components and concepts associated with the model, a general description is provided. After the specific study area is

INTRODUCTION

ASSESSMENT OF CURRENT EFFORTS IN MODELING

GENERAL DESCRIPTION OF 4 MODULES OF THE MODEL

DESCRIPTION OF STUDY AREA

DISCUSSION OF APPLICATION OF THE MODEL TO THE STUDY AREA

CONCLUSIONS

APPENDICES

Fig. 2. Organization of the Study

introduced a more detailed discussion of the application of the model is provided to demonstrate its applicability.

Chapter 1.0

The Case for An Integrated, Modular Model for Watershed Planning

In this chapter, the following areas will be reviewed:

1. an outline of the rationale supporting the development of the integrated, modular watershed planning model specifically identifying:

   a) the need for modules to be stable and independent

   b) the need for the model to accomodate modification in response to changing problem definitions.

2. observations about current efforts in modeling, noting problems and criteria for evaluaton.

3. an identification of how the modeling framework presented in Fig. 3 assists in addressing the problem of matching modeling strategies and problem types.

The field of environmental management is currently confronted with a plethora of models ranging in scope from those which attempt to forecast interactions at the global scale to those dealing with decay rates of single compounds in specialized surroundings.

Modeling of the environment has advanced beyond the stage of mathematical curiosity, but it has yet to be embraced fully at the decision stage of the spectrum. As effort continues to be expended on model development, the issue develops clearly on the side of having a crude model as opposed to having no model at all.

From the experience gained to date, several general comments can be made about environmental modeling:

1. Much emphasis should be placed on developing a model which can be used by someone other than the person who developed it.

2. Begin with a simple model and keep it simple.(3)

3. The processes of modeling and data collection should proceed in parallel.(4)

4. The model should be sufficiently flexible to be adjusted to fit the changes in the problem it was intended to solve.

The ideas contained in the previously noted four points provide the rationale for the development of a model which is modular and which links together several subsystems of the manmade as well as the natural environment.

Three goals have been set for the use of the model:

1. To be comprehensible by informed lay decision makers.

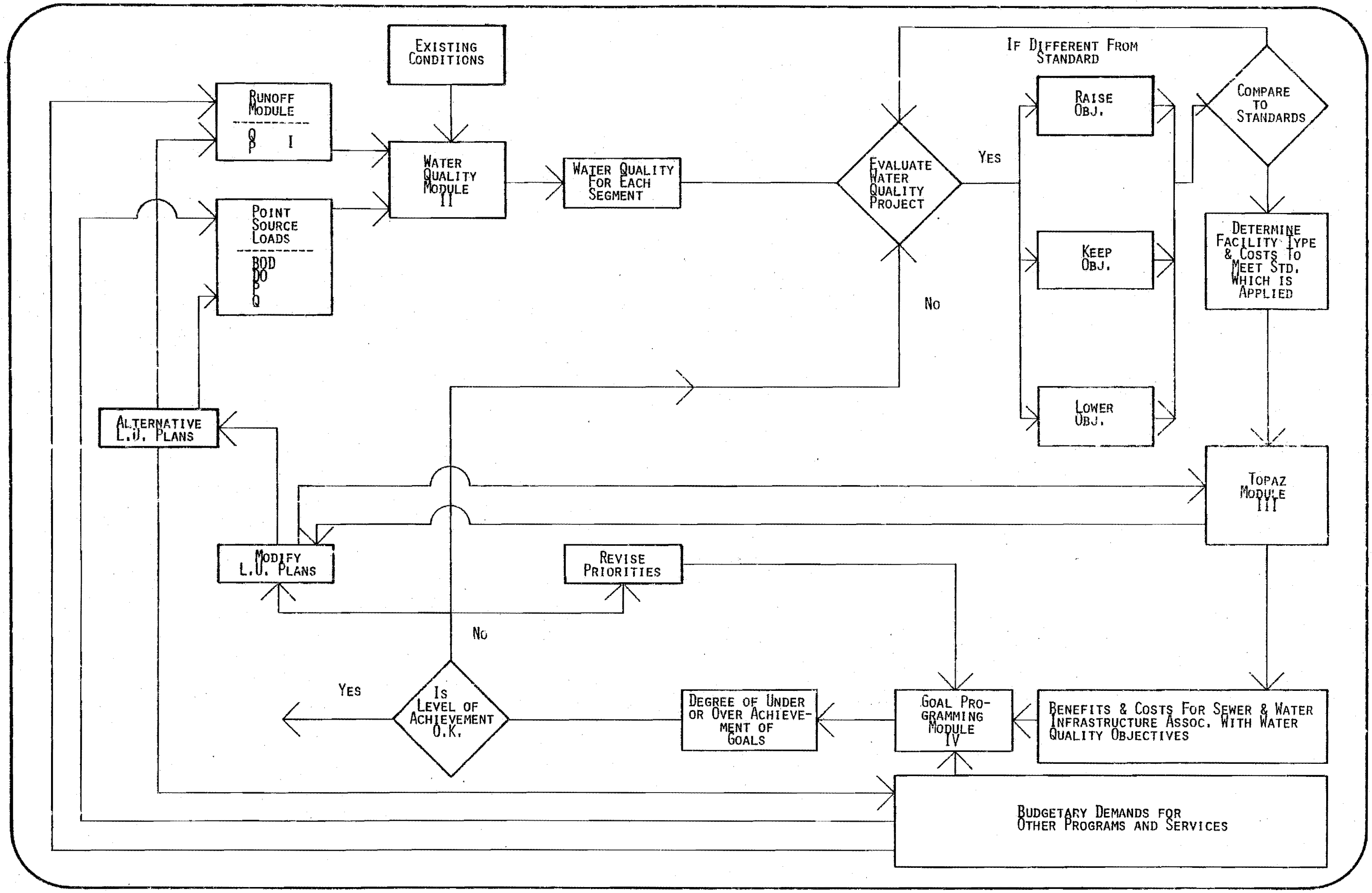


Fig. 3 Integrated, Modular Watershed Planning Model

2. To link several critical environmental subsystems together such that some indication of their impacts can be determined.

3. To tie the environmental indicators to a cost function.

The rationale for the development of a integrated, modular model exists at two levels. The first is at the applied level and the second level relates to the theory of modeling. At the applied level, a modular model (i.e., a model to which additional components can be added without entirely rebuilding the existing model) reflects the reality of the task of environmental management in that the perception of the problem is changing dramatically, requiring the simultaneous operations of including a wide range of factors, yet at the same time reducing data requirements. The modular concept also recognizes that the nature of decisions to be made may require changing levels of specificity in different parts of the model. For some types of decisions detailed analysis might be required from the the water quality module, for example, whereas the demands of another decision may only require a general indication regarding the impact on water quality.

From the perspective of modeling theory, the modular quality of the model also allows the model to evolve as the level of sophistication of the users increases and as the nature of the problem changes.

The simplicity of the proposed model is a relative rather than an absolute criterion. When the adjective simple is applied to the watershed model it refers to a level of modeling which could be employed by an engineering graduate with no advanced training.

Because the model is constructed of modular units, individual modules can be improved by users who may not necessarily understand the entire model. This form of evolution can be seen in such sophisticated devices as the automobile and the computer.

It is quite unlikely that any single individual fully understands the operations of all parts of one of IBM's large computers. However, through time, numerous designers have improved on parts of the machine. Each improvement was evaluated to see that it did not interfere with the operation of the other parts of the computer and also improved some lesser operation or component. In this manner the machine evolved to a more refined and sophisticated state of development.

Because the problem environment is not an isolated one, the model must possess the quality of integration. As noted earlier, one of the key difficulties in the development of the field of environmental management is that the problem has been considered in isolated segments. Internally, the individual modules must be linked in a fashion in which the outputs of one module not only provide information regarding the module itself, but also are a direct contribution to the input requirements of the next module in the series. Externally, the modules and the model as a whole must relate to the broader perspectives which face decision makers. The results of the model must be useful information, information which will assist decision makers in weighing the tradeoffs associated with each decision.

Numerous techniques such as systems analysis have been employed to perform the function of integrating the myriad of variables in environmental problems. They have to date not been particularly successful. There are three principal reasons for this:

1. The exclusion of significant externalities

2. The inability of the technique to encompass a sufficiently large number of variables

3. The lack of a clear conception of the interrelationships of system components.

It is hoped that the third difficulty, the lack of a clear conception of the interrelationships of system components, might be diminished by the construction of this model.

Therefore, the first step toward developing an integrated model is accomplished by identifying the key subsystems which impact upon the decision making process and then relating them within a logical framework. The flow diagram in Figure 3 outlines such a framework where the four modules are related to each other in a fashion which is logical and which indicates the relationships between the inputs and outputs of each of the four modules.

Contrary to the feelings of many skeptics, when it comes to the modeling of complex natural and manmade systems, information about only a relatively small number of variables is often sufficient because key factors can dominate or control a large percentage of the action. We do not need tremendous amounts of information about a great many variables to build revealing models.(5) The relationship, i.e., the hierarchical structure, between the variables reveals the greatest information about the system under study.

This idea is reflected in the small number of output variables associated with each of the modules. Although few in number compared to the number of elements in the system they are attempting to describe, the output variables are intended to be key indicators of the state of the system being modeled.

It is axiomatic that the environmental systems which are being dealt with are complex systems. Complex systems frequently take the form of a hierarchy. A hierarchical system implies a system which is composed of interrelated subsystems, each of the latter being, in turn, hierarchic in structure until some lowest level of elementary subsystem is reached.

In most systems the partitioning of which systems are elementary is somewhat arbitrary. For example, in one kind of biological research a cell may be treated as an elementary subsystem, in another a protein molecule, in still another, an amino acid.

Business firms, governments, and universities all have a clearly visible part within parts structure. Societies possess even more fundamental organizational elements when people are grouped in units of villages and families, etc.

The same hierarchical structure can be found in ecological systems composed of individual species, communities, linked communities, etc. The relationships which exist in the South River watershed should not be exempt from the types of hierarchical structures used as examples.

Hierarchy is one of the central structural schemes of complexity. The hierarchical structure makes possible the presence of intermediate stable states. These intermediate stable states facilitate the process of model evolution.(5) In the watershed model the separate modules are the equivalent of intermediate stable states. The presence of the modules allows for the modification of one part of the model without necessarily affecting other parts.

The case for a integrated, modular watershed model can be summarzied in the following points:

1. The changing nature of the environmental management problem demands flexibility in the responsiveness of the model which can be achieved by the modular concept.

2. The nature of decision making requiring the evaluation of sets of tradeoffs can only be assisted by a model which links a number of key subsystems together.

3. The increasing citizen involvement in the decision making process requires that assumptions and identifiable interrelationships be made explicit.

4. The modular building block concept decreases the level of sophistication required by the user; thereby, increasing the probability that the model will be used.

Endnotes

1. Thompson, Mark, "Systems Approach to Environmental Engineering," Behavioral Science, Vol. 20, No. 5, Sept 1975, p. 308.

2. Ibid.

3. Biswas, Asit K., Systems Approach to Water Management, McGraw Hill, 1976.

4. Ibid.

5. Simon, H. The Science of the Artificial, MIT Press, 1969.

1.1 Assessment of Current Environmental Modeling Efforts

Modeling a system provides the opportunity to group and symbolically structure reality so that the behavior of important aspects within the limits of our intellectual capacities can be dealt with. Modeling exercises have been only qualified successes to date. The models developed so far characterize the general trend in the development of knowledge in the field of environmental studies. The knowledge explosion in the last 25 years has sent us hurtling into separate disciplines and categories of knowledge, each of which has witnessed a continued increase in the amount of information with which it must cope. Often this has been at the expense of appreciating how that information fits into a larger framework.

Modeling, if it is to play a vital role, must move in the direction of providing not only the correct answers but also the output of models must be in a form which will allow the managers of the environment to have confidence in their results. For this reason it is imperative that the set of criteria developed from model evaluation not only consider the perspective of the builder of the model but also of the user. Techniques for user involvement in model development remain primitive at best.

In addition, the type of model or the levels of modeling must be more clearly articulated so that the appropriate modeling applications can be matched with the problem environment in which they are proposed to operate.

In the following paragraphs four criteria are identified which can be useful in appraising and comparing models. These four criteria are:

1. inclusion of key variables,
2. simplicity,
3. consistency with theory, and
4. cosistency with data.(2)

The first criterion is whether or not the modeler has included all of the variables which are necessary to accomplish the objectives of his model. For instance a model which is to be useful for making specific land use decisions must include a good deal of geographical detail. To engage in significant geographical aggregation would defeat the model's purpose. On the other hand, a model constructed to aid planning of financial aid to the cities by the Federal government might appropriately make use of a great deal of geographical aggregation. Or, to take another example of this criterion, a model which was aimed at providing a useful planning tool for local flooding problems could perhaps take federal policy as exogeneous.

Simplicity provides a second criterion with which to appraise models. It is the very essence of modeling that it is often useful to focus attention on key variables in a system so that they can be understood adequately, and as emphasized in the discussion of the first criterion, important variables certainly must be included in a model. It may often be counterproductive to clutter a model with a large number of variables which are not crucial to the model's basic purpose. Inclusion of these extraneous variables may make the model so complicated that the user is unable to gain any true understanding of the basic relationships between the key parameters in which he is interested, or as is often the case, may simply be unable to use the model because of effort and cost required.

A third criterion is consistency with theory. Long traditions of research in a variety of disciplines provide the prospective model builder with a variety of theoretical tools to help him with his task.

Finally, the fourth criterion is the consistency of the model with data. To be sure, data limitations often make rigorous attempts to fit a model to data impossible; and in any case, since all models necessarily involve abstracting from reality, perfect correspondence between variables in the model and real world data is not to be expected. Nevertheless, it is reasonable and often useful to ask whether or not the model builder, in constructing his model, has fully made use of whatever empirical resources were available. For a given model, at a given degree of aggregation, as much consistency as possible with the available data would appear to be mandatory.(3)

The use of simulation models to deal with the description of complex physical systems in any integrated fashion is a relatively recent phenomenon. As a result of the fact that those individuals in agencies who are involved in directing research or in making funding decisions have not been operating with a clear conception of what the characteristics of an effective, easily applied modeling framework would be, no strong statements can be made in either direction regarding the success or failure of the application of large scale environmental management models. Because of the recent advent of large scale models, there is not a sufficiently long history of their application and use in environmental management decisions to judge their effectiveness.

In addition, the public's acceptance of the output of these models cannot be confirmed. A parallel can be drawn between the use of environmental management models and the first use of large scale transportation models for highway planning in the 1950's. For some period of time a number of projects were accepted by the citizenry based on the explanation that the proposed project was the answer which came from a detailed computer analysis involving very sophisticated models that only a few people could understand. The computer was set up as a demigod not to be questioned. The mysticism of the computer was short lived. As the public began to see and frequently experience the consequences of these new projects, they began to expend the energies necessary to achieve a better understanding of the transportation planning process and to identify the leverage points within that process. The result of this increased understanding and decreased blind acceptance of computer aided decisions left many highway projects literally suspended in mid air.

New legislation dealing with environmental quality, for example the 208 program, specifically requires public participation. Not only are environmental managers dealing with a new legislative and judicial environment but also they are increasingly confronted with a more sophisticated public. The final tally has only just begun to come in on how large environmental models will be accepted under these new circumstances. Environmental management models are tools for accomplishing one portion of the planning process. Their effective use demands more than the technical expertise to select, prepare, execute and interpret the results of whatever model may be used. It is imperative that the use of such analytical tools in the analysis performed be properly and thoroughly integrated with the numerous other portions of the planning process. Adequate integration of activities does not occur automatically. It requires that the analyst and planner both recognize explicitly the different nature of their respective roles, the relation between modeling and planning, and the means whereby coordination can be achieved.

The process of modeling or otherwise performing the analyses needed for planning requires that the analyst participate in the description of the problem and in the selection of the analytical techniques to be used. In addition to performing the analyses, the analyst should be prepared to assist in the selection of alternative plans to be considered, evaluate the effect of assumptions, and assist in the presentation and interpretation of results. (4) To date a number of large scale environmental modeling projects have permitted the analysts to perform their duties in isolation from the broader decision environment in which the model has to be implemented. As a result local decision makers are confronted with a model they fail to understand, a decision that has not been clearly included in the model and the public which is suspicious of a group of individuals which have imposed goals on their community without fully communicating the ideas and objectives set forth in the model. Again as an example, the area wide waste treatment management plans directed by section 208b of Public Law 92-500 must include a community participation element.

Identification in Planning

It is extremely important that further efforts at problem solving with any model be conceptualized in a manner which allows them to operate effectively in a pluralistic decision framework.

There are few tools which possess greater potential for distortion and misuse than advanced environmental models. Their use must be carefully balanced with considerable questioning. By using carefully selected system indicators as well as carefully developed models, we can better comprehend the steps which must be taken in order to manage the environment effectively.

Another area of difficulty in current applications of environmental models is the failure to link the appropriate modeling approach to the type of problem to be solved. (5)

Endnotes

1. Stearns, Forest W. and Montag, T., The Urban Ecosystem, Dowden Hutchinson and Ross, 1974, p. 171.

2. Mathematica, Inc., A Guide to Models in Government Planning and Operations, Environmental Protection Agency, 1974, p. 72.

3. Ibid.

4. Biswas, Asit K., Systems Approach to Water Management, McGraw Hill, 1976.

5. Breidenbach, Andrew, "Toward a Common Language," Environmental Simulation and Modeling, Office of Research and Development and Office of Planning and Management, U.S. Environmental Protection Agency, 1976, p. 5.

6. "It was my intention when preparing this paper to give examples of modeling success stories. Yet with all these models in my program, we could not find one which was universally acclaimed for solving what we call a Big Problem."

1.2 Problem Typologies

The establishment of any modeling procedure to some extent presupposes the nature of the problem to be solved. Conversely, the nature of a problem determines the strategy for dealing with it.

Cartwright (1) has set forth a typology of problems which is of some assistance in the consideration of strategy selection. He identifies four different types of problems:

1. simple problems
2. compound problems
3. complex problems
4. meta problems.

Simple problems are ones which are completely understood. They are defined in terms of a specific number of calculable variables.

Compound problems are ones where some, but not all, of whose parts are known. They are defined in terms of an unspecified number of calculable variables.

Complex problems are defined in terms of a specified number of variables which are incalculable.

Metaproblems are defined in terms of an unspecified number of incalculable variables. (2)

Nature of Variable (3)

	Calculable	Incalculable
Specified	Simple Problem	Complex Problem
Unspecified	Compound Problem	Metaproblem

In order to clarify the distinctions between the problem types, consider the following example.

1. As a simple problem: poverty means an annual income of less than three thousand dollars.

2. As a compound problem: poverty means having an annual income of less than three thousand dollars, having an education below the eighth grade, living in substandard housing.

3. As a complex problem: poverty means the inability to obtain the minimum basic necessities of life.

4. As a metaproblem: poverty means relative social deprivation. (4)

The literature of planning and management is liberally sprinkled with terms such as comprehensive and rational along with Braybrooke and Lindblom's description of the process as disjointed and incremental. (5)

Experience tells us that environmental management problems fall at many points along the spectrum of descriptions defined by these two sets of terms. Implicit in the context of the problem types which have been outlined is the question of whether or not the four fundamental types of problems previously noted imply any special conditions for carrying out analysis and action. If so, what are the conditions and how do they relate to the use of the modeling approach outlined in this paper. A suggested respose to the question is outlined in the following summary:

<u>Simple Problem</u> (<u>specified number of calculable variables</u>)

Limits of Analysis: Complete understanding of all of the variables.

Limits of Action: Maximization or optimization

Strategy: Comprehensive and rational

<u>Compound Problem</u> (<u>unspecified number of calculable variables</u>)

Limit of Analysis: Complete understanding of some of the variables (in depth analysis of subproblems)

Limit of Action: Suboptimization, satisficing

Strategy: Disjointed and rational

Complex Problem (specified number of incalculable variables)

Limits of Analysis: Partial understanding of all of the variables (brief survey)

Limits of Action: Overall improvements (Pareto optima)

Strategy: Comprehensive and incremental

Metaproblem (unspecified number of incalculable variables)

Limits of Analysis: Partial understanding of some of the variables

Limits of Action: Partial improvement

Strategy: Disjointed and incremental

Linking the appropriate strategy to a problem might appear as an obvious step. However, this is not the case. One of the reasons why modeling efforts in general have fallen from favor is that false expectations were raised by promoters regarding what models could accomplish.

The next question which must be addressed is what problem solving strategies are inherent in the modular approach to watershed planning. In other words what limits of analysis are associated with this modeling configuration and how do they relate to the limits of action at the disposal of environmental managers and elected decision makers.

Within the context of the model the watershed planning problem can be categorized as compound. This view is supported by the fact that all of the factors included are calculable. Following the approach previously noted the users of the model would be constrained by being able to achieve an in depth analysis of subproblems: runoff, BOD, infrastructure costs. Furthermore, they would set goals for the application of the model which would be compatible with suboptimization and satisficing.

The appropriate strategy implied by our analysis is one which is rational yet by the manner in which elements of the problem have been defined is inherently disjointed.

To briefly state the dilemma faced by the environmental manager, they are faced with the philosophical commitment to holistic analysis of problems yet the applied concepts and techniques are rooted in the tradition of the scientific method which demands analysis - the taking apart of problems to form simple components.

Upon first thought it would seem that if a watershed planning problem is defined as a simple one such that the comprehensive and rational strategy could realistically be pursued then it is likely that the problem has been too narrowly defined. On the other hand if the condition is defined as a metaproblem, one could hope to achieve very little.

As one proceeds up the hierarchy of decision making, for example to the national level, the umbrella of concerns expands to include a very wide range of interrelated variables about which little specific information is known. As one moves down the hierarchy of decision making, functional responsibilities are clarified and the number of variables is reduced. Thus, the proliferation of governmental structure in one sense is the manifestation of the struggle to transform metaproblems into simple problems.

The Modular Structure Permits Another Approach to Planning

The modeling approach set forth in this research results from the belief of the author that the traditionally conceived approach to "comprehensive planning" is in fact an impossible and inappropriate goal; furthermore, it will not lead to the development of a conceptual framework which can be made operational and thereby solve the problem of land use and water quality.

Proponents of comprehensive planning have yet to address the problems of scale, quantity of information and limitations of time and resources in an effective manner. One simple example illustrates the limitations of traditional comprehensive planning.

Let us take an organizational structure which must coordinate its functions. Assume a .9 probability that the information transmitted from one function to another or from one level of the organization to another will be correctly received. If three levels were involved the probability of successful transmission from the first to the third would be .81 (.9 x .9) If there are only seven links in the communication chain, there is a .47 probability associated with successful transmission from the first to the seventh: less than a fifty-fifty chance. Organizations attempt to remedy this problem by increasing the amount of redundancy in the information transmissions, thereby, increasing the quantities of information which must be handled. The point of this example is that if comprehensiveness requires centralized control the system will fail under its own weight.

Contemporary complex organization theory suggests as the number of components of an organization increases the information requirements can increase in proportion to the square of the number of elements.

Certainly there must be policy coordination. However, regulation and control must be in the structural qualities of the components themselves.

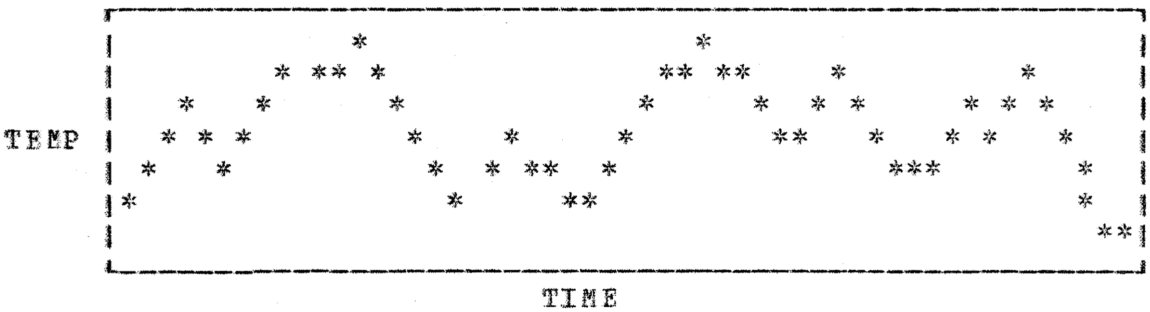
The Law of Requisite Variety and the Evolution of the Modeling Structure

There is an alternative to the central decision structure for environmental management. The Law of Requisite Variety plays a key role in this alternative view.

The Law of Requisite Variety comes from the field of cybernetics and refers to the characteristics of a system regulator and its ability to preserve a stable state, in the application to the South River, the stable states are the four modules. The law states that only variety can diminish variety. (6) To clarify the application of this law to the model two examples are offered. Consider the mechanism of the autopilot in an aeroplane which keeps it on a predetermined course. Conditions may change forcing the plane to go off course and the autopilot sensing this change institutes corrective action. In order to keep on a steady course the autopilot must have a response to deal with every disturbance presented to it by the changing flying conditions, or to preserve the steady state of the system the regulator must have a set of responses equal in variety to the possible disturbances from the environment.

For a second example consider a regulating device designed to keep one's bath water at a constant temperature. In order to enjoy a comfortable bath there should be no variety in the temperature of the water regardless of the disturbances.

A



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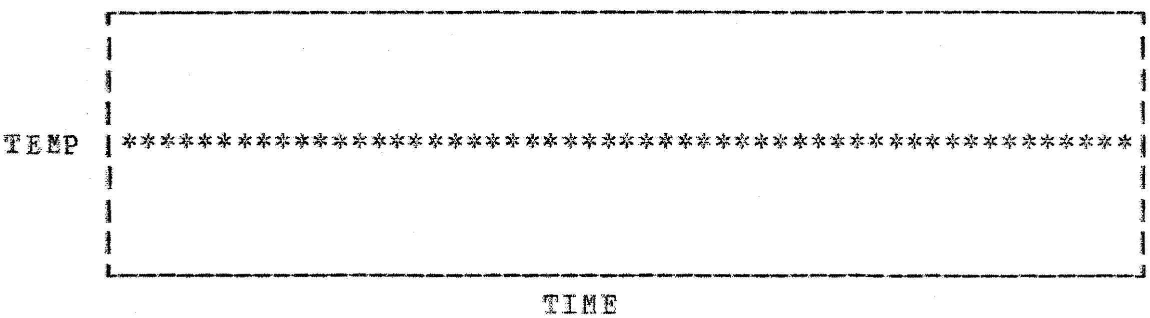

In order for the variety in water temperature to be zero the regulator must have a response for every disturbance in the temperature of the incoming water. If there are only two types of disturbances and the regulator has two appropriate responses then the variety can be zero. However, if there are two equally likely disturbances and the regulator has only one response then the variety is increased by fifty percent and the goal of a steady water temperature cannot be achieved. Indeed, if the disturbance is too great (i.e., the incoming water temperature 210 degrees) there can be no bath at all.

If the use of the watershed model is to remain effective over a long period of time, the model must be able to respond to the changing problem environment to preserve its stable state - which according to standards noted earlier is consistency with theory and data and relative simplicity.

What are the regulators in the model which will preserve the desired state? The regulating mechanisms in the model are of two types. The first is the structural configuration of the modules and data input. The requirements of the output of the modules are such that only the values of a few key indicators are required. The range of information required as input to the model will change at a much slower pace than the organization and manipulation of the data carried out within the various modules. As the state of the art improves in relation to each of the modules, the existing modules can be improved upon or entire new ones substituted.

The second manner in which the model preserves its responsiveness is in the range of inputs considered by the various modules and in the relationship of its inputs and outputs to the decisiom making process. This is particularly true in the Goal Programming Module where local and regional priorities as well as budgetary constraints are easily included. Through the ability of the model to accept incremental changes in its components the the relative simplicity and consistency with theory and data can be maintained.

Along these lines the concept of near decomposability has particular relevance to the model. The concept of near decomposability recognizes the difference in interaction within subsystems and between subsystems and describes a relationship in which:

1. the effect of short run behavior of subsystems is confined to those subsystems, and

2. the long run behavior of the subsystems impacts on the whole system in only an aggregate way.

Inherent in the term near decomposability is the idea that a holistic system can be viewed in terms of its constituent parts - it can be nearly decomposed. (7) The modules of the watershed model can each be modified in response to changing demands without destroying the model as long as the overall context is understood.

<u>Chapter Summary</u>

1. One of the major barriers to the successful implementation of environmental models has been that they are too complicated to be readily constructed, modified, or evaluated.

2. These problems outline the need for a model which is comparatively simple and which can be integrated into the existing decision making framework.

3. How simple can a model be yet reflect a real world which is complex? In response to this question, the concept of the hierarchical structure is presented. The hierarchical structure in the modeling process is the key point of interest. However, since the model is a symbolic construction of the natural and man-made systems being modeled, it must also be noted that these systems have a hierarchical structure. Since some properties of hierarchical systems are known, properties of the model can be determined. (8)

4. The two major properties of hierarchic systems to be contained in the model are:

a. near decomposability, and

b. evolution to greater complexity,

being facilitated by the presence of intermediate stable states. The quality of near decomposability is important because the individual modules must be able to be changed without destroying the integrity of the whole model. The second property, intermediate stable states, gives the model the potential to evolve in response to changing problems and changing needs of the user. In addition, from the field of cybernetics, the

Law of Requisite Variety is noted to identify those qualities of the modules necesary to preserve the intermediate stable states.

5. Finally, in an effort to address the strategic questions of the modeling process, a set of problem typologies and their associated strategies has been outlined.

Endnotes

1. Cartwright, T.J., "Problems, Solutions, and Strategies: A Contribution to the Theory and Practice of Planning," *Journal of the American Institute of Planners*, May 1973, p. 183.

2. *Ibid*.

3. *Ibid*.

4. *Ibid*.

5. Braybrooke, David and Lindblom, Charles, *A Strategy of Decision*, Free Press, New York, 1963.

6. Ashby, W. Ross, *An Introduction to Cybernetics*, Chapman and Hall Ltd., London 1964, p. 206.

7. Boulding, Kenneth, "General Systems Theory- The Skeleton of Science", *Modern Systems Research for the Behavioral Scientist*, Aldine, Chicago, 1968, p. 3.

8. Kuhn, Thomas, *The Structure of Scientific Revolutions*, University of Chicago Press, 1970.

Chapter 2.0

The Study Area

Efforts directed at producing a coordinated program of resource management continue to be confronted with problems of intergovernmental jurisdictions, diffusion of decision making authority, and perhaps most critically the lack of a comparable data base. Both technical officials and elected representatives have long ago recognized that the economies of scale are dependent upon the type of service to be provided and the nature of the goals to be accomplished. Traditionally the economies of scale sought were for administrative ease and responsiveness to the interest of a local electorate. The efficiencies of the systems and services being administered were only marginally considered.

As the understanding of the interrelationships between man and the environment increased and the cost of environmental protection began to consume a greater portion of both private and public budgets, operating efficiencies could no longer be overlooked.

In examining the need for a common denominator for coordination, it became apparent that the watershed is a natural basic element for coordination.

Runoff can be accounted for in the tributaries within the system. Air currents are partially contained by the ridges which delineate the outer boundaries. In addition to these factors other characteristics of settlement patterns reinforce the watershed concept. Because of the desire to locate along major transportation routes, (i.e., rivers, railroads) and because the transportation routes followed paths of least resistance (i.e., valleys) early settlements tended initially to be located within watersheds rather than on the edges of watersheds.

Because of the natural boundary provided, certain animal populations and other ecological communities are contained within the watershed.

Although economic forces such as market areas and technological progress in the form of major interstate highway systems transcend the natural boundary of the watershed, the watershed nevertheless serves as a logical basic unit for environmental planning management.

2.1 The South River Watershed

The South River watershed is part of the Potomac River drainage area. It is located in Augusta County, Virginia and consists of approximately 236 square miles. The upper watershed, the principal focus of this model, is approximately 136 square miles in area. The South River is 52.3 miles long. The elevation at its source is 2020 feet and at its mouth is 1040 feet. Although not a part of the maps, the outlet of the watershed occurs where the South River joins the North River to form the South Fork of the Shenandoah River.

The total population of the section of the watershed being studied was approximately 18,600 in 1975.(1) The main concentration occurring in the City of Waynesboro with lesser concentrations in the communities of Stuarts Draft and Lyndhurst. Current projections for this area for the year 2000 suggest that the population may reach 22,000.(2)

The topography ranges from steep to moderately rolling with the steeper portions occurring in the area which constitutes a portion of the George Washington National Forest.

The average annual precipitation ranges from 35 inches to 50 inches with an average annual snowfall of 35 inches. Average annual temperature is approximately 51 degrees Fahrenheit. All of the Potomac-Shenandoah Basin is subject to thunderstorms, hailstorms, tornadoes, and icestorms. The prevailing wind is from the southwest, which generally brings moist air from the Guld of Mexico. Polar air masses from the northwest clash with the warm air from the gulf to produce most of the climatological changes which occur.

The geology of the area is characterized by igneous rocks at the highest elevations with the Blue Ridge having igneous and metamorphic rock. At the western base of the Blue Ridge there is a contact of metamorphic and Paleozoic sedimentary rocks. There are a few Triassic igneous intrusicns found in Augusta County. During 1965, seven producers quarried and crushed limestone and dolomite for construction purposes. (3) An inspection of the existing land use maps of the developed portions within the watershed reveals that land use development patterns have not been untypical of any other community of this size. A general pattern of strip commercial development which traces major highway corridors alcng with single family dwellings characterize the development of the watershed. In response to the dramatic increase in housing costs in the last few years, there is an additicnal market for the rental of multi-family units and the ccnstruction of mobile home parks because housing costs are grcwing beyond the means of an increasing number of families whc reside in the area.

The area has a strong industrial base and is well located in terms of accessibility by the fact cf its proximity to the intersection of Interstate Route 81, a north-scuth corridor, and Interstate 64, a major east-west corridor, the eastern portion, of course, leading tc the ports of Norfclk and Hampton Roads.

The South River watershed was selected for examination because of the diversity of factors present both in terms of its physiographic features and the community awareness and understanding.

There has been a considerable amount of research centered around the South River. These studies ranged from the examination of individual compounds which are the by-products of certain industrial processes to the hydrologic models examining the runoff characteristics of the entire watershed. Such research activity has not been without an institutional framework. The State Water Control Board and the U. S. Soil Conservation Service have shown considerable interest in the development and progress being made in examining the South River watershed area.

Increasing problems of flooding in the lower portion of the upper watershed in Waynesboro as well as a desire on the part of most localities to attempt to respond to the problem of erosion control have lead to the establishment of the South River Flood Control Commission and the designation by the Governor that the U. S. Soil Conservation Service be a lead agency in continuing to work with the problems of the South River watershed. In addition, numerous studies have been conducted under the auspices of the Water Resources Center at the Virginia Polytechnic Institute and State University as well as a number of private consulting firms. Due to the nature of the studies previously referred to, there has not to date been an effort to deal with the development options for the watershed in a comprehensive manner. Hopefully, the result of this endeavor will be an overview which builds on the knowledge of the preceding investigations and establishes some alternative directions for the development of the watershed.

Based on the summaries of the necessary actions required to upgrade the existing sewage treatment plant facilities noted in the _Phase 1 Metropolitan Regional Water Quality Management Plan_, prepared by the Central Shenandoah Planning District Commission, it becomes apparent that several critical decisions will have to be made with regard to a growth strategy for the watershed. Already most facilities are operating beyond their capacity in terms of providing adequate treatment of effluent which is being discharged into the South River. If increased growth is to take place, then a serious financial commitment will be required on the part of the localities in order to preserve the existing water quality and hopefully improve it to meet the requirements of PL 92-500.

The current future land use plan for the region states that within the study area population densities are low and are not anticipated to increase significantly during the planning period for the year 2000. If current trends continue, increases in population are likely to be accommodated by the development of urban sprawl and consequent infilling of vacant parcels. This form of land development represents only one alternative for the development of the South River watershed. Pressures to preserve the environmental quality of the area brought about by forces within the watershed and forces outside the watershed may result in quite divergent views regarding the role of the watershed in the future. As previously noted, its proximity to major transportation routes may be a critical incentive for major industrial relocation which in turn brings with it dramatic increases in urban growth and more important dramatic increases in the need for the provision of urban services.

If the individuals and institutions responsible for the future of the South River watershed are concerned with preserving a number of strategic planning options so that they may respond effectively to whatever the future may bring, it is necessary that they examine more than one alternative future for the development of the watershed. The following options have been considered in this study:

1. To preserve the watershed as a natural area so that it may serve as a recreational area for the more urbanized regions of the state.

2. To develop the watershed in the current form at a moderate density taking advantage of existing industry and employment based in the area as well as its proximity to major transport and market areas.

3. To increase the population of the watershed by establishing several high density developments yet preserving open space and agricultural land.

None of the above alternatives is unlikely. The question is: What are the relative merits of each alternative and what are the associated impacts on environmental quality and the fiscal stability of local government?

2.2 Existing Sewer Facilities - Upper South River Subregion (4)

The Town of Stuarts Draft, the only principal concentration of population in the subregion, has a treatment plant located off Route 639 near the South River. Built in 1969, this plant is designed to accommodate 500,000 gallons per day in hydraulic capacity with a treatment efficiency of 87 percent. There were 111 connections recorded in 1972 and the plant currently serves approximately 160 connections with treatment consisting of a five acre aerated lagoon and a final clarifier followed by chlorination. The effluent from the plant is discharged to the South River. Composite BOD 5 samples indicate a very weak raw sewage with an average concentration of approximately 50 mg/l. The average effluent BOD discharged to the South River is approximately 17 mg/l. A brief analysis of this data makes it evident that infiltration is occurring. The area served by this plant is a low water table area and the plant site itself is often marshy during wet weather (5).

2.3 Existing Sewer Facilities - Lower South River Subregion

The principal population concentrations in this subregion are Waynesboro and Lyndhurst. In this portion of the watershed the water quality of the South River is marginal and has been highly polluted in previous years. In the city of Waynesboro, an area of principal growth, there are several waste dischage points which contribute to the water quality standards being violated during periods of low flow in the South River.

The Waynesboro sewage treatment plant is located off Route 865 on the South River at the northeast end of the city. The plant serves the population of aproximately 17,000 with approximately 12,000 domestic hookups and 10 industrial waste plants. The secondary treatment plant units consist of a bar screen, two comminutors, a grit chamber, two primary settling tanks, two high rate trickling filters with 100 percent recirculation capability, and two secondary clarification tanks. The plant effluent is chlorinated and discharged to the South River. Sludge is digested anaerobically and, after vacuum filtration, dried on drying beds. Although the treatment plant has doubled its size in 1970, it is still unable to handle the loads from these connections during heavy rains. As a result of the portion of the city's storm sewer lines being connected directly to the domestic sewer lines, the problem is exacerbated during periods of wet weather. The plant has been averaging flows of approximately 2.6 million gallons per day and an efficiency range between 80 and 90 percent. However, the infiltration in wet weather allows flows to reach between 3.5 and 4.0 million gallons per day. The plant was designed to accommodate a capacity of 4 million gallons per day.(6) From January 1973 to March 1974, BOD effluent ranged from a low of 12.0 mg/l to a high of 38.4 mg/l. The average was 21.9 mg/l over this time period.

Endnotes

1. Central Shenandoah Planning District Commission, Phase 1 Metropolitan Regional Water Quality Management Plan, 1974, p. 253, p. 257, p. 262.

2. Ibid., p. 262.

3. Division of Water Resources, Potomac-Shenandoah River Basin, Comprehensive Water Resources Plan, Vol. 1, 1968, p.69-79.

4. The upper South River subregion is composed of Stuarts Draft, Jolliville, Fishersville. The 1975 population of Stuarts Draft was 1075. The lower South River subregion is composed of Waynesboro, Lyndhurst, Ladd and Dooms; however, Dooms has been excluded from this study. The 1970 population for Waynesboro was 17,000 and is expected to reach 19,000 by the year 2000. Based on a count of residential units from aerial photographs the population of Lyndhurst is estimated at 510 for 1975 assuming a family size of 3.0 persons per household (170) units.

5. Ibid., p. 257.

6. Ibid., p. 258.

Chapter 3.0

Watershed Model - General Explanation

The simulation model attempts to identify the consequences of the three alternative development strategies for the watershed. In addition the model is designed in an integrated, modular fashion which will permit it to evolve in response to the changing problem environment as well as to provide output in varying degrees of specificity depending upon the complexity of the module or sequence of modules the user chooses to employ.

3.1 The Methodology

Prior to a detailed description of each of the modules which comprise the watershed model, it is useful to outline the basic methodology behind the modeling effort.

The watershed model consists of four major modules:

Module I - Runoff and Routing Module

Module II - Water Quality

Module III - TOPAZ (sewer and water submodel)

Module IV - Goal Programming

The model has characteristics which are hierarchical and iterative. The modeling sequence outlined in Fig. 4

illustrates the nature of the model. The hierarchical quality of the model is present in two forms. The Water Quality, TOPAZ, and Goal Programming Modules have hierarchical structures. The second form of hierarchic structure in the model is more abstract in nature but nevertheless important. This structure is the relationship between the current state of the model and the states into which it can be transformed (i.e., intermediate stable states facilitate the evolution of the model). Each major module has several sub-module components. Fig. 4 outlines the sequence of application of the modules.

The objectives of the model are as follows:

1. To determine the impact of development in the watershed on water quality as measured by BOD and DO.

2. To determine which development patterns will result in the least costly sewer and water systems yet maintain satisfactory levels of BOD and DO in the South River.

3. To provide a means of quantifying the tradeoffs between the increased expenditures necessary to maintain high levels of water quality in light of development and other local, regional, and national objectives when there are limits to the budgetary resources.

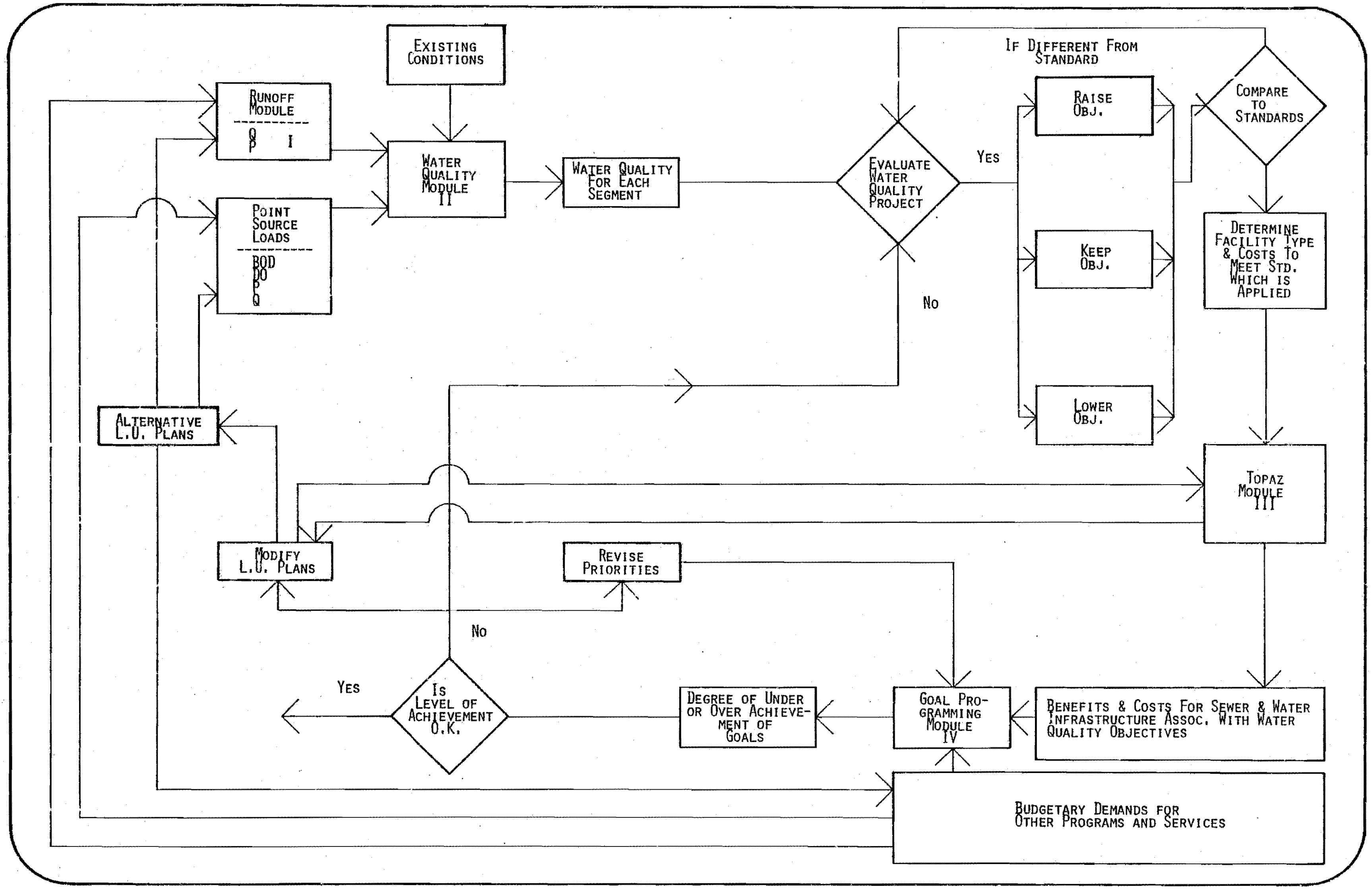

Fig. 4 Integrated, Modular Watershed Planning Model

As an example, in the study area, every dollar spent to improve water quality is likely to have several alternative uses. The decision maker may be faced with a tradeoff decision between expenditure for funds for day care centers versus funds for a new treatment plant.

Three different development alternatives will be compared by the model. The modeling sequence is designed to follow the steps in Fig. 4; however, there is an exception in the following description for the application in this study. Values for the non-point source contributions were taken from the <u>Water Quality Management Plan</u> rather than the output of the Runoff Module. The modeling sequence is:

1. The model is run for the current development in the South River watershed in order to establish a base line condition for purposes of comparison.

2. Based on population levels, geographic location, and density, pollutant loads are computed for each segment of the South River from point source and non point sources. The non point source loading is based on outputs from a six element combined runoff and routing model. Point source information is based on loading from treatment plants whose effluents enter the South River.

3. The Water Quality module computes the dissolved oxygen level and the biochemical oxygen demand

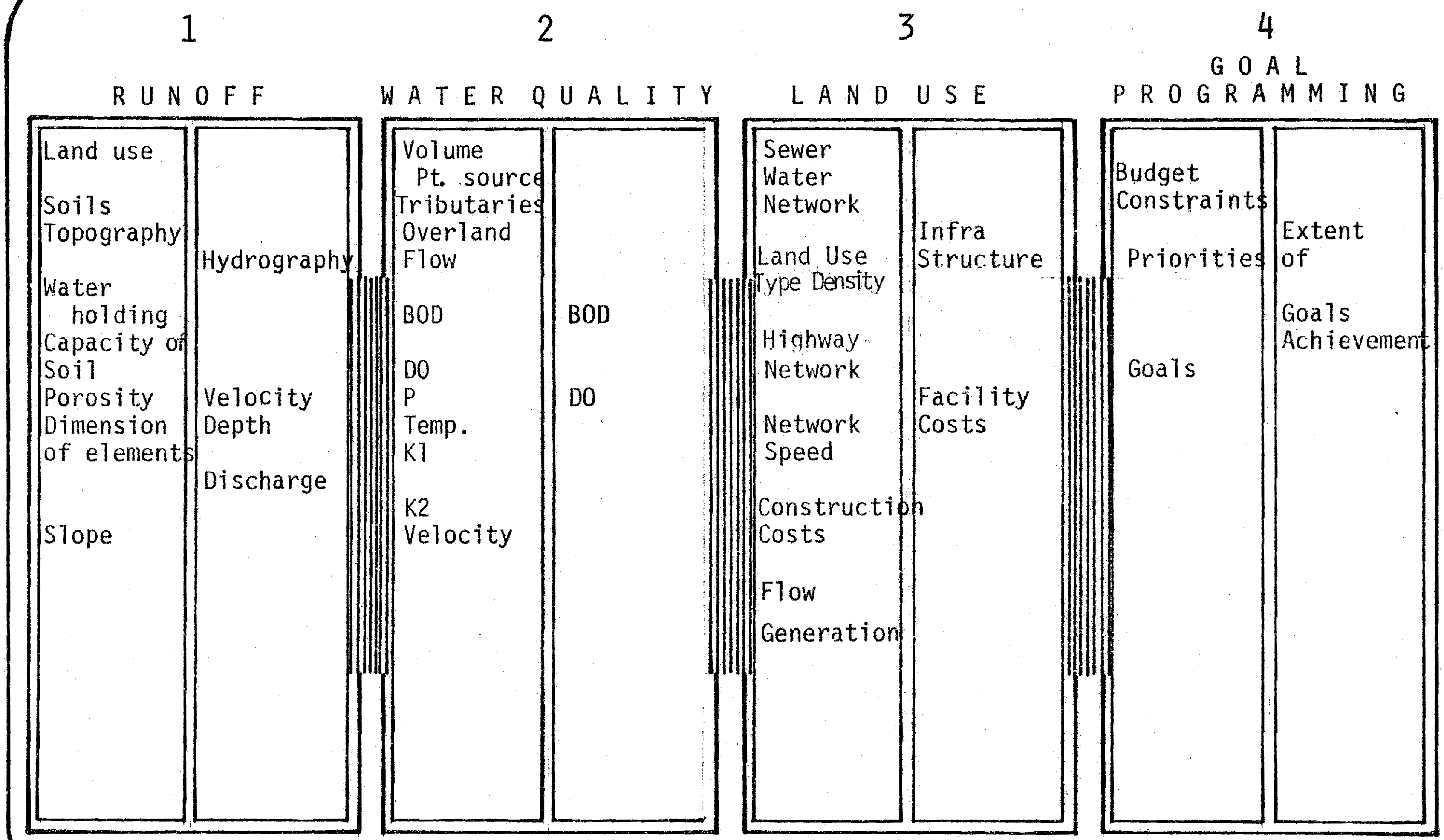

Fig. 5 SUMMARY OF INPUTS AND OUTPUTS OF MODULES FOR WATERSHED MODEL

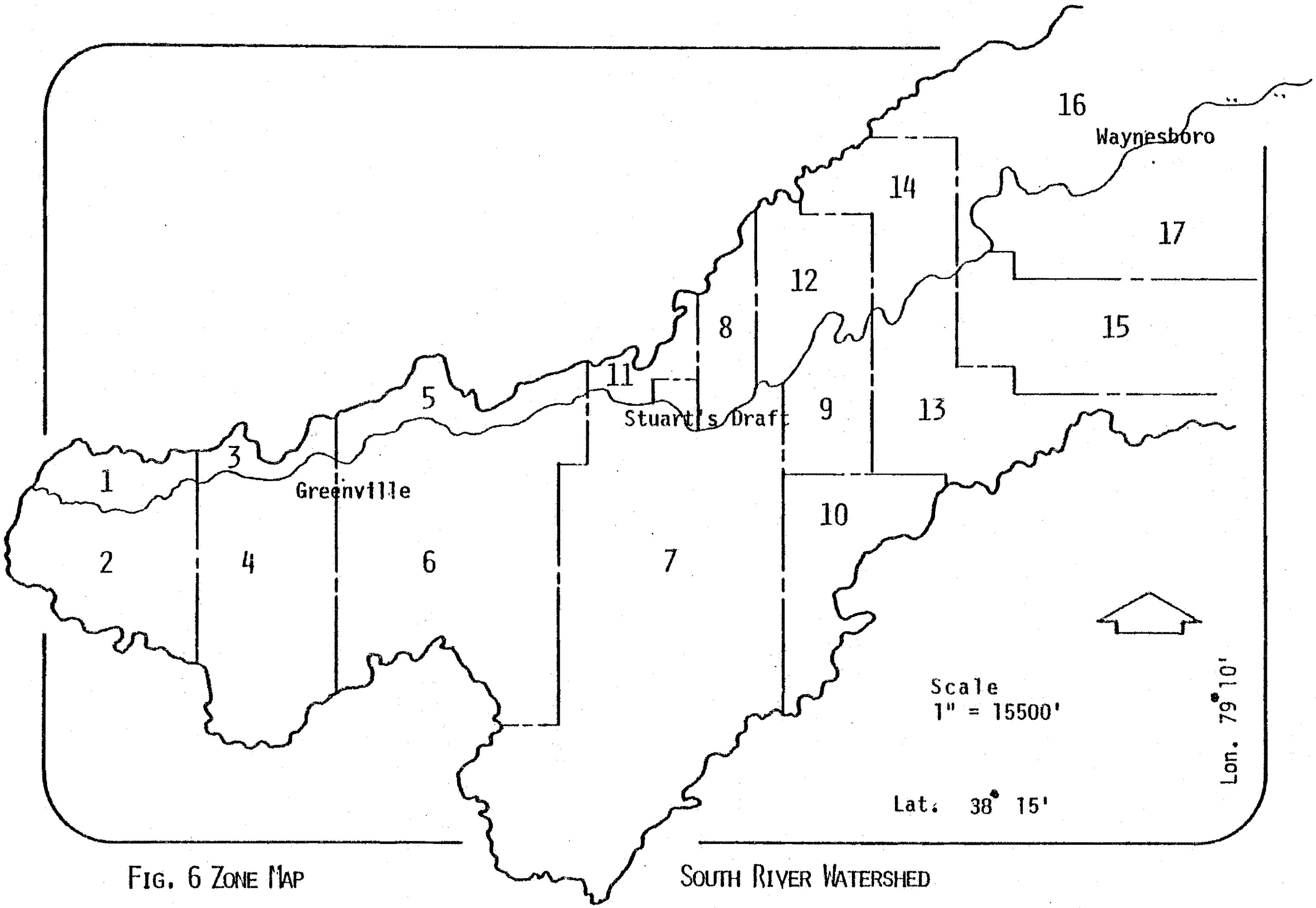

FIG. 6 ZONE MAP SOUTH RIVER WATERSHED

-56-

for any number of segments of the river. It relies on the standard Streeter-Phelps equation. Segments have been created where either tributaries join the river or pcint source loadings occur. The model corrects for temperature changes along the various segments as well as changes in flow characteristics of the river.

4. When it is found that the level of water quality associated with any of the land use alternatives is in violation of standards a computation is made which estimates the expenditure required to bring the pollutant loads into compliance.

This remedial action may take the form of increased STP capacity or level of treatment or it may reflect necessary increases in expenditures for such measures as erosion control or storm water management. These cost estimates for facilities are introduced into the TOPAZ module along with the system requirements of the particular land use plan.

5. The TOPAZ (Technique for the Optimum Placement of Activities in Zones) module computes the costs and benefits of sewer and water systems associated with a particular land use alternative, based on land use information and costs relevant to the South River watershed, preliminary design for sewer and water systems is carried out in the sewer and water submodel based on density and locational inputs.

6. The Goal Programming module provides an explicit treatment of tradeoff decisions involved in the allocation of budgetary resources. More specifically, an objective function is constructed and is subjected to constraints on expenditures associated with eight variables in the seventeen zones into which the watershed is divided. In addition there are a number of equations which define the relationships between zones. For example, the town of Stuarts' Draft and the City of Waynesboro may enter into an agreement regarding expenditures for advanced waste treatment facilities. Since both municipalities load waste into the South River the success of the abatement program could likely be contingent upon both parties upholding their part of the agreement to construct new facilities.

From one to ten priorities can be assigned to the allocation of resources associated with the variables. The actual solution process is iterative in nature. Higher priority constraints are satisfied first.

The end result of the Goal Programming module is a description of the allocation of resources according to a particular set of priorities and constraints.

As noted in the flow chart (Fig. 4) which depicts the sequence of events in the modeling procedure, there are several points where key decision parameters can be modified. An obvious as well as important one is the water quality standard required for the South River. In the appendices is a description of the sensitivity analyses of the Water Quality Module. After one iteration of the modeling process is complete the decision maker can choose which variables to modify and proceed to examine the consequences of those modifications. Alternative strategies can be examined by repeating all or part of the steps of the modeling process until the most appropriate one is found.

Fig. 5 identifies the inputs and outputs associated with each of the modules. Fig. 6 outlines the zones into which the watershed was subdivided for use in organizing land use information as well as other inputs for the TOPAZ and Goal Programming Modules.

DATA BASE

One of the critical considerations in the development of a model of this scope is the feasibility and resource requirements of the data base. Although the data considerations for each of the modules will be discussed in detail, it is beneficial to outline some of the factors which play an important role. There are five principal areas of interest:

1. mechanisms for updating

2. ease of understanding the structure of the data base

3. type and form of existing information

4. cost

5. equipment required for operation.

Mechanisms for Updating

The majority of the information required to make the model operational can be obtained from existing data sources. This information exists in a number of local, regional, and state agencies and is frequently part of an information update program.

The specific mechanisms for updating the data base are dependent upon where the model and hardware reside. In the case of the South River watershed, major use of the model would be made by the planning district commission with supplemental support from the State Water Control Board.

Ease of Understanding Structure of Data Base

As has been previously stated, it is unlikely that a large number of the staff of the user agency will have a complete understanding of the operations of the model. However, there is a need for the principal users to have some conception of how the data base is organized to facilitate their day to day decisions. Modifications to specific modules can be accomplished without disrupting the overall modeling sequence as long as the inputs and outputs of the module are not diminished or modified in format.

Computing Equipment Required and Costs

The integrated-modular-watershed planning model was developed using the CMS (Conversational Monitoring System) environment of the IBM 370/158 at the Computing Center of the Virginia Polytechnic Institute and State University. Each module is limited to 650K of memory under CMS.

The CMS environment allows the model to be accessed from a remote terminal which also permits remote data entry and manipulation. Because of the remote terminal access capability, the economic feasibility of the use of such a model is increased considerably. The local user agency need only have the terminal and can rent storage and time from any one of the major computers in the state. Because of the existence of a state computing network, data can also be transported via telephone lines from one agency to another.

The cost of running the separate modules was quite modest. It ranged from $3.50 for the Water Quality module to $8.00 for running TOPAZ.

Spatial Resolution

One factor that each of the modules shares is the need to divide the watershed into zones, sectors, overland flow planes, etc. Differing data requirements demand different organizational patterns for the various zones.

The parameters for delineating the boundaries of the zones for the first two modules are dominated by topographical concerns. The second two modules are principally concerned with land use and jurisdictional data which frequently is not bound by natural features.

The system of zones into which the watershed has been subdivided pays particular attention to the topographic features of the watershed.

The end result is that smaller zones which may be required for one module can be aggregated to form the larger zones.

3.2 Components of the Watershed Model

The following is a description of each of the four modules noting inputs, outputs, and principal characteristics.

MODULE I

3.21 Runoff and Routing Module

The runoff considerations for the watershed model are comprised of two parts. The first submodel computes the excess precipitation for various land uses and rainfall conditions. The second submodel simulates the overland flow over the watershed and open channel flow in the main streams.

The finite element numerical method was employed in the models because it allows changes in land use to be easily incorporated.

As noted in the logic diagram and the previous description of the elements of the model, the runoff and routing module provides the quantities of water in the tributary streams to the South river. The model simulates the flows which result from single storm events. However, the models can be modified to simulate continuous flows.

Since the dissolved oxygen level is a critical indicator of the health of a stream, it is important that DO be related to runoff. This presented a basic problem in terms of integrating the output of the Runoff and Routing Module with the input to the Water Quality Module. The tradeoff was between representing non-point source contributions which occur in a comparatively continuous fashion along the river with a water quality model which has as one of its basic characteristics the division of the river into segments for which BOD and DO computations are performed.

Of course, the reality of data handling costs and the law of diminishing returns results in the need to determine a practical limit to the number of overland flow planes into which the study area can be divided.

The question was resolved by having the ends of the segments into which the river was divided for the Water Quality Module correspond with the end of the overland flow planes. Where the runoff is routed to a tributary to the river, the contribution of that tributary is added into the loading on the particular river segment at a single point. Where this was not the case the contribution was added in at the beginnung of the next segment.

Oxygen sag studies show that the question of impact of urban storm water runoff on the oxygen content of downstream reaches is very complex. Many factors are involved, and there are large variations from place to place and from storm to storm. It does appear, however, that some generalizations are appropriate.

The reaeration coefficient in the downstream reach is highly variable, being a function of the channel characteristics and the rate of flow. Studies using the O'Connor and Dobbins formulations shows that the rate of reaeration is inversely related to the flow rate, provided there is significant flow. At very low flows, water tends to collect in channel depressions and irregularities such that velocity is essentially zero over much of the channel length. The commonly accepted reaeration coefficients for these conditions are very low, on the order of 0.10 to 0.15 per day (base e) or .043 to .065 (base 10). (1) The Water Quality Module is designed to incorporate different K2 values for each segment to permit a greater sensitivity to this phenomenon.

The studies confirm the existence of a first flush effect, evidencing higher pollutant concentrations in the early storm stages which decrease as the storm progresses. The interactions of changing BOD concentrations and changing reaeration rates produce the greatest dissolved oxygen deficit in the plug of water which includes peak flow.

As storm size increases, the depletory effect on down stream dissolved oxygen is more pronounced. At comparative time intervals larger storms have higher BOD concentrations and lower reaeration rates. Small storms frequently result in no deficit whatever in dissolved oxygen. It is important to note, however, that the value of the reaeration rate constant, K2, is difficult to predict at low flows because of the effect of channel irregularities.

If it is accepted that the 7-day, 10-year low flow is an appropriate design criterion for dry conditions in the stream, contravention of minimum standards would be expected on an average of once in ten years. Hypothetical studies of the impact of urban land runoff on water quality indicate that the 5-year storm may impose more severe depletions of dissolved oxygen than the accepted dry-flow criterion.(2) Therefore, to be consistent in overall water management, it appears necessary to develop concepts and criteria applying to urban stormwater runoff. While the degree of oxygen depletion may be more severe in a large storm event than in a protracted dry period, it is also of shorter duration.

Urban land runoff can be a significant source of pollution when compared to raw municipal waste. In a study of an urban watershed in Durham, North Carolina prepared for EPA, urban runoff yields of COD were equal to 91 percent of the raw sewage yield, the BOD yield was equal to 67 percent, and the urban runoff suspended solids yield was 20 times that contained in raw municipal wastes for the same area.

The major role that non-point source pollution plays leads to the question of how much expenditure should be made in upgrading secondary municipal waste treatment plants without associated steps to moderate the adverse effects of urban land runoff.

The tradeoff decision between increased expenditures for treatment facilities and implementation procedures to reduce soil erosion and non-point source pollution are made explicit in Module IV - the Goal Programming Module.

Excess Precipitation Submodel

In order to be useful in examining the effects of land use changes on runoff generation, it is important that spatial uniqueness be maintained so that the runoff from a specific point in the watershed can be traced. To satisfy this requirement the watershed was subdivided into hydrologic response units. The following is a listing of the inputs required by the model:

Spatial Data:

1. land use map
2. soils map
3. topographic map.

The land use map in combination with the soils map is used to define the hydrologic response unit (HRU) for rainfall excess computations. The topographic map serves to define a finite element structure for flow routing which includes sub-sheds (tributary drainage units), strips (unit overland flow planes), and elements.

Soil Characteristics:

1. total porosity
2. water holding capacity at .33 atmospheres

3. water holding capacity at 15 atmospheres

4. soil depth, usually the A horizon; however, with some soil types part of the B horizon may be included.

Land Use Classification:

This factor is described in terms of an index of porosity of the cover (e.g., completely impervious = 1.0). Fig. 7 identifies the characteristics of the element.

Element Characteristics:

1. top width in feet
2. bottom width in feet
3. cross-section (channel)
4. roughness coefficient
5. slope.

Output from the Module:

Stage - time (hydrograph) listing, also available for all nodal points from the computations:

1. velocity
2. depth
3. discharge
4. area.

Figure 8 outlines the sequence of activities included in the model. The second model utilizes runoff hydrographs and can assist in determining the river's behavior as a

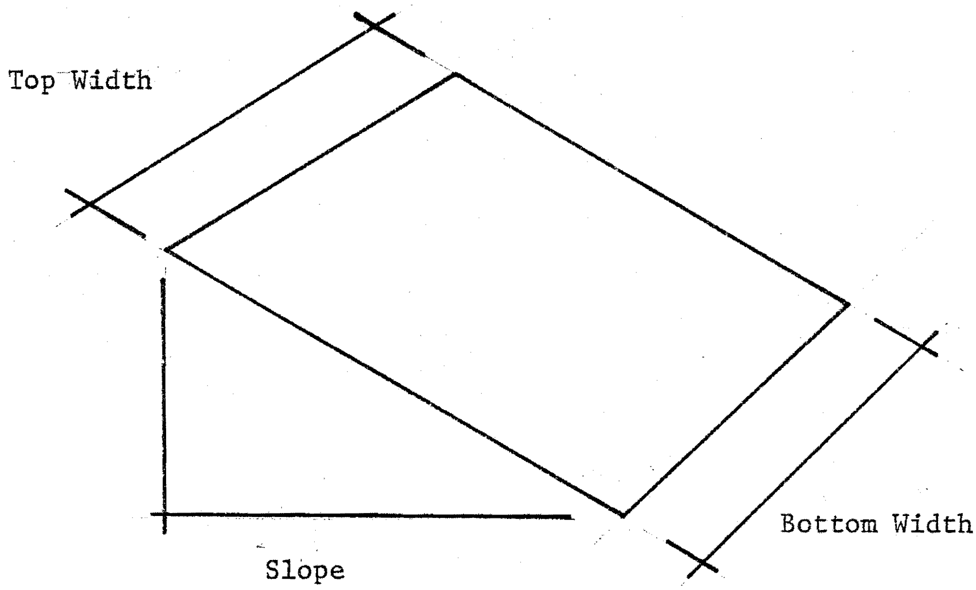

FIG. 7 - CHARACTERISTICS OF A FINITE ELEMENT

MAIN
Precipitation data and program control data entered

|

PRECIP
Ccllects the constants necessary for the two infiltration models, passes them to the subroutine XMEIN and HOLTAN, summarizes and prints the results of the calculations

|

XMEIN
Calculates the precipitation excess for each storm event for all response units using Mein and Larson equations.

|

HOLTAN
Calculates the precipitation excess for each storm event for all response units using the Holtan equation

|

TOPLOT
Plots recorded data and accumulated simulated precipitation excess versus time.

|

SOILS
Soils data read in by hydrologic response units

Fig. 8 Outline of Runoff Model (8)

result of changes in land use and rainfall. Fig. 7 illustrates the delineation of elements over an area of the South River.

The model has been tested with rainfall data for a 100 year event and a series of population forecasts from the Tayloe Murphy Institute, in an effort to determine the effect of land use changes on the watershed. (4) Based on these tests, it was concluded that land use had little effect on runoff during precipitation events of this magnitude. The reason for this is that the soil rapidly becomes saturated. It is likely that the effect of land use on runoff during lesser storms would be somewhat different.(5)

Although the program appears in its entirety in the Appendix, the Holtan equation is briefly outlined to provide an insight into that aspect of the module.

The Holton equation defines infiltration as a function of soil water volume (6):

f = a*(s-F)**N+f(c)

where,

f=rate of infiltration in inches per hour

s=unfilled storage potential of a soil above the impeding strata, in inches. This value is usually assumed to be equal to the soil water storage potential between saturation and wilting point (15 atms.).

F=accumulated infiltration in inches

f(c)=constant rate of infiltration after prolonged wetting, in inches per hour.

a and n are constants for a particular soil-vegetative complex.(7)

The runoff section of the watershed model provides the quantities of water contributed to the South River by overland flows. These quantities are introduced at the appropriate river segment in the Water Quality Module.

Endnotes

1. Colston, Newton, V., *Characteristics and Treatment of Urban Land Runoff*, Environmental Protection Agency, 1974, p. 96.

2. *Ibid*., p. 46.

3. Li, Shanholtz, Contractor, and Carr, *Hydrologic Response Units Based on Characteristics of the Soil Vegetative Complex With a Drainage Basin*, Virginia Polytechnic Institute and State University, 1976, p. 7.

4. *Ibid*., p. 25.

5. Ross, Blake, *A finite Element Model to Determine the Effect of Land Use Changes on Flood Hydrographs* Master's thesis, Virginia Polytechnic Institute and State University, 1975.

6. *Ibid*., p. 6.

7. A is a constraint which reflects the effect of vegetative cover. It is assumed constant for a given storm, but will vary with the season. More recently, N has been defined as the ratio of plant available water to gravitational water in the "A" soil horizon.

8. Li, Shanholtz, Contractor, and Carr, p. 63.

9. A storm hydrograph model has recently been structured (Shanholtz, *et al*.) to provide an effective simulation of storm runoff from a given watershed with input data that contains different levels of spatial resolution. The

basic assumption was that by minimizing the aggregation of those watershed related properties that inherently can have tremendous spatial and temporal variability, storm water runoff predictions can be improved for unguaged areas.

Spatial variation is described by two distinctly different discretization processes. Soils and land use data were used to delineate "homogeneous" response units to improve spatial and temporal estimates of rainfall excess. These sub-divisions focused on the minimization of the aggregation of the dynamic hydraulic storage properties of soils and surface conditions. A parametric soil moisture accounting algorithm was used to generate rainfall excess for each unique response unit.

MODULE II

3.22 Water Quality Module

This sector of the model deals with the quality of the water in the South River within the Upper South River watershed.

Inputs and Outputs of the Module

The listing of inputs and outputs and the abbreviated flow diagram, Fig. 9, outline the basic operations of the Water Quality Module. The model can accommodate point source inputs for up to 1000 stream segments of any length.

Inputs to the model -

K1 (deoxygenation rate) for stream segment

K2 (reaeration rate) for stream segment

Temperature of stream segment (degrees Celcius)

Length of stream segment (miles)

Velocity of stream (feet per sec.)

Cross sectional area of stream segment (square feet)

Cross sectional area of waste conduit (square feet)

Dissolved oxygen level of waste (mg per liter)

Dissolved oxygen level of stream segment (mg per liter)

BOD5 of waste (mg per liter)

BOD5 of stream (mg per liter)

Outputs from the model -

BOD residual for each stream segment (mg per liter)

DO level for each stream segment (mg per liter)

There is a wide range of factors which can affect water quality. The model measures the effect of several of these factors in terms of the amount of deviation from a desired steady state condition of the stream.(1) Ideally it would be desirable that the stream always contain maximum oxygen saturation. Waste loading is measured in terms of the bio-chemical oxygen demand, BOD, it creates in the stream. If this oxygen demand is excessive, perhaps resulting in DO levels below the 5 mg/l daily average state standard, (2) then the conditions in the stream are destabilized leading to changes in the quality of water as well as the type of organisms which inhabit the stream.

The BOD value represents the amount of oxygen required by bacteria to decompose aerobically an amount of organic matter in a given period of time at a stated temperature. BOD is determined by the standard equation:

y(t) = L*(1-10**-kt)

As this demand for oxygen increases the availability of oxygen for other living organisms which constitute a healthy stream is reduced - frequently to the point where the organ-isms capable of surviving in the oxygen depleted environment cause dramatic changes in the ecological structure of the stream. The transformation in ecological structure com-pounds problems and can lead to the development of water quality characteristics which render the stream undesirable

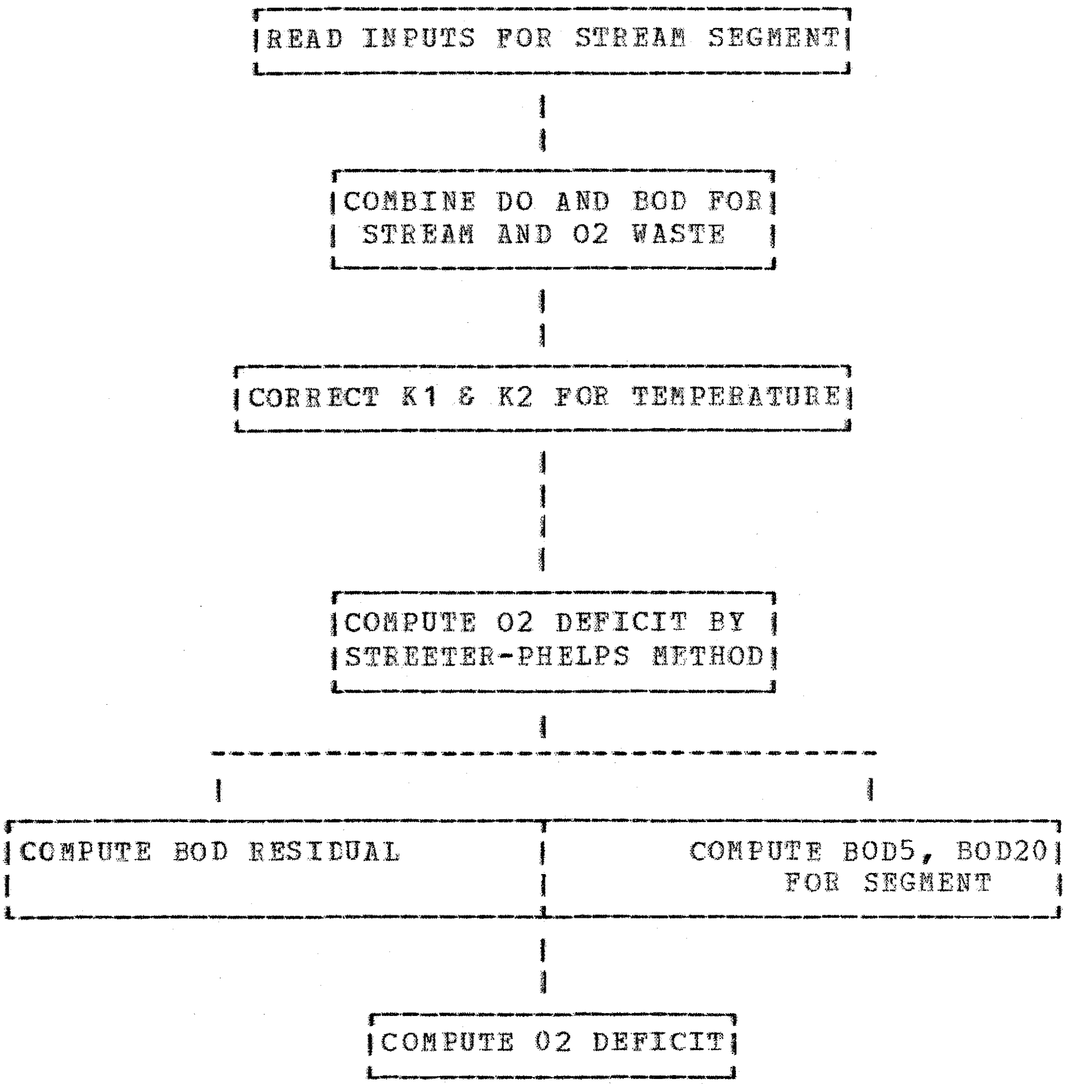

Fig. 9 Flow Chart -- Water Quality Module

for purposes of recreation, industrial production, or consumption.(3)

Phosphorus Loading

Nutrient loadings, particularly phosphorus, are an increasing problem in both treated effluent and non-point source runoff.

All surface water supplies support growths of minute aquatic organisms. The free swimming and floating organisms are called plankton and are composed of animals, zooplankton, and plants, phytoplankton. The latter are predominately algae, and since they are chlorophyll-bearing organisms, their growth is influenced by the amount of fertilizing elements found in the water. Research has shown that nitrogen, phosphorus, and carbon are essential for the growth of algae and that limitations in amounts of these elements is usually the factor that controls their rate of growth.

When nitrogen, phosphorus, or carbon are plentiful, algal blooms occur which may produce a variety of problem conditions. Experience has shown that these blooms do not occur when these materials are present in limited amounts. The critical level for phosphorus has been established as somewhere near 0.01 mg. per liter.(4)

There are other views regarding the levels of P which should not be exceeded. Makenthun recommended that 0.1 mg/l P is an appropriate limit.(5) The South River above Waynesboro has had concentrations of nutrients which exceeded the limiting value of 0.01 mg/l noted by Sawyer.

As noted in the WQM plan (p. 253) the 1975 projected domestic raw waste phosphorus (as PO_4) was 50.8 lbs. per day or 10,200 mg/capita/day. Appendix V of the regional water quality management plan contains phosphorus levels determined over a period of three months during the spring. The mean was .14 mg/l. Studies by Southerland noted an average concentration of .12 mg/l for the months of June and July. It is important to note that in most instances the phosphorus levels exceeded the .01 mg/l critical level.

Most researchers agree that the most vital algae limiting nutrient is inorganic phosphorus.(6) However, this may or may not be the case for the South River.

Because of the importance of phosphorus levels in streams, the various forms of phosphorus should be mentioned. The inorganic compounds of phosphorus of interest are phosphates or their molecularly dehydrated forms. These are normally referred to as polyphosphates. Organically bound phosphorus is normally not a major consideration.(7) The growth of algae is affected by inorganic phosphorus.

All molecularly dehydrated phosphates gradually hydrolyze in the stream and revert to the ortho form from which they were derived.

The amount of phosphorus released by a human is a function of protein intake and, for the average person in the United States, this is considered to be about 1.5 g/day.(9)

The presence of nitrogen in a stream impacts on DO levels. Oxygen is required for the autotrophic conversion of amonia to nitrites and nitrates. Nitrates have already been shown to be a health hazard in drinking water, and nitrites have been revealed to cause brain damage in animals (Brody, 1971).(9) Because of such risks to public health converting nitrogen from the reduced to the oxidized form to eliminate the oxygen deficiency problem may create other more serious problems.

Carbon dioxide is employed by algae in photosynthetic activity. This removal of carbon dioxide can result in pH levels of 8 and 9 in waters with moderate alkalinity. Algae can reduce carbon dioxide concentrations below its equilibrium concentration with an even greater increase in pH. As the pH increases, the alkalinity forms change such that carbon dioxide can be extracted for algal growth from both carbonates and bicarbonates.(10) During the day, algae give off oxygen as a by-product of photosynthesis, but during the night they do not give off oxygen but utilize it in respiration. Variations due to algae production are most pronounced on sunny days. The effect of algae is most noticeable around noon to 3:00 p.m. and least influential on DO levels just before day break.(11)

Equations

The oxygen deficit in a stream can be expressed by the Streeter-Phelps sag equation (12) (Note: The equation is expressed in Fortran programming language because of the inability of the computer to print exponents.)

** = exponent, * = multiplication, / = division

```
D = ((K1*La)/(K2-K1))*((1/10**(K1*t)) - (1/10**(K2*t)))
      + Da*(1/(10**(K2*t)) Where,
```

D = Oxygen deficit at time t, days

La = Initial BOD

Da = Initial 02 deficit, mg/1

K1 = Deoxygenation rate

K2 = Reaeration rate

The Streeter-Phelps equation incorporates two factors identified in the causal diagram, the BOD level and the reaeration from the atmosphere. In an effort to improve the use of the oxygen sag equation as an indicator of water quality, a computer program was developed which permitted coefficients and variables in the model to be dynamic. The South River was subdivided into segments. For each river segment the following are determined:

1. K1 and K2 values
2. temperature
3. velocity and length
4. water flowing into segments from tributaries to the South River
5. point source contributions from STP's

As the plug flows downstream, DO and BOD levels are computed at the end of each segment. K1 and K2 coefficients can be different for each segment and are corrected for temperature. DO and BOD levels as well as water volumes associated with point source contributions from STP's or from tributaries to the South River are combined with levels and volumes from the previous segment.

Contributions from runoff are introduced into segments at several points along the length of the river. The specific segment in which the runoff is introduced into the model is based on values obtained from the water quality management plan for runoff generated in subwatershed areas. These contributions are indicated by Q* in Figure 18, Schematic of the South River. (See page 137)

Specific assumptions required for the use of the model in the South River watershed are outlined in Chapter 4, Application of the Model.

The BOD and DO levels for each river segment which are the output of the water quality Module are next compared with the desired or legally required water quality standards, as indicated in Figure 3, the flow diagram of the model. Within the next module, TOPAZ, costs are estimated for achieving the desired water quality level.

Endnotes

1. In the initial stages of the development of the model, functions were included to reflect respiration levels associated with algae blooms which result from excessive phosphorus loading. Additional equations were developed to incorporate the production of oxygen through photosynthesis. since the South River is not likely to be a phosphorus limited system, these portions of the model and the the results have not been included in the discussion.

2. Virginia State Water Control Board, Water Quality Standard, Nov. 1974, p. 4.

3. Reduction in oxygen levels presents conditions which allow anaerobic organisms to become more successful. Blooms can in turn reduce light penetration in the stream which retards photosynthesis and finally reduces oxygen production.

4. Sawyer, C. N. and McCarty, Perry L., Chemistry for Sanitary Engineers, McGraw-Hill, New York, 1967, p. 467.

5. Southerland, Elizabeth, Agricultural and Forest Land Runoff in Upper South River, Masters Thesis, Virginia Polytechnic Institute and State University, 1974.

6. Ibid.

7. Nemerow, Nelson L., Scientific Stream Pollution Analysis, Scripta Book Co., 1974, p. 115.

8. Sawyer and McCarty, p. 467.

9. Nemerow, p. 115.

10. Sawyer and McCarty, p.338.

11. Nemerow, p. 42.

12. Nemerow, p. 70.

13. Southerland, p. 110.

MODULE III

3.23 TOPAZ Module

One of the principal weaknesses of the analysis of environmental quality has been in relating changes in land use with their associated environmental consequences. The land use sector is comprised of the TOPAZ model.

TOPAZ was first used in the Melbourne, Australia, metropolitan area. The basic idea of TOPAZ, as envisioned by Brotchie, Sharpe, and Toakley, was to use readily available mathematical programming schemes to organize land use development in an urban area. Initially the minimization of public service and travel costs was the main siting objective, although it was recognized from the start that costs were not the only items of concern. Public service expenses included those for water and sewerage, local streets, hospitals, and schools, etc. A prediction was made of how much land would be needed by 1985 for high and low density residential and industrial purposes. TOPAZ then was employed to detemine the amount of each land use activity to allocate to each zone in the metropolitan area so as to minimize public service and travel costs. All solutions were constrained such that (1) areas available for development in each zone of the city were not filled above capacity and (2) all future amounts of needed land uses were allocated. The minimum cost patterns obtained with TOPAZ proved to have some interesting ramifications for development policies in Melbourne (1).

Since its initial application in the Melbourne study, TOPAZ has been expanded in scope and applied to a number of geographic areas. Depending on the particular application of TOPAZ, the objective functions have varied according to such concerns as:

1. Minimizing the total of urban service and transportation costs.

2. Minimizing travel.

3. Minimizing air pollution emissions and gasoline energy consumption.

4. Maximizing accessibility.

In some instances, the opposite objectives have been employed in order to determine the worst case condition for land in an urban area.

It has also been possible to constrain land use developments in various ways. Examples include the prohibition of growth in certain areas of a city, the restraint that urban services must be provided to the existing population before being extended to newcomers, etc. The flexibility to incorporate new objectives and constraints with relatively little change in the overall program structure has now become one of TOPAZ's greatest assets. Added to this advantage is the ability of TOPAZ to indicate the sensitivity of the many outputs (e.g., land use patterns) to changes in difficult to predict inputs (e.g., future population levels). Together, these capabilities for flexibility and sensitivity analysis provide powerful tools for aids to planning and design decision making.(2)

The following are a number of benefits associated with the use of TOPAZ:

1. It highlights extreme positions - usually ones that were never thought of before.

2. It gives decision makers a quantitative basis for helping to make tradeoffs with nonquantifiable benefits and costs.

3. After initial data collection, it can be utilized quickly, even with large scale problems.

4. It can be used simply to cost out or even help verify a variety of solutions arrived at by other means.(3)

Of course, there are disadvantages as well:

1. It requires explicit, well formulated, agreed-upon objective functions and constraints. Such are not usually readily available.

2. It requires accurate data, which often are difficult and expensive to collect.

3. It is based on the assumption of homogeneity within zones and nonconnectivity with parts of the world outside the study area.(4)

It should be noted at this point in the discussion that no quantitative technique can be successfully employed without being taken in the context of well-informed judgement.

The application of TOPAZ to the South River watershed will provide a means of prediction by way of a tested model future land use patterns which would be the result of various population horizons.

Although only the sewer and water submodel was applied in this study, by linking TOPAZ to the other environmental quality models the following objectives can be accomplished:

1. Using the costing function for sewer and water facilities, costs for the provision of service for each land use configuration can be determined.

2. For various population horizons, the environmental consequences in terms of water quality can be forecast.

3. Perhaps most important, solving environmental quality problems from the perspective of land use development strategy compared to the provision of treatment facilities can be compared via a cost function.

Water and Sewer Cost Model

The models described are capable of providing cost estimates for any type of development pattern in any part of the developing area. This capability is much more exhaustive than the traditional one in which the designer has only to determine the costs for various size pipes and treatment plants to fit prespecified amount and distribution of activities. The models thus take advantage of as many general conditions as possible. As an example, although different models are proposed for the water and sewer systems, these services have essentially the same form and structure. Both are composed of basic elements that may be identified as sources of headworks (water and sewage treatment plants) and piping networks that distribute water or collect sewage. Both trunk lines and secondary lines are considered here to be part of the piping networks, although the major focus is on trunk lines.

The overall model depends first upon information regarding the existing systems that may be improved or expanded. By utilizing this information along with estimates of the increased demands imposed on the systems by the total amount of future activities, the planner can utilize the system more fully or construct new lines.

The complete utilization of existing lines involves only the costs of a connection fee plus some incidental costs for secondary lines. These latter costs vary according to the existing degree of development of the zones. However, after the demand on the system reaches the ultimate capacity of the system, new lines must be constructed or older lines replaced by larger ones. The new construction depends on the length and size of the line required and on the other physical elements such as slope, bedrock conditions, and elevation. This new construction expense is prorated to various zones on a per acre cost basis, which varies with the activities to be assigned to a zone and with the pattern of development of adjacent zones. The models thus take into account economies both of scale and of staging construction from zone to zone.(13)

Because of the similarity in the models for water and sewer systems, only an outline of one will be presented.

Input data regarding existing development and that to be allocated to each zone are provided by TOPAZ. For each link in either system the model then performs the following operations:

1. Calculates Demand- The designs of both sewer and water systems are normally based on the demand created by certain population levels in a study area. Since land uses in TOPAZ are distributed in acres, demand calculations in the cost models have been specified in these terms. To simplify matters, demand has been given a common base of the quantity generated by one acre of single family development. The demands for all other activities are assumed to be proportional to

that for this common base. Design flows are then calculated by multiplying the number of acres of each allocated activity by the appropriate ratio to the single family base. This procedure utilizes the population densities of each activity found in TOPAZ plus subjective information regarding the flow demanded by certain activities that have no constant density, i.e., parks and commercial activities. For the purposes of this analysis equivalent demands are placed on both the water and the sewer systems. In other words, one acre of single family activity places a demand on the water system of 4400 gallons per day and generates the same amount of sewage. Although the actual sewage generation may in fact be only about 80 percent of water consumption, factors such as groundwater infiltration and other extraneous flows into the sewer system have been assumed to make up the difference.

2. Compares demand with link capacity.
3. If inadequate, selects next larger line.
4. Determine cost of links.
5. Allocate cost to zones.

The output of TOPAZ is an estimate of the cost of the sewer and water system required to service the demands generated by any particular land use plan whose data has been fed into the model. These cost estimates combined with the cost of treatment facilities listed in Appendix C are combined to serve as input to Module IV, the Goal Programming Module.

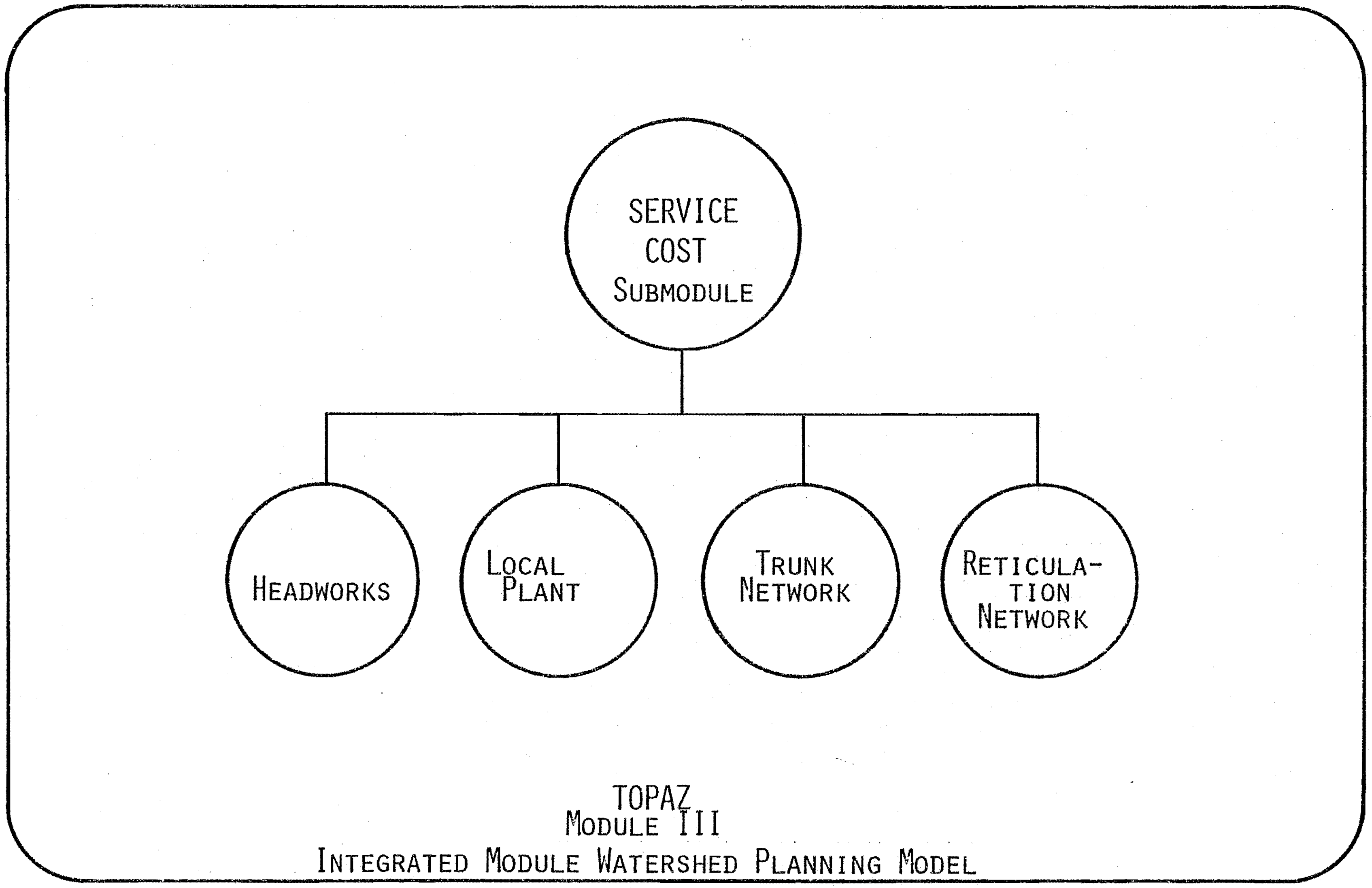

FIG. 10 STRUCTURE OF TYPICAL SERVICE COST MODULE (10)

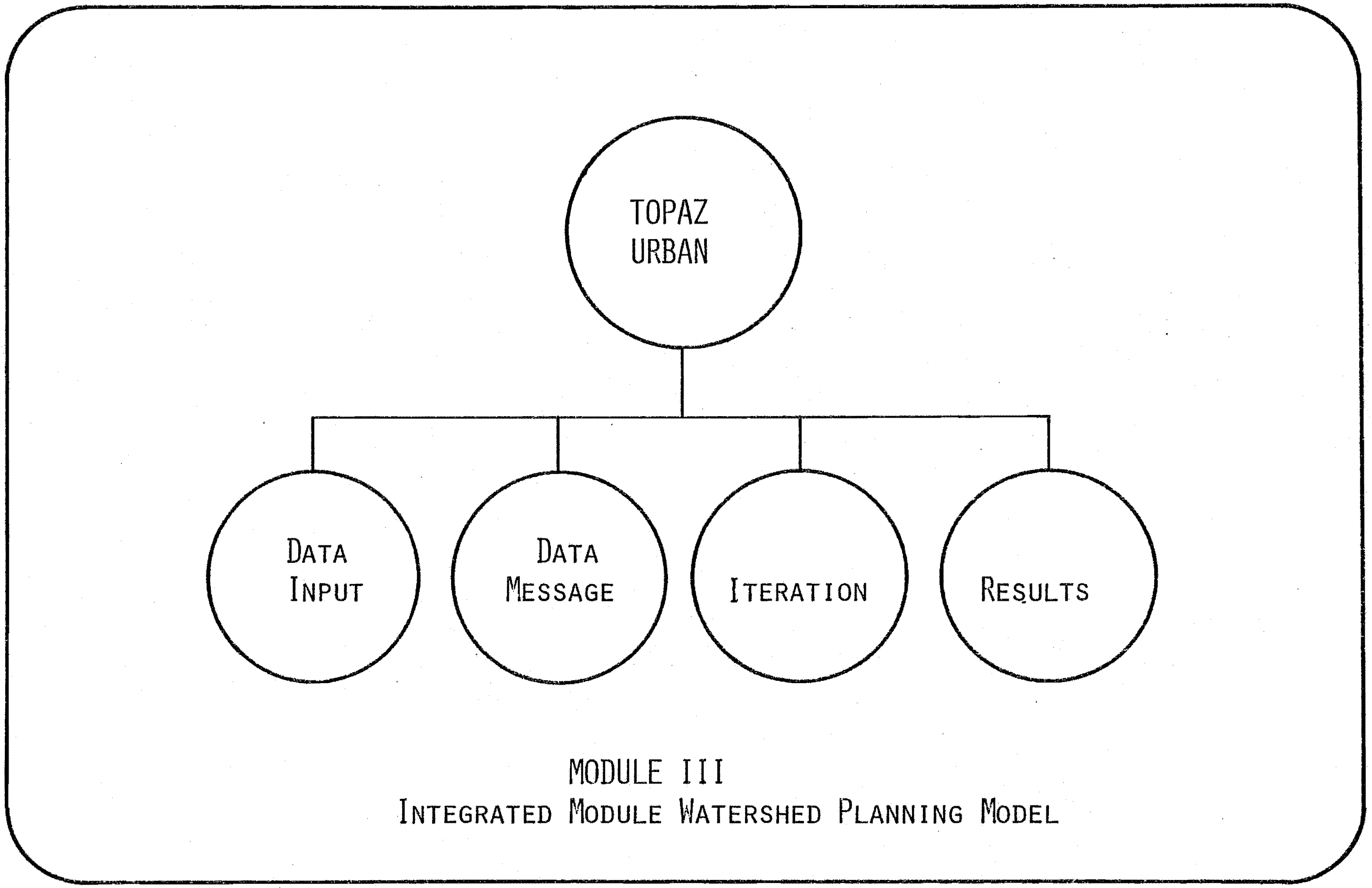

FIG. 11 MODULAR STRUCTURE - TOPAZ TOP LEVEL OF HIERARCHY

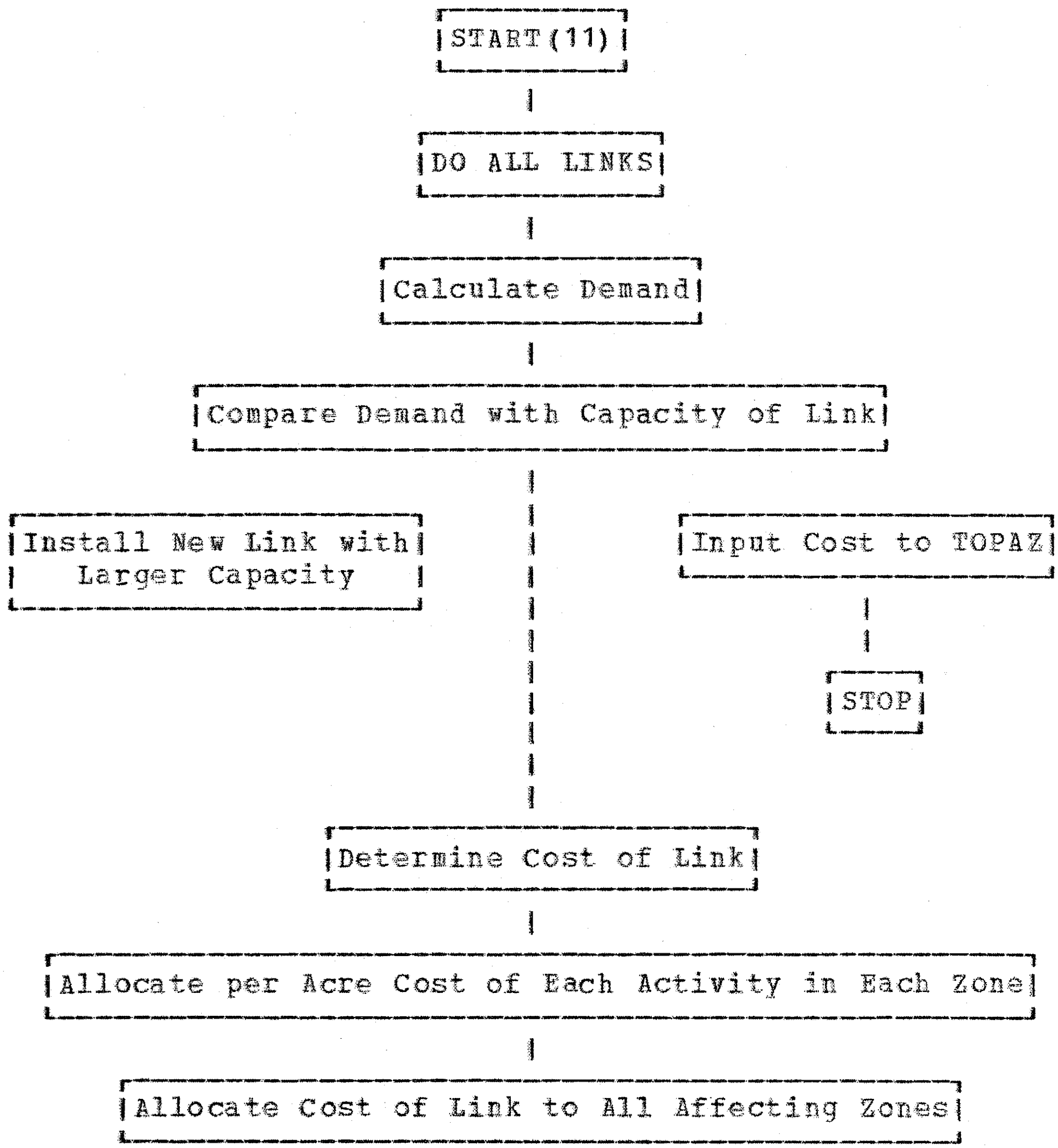

Fig. 12 - Flow Diagram - Sewer and Water Submodels.

Endnotes

1. Brotchie, J., Dickey, J., Sharpe, R., Topaz (Technique for the Optimum Placement of Activities In Zones), Planning Techniques and Applications, under review by Pergamon Press, London, 1977, p. 1.8.

2. Ibid., p. 1.9.

3. Ibid., p. 2.11.

4. Ibid., p. 2.11.

5. Ibid., p. A.3.

6. The explanation is taken directly from Appendix B of Brotchie, et al.

7. Brotchie, Dickey, Sharpe, p. C.1. The listing of inputs is taken directly.

8. Op cit., p. C.1.

9. Ibid., p. 7.11.

10. Ibid., p. C.3.

11. Ibid., p. C.1.

12. Anthony, J. ,Dickey, J., Development of Water and Sewer Cost Models for Utilization in an Urban Land Use Allocation Technique, ORSA/TIMS conference paper, Puerto Rico, 1974, p. 14.

13. Ibid.

MODULE IV

3.24 Goal Programming Module

As a result of increasing pressures from local, state and national constituencies to clean up the environment, the federal government and particularly the Environmental Protection Agency (EPA) have an increasing incentive to carry out programs to accomplish a wide range of environmental objectives. In order to implement any form of environmental management program, objectives and priorities of federal, state, and local government must be tied to and translatable into constraints at each level of the public budgeting process. As stated in the brief summary of the elements of the model, these objectives and attendant priorities must be viewed in the context of other demands for schools, welfare, etc.

The bottom up approach to this model construction echoes the increasing reference to the strategy of decentralizing national water quality management responsibility to the states. Regional offices will give higher priority to integrating their efforts with those of the States, and delegation of specific program areas will be stressed. By the end of FY 1978, EPA hopes that for each of the significant operational areas, other than marine protection (a Federal program), a majority of the states will have assumed the fundamental responsibilities for the conduct of the program.

This view is, of course, contingent upon the States receiving sufficient funding. Also, budget constraints at local, state, and Federal levels may dim this goal.(1)

By linking environmental quality objectives to budgetary constraints, the potential for citizen input is also increased. EPA has stated that States and local agencies must develop effective mechanisms for workable community involvement. For example, State or local advisory committees may be established for each planning area. These committees should include appropriate elected officials as well as other individuals and groups. Constructive participation can benefit all parties. It will help assure decisions which reflect the community's concerns, and it will enhance the public's appreciation of the factors leading to those decisions. An openly developed, responsive water quality management program should enjoy public acceptance and support which is critical to its success.(2)

For the thrusts of EPA's program to become realities and maintain an effective and responsive link with implementation agencies as the scope of federal programs increases, it becomes necessary to begin to decentralize decision making functions. The strategies for this decentralization are dependent upon three factors:

1. Levels of the decision making hierarchy which are most effective for implementing the various programs.

2. Environmental priorities relative to the level of government as well as the geographical and population characteristics where and when the program is to be implemented.

3. The budgetary constraints imposed by a) the tax base and, b) the conflicting needs presented by other necessary programs for which a community must spend its limited resources.

Objectives

The objectives for the development of this module are as follows:

1. To explore the effect of shifting priorities at different levels in the decision-making hierarchy on the achievement of goal sets.

2. To demonstrate a means of linking within the same goal set areas which are more readily quantifiable such as water quality and other programs such as child care whose value is less easily quantified.

3. To make explicit the tradeoffs in terms of goals achievement between the many factors competing for limited resources.

Federal

--1

State

--2

Regional (Planning District Commission)

--3

Local

--4

Individual Citizens

--5

Fig. 13 Hierarchy of Decision-Making Levels

Goal programming finds its origins in the concepts of linear programming. In fact, it represents an extension of linear programming in which goals that are unattainable within the limits of available resources are incorporated into the process. Goal programming recognizes the reality of the inability to achieve goals yet it does provide a means of minimizing the deviation from the specified goals.(4)

While linear programming can deal with complex phenomena, it is bounded by the one-dimensional quality of its objective function. Perhaps the most significant characteristic of goal programming is its ability to accommodate multi-dimensional problems, where the limits can be specified for subgoals. Goal programming achieves its multi-dimensional quality by establishing a hierarchy of importance among incompatible goals so that lower order goals are considered only after higher order goals are satisfied or have reached the point where no further improvements are desired.

An additional strength of goal programming is that the objective function of a goal programming model may be composed of heterogeneous units of measure, for example, CFM (cubic feet of effluent per minute), BOD (milligrams per liter of biochemical oxygen demand), etc. If it is possible for decision makers to provide an ordinal ranking of goals in terms of their contributions or importance to those affected and all goal constraints are in linear relationships, the problem can be solved by goal programming.

To more clearly illustrate the possible application of goal programming to physical environmental planning it may be helpful to first examine a simple example before proceeding to a more complex problem.

Consider a case where the goal can be achieved by collectively achieving a set of subgoals, x(1), x(2) . . . x(n):

(1) f(x(1), x(2) . . ., x(n)) = a(1)x(1) + a(2)x(2)+ . . . + a(n)x(n) = b

where a(1), a(2) . . ., a(n) are real numbers. If we let x be a column vector with the components x(1), x(2), . . ., x(n) and let a be a row vector composed of a(1), a(2), . . ., a(n), then equation (1) can be expressed as follows:

(2) ax = b

Utilizing the goal programming formulations, equation (2) can be rearranged as:

(3) Min Z = d(-) + d(+)

Subject to ax + d(-) - d(+) = b

x, d(-), d(+) ≠ 0

d(+) and d(-) represent vectors of deviational variables from the corresponding goal. (5)

If the objective function in equation (3) is expanded to reflect an additional variable, $x(2)$, it would take on the form:

$$\text{Min } Z = d(1)(-) + d(1)(+) + d(2)(-) + d(2)(+)$$

(4) Subject to $ax(1) + d(1)(-) - d(1)(+) = b$

or,

$$x(1) + x(2) + d(1)(-) - d(1)(+) + d(2)(-) - d(2)(+) = 0$$

If $x(1)$ was of a higher priority than $x(2)$, the objective function would take the form:

$$\text{Min } Z = P(2)d(1)(-) + P(2)d(1)(+) + P(1)d(2)(-) + P(1)d(2)(+)$$

(5) Subject to the same constraints.

For example, $x(1)$ may be expenditures for erosion control for a particular zone in the watershed and $2000 the maximum expenditure permited for the item.

The constraint equation would take the following form:

$$x(1) + d(1)(-) - d(1)(+) \leq \$2000$$

where, $x(1)$ = amount expended for erosion control

$d(1)(-)$ = deviation below goal

$d(1)(+)$ = deviation above goal

$2000 = budgetary constraint

Goal Selection

Constraint equations are developed for key goals for watershed planning. As a result of several other studies

(6) being carried out at the University a comprehensive list of goals for watershed planning had been developed to accommodate virtually all areas of concern for directing the quality and quantity of watershed development.

From this list of goals the following objectives relating particularly to the water quality aspect of environmental management were developed. The goal equations link the following budgetary factors to budgetary allocations:

Equation No. 1	Nursery school facilities
Equation No. 2	Solid waste disposal
Equation No. 3	Recreational programs
Equation No. 4	Roadway improvements
Equation No. 5	Water treatment
Equation No. 6	Wastewater treatment
Equation No. 7	Runoff control
Equation No. 8	Erosion control.

These equations are of the same form as the previous example (x(n) +d(n)(-)-d(n)(+) = some constraint). The specifics of the equations are outlined in the section, Outputs of the Model.

There are eight equations for each of the 16 zones into which the study area is divided. These 128 equations reflect local preferences and needs as indicated by the extent of the budgetary allocation associated with each item.

Although the budgetary constraint for each item will vary from zone to zone the basic eight equations are repeated for each zone. For example, x(8) is expenditure on erosion control in zone 1; x(16) is expenditure on erosion control in zone 2, etc.

Joint activities between zones motivated by local cooperation or required by state and federal programs are identified by Global Constraint Equations. The following Global Constraint Equations were used in the study of the South River Watershed and are characteristic of the types of budgetary linkages likely to occur between zones.

<u>Equation 1 - Solid Waste</u>

In order to operate an economically efficient solid waste disposal program, all developed areas must participate.

This equation reflects a linking of expenditures for solid waste disposal by three jurisdictions within the watershed. Greenville is in zone 1, therefore the expenditure for solid waste disposal is x(2), the second jurisdiction is in zone 2, therefore expenditure for solid waste disposal is represented as x(10), (e.g., each zone has eight equations, the second of which is for solid waste disposal; therefore, the second equation for the second zone is the tenth variable in the overall set of variables for the watershed.)

$x(2) + x(10) + x(50) + d(65)(-) - d(65)(+) = 2300$

Equation 2 - Erosion Control

The following equation identifies a cooperative effort in eight of the unurbanized zones to minimize erosion in an effort to reduce non-point source pollution.

$x(8) + x(16) + x(24) + x(32) + x(40) + x(48) + x(56) + x(64) + d(66)(-) - d(66)(+) = 14{,}500$

Equation 3 - Roadway Improvements

In order to be eligible for matching funds, the community of Greenville must make an expenditure equal to 15% of the project costs.

$x(4) + x(12) + d(67)(-) - d(67)(+) = 12{,}500$

Equation 4 - Wastewater Treatment

In order to solve the problem of the effluent which is currently being discharged into the South River, Greenville must upgrade its sewage treatment plant. Part of the expansion costs will involve erosion control as well.

$x(6) + x(8) + d(68)(-) - d(68)(+) = 300$

The constraints for each of the objectives were derived from budget figures characteristic of communities in the South River Watershed area. The dollar values represent expenditures for only one year. The lifecycles of various capital facilities associated with a number of the objectives may vary considerably and the variability may result in priority assignments different from those assigned in the model.

The end result of the Goal Programming Module is a computation in dollars of over or under expenditures for each variable in each zone given a set of predetermined priorities and constraints. As noted earlier in Figure 3, if the degree of goal achievement is not satisfactory, a number of options are available to attempt to achieve a higher degree of goal satisfaction.

Endnotes

1. Environmental Protection Agency, Water Quality Strategy Paper, internal working paper, EPA, 1975.

2. Ibid.

3. Ibid.

4. Lee, Sang M., Goal Programming for Decision Analysis, Auerbach Publishers, Philadelphia, 1972, p. 15.

5. Lee, p. 23.

6. Giles, Robert, Design of a Land Use Guidance System for Urbanizing Watersheds, unpublished.

The objectives were taken from a comprehensive list which appears in the above document. However, in order to be fully appreciated they should be considered within the context of other publications prepared by Dr. Giles on watershed planning.

Chapter 4.0

Application of the Model

The application of the model, although simplified, still requires a significant amount of data. Because of the magnitude of the task, the model was tested at two levels. The first level ensured that each of the modules was operational and did in fact produce results which were reasonable and from which intelligent assumptions could be derived for more detailed examination of the other modules. This was done for both the Runoff and Goal Programming Modules. The second level of application involved a more detailed evaluation of the remaining two of the four modules: the Water Quality and TOPAZ Modules. These two modules were selected for detailed evaluation for the following reasons:

1. The problems addressed by these two modules (i.e., preserving an adequate level of water quality while not making unreasonable financial demands on the localities for the provision of infrastructure and relating these water quality constraints to the attendant land use patterns) are perhaps the most pressing problems faced by local, state and regional agencies today.

2. The data bases necessary for utilization of Modules II and III are significantly better than those required by Modules I and IV.

3. The potential for a contribution to the development of the options for the South River watershed is most easily facilitated by the use of these modules.

The second level of analysis involved the following sequence of events:

1. Several runs of the Water Quality Module were conducted using as input assumptions for pollutant loading resulting from the three alternative development plans for the watershed.

2. The indication of the water quality levels which could be expected from the various land use alternatives are compared with the relevant water quality standards.

3. Where there are differences in water quality standards, a number of alternative patterns of infrastructure, i.e., sewer and water networks, were examined employing Module III, the TOPAZ Module.

4. The results of the two modules combined is a description of the various costs associated with alternative schemes necessary to achieve acceptable standards of water quality. The model involved runs of TOPAZ which examined the relationships between three

water quality standards for each of the three alternative land use development plans for the watershed. These three water quality standards were constructed to reflect the requirements of PL-92-500:

a. Best practicable technology, 1977,

b. Best available technology, 1983, and

c. Goal of Zero discharge, 1985.

Figure 14. provides a graphic illustration of the modeling sequence.

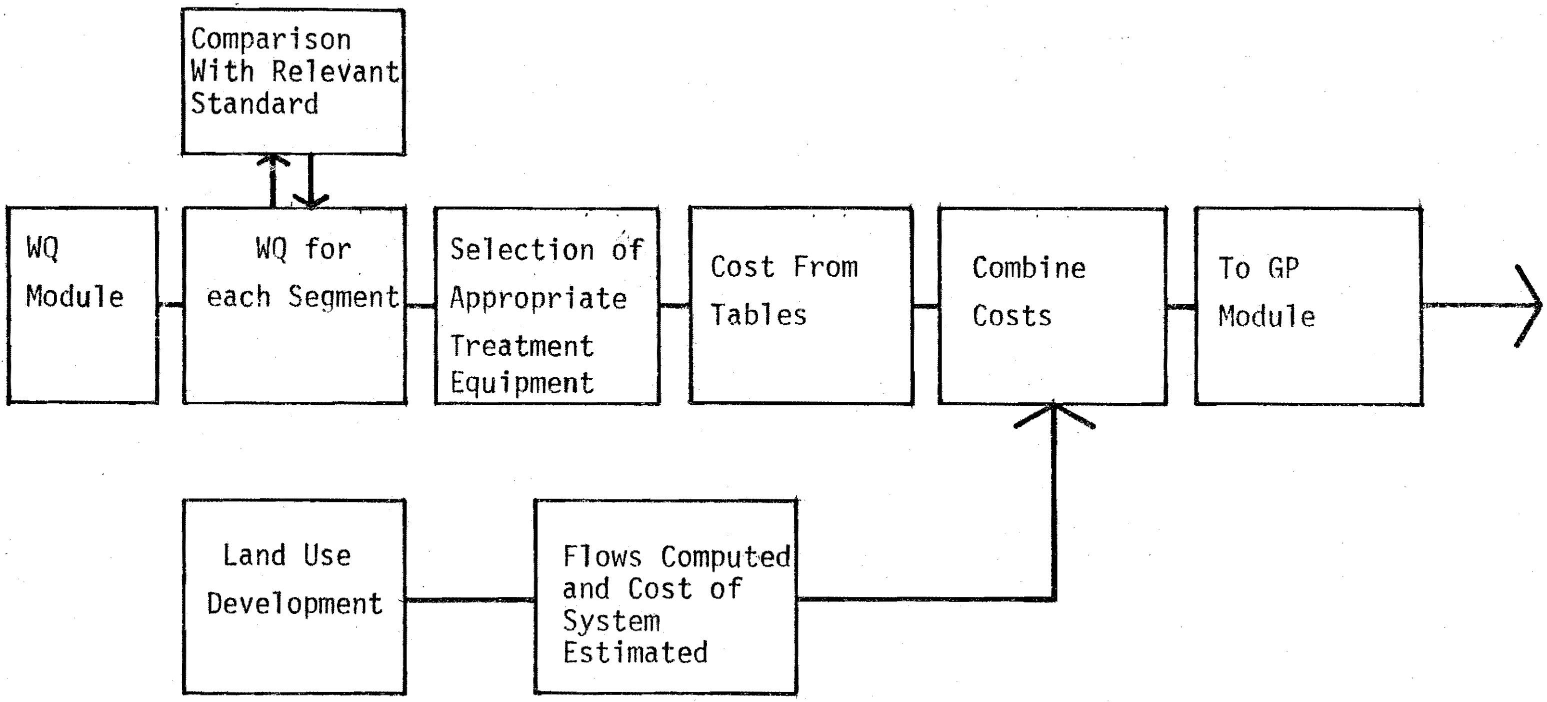

FIG. 14- SEQUENCE OF EVENTS - WATER QUALITY AND LAND USE MODULES

4.1 Alternative Development Plans

As noted earlier three development alternatives for the watershed have been proposed. The alternatives were proposed for the purposes of identifying several likely options for the future use of the watershed as well as to provide three distinct conditions under which the approach to modeling set forth can be more adequately examined.

Studies indicate (1) that there is an increasing need to manage the quantity as well as the quality of the water resources present in the South River watershed. The annual flood damage of approximately 3.28 million dollars (2) in the Potomac-Shenandoah basin of which the South River watershed is a part attests to the fact that the management of water resources is integrally linked to land use development considerations.

The outlines of the land use development alternatives set forth here are intentionally brief since the objective of this work is not to develop a land use plan for the area, but to test the modeling procedure. However, the plans do reflect real options available to the residents of the area and their elected decision makers.

It is also important not to view the development of the South River watershed in isolation. There will be increasing demands for fresh water by the urbanizing areas of the state. A major project has been proposed by the U.S. Corps of Engineers for Verona, Virginia on the Middle River(3).

Studies prepared by the Virginia Division of Water Resources (4) suggest that a well system of approximately 260 wells in the Staunton and Waynesboro area could provide up to 65 million gallons per day. This quantity of additional water could easily support the population projected in the land use development Alternatives 2 and 3.

Discussions of approaches to modeling can be useful up to a point; however, in order to appreciate the critical problems associated with implementation it is necessary that the proposed modeling procedure go through the steps of development and implementation.

In this way problems associated with compatibility as well as lack of information can be identified and the model can be modified to accommodate them.

Three alternatives have been developed for the South River watershed. They are as follows:

1. To preserve the watershed as a natural area so that it may serve as a recreational area for the more urbanized regions of the state.

2. To develop the watershed at moderate density following current patterns.

3. To develop the watershed at a moderate density, but in a polynucleated form rather than continuing the existing sprawl configuration.

Arguments supporting each of these alternatives along with detailed descriptions of land use patterns and infrastructure requirements will be developed. In addition it is important to note that the principal objective of the exercise is to uncover difficulties which may be associated with the integrated, modular configuration of the model as well as how simple it can actually be while continuing to remain of value to the user.

Alternative 1 - Preservation of the Natural Area - Retaining the Current Level of Population

Just as the urbanizing areas of the state will encounter an increase in the demand for water, so too will there be an increase in the demand for open space and recreational areas. Given the natural beauty of this watershed and the fact that a significant portion of its land area is in the George Washington National Forest, one option which might benefit the citizens of the state as well as be endorsed by the citizens of the immediate area would be to preserve the status quo.

The conditions reflected in this alternative represent population levels for 1975.

Alternative 1 is based on the following assumptions:

1. The residents of the area would endorse a tradeoff decision which favors preserving the current population levels over expanding industry and employment.

2. There will be an increased demand for natural recreational areas of the type present in the South River watershed.

The following table outlines the land use and population distributions associated with this plan.

Table 1
Alternative 1 Land Use and Population Distribution

Zone	Res acres	Comm	Agr+Open	Ind	Pop people	Total acres
1	10	0	1508	0	25	1518
2	50	0	6528	0	215	6575
3	10	0	572	0	38	582
4	65	2	9976	1	656	10044
5	40	3	1577	0	240	1620
6	37	1	8311	0	230	8349
7	95	2	7493	0	544	7590
8	42	1	3752	0	225	3795
9	35	1	3000	0	265	3036
10	75	1	12321	0	352	12397
11	20	0	14654	0	112	14674
12	85	8	2938	5	595	3036
13	75	3	5488	0	768	5566
14	75	10	3452	5	640	3542
15	6	0	5307	0	145	5313
16	382	38	5181	40	10200	5641
17	200	25	1286	133	6800	1644
18	18	0	730	0	102	748
19	5	0	745	0	50	750
20	45	9	693	3	250	375
21	11	1	29	1	55	42
22	28	4	20	0	140	52
23	12	0	44	0	32	56
24	60	3	6	5	217	74

Note: The increase in the number of zones from 16 to 24 is a result of the disaggregation of the zone which contained Stuart's Draft. This was done in order to preserve the option of testing the sensitivity of the TOPAZ model at a smaller scale. Therefore, where TOPAZ is run 24 zones are used. When the Goal Programming Module is run zones are aggregated to 16. Since TOPAZ precedes Goal Programming in the modeling sequence, there is no difficulty in organizing input data for the Goal Programming Module.

Alternative 2 - Development of Moderate Density Following Current Patterns

1. Given the current structure of the construction industry and the ownership and selling patterns of land development, there is no indication based on observing the development which has already occurred in the area that there will be any deviation from the current sprawl pattern.

2. The principal generators and directors of growth will continue to be new roadway improvements and the provision of the sewer and water service. Their location, however, will be in response to builder's demands rather than be used as a tool to coordinate development.

3. In spite of continuing price increases in the housing industry, the dominant form of housing will remain the single family dwelling.

Table 2 outlines the land use distributions for each of the zones in the watershed area.

Table 2
Alternative 2 Land Use and Population Distribution

Zone	Res acres	Comm	Agr+Open	Ind	Pop people	Total acres
1	13	0	1505	0	30	1518
2	63	0	6515	0	270	6578
3	13	0	569	0	47	582
4	81	2	9959	2	820	10044
5	10	4	1566	0	300	1620
4	6	1	8302	0	287	8349
7	118	3	7469	0	680	7590
8	52	1	3742	0	280	3795
9	44	1	2991	0	331	3036
10	94	2	12302	0	440	12397
11	25	0	14649	0	140	14674
12	106	10	2913	7	743	3036
13	94	4	5468	0	1460	5566
14	94	12	3429	7	1300	3542
15	8	0	5305	0	181	5313
16	477	48	5066	50	12750	5641
17	250	31	1230	166	7500	1644
18	22	0	726	0	125	748
19	6	0	744	0	60	750
20	56	11	680	3	312	375
21	14	1	26	1	68	42
22	35	5	12	0	175	52
23	15	0	41	0	40	56
24	64	4	0	6	270	74

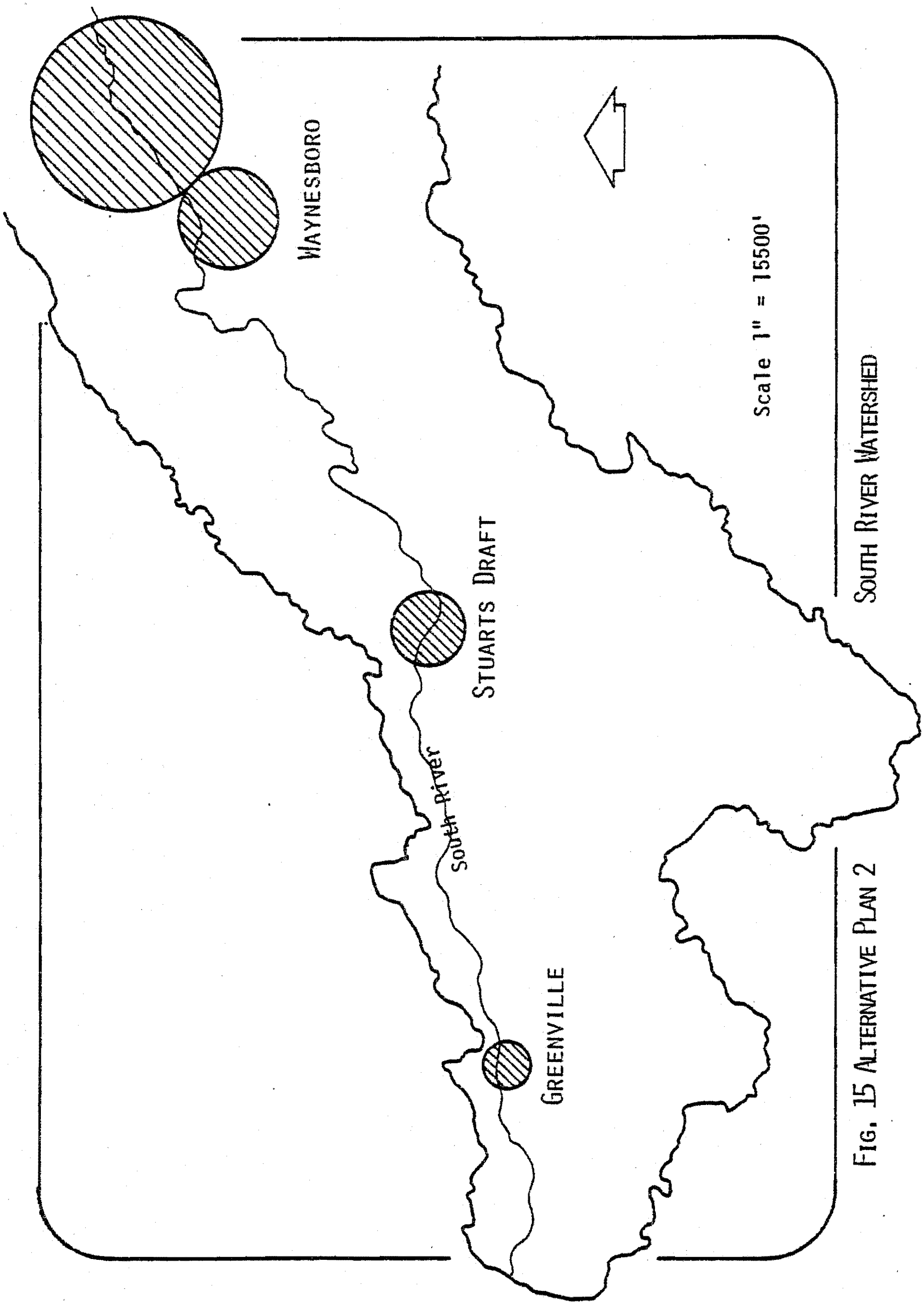

FIG. 15 ALTERNATIVE PLAN 2

Alternative 3 - Existing Pattern Increased to Moderate Density in a Polynucleated Configuration

This third alternative represents another strategy which can be employed by those charged with planning the future development of the watershed. As noted earlier, if the population level of the watershed increases water supply management procedures will be necessary in order to ensure sufficient quantities during low flow conditions.

It is not unreasonable to also anticipate the need to more carefully manage the growth of the land use and population levels. This plan is based on the following assumptions:

1. Prime agricultural land such as that present in the South River watershed will be in increasing demand.

2. An increasingly large sector of the population will continue to migrate from the problems of urban areas in search of a lifestyle which will allow them greater contact with nature.

3. Alternate patterns for rural development must be found which can provide residents with the amenities of both urban and rural lifestyles yet preserve land for agricultural production.

4. The polynucleated configuration makes the most efficient use of the land as well as minimizes the cost of infrastructure.

Table 3 identifies the population and land use distributions associated with this alternative.

Table 3
Alternative 3 Land Use and Population Distribution

Zone	Res acres	Comm	Agr+Open	Ind	Pop people	Total acres
1	10	0	1508	0	25	1518
2	50	0	6528	0	215	6578
3	10	0	572	0	38	582
4	300	10	9719	15	3506	10044
5	40	3	1577	0	240	1620
6	37	1	8311	0	230	8349
7	95	2	7493	0	544	7590
8	42	1	3752	0	225	3795
9	35	1	3000	0	265	3036
10	75	1	12321	0	352	12397
11	20	0	14654	0	112	14674
12	85	8	2938	5	595	3036
13	75	3	5488	0	768	5566
14	158	25	3349	10	3490	3592
15	6	0	5307	0	145	5313
16	382	38	5181	40	10200	5641
17	200	25	1286	133	6800	1644
18	18	0	730	0	102	748
19	5	0	745	0	50	750
20	45	9	693	3	250	375
21	11	1	29	1	55	42
22	28	4	20	0	140	52
23	12	0	44	0	32	56
24	60	3	6	5	217	74

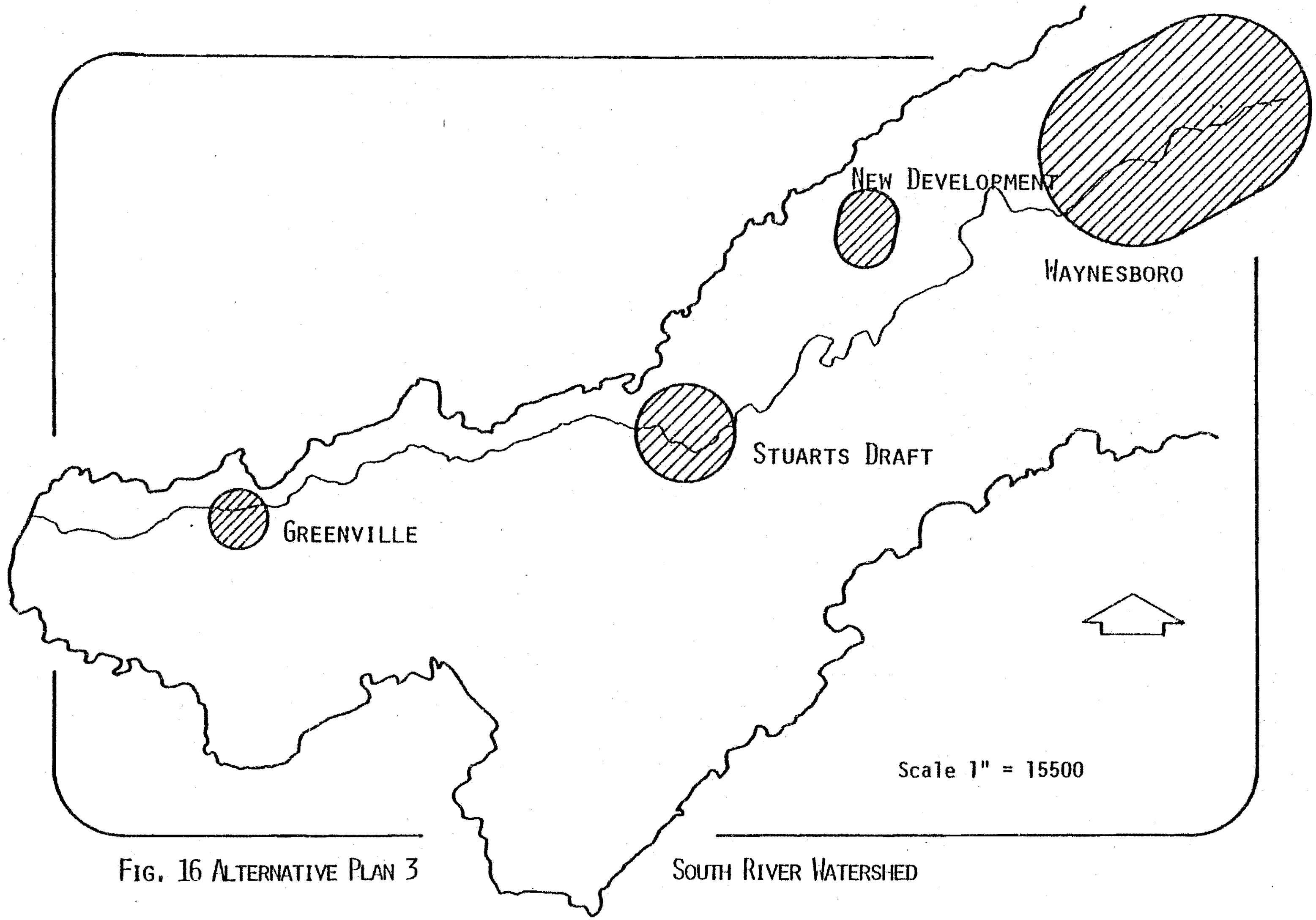

Fig. 16 Alternative Plan 3

South River Watershed

Endnotes

1. Potomac-Shenandoah River Basin, Comprehensive Water Resources Plan, Virginia Department of Conservation and Economic Development, Division of Water Resources, Vol. IV, Water Resources Requirements, 1969, p. 28.

2. Ibid., p. 176.

3. Potomac-Shenandoah River Basin, Comprehensive Water Resources Plan, Vol. V, Engineering Development Alternatives, p. 65.

4. Ibid., p. 86.

4.2 MODULE I - The Runoff and Routing Module

The interpretation of the Runoff and Routing Module requires the user to have some understanding of what type of information he wishes to obtain and a perception of the confidence which is associated with the different applications of the model.

In addition to providing the overland flow, the output of the module provides the data necessary to plot a stream hydrograph. Since one of the objectives of developing a simulation model is to permit the examination of alternative courses of action prior to their implementation, the module possesses the desirable feature of simulating the placement of various retention structures at locations throughout the watershed.

For its use in the Simple Integrated Modular Watershed Model the volumes of discharge are indicators of the quantities of pollutant, BOD. The finite element approach to modeling permits the division of the study area into elements.

Determining the number of elements depends on the distribution pattern and the type of land uses being studied. Obviously, there is the tradeoff decision between the increased data acquisition costs when a large number of elements are used as compared to the increased sensitivity and reliability of the model. Phrased differently, the modeler must determine if the costs of not knowing exceed the costs of finding out.

For the South River watershed it appears that unless only very gross approximations are desired, the six element grid would not provide a satisfactory level of information. Also, because of the land use pattern in the watershed an assymetrical distribution of elements will be present. The southwest side of the upper South River watershed is principally composed of the George Washington National Forest. Any population increases will likely occur either directly adjacent to each side of the river or in the already existing population nodes of Waynesboro, Stuart's Draft, Lyndhurst, and Greenville.

In addition to providing input to the Water Quality Module, this module will assist in providing local and regional planning agencies with data to serve as a basis for flood plain zoning, design of retention structures, reservoirs, and storm sewers. One of the major strengths of the finite element method of runoff modeling is the ability of the hydrologic response unit concept to maintain the spatial uniqueness of the area. This is of particular value in larger watersheds such as the South River because storms over large areas are rarely uniform (1).

Currently, there are more flexible versions of this type of model being developed. Many are capable of a continuous simulation as opposed to a discrete storm event. The fact that this is occurring only serves to reinforce the view that a modular approach to modeling, one which will permit the evolution of the constituents of the model in response to the changing problem environment, is necessary if environmental modeling problems are to be effectively addressed.

As noted in Chapter 3, which outlines the inputs and outputs of the Runoff Module, point source contributions to the South river are based on the discharges in tributaries. In addition non-point source discharges can be estimated based on excess precipitation associated with the overland flow planes.

As initially stated, a detailed analysis of this module has not been carried out; therefore, the inputs to the Water Quality Module are predicated on a number of assumptions regarding flows and the level of pollutants associated with those flows. The principal source for the flow information was the background material for the preparation of the Water Quality Management Plan for the Central Shenandoah PDC.

The non-point source discharges are noted in Fig. 19 which summarizes inputs to the Water Quality Module and the level of pollutant loading are noted in the list of assumptions. Figure 17 is an illustration of the output of the Runoff Module. (2)

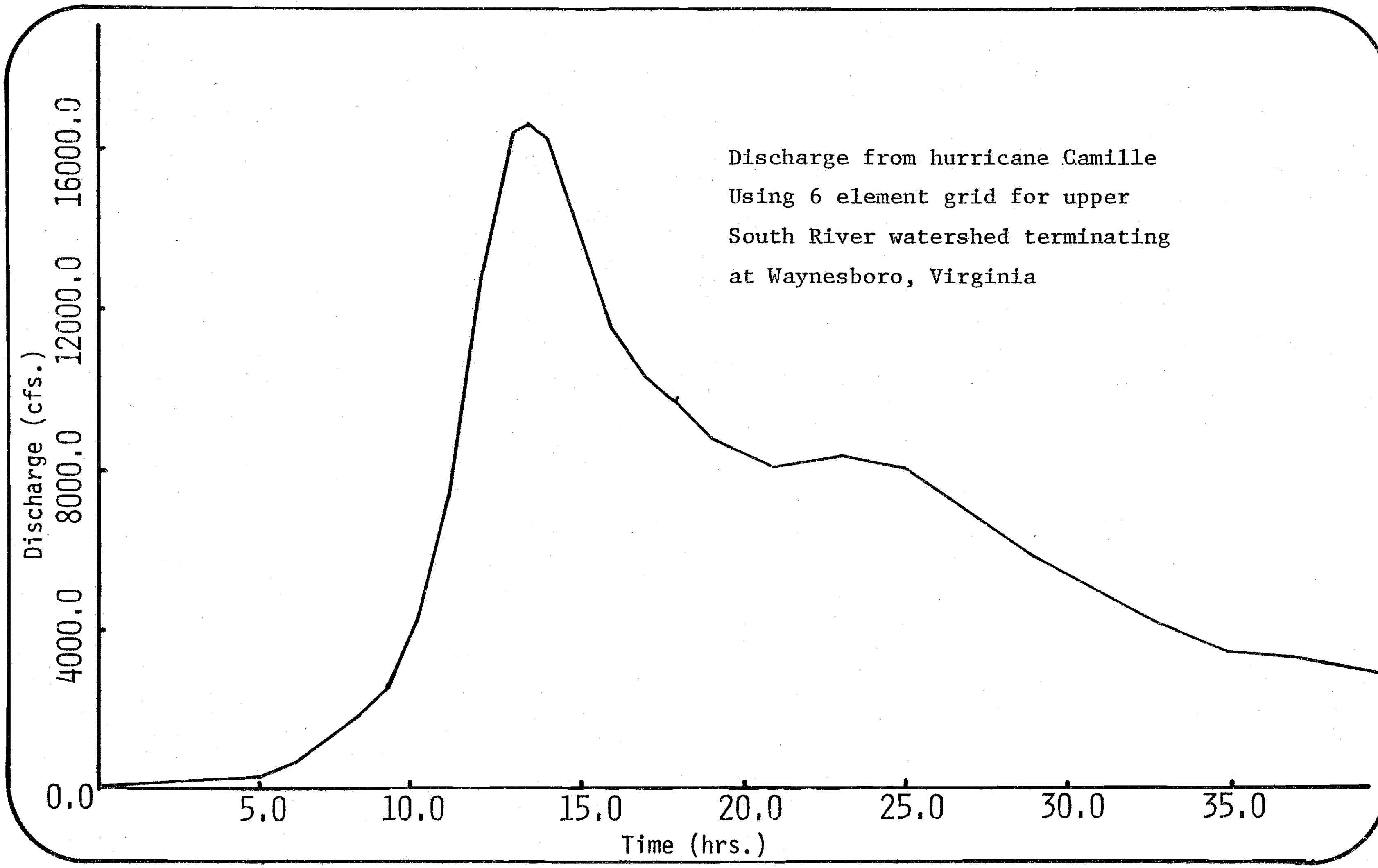

FIG. 17 STAGE TIME HYDROGRAPH

Endnotes

1. Li, Shanholtz, Contractor, Carr, *Hydrologic Response Units Based on Characteristics of the Soil-Vegetative Complex Within a Drainage Basin*, Virginia Polytechnic Institute and State University, p. 48.

2. Ross, Blake, *A Finite Element Model to Determine the Effect of Land use Changes on Flood Hydrographs*, Master's Thesis, Virginia Polytechnic Institute and State University, 1975.

4.3 MODULE II - The Water Quality Module

Three runs of the model were made for each of the land use development alternatives for the watershed. The three runs reflected treatment levels associated with the 1977, 1983, and 1985 goals outlined in PL 92-500. The levels of water quality indicated by the various runs of the model will, when compared with stream standards, indicate the efficiency of treatment which must be provided in order to meet the relevant standards. The cost and capacity of the facilites required to obtain the desired treatment will be taken from the cost tables as outlined in Appendix C. These costs are combined with the results of the TOPAZ sewer and water submodel so that total costs for each alternative can be compared.

Prior to a discussion of the output from the model it is appropriate to outline the assumptions which were made where either data was completely unavailable or where there were conflicting opinions. The nineteen segments into which this portion of the South River was divided resulted from the number of points at which either a tributary intersected the river or where a point source from a municipality or industry was located. As noted in the earlier section, Watershed Model - General Explanation, the number and types of data input required for output to reflect specific qualities of each of the river segments were in most cases not available. This lack of availability of data is not the result of the model requiring particularly complex information but rather the disjointed and incremental nature of the empirical studies of the South River from which data was taken.

The following is a brief discussion of assumptions and data sources used in the application of the model.

Temperature (temp) - The model is structured to use a separate temperature reading for each segment. The model corrects K1 and K2 coefficients for temperature change before the DO and BOD levels are computed. Temperature data were available for points along the upper South River from consultant's reports as well as the Appendix to the water quality management plan. Results of the model in this study are based on the use of the state standard (1) for mountain zones, 87 degrees F or 30.56 degrees C was used for each segment. As temperature measurements are taken the information could be added to the data base. For example, if one of the industrial operations increased its thermal load, the new temperature reading for the segment could be accommodated by changing a single data point.

Stream Velocity (vs) - Velocity estimates were taken from a report prepared on the South River by Camp, Dresser, and McKee (2). The study noted that the lowest velocity of any of the data samples was 1.85 fps. Upstream from Waynesboro the 7-day, 10-year low flow is approximately 27 cfs (cubic feet per second). The volume of the Waynesboro discharge is approximately 16 cfs. (Camp, Dresser & McKee, p. 5) For purposes of this model, the velocities used ranged from 4.0 fps in the upper reaches of the river to 1.85 fps in the area around Waynesboro. Cairns and Dickson (3) describe the South River as a small river consisting of a series of mill ponds and free flowing areas. They also noted that it is not uncommon to have a flow rate as low as 25 cfs in the critical high temperature time of the year. These characteristics of the South River support the need to employ a model which has the ability to correct for changes in stream characteristics on a segment by segment basis.

The stream velocity is the critical variable in the model because the time, t, used in the oxygen sag and BOD equations is based on the velocity of the

K1 and K2 - Although mention is made in the Sensitivity Analysis - Appendix A there is still not complete agreement on the K2 values which should be used for the South River.

One of the critical factors in the use of the Streeter-Phelps equation is the value assigned to K2. The model used by the Virginia State Water Control Board incorporates the general formula presented by Churchill, Elmore, and Buckingham in 1962 (4).

K2 = aV**b(1)/R**b(2)

where, V = velocity in feet per second

R = mean depth in feet

and, a, b(1), b(2) are constants.

at 20 degrees C K2 (base 10) = 5.026V**0.929/H**1.673

Quite obviously these general values of a, b(1), and b(2) cannot be applied equally well to all of the stream segments. K2 values ranging between .05 and 2.5 or higher resulted from computations which reflected the range of velocities and mean depth for the South River. This view was confirmed in discussions with individuals at the State Water Control Board.

Segment Length (SEG) - The determination of the number and length of segments into which the river was divided was based on two factors. First the location of any point source discharge by municipalities or industries; and second, the location of tributaries to the South River. Obviously the river segments would not occur where every tiny branch intersects the river; however, they were made where major creeks intersected. Segment lengths used in the model are noted in Fig. 18, Schematic of the South River.

K2 - Reaeration Coefficient - K2 at 20 degrees Centigrade (base 10) values range from .05 for small ponds and backwater to 2.5 or higher for rapids and waterfalls. The portion of the South River being examined in this study varies from a small moderate velocity stream to a somewhat larger more slowly moving body of water as it passes the City of Waynesboro. K2 values were determined on a segment

Fig. 18 - Schematic of South River

by segment basis. The formula for the determination of K2 values used by the Virginia State Water Control Board resulted in the previously noted values. K2 values ranged from 1.82 in segment 1 to .14 in segment 19.

K1 - Deoxygenation Coefficient - Just as with K2 the values for K1 are determined on a segment by segment basis. The model corrects K1 and K2 coefficients for temperature. K1 values input to the model ranged from .20 to .40.

VW - Velocity of Waste - The velocity of effluent being discharged into the stream is measured in feet per second. Particular note should be given to this variable because it is also used to account for water from tributaries to the South River. Creeks are considered as point source discharges just as might come from municipal sewage treatment plants. The model can accept this input in two forms. The quantity of discharge can be read in directly or if the dimensions of the stream or effluent pipe along with velocity are provided, the model will compute the volume in the correct units.

AS - Cross Sectional Area of Stream - This variable refers to a typical cross section of the stream taken at the end of the segment measured in in square feet.

AW - Cross Sectional Area of Waste Conduit - This variable is measured in square feet and as with VW also applies to creeks which may feed into the South River.

<u>DOW</u> - <u>Dissolved Oxygen Level of Waste</u> - Measured in mg/l, two means of were employed in determining the value of this variable for the alternative land use plans. For the existing condition of DO values were taken directly from the regional water quality management plan. For the alternative land use plans, DO levels were based on the efficiency of the treatment facilities in the removal of DO based on the equipment associated with BPT and BAT. The cost of those facilities will, of course, be reflected in the TOPAZ sewer and water submodel.

<u>DOS</u> - <u>Dissolved Oxygen Level of Stream</u> - This variable is the DO level in the stream just prior to the discharge point which delineates the new stream segment. It should be noted that no special consideration has been given to the mixing zone.

<u>BODW</u> - <u>Biochemical Oxygen Demand of Waste</u> - As in the case of previous variables, BOD levels for existing conditions were taken from WQM plans whereas for other alternatives estimates were developed based on treatment efficiencies which reflect the current state of the art.

<u>BODS</u> - <u>Biochemical Oxygen Demand of Stream</u> - This represents the existing BOD level in the stream.

An integral part of the water quality equation is the type and level of treatment applied by the localities. The three treatment levels assumed when estimating the effluent discharged to the South River are designed to reflect BPT, BAT, and zero discharge goals. However, what constitutes these conditions is subject to discussion.

Current operational interpretations of BPT are outlined by the following example. If an influent of BOD5 = 240 mg/l, suspended solids SS = 240 mg/l, the effluent would be BOD5 = 30 mg/l and the SS = 30 mg/l. This degree of treatment would reflect efficiency levels of approximately 87.5%.

The Best Available Technology, BAT, is by definition tied to economic constraints. A typical application might include: 1) secondary treatment, 2) chemical addition and settling, and 3) filtration. Assuming the previously noted level of influent, the effluent would be for BOD5 = 1-2 mg/l and for SS = 0-1 mg/l. (5)

In the opinion of some practitioners, levels of treatment for the goal of zero discharge are likely to be the same for BAT.

The Results of the Model

As noted in the earlier description of the model, BOD and DO levels are computed by the Streeter-Phelps equation with coefficients being corrected and modified for each stream segment.

Table 4 outlines the results of the Water Quality Module and compares them to the values shown in the water quality management plan. The results included in the table are BOD and DO levels below duPont at Waynesboro. The specific location is segment 19 of the South River as illustrated in the schematic diagram, Figure 18. Notation in the table relates three levels of treatment to the three alternative land use development patterns proposed for the Upper South River watershed. For example, A2Q2 refers to Alternative Plan 2 with treatment levels equal to BAT.

Three types of observations can be made to illustrate the application of the model's output . They are:

1. description of BOD and DO levels within each of the river segments

2. comparison of the three land use alternatives in terms of BOD and DO impacts on the stream

3. comparison of forecast BOD and DO levels to those which were estimated in the Water Quality Management Plan.

Only Alternative Plan 1 will result in DO levels which satisfy state standards. Since Alternative Plan 1, A1Q2 and A1Q3, is the only one of the three which calls for no increase in population, it can be concluded that regardless of whether the watershed experiences growth in the form of sprawl or the proposed polynucleated fashion, additional treatment facilities will be required for Waynesboro to achieve state standards for DO.

Table 4 Summary Table

DO and BOD Values for Segment 19 South River

at Waynesboro, Virginia

	Water Quality Module		WQMP	
	BOD	DO	BOD	DO
A1Q1	17.0	5.0	3.22	6.06
A1Q2	6.5	6.0		
A1Q3	1.5	6.7		
A2Q1	20.0	3.3		
A2Q2	7.9	4.5		
A2Q3	2.1	4.6		
A3Q1	20.0	3.5		
A3Q2	7.8	4.5		
A3Q3	2.1	4.6		

When the values from the WQMP are compared with the results of the module, the following observations can be made. Since Alternative Plan 1 and the WQMP reflect the same population levels, how can the variations in, for example, DO levels be explained.

There are two types of errors present. A portion of the difference can be explained by the fact that the Water Quality Module assumes a worst case condition for many variables whereas the WQMP represents DO values for a particular time of the year. A second factor is the systematic error contained in the model as it proceeds through the steps of computation. While the 5.0 mg/l from the model and the 6.06 from the WQMP are within the same range, there is of course a 20% higher DO level in the WQMP.

For purposes of examining the use of the Water Quality Module and its interaction with the Land Use Module, let us assume the results are in fact correct. Using Alternative 3, Q2 BAT, the DO level is 4.5 mg/l, a result in violation of state standards. Such a result informs the decision makers that they have several optional means of alleviating the problem. The most obvious is to improve treatment facilities, however, comparison with the DO levels associated with the other two development alternatives illustrates that changes in density and the location of development may also serve to increase DO.

From the Summary Table when A1Q3 and A3Q3 are compared, the DO level of 6.7 mg/l results from permitting no additional population growth to occur in the watershed whereas A3A3 reflects an increase of three thousand in the population.

Also, inspection of the graph quickly reveals areas of the river where no further development should be encouraged, notably segments 7 thru 12. The capability to be refined to fit the area to which it is being applied is a major strength of the model because it permits the changes in land use development patterns, runoff characteristics, inflow from tributaries, temperature, K1 values and the many other factors noted in the description to be reflected in the output of the model. Table 5 outines existing DO and BOD levels along the segments of the river.

The value of the Water Quality Module permits planners and decision makers the opportunity to examine the consequences of land use plans, with varying population distributions and industrial locations. The impact of these decisions can then be computed with the relevant water quality standards and the treatment capabilities of the appropriate jurisdiction.

For example, consider the condition of the treatment facilities at Stuart's Draft. Currently, treatment facilities consist of a 5 acre aerated lagoon and a final clarifier followed by chlorination. The plant is built for 500,000 gpd hydraulic capacity. Given the legislative requirements and the likelihood of some population increase, Stuart's Draft may wish to upgrade its facilities. Using the cost tables in Appendix C, it is possible to relate flows and combinations of treatment processes to costs.

Assume that Stuart's Draft was considering the use of activated sludge, the following costs from the tables could be factored into the decision:

Table 5

BOD and DO Levels of Inflow to Upper South River

Used as Input to the Water Quality Module

Segment No	Q1		Q2		Q3	
	BOD5	DO	BOD5	DO	BOD5	DO
Alternative Plan 1						
8	17.0	4.8	6.5	5.0	2.6	4.8
9	3.2	4.0	3.2	5.0	3.2	4.8
11	17.0	5.0	15.5	5.0	6.0	6.3
16	5.0	5.0	2.0	6.5	1.8	6.1
18	17.0	5.0	6.5	6.5	2.6	6.5
Alternative Plan 2						
4	17.0	3.5	6.5	4.5	2.6	4.5
8	17.0	3.5	6.2	4.1	3.0	4.5
11	17.0	3.5	6.2	4.1	3.0	4.5
16	3.8	4.4	3.8	4.1	3.8	4.4
18	20.0	3.3	7.5	4.1	2.6	4.4
Alternative Plan 3						
4	17.0	3.5	6.2	4.5	2.1	4.5
8	17.0	4.6	6.5	4.6	2.6	4.6
11	17.0	3.5	6.5	4.6	2.6	4.6
15	20.0	3.5	7.5	4.6	2.0	4.6
16	2.1	3.5	2.1	3.5	2.1	3.5
18	20.0	3.5	7.5	4.5	2.0	4.5

Capital costs= $916,945

Operations and maintenance = $45,357

Annual costs = $128,575

Present worth = $1,416,711

As the reader is likely to be aware the addition of secondary and/or tertiary treatment is not simply a matter of connecting a single device to a treatment plant. Secondary treatment may be accomplished by activated sludge or trickling filters plus sedimentation and tertiary treatment, depending on the problems, may involve a series of physical and chemical procedures. Accordingly there are different treatment efficiencies associated with any of these combinations.

One principal consideration for the locality is how to satisfy the effluent standard yet minimize the capital and operations and maintenance costs. Knowing the BOD and DO levels from the Water Quality Module and the costs associated with the various combinations of treatment required to achieve standards, decision makers have better information from which to make intelligent decisions. This information is combined with the output of the TOPAZ Module. A detailed description of its use and relation to the Water Quality Module is outlined in the following section.

Endnotes

1. Water Quality Standards, Virginia State Water Control Board, Nov. 1974, p. 4.

2. Engineering Investigation of Waste Load Allocation in the Shenandoah River Basin, prepared for the Virginia State Water Control Board by Camp, Dresser, & McKee, . p. 5.

3. Cairns, John, and Dickson, K. L., Bulletin 54, An Ecosystematic Study of the South River Virginia, Water Resources Research Center, Virginia Polytechnic Institute and State University, July 1972, p. 3.

4. Churchill, M. A., Elmore, H. L., and Buckingham, R. A., "Prediction of Stream Reaeration Rates", Journal of the Sanitary Engineering Division, ASCE, Vol. 88, No. SA4, pp. 1-46, July 1962.

5. Wiley and Wilson, Inc., Engineers, Architects, and Planners; Lynchburg, virginia.

6. Culp, R.L. and Culp, G. L., Advanced Wastewater Treatment, Van Nostrand Reinhold, 1971.

4.4 MODULE III - TOPAZ Module

Because of the scale of the watershed and the structure of the model, it was necessary to develop separate data sets for Greenville, Stuart's Draft and Waynesboro. For each of these communities data was generated which reflected land use and population characteristics of the land use alternatives.

The function of TOPAZ in the context of the integrated, modular watershed plannng model is to provide a link between land use development, water quality and the cost of facilities and the infrastructure associated with these two elements. Given information on the highway and sewer and water networks regarding cost, capacity and location, the model allocates future population over available land in the study area. The sewer network associated with the flows generated by the particular land use distribution is sized and cost figures generated. Fig. 19 depicts the type of interaction which occurs between the TOPAZ and Water Quality modules.

To explain the diagram consider the following. SA2 is the land use pattern and attendant location of sewer and water facilities reflected in Alternative 2 for the town of Stuart's Draft. The output from the TOPAZ model is the cost of this particular sewer and water system.

By comparing the output of the Water Quality Module with the relevant State standard , it can be determined if additional treatment is necessary. Over the next seven to ten years, depending on the extensions congress passes to delay the implementation of PL-92-500, each locality must provide treatment facilities to comply with the treatment levels and efficiencies associated with BPT, BAT, and zero discharge. The cost tables in Appendix C are designed to provide cost estimates for a number of possible combinations of treatment facilities. The cost estimates taken from the tables are combined with the costs generated by TOPAZ to provide an estimate of the funds required for the sewer and water lines and treatment facilities for each land use plan. In figure 19 the cost estimates from TOPAZ for Stuart's Draft for Alternative Plan 2, SA2, would be combined with treatment facility cost to attain, for example, BPT, which is represented in the diagram as Q2. The boxes labeled 1 thru 5 for each water quality level represent the possible combinations of costs of the sewer and water systems and treatment facilities for the five community plans examined by the model. The combination of these two components for alternative land use plans provides decision makers with an informed base for action.

<u>Assignment of Capital Costs</u>

Before any overall conclusions can be drawn in favor of any of the development proposals for the watershed, it is necessary to assign the cost of treatment facilites to each of the networks.

Because of the changing economic environment, this in itself is a difficult task. Capital costs and operations and maintenance costs were determined(1) for the following prccesses:

1. preliminary treatment
2. pumping
3. primary sedimentation
4. trickling filter
5. activated sludge
6. filtration
7. activated carbon
8. two stage tertiary lime
9. biological nitrification
10. ion exchange
11. breakpoint chlorination
12. ammonia stripping
13. disinfection.

Costs were also determined for the following sludge handling processes:

1. anaerobic digestion
2. heat treatment
3. air drying
4. dewatering
5. incineration

6. recalcination

7. landfill.

Costs for one through five million gallon per day facilities were based on these assumptions:

1. 6.5% interest rate

2. 20 year amortization period

3. land cost $3000 per acre

4. 270.3 national average wastewater treatment plant cost index (Base Year 1958, for 1977 the index equaled 278.3)

5. 191.6 wholesale price index for industrial commodities

6. $6.25/man hour labor rate.

Appendix C contains a complete description of costs used in conjunction with the TOPAZ model.

Assuming that the data from the Water Quality Module resulted from a model which has been calibrated with up to date laboratory analysis, a comparison between the relevant water quality standard and the model results would indicate the magnitude of additional treatment required.

The TOPAZ model links with the Goal Programming Module by providing specific costs for the sewer and water networks. This combined with the cost of treatment facilities is then translated into constraint equations for the Goal Programming Module.

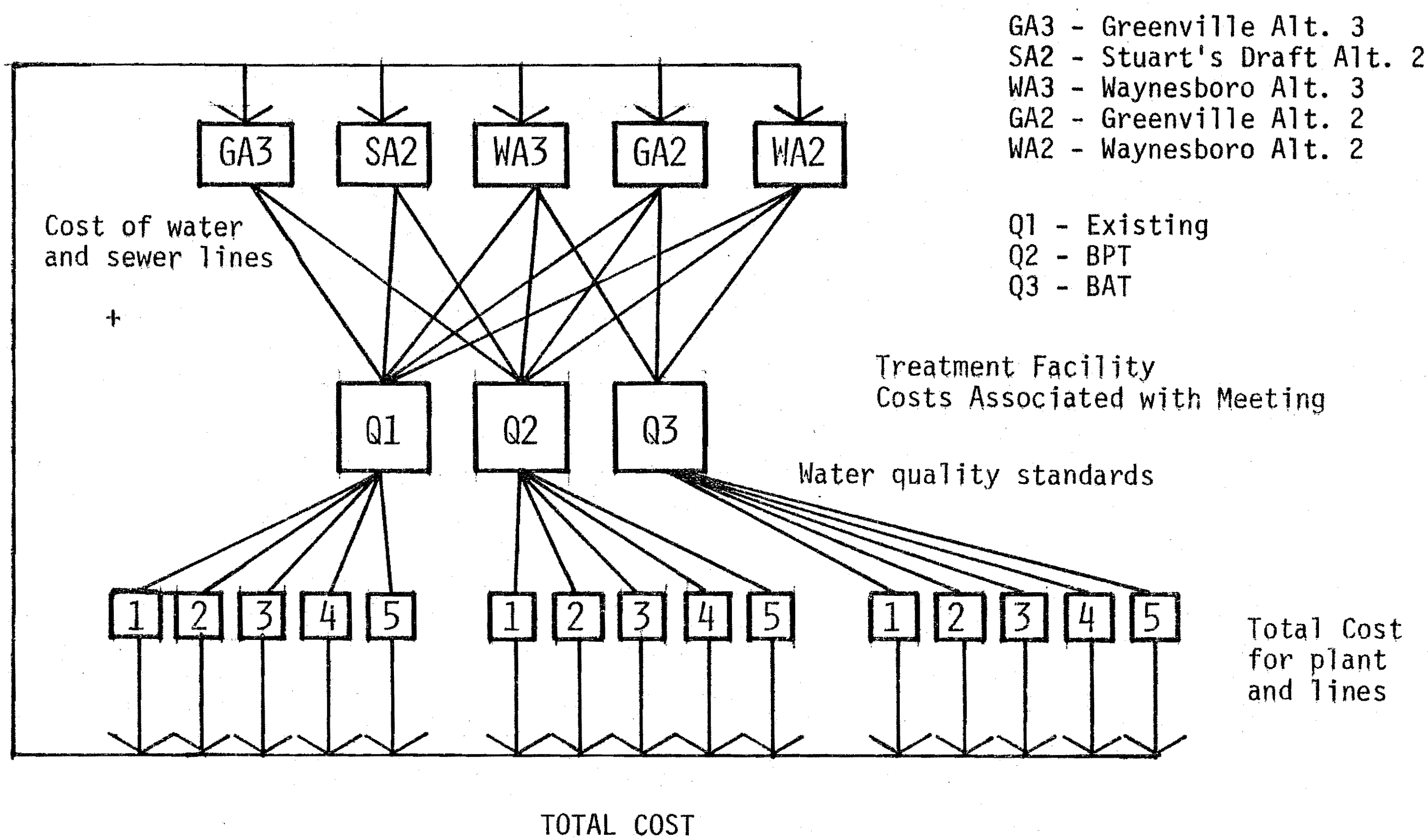

FIG. 19 COST COMBINATION PROCESS FOR NETWORK AND FACILITIES

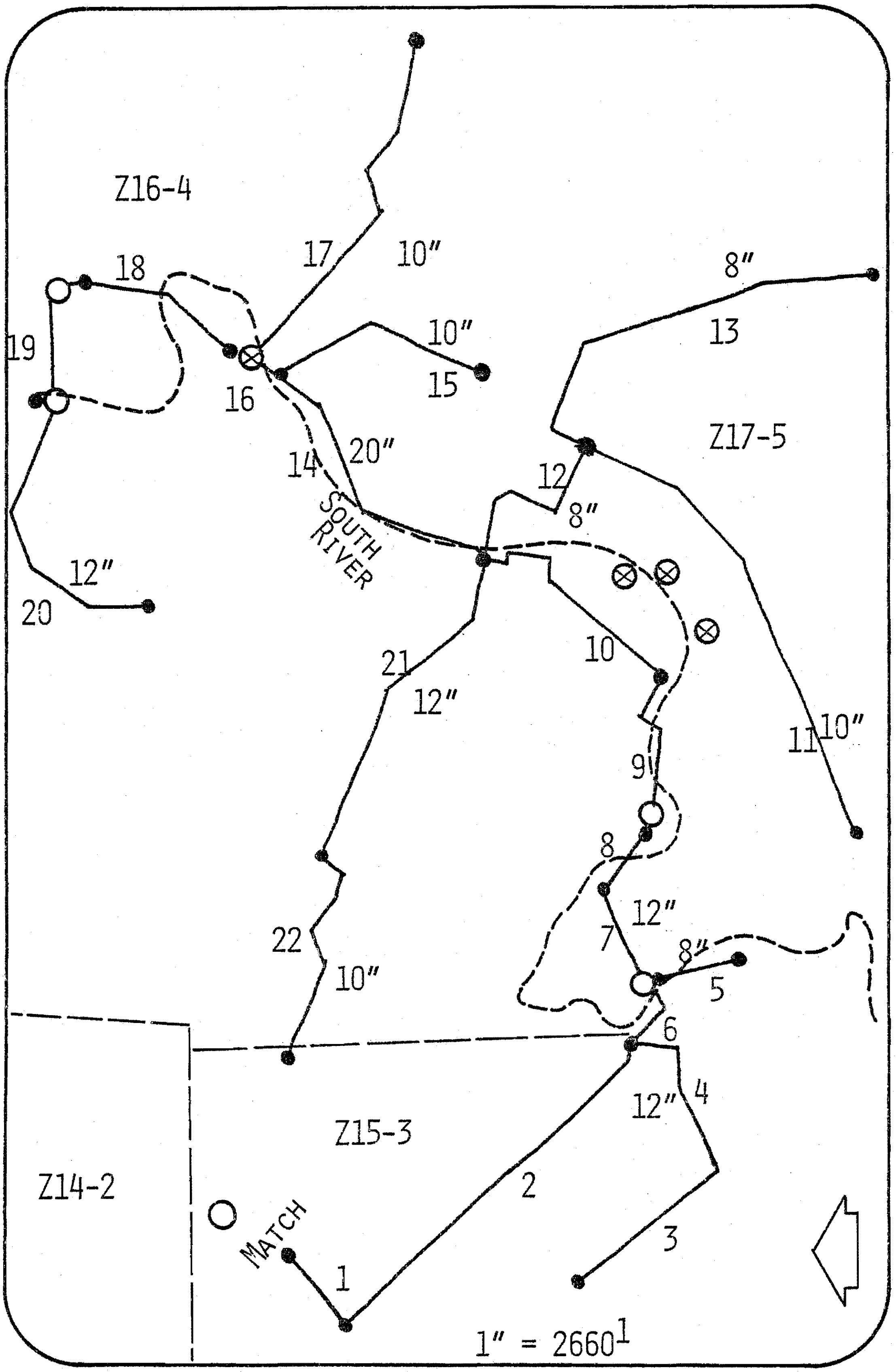

FIG. 20 SEWER NETWORK WAYNESBORO, VIRGINIA

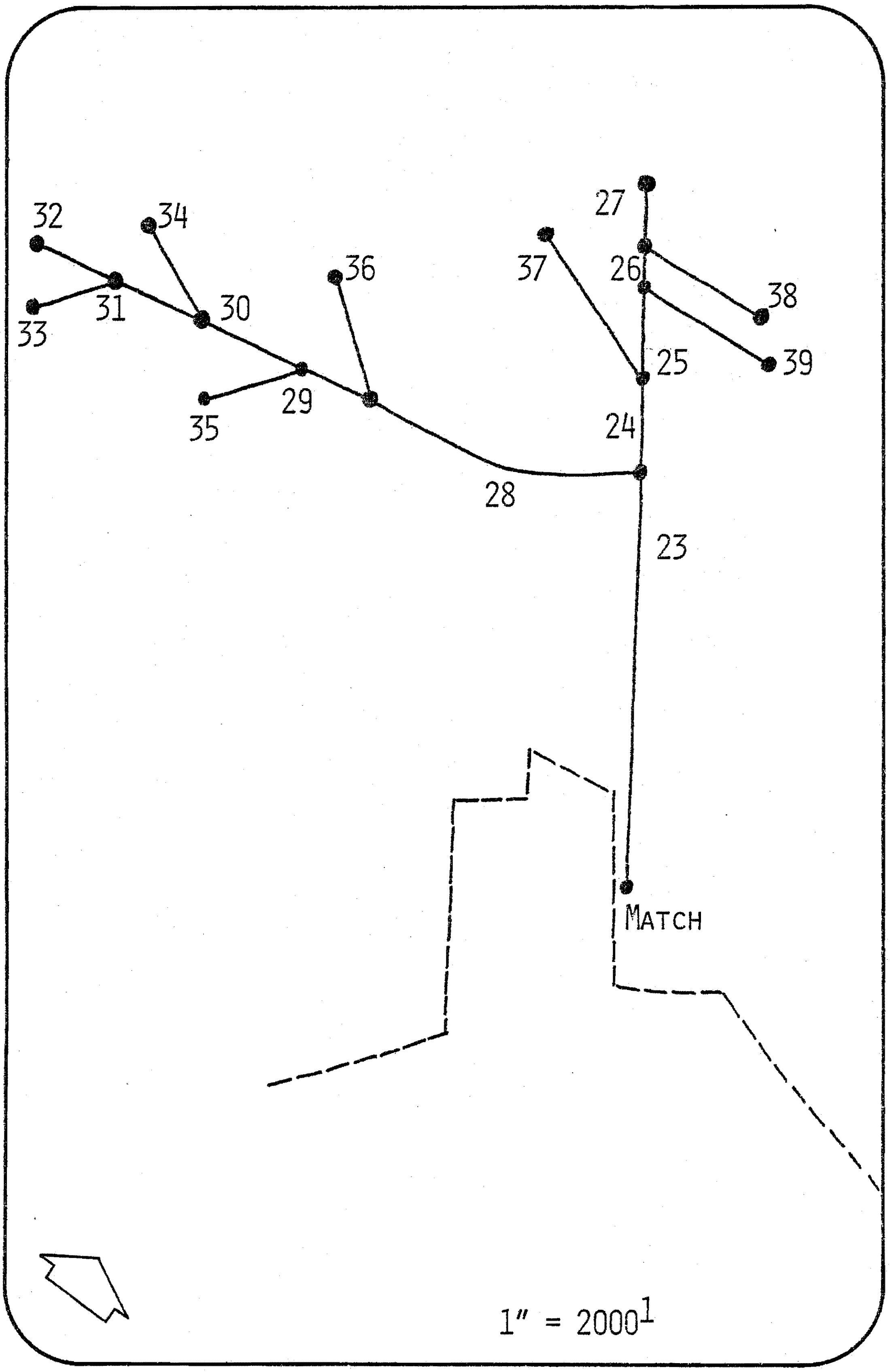

FIG. 21 SEWER NETWORK WAYNESBORO, VIRGINIA

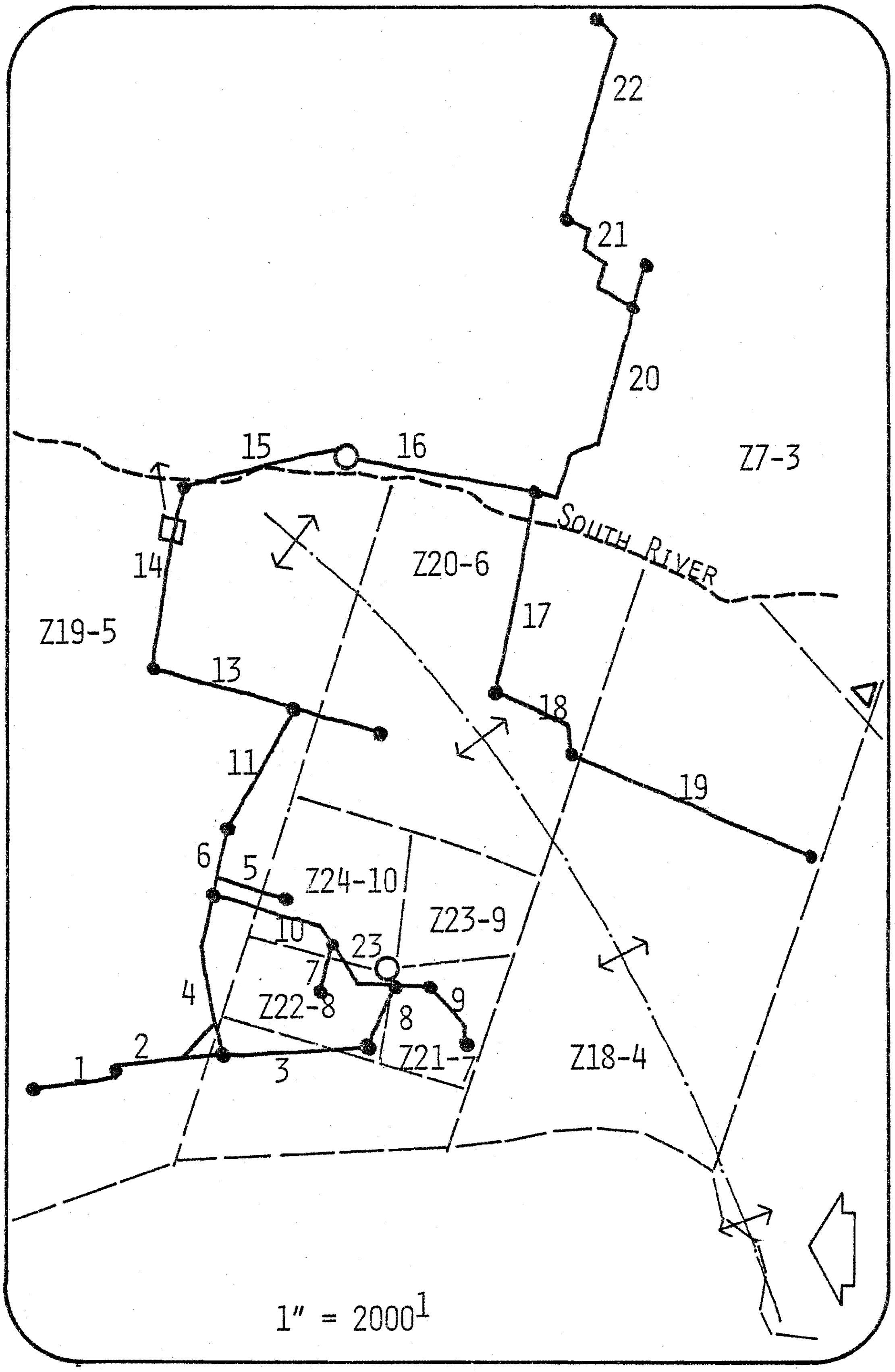

Fig. 22 Sewer Network Stuart's Draft, Virginia

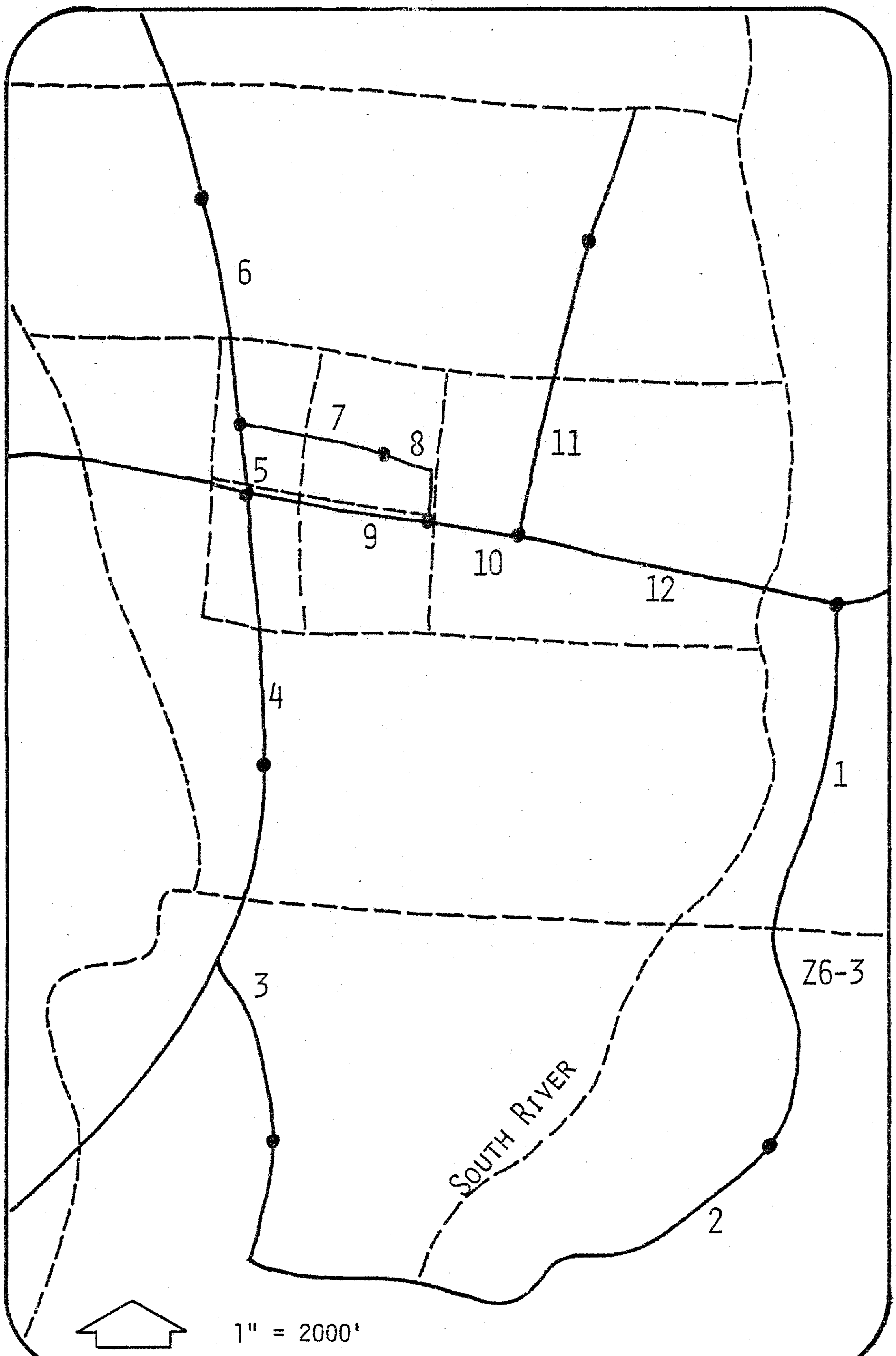

FIG. 23 HIGHWAY NETWORK STUART'S DRAFT, VIRGINIA

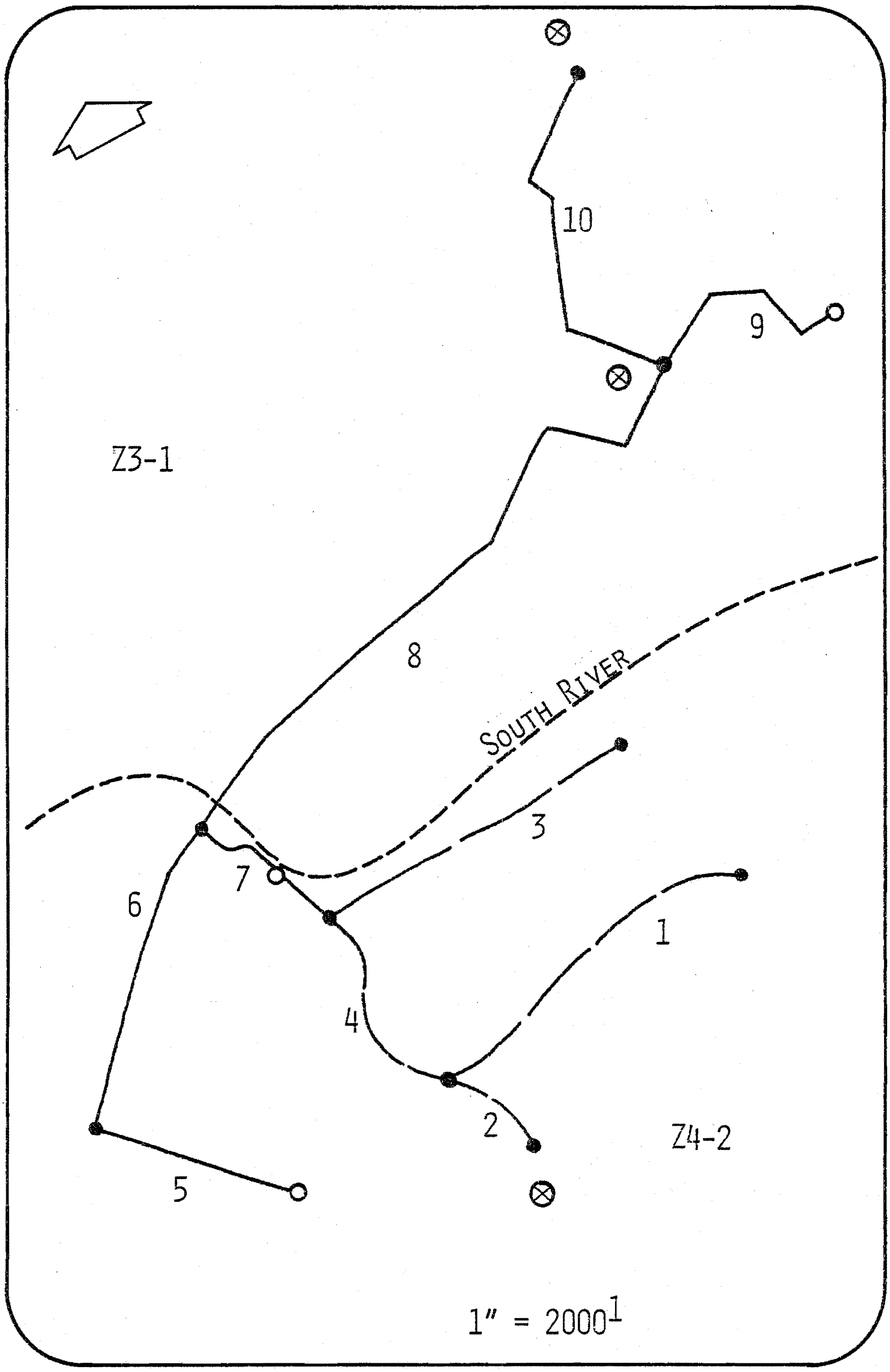

FIG. 24 SEWER NETWORK GREENVILLE, VIRGINIA

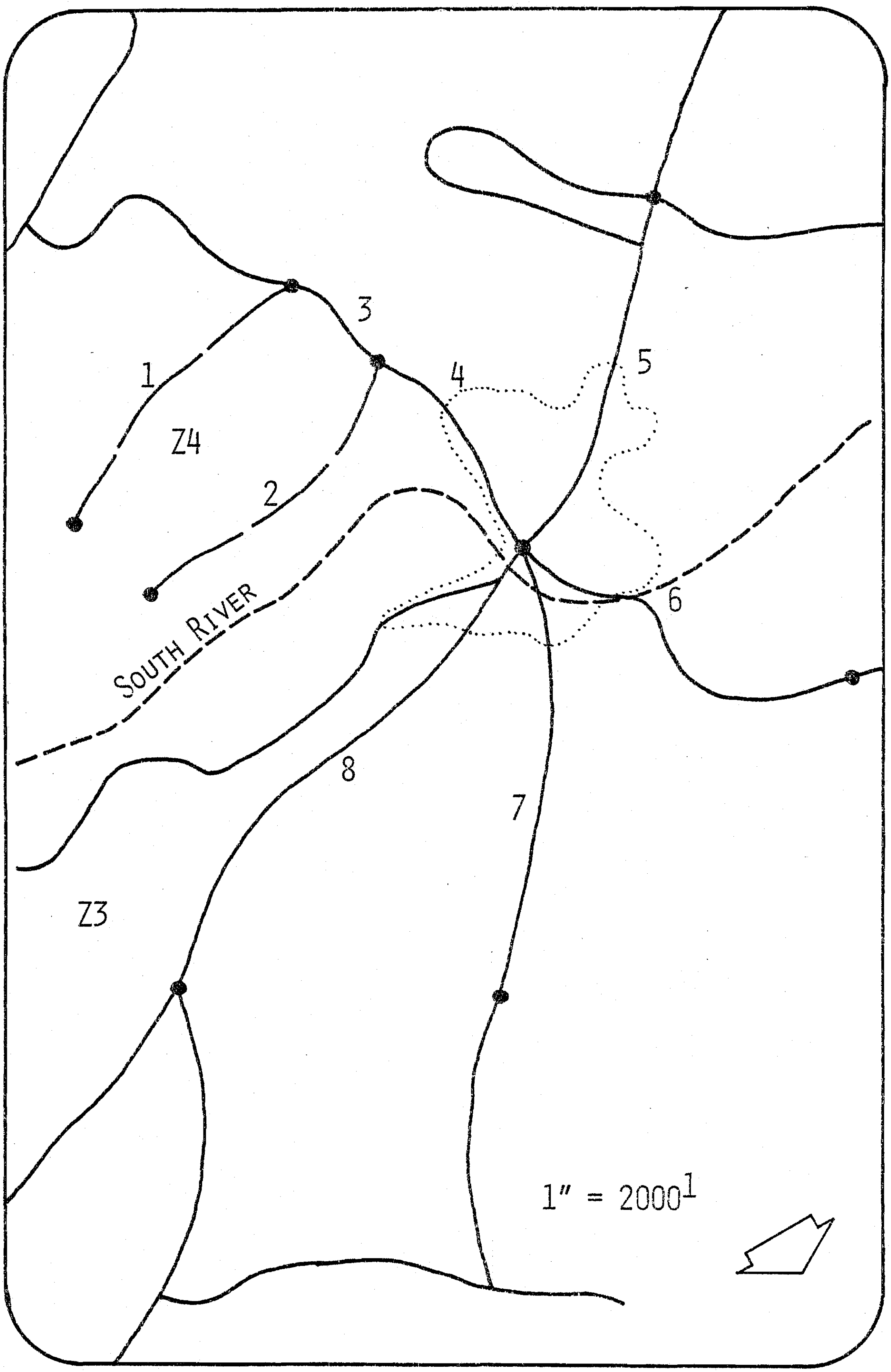

FIG. 25 HIGHWAY NETWORK GREENVILLE, VIRGINIA

<u>Consequences of the Alternative Plans</u>

The alternative plans for the region will be discussed first in terms of the three communities in question and second in terms of the impact on the watershed as a whole.

Based on land use Alternative Three, the entire increase in population for the watershed occurs at two points, one outside Waynesboro and the other at the edge of the community of Greenville. No additional population growth would occur in Stuart's Draft. Alternative 2 distributed the additional 6000 persons in Greenville, Stuart's Draft, and Waynesboro in the same proportions as they currently constitute the existing population of the watershed. The following table summarizes the costs associated with the alternative land use proposals.

The sum of the costs under A2 represent the expenditure for sewer and water systems required to accommodate an additional population of 6000 if current development patterns continue. Subtracting A2 from A3 it can be concluded that the polynucleated pattern would require 10.72 million dollars additional expenditure. Subtracting A1, the existing facilities, from A2, the cheapest alternative, 4.21 million dollars is required to provide services to the additional population. Planners could ask whether or not the anticipated benefit from the population increase justifies the expenditure.

Table 6 - Cost Comparison - Sewer and Water Systems

	A1	A2	A3
		(millions of dollars)	
Greenville	.25	.57	4.20
Stuart's Draft	2.13	2.82	2.13
Waynesboro	18.20	21.40	29.18
	20.58	24.79	35.51

The comparison of costs associated with each of the alternatives provides results which would not likely have been anticipated.

The initial thought would be that the concentration of the two developments of 3000 each would result in significant savings over permitting the growth of "urban sprawl". The outcome is quite the opposite.

What are the possible explanations for this? If the pattern of existing development is examined, it can be seen that a great deal of leapfrogging or uneveness in the development has taken place. This uneven land use development pattern produced large underdeveloped or unused parcels of land; a sufficiently large number to accommodate the future population growth without requiring major modifications to the existing infrastructure.

Given the amount of literature against urban sprawl, it is likely that land use planners would not have anticipated that a continuation of past mistakes would be the least costly alternative.

In order to complete the linkage between the Land Use Module and the Water Quality Module a comparison between the relevant water quality standard and the output of the Water Quality Module must be made and the appropriate treatment facilities identified. The costs of these facilities are arrayed in Appendix C. Again employing the example of the proposed improvements for Stuart's Draft, the present worth of those facilities, $1.4 million, would be added to the $2.8 million required for the sewer and water network for Alternative 2.

Three observations regarding development strategies can be gleaned from the output of the module:

1. To a large degree once the developmental pattern of the infrastructure has been established, the capital investment involved makes the process almost irreversible once it has begun.

2. The development of the watershed is not an instantaneous event. It is composed of thresholds and states of development, some more stable than others. The 6000 person population increase forecast for the watershed lies just under a developmental threshold.

If, for example, the population were to be 20,000 rather than 6,000, the existing infrastructure would not accommodate the population growth. Continuation of the existing pattern may then result in diseconomies of scale. For a population increase of 20,000 the polynucleated development pattern may be less costly.

3. Finally, in order to ensure the implementation of the most cost effective development pattern, the stages and thresholds of development must be identified. Assuming that one is confronted with ranges of forecasts, it is of great importance that the development strategy (e.g., orthogonal grid pattern, polynucleated, etc.) prove to be satisfactory for both the upper and lower limits of the forecasts and that cost be evaluated over a time frame similar to that of the economic life of the infrastructure.

Another diagram of the structure of the model has been included for reference at this point to reinforce the point of the wide range of strategies which can be evaluated by the integrated, modular watershed model.

In order to illustrate the application of the combined results of the Water Quality and TOPAZ Modules, let us procede in a step by step fashion through the results obtained for Stuart's Draft.

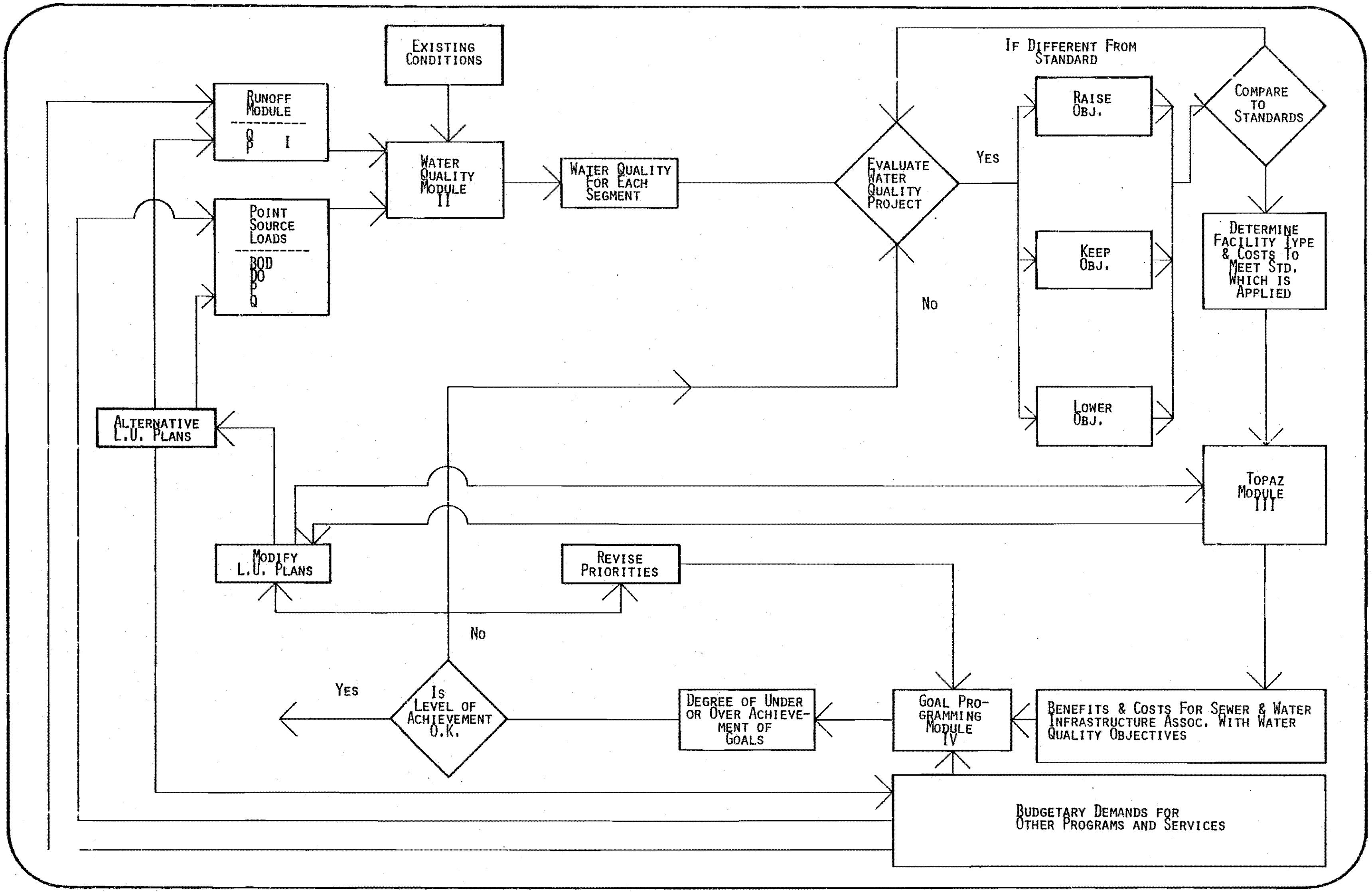

Fig. 26 INTEGRATED, MODULAR WATERSHED PLANNING MODEL

The initial results of the Water Quality Module indicated that for the increased population which would be present in the Stuart's Draft area under Alternative Plan 2. DO levels at the discharge point in the South River would be .5 mg/l below the current standard of 5 mg/l average. If it is assumed that the 1983 water quality standards of BAT will be applicable, what steps should the community of Stuart's Draft take?

The results from the TOPAZ model indicate a cost of 916 thousand dollars for the provision of infrastructure to accommodate the additional population. Next it is necessary to determine what constitutes BAT for this particular situation and if in fact it will result in effluent which brings the South River at this point in compliance with the relevant standard.

As noted earlier, current treatment facilities at Stuart's Draft are composed of a five acre aerated lagoon and a final clarifer followed by chlorination. Recent flows of 350,000 gpd have been recorded for a population of approximately 1100 people. If a daily usage rate of 150 gpd is used only 165,000 gpd are generated. Studies indicate that there is considerable infiltration occurring. Assuming the infiltration problem can be solved, it is unlikely that any additional treatment capacity would be required. The problem lies in the efficiency of the process.

Although more detailed engineering studies would be required before specific recommendations could be made, in this instance BAT could possibly be accommodated by the more carefull regulation of the operation of existing facilities or as flows increase replacing the present lagoon with trickling filters or an activated sludge process.

For purposes of this example let us assume an activated sludge process is installed. Based on the cost tables (Appendix C) which have been generated for costs of various types of facilities, the following costs would be associated with the new facility.

Assumming:

6.5% interest rate

20 year amortization period

270.3 National Average Wastewater Treatment Index

191.6 Wholesale Price Index

$6.25 labor rate per hour

$3000 land cost per acre.

The following cost estimates apply:

Capital Cost = $550,167

Operations and Maintenance = $27,214

Annual Cost = $77,145

Present Worth = $850,026.

The present worth must be combined with the present worth of costs generated by TOPAZ of $916,000 for the sewer and water network. The resulting cost is $1.76 millions.

The cost estimate takes on meaning only when it is compared to alternatives for development. If several alternative land use allocations were developed at the same population levels, the most cost effective land use plan in terms of infrastructure could be determined.

Two questions should be raised at this point:

> What relevance does this have for evaluating development alternatives for the watershed?
>
> How are the cost estimates integrated into the next module?

Alternative development patterns can be evaluated at two levels. First in terms of the cost for each locality, and second in terms of the overall expenditure for the entire watershed. Alternatives evaluated in this study compare the continuation of existing land use development patterns with the concentrating of future additional population in two new developments, one near Waynesboro and the second near Greenville.

At the local level the output offers a realistic view of the cost of providing sewer and water facilities for proposed new development. Frequently, the need to build parallel pipelines or replace existing ones cannot be anticipated by looking only at new developments one at a time. This piecemeal approach to the evaluation of new developments characterizes the process used by most localities.

At the watershed level regional planning agencies can evaluate and compare the costs associated with any number of alternative land use plans for the watershed. When one considers the large investment required to provide sewer and water at the watershed scale a technique which might make possible even a five percent improvement could result in savings of hundreds of thousands and perhaps millions of dollars.

TOPAZ also provides the capability of examining ranges of land development costs for each of the land use activities as well as testing variations or interest rates, facility life, etc.

How do these cost estimates relate to the Goal Programming Module? Cost estimates for the construction of sewer and water lines as well as additional facilities are introduced into the Goal Programming Module as budget goals as well as constraints. Since a satisfactory objective would be to build the facility at the cost budgeted, it is a reasonable constraint. These costs are assigned priorities as are other elements in the budget. Full funding of each item in the budget without exceeding available resources is the obvious goal.

Endnotes

1. The computer program which computed costs is the property of Wiley & Wilson, Inc., Engineers, Architects, and Planners, Lynchburg, Virginia. The program was run on Wiley & Wilson's IBM 1130.

4.5 MODULE IV - Goal Programming Module

As noted in the general description of the watershed model, the objectives of the Goal Programming Module were to make explicit the relationship between the public budgeting function and local, regional and state priorities associated with the broad range of factors which compete for the limited budgetary resources. Of particular interest in this study was the development of a tool which could place the concerns for water quality expressed in terms of priorities and budgetary allocations in the spectrum of decisions which the local leaders must operate. This procedure not only enables the decision maker to achieve a better understanding of the consequences of his decision but also makes the tradeoffs explicit so that the public may be made more fully aware of the consequences of establishing sets of priorities and goals to which they expect decision makers to respond.

In the application to the South River watershed, 128 variables were employed to describe the budgetary goal for the eight factors in each of 16 zones (zones 16 and 17 were consolidated to one for Waynesboro in order to keep matrix size to a minimum). Table 7 summarizes the budgetary goals used as input to the model. The output of the model is the degree to which each of the budgetary goals is either over or under achieved subject to a specific set of constraints and priorities. Table 8 summarizes the priorities assigned in each of the three runs of the model and the extent of deviation from the budgetary goal.

In addition to the examination of the distribution of funds for the various zones of the South River watershed, the Goal Programming Module also provides a means of examining the sensitivity of the budgetary process to different combinations of priorities. Two questions can be raised:

1. What effect do changes in priorities on local goals have on achieving regional goals?

2. What effect do changes in regional priorities have on achieving local goals?

Three runs of the model were made in order to explore these questions. The following are the specific equations used in the Goal Programming Module in Zone 1 of the South River watershed. Eight equations were developed for each of the 16 zones. The expenditure levels contained in the right hand side of the equations are based on estimates generated from a review of the budgets of localities in the region. It should be noted that expenditures are estimates prepared for purposes of this study.

<u>Zonal Equations</u>

Equation 1 - Nursery School Facilities

$$x(1) + d(1)(-) - d(1)(+) = 0$$

Equation 2 - Solid Waste Disposal

$$x(2) + d(2)(-) - d(2)(+) = 0$$

Equation 3 - Recreational Program

$$x(3) + d(3)(-) - d(3)(+) = 0$$

Equation 4 - Roadway Improvements

$$x(4) + d(4)(-) - d(4)(+) = 3000$$

Equation 5 - Water Treatment

$$x(5) + d(5)(-) - d(5)(+) = 0$$

Equation 6 - Wastewater Treatment

$$x(6) + d(6)(-) - d(6)(+) = 0$$

Equation 7 - Runoff Control

$$x(7) + d(7)(-) - d(7)(+) = 1000$$

Equation 8 - Erosion Control

$$x(8) + d(8)(-) - d(8)(+) = 1000$$

In order to link the activities within zones to other zones and reflect regional priorities five global constraint equations were also developed.

Global Constraint Equations

Equation 1 - Solid Waste

The relationship reflected in this equation requires that Greenville, Stuart's Draft, and Waynesboro each contribute to the cost of maintaining a land fill for the disposal of solid waste. Much of the operating cost for a landfill are fixed, therefore, in order to meet those costs each locality must pay its share or an undue burden will be placed on the remianing contributors to the land fill operation.

$$x(18) + x(58) + x(82) + x(106) + x(114) + x(112) +$$

d(65)(-) - d(65)(+) = \$58,650

Equation 2 - Erosion Control

x(8) + x(58) + x(48) + x(72) + x(96) + x(104) +d(66)(-) - d(66)(+) =\$24,900

Equation 3 - Roadway Improvements

In order for a particular project to receive funding, it is necessary that the urbanized areas provide 15% matching funds.

x(20)+x(36)+x(60)+x(84)+x(92)+x(108)+d(67)(-)-d(67)(+) = \$57,150

Equation 4 - Waste Water Treatment

As required by new effluent standards, the City of Waynesboro must upgrade its plant to include tertiary treatment.

x(110)+x(118)+x(126)+d(68)(-)-d(68)(+) = \$110,500

Equation 5 - Total Budget for all localities in watershed

{x(i..n)+d(i..m)(-)-d(i..m)(+) = 2,198,400

Where n= 128 variables in the model

and, m = 133 deviations, inclusive of all global constraint equations.

TABLE 7 Summary of Inputs to Goal Programming Module

ZONE	VARIABLE 1	2	3	4	5	6	7	8
1	0	0	0	3000	0	0	1000	1800
2	6000	2000	5000	8000	6000	4000	3500	3500
3	400	800	500	2000	1000	500	250	300
4	500	200	0	2000	0	0	300	300
5	5000	2000	8000	5000	6000	2000	500	500
6	500	200	0	2000	0	0	300	300
7	500	200	0	2000	0	0	300	300
8	2000	1000	2000	7000	6000	2000	8500	7500
9	5000	2000	5000	10000	6000	6000	2500	2500
10	5000	2000	8000	5000	6000	6000	2500	2500
11	63000	50000	45000	95000	55000	95000	11000	10000
12	500	1000	400	10000	6000	4000	5000	6000
13	24000	20000	18000	36000	45000	20000	3000	4000
14	2500	1100	1250	5000	9000	15000	4000	4000
15	0	50	250	2000	1000	5000	2000	2000
16	20000	5700	27000	12000	32000	95000	10500	10500

TABLE 8 Priority Assignments and Deviations

for the Goal Programming Module

Zone	VarNo	Run 1 priority	Run 1 dev	Run 2 priority	Run 2 dev	Run 3 priority	Run 3 dev
	1	1	0	5	0	1	0
	2	1	0	1	0	2	0
	3	1	0	4	0	1	0
1	4	1	0	1	0	3	0
	5	1	0	2	50	4	0
	6	1	0	2	0	3	0
	7	1	0	3	1000	2	0
	8	1	0	2	240	2	0
	9	1	0	5	6000	1	0
	10	1	0	3	200	4	260
	11	1	0	4	5000	2	0
	12	1	0	1	0	3	0
2	13	1	0	2	720	4	3800
	14	1	0	2	600	1	0
	15	1	0	2	4500	1	0
	16	1	3000	2	420	1	0
	17	1	0	5	400	1	0
	18	1	0	1	0	4	510
	19	1	0	4	500	2	0
	20	1	0	2	420	4	1250
3	21	1	0	2	240	5	1000
	22	1	0	2	800	4	320
	23	1	0	3	250	1	0
	24	1	300	2	20	3	0
	25	1	0	5	500	1	0
	26	1	0	2	0	5	200
	27	1	0	4	0	3	0
	28	1	0	2	420	1	0
4	29	1	0	2	0	2	0
	30	1	0	2	0	1	0
	31	1	0	3	300	1	0
	32	1	300	2	10	5	300
	33	1	0	3	5000	2	0
	34	1	0	1	0	4	1250
	35	1	0	4	8000	1	0
	36	1	0	2	600	4	3200
5	37	1	0	2	1000	3	0
	38	1	0	2	450	3	0
	39	1	0	2	25	3	0
	40	1	500	2	25	3	0

TABLE 8 (cont'd)

	41	1	0	3	500	2	0
	42	1	0	2	0	3	0
	43	1	0	1	0	4	0
	44	1	0	2	270	4	1300
6	45	1	0	2	0	4	0
	46	1	0	2	0	4	0
	47	1	0	2	40	4	0
	48	1	300	2	20	4	190
	49	1	0	3	500	2	0
	50	1	0	3	200	5	210
	51	1	0	4	0	2	0
7	52	1	0	2	250	3	0
	53	1	0	2	0	3	0
	54	1	0	2	0	3	0
	55	1	0	2	35	3	0
	56	1	300	1	0	5	300
	57	1	0	3	2000	1	0
	58	1	0	2	100	3	0
	59	1	0	4	200	2	0
	60	1	0	2	900	5	7000
8	61	1	0	2	1040	3	0
	62	1	0	3	2000	2	0
	63	1	0	1	0	4	5100
	64	1	7500	2	1250	2	0
	65	1	0	4	5000	1	0
	66	1	0	2	300	3	0
	67	1	0	1	0	5	500
	68	1	0	1	0	5	10000
9	69	1	0	3	6000	2	0
	70	1	0	1	0	5	6000
	71	1	0	4	0	3	0
	72	1	2500	2	350	4	1750
	73	1	0	3	5000	2	0
	74	1	0	2	200	3	0
	75	1	0	2	1025	3	0
	76	1	0	3	5000	2	0
10	77	1	0	3	6000	2	0
	78	1	0	1	0	4	3800
	79	1	0	4	4500	1	0
	80	1	2500	4	4500	1	0

TABLE 8 (cont'd)

	81	1	0	2	0	3	0
	82	1	0	2	5140	3	0
	83	1	0	1	0	4	29500
	84	1	0	2	9000	3	0
11	85	1	0	2	8000	1	0
	86	1	0	1	0	2	0
	87	1	0	2	1400	2	0
	88	1	10000	2	1080	3	0
	89	1	0	2	120	3	0
	90	1	0	2	150	3	0
	91	1	0	3	400	2	0
	92	1	0	5	10000	2	0
12	93	1	0	2	1050	3	0
	94	1	0	1	0	4	2800
	95	1	0	4	5000	2	0
	96	1	6000	2	1140	3	0
	97	1	0	1	0	2	0
	98	1	0	2	3300	3	0
	99	1	0	4	1800	3	0
	100	1	0	2	5000	3	0
13	101	1	0	2	5520	3	0
	102	1	0	1	0	4	1280
	103	1	0	2	450	3	0
	104	1	4000	1	0	4	2600
	105	1	0	1	0	5	2500
	106	1	0	1	0	5	1100
	107	1	0	2	160	4	800
	108	1	0	3	5000	2	0
14	109	1	0	3	9000	2	0
	110	1	0	1	0	4	9500
	111	1	0	2	500	4	2300
	112	1	1400	2	500	4	2300
	113	1	0	1	0	4	0
	114	1	0	2	5	4	35
	115	1	0	5	250	3	0
	116	1	0	4	2000	2	0
15	117	1	0	3	1000	2	0
	118	1	0	1	0	4	3000
	119	1	0	3	2000	4	1200
	120	1	2000	2	2500	4	1200

TABLE 8 (cont'd)

	121	1	0	2	3000	4	14000
	122	1	0	1	0	4	3500
	123	1	0	2	3800	4	18000
	124	1	0	4	12000	2	0
16	125	1	0	2	4900	2	0
	126	1	0	1	0	4	59500
	127	1	0	2	1200	3	0
	128	1	10500	1	0	4	6750
Global Constraint Equations							
	129	1	0	1	5240	5	5145
	130	1	0	1	2850	5	4540
	131	1	0	1	25920	5	11450
	132	1	0	1	0	5	3500
	133	1	53700	1	0	1	0

Run 1 - The Base Condition

Using the constraint equations as outlined in the description of the module, the model was run with all priorities equal. The results of this run indicated the following level of achievement of the various goals.

If all budget goals are combined, there is a level of achievement of approximately 80% for the goals expressed in the objective function. Three types of constraining factors were at work. The first is the budget limit associated with the particular variable. The second is the budget limit set on combinations of variables contained in the global constraint equations. The third constraint is the intentional introduction of a global constraint which would not permit the sum of all expenditures to exceed 90% of the budget.

It seems a perculiarity of the structure of the program that every eighth variable was not satisfied (Table 8). This occurs in each instance except the global constraint equations where the values of several variables are summed to equal a budgetary goal. Of the goal constraint equations only the one for erosion control was completely satisfied.

Because of the character of the results, it would be unwise to place any value or attempt to draw any conclusions about the South River watershed when the model is run with all priorities set equal.

Run 2 - Rational Distribution of Priorities

The second run of the model was made with a reasonable distribution of priorities. Regional objectives which reflected spending levels designed to comply with federal and state standards were set at higher priorities. Decreasing priorities were placed on such factors as recreational programs, landscaping, etc.

As noted, the goal programming model seeks to satisfy the highest priority goals first. If the model is run without including the global constraint equations, all expenditure goals are satisfied because the zone level equations, which could be considered analagous to line items on a budget, have only one constraint for each of the eight variables and therefore no competition for resources.

The results change as the global constraint equations are introduced. The global constraint equations link achievement of particular goals to expenditures in several zones. The sum of the underachievement of goals is set by the 20% budget reduction reflected in the last global constraint equation. The manner in which the 20% is distributed can be explained by the assignment of priorities. There are three factors associated with the distribution of priorities which account for the results obtained in the second run of the model. They are:

1. whether or not there were a large number of priority levels employed to distinguish between the importance of the variables.

2. whether or not variables were included in both zone equations as well as global constraint equations.

3. whether or not variables which were contained in both zone level and global constraint equations were assigned the same or conflicting priority levels.

The element of interest in this run is the relationship between the various priority levels and the extent of underachievement associated with each of them.

Normally one might suspect all first priority goals to be satisfied. Whether or not this occurs is dependent upon the hierarchical structure of the goals.

To reflect interjurisdictional agreements a zonal variable may be assigned one priority indicating the relationship within one particular zone and be assigned a higher priority in another zone or when the variable is part of a global constraint equation.

Another factor worth noting is that the variables assigned first priority usually had larger budgetary goals, thereby making them less likely to be 100% satisfied.

As more of these types of relationships are introduced, the value of the goal programming module increases since the results increasingly become counter intuitive.

Run 3 - Inversion of Priorities

To examine the sensitivity of the model and to determine the impact on goals achievement of changes in priorities, priorities opposite to the pattern in Run 2 were introduced.

The results of this run were perhaps the most easily anticipated of the three. The inversion of priorities resulted in the global constraint equations receiving fifth priority and goals associated with items such as runoff control in a particular zone being assigned first priority. Since the first priority goals have few if any interrelationships, the constraints which must be satisfied to attain these goals are much less complex. As a result of the reduction in the number of interrelationships, all priority one goals were satisfied.

From this brief examination of the sensitivity of goal achievement at both the local and regional levels, several possible conclusions can be drawn regarding the development of approaches to environmental quality problems:

1. As might be anticipated, levels of achievement of goals which require interjurisdictional cooperation are likely to be lower than those which do not.

2. When goal constraints are linked in a semi-lattice hierarchical structure, the variable which is the greatest impediment to goal achievment is not easily anticipated.

3. For the South River watershed, changes in priotity of regional goals in terms of the watershed context does not dramatically affect the achievement of local goals.

Generation of Alternative Sets of Priorities

It is obviously not a very efficient means of testing varying combinations of priorities if the input to the Goal Programming Module has to be keyed in by the user for each run. This barrier would defeat the objective of attempting to develop a comparatively simple model. For this reason several programs were developed to permit the user to generate a wide range of priority distributions, thereby, permitting an analysis of the consequences of various budgeting priorities and the levels of goals achievement.

The output of the priority generation routine can be used as input to the goal programming module without any modification. This routine is quite simple to use and easily integrated into the major program module.

The output of the Goal Programming Module provides several levels of information. First, the output provides a listing of all the input data (the right-hand side, the substitution rates, and objective function data) so that users of the program may check data to ensure that errors are not the result of improper inputs. Also contained in the output is the final simplex solution table which includes an evaluation of the objective function, slack analysis, variable analysis, and the analysis of the objective.

In order to improve the understanding of the uses of the output, let us analyze each item in more detail. For reasons of economy of space, only a small portion of the actual computer run will be used as an illustrative example. The first element of the simplex solution is the right-hand side.

Simplex Solution

The Right Hand Side

	Variable No.	Budgetary Assignment
Solid waste	73	0.
Recreation	74	0.
Roadways	75	0.
Waste Treatment	76	3000.

The numbers on the left are variable numbers for basic variables. In this example 3000 represents the value of the basic variable, for example, an expenditure limit of $3000 for variable 76 which is the expenditure goal for wastewater treatment in Zone 10.

The array of substitution rates is based on the column arrangement of d(i)-, d(i)+, x(j), in that order. Further inspection of the substitution rates will identify more specific tradeoffs between the variables and their associated priorities.

Perhaps the most important element of the output of this module is the evaluation of the objective function. The values are the underattained portion of the goals. For example, the output from a run of the South River model resulted in the following output.

Evaluation of the Objective

underachievement of goal	priority level
0.	5
3500.	4
0.	3
9200.	2
16190.	1

From this it can be seen that the first, second, and fourth priority levels of goals were attained only partially whereas the third and fifth were attained completely.

The slack analysis also is useful in interpreting the output of the Goal Programming Module. It presents the values of the right-hand side and also values of the negative and positive deviations for each equation. From the previously mentioned output the slack analysis for equation 16 was:

Available = 3500

Positive Slack = 0.0

Negative Slack = 3000.

Equation 16 represents the allocation of budgetary resources for erosion control in Zone 2 of the watershed. The equation:

$$x(16) + d(16)^{-} - d(16)^{+} = 3500$$

Therefore in this particular run $d(16)^{-}$ = $3000., i.e., the amount by which the goal for budgetary allocation for erosion control was not achieved. To state this positively, given the set of conflicting goals, budgetary relationships, and priority assignments only $500 of the $3500 goal will actually be available for erosion control in Zone 2. In this run of the model, runoff control was assigned a priority level of 3.

Careful study of all materials provided in the output can provide the user with the ability to more accurately assess the sensitivity of the model to changes in the relationships between variables. This is of particular value when the number of variables is large and the decision environment complex. The Goal Programing Module for the South River watershed contained 128 variables and 5 priority levels.

Simple Integrated Modular Watershed Planning Model
Priority Generation Routine

This routine is used in conjunction with MODULE IV - the Goal Programming Module to generate the data base for testing alternative priorities assigned to the goal programming objective function.

Generation of the Objective Function Card

```
      DIMENSION SIGN(60),WGHT(60),VAL(60),EQN(60)
      INTEGER ROWN(60),PRT(60),ZONE(60),ROW(60),COL(60),
     1 COLN(60),ZN(60)
      DO 20 J=1,16
      DO 10 I=1,16
      READ (5,1) SIGN(I),ROW(I),PRT(I),WGHT(I)
1     FORMAT (A3,3X,I3,2X,I3,8X,F3.1)
      SHIFT=J*8
      ROWN(I)=ROW(I)+SHIFT
      ZONE(I)=J
      WRITE (7,2) SIGN(I),ROWN(I),PRT(I),WGHT(I),ZONE(I)
2     FORMAT (A3,3X,I3,2X,I3,8X,F3.1,52X,I3)
10    CONTINUE
20    CONTINUE
      STOP
      END
```

It would be unwise at best to draw any sweeping conclusions from this portion of the model. Its advantage of making tradeoffs explicit and allowing new sets of relationships to be tested has considerable potential value to the public as well as their elected officials. Using the data base and support programs new values and constraints can be added by very simple operations and if online computing ability is present results can be obtained in a matter of minutes.

Chapter 5.0

Conclusions

In the concluding section three areas will be covered. They are:

1. a description of what was accomplished and the criteria employed in that determination
2. observations regarding the process and problems of constructing the model
3. observations related to the South River watershed.

What Was Accomplished

The results of this investigation manifest themselves in terms of a watershed planning model, a product, and the process necessary to produce the model and make its application possible.

The four modules which comprise the modeling sequence describe indicators of change for key subsystems within the watershed. It is not difficult to defend the position that the four modules of the watershed model deal with four critical areas which must be recognized if the results of the model are to be used in decision making and their associated recommendations applied. Nevertheless, there are a number of problems as well as strengths associated with the modeling process.

Strengths

The strengths of this modeling effort can be summarized by the following points:

1. When compared to existing large scale models designed to address problems as complex as watershed planning, two points can be made regarding the modular approach employed in this study. The first is that although data requirements of the modular model are large, the structure is reasonably simple and each component can be removed from the whole and its function discerned.

2. One major problem which plagues large scale modeling is that builders of large models frequently do not begin with a particular policy problem which needs a solution but have instead chosen to develop a methodology that needs applying(1). This study has taken the opposite approach in that the problems associated with watershed planning were examined and a modeling framework was generated as a response to the problem condition.

3. Numerous authors from a variety of backgrounds have written on the topic of modeling. In their writing there is one resounding theme upon which they all agree. Build only simple models. (3) In the earlier discussion on complex systems, the explanation of how comparatively simple models can reflect a complex, real system was outlined. First, the model is structured so that it is not necessary to deal with the entire set of variables included in the four modules in order to examine one portion of the model. Second the modular configuration permits the user to modify modules or substitute new ones provided that the necessary input data for the next module in the sequence is generated. This can be achieved without destroying the integrity of the module.

The purpose of the model can be understood by those possessing mid-level skills in planning, engineering, and environmental management. Currently research is underway to improve the procedures used in Module I, the Runoff and Routing Module.

Problems

There are, however, a number of potential problems inherent in the model:

1. Regardless of the comparatively simple structure of the model the data requirements remain large. Of the four modules, the Runoff and Routing Module has the most demanding data requirements in terms of initial input. With regard to data base maintenance, the two modules which deal directly with cost, the Goal Programming and TOPAZ Modules, are the most problematic. This difficulty can be attributed to the maintenance of current budgetary and cost information.

2. The linkage via the model of a broader cross section of the decision spectrum may be considered a weakness as well as a strength.

The legal precedent in support of allowable levels of pollution for point source discharges has been made clear particularly over the past few years. The mandate has not been as clear regarding other factors dealt with in several of the modules such as:

a. the extent to which the public has a right to participate in the budgeting process (Goal Programming Module)

b. the extent to which land use controls can be required to reduce non-point source pollution and excess runoff which contribute to flooding. (Runoff and Routing Module)

The components of the model tie different types of decisions together. This is particularly true in terms of linking the goal programming technique for budgeting to the costs of providing waste treatment facilities and networks. The identification of more explicit relationships in the model provides more accurate information, but this increased amount of information may result in decision makers being less inclined to utilize the model because too much informaion is open to public review and scrutiny.

Observations Regarding the South River Watershed

The model has been described as an indicator model which reflects the the state of key systems within the watershed. In order to demonstrate that the modeling procedure is of value to decision makers as well as the value of employing the modules in an interactive fashion, the decision regarding development strategy for the watershed will be briefly reviewed using the results of the modules as a basis for the recommendation.

The results of the Water Quality Module indicated that for each of the development alternatives additional wastewater treatment facilities would be required for Greenville, Stuart's Draft, and Waynesboro.

In the final analysis public decision makers must achieve a balance between the wide range of interests competing for budgetary resources. Some constraints such as those imposed on local government by water quality legislation must be met; whereas, some flexibility is present in dealing with other demands, for example, public recreation programs, etc.

The watershed model is a tool which can be employed to assess the consequences of taking certain actions within the decision environment outlined in the causal diagram, Figure 27.

As illustrated in Fig. 27, there is the distinct possibility that if localities fund the construction of new wastewater treatment facilities which comply with the requirements of PL 92-500 they may reach the limits to bonded indebtedness set by the state.

If there are scarce resources and there is no alternative but to make these expenditures for additional treatment facilities then the localities are faced with the problem of generating additional revenues either through increasing property tax, sales tax, business license tax, etc., or generating revenues from new sources such as the imposition of new taxes or seeking federal grants. Considering the alternatives open to the local decision makers, how can the results of the model assist them in assessing their options?

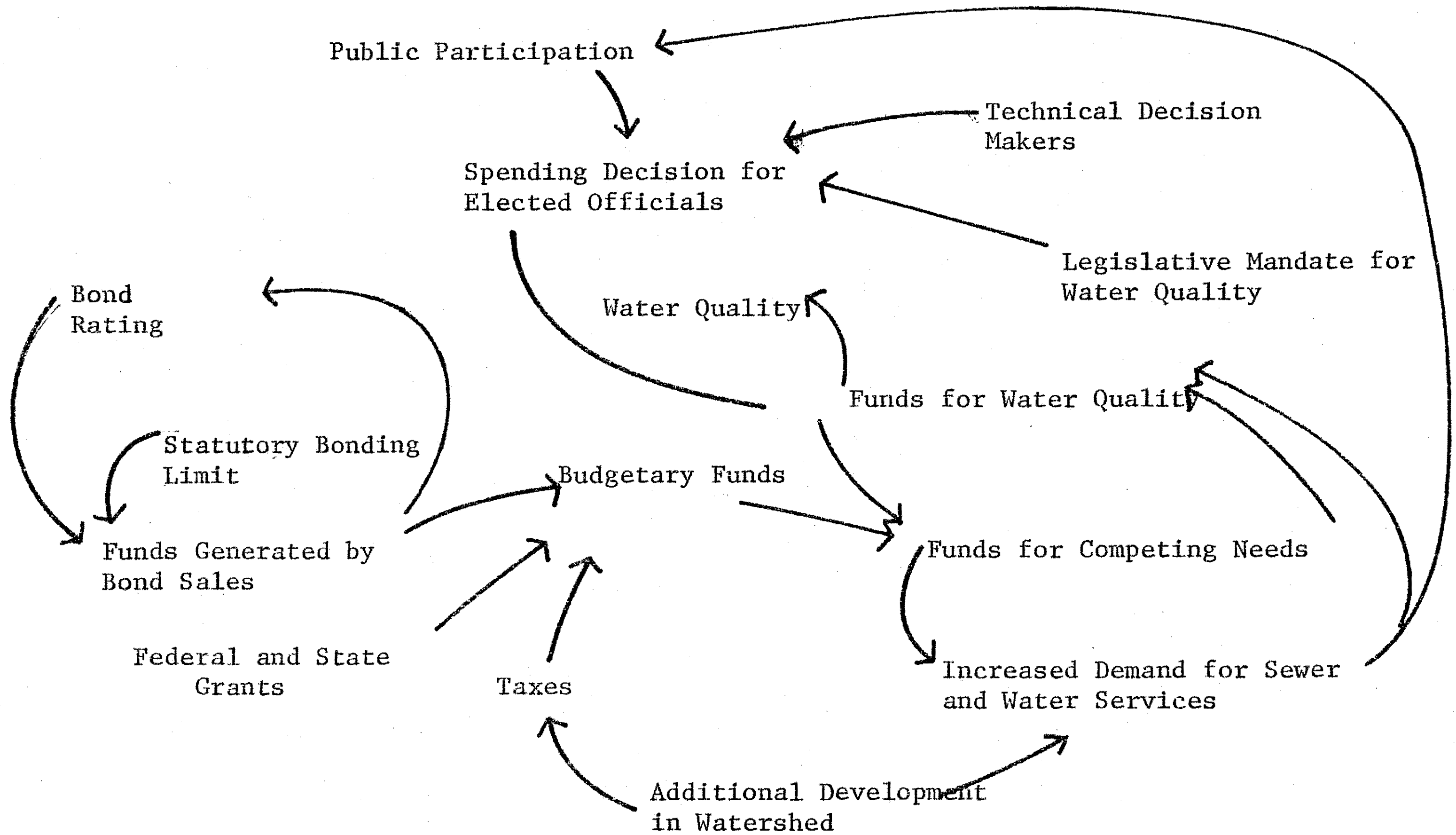

FIG. 27 CAUSAL DIAGRAM - WATERSHED DEVELOPMENT STRATEGY

The problem is a compound one which requires an increase in revenues without further damaging the water quality in the South River or the vitality of the economy within the watershed. The following options might be considered:

1. Encourage further development to increase the tax base.

2. Impose additional taxes on existing property.

3. Increase sales taxes.

4. Institute an extensive program of non-point source pollution control in an effort to reduce the expenditure required for additional treatment facilities.

Each of these options has associated impacts.

1. Additional Development -

a. requires more treatment facilities

b. expenditure for services must be made in advance of return in increased tax revenue

c. could exacerbate the non-point source pollution resulting from erosion due to construction and eutrophication due to establishing and maintaining new vegetation, etc.

2. Additional Taxes - are likely to discourage further development in the watershed.

3. Increase Non-Point Source Pollution Control Program.

At the upper portion of the watershed the flow of the South River is rather small, approximately .935 MGD as the river approaches the town of Stuart's Draft. The resulting condition is that in the upper portion of the watershed where there is a considerable amount of underdeveloped land there is a small flow and of course a reduced assimilative capacity. At the lower portion of the watershed where the flow of the South River exceeds 14 MGD there is a substantial amount of development and the attendant waste loading.

Consider option one, additional development for the City of Waynesboro. The proposed budget for the city ending June 30, 1979 is $10,358,519. The following are expenditures directly tied to wastewater treatment.

Maintenance and operation of STP	$169,882
Maintenance of system	83,468
Capital outlays	115,100
Total	$368,450

This sum equals 3.5% of the annual budget. In Alternative 3 where an additional three thousand persons would be added to the population of Waynesboro, additional wastewater treatment capability would be required.

150 gpd per person x 3000 persons = .45 MGD

The cost of an additional .5 MGD facility taken from the table in Appendix C which included tertiary treatment would be:

	OMC	AC
Preliminary Treatment	5641	8658
Pumping	3310	18573
Primary Sedimentation	6714	21428
Anaerobic digestion	4450	17098
Dewaterating	13578	30438
Disinfection	2236	8565
Activated Sludge	22678	64287
Activated Carbon	12090	79320
Ammonia Stripping	17108	25791
	--------	-------
Total	$ 87805	274158

The sum of the operations and maintenance costs plus the annual cost equals $361,963 or 3.5% of the annual budget of the city. To place this cost in perspective, the equivalent amount is currently expended for the library, summer school, school buses, adult education, and all recreational programs. If only a 4 MGD amonia stripping facility were added to the existing plant, the capital cost would be $657,000 at 6% over 20 years with a resulting annual cost of $ 122,974. This is equal to 33% of current expenditure for treatment. To further explore the consequences of these actions, the costs associated with additonal waste treatment facilities were fed into the Goal Programming Module along with the cost of the network generated by the TOPAZ Module. Expenditures for the treatment facility and the network were assigned first priority. The remaining items were assigned mixed priorities as in Run 2 discussed earlier.

Because of the magnitude of the expenditure for wastewater treatment facilities, the satisfaction of expenditure goals assigned even second priority was diminished. The implications for the South River watershed can be summarized by the following points:

1. Based on the results of the Water Quality Module and the necessity to comply with PL 92-500, advanced wastewater treatment facilities will be required.

2. Based on the results of the TOPAZ module the two alternative land use plans which call for an increase in population, the costs of the sewer and water networks was estimated for each alternative. The second alternative, the continuation of the existing sprawl development pattern was demonstrated to be the less costly of the two.

3. The Goal programming Module demonstrated that if water quality goals are to be met then other expenditures for day care, recreation, etc. must be diminished.

In the final analysis unless it can be demonstrated that new residents to the area can generate more tax revenues than they consume, no growth should be encouraged. If growth is inevitable, zoning ordinances and comprehensive plans should focus on consolidating development within the framework of the existing sewer and water networks if the fiscal integrity of the communities within the watershed is to be preserved.

Areas for Further Study

The efforts discussed here are only a beginning of what could be a productive approach to environmental planning and management at the watershed scale. More specifically, the following activities could be pursued.

1. continued refinement of the individual modules
2. evaluation and consolidation of data base requirements
3. calibration of the model and more extensive sensitivity analysis
4. pilot application.

Endnotes

1. Stearns, Forest W. and Montag, T., The Urban Ecosystem, Dowden Hutchinson and Ross, 1974, p. 171.

2. Biswas, Asit K., Systems Approach to Water Management, McGraw Hill, 1976.

3. City of Waynesboro, Virginia; Proposed budget for year ending June 30, 1978.

4. Revenue Resources and Economic Commission Report to the Governor and General Assembly and Local Fiscal Issues a Staff Report, December 1977, Richmond, Virginia, p. 138.

5. The calculation is corrected for inflation using 1974 as the base year.

6. Ibid., p. 139.

Appendix A

Public Law 92-500, Summary

Section 208

Basically, Section 208 of Public Law 92-500 of October 18, 1972, is concerned with encouraging and facilitating the development and implementation of areawide waste treatment management plans.

A unique and important feature of Section 208 is the increased local participation commencing with the designation of urban-industrial complexes with substantial water quality problems by the state governors to the development of local policy and technical administration, guidance, direction and broad supervision of the preparation of the water quality plans.

This aspect of Section 208 of PL 92-500 is extremely important in that in the past, relatively little coordination has been accomplished. In addition to the important elements of correlating, verifying, amplyfing and bringing together much of the earlier diverse water quality planning programs; the Section 208 criteria provide for considerably increased in depth treatment. In other areas, including infiltration/inflow, storm water and solid waste, relatively little construction work has been accomplished. While many earlier studies have underscored land use and full evaluation of social, transportation and other demographic elements, many plans have provided relatively little serious consideration of these vital factors. To make the plans of value to the region, great emphasis is given to management, institutional arrangements and implementation of the plans.

All aspects of the many increments of the developed plan must receive thorough treatment, evaluation and consideration of alternate approaches. Finally, to make the plans fully acceptable to the individual jurisdiction, complete public participation and public information is necessary.

In order to more fully understand the 208 program it is useful to examine how it fits into the scheme of other programs. Section 201 of the act is conducted incident to building or modifying a sewage treatment plant and its related facilities, such as sewer and water lines. The result is a highly detailed plan that considers technical and environmental data. Areawide planning expands the scope of a facilities plan. The 208 planning area can include one or more 201 facilities planning areas. By dealing with such related issues as land use, development and the combined effect of all treatment plants within a planning area. The 208 plan permits a more comprehensive view of the problem and its possible solutions.

Section 303, the basin plan, deals with a typically large geographical area. The basin plan assesses the extent to which a basin's waters are polluted and defines the nature and volume of pollutant that can be discharged without violating standards.

Since 208 areawide planning is concerned with a particular part of a river basin and deals with both treatment plants and water quality goals, the areawide plan must conform to the management strategy and constraints spelled out in the basin plan.

Under Section 209, the water resources basin plan, is a general plan which sets forth a broad strategy for the long term management of a river basin. Its scope encompases water supply, water quality, recreation, transportation and other related fields. For this longrange approach to be successful, however, the 209 plan must build upon the provisions of the appropriate areawide waste treatment management strategy.

Division of Responsibilities

The 208 program is intended to involve local, regional, and state officials and agencies as fully as possible. Local elected officials advise the Governor about the designation of planning areas and agencies. Local officials also assist in the identification of a management structure that is capable of carrying out the plan. As part of the state role, the Governor designates planning areas within his state. He also designates each planning agency. In addition the Governor bears the responsibilities of public hearings of critical issues and annual recertification. Members of state agencies may take part in the preparation of a 208 plan as well as oversee planning at the local level to ensure its compliance with state policies. Once a 208 plan has been completed and approved, state agencies help to administer the plan by monitoring the progress of the management agencies.

At the Federal level, no planning can begin until EPA has approved the designation of each planning agency. And before a completed plan can be implemented, EPA must approve both the plan itself and the designated management structure. The Federal Government makes grants available for 100 percent of elegible costs incurred over a two year grant period.

Appendix B - Sensitivity Analysis for the Water Quality Module

Since the Water Quality Module was constructed by the author, a sensitivity test was necessary to determine if any particular aspects of the model demonstrated an improper degree of response as they operated over a range of values normally associated with the environmental conditions where models of this type would be applied.

Tests were conducted for the following variables;

PHL - Phosphorus loading rate (mg/l/day)

BIO - Biomass of respiring organisms (mg/l)

RO2 - Oxygen consumption due to respiration (mg/l/mg of biomass/hr)

CL - Chlorophyl level (g/square meter)

PO2 - Oxygen produced as a result of photosynthesis (mg/hr/g of chlorophyll/square meter)

K1 - deoxygenation rate in the Streeter-Phleps equation

K2 - reaeration rate in the Streeter-Phelps equation

BR - the factor by which the respiration rate is multiplied as a result of bloom conditions.

Prior to describing the results of the sensitivity test, it should be noted that the model computes the water quality indicators, DO and BOD, by two procedures so that the results can be compared. The first method simply computes the resultant BOD and DO levels based on what is present in the stream plus the addition of the effluent dischargeed into the stream. This is done by the standard BOD and oxygen sag equations.

The second procedure attempts to incorporate a number of these factors which the traditional Streeter-Phelps method is criticized for excluding. For example, O2 production from photosynthesis-respiration due to algae blooms triggered by increased phophorus levels in the stream segment. A more detailed description of the structure of the model appears in the section, General Description of the Watershed Model and Application of the Model - Water Quality Module.

Twenty to forty values were used to test each of the variables while the values of the other variables were, of course, held constant.

Where it was appropriate BOD computations were carried out for a fifteen day period. In all other cases BOD and DO values were compared on the basis of 5 day levels.

The results of the test can be categorized into three groups:

1. Outputs which are exponential in nature, K1 and K2 - these inherently have greater impact on the results of the model.

2. Outputs which are linear but have no major impact on the results of the model.

3. Outputs which are linear and have major impact on the output of the model.

The deoxygenation rate, K1, and the reaeration rate K2, comprise the first caterogy. Forty values which ranged from .1 to 4.0 were inserted into the model for each of these variables. Increments were .1. The most dramatic results were obtained in the range between .2 and .6. When K2 ranged from .3 to .4 there was a 56 percent change from the previous DO value. As values increased beyond .6 the extent of difference decreased.

The range of values of these stream pollution constants for most American streams handling nontoxic wastes during warm months are for K1 .06 - .36 and for K2 .06 - .96 (1).

The DO levels which resulted from changes in the values for K2 are most noticeable for values between .1 and .4. As values are increased beyond .4 the extent of difference in DO levels for the next higher value of K2 decrease linearly.

There are four variables which fall into the second category, those which are linear and have no major impact on the results of the model. They are: 1) oxygen producion rate due to photosynthesis (PO2), 2) chlorophyll level present in organisms (CL), 3) the multiplier for increased respiration rate due to bloom conditions (BR), and 4) the amount of O2 consumed by respiration (RO2).

Only one variable is included in the third group, those which are linear and have some noticeable impact on the result of the model, the quantity of biomass (BIO). For example, as the value of BIO was increased from .001 to .002 there was a 59 percent change in the DO level. As the value of BIO was increased to .008 the extent of change declined to 18 percent. Also, when DO levels determined by the two methods were compared the difference in DO levels was directly proportional to the increase in values of BIO.

From this it can be concluded that particular caution should be exercized in determining the value of this variable for each of the segments of the stream.

Endnotes

1. Nemerow, *Scientific Methods for Stream Pollution Analysis*.

Appendix C

Cost of Treatment Facilities

The following is a listing of treatment processes and their associated costs for 1 thru 5 MGD facilities, primary, secondary, and tertiary treatment; with and without sludge handling.

Key to Tables

Preliminary Treatment	AA
Pumping	AB
Primary Sedimentation	A-1 thru A-5
Trickling Filter	B-1 thru B-3
Activated Sludge	C-1 thru C-8
Filtration	D
Activated Carbon	E
Two Stage Tertiary Lime	F-1 thru F-2
Biological Nitrification	G-1 thru G-4
Biological Denitrification	H
Ion Exchange	I
Breakpoint Chlorination	J
Ammonia Stripping	K
Disinfection	R

Guide To Tables

CC = Capital Costs

OMC = Operation and Maintanence Costs

AC = Annual Costs

PW = Present Worth

PRIMARY

1. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	66466.	11283.	17316.	190798.
AB	336353.	6621.	37147.	409313.
A1	324242.	13429.	42856.	472216.
L1	278733.	8900.	34197.	376800.
O1	371544.	27156.	60876.	670766.
R	139479.	4472.	17131.	188764.
Totals	1516819.	71864.	209525.	2308659.

PRIMARY

2. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	101444.	12573.	21780.	239989.
AB	516933.	8542.	55457.	611059.
A1	360248.	18335.	51030.	562281.
L1	327307.	9819.	39524.	435500.
O1	428243.	38321.	77187.	850490.
R	150092.	10337.	23959.	263998.
Totals	1884269.	97930.	268940.	2963319.

PRIMARY

3. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	129910.	13863.	25653.	282667.
AB	664678.	10382.	70706.	779081.
A1	396255.	22024.	57987.	638933.
L1	375880.	10738.	44851.	494199.
O1	484941.	48912.	92923.	1023882.
R	160705.	15918.	30503.	336103.
Totals	2212372.	121840.	322626.	3554867.

PRIMARY

4\. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20\. = Years (Amortization Period)

3000\. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	154830.	15153.	29205.	321800.
AB	794462.	12148.	84250.	928318.
A1	432261.	25097.	64327.	708798.
L1	424454.	11657.	50179.	552898.
O1	541640.	59152.	108309.	1193411.
R	171319.	21345.	36893.	406511.
Totals	2518969.	144554.	373166.	4111738.

PRIMARY

5. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	177407.	16443.	32544.	358589.
AB	912342.	13843.	96644.	1064882.
A1	468268.	27782.	70280.	774387.
L1	473028.	12576.	55506.	611598.
O1	598339.	69142.	123445.	1360187.
R	181932.	26670.	43182.	475802.
Totals	2811317.	166458.	421603.	4645445.

SECONDARY

1. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	66466.	11283.	17316.	190798.
AB	336353.	6621.	37147.	409313.
A1	324242.	13429.	42856.	472216.
L1	278733.	8900.	34197.	376800.
O1	371544.	27156.	60876.	670766.
R	139479.	4472.	17131.	188764.
C1	916945.	45357.	128575.	1416711.
Totals	2433764.	117221.	338101.	3725370.

SECONDARY

2. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	101444.	12573.	21780.	239989.
AB	516933.	8542.	55457.	611059.
A1	360248.	18335.	51030.	562281.
L1	327307.	9819.	39524.	435500.
O1	428243.	38321.	77187.	850490.
R	150092.	10337.	23959.	263998.
C1	1093531.	66864.	166109.	1830280.
Totals	2977800.	164795.	435049.	4793599.

SECONDARY

3. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	129910.	13863.	25653.	282667.
AB	664678.	10382.	70706.	779081.
A1	396255.	22024.	57987.	638933.
L 1	375880.	10738.	44851.	494199.
O1	484941.	48912.	92923.	1023882.
R	160705.	15918.	30503.	336103.
C1	1269888.	84260.	199511.	2198318.
Totals	3482261.	206101.	522138.	5753185.

SECONDARY

4\. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20\. = Years (Amortization Period)

3000\. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	154830.	15153.	29205.	321800.
AB	794462.	12148.	84250.	928318.
A1	432261.	25097.	64327.	708798.
L1	424454.	11657.	50179.	552898.
O1	541640.	59152.	108309.	1193411.
R	171319.	21345.	36893.	406511.
C1	1446111.	99476.	230719.	2542189.
Totals	3965080.	244030.	603886.	6653926.

SECONDARY

5. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	177407.	16443.	32544.	358589.
AB	912342.	13843.	96644.	1064882.
A1	468268.	27782.	70280.	774387.
L1	473028.	12576.	55506.	611598.
O1	598339.	69142.	123445.	1360187.
R	181932.	26670.	43182.	475802.
C1	1622239.	113271.	260499.	2870319.
Totals	4433556.	279730.	682103.	7515764.

TERTIARY

1\. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20\. = Years (Amortization Period)

3000\. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	66466.	11283.	17316.	190798.
AB	336353.	6621.	37147.	409313.
A1	324242.	13429.	42856.	472216.
L1	278733.	8900.	34197.	376800.
O1	371544.	27156.	60876.	670766.
R	139479.	4472.	17131.	188764.
C1	916945.	45357.	128575.	1416711.
E	1481537.	24181.	158640.	1747978.
G1	555569.	37080.	87502.	964141.
K	191346.	34216.	51582.	568360.
Totals	4662215.	212699.	635825.	7005849.

TERTIARY

2\. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20\. = Years (Amortization Period)

3000\. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	101444.	12573.	21780.	239989.
AB	516933.	8542.	55457.	611059.
A1	360248.	18335.	51030.	562281.
L1	327307.	9819.	39524.	435500.
O1	428243.	38321.	77187.	850490.
R	150092.	10337.	23959.	263998.
C1	1093531.	66864.	166109.	1830280.
E	1668152.	48327.	199722.	2200646.
G1	678882.	47815.	109428.	1205736.
K	354677.	43915.	76104.	838555.
Totals	5679511.	304853.	820304.	9038534.

TERTIARY

3. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	129910.	13863.	25653.	282667.
AB	664678.	10382.	70706.	779081.
A1	396255.	22024.	57987.	638933.
L1	375880.	10738.	44851.	494199.
O1	484941.	48912.	92923.	1023882.
R	160705.	15918.	30503.	336103.
C1	1269888.	84260.	199511.	2198318.
E	1854766.	72438.	240770.	2652927.
G1	802065.	57374.	130167.	1434248.
K	508859.	53613.	99795.	1099601.
Totals	6647951.	389527.	992871.	10939960.

TERTIARY

4. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	154830.	15153.	29205.	321800.
AB	794462.	12148.	84250.	928318.
A1	432261.	25097.	64327.	708798.
L1	424454.	11657.	50179.	552898.
O1	541640.	59152.	108309.	1193411.
R	171319.	21345.	36893.	406511.
C1	1446111.	99476.	230719.	2542189.
E	2041381.	96514.	281782.	3104822.
G1	925171.	66251.	150216.	1655166.
K	657383.	63312.	122974.	1354990.
Totals	7589014.	470108.	1158859.	12768902.

TERTIARY

5. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC (Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	177407.	16443.	32544.	358589.
AB	912342.	13843.	96644.	1064882.
A1	468268.	27782.	70280.	774387.
L1	473028.	12576.	55506.	611598.
O1	598339.	69142.	123445.	1360187.
R	181932.	26670.	43182.	475802.
C1	1622239.	113271.	26499.	2870319.
E	2227995.	120555.	322760.	3556334.
G1	1048222.	74658.	169791.	1870845.
K	801838.	73010.	145782.	1606309.
Totals	8511610.	547954.	1320437.	14549250.

PRIMARY

1\. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20\. = Years (Amortization Period)

3000\. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	66466.	11283.	17316.	190798.
AB	336353.	6621.	37147.	409313.
A1	324242.	13429.	42856.	472216.
L1	278733.	8900.	34197.	376800.
O1	371544.	27156.	60876.	670766.
R	139479.	4472.	17131.	188764.
R3	29499.	1775.	4452.	49058.
Totals	1546318.	73639.	213977.	2357718.

PRIMARY

2. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	101444.	12573.	21780.	239989.
AB	516933.	8542.	55457.	611059.
A1	360248.	18335.	51030.	562281.
L1	327307.	9819.	39524.	435500.
O1	428243.	38231.	77187.	850490.
R	150092.	10337.	23959.	263998.
R3	56777.	3845.	8998.	99150.
Totals	1941046.	101776.	277938.	3062469.

PRIMARY

3. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	129910.	13863.	25653.	282667.
AB	664678.	10382.	70706.	779081.
A1	396255.	22024.	57987.	638933.
L1	375880.	10738.	44851.	494199.
O1	484941.	48912.	92923.	1023882.
R	160705.	15918.	30503.	336103.
R3	83499.	6047.	13626.	150139.
Totals	2295872.	127887.	336253.	3705006.

PRIMARY

4. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	154830.	15153.	29205.	321800.
AB	794462.	12148.	84250.	928318.
A1	432261.	25097.	64327.	708798.
L1	424454.	11657.	50179.	552898.
C1	541640.	59152.	108309.	1193411.
R	171319.	21345.	36893.	406511.
R3	109905.	8341.	18315.	201813.
Totals	2628874.	152895.	391482.	4313550.

PRIMARY

5. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	177407.	16443.	32544.	358589.
AB	912342.	13843.	96644.	1064882.
A1	468268.	27782.	70280.	774387.
L1	473028.	12576.	55506.	611598.
O1	598339.	69142.	123445.	1360187.
R	181932.	26670.	43182.	475802.
R3	136093.	10705.	23056.	254047.
Totals	2947411.	177163.	444660.	4899492.

SECONDARY

1\. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20\. = Years (Amortization Period)

3000\. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	66466.	11283.	17316.	190798.
AB	336353.	6621.	37147.	409313.
A1	324242.	13429.	42856.	472216.
L1	278733.	8900.	34197.	376800.
O1	371544.	27156.	60876.	670766.
R	139479.	4472.	17131.	188764.
R3	29499.	1775.	4452.	49058.
C1	916945.	45357.	128575.	1416711.
Totals	2463263.	118996.	342553.	3774429.

SECONDARY

2. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	101444.	12573.	21780.	239989.
AB	516933.	8542.	55457.	611059.
A1	360248.	18335.	51030.	562281.
L1	327307.	9819.	39524.	435500.
O1	428243.	38321.	77187.	850490.
R	150092.	10337.	23959.	263998.
R3	56777.	3845.	8998.	99150.
C1	1093531.	66864.	166109.	1830280.
Totals	3034577.	168641.	444048.	4892749.

SECONDARY

3. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	129910.	13863.	25653.	282667.
AB	664678.	10382.	70706.	779081.
A1	396255	22024.	57987.	638933.
L1	375880.	10738.	44851.	494199.
O1	484941.	48912.	92923.	1023882.
R	160705.	15918.	30503.	336103.
R3	83499.	6047.	13626.	150139.
C1	1269888.	84260.	199511.	2198318.
Totals	3565760.	212148.	535764.	5903324.

SECONDARY

4\. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20\. = Years (Amortization Period)

3000\. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	154830.	15153.	29205.	321800.
AB	794462.	12148.	84250.	928318.
A1	432261.	25097.	64327.	708798.
L1	424454.	11657.	50179.	552898.
O1	541640.	59152.	108309.	1193411.
R	171319.	21345.	36893.	406511.
R3	109905.	8341.	18315.	201813.
C1	1446111.	99476.	340729.	2542189.
Totals	4074985	252371.	622202.	6855738.

SECONDARY

5. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	177407.	16443.	32544.	358589.
AB	912342.	13843.	96644.	1064882.
A1	468268.	27782.	70280.	774387.
L1	473028.	12576.	55506.	611598.
O1	598339.	69142.	123445.	1360187.
R	181932.	26670.	43182.	475802.
R3	136093.	10705.	23056.	254047.
C1	1622239.	113271.	260499.	2970319.
Totals	4569649.	290435.	705160.	7769811.

TERTIARY

1\. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20\. = Years (Amortization Period)

3000\. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	66466.	11283.	17316.	190798.
AB	336353.	6621.	37147.	409313.
A1	324242.	13429.	42856.	472216.
L1	278733.	8900.	34197.	376800.
O1	371544.	27156.	60876.	670766.
R	139479.	4472.	17131.	188764.
R3	29499.	1775.	4452.	49058.
C1	916945.	45357.	128575.	1416711.
E	1481537.	24181.	158640.	1747978.
G1	555569.	37080.	87502.	964141.
K	191346.	34216.	51582.	568360.
Totals	4691715.	214474.	640278.	7054907.

TERTIARY

2\. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20\. = Years (Amortization Period)

3000\. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	101444.	12573.	21780.	239989.
AB	516933.	8542.	55457.	611059.
A1	360248.	18335.	51030.	562281.
L1	327307.	9819.	39524.	435500.
O1	428243.	38321.	77187.	850490.
R	150092.	10337.	23959.	263998.
R3	56777.	3845.	8998.	99150.
C1	1093531.	66864.	166109.	1830289.
E	1668152.	48327.	199722.	2200646.
G1	678882.	47815.	109428.	1205736.
K	354677.	43915.	76104.	838555.
Totals	5736288.	308698.	829303.	9137684.

TERTIARY

3. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	129910.	13863.	25653.	282667.
AB	664678.	10382.	70706.	779081.
A1	396255.	22024.	57987.	638933.
L1	375880.	10738.	44851.	494199.
O1	484941.	48912.	92923.	1023882.
R	160705.	15918.	30503.	336103.
R3	83499.	6047.	13626.	150139.
C1	1269888.	84260.	199511.	2198318.
E	1854766.	72438.	240770.	2652927.
G1	802065.	57374.	130167.	1434248.
K	508859.	53613.	99795.	1099601.
Totals	6731450.	395575.	1006497.	11090098.

TERTIARY

4. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	154830.	15153.	29205.	321800.
AB	794462.	12148.	84250.	928318.
A1	432261.	25097.	64327.	708798.
L1	424454.	11657.	50179.	552898.
O1	541650.	59152.	108309.	1193411.
R	171319.	21345.	36893.	406511.
R3	109905.	8341.	18315.	201813.
C1	1446111.	99476.	230719.	2542189.
E	2041381.	96514.	281782.	3104822.
G1	925171.	66251.	150216.	1655166.
K	657383.	63312.	122974.	1354990.
Totals	7698919.	478449.	1177175.	12970714.

TERTIARY

5. = Q (Flow MGD)

0.065 = Rate (Interest Rate)

20. = Years (Amortization Period)

3000. = ULC(Land Cost $/Acre)

Unit Process	CC	OMC	AC	PW
AA	177407.	16443.	32544.	358589.
AB	912342.	13842.	96644.	1064882.
A1	468268.	27782.	70280.	774387.
L1	473028.	12576.	55506.	611598.
O1	598339.	69142.	123445.	1360187.
R	181932.	26670	43182.	475802.
R3	136093.	10705.	23056.	254047.
C1	1622239.	113271.	260499.	2870319.
E	2227995.	120555.	322760.	3556334.
G1	1048222.	74658.	169791.	1870845.
K	801838.	73010.	145782.	1606309.
Totals	8647704.	558659.	1343494.	14803296.

Appendix D

A More Detailed Description of TOPAZ

The principal method of solution in the TOPAZ model is linear programming. The iterative linear programming technique was chosen because all of the constraints in the model are linear and because linear programming is the most reliable and developed optimization technique.(5)

The skeleton of TOPAZ can be outlined in the following manner. To begin, let a(ijm) be a portion of total activity A(im) of type i to be allocated to zone j during time period m.(6)

Further, let:

U(a(ijm)) = total merit (usually costs-benefits) of allocating a portion of a(ijm) of activity i to zone j in time period m.

S(ijklmn) = amount of interaction between the portion of new plus existing activity i in zone j and the portion of new plus existing activity k in zone l, for the nth mode of interaction during time period m.

R(jlmn) = length of travel path or travel time between zones j and l for the nth node of interaction during time period m.

B(ijklmn) = benefit less cost of a unit of interaction S(ijklmn) along a unit length of path between zones j and l.

C(ijm) = benefit less cost of establishing and operating a unit of activity i in zone j during time period m.

Z(j) = area available for all activities in zone j.

Also:

N = number of activities

M = number of zones

T = number of time periods

Y = number of modes of interaction.

The most simplified version of TOPAZ thus becomes:

Min U(a(ijm)) = S(ijklmn)R(jlmn) B(ijklmn) +

a(ijm) c(ijm) E1

s.t.

N T a(ijm) = Z(j) (for j= 1,2,..m) E2

M a(ijm = A(im)(for i - 1,2...N; m=1,2...T; and im=NT+1) E3

A(rt+1) + N T A(im = M Z(j) E4

a(ijm-0) (for all i, j, m) E5

The objective function, E1, is for minimizing the costs minus benefits for interaction (first term) and establishment of activities (second term).

The first constraint, Equation E2, ensures that each zone is filled with one or more activities including vacant space in some cases.

The second constraint, Equation E3, ensures that each activity is fully allocated.

The third constraint, Equation E4, ensures that the total amount of activity equals the total zone capacity. This constraint is essential only to simplify the solution process.

The fourth constraint, Equation E5, ensures that the portions of activity a(ijm) are non-negative, however this does not preclude the possibility of an activity A(im) being negative.

<u>The Modular Structure of TOPAZ</u>

TOPAZ is composed of modules which are linked together in a hierarchical structure. TOPAZ is specialized to planning problems by means of the submodels utilized. Fig. 10 shows the modular structure for TOPAZ-URBAN used in a number of studies.(7)

Each family of modules may be regarded as a submodel. This concept possesses several advantages:

1. Crude submodels may be used initially in a particular study and then be refined as the study progresses and if the accuracy of these models becomes critical.

2. The modular structure also facilitates the conversion of a submodel into a computer program.

<u>Description of Modular Structure</u>

TOPAZ-URBAN is split into four modules as noted in the previous diagram.

Data Input - assembles and stores the data.

Data Message - prepares the data in a form suitable for the intertion phase and sets the starting solution.

Iteration - searches for the optimum solution in a cyclic step-wise manner.

Results - prints the resulting allocation of activities, costs, flows, etc.

<u>DATA INPUT</u> -

KEY Data include:

1. study title
2. number of activities, N
3. number of zones, M
4. number and length of time periods, T
5. number of establishment benefit-cost sets, NE
6. base year data

7. discount rate in percent per year, DR
8. weighting factors for components of the merit function.

ACTIVITY DATA

1. population increment and density for each activity in each time period, A(im) = Pop(im)/den(im)

ZONE DATA

1. area available for development for each activity in each zone, Z(j)

2. existing levels of activity in each zone if any, E(ij)

3. starting solution if any, a(ijm).

INTERACTION DATA

1. benefits and costs associated with establishing each activity in each zone in each time period (dollars n, or dcllars per acre or hectare), for services, such as, sewerage, water, telephone, drainage, streets, foundation preparation, social and recreational amenity, view, etc.

2. submodels may be used to design and cost networks for sewage, drainage, water, streets, etc.

ITERATION is divided into four modules. It takes an initial solution input as data, or generated by DATA MESSAGE, evaluates it in terms of costs and benefits and uses it as a basis to search an optimum solution. The search procedure is cyclic, with an improved solution being generated in each cycle, and terminates when the solution converges.

MERIT evaluates the merit value, Un, of the current solution in the nth cycle and calculates the benefit-cost of adding one more unit of each activity to each zone in each time period, (du/da(ijm))**n.

CONSTRAINTS sets up the constraints that the solution must obey.

TRANSPORTATION LP uses the output from MERIT and CONSTRAINTS to find an improved solution.

NEW SOLUTION modifies the new solution generated by the LP if the merit of the new solution, U**n+1, exceeds that of the previous solution, U**n.

RESULTS gives an evaluation of the optimum solution

ACTIVITY ALLOCATIONS gives for each zone the amount of activity allocated to it in each time period.

COST SUMMARY gives the discounted total and per capita costs for each establishment benefit-cost component and for each trip type.

MARGINAL COSTS gives the benefit-cost of adding one more unit of each activity to each zone in each time period.

TRANSPORT FLOWS gives the level of interaction between each pair of zones for each trip type in each time period.

ACCESSIBILTIES gives the level of accessibility of each zone to each activity in each time period.

MERIT is divided into two modules.

ESTABLISHMENT MERIT calculates the total benefit less cost of establishing a unit of activity in each zone in each time period, C(ijm). Service cost submodels may be required to calculate in detail the cost of water supply, sewerage, etc.

INTERACTION MERIT calculates the total benefit less cost of interaction for a unit of activity (including existing acitivity) in each zone in each time period. This module is further subdivided for differing types of trips if so desired.

SERVICE COSTS submodels may be used to refine initial cost estimates for supplying water, sewerage, etc.

HEADWORKS calculates the cost of installing main reservoirs in a water system,or sewerage treatment plant and outfalls in a sewer system, or power generation plants.

LOCAL PLANT calculates the cost of water service reservoirs or local sewage treatment plants, or electrical substations, etc.

TRUNK NETWORK calculates the cost at the neighborhood level of pipes or wires.

RETICULATION NETWORK calculates the cost at the neighborhood level of installing pipes and wires.

Appendix E - Runoff Module - Program Listing

```
*****  * * * * * * * * * *  MODULE 1  * * * * * * * * * * * * * * *****
*
                       RUNOFF GENERATION
*
*       SIMPLE INTEGRATED MODULAR WATERSHED PLANNING MODEL
*
*
*  THE RUNOFF GENERATION MODULE DETERMINES THE AMOUNT OF RUNOFF ASSOCIAT
    ED WITH A SELECTED RAINFALL EVENT AND IDENTIFIES THE QUANTITY
*   AND LOCATION OF THE RUNOFF.  GIVEN THE KNOWLEDGE OF THE FLOWS
*  EITHER OVERLAND TO THE RIVER OR ITS TRIBUTARIES AND BASED ON
   ASSUMPTIONS REGARDING THE PRESENCE OF PHOSPHORUS AND BOD IN THE
   RUNOFF POLLUTANT LOADINGS CAN BE DETERMINED.
*
   THE OUTPUT OF THIS MODULE BECOMES A PORTION OF THE INPUT
   DATA OF MODULE 2, THE WATER QUALITY MODULE.
*
**** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
      COMMON/BLK1/XL(5),SO(5),RN(5),TAVE(5),NES(10)
      COMMON/BLK2/RH(6),T(6),AO(6),AA(6),QO(6),QQ(6),NNS(10)
      COMMON/BLK5/AD(2,6),KODE(2)
      COMMON/BLK6/REFE(32,31)
C     MAIN PROGRAM
C     DT=TIME INCREMENT
C     G=GRAVITY
C     NH=TIME OF RAIN IN HOURS
C     TS=TIME OF RAIN IN SECONDS
C     FT=FINAL TIME OF CALCULATION IN SECONDS
C     N=NO OF OVERLAND FLOW PLANES
C     JS=NO OF STRIPS
C     NES=NO OF ELEMENTS IN A STRIP
```

```
C      NNS=NO OF NODES IN A STRIP
C      T=TOP WIDTH OF NODE
C      XL=LENGTH OF ELEMENT
C      SO=SLOPE OF ELEMENT
C      RN=MANNINGS N FOR ELEMENT
C      KODE=1 FOR AN ELEMENT NOT CONTAINING A FLOOD-DETENTION STRUCTURE
C      KODE=2 FOR AN ELEMENT CONTAINING A FLOOD-DETENTION STRUCTURE
C      ND=NUMBER OF FLOOD-DETENTION STRUCTURES IN AN ELEMENT
C      AD=AREA OF THE FLOOD-DETENTION STRUCTURE DRAINAGE IN AN ELEMENT
       CALL EXCESS
       N=1
       READ(5,5)DT,G
     5 FORMAT(F10.0,F10.1)
       WRITE(6,3)
     3 FORMAT(////1X,'TIME INCREMENT')
       WRITE(6,2)DT
     2 FORMAT(F10.0)
       READ(5,4)NH,TS,FT
     4 FORMAT(I10,2F10.0)
       NSEL=0
       DO 85 N=1,3
C      WRITE(6,6)
     6 FORMAT(///22X,'OVERLAND FLOW PLANE NUMBER')
C      WRITE(6,7)N
     7 FORMAT(30X,I5)
       READ(5,10)JS
    10 FORMAT(I5)
C      WRITE(6,15)
    15 FORMAT(/1X,'NUMBER OF STRIPS')
C      WRITE(6,20)JS
    20 FORMAT(4X,I5)
C      WRITE(6,25)
```

```
   25 FORMAT(/1X,'NO OF ELEMENTS',5X,'NO OF NODES')
      DO 30 K=1,JS
      READ(5,35)NES(K),NNS(K)
   35 FORMAT(2I5)
C     WRITE(6,40)NES(K),NNS(K)
   40 FORMAT(3X,I5,13X,I5)
   30 CONTINUE
      DO 50 K=1,JS
      ME=NES(K)
      NM=NNS(K)
      READ(5,55)(T(J),J=1,NM)
   55 FORMAT(6F10.0)
      DO 70 I=1,ME
      READ(5,75)XL(I),SO(I),RN(I),KODE(I)
   75 FORMAT(F10.0,F10.5,F10.4,I10)
      IF(KODE(I).NE.2)GO TO 70
      READ(5,60)ND
   60 FORMAT(I5)
      READ(5,65)(AD(I,L),L=1,ND)
   65 FORMAT(6F10.0)
   70 CONTINUE
      CALL OVERL(K,N,DT,G,NH,TS,FT,ND,NSEL)
   50 CONTINUE
85    CONTINUE
      DO 90 N=1,3
      CALL CHANL(N,DT,G)
   90 CONTINUE
      STOP
      END
      SUBROUTINE EXCESS
      COMMON/BLK7/DEPTH(69),AH(69),FAW(69),FGW(69),FC(69),TP(6
     19),STO(69),PRECIP(2,31),FHW(69),STOI(69)
```

```
      COMMON/BLK8/REHRU(69,2,31)                                        ROC00970
      COMMON/BLK6/REFE(32,31)                                           ROC00980
      DIMENSION KIHRU(69),NHRU(32),IHRU(32,20),FHRU(32,20),NRR(32)      ROC00990
      READ(5,1) NTELEM,NDHRU                                            ROC01000
 1    FORMAT(2I10)                                                      ROC01010
      DO 2 I=1,NDHRU                                                    ROC01020
      KIHRU(I)=0                                                        ROC01030
 2    CONTINUE                                                          ROC01040
      DO 6 I=1,NTELEM                                                   ROC01050
      READ(5,3) NHRU(I)                                                 ROC01060
 3    FORMAT(I10)                                                       ROC01070
      N=NHRU(I)                                                         ROC01080
      READ(5,4)(IHRU(I,J),J=1,N)                                        ROC01090
 4    FORMAT(16I5)                                                      ROC01100
      READ(5,5)(FHRU(I,J),J=1,N)                                        ROC01110
 5    FORMAT(16F5.2)                                                    ROC01120
 6    CONTINUE                                                          ROC01130
      READ(5,7)NTRR,NH,SMC,C                                            ROC01140
 7    FORMAT(2I10,2F10.2)                                               ROC01150
      READ(5,29)NST,MONTH,NDAY,NYEAR                                    ROC01160
 29   FORMAT(4I5)                                                       ROC01170
C     WRITE(6,23)                                                       ROC01180
 23   FORMAT(///17X,'SUMMARY OF HYDROLOGIC RESPONSE UNITS')             ROC01190
C     WRITE(6,24)                                                       ROC01200
 24   FORMAT(//3X,'HRU NO',8X,'A',8X,'FAW',7X,'FGW',7X,'FHW',8X,'FC',7X,ROC01210
     1'DEPTH')                                                          ROC01220
      DO 21 I=1,NDHRU                                                   ROC01230
      READ(5,22)AH(I),FAW(I),FGW(I),FHW(I),FC(I),DEPTH(I)               ROC01240
 22    FORMAT(5F10.3,F10.0)                                             ROC01250
C     WRITE(6,26)I,AH(I),FAW(I),FGW(I),FHW(I),FC(I),DEPTH(I)            ROC01260
 26   FORMAT(I7,3X,5F10.3,F10.1)                                        ROC01270
      TP(I)=(FAW(I)+FGW(I)+FHW(I))*DEPTH(I)                             ROC01280
```

```
      STOI(I)=TP(I)-(SMC*TP(I))
21    CONTINUE
      READ(5,8)(NRR(L),L=1,NTELEM)
8     FORMAT(16I5)
      DO 12 I=1,NTRR
      DO 101 L=1,NTELEM
      IF(NRR(L).NE.I)GO TO 101
      N=NHRU(L)
      DO 50 M=1,N
      MN=IHRU(L,M)
      KIHRU(MN)=I
50    CONTINUE
101   CONTINUE
      IF (NTRR.EQ.1)GO TO 55
C     WRITE(6,30)
30    FORMAT(///5X,'RAINFALL INTENSITY NO')
C     WRITE(6,35)I
35    FORMAT(11X,I5)
55    DO 11 J=1,NH
      READ(5,9)PRECIP(I,J)
9     FORMAT(F10.2)
      DO 10 K=1,NDHRU
      KIHRU(K)=1
      IF(KIHRU(K).NE.I)GO TO 10
      IF(J.EQ.1)STO(K)=STOI(K)
      CALL HOLTAN(K,I,J,C)
10    CONTINUE
11    CONTINUE
12    CONTINUE
      DO 16 I=1,NTRR
      DO 15 L=1,NTELEM
      IF(NRR(L).NE.I)GO TO 15
```

```
      DO 14 J=1,NH
      REFEX=0.0
      MHRU=NHRU(L)
      DO 13 N=1,MHRU
      K=IHRU(L,N)
      REFE(L,J)=REFEX+REHRU(K,I,J)*FHRU(L,N)
      REFEX=REFE(L,J)
13    CONTINUE
14    CONTINUE
15    CONTINUE
16    CONTINUE
C     CALL TABLE(NST,MONTH,NDAY,NYEAR,NTRR,NH,NDHRU,NTELEM)
      RETURN
      END
      SUBROUTINE HOLTAN(K,I,J,C)
      COMMON/BLK7/DEPTH(69),AH(69),FAW(69),FGW(69),FC(69),TP(6
     19),STO(69),PRECIP(2,31),FHW(69),STOI(69)
      COMMON/BLK8/REHRU(69,2,31)
      IF(STO(K).LT.0.0)STO(K)=0.0
      IF(STO(K).EQ.0.0.AND.FC(K).EQ.0.0)XINF=0.0
      IF(STO(K).EQ.0.0.AND.FC(K).EQ.0.0)GO TO 7
      F1=AH(K)*STO(K)**C+FC(K)
      XP=STO(K)-PRECIP(I,J)
      F2=FC(K)
      IF(XP.GT.0.0)F2=AH(K)*XP**C+FC(K)
      FA=(F1+F2)/2.0
      TA=PRECIP(I,J)/FA
      EPS1=0.0
      IF(TA.LE.1.0)GO TO 2
1     EPS1=EPS1+0.0001
      TESTIN=PRECIP(I,J)-EPS1
      XXP=STO(K)-TESTIN
```

```
      F2=FC(K)                                                          ROC01930
      IF(XXP.GT.0.0)F2=AH(K)*XXP**C+FC(K)                               ROC01940
      FA=(F1+F2)/2.0                                                    ROC01950
      TA=TESTIN/FA                                                      ROC01960
      IF(TA.GT.1.0)GO TO 1                                              ROC01970
C     TA=ABS(TA-1.0)                                                    ROC01980
      XINF=TESTIN                                                       ROC01990
      GO TO 7                                                           ROC02000
C     IF(TA.LE.0.005)GO TO 7                                            ROC02010
C     GO TO 1                                                           ROC02020
2     CONTINUE                                                          ROC02030
                                                                        ROC02040
      XINF=PRECIP(I,J)                                                  ROC02050
      IF(XINF.LE.STO(K))GO TO 7                                         ROC02060
      XINF=STO(K)                                                       ROC02070
      STO(K)=0.0                                                        ROC02080
      GO TO 8                                                           ROC02090
7     STO(K)=STO(K)-XINF                                                ROC02100
8     REHRU(K,I,J)=PRECIP(I,J)-XINF                                     ROC02110
      IF(REHRU(K,I,J).LT.0.0)REHRU(K,I,J)=0.0                           ROC02120
      RETURN                                                            ROC02130
      END                                                               ROC02140
      SUBROUTINE TABLE(NST,MONTH,NDAY,NYEAR,NTRR,NH,NDHRU,NTELEM)       ROC02150
      COMMON/BLK6/REFE(32,31)                                           ROC02160
      COMMON/BLK8/REHRU(69,2,31)                                        ROC02170
      COMMON/BLK7/DEPTH(69),AH(69),FAW(69),FGW(69),FC(69),TP(6          ROC02180
     19),STO(69),PRECIP(2,31),FHW(69),STOI(69)                          ROC02190
      DIMENSION NUMBER(24)                                              ROC02200
      I=NTRR                                                            ROC02210
C     WRITE(6,1)                                                        ROC02220
1     FORMAT(///54X,'RAINFALL EXCESS FOR STORM')                        ROC02230
C     WRITE(6,2)NST,MONTH,NDAY,NYEAR                                    ROC02240
```

```
2       FORMAT(51X,'BEGINNING AT',1X,I2,':00',1X,'ON',1X,I2,'/',I2,'/',I2)
C       WRITE(6,3)
3       FORMAT(///43X,'HRU RAINFALL EXCESS FOR EACH HOUR OF THE STORM')
        AHOUR=NH
        NTAB=AHOUR/24.0+.99
        L=0
        LH=1
        DO 100 MN=1,NTAB
        WRITE(6,4)
4       FORMAT(//49X,'TIME FROM START OF STORM IN HOURS')
        DO 5 M=1,24
        L=L+1
5       NUMBER(M)=L
        WRITE(6,33)NUMBER
33      FORMAT(3X,24I5)
        WRITE(6,6)
6       FORMAT(/59X,'ACTUAL RAINFALL')
        KH=24*MN
        IF(MN.EQ.NTAB)KH=NH
        WRITE(6,7)(PRECIP(I,K),K=LH,KH)
7       FORMAT(5X,24F5.2)
        WRITE(6,8)
8       FORMAT(/1X,'HRU',55X,'RAINFALL EXCESS',52X,'HRU')
        DO 10 J=1,NDHRU
        WRITE(6,9)J,(REHRU(J,I,K),K=LH,KH)
9       FORMAT(1X,I3,1X,24F5.2)
10      CONTINUE
        LH=KH+1
100     CONTINUE
        WRITE(6,11)
11      FORMAT(///41X,'ELEMENT RAINFALL EXCESS FOR EACH HOUR OF THE STORM'
       1)
```

```
      L=0
      LH=1
      DO 101 MN=1,NTAB
      WRITE(6,12)
12    FORMAT(//49X,'TIME FROM START OF STORM IN HOURS')
      DO 30 M=1,24
      L=L+1
30    NUMBER(M)=L
      WRITE(6,31)NUMBER
31    FORMAT(3X,24I5)
      WRITE(6,14)
14    FORMAT(/59X,'ACTUAL RAINFALL')
      KH=24*MN
      IF(MN.EQ.NTAB)KH=NH
      WRITE(6,15)(PRECIP(I,K),K=LH,KH)
15    FORMAT(5X,24F5.2)
      WRITE(6,16)
16    FORMAT(/1X,'ELE',55X,'RAINFALL EXCESS',52X,'ELE')
      DO 18 J=1,NTELEM
      WRITE(6,17)J,(REFE(J,K),K=LH,KH)
17    FORMAT(1X,I3,1X,24F5.2)
18    CONTINUE
101   CONTINUE
      RETURN
      END
      SUBROUTINE OVERL(K,N,DT,G,NH,TS,FT,ND,NSEL)
      COMMON/BLK1/XL(5),SO(5),RN(5),TAVE(5),NES(10)
      COMMON/BLK2/RH(6),T(6),AO(6),AA(6),QO(6),QQ(6),NNS(10)
      COMMON/BLK3/RI(5),AAD(6),QD(6),TWD(6),VOL(6),NPTS(6),STO(6,20),F(6
     1,20)
      COMMON/BLK4/QOUT(10,720,3),QC(720,3)
      COMMON/BLK5/AD(2,6),KODE(2)
```

```
      COMMON/BLK6/REFE(32,31)                                           ROC02890
      DIMENSION Q(5),C(5),SE1(2,2),S1(5,2),RE1(2),RE2(2),A1(5,5),A(36),RROC02900
     11(5),R2(5),RC(36),RQ(5),AE(5)                                     ROC02910
C     OVERLAND FLOW MODEL                                               ROC02920
C     ST=STARTING TIME                                                  ROC02930
C     MAP=1 FOR A STRIP NOT CONTAINING A FLOOD-DETENTION STRUCTURE      ROC02940
C     MAP=2 FOR A STRIP CONTAINING A FLOOD-DETENTION STRUCTURE          ROC02950
C     AO=INITIAL CROSS SECTIONAL AREA                                   ROC02960
C     QO=INITIAL FLOW                                                   ROC02970
C     SL=LENGTH OF A STRIP                                              ROC02980
C     TTWD=TOTAL SUM OF WIDTHS OF STRUCTURE DRAINAGE AREAS              ROC02990
C     QST=TOTAL FLOW RELEASED FROM ALL STRUCTURES IN AN ELEMENT         ROC03000
C     TAVE=AVERAGE WIDTH OF AN ELEMENT                                  ROC03010
C     AE=AREA OF ELEMENT                                                ROC03020
C     TWD=WIDTH OF A STRUCTURE DRAINAGE AREA                            ROC03030
C     VOL=CALCULATED STORAGE IN A RESERVOIR                             ROC03040
C     AAD=CALCULATED AREA OF FLOW INTO THE RESERVOIRS                   ROC03050
C     QD=CALCULATED FLOW INTO THE RESERVOIRS                            ROC03060
C     MPTS=NUMBER OF POINTS DEFINING STORAGE AND FLOW FROM STRUCTURE    ROC03070
C     F=FLOW FROM STRUCTURE DEFINED                                     ROC03080
C     STO=STORAGE IN RESERVOIR DEFINED                                  ROC03090
C     RI=RAINFALL EXCESS IN INCHES/HOUR                                 ROC03100
C     VK=VELOCITY OF FLOW                                               ROC03110
C     FR=FROUDE NUMBER                                                  ROC03120
C     WK=KINEMATIC WAVE NUMBER                                          ROC03130
C     RQ=RAINFALL EXCESS IN CFS/ONE FOOT LENGTH                         ROC03140
C     AA=CALCULATED CROSS SECTIONAL AREA                                ROC03150
C     Q=CALCULATED FLOW                                                 ROC03160
C     QQ=OVERLAND FLOW OUTPUT IN CFS/FT                                 ROC03170
C     RH=HYDRAULIC RADIUS                                               ROC03180
C     QOUT=OVERLAND FLOW INTO CHANNEL                                   ROC03190
      ST=0.0                                                            ROC03200
```

```
      MAP=1
      WARN=1
      NE=NES(K)
      NN=NNS(K)
      DO 100 I=1,NN
      AO(I)=0.0
      QO(I)=0.0
  100 CONTINUE
C     WRITE(6,20)
   20 FORMAT(//26X,'STRIP NUMBER')
C     WRITE(6,25)K
   25 FORMAT(28X,I5)
C     WRITE(6,30)
   30 FORMAT(/4X,'ELEMENT NO',5X,'LENGTH',5X,'AVG. WIDTH',5X,'SLOPE',5X,
     1'MANNINGS N')
      SL=0.0
      TTWD=0.0
      QST=0.0
      DO 32 I=1,NE
      SL=SL+XL(I)
   32 CONTINUE
      DO 45 I=1,NE
      TAVE(I)=(T(I)+T(I+1))/2.0
C     WRITE(6,35)I,XL(I),TAVE(I),SO(I),RN(I)
   35 FORMAT(I10,6X,F10.0,3X,F10.0,2X,F10.3,3X,F10.3)
      AE(I)=TAVE(I)*XL(I)
      IF(KODE(I).NE.2)GO TO 45
      MAP=2
      DO 36 L=1,ND
      TWD(L)=AD(I,L)/SL
      TTWD=TTWD+TWD(L)
   36 CONTINUE
```

```
   45 CONTINUE
      IF(MAP.NE.2)GO TO 1000
      DO 46 L=1,ND
      VOL(L)=0.0
      AAD(L)=0.0
      QD(L)=0.0
      READ(5,44)NPTS(L)
   44 FORMAT(I5)
   46 CONTINUE
      DO 49 L=1,ND
      MPTS=NPTS(L)
      DO 48 J=2,MPTS
      READ(5,47)F(L,J),STO(L,J)
   47 FORMAT(2F10.0)
   48 CONTINUE
   49 CONTINUE
      RND=0.0
      SOD=0.0
      TAVED=0.0
      DO 52 I=1,NE
      RND=RND+RN(I)
      SOD=SOD+SO(I)
      TAVED=TAVED+TAVE(I)
   52 CONTINUE
      RN(1)=RND/NE
      SO(1)=SOD/NE
      TAVE(1)=TAVED/NE
      TAVE(1)=TAVE(1)-TTWD
      XL(1)=SL
 1000 NE=NES(K)
      J=ST/3600.0+1
      L=NSEL+NE
```

```
      IF(MAP.EQ.2)NE=1
      IF(REFE(L,J).EQ.0.0)GO TO 2000
      QMAX=REFE(L,J)*SL/43200.0
      HK=(QMAX*RN(NE)/(1.49*(SO(NE))**0.5))**0.6
      VK=QMAX/HK
      FR=VK/SQRT(G*HK)
      WK=SO(NE)*SL*G/(VK**2.0)
      IF(FR.GT.1.5)GO TO 60
      IF(WK.LT.10.0)GO TO 60
      GO TO 95
   60 IF(WARN.EQ.2.0)GO TO 80
      WRITE(6,70)
   70 FORMAT(/5X,'TIME',5X,'FROUDE NUMBER',5X,'KINEMATIC WAVE NUMBER')
      WARN=2
   80 WRITE(6,90)ST,FR,WK
   90 FORMAT(F10.0,3X,F10.3,13X,F10.2)
   95 NE=NES(K)
 2000  DO 105 I=1,NE
      J=ST/3600.0+1
      L=NSEL+I
      RQ(I)=(REFE(L,J)/43200.0)*TAVE(I)
  105 CONTINUE
      IF(MAP.NE.2)GO TO 115
      L=NSEL+NE
      RQ(I)=(REFE(L,J)/43200.0)*TAVE(I)
      NE=1
      NN=2
      GO TO 115
 3000 DO 110 I=1,NN
      RI(I)=0.0
      RQ(I)=0.0
  110 CONTINUE
```

```
  115 DO 120 I=1,NN                                         ROC04170
      R1(I)=0.0                                             ROC04180
      R2(I)=0.0                                             ROC04190
  120 CONTINUE                                              ROC04200
      DO 125 I=1,NN                                         ROC04210
      DO 125 J=1,2                                          ROC04220
      S1(I,J)=0.0                                           ROC04230
  125 CONTINUE                                              ROC04240
      SE1(1,1)=2.0/3.0                                      ROC04250
      SE1(1,2)=1.0/3.0                                      ROC04260
      SE1(2,1)=SE1(1,2)                                     ROC04270
      SE1(2,2)=SE1(1,1)                                     ROC04280
      M=0                                                   ROC04290
  130 M=M+1                                                 ROC04300
      RE1(1)=(QO(M+1)-QO(M))/(XL(M))                        ROC04310
      RE1(2)=RE1(1)                                         ROC04320
      RE2(1)=RQ(M)                                          ROC04330
      RE2(2)=RE2(1)                                         ROC04340
      R1(M)=R1(M)+RE1(1)                                    ROC04350
      R1(M+1)=R1(M+1)+RE1(2)                                ROC04360
      R2(M)=R2(M)+RE2(1)                                    ROC04370
      R2(M+1)=R2(M+1)+RE2(2)                                ROC04380
      S1(M,1)=S1(M,1)+SE1(1,1)                              ROC04390
      S1(M,2)=S1(M,2)+SE1(1,2)                              ROC04400
      S1(M+1,1)=S1(M+1,1)+SE1(2,2)                          ROC04410
      IF(M.LT.NE)GO TO 130                                  ROC04420
      DO 140 I=1,NN                                         ROC04430
      A1(I,I)=S1(I,1)                                       ROC04440
      J=I+1                                                 ROC04450
      IF(J.GT.NN)GO TO 145                                  ROC04460
      A1(I,J)=S1(I,2)                                       ROC04470
      A1(J,I)=A1(I,J)                                       ROC04480
```

```
      NK=J+1                                                            ROC04490
      IF(NK.GT.NN)GO TO 140                                             ROC04500
      DO 135 L=NK,NN                                                    ROC04510
      A1(I,L)=0.0                                                       ROC04520
      A1(L,I)=0.0                                                       ROC04530
  135 CONTINUE                                                          ROC04540
  140 CONTINUE                                                          ROC04550
  145 ST=ST+DT                                                          ROC04560
      DO 155 I=1,NN                                                     ROC04570
      SUM=0.0                                                           ROC04580
      DO 150 J=1,NN                                                     ROC04590
      C(J)=A1(I,J)*A0(J)/DT                                             ROC04600
      SUM=SUM+C(J)                                                      ROC04610
  150 CONTINUE                                                          ROC04620
      RC(I)=SUM+R2(I)-R1(I)                                             ROC04630
  155 CONTINUE                                                          ROC04640
      LL=0                                                              ROC04650
      LC=0                                                              ROC04660
      DO 165 I=1,NN                                                     ROC04670
      LL=LL+1                                                           ROC04680
      LB=2                                                              ROC04690
      IF(I.EQ.1.OR.I.EQ.NN)LB=1                                         ROC04700
      LE=LL+LB                                                          ROC04710
      DO 160 J=LL,LE                                                    ROC04720
      LC=LC+1                                                           ROC04730
      A(LC)=A1(I,J)                                                     ROC04740
  160 CONTINUE                                                          ROC04750
      IF(I.EQ.1)LL=0                                                    ROC04760
  165 CONTINUE                                                          ROC04770
      CALL GELB(RC,A,NN,1,1,1,5.0E-7,IER)                               ROC04780
      DO 170 I=1,NN                                                     ROC04790
      AA(I)=RC(I)*DT                                                    ROC04800
```

```
  170 CONTINUE
      DO 175 I=1,NE
      Q(1)=0.0
      QQ(1)=0.0
      IF(AA(I+1).LT.0.0)Q(I+1)=0.0
      IF(AA(I+1).LT.0.0)GO TO 175
      RH(I+1)=AA(I+1)/T(I+1)
  172 Q(I+1)=(1.49*SQRT(SO(I))*RH(I+1)**0.67)/RN(I)*AA(I+1)
      QQ(I+1)=Q(I+1)/T(I+1)
      IF(MAP.NE.2)GO TO 175
      CALL STRUC(I,DT,ND,ST,JT,NDT,QST,SL,NE)
  175 CONTINUE
      IT=ST/DT+0.5
      JT=IT
      QOUT(K,JT,N)=QQ(NN)+(QST/T(NN))
      DO 180 I=1,NN
      AO(I)=AA(I)
      QO(I)=Q(I)
  180 CONTINUE
      TI=ST/3600.0
      NI=TI
      IF(NI.GE.NH)GO TO 5000
      IF(NI-TI)4000,1000,4000
 4000 IF(ST-TS)2000,5000,5000
 5000 IF(ST-FT)3000,6000,6000
6000  NSEL=NSEL+NE
      RETURN
      END
      SUBROUTINE STRUC(I,DT,ND,ST,JT,NDT,QST,SL,NE)
      COMMON/BLK1/XL(5),SO(5),RN(5),TAVE(5),NES(10)
      COMMON/BLK3/RI(5),AAD(6),QD(6),TWD(6),VOL(6),NPTS(6),STO(6,20),F(6
     1,20)
```

```
      DIMENSION QS(6)                                                   ROC05130
C     QS=CALCULATED FLOW FROM DAM                                       ROC05140
      DO 18 L=1,ND                                                      ROC05150
      AAD(L)=AAD(L)-(DT*((QD(L)/SL)-((RI(1)/43200.0)*TWD(L))))         ROC05160
      QD(L)=(1.49*SQRT(SO(1))*((AAD(L)/TWD(L))**0.67))/RN(1)*AAD(L)    ROC05170
      VOL(L)=VOL(L)+(QD(L)*DT)                                          ROC05180
   18 CONTINUE                                                          ROC05190
      DO 50 L=1,ND                                                      ROC05200
      MPTS=NPTS(L)                                                      ROC05210
      DO 20 J=2,MPTS                                                    ROC05220
      F(L,1)=0.0                                                        ROC05230
      STO(L,1)=0.0                                                      ROC05240
      IF(VOL(L)-STO(L,J))40,30,20                                       ROC05250
   20 CONTINUE                                                          ROC05260
   30 QS(L)=F(L,J)                                                      ROC05270
      GO TO 50                                                          ROC05280
   40 QS(L)=F(L,J)-(F(L,J)-F(L,J-1))*(STO(L,J)-VOL(L))/(STO(L,J)-STO(L,JROC05290
     1-1))                                                              ROC05300
   50 CONTINUE                                                          ROC05310
      QST=0.0                                                           ROC05320
      DO 60 L=1,ND                                                      ROC05330
      VOL(L)=VOL(L)-(QS(L)*DT)                                          ROC05340
      QST=QST+QS(L)                                                     ROC05350
   60 CONTINUE                                                          ROC05360
   70 RETURN                                                            ROC05370
      END                                                               ROC05380
      SUBROUTINE CHANL(N,DT,G)                                          ROC05390
      COMMON/BLK1/XL(5),SO(5),RN(5),TAVE(5),NES(10)                     ROC05400
      COMMON/BLK2/RH(6),T(6),AO(6),AA(6),QO(6),QQ(6),NNS(10)            ROC05410
      COMMON/BLK4/QOUT(10,720,3),QC(720,3)                              ROC05420
      DIMENSION Q(6),C(6),SE1(2,2),S1(6,2),RE1(2),RE2(2),A1(6,6),A(36),RROC05430
     11(6),R2(6),RC(36),B1(6),B2(6),B3(6),W1(6),W2(6),W3(6),RQ(6)       ROC05440
```

```
C       CHANNEL FLOW MODEL
C       ST=STARTING TIME
C       TCS=TIME OF CALCULATION
C       CL=LENGTH OF CHANNEL
C       NE=NO OF ELEMENTS
C       NN=NO OF NODES
C       XL=LENGTH OF ELEMENT
C       SO=SLOPE OF ELEMENT
C       RN=MANNINGS N FOR CHANNEL
C       KPTS=NO OF POINTS DEFINING CHANNEL CROSS SECTION
C       B=AREA OF CHANNEL CROSS SECTION DEFINED
C       W=TOP WIDTH OF CHANNEL CROSS SECTION DEFINED
C       AO=INITIAL AREA
C       QO=INITIAL FLOW
C       RQ=INPUT TO CHANNEL FROM OVERLAND FLOW
C       AA=CALCULATED AREA
C       RH=HYDRAULIC RADIUS
C       Q=CALCULATED FLOW
C       QC=FLOW AT THE CONFLUENCE OF THE CHANNELS
        ST=0.0
        WRITE(6,10)
     10 FORMAT(///15X,'CHANNEL NUMBER')
        WRITE(6,15)N
     15 FORMAT(18X,I5)
        READ(5,30)TCS,CL,NE,NN
     30 FORMAT(2F10.0,2I5)
        READ(5,50)JS
     50 FORMAT(I5)
        WRITE(6,60)
     60 FORMAT(/4X,'ELEMENT NO',5X,'LENGTH',5X,'SLOPE',5X,'MANNINGS N')
        DO 90 K=1,NE
        READ(5,70)XL(K),SO(K),RN(K)
```

```
   70 FORMAT(F10.0,F10.5,F10.4)
      WRITE(6,80)K,XL(K),SO(K),RN(K)
   80 FORMAT(I10,6X,F10.0,F10.3,3X,F10.3)
   90 CONTINUE
      WRITE(6,85)
   85 FORMAT(//7X,'TIME',16X,'DISCHARGE')
      DO 95 I=2,NN
      READ(5,93)B1(I),W1(I),B2(I),W2(I),B3(I),W3(I)
93    FORMAT(6F10.2)
   95 CONTINUE
      DO 100 I=1,NN
      AO(I)=0.0
      QO(I)=0.0
  100 CONTINUE
 1000 ST=ST+DT
      IT=ST/DT+0.5
      JT=IT
      LS=JS/2
      DO 105 I=1,LS
      RQ(I)=QOUT(2*I-1,JT,N)+QOUT(2*I,JT,N)
  105 CONTINUE
      DO 120 I=1,NN
      R1(I)=0.0
      R2(I)=0.0
  120 CONTINUE
      DO 125 I=1,NN
      DO 125 J=1,2
      S1(I,J)=0.0
  125 CONTINUE
      SE1(1,1)=2.0/3.0
      SE1(1,2)=1.0/3.0
      SE1(2,1)=SE1(1,2)
```

```
      SE1(2,2)=SE1(1,1)                                                 ROC06090
      M=0                                                               ROC06100
  130 M=M+1                                                             ROC06110
      RE1(1)=(QO(M+1)-QO(M))/(XL(M))                                    ROC06120
      RE1(2)=RE1(1)                                                     ROC06130
      RE2(1)=RQ(M)                                                      ROC06140
      RE2(2)=RE2(1)                                                     ROC06150
      R1(M)=R1(M)+RE1(1)                                                ROC06160
      R1(M+1)=R1(M+1)+RE1(2)                                            ROC06170
      R2(M)=R2(M)+RE2(1)                                                ROC06180
      R2(M+1)=R2(M+1)+RE2(2)                                            ROC06190
      S1(M,1)=S1(M,1)+SE1(1,1)                                          ROC06200
      S1(M,2)=S1(M,2)+SE1(1,2)                                          ROC06210
      S1(M+1,1)=S1(M+1,1)+SE1(2,2)                                      ROC06220
      IF(M.LT.NE)GO TO 130                                              ROC06230
      DO 140 I=1,NN                                                     ROC06240
      A1(I,I)=S1(I,1)                                                   ROC06250
      J=I+1                                                             ROC06260
      IF(J.GT.NN)GO TO 145                                              ROC06270
      A1(I,J)=S1(I,2)                                                   ROC06280
      A1(J,I)=A1(I,J)                                                   ROC06290
      NK=J+1                                                            ROC06300
      IF(NK.GT.NN)GO TO 140                                             ROC06310
      DO 135 L=NK,NN                                                    ROC06320
      A1(I,L)=0.0                                                       ROC06330
      A1(L,I)=0.0                                                       ROC06340
  135 CONTINUE                                                          ROC06350
  140 CONTINUE                                                          ROC06360
  145 DO 155 I=1,NN                                                     ROC06370
      SUM=0.0                                                           ROC06380
      DO 150 J=1,NN                                                     ROC06390
      C(J)=A1(I,J)*AO(J)/DT                                             ROC06400
```

```
      SUM=SUM+C(J)                                                      ROC06410
  150 CONTINUE                                                          ROC06420
      RC(I)=SUM+R2(I)-R1(I)                                             ROC06430
  155 CONTINUE                                                          ROC06440
      LL=0                                                              ROC06450
      LC=0                                                              ROC06460
      DO 165 I=1,NN                                                     ROC06470
      LL=LL+1                                                           ROC06480
      LB=2                                                              ROC06490
      IF(I.EQ.1.OR.I.EQ.NN)LB=1                                         ROC06500
      LE=LL+LB                                                          ROC06510
      DO 160 J=LL,LE                                                    ROC06520
      LC=LC+1                                                           ROC06530
      A(LC)=A1(I,J)                                                     ROC06540
  160 CONTINUE                                                          ROC06550
      IF(I.EQ.1)LL=0                                                    ROC06560
  165 CONTINUE                                                          ROC06570
      CALL GELB(RC,A,NN,1,1,1,5.0E-7,IER)                               ROC06580
      DO 170 I=1,NN                                                     ROC06590
      AA(I)=RC(I)*DT                                                    ROC06600
  170 CONTINUE                                                          ROC06610
  200 DO 270 I=2,NN                                                     ROC06620
      IF(AA(I).LT.0.0)Q(I)=0.0                                          ROC06630
      IF(AA(I).LT.0.0)GO TO 270                                         ROC06640
      IF(AA(I)-B1(I))240,240,250                                        ROC06650
240   T(I)=W1(I)*(AA(I)/B1(I))                                          ROC06660
      GO TO 260                                                         ROC06670
250   IF(AA(I)-B2(I))251,251,252                                        ROC06680
251   T(I)=W1(I)+2.0*((AA(I)-B1(I))/W2(I))                              ROC06690
      GO TO 260                                                         ROC06700
252   T(I)=W1(I)+2.0*((B2(I)-B1(I))/W2(I))+((W3(I)-W2(I))*(AA(I)-B2(I)))ROC06710
     1/(B3(I)-B2(I))                                                    ROC06720
```

```
      IF(T(I).EQ.0.0)Q(I)=0.0
      IF(T(I).EQ.0.0)GO TO 270
  260 RH(I)=AA(I)/T(I)
      Q(I)=(1.49*SQRT(SO(I-1))*RH(I)**0.67)/RN(I-1)*AA(I)
  270 CONTINUE
      Q(1)=0.0
      IF(N.EQ.3)Q(1)=QC(JT,1)+QC(JT,2)
      QC(JT,N)=Q(NN)
      TI=ST/1800.0
      NI=TI
      IF(NI-TI)310,290,310
C 290 WRITE(6,300)ST,Q(NN)
  290 WRITE(6,300)ST,Q(NN),Q(2),Q(3),Q(4),Q(5)
C 290 WRITE(6,300)ST,Q(NN),QOUT(1,JT,3),QOUT(2,JT,3)
C 300 FORMAT(2X,F10.0,13X,F10.2)
  300 FORMAT(2X,F10.0,13X,F10.2,4F10.2)
C 300 FORMAT(2X,F10.0,13X,F10.2,2F10.4)
  310 DO 320 I=1,NN
      AO(I)=AA(I)
      QO(I)=Q(I)
  320 CONTINUE
      IF(ST-TCS)1000,2000,1000
 2000 RETURN
      END
      SUBROUTINE GELB(R,A,M,N,MUD,MLD,EPS,IER)
      DIMENSION R(36),A(36)
C     TEST ON WRONG INPUT PARAMETERS
      IF(MLD)47,1,1
    1 IF(MUD)47,2,2
    2 MC=1+MLD+MUD
      IF(MC+1-M-M)3,3,47
C     PREPARE INTEGER PARAMETERS
```

```
C          MC=NUMBER OF COLUMNS IN MATRIX A
C          MU=NUMBER OF ZEROS TO BE INSERTED IN FIRST ROW OF MATRIX A
C          ML=NUMBER OF MISSING ELEMENTS IN LAST ROW OF MATRIX A
C          MR=INDEX OF LAST ROW IN MATRIX A WITH MC ELEMENTS
C          MZ=TOTAL NUMBER OF ZEROS TO BE INSERTED IN MATRIX A
C          MA=TOTAL NUMBER OF STORAGE LOCATIONS NECESSARY FOR MATRIX A
C          NM=NUMBER OF ELEMENTS IN MATRIX R
    3 IF(MC-M)5,5,4
    4 MC=M
    5 MU=MC-MUD-1
      ML=MC-MLD-1
      MR=M-ML
      MZ=(MU*(MU+1))/2
      MA=M*MC-(ML*(ML+1))/2
      NM=N*M
C     MOVE ELEMENTS BACKWARD AND SEARCH FOR ABSOLUTELY GREATEST ELEMENT
C     (NOT NECESSARY IN CASE OF A MATRIX WITHOUT LOWER CODIAGONALS)
      IER=0
      PIV=0
      IF(MLD)14,14,6
    6 JJ=MA
      J=MA-MZ
      KST=J
      DO 9 K=1,KST
      TB=A(J)
      A(JJ)=TB
      TB=ABS(TB)
      IF(TB-PIV)8,8,7
    7 PIV=TB
    8 J=J-1
    9 JJ=JJ-1
C     INSERT ZEROS IN FIRST MU ROWS (NOT NECESSARY IN CASE MZ=0)
```

```
      IF(MZ)14,14,10
   10 JJ=1
       J=1+MZ
      IC=1+MUD
      DO 13 I=1,MU
      DO 12 K=1,MC
      A(JJ)=0
      IF(K-IC)11,11,12
   11 A(JJ)=A(J)
      J=J+1
   12 JJ=JJ+1
   13 IC=IC+1
C     GENERATE TEST VALUE FOR SINGULARITY
   14 TOL=EPS*PIV
C     START DECOMPOSITION LOOP
      KST=1
      IDST=MC
      IC=MC-1
      DO 38 K=1,M
      IF(K-MR-1)16,16,15
   15 IDST=IDST-1
   16 ID=IDST
      ILR=K+MLD
      IF(ILR-M)18,18,17
   17 ILR=M
   18 II=KST
C     PIVOT SEARCH IN FIRST COLUMN (ROW INDEXES FROM I=K UP TO I=ILR)
      PIV=0
      DO 22 I=K,ILR
      TB=ABS(A(II))
      IF(TB-PIV)20,20,19
   19 PIV=TB
```

```
      J=I                                                               ROC07690
      JJ=II                                                             ROC07700
   20 IF(I-MR)22,22,21                                                  ROC07710
   21 ID=ID-1                                                           ROC07720
   22 II=II+ID                                                          ROC07730
C     TEST ON SINGULARITY                                               ROC07740
      IF(PIV)47,47,23                                                   ROC07750
   23 IF(IER)26,24,26                                                   ROC07760
   24 IF(PIV-TOL)25,25,26                                               ROC07770
   25 IER=K-1                                                           ROC07780
   26 PIV=1./A(JJ)                                                      ROC07790
C     PIVOT ROW REDUCTION AND ROW INTERCHANGE IN RIGHT HAND SIDE R      ROC07800
      ID=J-K                                                            ROC07810
      DO 27 I=K,NM,M                                                    ROC07820
      II=I+ID                                                           ROC07830
      TB=PIV*R(II)                                                      ROC07840
      R(II)=R(I)                                                        ROC07850
   27 R(I)=TB                                                           ROC07860
C     PIVOT ROW REDUCTION AND ROW INTERCHANGE IN COEFFICIENT MATRIX A   ROC07870
      II=KST                                                            ROC07880
      J=JJ+IC                                                           ROC07890
      DO 28 I=JJ,J                                                      ROC07900
      TB=PIV*A(I)                                                       ROC07910
      A(I)=A(II)                                                        ROC07920
      A(II)=TB                                                          ROC07930
   28 II=II+1                                                           ROC07940
C     ELEMENT REDUCTION                                                 ROC07950
      IF(K-ILR)29,34,34                                                 ROC07960
   29 ID=KST                                                            ROC07970
      II=K+1                                                            ROC07980
      MU=KST+1                                                          ROC07990
      MZ=KST+IC                                                         ROC08000
```

```
      DO 33 I=II,ILR
C     IN MATRIX A
      ID=ID+MC
      JJ=I-MR-1
      IF(JJ)31,31,30
   30 ID=ID-JJ
   31 PIV=-A(ID)
      J=ID+1
      DO 32 JJ=MU,MZ
      A(J-1)=A(J)+PIV*A(JJ)
   32 J=J+1
      A(J-1)=0
C     IN MATRIX R
      J=K
      DO 33 JJ=I,NM,M
      R(JJ)=R(JJ)+PIV*R(J)
   33 J=J+M
   34 KST=KST+MC
      IF(ILR-MR)36,35,35
   35 IC=IC-1
   36 ID=K-MR
      IF(ID)38,38,37
   37 KST=KST-ID
   38 CONTINUE
C     END OF DECOMPOSITION LOOP
C     BACK SUBSTITUTION
      IF(MC-1)46,46,39
   39 IC=2
      KST=MA+ML-MC+2
      II=M
      DO 45 I=2,M
      KST=KST-MC
```

```
      II=II-1
      J=II-MR
      IF(J)41,41,40
   40 KST=KST+J
   41 DO 43 J=II,NM,M
      TB=R(J)
      MZ=KST+IC-2
      ID=J
      DO 42 JJ=KST,MZ
      ID=ID+1
   42 TB=TB-A(JJ)*R(ID)
   43 R(J)=TB
      IF(IC-MC)44,45,45
   44 IC=IC+1
   45 CONTINUE
   46 RETURN
C     ERROR RETURN
   47 IER=-1
      RETURN
      END
```

Appendix F - Water Quality Module - Program Listing

```
C*** * * * * * * * * * * * * MODULE 2 * * * * * * * * * * * * * * *
C
C                        WATER QUALITY MODULE
C
C          SIMPLE INTEGRATED MODULAR WATERSHED PLANNING MODEL
C
C
C    THE WATER QULAITY MODULE COMPUTES THE DISSOLVED OXYGEN
C    LEVEL AND BIOCHEMICAL OXYGEN DEMAND FOR ANY NUMBER OF
C    MENTS IN THE RIVER.  THE OBJECTIVE OF THIS MODULE IS TO
C    PROVIDE AN INDICATOR OF WATER QUALITY BY MEANS OF SIMPLE
C    EASILY DETERMINED INDICATORS.
C
C    THE OUTPUTS FROM THE WATER QUALITY MODULE ARE USED IN
C    CONJUNCTION WITH MODULE 3, TOPAZ.
C
C*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C    WATER QUALITY SECTOR OF WATERSHED MODEL
      DIMENSION DAY(50),BOD5(50),SEG(50),T(50),RESR(50)
      DIMENSION PHL(50),PLR(50),RO2(50),CL(50),PO2(50)
      DIMENSION RK1(50),RK2(50),TEMP(50),QW(50)
      DIMENSION VS(50),VW(50),AS(50),AW(50),DOW(50),BODW(50)
      DIMENSION AA(50),BB(50),CC(50),DD(50),TDD(50),TPO2(50)
      DIMENSION DN(50),DOS(50),BODS(50)
      DIMENSION AB(50),BOD(50),BODR(50)
      REAL K1(50),K2(50)
      N=19
      QS=.935
      DNR=5.00
      BR=4.
      BIO=10.
      BODN=3.80
```

```
C   N - NUMBER OF SEGMENTS INTO WHICH THE RIVER IS DIVIDED                  WQ 00340
C                                                                           WQ 00350
      M=5                                                                   WQ 00360
C   M - NUMBER OF DAYS BOD CALCULATION IS CARRIED OUT FOR EACH SEGMENT      WQ 00370
8     FORMAT(F10.4,F11.3,F11.0,F11.2,F11.0)                                 WQ 00380
C   VS - STREAM VELOCITY (FT/SEC)                                           WQ 00390
C   VW - VELOCITY OF WASTE FLOW (FT/SEC)                                    WQ 00400
C   AS - CROSS SECTIONAL AREA OF STREAM (SQ FT)                             WQ 00410
C   AW - CROSS SECTIONAL AREA OF WASTE CONDUIT (SQ FT)                      WQ 00420
C   DOW - DISSOLVED OXYGEN LEVEL OF WASTE (MG/L)                            WQ 00430
C   DOS - DISSOLVED OXYGEN LEVEL OF STREAM (MG/L)                           WQ 00440
C   BODW - BIOCHEMICAL OXYGEN DEMAND OF WASTE (MG/L)                        WQ 00450
C   BODS - BIOCHEMICAL OXYGEN DEMAND OF STREAM (MG/L)                       WQ 00460
C   CORRECTION OF K1 K2 K3 FOR TEMPERATURE                                  WQ 00470
C   SEG - LENGTH OF RIVER SEGMENT FOR RESIDUAL COMPUTED (MILES)             WQ 00480
      READ(5,8)(PHL(J),J=1,N),(PLR(J),J=1,N),(RO2(J),J=1,N),                WQ 00490
     1(CL(J),J=1,N),(PO2(J),J=1,N)                                          WQ 00500
      READ(5,26)(RK1(J),J=1,N),(RK2(J),J=1,N),(TEMP(J),J=1,N),              WQ 00510
     1(SEG(J),J=1,N),(QW(J),J=1,N)                                          WQ 00520
26    FORMAT(5X,F6.2,F5.2,5X,2F6.2,11X,F11.3)                               WQ 00530
      READ(5,18)(VS(J),J=1,N),                                              WQ 00540
     1(DOW(J),J=1,N),(DOS(J),J=1,N),(BODW(J),J=1,N)                         WQ 00550
     1,(BODS(J),J=1,N)                                                      WQ 00560
18    FORMAT(F5.2,18X,4F6.2)                                                WQ 00570
      DO 30 J=1,N                                                           WQ 00580
      QS=QS+QW(J)                                                           WQ 00590
      DNR=((DOW(J)*QW(J))+(DNR*QS))/(QW(J)+QS)                              WQ 00600
      BODN=((BODW(J)*QW(J))+(BODN*QS))/(QW(J)+QS)                           WQ 00610
      IF(TEMP(J).EQ.20.) GO TO 16                                           WQ 00620
      K1(J)=(RK1(J))*(1.047**(TEMP(J)-20.))                                 WQ 00630
      K2(J)=(RK2(J))*(1.047**(TEMP(J)-20.))                                 WQ 00640
      T(J)=((SEG(J)*5280.)/VS(J))/(86400.)                                  WQ 00650
```

```
      WRITE(6,99) T(J)
99    FORMAT(F20.5)
   16 CONTINUE
      K1(J)=RK1(J)
      K2(J)=RK2(J)
C  DN - INITIAL OXYGEN DEFICIT
C  BODN - INITIAL BOD LEVEL
C  P - RATE OF BOD ADDITION TO OVERLYING WATER BY BENTHAL DEPOSITS (MG
C  PHL - INITIAL PHOSPHORUS LEVEL (MG/L)
C  PLR - PHOSPHORUS LOADING RATE (MG/L/DAY)
C  CL - CHLOROPHYL LEVEL (G/SQUARE METERS)
C    D - OXYGEN DEFICIT
C    DO - DISSOLVED OXYGEN LEVEL
C    BOD - BIOCHEMICAL OXYGEN DEMAND
C    T - TIME IN DAYS
C    K1 - DEOXYGENATION RATE(MG/L)
C    K2 - REAERATION RATE (MG/L)
C    K3 - RATE OF BOD SETTLING (MG/L/D)
C  PO2 - OXYGEN PRODUCED (MG/HR/G/SQUARE METER) OF CHLORYPHYL
C  TPO2 - OXYGEN PRODUCED BY PHOTOSYNTHESIS (MG/L/D)
      TPO2(J)=CL(J)*PO2(J)*.41*24.
      PHL(J)=PHL(J)+((PLR(J)*T(J))/(QW(J)+QS))
      IF(PHL(J).GT..1) GO TO 1
C     RESR - O2 CONSUMPTION DUE TO RESPIRATION (MG/L/D)
C  RESR - RESPIRATION RATE
C     RO2 - O2 CONSUMPTION DUE TO RESPIRATION (MG/L/MG BIOMASS/HR)
      GO TO 7
    1 RESR(J)=(BIO*RO2(J)*24.)*BR
C  BR - MULTIPLIER FOR RESPIRATION RATE UNDER BLOOM CONDITIONS
C     COMPUTE RESPIRATION RATE FOR CRITICAL LEVEL OF .01 MG/L PHOSPHORUS
      GO TO 66
    7 CONTINUE
```

```
      RESR(J)=(BID*RO2(J)*24.)
C  COMPUTATION OF OXYGEN DEFICIT BY STREETER PHELPS METHOD
66    CONTINUE
      AB(J)=K1(J)*BODN/(.30-K1(J))
      BB(J)=(1/(10**(K2(J)*T(J))))-(1/(10**(K1(J)*T(J))))
      CC(J)=DNR*(1/(10**(K2(J)*T(J))))
      DD(J)=AB(J)*BB(J)+CC(J)
      WRITE(6,15)
   15 FORMAT(10X,'DAY',15X,'BOD',13X,'PHL',13X,'DD',13X,'TDD',15X,
     1'BODR')
C  TD - TOTAL OXYGEN DEFICIT
      TDD(J)=DD(J)-TPO2(J)+RESR(J)
      IF(TDD(J).LT.-9.) GO TO 20
      GO TO 21
   20 TDD(J)=-9.
   21 CONTINUE
      BOD(J)=BODN*(1-1/(10.**(K1(J)*T(J))))
      BODR(J)=BOD(J)+BODN
      WRITE(6,4)T(J),BOD(J),PHL(J),DD(J),TDD(J),BODR(J)
    4 FORMAT(10X,F4.1,3X,5F10.2)
   30 CONTINUE
      PHL(J)=0
      STOP
      END
```

```
C*** * * * * * * * * * * MODULE 3 * * * * * * * * * * * * * * * *
C
C   LAND USE, INFRASTRUCTURE LOCATION AND COSTS
C
C                         TOPAZ
C TECHNIQUE FOR THE OPTIMUN PLACEMENT OF ACTIVITIES IN ZONES
C
C   SIMPLE INTEGRATED MODULAR WATERSHED PLANNING MODEL
C
C  GIVEN A LAND USE DEVELOPMENT PATTERN, MODULE 3 PERFORMS AN OPTIMI
C  ZATION WHICH RESULTS IN AN IDENTIFICATION OF COSTS AND
C
C
C     SIMPLE INTEGRATED
C*** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMMON ACTS(10,10),EXIST(10,10),A(10),B(10),C(10,10),X(10,10)
      COMMON ESTCST(12,12,12),CC(10,10),TOTESC(10,10),ESTAB(10,10)
      COMMON M,NACTS,NECTCM,NL,NLOOP,NZP,NUM
      COMMON G,S1,S2,T,T2
      COMMON DLINK(15,2),DIST(10,10),CCC(18),ATTRCO(10),PRODCO(10)
      COMMON PR(10),AT(12),SA(10),TRIPS(10,10),BB(10,10),FTA(12,12)
      COMMON NQ,C2(10,10)
      COMMON COSTS(6,10),TOTCCT(6)
      COMMON PPU(5),APU(5),RATIO(5),RPIN(6)
      DIMENSION ENTRST(6),SERLIF(6)
      DIMENSION TITLE(18)
      DIMENSION LETTER(18)
      DIMENSION FLOW(23,10), TOTFLO(30), LINK(23,10), ALT(23,5,3)
      DIMENSION FAC(10), PRCNT(23,10), ZCOST(23,10), CONST(12,2)
      DIMENSION LAND(23,10)
      REAL LAND
      REAL*8 TITLE
```

```
      INTEGER AA,ZZ,CCC                                                 SMS00330
      INTEGER X,C,A,B,COST                                              SMS00340
C                                                                       SMS00350
C                                                                       SMS00360
C     MAIN PURPOSE OF THE MAIN PROGRAM IS TO READ INPUTS , DO SOME PRELISMS00370
C     CALCULATIONS , AND CALL SUBROUTINES IN THE ITERATION PROCESS .    SMS00380
C                                                                       SMS00390
C     *************************                                         SMS00400
C     WRITE HEADING                                                     SMS00410
      LK=25                                                             SMS00420
      DO 8 LKK=1,LK                                                     SMS00430
    7 READ(8,5)(LETTER(L),L=1,18)                                       SMS00440
    5 FORMAT(18A4)                                                      SMS00450
    8 WRITE(6,6)(LETTER(L),L=1,18)                                      SMS00460
    6 FORMAT(1H ,18A4)                                                  SMS00470
      WRITE(6,9)                                                        SMS00480
    9 FORMAT(1H1)                                                       SMS00490
C     *************************************                             SMS00500
 1009 FORMAT(10X,2H* ,1X,10(I4,2X))                                     SMS00510
 1005 FORMAT(73(1H*),/)                                                 SMS00520
      WRITE(6,1002)                                                     SMS00530
 1002 FORMAT(20X,'TOPAZ APPLICATION CONTROL PARAMETERS')                SMS00540
      READ(8,1000) M,NACTS,NECTCM,NL,NLOOP                              SMS00550
 1000 FORMAT(5I4)                                                       SMS00560
C                                                                       SMS00570
C     ENTRST(I)=THE INTEREST RATE ASSUMED FOR COST COMPONENT (I)        SMS00580
C     SERLIF(I)=THE EXPECTED LIFE OF COST COMPONENT (I)                 SMS00590
C                                                                       SMS00600
      READ(8,1)(ENTRST(I),I=1,NACTS)                                    SMS00610
      READ(8,2)(SERLIF(I),I=1,NACTS)                                    SMS00620
    1 FORMAT(6F3.2)                                                     SMS00630
    2 FORMAT(6F3.0)                                                     SMS00640
```

```
      WRITE(6,1005)
      WRITE(6,1093) M,NACTS,NECTCM,NL,NLOOP
 1093 FORMAT(10X,'M=NUMBER OF ZONES =',I5,/,
     *10X,'NACTS= NUMBER OF ACTIVITY TYPES =',I3,/,
     *10X,'NECTCM= NUMBER OF COST COMPONENTS =',I3,/,
     *10X,'NL=NUMBER OF LINKS IN HIGHWAY NETWORK =',I3,/,
     *10X,'NLOOP=NUMBER OF ITERATIONS IN "TRNSPT" SUBROUTINE =',I3)
C
C     SET ITERATION LOOP COUNTERS
C
      NLP=1
      NQ=1
      WRITE(6,1005)
      WRITE(6,1008)
 1008 FORMAT(/,1X,'ZONE NO. ',2H* ,10X,'EXISTING ZONAL ACTIVITIES')
      WRITE(6,1005)
      WRITE(6,1009)(I,I=1,NACTS)
      WRITE(6,1005)
      DO 24 J=1,M
      READ(8,2000) (EXIST(I,J),I=1,NACTS)
 2000 FORMAT(5X,10F4.0)
   24 WRITE(6,1010) J,(EXIST(I,J),I=1,NACTS)
 1010 FORMAT(4X,I2,4X,2H* ,10(1X,F5.0))
      WRITE(6,1005)
      DO 508 K2=1,NECTCM
      DO 508 I=1,NACTS
      DO 507 J=1,M
  507 ESTCST(I,J,K2)=0.
  508 CONTINUE
C
C     READ TITLES (ON CARDS) FOR ESTABLISHMENT COST OR BENEFIT COMPONENT
C
```

```
      DO 10 K2=2,NECTCM
      DO 503 I=1,4
C  I = =NUMBER OF ACTIVITIES
  503 READ(8,8990) ESTCST(I,1,K2)
 8990 FORMAT(F7.0)
      DO 504 I=1,4
C I=1,NUMBER OF ACTIVITIES
      DO 504 J=2,M
  504 ESTCST(I,J,K2)=ESTCST(I,1,K2)
  501 CONTINUE
  735 CONTINUE
   10 CONTINUE
C
C   CALCULATE THE CAPITAL RECOVERY FACTOR, RPIN(K2), FOR COST COMPONENT(
C   AN INTEREST RATE OF ENTRST(K2) AND A SERVICE LIFE OF SERLIF(K2)
C
      DO 9990 K2=1,NACTS
      RPIN(K2)=ENTRST(K2)*((1.+ENTRST(K2))**SERLIF(K2))/((1.+ENTRST(K2))
     1**SERLIF(K2)-1.)
      DO 9990 I=1,NACTS
      DO 9990 J=1,M
 9990 ESTCST(I,J,K2)=ESTCST(I,J,K2)*RPIN(K2)
      CALL ALCATE
      DO 1530 JI=1,NL
      READ(8,2006)(DLINK(JI,KI),KI=1,2)
 2006 FORMAT(19X,F3.1,F4.0)
C
C   LINK LENGTH DATA INPUTTED IN INCHES ON 800 SCALE MAP . THE 0.1575 FA
C   CONVERTS THESE INCHES TO MILES .
C
      DLINK(JI,1)=DLINK(JI,1)*.03787
 1530 CONTINUE
```

```
C
C   FOR THOSE ZONES NOT INCLUDED IN THE TOPAZ , THE INTERZONAL DISTANCES
C   TRAVEL TIMES HAVE ARBITRARILY BEEN SET = 9.9999 AND 8.888 RESPECTIVE
C   ANY POSITIVE VALUES ARE ACCEPTABLE HERE , AND THEY ARE NOT ACTUALLY
C   RECOGNIZED IN TOPAZ (ZEROS WOULD MESS UP GRAVITY MODEL)
C
      DO 5324 AA=1,M
      DO 5323 ZZ=1,M
      DIST(AA,ZZ)=9.999
 5323 FTA(AA,ZZ)=8.888
 5324 CONTINUE
      DO 4001 KJ=1,45
C KJ - 1,NUMBER OF MINIMUN TIME PATHS BETWEEN ZONES
C
C   FOR EACH ZONAL PAIR , THE MINIMUM TIME PATH HAS BEEN IDENTIFIED BEFO
C   THE CCC(JJ)'S ARE THE LINK NUMBERS ON EACH MINIMUM PATH . KEEP ZONE
C   DATA IN ORDER , E.G., 1-1, 1-2, ........, 61-61
C
      READ(8,4003) AA,ZZ,(CCC(JJ),JJ=1,18)
 4003 FORMAT(4X,I3,I3,18I3)
      FTAT=0.0
C
C   COMPUTATION OF MINIMUM TIME PATHS AND CORRESPONDING DISTANCES .
C
      ADIST=0
      DO 4111 JJ=1,18
C  JJ=1,NUMBER OF MINIMUM TIME PATHS BETWEEN ZONES
      IF(CCC(JJ).EQ.0)GO TO 4111
      JKLM=CCC(JJ)
      IF(DLINK(JKLM,2).LE.1.) GO TO 4111
      FTAT=FTAT+DLINK(JKLM,1)*60./DLINK(JKLM,2)
      ADIST=ADIST+DLINK(JKLM,1)
```

```
 4111 CONTINUE
      FTA(AA,ZZ)=FTAT
      DIST(AA,ZZ)=ADIST
 4001 CONTINUE
      DO 7501 LN=1,10
C   LN= 1, NUMBER OF ZONES
      DO 7501 LK=LN,10
C   LK= LN,NUMBER OF ZONES
      DIST(LK,LN)=DIST(LN,LK)
      FTA(LK,LN)=FTA(LN,LK)
 7501 CONTINUE
      READ(8,2525)(PRODCO(I),I=1,NACTS)
 2525 FORMAT(10F4.1)
      READ(8,2525)(ATTRCO(I),I=1,NACTS)
      SW=1
C    SKIP WATER AND SEWER MODEL IF SW=0.
C    CHANGE SW TO RUN WATER AND SEWER MODEL.
      IF(SW.NE.0)GO TO 279
      READ(8,278)
  278 FORMAT(108(/))
      GO TO 700
  279 CONTINUE
      LL=23
C   LL= NUMBER OF LINKS IN SEWER SYSTEM
      NZ=10
C   NZ= NUMBER OF ZONES
      READ(8,280)(FAC(I),I=1,NACTS)
  280 FORMAT(10F4.2)
      DO 284 K3=1,2
  284 READ(8,211)(CONST(J,K3),J=1,M)
  211 FORMAT(10F5.0)
      DO 285 NL=1,23
```

```
C  NL=1, NUMBER OF LINKS IN SEWER SYSTEM
      DO 285 NI=1,10
C  NI=1,NUMBER OF ZONES
  285 PRCNT(NL,NI)=1.0
      DO 601 NL=1,23
C  NL=1,NUMBER OF LINKS IN SEWER SYSTEM
  601 READ(8,281)(PRCNT(NL,NI),NI=1,NZ)
  281 FORMAT(10F4.2)
      DO 602 NL=1,LL
      DO 602 LP=1,3
C  LP = 1, NUMBER OF ALTERNATIVE PIPES
  602 READ(8,282)(ALT(NL,LP,NC),NC=1,3)
  282 FORMAT(F9.0,2X,F7.0,2X,F2.0)
      DO 391 NL=1,LL
  391 READ(8,283)(LINK(NL,NI),NI=1,NZ)
  283 FORMAT(10I2)
C
C   ADDITION OF ALL ESTABLISHMENT UNIT COMPONENT COSTS AND BENEFITS (IN
C   OF $) .
C
      DO 100 I=1,NACTS
      DO 100 J=1,M
      TOTESC(I,J)=0.
      DO 99 K2=1,NECTCM
   99 TOTESC(I,J)=TOTESC(I,J)+ESTCST(I,J,K2)/1000000.
  100 CONTINUE
C
C   CHECK TO SEE IF ANY INTERZONAL TRAVEL TIME HAS BEEN INADVERTENTLY SE
C   ZERO (WHICH WOULD MESS UP GRAVITY MODEL) .
C
      KK=0
      DO 805 J=1,M
```

```
      DO 804 K=J,M
      IF(FTA(J,K).LE.0.001) GO TO 3737
      GO TO 804
3737  WRITE(6,3747) J, K
 3747 FORMAT(' FTA ZERO CHECK ',2X,I5,I5)
  804 CONTINUE
805   CONTINUE
C
C   START OF ITERATIONS USING TRNSPT (TRANSPORTATION PROBLEM) . INITIAL
C   IS "COSTED" FIRST .
C     *********************************************************************
C
C     SEWR COSTS DETERMINED.  MODEL EXTENDS TO STATEMENT 699
C
C     FAC(I)=WEIGHT FACTOR OF A(I) FOR SEWERAGE NEEDS.
C     NL=LINK NUMBER
C     PRCNT(NL,J)=PERCENT OF J FLOWING INTO NL.
C     ALT(NL,LP, 1 2 OR 3)=ALTERNATIVE PIPE FOR NL.  LP IS TH PIPE USED.
C                          1=CAPACITY, 2=COST, AND 3=SIZE OF PIPE.
C     FLOW(NL,J)=FLOW OF SEWAGE FROM J INTO LINK NL.
C     TOTFLO(NL)=TOTAL SEWAGE FLOW THROUGH NL.
C     LINK(NL,NI)=TRIBUTARY AREA OF LINK NL BY ZONES.
C     NI=NUMBER OF THE ZONE (OR ZONES) IN TRIBUTARY AREA OF NL.
C     ZCOST(NL,J)=COST OF NL ATTRIBUTABLE TO ZONE J.
  150 DO 610 J=1,10
C  J=1,NUMBER OF ZONES
      DO 610 K3=1,10
C  K3=1,NUMBER OF ZONES
      K2=K3+2
      ESTCST(4,J,K2)=0.
      DO 610 I=1,2
  610 ESTCST(I,J,K2)=CONST(J,I)
```

```
      DO 620 NL=1,23                                                    SMS02570
C   NL=1,NUMBER OF LINKS IN SEWER SYSTEM                                SMS02580
      DO 620 NI=1,10                                                    SMS02590
C   NI=1,NUMBER OF ZONES                                                SMS02600
      LAND(NL,NI)=0.                                                    SMS02610
  620 FLOW(NL,NI)=0.                                                    SMS02620
      K2=3                                                              SMS02630
      DO 690 NL=1,LL                                                    SMS02640
      IF (NL.GT.4) K2=4                                                 SMS02650
      BSUM=0.                                                           SMS02660
      DO 603 NI=1,NZ                                                    SMS02670
      J=LINK(NL,NI)                                                     SMS02680
      IF (J.EQ.0) GO TO 611                                             SMS02690
      PLUS=0.                                                           SMS02700
      SUM=0.                                                            SMS02710
      DO 604 I=1,NACTS                                                  SMS02720
      PLUS=PLUS+(EXIST(I,J)+ACTS(I,J))*FAC(I)                           SMS02730
  604 SUM=PLUS*PRCNT(NL,NI)                                             SMS02740
      LAND(NL,NI)=PLUS                                                  SMS02750
      FLOW(NL,NI)=SUM*4400.                                             SMS02760
      BSUM=BSUM+FLOW(NL,NI)                                             SMS02770
  603 TOTFLO(NL)=BSUM                                                   SMS02780
  611 LP=0                                                              SMS02790
  605 LP=LP+1                                                           SMS02800
      IF (LP.GT.4) GO TO 4                                              SMS02810
      GO TO 252                                                         SMS02820
    4 WRITE(6,251) NL,NI                                                SMS02830
  251 FORMAT(1X,2I5,'TOO BIG')                                          SMS02840
      LP=1                                                              SMS02850
      ALT(NL,LP,2)=100000.                                              SMS02860
      F=999999999.                                                      SMS02870
      GO TO 679                                                         SMS02880
```

```
  252 CONTINUE                                                          SMS02890
      IF (LP.EQ.1) GO TO 608                                            SMS02900
      F=ALT(NL,1,1)+ALT(NL,LP,1)                                        SMS02910
  679 IF (TOTFLO(NL).GT.F) GO TO 605                                    SMS02920
      GO TO 607                                                         SMS02930
  608 IF (TOTFLO(NL).GT.ALT(NL,LP,1)) GO TO 605                         SMS02940
  607 DO 690 NI=1,NZ                                                    SMS02950
      J=LINK(NL,NI)                                                     SMS02960
      IF (J.EQ.0) GO TO 690                                             SMS02970
      IF (TOTFLO(NL).EQ.0.) GO TO 689                                   SMS02980
      K3=K2-2                                                           SMS02990
      ZCOST(NL,NI)=FLOW(NL,NI)*ALT(NL,LP,2)/TOTFLO(NL)                  SMS03000
      GO TO 690                                                         SMS03010
  689 ZCOST(NL,NI)=0.                                                   SMS03020
  690 CONTINUE                                                          SMS03030
C      *****************************************************************SMS03040
      K2=3                                                              SMS03050
      DO 698 NL=1,LL                                                    SMS03060
      IF (NL.GT.3) K2=4                                                 SMS03070
      DO 699 NI=1,NZ                                                    SMS03080
      J=LINK(NL,NI)                                                     SMS03090
      IF (J.EQ.0) GO TO 698                                             SMS03100
      IF (LAND(NL,NI).EQ.0.) GO TO 698                                  SMS03110
      DO 699  I=1,NACTS                                                 SMS03120
  699 ESTCST(I,J,K2)=ESTCST(I,J,K2)+ZCOST(NL,NI)*FAC(I)/LAND(NL,NI)     SMS03130
  698 CONTINUE                                                          SMS03140
  700 CONTINUE                                                          SMS03150
      DO 612 K2=3,4                                                     SMS03160
      DO 612 I=1,NACTS                                                  SMS03170
      DO 612 J=1,M                                                      SMS03180
  612 ESTCST(I,J,K2)=ESTCST(I,J,K2)*RPIN(K2)                            SMS03190
C      *****************************************************************SMS03200
```

```
C       ****************************************************************SMS03210
      CALL AMNITY(NLP)                                                  SMS03220
      CALL ESTIM                                                        SMS03230
      CALL SUMMRY                                                       SMS03240
      DO 820 J=1,M                                                      SMS03250
      DO 820 I=1,NACTS                                                  SMS03260
C                                                                       SMS03270
C   NOTE: THE C(I,J)'S SHOULD BE SCALED UP SO AS TO BE VERY LARGE SINCE SMS03280
C   INTEGERS IN SUBROUTINE TRNSPT . (COSTS LESS THAN 1 ARE ROUNDED OFF) SMS03290
C                                                                       SMS03300
C   IF DESIRE IS TO MAXIMIZE , THEN USE  820 C(I,J)=-C2(I,J)*1000000 .  SMS03310
C                                                                       SMS03320
  820 C(I,J)=C2(I,J)*1000000.                                           SMS03330
      INF=2147483646                                                    SMS03340
      CALL TRNSPT(NACTS,M,INF,10,10)                                    SMS03350
      DO 600 I=1,NACTS                                                  SMS03360
      DO 600 J=1,M                                                      SMS03370
  600 ACTS(I,J)=X(I,J)                                                  SMS03380
      IF(NLP.EQ.NLOOP) GO TO 50                                         SMS03390
      NLP=NLP+1                                                         SMS03400
      GO TO 700                                                         SMS03410
   50 STOP                                                              SMS03420
C           DEBUG INIT,SUBCHK                                           SMS03430
      END                                                               SMS03440
      SUBROUTINE ALCATE                                                 SMS03450
C                                                                       SMS03460
C   THIS SUBROUTINE READS IN OR CALCULATES THE AMOUNT OF EACH ACTIVITY  SMS03470
C   TO BE ALLOCATED AND THE AMOUNT OF LAND AVAILABLE FOR DEVELOPMENT.   SMS03480
C   A(I) = FUTURE AMOUNT OF ACTIVITY (I) TO BE ALLOCATED.               SMS03490
C   PINCR = POPULATION INCREASE                                         SMS03500
C   RATIO(I) = PERCENTAGE OF POPULATION INCREASE THAT WILL DEMAND       SMS03510
C   HOUSING TYPE (I)                                                    SMS03520
```

```
C    APU(I) = ACRES/UNIT OF HOUSING TYPE (I).                          SMS03530
C    PPU(I) = PEOPLE/UNIT OF HOUSING TYPE (I).                         SMS03540
C                                                                      SMS03550
      COMMON ACTS(10,10),EXIST(10,10),A(10),B(10),C(10,10),X(10,10)    SMS03560
      COMMON ESTCST(12,12,12),CC(10,10),TOTESC(10,10),ESTAB(10,10)     SMS03570
      COMMON M,NACTS,NECTCM,NL,NLOOP,NZP,NUM                           SMS03580
      COMMON G,S1,S2,T,T2                                              SMS03590
      COMMON DLINK(15,2),DIST(10,10),CCC(18),ATTRCO(10),PRODCO(10)     SMS03600
      COMMON PR(10),AT(12),SA(10),TRIPS(10,10),BB(10,10),FTA(12,12)    SMS03610
      COMMON NQ,C2(10,10)                                              SMS03620
      COMMON COSTS(6,10),TOTCCT(6)                                     SMS03630
      COMMON PPU(5),APU(5),RATIO(5),RPIN(6)                            SMS03640
      INTEGER A,VACNT,B                                                SMS03650
 1005 FORMAT(73(1H*),/)                                                SMS03660
 1009 FORMAT(10X,2H* ,1X,10(I4,2X))                                    SMS03670
      WRITE(6,1012)                                                    SMS03680
 1012 FORMAT(/,5X,'AMOUNT OF FUTURE ACTIVITIES OF EACH TYPE TO BE ALLOCASMS03690
     *TED')                                                            SMS03700
      WRITE(6,1005)                                                    SMS03710
      READ(8,2001)(A(I),I=2,NACTS)                                     SMS03720
 2001 FORMAT(7X,3I4)                                                   SMS03730
      READ(8,2000)PINCR                                                SMS03740
 2000 FORMAT(F7.0)                                                     SMS03750
      DO 2006 I=2,4                                                    SMS03760
C   I=2,NUMBER OF ACTIVITIES , THIS EXCLUDES HOUSING                   SMS03770
 2006 A(I)=A(I)*PINCR/12000                                            SMS03780
      DO 2003 I=1,1                                                    SMS03790
C   I=1, NUMBER OF TYPES OF RESIDENTIAL                                SMS03800
      A(I)=0.0                                                         SMS03810
 2003 READ(8,2002)RATIO(I),PPU(I),APU(I)                               SMS03820
 2002 FORMAT(F7.4,F5.2,F5.2)                                           SMS03830
      WRITE(6,444)                                                     SMS03840
```

```
444   FORMAT(10X,'TEST2')
      DO 2999 I=1,1
C  I=1,NUMBER OF TYPES OF RESIDENTIAL
 2999 A(I)=PINCR*RATIO(I)/PPU(I)*APU(I)
      WRITE(6,445)
445   FORMAT(10X,'TEST3')
C
C    MAKE SURE THAT THE FUTURE AMOUNT OF ACRES ALLOCATED ARE EQUAL TO THE
C    EXISTING AMOUNT OF UNDEVELOPED LAND BY ADJUSTING A(16),THE FUTURE
C    ACRES OF UNDEVELOPED LAND, IF IT IS NECESSARY.
C    VACNT AND ISUM ARE DUMMY VARIABLES USED FOR ACCUMULATING EXISTING
C    ACRES OF UNDEVELOPED LAND AND FUTURE ALLOCATIONS OF ACTIVITIES
C    1 -15,RESPECTIVELY.
C
      VACNT=0
      DO 2004 J=1,M
 2004 VACNT=VACNT+EXIST(4,J)
C EXIST(NUMBER OF ACTIVITIES,J)
      ISUM=0
      DO 2005 I=1,3
C  I=1,NUMBER OF ACTIVITIES MINUS ONE
 2005 ISUM=ISUM+A(I)
      A(4)=VACNT-ISUM
C  A(NUMBER OF ACTIVITIES)
      WRITE(6,1016) (A(I),I=1,NACTS)
1016  FORMAT(8X,'A(1)=FUTURE ACRES OF S FAM AND PUD =',I8,/,
     *8X,'A(2)=FUTURE ACRES OF APARTMENTS, TOWNHOUSES=',I8,/,
     *8X,'A(3)=FUTURE ACRES OF MOBILE HOMES =',I8,/,
     *8X,'A(4)=FUTURE AG AND OPEN =',I8)
      WRITE(6,1005)
      IP=PINCR
      DO 70 J=1,M
```

```
   70 B(J)=EXIST(4,J)
C  EXIST(NUMBER OF ACTIVITIES,J)
C
C   IN ALL ZONES THE AMOUNT OF LAND PRESENTLY VACANT IS SET EQUAL TO THA
C   AVAILABLE FOR FUTURE DEVELOPMENT . THIS MAY NOT ALWAYS BE DESIRABLE
C   REMEMBER THAT SUM A(I) MUST = SUM B(J).
C
      WRITE(6,1029)
 1029 FORMAT(/,2X,'ZONE NO. ',7X,'INITIAL ALLOCATIONS - FUTURE ACTIVITIE
     *S TO ZONES')
      WRITE(6,1005)
      WRITE(6,1009)(I,I=1,NACTS)
      WRITE(6,1005)
      DO 73 J=1,M
   73 READ(8,1031)(ACTS(I,J),I=1,NACTS)
 1031 FORMAT(5X,10F4.0)
C
C   STATEMENT NUMBERS FROM 1034 TO 1038 CHECK TO SEE IF THE CORRECT
C   AMOUNT OF EACH ACTIVITY HAS BEEN ALLOCATED IN THE INITIAL SOLUTION.
C   IF THE INITIAL SOLUTION IS INCORRECT, ADJUSTMENTS ARE MADE TO
C   CORRECT IT.
C   ITACT = DUMMY VARIABLE USED TO ACCUMULATE THE ACRES OF A PARTICULAR
C   ACTIVITY (I) THAT HAS BEEN ALLOCATED TO ALL 61 ZONES.
C   ICHNG = DIFFERENCE BETWEEN THE TOTAL AMOUNT OF AN ACTIVITY THAT MUST
C   BE ALLOCATED,A(I), AND THE AMOUNT THAT HAS ACTUALLY BEEN ALLOCATED
C   TO THE ZONES,ITACT.
C
C   IF DESIRED THE PROGRAM WILL GENERATE AN INITIAL SOLUTION IF THE FOLL
C   STATEMENTS ARE INSERTED AT THIS POINT IN THE PROGRAM.
C              DO 5000 J=1,M
C              DO 5000 I=1,15
C              ACTS(16,J)=ACTS(16,J)+ACTS(I,J)
```

```
C          5000 ACTS(I,J)=0.0                                          SMS04490
C                                                                      SMS04500
 1034 DO 1033 I=1,NACTS                                                SMS04510
      ITACT=0                                                          SMS04520
      DO 1032 J=1,M                                                    SMS04530
 1032 ITACT=ITACT+ACTS(I,J)                                            SMS04540
      ICHNG=A(I)-ITACT                                                 SMS04550
C   NE. NUMBER OF ACTIVITIES                                           SMS04560
      IF(ICHNG.EQ.0)GO TO 1043                                         SMS04570
      IF(I.NE.4)GO TO 1043                                             SMS04580
      WRITE(6,1040)                                                    SMS04590
C                                                                      SMS04600
C    'FLAG - ALLOCATION PROBLEM' INDICATES THAT THERE IS AN INCONSISTENCYSMS04610
C    BETWEEN THE TOTAL AMOUNT TO BE ALLOCATED, A(I), AND THE TOTAL AMOUNTSMS04620
C    THAT WAS ACTUALLY ALLOCATED,ACTS(I,J), IN THE ADJUSTED INITIAL    SMS04630
C    SOLUTION.                                                         SMS04640
C                                                                      SMS04650
 1040 FORMAT(/,10X,' FLAG-ALLOCATION PROBLEM')                         SMS04660
      GO TO 74                                                         SMS04670
 1043 IF(ICHNG)1037,1033,1035                                          SMS04680
 1033 CONTINUE                                                         SMS04690
      GO TO 74                                                         SMS04700
 1035 DO 1036 J=1,M                                                    SMS04710
      IF(ACTS(4,J).LT.ICHNG)GO TO 1039                                 SMS04720
C   ACTS(NUMBER OF ACTIVITIES,J)                                       SMS04730
      ACTS(I,J)=ACTS(I,J)+ICHNG                                        SMS04740
      ACTS(4,J)=ACTS(4,J)-ICHNG                                        SMS04750
      GO TO 1034                                                       SMS04760
 1039 ACTS(I,J)=ACTS(I,J)+ACTS(4,J)                                    SMS04770
      ICHNG=ICHNG-ACTS(4,J)                                            SMS04780
      ACTS(4,J)=0.0                                                    SMS04790
 1036 CONTINUE                                                         SMS04800
```

```
      GO TO 1034
 1037 DO 1038 J=1,M
      IF(ACTS(I,J).LT.IABS(ICHNG))GO TO 1041
      ACTS(I,J)=ACTS(I,J)+ICHNG
      ACTS(4,J)=ACTS(4,J)-ICHNG
      GO TO 1034
 1041 ICHNG=ICHNG+ACTS(I,J)
      ACTS(4,J)=ACTS(4,J)+ACTS(I,J)
      ACTS(I,J)=0.0
 1038 CONTINUE
   74 DO 72 J=1,M
   72 WRITE(6,1010) J,(ACTS(I,J),I=1,NACTS)
 1010 FORMAT(4X,I2,4X,2H* ,10(1X,F5.0))
      WRITE(6,1005)
      RETURN
C              DEBUG INIT,SUBCHK
      END
      SUBROUTINE AMNITY(NLP)
C
C   THIS SUBROUTINE DETERMINES THE AMENITY BENEFIT COST COMPONENT FOR EA
C   FOR THIS COMPONENT, WHICH IS BASED ON ASSESSED LAND VALUE, THE COST
C   BENEFIT IS THE SAME FOR ALL ACTIVITIES IN A PARTICULAR ZONE.
C   NLP=ITERATION OR LOOP COUNTER
C   Z(K,J)=THE VALUE OF REGRESSION EQUATION VARIABLE K IN ZONE J.
C    Z(1,J)=INVERSE OF DISTANCE FROM CBD(ZONE 50) TO ZONE J.
C    Z(2,J)=PROPORTION OF LAND IN ZONE J ALLOCATED TO COMMERCIAL ACTIVIT
C    Z(3,J)=PROPORTION OF ZONE J ALLOCATED FOR MULTI-FAMILY HOUSING
C    Z(4,J)=PROPORTION OF ZONE J ALLOCATED FOR SINGLE FAMILY HOUSING.
C    Z(5,J)=FUTURE POPULATION DENSITY(PEOPLE/ACRE) IN ZONE J.
C   USE(I,J)=EXISTING + FUTURE AMOUNT OF ACTIVITY I ALLOCATED TO ZONE J.
C   TOTLND(J)=TOTAL AMOUNT OF LAND(ACRES) IN ZONE J.
C   CONSTN=CONSTANT IN THE LAND VALUE REGRESSION EQUATION.
```

```
C     POP(J)=EXISTING POPULATION IN ZONE J.
C     APOP(J)=FUTURE POPULATION IN ZONE J.
C     DIST(J,50)=DISTANCE FROM ZONE J TO THE CBD(ZONE 50).
C
      COMMON ACTS(10,10),EXIST(10,10),A(10),B(10),C(10,10),X(10,10)
      COMMON ESTCST(12,12,12),CC(10,10),TOTESC(10,10),ESTAB(10,10)
      COMMON M,NACTS,NECTCM,NL,NLOOP,NZP,NUM
      COMMON G,S1,S2,T,T2
      COMMON DLINK(15,2),DIST(10,10),CCC(18),ATTRCO(10),PRODCO(10)
      COMMON PR(10),AT(12),SA(10),TRIPS(10,10),BB(10,10),FTA(12,12)
      COMMON NQ,C2(10,10)
      COMMON COSTS(6,10),TOTCCT(6)
      COMMON PPU(5),APU(5),RATIO(5),RPIN(6)
      DIMENSION Z(5,10),USE(10,10),TOTLND(10),COEF(5),VALUE(10),POP(10),
     1APOP(10)
      DO 3020 K=1,5
      DO 3020 J=1,M
 3020 Z(K,J)=0.0
      DO 3002 I=1,NACTS
      DO 3002 J=1,M
 3002 USE(I,J)=EXIST(I,J)
      IF(NLP.NE.1)GO TO 3011
 3006 DO 3000 J=1,M
      TOTLND(J)=0.0
      DO 3000 I=1,NACTS
 3000 TOTLND(J)=TOTLND(J)+EXIST(I,J)
 3008 READ(8,3009)CONSTN,(COEF(K),K=1,5)
      READ(8,3010)(POP(J),J=1,M)
 3009 FORMAT(6F10.2)
 3010 FORMAT(15F5.0)
C
C     CALCULATE THE ESTIMATED FUTURE POPULATION IN ZONE J. THE CALCULATION
```

```
C    BASED ON THE EXISTING POPULATION AND THE ALLOCATION OF FUTURE HOUSIN
C    ACTIVITIES TO ZONE J.
C
 3011 DO 3012 J=1,M
      APOP(J)=POP(J)
      DO 3012 I=1,1
C   I=1,NUMBER OF TYPES OF RESIDENTIAL
 3012 APOP(J)=APOP(J)+ACTS(I,J)*PPU(I)/APU(I)
      WRITE(6,446)
446   FORMAT(10X,'TEST1')
      DO 3013 I=1,NACTS
      DO 3013 J=1,M
 3013 USE(I,J)=USE(I,J)+ACTS(I,J)
C
C    DETERMINE THE VALUE OF EACH REGRESSION EQUATION VARIABLE FOR ZONE J.
C
 3007 DO 3001 J=1,M
      WRITE(6,448)DIST(J,2)
448   FORMAT(10X,F20.10)
      IF(EXIST(4,J).EQ.0.)GO TO 3001
C   EXIST(NUMBER OF ACTIVITIES,J)
      Z(1,1)=1./1.22
      Z(1,2)=1./1.75
      Z(1,3)=1./1.40
      Z(1,4)=1./.595
      Z(1,5)=1./.875
      Z(1,6)=1./.70
      Z(1,7)=1./.28
      Z(1,8)=1./.53
      Z(1,10)=1./.35
      WRITE(6,447)
447   FORMAT(10X,'TEST4')
```

```
      Z(2,J)=USE(2,J)/TOTLND(J)
      Z(3,J)=USE(2,J)/TOTLND(J)
      Z(4,J)=APOP(J)/TOTLND(J)
 3001 CONTINUE
C
C   CALCULATE THE LAND VALUE OR AMENITY BENEFIT IN EACH ZONE.
C
      DO 3003 J=1,M
      VALUE(J)=0.0
      IF(EXIST(4,J).EQ.0.)GO TO 3003
      VALUE(J)=CONSTN
      DO 3004 K=1,4
 3004 VALUE(J)=VALUE(J)+COEF(K)*Z(K,J)
C
C   IF THE LAND VALUE IS LESS THAN 0 IT IS SET EQUAL TO 0.
C
      IF(VALUE(J).LT.0.)VALUE(J)=0.
C
C   LAND VALUATIONS IN THIS CASE WERE ASSESSED AT 20% OF MARKET VALUE SO
C   CONVERSION WAS NECESSARY. ALSO SINCE THEY ARE A NEGATIVE COST COMPON
C   THE LAND VALUES OR AMENITY BENEFITS ARE GIVEN A NEGATIVE VALUE.
C
      VALUE(J)=-VALUE(J)/.20
 3003 CONTINUE
      DO 3005 I=1,10
C  I=1,NUMBER OF ZONES
      DO 3005 J=1,M
 3005 ESTCST(I,J,1)=VALUE(J)*RPIN(1)
      DO 3014 I=1,NACTS
      DO 3014 J=1,M
      TOTESC(I,J)=0.0
      DO 3015 K2=1,NECTCM
```

```
 3015 TOTESC(I,J)=TOTESC(I,J)+ESTCST(I,J,K2)/1000000.
 3014 CONTINUE
      RETURN
C            DEBUG INIT,SUBCHK
      END
      SUBROUTINE ESTIM
C
C    THIS SUBROUTINE "COSTS OUT" ALLOCATIONS (INCLUDING USE OF GRAVITY MO
C    SETS UP ARTIFICIAL COST COEFFICIENTS FOR THE TRNSPT SUBROUTINE .
C
      COMMON ACTS(10,10),EXIST(10,10),A(10),B(10),C(10,10),X(10,10)
      COMMON ESTCST(12,12,12),CC(10,10),TOTESC(10,10),ESTAB(10,10)
      COMMON M,NACTS,NECTCM,NL,NLOOP,NZP,NUM
      COMMON G,S1,S2,T,T2
      COMMON DLINK(15,2),DIST(10,10),CCC(18),ATTRCO(10),PRODCO(10)
      COMMON PR(10),AT(12),SA(10),TRIPS(10,10),BB(10,10),FTA(12,12)
      COMMON NQ,C2(10,10)
      COMMON COSTS(6,10),TOTCCT(6)
      COMMON PPU(5),APU(5),RATIO(5),RPIN(6)
C
C    ELIMINATION OF VACANT LAND (LAST ACTIVITY NUMBER) IN CALCULATIONS .
C
      NACMUL=NACTS-1
C
C    START CALCULATIONS FOR GRAVITY MODEL .
C
C
C
      AT(11)=5
      AT(12)=6
      DO 922 J=1,M
      SA(J)=0.
```

```
      AT(J)=0.
      PR(J)=0.
      DO 922 I=1,NACMUL
      PR(J)=PR(J)+PRODCO(I)*(ACTS(I,J)+EXIST(I,J))
  922 AT(J)=AT(J)+ATTRCO(I)*(ACTS(I,J)+EXIST(I,J))
      DO 9999 J=1,10
C  I=1, NUMBER OF ZONES
      DO 9999 L=1,12
C  L=1,NUMBER OF LINKS IN THE TRANSPORT NETWORK
      FTA(J,L)=.05
      SA(J)=SA(J)+AT(L)*(1.)/(1.**2)
9999  CONTINUE
C
C       CC(J,K) IS PARTIAL CONTRIBUTION OF GRAVITY MODEL TO TRNSPT COST C
C
      DO 940 J=1,M
      DO 940 K=1,M
      CC(J,K)=0.0
  940 CONTINUE
      DO 8999 J=1,10
C  J=1, NUMBER OF ZONES
      DO 8999 K=1,4
C  K=1, NUMBER OF ACTIVITIES
      CC(J,K)=AT(K)*((1.)/(1.**2))/SA(J)
8999  CONTINUE
C
C   CHECK TO INSURE THAT IF NO EXISTING ACTIVITY (INCLUDING VACANT) AT A
C   ZONE , NO COST OF TRAVEL TO OR FROM THAT ZONE IS CALCULATED .
C
      DO 88 J=1,M
      DO 88 K=J,M
      BLAH1=0.
```

```
      BLAH2=0.                                                          SMS06690
      DO 80 I=1,NACTS                                                   SMS06700
      BLAH1=BLAH1+EXIST(I,J)                                            SMS06710
   80 BLAH2=BLAH2+EXIST(I,K)                                            SMS06720
      BB(J,K)=0                                                         SMS06730
      IF(BLAH1.EQ.0.) GO TO 88                                          SMS06740
      IF(BLAH2.EQ.0.) GO TO 88                                          SMS06750
C                                                                       SMS06760
CC  CALCUALTION OF TRAVEL COST($ MILLIONS).  ASSUMED THAT EACH DAILY    SMS06770
C     TRIP FROM GRAVITY MODEL WILL BE REPEATED 200 TIMES PER YEAR       SMS06780
C                                                                       SMS06790
      BB(J,K)=DIST(J,K)*0.065*200./1000000.                             SMS06800
   88 BB(K,J)=BB(J,K)                                                   SMS06810
C                                                                       SMS06820
C   CALCULATION OF ARTIFICIAL COST FOR TRNSPT                           SMS06830
C                                                                       SMS06840
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    QUICK AND DIRTY ADDITION TO INITIALIZE TOTESC
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DO 87 I=5,10
      DO 87 J=1,10
      TOTESC(I,J)=1.0
  87  CONTINUE
      DO 950 I=1,M                                                      SMS06850
      DO 950 J=1,M                                                      SMS06860
      C2(I,J)=0.                                                        SMS06870
C                                                                       SMS06880
C  IF TRAVEL COST IS NOT TO BE CONSIDERED, ELIMINATE NEXT FOUR STATEMENTSMS06890
C  CHANGE STATEMENT 950 TO READ: 950 C2(I,J)=C2(I,J)+TOTESC(I,J) . ONLY SMS06900
C  TWO ITERATIONS OF TRNSPT (NLOOP=2)  UNDER THESE CIRCUMSTANCES.       SMS06910
```

```
C
950    C2(I,J)=C2(I,J) + TOTESC(I,J)
       S2=0.
C
C  CALCULATION OF INTERZONAL PERSON TRIPS, TOTAL TRIPS, AND TOTAL TRAVEL
C
       T=0.
       DO 926 J=1,M
       DO 926 K=1,M
       TRIPS(J,K)=0.0
       TRIPS(J,K)=PR(J)*AT(K)*((1.)/(FTA(J,K)**2))/SA(J)
  555  T=T+TRIPS(J,K)
       S2=S2+TRIPS(J,K)*BB(J,K)
926    CONTINUE
C
C   CALCULATION OF TOTAL ESTABLISHMENT COMPONENT COSTS AND TOTAL OVERALL
C   SOLUTION ($ MILLIONS) .
C
       DO 704 K2=1,NECTCM
       TOTCCT(K2)=0.
       DO 704 J=1,M
       COSTS(K2,J)=0.
       DO 705 I=1,NACTS
  705  COSTS(K2,J)=COSTS(K2,J)+ACTS(I,J)*ESTCST(I,J,K2)
  704  CONTINUE
       DO 706 K2=1,NECTCM
       DO 706 J=1,M
  706  TOTCCT(K2)=TOTCCT(K2)+COSTS(K2,J)
       T2=0.
       DO 707 K2=1,NECTCM
  707  T2=T2+TOTCCT(K2)/1000000.
       G=T2+S2
```

```
      RETURN                                                            SMS07240
C           DEBUG INIT,SUBCHK                                           SMS07250
      END                                                               SMS07260
      SUBROUTINE SUMMRY                                                 SMS07270
C                                                                       SMS07280
C   THIS SUBROUTINE IS FOR PRINTING OUT RESULTS OF CALCULATIONS WITH RESSMS07290
C   EACH SOLUTION . INTERZONAL TRIPS ARE PRINTED ONLY FOR INITIAL AND LASMS07300
C   SOLUTION .                                                          SMS07310
C                                                                       SMS07320
      COMMON ACTS(10,10),EXIST(10,10),A(10),B(10),C(10,10),X(10,10)     SMS07330
      COMMON ESTCST(12,12,12),CC(10,10),TOTESC(10,10),ESTAB(10,10)      SMS07340
      COMMON M,NACTS,NECTCM,NL,NLOOP,NZP,NUM                            SMS07350
      COMMON G,S1,S2,T,T2                                               SMS07360
      COMMON DLINK(15,2),DIST(10,10),CCC(18),ATTRCO(10),PRODCO(10)      SMS07370
      COMMON PR(10),AT(12),SA(10),TRIPS(10,10),BB(10,10),FTA(12,12)     SMS07380
      COMMON NQ,C2(10,10)                                               SMS07390
      COMMON COSTS(6,10),TOTCCT(6)                                      SMS07400
      COMMON PPU(5),APU(5),RATIO(5),RPIN(6)                             SMS07410
 1005 FORMAT(73(1H*),/)                                                 SMS07420
 1009 FORMAT(10X,2H* ,1X,10(I4,2X))                                     SMS07430
 1010 FORMAT(4X,I2,4X,2H* ,10(1X,F5.0))                                 SMS07440
      IF((NQ.GT.1).AND.(NQ.EQ.3))GO TO 51                               SMS07450
      WRITE(6,9007) NQ                                                  SMS07460
 9007 FORMAT(///,10X,'DESIGN LOOP',I5,//)                               SMS07470
      WRITE(6,3505)                                                     SMS07480
 3505 FORMAT(//,10X,'TOTAL COSTS - BENEFITS  ($M)')                     SMS07490
      WRITE(6,1005)                                                     SMS07500
      WRITE(6,3510) T2,S2,G                                             SMS07510
 3510 FORMAT(10X,'TOTAL ESTABLISHMENT COSTS - BENEFITS =',F16.4,/,      SMS07520
     *10X,      '                   TOTAL TRAVEL COSTS =',F16.4,/,      SMS07530
     *10X,      '             SUM TOTAL COSTS - BENEFITS =',F16.4)      SMS07540
      WRITE(6,1005)                                                     SMS07550
```

```
      WRITE(6,3712)
 3712 FORMAT(//,10X,2H* ,10X,'COMPONENT COSTS AND BENEFITS IN EACH ZONE
     * ($)')
      WRITE(6,1005)
      WRITE(6,3713)
 3713 FORMAT(1X,'ZONE NO. ',2H* ,1X,'BENEFITS',2X,'BLD.UNIT',2X,'WATER',
     *5X,'SEWER',3X,'STREETS',6X,'ELEC')
      WRITE(6,1005)
      DO 372 J=1,M
  372 WRITE(6,3714) J,(COSTS(K2,J),K2=1,NECTCM)
 3714 FORMAT(1X,I2,6X,6F10.0)
      WRITE(6,1005)
      WRITE(6,3715)(TOTCCT(K2),K2=1,NECTCM)
 3715 FORMAT(2X,'TOTALS',1X,6F10.0)
      WRITE(6,1005)
      IF(NQ.EQ.1)GO TO 51
      WRITE(6,3515)
 3515 FORMAT(//,1X,'ZONE NO. ',2H* ,10X,'ALLOCATIONS OF FUTURE ACTIVITIE
     *S TO ZONES')
      WRITE(6,1005)
      WRITE(6,1009)(I,I=1,NACTS)
      WRITE(6,1005)
      DO 20 J=1,M
   20 WRITE(6,1010) J,(ACTS(I,J),I=1,NACTS)
      WRITE(6,1005)
   51 NQ=NQ+1
      IF(NQ.EQ.4) GO TO 450
      RETURN
450   CONTINUE
      RETURN
C          DEBUG INIT,SUBCHK
      END
```

```
      SUBROUTINE TRNSPT(M,N,INF,M1,N1)
      COMMON ACTS(10,10),EXIST(10,10),A(10),B(10),C(10,10),X(10,10)
      COMMON ESTCST(12,12,12),CC(10,10),TOTESC(10,10),ESTAB(10,10)
      COMMON MM,NACTS,NECTCM,NL,NLOOP,NZP,NUM
      COMMON G,S1,S2,T,T2
      COMMON DLINK(15,2),DIST(10,10),CCC(18),ATTRCO(10),PRODCO(10)
      COMMON PR(10),AT(12),SA(10),TRIPS(10,10),BB(10,10),FTA(12,12)
      COMMON NQ,C2(10,10)
      COMMON COSTS(6,10),TOTCCT(6)
      COMMON PPU(5),APU(5),RATIO(5),RPIN(6)
      DIMENSION V(10),XSJ(10),S(10),R(10),
     *LISTV(10),U(10),XIS(10),D(10),G(10),LISTU(10),XB(10,10)
      INTEGER COST,C,X,A,B
      INTEGER P,H,Y,T,V,XSJ,S,R,LISTV,U,XIS,D,G,LISTU
      LOGICAL XB
C
C     THE PARAMETERS ARE C(I,J) - ARRAY OF COSTS
C                        A(I)   - QUANTITIES AVAILABLE
C                        B(J)   - QUANTITIES REQUIRED
C                        I=1,....M , J=1,....N
C     SUM OF A(I) = SUM OF B(J)
C     - INF - HAS TO BE THE GREATEST +VE INTEGER WITHIN MACHINE CAPACITY
C     ALL QUANTITIES HAVE TO BE INTEGER
C     THE FLOWS * X(I,J) * ARE COMPUTED BY THE  PRIME-DUAL-ALGORITHM
C     CITED IN  HADLEY,G.  LINEAR PROGRAMMING , READING,LONDON, 1962.
C     THE PROCEDURE FOLLOWS THE DESCRIPTION GIVEN ON P357.
C     MULTIPLE SOLUTIONS ARE LEFT OUT OF ACCOUNT.
C
C     ARRAY - XB(I,J) - FOR NOTATION OF  CIRCLED CELLS.
C     - LISTU(I) - AND - LISTV(J) - LISTS OF LABELED ROWS AND COLUMNS
C     OTHER NOTATIONS FOLLOW HADLEY.
C
```

```
C                                                                       SMS08190
      DO 10 I=1,M                                                       SMS08200
   10 XIS(I)=A(I)                                                       SMS08210
      DO 20 J=1,N                                                       SMS08220
   20 XSJ(J)=B(J)                                                       SMS08230
      DO 70 I=1,M                                                       SMS08240
      H=INF                                                             SMS08250
      DO 30 J=1,N                                                       SMS08260
      X(I,J)=0                                                          SMS08270
      P=C(I,J)                                                          SMS08280
      IF (P.LT.H) H=P                                                   SMS08290
   30 CONTINUE                                                          SMS08300
      U(I)=H                                                            SMS08310
      DO 60 J=1,N                                                       SMS08320
      IF (C(I,J).EQ.H) GO TO 40                                         SMS08330
      GO TO 50                                                          SMS08340
   40 XB(I,J)=.TRUE.                                                    SMS08350
      GOTO 60                                                           SMS08360
   50 XB(I,J)=.FALSE.                                                   SMS08370
   60 CONTINUE                                                          SMS08380
   70 CONTINUE                                                          SMS08390
      DO 120 J=1,N                                                      SMS08400
      H=INF                                                             SMS08410
      DO 100 I=1,M                                                      SMS08420
      IF (XB(I,J)) GO TO 80                                             SMS08430
      GO TO 90                                                          SMS08440
   80 V(J)=0                                                            SMS08450
      GOTO 120                                                          SMS08460
   90 D(I)=C(I,J)-U(I)                                                  SMS08470
      P=C(I,J)-U(I)                                                     SMS08480
      IF (P.LT.H) H=P                                                   SMS08490
  100 CONTINUE                                                          SMS08500
```

```
      V(J)=H
      DO 110 I=1,M
      IF (D(I).EQ.H) XB(I,J)=.TRUE.
  110 CONTINUE
  120 CONTINUE
      DO 130 J=1,N
  130 LISTV(J)=0
      DO 140 I=1,M
  140 LISTU(I)=0
  150 DO 210 I=1,M
      DO 200 J=1,N
      IF (XB(I,J)) GO TO 160
      GO TO 200
  160 IF (XSJ(J).LE.XIS(I)) GO TO 170
      GO TO 180
  170 H=XSJ(J)
      X(I,J)=XSJ(J)
      GOTO 190
  180 H=XIS(I)
      X(I,J)=XIS(I)
  190 XSJ(J)=XSJ(J)-H
      XIS(I)=XIS(I)-H
  200 CONTINUE
  210 CONTINUE
  220 ISUM=0
      DO 221 J=1,N
  221 ISUM=ISUM+XSJ(J)
      IF (ISUM.EQ.0) GOTO 610
      DO 230 J=1,N
      R(J)=0
  230 S(J)=0
      H=0
```

```
      K=1
  240 DO 300 I=1,M
      IF (XIS(I).GT.0) GO TO 250
      GO TO 290
  250 D(I)=XIS(I)
      G(I)=2*N
      DO 280 J=1,N
      IF (XB(I,J).AND.R(J).EQ.0) GO TO 260
      GO TO 280
  260 S(J)=D(I)
      R(J)=I
      LISTV(K)=J
      K=K+1
      IF (XSJ(J).GT.H) GO TO 270
      GO TO 280
  270 H=XSJ(J)
      P=J
  280 CONTINUE
      GOTO 300
  290 D(I)=0
      G(I)=0
  300 CONTINUE
  310 IF (K.EQ.1) GOTO 440
      L=1
      DO 370 K=1,N
      J=LISTV(K)
      LISTV(K)=0
      IF (J.EQ.0) GOTO 380
      DO 360 I=1,M
      IF (XB(I,J).AND.X(I,J).GT.0.AND.G(I).EQ.0) GO TO 320
      GO TO 360
  320 IF (X(I,J).LE.S(J)) GO TO 330
```

```
      GO TO 340
  330 D(I)=X(I,J)
      GOTO 350
  340 D(I)=S(J)
  350 G(I)=J
      LISTU(L)=I
      L=L+1
  360 CONTINUE
  370 CONTINUE
  380 IF (L.EQ.1) GOTO 440
      K=1
      DO 420 L=1,M
      I=LISTU(L)
      LISTU(L)=0
      IF (I.EQ.0) GOTO 430
      DO 410 J=1,N
      IF (XB(I,J).AND.R(J).EQ.0) GO TO 390
      GO TO 410
  390 S(J)=D(I)
      R(J)=I
      LISTV(K)=J
      K=K+1
      IF (XSJ(J).GT.H) GO TO 400
      GO TO 410
  400 H=XSJ(J)
      P=J
  410 CONTINUE
  420 CONTINUE
  430 GOTO 310
C
C     END OF LABELING PROCESS
C
```

```
440 IF (H.GT.0) GO TO 490                                               SMS09470
    GO TO 460                                                           SMS09480
460 ISUM=0                                                              SMS09490
    DO 461 J=1,N                                                        SMS09500
461 ISUM=ISUM+XSJ(J)                                                    SMS09510
    IF (ISUM.EQ.0) GO TO 610                                            SMS09520
    GO TO 530                                                           SMS09530
490 K=P                                                                 SMS09540
    IF (S(K).LT.XSJ(K)) GO TO 500                                       SMS09550
    GO TO 510                                                           SMS09560
500 H=S(K)                                                              SMS09570
    GOTO 520                                                            SMS09580
510 H=XSJ(K)                                                            SMS09590
520 Y=R(K)                                                              SMS09600
    X(Y,K)=X(Y,K )+H                                                    SMS09610
    XIS(Y)=XIS(Y)-H                                                     SMS09620
    XSJ(K)=XSJ(K)-H                                                     SMS09630
    T=G(Y)                                                              SMS09640
    IF (T.EQ.2*N) GOTO 220                                              SMS09650
    X(Y,T)=X(Y,T)-H                                                     SMS09660
    XIS(Y)=XIS(Y)+H                                                     SMS09670
    XSJ(T)=XSJ(T)+H                                                     SMS09680
    K=T                                                                 SMS09690
    GOTO 520                                                            SMS09700
530 H=INF                                                               SMS09710
    DO 560 I=1,M                                                        SMS09720
    DO 550 J=1,N                                                        SMS09730
    IF (G(I).NE.0.AND.R(J).EQ.0) GO TO 540                              SMS09740
    GO TO 550                                                           SMS09750
540 P=C(I,J)-U(I)-V(J)                                                  SMS09760
    IF (P.LT.H) H=P                                                     SMS09770
550 CONTINUE                                                            SMS09780
```

```
  560 CONTINUE
      DO 570 I=1,M
      IF (G(I).NE.0) U(I)=U(I)+H
  570 CONTINUE
      DO 580 J=1,N
      IF (R(J).NE.0) V(J)=V(J)-H
  580 CONTINUE
      DO 600 I=1,M
      DO 590 J=1,N
      IF(C(I,J).NE.U(I)+V(J)) GO TO 590
      XB(I,J)=.TRUE.
  590 CONTINUE
  600 CONTINUE
      GO TO 220
  610 COST=0
      DO 620 I=1,M
  620 COST=COST+A(I)*U(I)
      DO 630 J=1,N
  630 COST=COST+B(J)*V(J)
      RETURN
C          DEBUG INIT,SUBCHK
      END
```

Appendix H - Goal Programming Module - Program Listing

```
**** * * * * * * * * * * * MODULE 4 * * * * * * * * * * * * * * * * *
*
*                        GOAL PROGRAMMING
*
*   SIMPLE INTEGRATED MODULAR WATERSHED PLANNING MODEL
*
*
    THE GOAL PROGRAMMING MODULE PROVIDES FOR AN EXPLICIT
    TREATMENT OF TRADEOFF DECISIONS INVOLVED IN THE ALLOCATION
    OF BUDGETARY RESOURCES.  THE OUTPUT OF THIS MODULE IS A
    DESCRIPTION OF THE EXTENT TO WHICH PARTICULAR GOALS ARE
    ACHIEVED GIVEN A PREDETERMINED SET OF PRIORITIES AND
    BUDGETARY CONSTRAINTS.
*
*
**** * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      DIMENSION KEPT(140)
      DIMENSION RHS(140)
      DIMENSION VALY(140,10)
      DIMENSION RHS1(140)
      DIMENSION Y(140),PRDT(140)
      DIMENSION AMT(140)
      DIMENSION  ZVAL(10)
      DIMENSION C(140,140)
      DIMENSION DOD(140),DUD(140)
      DIMENSION VALX(10,140)
      DIMENSION X(140)
      DIMENSION RVLX(10,140)
      DIMENSION D(140,140)
C     GOAL PROGRAMMING
      CALL START(N,M,L,C,VALX,VALY,PRDT,RHS1,KPCK,KEPT,TEST)
      DO 21 J=1,M
```

```
   21 X(J)=J                                                               GP 00330
      DO 20 I=1,N                                                          GP 00340
   20 Y(I)=I                                                               GP 00350
   15 FORMAT(13F12.2)                                                      GP 00360
   12 FORMAT(10F8.3)                                                       GP 00370
   13 FORMAT(8F9.0)                                                        GP 00380
      DO 25 K=1,L                                                          GP 00390
      DO 25 I=1,N                                                          GP 00400
      VALY (I,K)=VALX(K,I)                                                 GP 00410
   25 CONTINUE                                                             GP 00420
      ITAB=0                                                               GP 00430
C     BRING IN NEW VARIABLES                                               GP 00440
      ITER=0                                                               GP 00450
C     CALCULATE NET CONTRIBUTION OF EACH VARIABLE (RVLX(K,J))              GP 00460
   31 L1=0                                                                 GP 00470
   32 K3=L-L1                                                              GP 00480
   33 IF(K3-1) 800,40,40                                                   GP 00490
   40 DO 60 K=1,K3                                                         GP 00500
      DO 60 J=1,M                                                          GP 00510
      SUMP=0                                                               GP 00520
      DO 50 I=1,N                                                          GP 00530
      P=VALY(I,K)*C(I,J)                                                   GP 00540
      SUMP=SUMP+P                                                          GP 00550
   50 CONTINUE                                                             GP 00560
      RVLX(K,J)=SUMP-VALX(K,J)                                             GP 00570
   60 CONTINUE                                                             GP 00580
      ITER=ITER+1                                                          GP 00590
C     BRING IN X(K2)                                                       GP 00600
      ZMAX=0.                                                              GP 00610
      DO 90 J=1,M                                                          GP 00620
      IF(K3-L) 92,70,70                                                    GP 00630
   92 K4=K3+1                                                              GP 00640
```

```
      DO 91 K=K4,L                                                      GP 00650
      IF(RVLX(K,J)) 90,91,91                                            GP 00660
   91 CONTINUE                                                          GP 00670
   70 IF(RVLX(K3,J)-ZMAX) 90,90,80                                      GP 00680
   80 ZMAX=RVLX(K3,J)                                                   GP 00690
      K2=J                                                              GP 00700
   90 CONTINUE                                                          GP 00710
   95 IF(ZMAX) 790,790,100                                              GP 00720
C     WHICH VARIABLE IS REMOVED FROM THE BASIS                          GP 00730
C     CALCULATE LIMITING AMT FOR EACH BASIS VARIABLE                    GP 00740
  100 DO 150 I=1,N                                                      GP 00750
      IF(PRDT(I)) 110,120,120                                           GP 00760
  110 WRITE(6,13) PRDT(I)                                               GP 00770
      GO TO 830                                                         GP 00780
  120 IF(C(I,K2)) 130,130,140                                           GP 00790
  130 AMT(I)=-1.                                                        GP 00800
      GO TO 150                                                         GP 00810
  140 AMT(I)=PRDT(I)/C(I,K2)                                            GP 00820
  150 CONTINUE                                                          GP 00830
C     SELECT SMALLEST POSITIVE LIMITING AMT                             GP 00840
      I=1                                                               GP 00850
  160 IF(AMT(I)) 170,210,210                                            GP 00860
  170 I=I+1                                                             GP 00870
      IF(I-N) 160,160,180                                               GP 00880
  180 WRITE(6,13) AMT(N)                                                GP 00890
      GO TO 830                                                         GP 00900
  210 ZMIN=AMT(I)                                                       GP 00910
      K1=I                                                              GP 00920
  220 I=I+1                                                             GP 00930
      IF(I-N) 230,230,300                                               GP 00940
  230 IF(AMT(I)) 220,240,240                                            GP 00950
  240 IF(ZMIN-AMT(I)) 220,220,210                                       GP 00960
```

```
C       REMOVE Y(K1)
  300 Y(K1)=X(K2)
      DO 310 K=1,L
      VALY(K1,K)=VALX(K,K2)
  310 CONTINUE
C       CALCULATE NEW RIGHT-HAND SIDES
      DO 400 I=1,N
      PRDT(I)=PRDT(I)-ZMIN*C(I,K2)
  400 CONTINUE
      PRDT(K1)=ZMIN
C       CALCULATE NEW SUBSTITUTION RATES
      DO 500 J=1,M
      DO 500 I=1,N
      D(I,J)=C(I,J)-C(K1,J)*(C(I,K2)/C(K1,K2))
  500 CONTINUE
      DO 510 J=1,M
      D(K1,J)=C(K1,J)/C(K1,K2)
  510 CONTINUE
      DO 520 J=1,M
      DO 520 I=1,N
      C(I,J)=D(I,J)
  520 CONTINUE
C       WRITE ALL TABLES OR JUST OPTIMAL TABLE
      IF(ITAB) 40,40,600
C       WRITE EACH TABLE
  600 DO 610 I=1,N
      WRITE(6,13) Y(I),PRDT(I)
  610 CONTINUE
      DO 620 I=1,N
      WRITE(6,12) (C(I,J),J=1,M)
  620 CONTINUE
      GO TO 40
```

```
C       MOVE TO NEXT LOWER PRIORITY LEVEL
  790   L1=L1+1
        GO TO 32
C       WRITE FINAL RESULTS
  800   WRITE(6,1014)ITER
        WRITE(6,1015)
 1015   FORMAT(1H1)
 1014   FORMAT(10X,'ITERATIONS..............',I5)
        WRITE(6,5000)
 5000   FORMAT(55X,'THE SIMPLEX SOLUTION',25X,'PAGE 05')
        WRITE(6,5001)
 5001   FORMAT(' THE RIGHT HAND SIDE')
  801   DO 810 I=1,N
        WRITE(6,13) Y(I), PRDT(I)
  810   CONTINUE
        WRITE(6,5002)
 5002   FORMAT(' THE SUBSTITUTION RATES')
  811   DO 812 I=1,N
        WRITE(6,12)(C(I,J),J=1,M)
  812   CONTINUE
        WRITE(6,5003)
 5003   FORMAT(' THE ZJ-CJ MATRIX'   )
  813   DO 814 K=1,L
        WRITE(6,12) (RVLX(K,J), J=1,M)
  814   CONTINUE
C       EVALUATE OBJECTIVE FUNCTION
        DO 820 K=1,L
        ZVAL(K)=0.
        DO 820 I=1,N
        ZVAL(K)=ZVAL(K)+PRDT(I)*VALY(I,K)
  820   CONTINUE
        WRITE(6,5004)
```

```
 5004 FORMAT( ' AN EVALUATION OF THE OBJECTIVE FUNCTION')
      DO 821 K=1,L
      KK=L-K
      IF(TEST.EQ.1.0)GO TO 89
      KK=KK+1
   89 WRITE(6,15) KK,ZVAL(K)
  821 CONTINUE
      CALL FINISH(RHS1,PRDT,VALY,L,KPCK,Y,N,KEPT,TEST)
  830 STOP
      END
      SUBROUTINE START(NROWS,NVAR,NPRT,C,VALX,VALY,RHS ,RHS1,KPCK,KEPT,T
     %EST)
C         THE START SUBROUTINE IS DESIGNED TO TAKE INFORMATION IN A SPEC-
C         IFIED FORMAT AND TRANSFORM IT INTO A SERIES OF USABLE MATRICES.
C.......................................................................
      REAL NEG
      REAL L
      NV=312
      NR=250
    1 FORMAT(A4,3I3)
      DATA POS,NEG/'POS ','NEG '/
      DATA DATA/'DATA'/
      DATA OBJ/'OBJ '/
      DATA PROB/'PROB'/
      DATA B /'B'/
      DATA E,G,L/'E','G','L'/
      DIMENSION RHS(140)
      DATA RGHT/'RGHT'/
      DIMENSION VALY(140,10)
      DIMENSION C(140,140),VALX(10,140)
      DIMENSION EQUALS(140),RVLX(10,140)
      DIMENSION KEPT(140)
```

```
      DIMENSION RHS1(140)
      TEST=0.0
C
C
C
C
C        READ THE PROBLEM CARD FOR THE NUMBER OF ROWS,VARIABLES, AND
C.........................................................................
   10 READ(5,1)ANAME,NROWS,NVAR,NPRT
      LISP=NPRT+1
      IF(NVAR.LE.0) GO TO 1020
      IF(NPRT.LE.0) GO TO 1020
      IF(NROWS.LE.0) GO TO 1020
      IF(ANAME.NE.PROB) GO TO 901
C
C
C        READ THE SIGN CARD.
C        IT WILL CONTAIN ONE OF THE FOLLOWING LETTERS FOR EACH ROW
C        FOR EQUALS                    E
C        FOR LESS THAN OR EQUAL TO     L
C        FOR GREATER THAN OR EQUAL TO  G
C        FOR BOTH DEVIATIONS           B
C.........................................................................
      READ(5,11)(EQUALS(I),I=1,NROWS)
   11 FORMAT(80A1)
C
C
      NART=0
C        COUNT THE NUMBER OF POSITIVE SLACK VARIABLES
C.........................................................................
      NFLDS=0
      DO 12 I=1,NROWS
```

```
      IF(EQUALS(I).EQ.B)NFLDS=NFLDS+1
   12 IF(EQUALS(I).EQ.G)NFLDS=NFLDS+1
C
C
C         TEST FOR SIZE
C.......................................................................
      NSIZE=NFLDS+NROWS+NVAR
      IF(NROWS.GT.NR) GO TO 911
C
C
C
C         CLEAR ALL MATRICES
C.......................................................................
      KDUD=NPRT+1
      DO 16 J=1,NSIZE
      DO 16 I=1,NROWS
      KEPT(I)=0
      IF(I.GT.KDUD) GO TO 17
      K=I
      RVLX(K,J)=0.0
      VALX(K,J)=0.0
   17 IF(I.GT.J) GO TO 99
   99 C(I,J)=1.0
      VALY(I,K)=0.0
      IF(I.NE.J) C(I,J)=0.0
   16 CONTINUE
      KPCK=0
      K=KDUD
C
C
C         ADJUST THE SLACK VARIABLES AND OBJECTIVE FUNCTION TO MEET THE
C         REQUIREMENTS OF THE SIGN
```

```
C...............................................................................
      DO 13 I=1,NROWS
      IF(EQUALS(I).EQ.E) GO TO 14
      IF(EQUALS(I).EQ.G) GO TO 15
      IF(EQUALS(I).EQ.L) GO TO 13
      IF(EQUALS(I).EQ.B)GO TO 18
      GO TO 910
   14 J=I
      VALX(K,J)=1.0
      NART=NART+1
      TEST=1.0
      GO TO 13
   15 KPCK=KPCK+1
      J=NROWS+KPCK
      C(I,J)=-1.0
      KEPT(I)=J
      J=I
      VALX(K,J)=1.
      NART=NART+1
      TEST=1.0
      GO TO 13
   18 KPCK=KPCK+1
      J=KPCK+NROWS
      C(I,J)=-1.0
      KEPT(I)=J
   13 CONTINUE
C
C
C         READ THE OBJECTIVE FUNCTION
C...............................................................................
      READ(5,21)ANAME
   19 I=0
```

```
      IF(ANAME.NE.OBJ) GO TO 920
      IF(ANAME.EQ.OBJ) GO TO 20
   20 READ(5,21)ANAME,I,M,TEMP
      IF(ANAME.EQ.DATA) GO TO 30
      IF(M.LE.0) GO TO 1022
      K=LISP-M
   21 FORMAT(A4,2I5,F16.0)
      IF(J.LE.0) GO TO 1022
      IF(K.GT.NPRT)  GO TO 1024
      IF(ANAME.EQ.NEG) GO TO 26
      IF(ANAME.EQ.POS) GO TO 25
      GO TO 27
   26 J=I
      VALX(K,J)=TEMP
      GO TO 20
   25 J=KEPT(I)
      IF (KEPT(I).EQ.0) GO TO 1026
      VALX(K,J)=TEMP
      GO TO 20
   27 IF(TEMP)926,20,926
C
C
C        READ THE DATA MATRIX IN
C.......................................................................
   30 READ(5,21)ANAME,I,J,TEMP
      IF(ANAME.EQ.RGHT) GO TO 40
      IF(I.LE.0) GO TO 1090
      IF(J.EQ.0) GO TO 1090
      J=KPCK+NROWS+J
      C(I,J)=TEMP
      GO TO 30
C
```

```
C
C         READ THE RIGHT HAND SIDE
C.............................................................................
   40 READ(5,44)(RHS(I),I=1,NROWS)
   44 FORMAT(8F10.0)
C
C
C         WRITE THE ABOVE RESULTS
C.............................................................................
      WRITE(6,5015)
 5015 FORMAT(55X,'THE RIGHT HAND SIDE-INPUT',33X,'PAGE 01')
      DO 41  I=1,NROWS
      IF(RHS(I))941,42,43
   42 RHS(I)=.00001
   43 RHS1(I)=RHS(I)
      WRITE(6,1111)I,RHS(I)
 1111 FORMAT(10X,I3,2X,F15.5 )
   41 CONTINUE
      WRITE(6,620)
  620 FORMAT(1H1)
      WRITE(6,5016)
 5016 FORMAT(55X,'THE SUBSTITUTION RATES-INPUT',18X,'PAGE 02')
      DO 1112 I=1,NROWS
      WRITE(6,2519) I
 2519 FORMAT(1X,'ROW',I5)
 1112 WRITE(6,1113)(C(I,J),J=1,NSIZE)
 1113 FORMAT(10F8.3)
      WRITE(6,620)
      WRITE(6,5017)
 5017 FORMAT(55X,'THE OBJECTIVE FUNCTION-INPUT',19X,'PAGE 03')
      DO 1114 K=1,NPRT
      M=LISP-K
```

```
      WRITE(6,2150) M
 2150 FORMAT(' PRIORITY',I5)
 1114 WRITE(6,1113)(VALX(K,J),J=1,NSIZE)
      WRITE(6,620)
      WRITE(6,5018)
 5018 FORMAT(55X,'SUMMARY OF INPUT INFORMATION ',19X,'PAGE',' 04')
      NVAR=NSIZE
      WRITE(6,2017) NROWS,NVAR,NPRT,NART
 2017 FORMAT(10X,'NUMBER OF ROWS..........',I5,/,10X,'NUMBER OF VARIABLES
     *....'    ,I5,/,10X,'NUMBER OF PRIORITIES...',I5,/,10X,'ADDED PRIOR
     2ITIES.......',I5)
      IF(NART.GT.0)   NPRT=NPRT+1
      RETURN
  910 WRITE(6,914)
  914 FORMAT('PROGRAM CONTAINS AN ERROR EITHER IN THE NUMBER OF ROWS PUN
     1CHED OR IN THE SIGN CARD.THE VALUE IS SOMETHING OTHER THAN "E","G"
     2,OR"L"')
      GO TO 999
 1090 WRITE (6,1091)
 1091 FORMAT('   IMPROPER DATA COLUMN OR ROW DEFINITION')
      GO TO 999
  920 WRITE(6,921)
  921 FORMAT('  AN OBJECTIVE CARD WITH THE VALUE',F16.3,'               I
     1S FOUND BUT INSTRUCTIONS AS TO WHICH DEVIATION HAS BEEN NEGLECTED.
     2EXAMINE YOUR DATA ')
      GO TO 999
 1020 WRITE (6,1021)
 1021 FORMAT('   NUMBER OF ROWS, VARIABLES, OR PRIORITIES CANNOT BE EQUA
     1L TO ZERO UNDER ANY CIRCUMSTANCES')
      GO TO 999
 1022 WRITE (6,1023)
 1023 FORMAT('   COLUMN VALUE OR PRIORITY VALUE IS EQUAL TO OR LESS THAN
```

```
     1ZERO           ')
      GO TO 999
  911 WRITE(6,912)
  9120FORMAT('  THE NUMBER OF VARIABLES NEEDED TO COMPUTE THIS PROGRAM')
      GO TO 999
 1026 WRITE(6,1027)
 1027 FORMAT('  ATTEMPT IS MADE TO MINIMIZE NON EXISTANT POSITIVE  DEVIA
     1TION')
      GO TO 999
 1024 WRITE(6,1025)
 1025 FORMAT('  OBJECTIVE FUNCTION PRIORITY EXCEEDS STATED NUMBER OF PRI
     1ORITIES')
      GO TO 999
  901 WRITE(6,902)
  902 FORMAT(' PROBLEM CARD MISSING OR MISPUNCHED')
      GO TO 999
  926 WRITE(6,927)
  927 FORMAT('  A CARD IN THE OBJECTIVE SECTION DEFINED SOME VALUE FOR')
  941 WRITE(6,942)
  942 FORMAT('  NEGATIVE VALUES ARE NOT ALLOWED ON THE RIGHT HAND SIDE.
     1 CORRECT PROBLEM BY MULTIPLYING ENTIRE CONSTRAINT THROUGH BY MINU
     2S ONE.')
      GO TO 999
  999 STOP
      END
      SUBROUTINE FINISH(RHS1,RHS,VALY,NPRT,KPCK,Y,NROWS,KEPT,TEST)
      REAL NEGSLK
      DIMENSION KEPT(140),RHS1(140),VALY(140,140)
      DIMENSION ZVAL(140)
      DIMENSION RHS(140),Y(140)
C         RHS1 IS THE RESERVED VECTOR OF RHS VALUES FROM THE BEGINNING.
C         THE ENDING RHS VALUES ARE SUBTRACTED FROM THE BEGINNING ONES
```

```
C          AND THE RESULT IS PLACED INTO THE APPROPRIATE SLACK COLUMN.
C          THE REMAINDER OF THE VALUES  ARE PRINTED ON PAGE TWO OF THE RE-
C          SULTS.
C
C
C       SLACK ANALYSIS
C
        WRITE(6,21)
     21 FORMAT(1H1,120X,'PAGE  06'//,50X,'SLACK ANALYSIS')
      1 FORMAT(////)
        WRITE(6,1)
        WRITE(6,8)
      8 FORMAT(10X,'ROW',6X,'AVAILABLE',12X,'POS SLK',12X,'NEG SLK')
        WRITE(6,1)
        DO 19 I=1,NROWS
        NEGSLK=0.0
        POSSLK=0.0
        DO 11 J=1,NROWS
        M=Y(J)
        IF(I-M) 9,10,9
      9 IF(M-KEPT(I))  11,12,11
     11 CONTINUE
        GO TO 13
     10 NEGSLK=RHS(J)
        GO TO 13
     12 POSSLK=RHS(J)
     13 WRITE(6,14)I,RHS1(I),POSSLK,NEGSLK
     14 FORMAT(10X,I3,3F20.5)
     19 CONTINUE
     43 FORMAT(10X,I3,3X,F15.5)
C
C       VARIABLE AMOUNTS
```

```
C
      WRITE(6,44)
   44 FORMAT(1H1,120X,'PAGE 07'//,50X,'VARIABLE ANALYSIS')
      WRITE(6,45)
   45 FORMAT(////,7X,'VARIABLE        AMOUNT',//)
      DO 41 I=1,NROWS
      NCHCK=Y(I)-KPCK-NROWS
      IF(NCHCK)41,41,42
   42 WRITE(6,43)NCHCK,RHS(I)
   41 CONTINUE
      WRITE(6,72)
   72 FORMAT(1H1)
      WRITE(6,50)
   50 FORMAT(//,55X,'ANALYSIS OF THE OBJECTIVE',23X,'PAGE 8',////,50X,'P
     %RIORITY',10X,'UNDER-ACHIEVEMENT',/)
      DO 52 K=1,NPRT
      ZVAL(K)=0.0
      DO 51 I=1,NROWS
   51 ZVAL(K)=ZVAL(K)  +VALY(I,K)*RHS(I)
      LISP=NPRT+1
      KK=LISP-K
      IF(TEST.EQ.0.0)  GO TO 52
      KK=NPRT-K
      IF(KK.GT.0) GO TO 52
      WRITE(6,78) ZVAL(K)
   78 FORMAT(/,45X,'ARTIFICIAL',5X,F20.5)
      GO TO 77
   52 WRITE(6,53) KK,ZVAL(K)
   53 FORMAT(1H0,52X,I2,5X,F20.5)
   77 CONTINUE
      STOP
      END
```

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Signature

AN INTEGRATED MODULAR WATERSHED PLANNING MODEL APPLIED TO THE UPPER SOUTH RIVER WATERSHED, WAYNESBORO, VIRGINIA

by

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(ABSTRACT)

The problems associated with urban development and its resultant effects on environmental quality present increasingly complex decisions for elected and technical officials. Current approaches to modeling often result in the development of models which are too complex to be understood and require such long time periods to be modified that by the time the model is operational the problem has changed.

A modular modeling framework is proposed which considers land use, runoff, and water quality and connects these factors to a budgetary function. In addition, the modular configuration facilitates the process of modifying components of the model in response to a changing problem environment.

In order to test the feasibility of the proposed modeling approach, the model is applied to the Upper South River watershed, Waynesboro, Virginia. The following three alternative development plans are evaluated:

1. To permit no additional population growth and preserve the area for agriculture and recreation.
2. To permit concentrated development in the form of two new communities each with a population of three thousand persons.
3. To increase the population by three thousand persons but to allow development to continue to follow the existing pattern of urban sprawl.

The study concludes by stating that if zoning ordinances and comprehensive plans focus on consolidating development within the framework of existing water and sewer networks, the cost of providing the sewer network for Alternative 2 will be ten million dollars less than Alternative 3 for the same increase in population.