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Water Allocation Models Based on An Analysis for the Kissimmee River Basin

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ABSTRACT

WATER ALLOCATION MODELS BASED ON AN ANALYSIS FOR THE KISSIMMEE RIVER BASIN

Two types of models for allocating water among alternative uses and between watersheds in the Kissimmee River Basin were developed and empirically evaluated. The value of water in agricultural and recreational uses was estimated for use in the allocation models. A linear programming model of the hydrologic-economic system was developed to determine the economic consequences of broad operational policy alternatives and the relative trade-offs based on economic returns from water allocation among different uses, locations and time periods. A simulation model that incorporated hydrologic and physical relationships for the basin was evaluated as an alternative type of water allocation model. The two different types of water management models evaluated in this study can serve different purposes. The simulation model, because of its detailed approach, is best suited for developing and evaluating specific operational policies for individual basins. The linear programming model is better suited for assessing effects of broad operational policy alternatives and for determining optional choices. This study demonstrated the feasibility and usefulness of water management system modelling as a means of providing information for selecting water management policy alternatives.

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CHAPTER I

INTRODUCTION

The Problem and Its Setting

Since rainfall is not evenly distributed with respect to time or location, floods and droughts may occur at different times or locations. Man has, therefore, attempted to manage water resources to minimize floods during wet seasons and/or to store water for use during dry seasons. The use of water has been important to the economic development of many areas. In humid areas such as Florida, water management systems were built largely for flood control purposes. In contrast, reservoirs were built on rivers in the West to store water for irrigation in arid areas and/or for hydroelectric power generation. In both types of areas people are aware that water is either presently or rapidly becoming a scarce resource. As a result water use is often burdened with uncertainties and conflicts between users and potential users. These conflicts intensify as the demand for water increases and it becomes necessary to make decisions regarding the allocation of a limited amount of water among alternative users.

Although man has manipulated the supply of water with respect to time and place, the total supply of water on earth today is about the same as it was thousands of years ago. This is not the case, however, with the demand for water. The demand for water has increased rapidly, and projections for the future indicate the demand will continue to expand. In many areas of the country, such as southern Florida, there will be strong competition among agricultural, municipal, industrial, and other users of water. Problems of allocating water among alternative uses arise when water becomes scarce and there is competition for it.

The Central and Southern Florida Flood Control District is typical of many water management districts that need to make decisions regarding the allocation of a limited amount of water among uses and users. Because of the high degree of urbanization, agricultural development and unique environment found in the area, it faces many of the problems that other water management districts confront. The Central and Southern Florida Flood Control District was created as a statutory agency in Florida in 1949 and given the responsibility for managing the water resources in this area with the major objective being flood control.

Before the Central and Southern Florida Flood Control District was formed, central and southern Florida was a land of recurring drought and floods because of the low level of the land. The early Indians of Florida dug a few canals for navigational purposes but generally left the natural drainage system unchanged. It was not until after the Civil War that settlers began to migrate in great numbers to this part of the state. It became apparent to state leaders that drainage was necessary if certain large areas were to be settled permanently. In 1881, Hamilton Disston, a Philadelphia saw manufacturer, bought four million acres from the state and began his drainage project which gave Lake Okeechobee an outlet to the Gulf and opened the Kissimmee River system to steamboat navigation. The state sold other large blocks of land in the Kissimmee Basin to individuals who drained the land and put cattle on it. After the turn of the century, efforts to drain the rich mucklands around Lake Okeechobee and the Everglades began in earnest. Many new drainage projects were proposed. From 1924 to 1930 there were a number of floods. A 1926 hurricane took over 200 lives, and the hurricane of 1928 killed more than 2,000 people. During the 1930's, droughts caused the drained mucklands to burn causing a few people to realize the significance of drainage done in a reckless manner. In 1941 there were more floods. From 1943 to 1946 droughts caused the muckland to burn, and many cattle died from the lack of water in the pastures of the Kissimmee River Basin. In 1947 the torrential rains took over. A large part of the land area of central and southern Florida was turned into a land-locked sea and the flooding resulted in an estimated $59 million of property damage.

Following the 1947 flood, public demand resulted in the U.S. Army Corps of Engineers developing a comprehensive plan for flood control and water conservation which would benefit the greatest number of people and the largest portion of the area. The plan was approved by the state and by Congress in 1948. In 1949 the Florida legislature created the Central and Southern Florida Flood Control District to have the state and local responsibility for carrying out the plan.

Like many water management systems, the Central and Southern Florida Flood Control District was designed to fulfill one or two purposes. The Flood Control District (FCD) was developed with the emphasis on facilities to provide relief from flooding. However, flooding occurred during the wet season, and there was a dry season of about equal length when critical water shortages often occurred. Water management responsibilities in addition to those recognized in the original design have become important to the public and consequently also received recognition by those responsible for managing the water. Some of the water management responsibilities recognized today include flood damage prevention, water supply, public recreation, water conservation, improvement of navigation and the preservation and enhancement of fish and wildlife. To accomplish these responsibilities, the Flood Control District operates a complex system of canals, levees, pumping stations, spillways, navigation locks and retention basins.

The Flood Control District's operating rules were developed for the original design objective. Objectives other than flood control have been recognized but need to be incorporated into the management of the water resources system. The problem is to determine how to achieve the current set of objectives with the existing water management system.

Objectives of the Study

The major purpose of this project was to develop and empirically test a model for the temporal allocation of water among alternative uses and between watersheds. This task involves the allocation of water among alternative uses within a time period and between uses in different time periods under physical and institutional restrictions. The specific objectives of the project were:

(1) To formulate and test a model or models capable of allocating the water controlled by the FCD among alternative uses within time periods and between uses in different time periods under physical and institutional restrictions.

(2) To determine alterations in the allocation of water that result from different availabilities of water or from changes in the physical and institutional restrictions on particular uses.

(3) To determine data requirements, availability of needed data and the cost associated with using water allocation models to aid in the selection of water management policies for a large area such as the Central and Southern Florida Flood Control District and to assess the feasibility of this approach.

Selection of the Study Area

The Central and Southern Florida Flood Control District covers approximately 15,673 square miles and includes many different water utilization problems. Many groups representing the interests of water users are concerned about water allocation and believe the present operational techniques do not provide optimum benefits. The Flood Control District realizes that the operational rule curves based on flood control design criteria and previously existing demands can possibly fall short of generating optimum benefits when the nature of land use, drainage, urbanization, pollution, industrialization and other things within the project boundaries change. Desiring to develop a rational system of water management which would better satisfy the various users of water, the Flood Control District has undertaken a program to derive additional criteria by which to operate. It was believed that a model incorporating the important hydrologic features and the various water using activities in the area would give greater knowledge of how to manage the system. Such a model would not be possible immediately because of the lack of knowledge about both the hydrologic characteristics and the water use activities. Instead, such a model would be developed over time. A logical first step in developing a model which involves such complexities is to consider an area smaller than the entire Flood Control District and use this as a pilot study for future work. The Kissimmee River Basin was chosen as a pilot study area because it was of manageable size for developing a workable model by which water can be allocated among alternative uses, watersheds and time periods. It was an area where the Flood Control District had detailed hydrologic data available. The development and application of a water allocation model to the Kissimmee River Basin would provide guidelines for water allocation and management by reflecting the interaction of the various economic activities and the effect that hydrology has on the benefits accruing to the area due to the use of water.

The Kissimmee River Basin stretches from Orlando on the north to Lake Okeechobee on the south. The Central Florida Ridge forms the western boundary of the Kissimmee River Basin (see Figure 1). The region

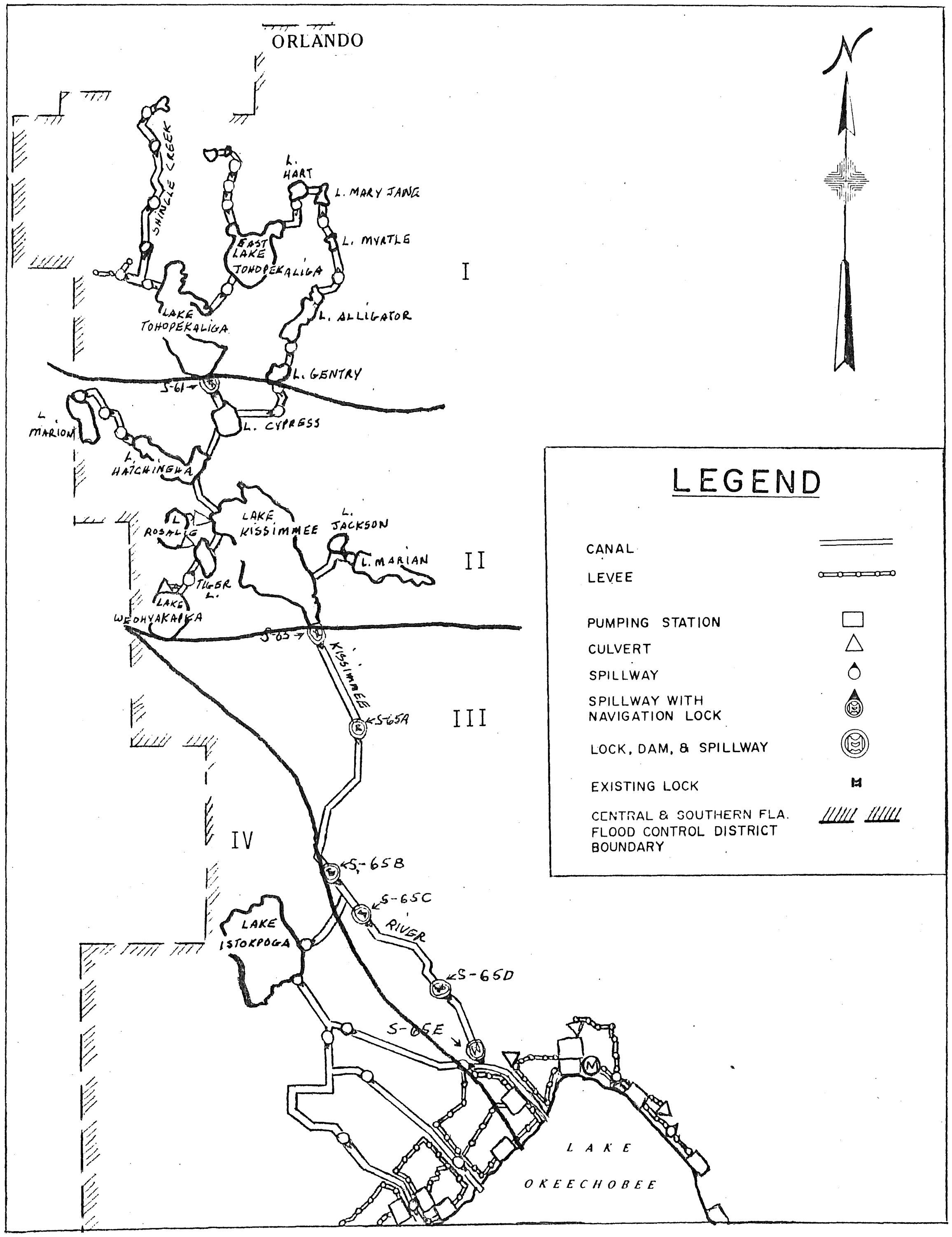

Figure 1. -- The Kissimmee River Basin.

originally had many shallow lakes and swamps with small streams running between them. Water moved south in a broad path and into the Kissimmee River, a poorly defined stream consisting of many small channels and a two-mile wide swampy flood plain. This was a major source of water for Okeechobee and south Florida.

In recent times the basin has been greatly modified. Canals have been dug and structures installed to control flooding. The major lakes are connected by these canals and small streams connect the smaller lakes. Figure 1 illustrates the canals and control structures that are located throughout the basin.

The planning and design of the water management system in the Kissimmee River Basin has been completed and the major elements of the system are now in existence. The current operational procedures are based on a fixed seasonal rule curve. The rule curve requires that a prescribed amount of flood storage space be available in each reservoir, each year, in the two or three month period preceding October 1. Operational decisions are predetermined and governed by the date on the calendar [31]. The fixed seasonal rule curves based on design criteria and pre-existing conditions and demands often fall short of obtaining the maximum benefit and the optimal distribution of benefits from the physical system when the demands on the system change.

The Flood Control District took its first steps toward developing a new approach to operations when it investigated the possibility of adapting mathematical modeling techniques to its system [31]. Mathematical modeling was seen as a tool which, if properly applied, would permit a much greater flexibility in reservoir operations than was allowed by the rule curve and provide a basis for rational longer range management policies, thus producing a wider range of water-based benefits. A three-pronged research and development approach was established to develop the following models: (1) physical systems model, (2) prediction model, and (3) allocation model.

The Flood Control District's efforts in physical system modeling have been reported by Sinha [28] and by Sinha and Lindahl [29]. This program was undertaken to develop knowledge of hydrologic and hydraulic responses and mathematical relationships for simulating streamflow for extended periods and to compute water surface elevations. The prediction model was developed for the purpose of providing long range estimates of rainfall within reasonable limits of confidence. Detailed statistical analyses of the rainfall have been made by the Flood Control District and are reported for the Kissimmee River Basin by Sinha and Khanal [30]. This study was formulated for the development of the allocation model.

Methods and Procedures

To decide upon the "best" or an "acceptable" operational policy which will meet the multi-objectives of the district, decision makers need information on the outcome of various policy alternatives with respect to the hydrologic, economic and institutional aspects of the system. Given this kind of management framework, two analytical techniques seem to be appropriate.

To determine the economic consequences of broad operational policy alternatives, and the relative trade-offs based on economic returns from various water time-space-use allocations, a linear programming model of the hydrologic-economic aspects of the system is appropriate. The input data requirements for such a model are relatively simple, and in addition, if one chooses as an objective function the maximization of economic benefits, the costs of trade-offs between water uses in time and space will be shown in the results.

For selecting the operational policies which are more specific, such as water level regulation schedules, a simulation model of the hydrologic-economic aspects of the system seems best suited. Both of these types of system modeling techniques were applied to the Kissimmee River Basin in this study. A basic time period of one year was assumed for this study. For the purpose of data collection and developing the linear programming allocation model, however, the year was divided into four time periods. The determination of the time periods was based on the amount of precipitation, the demand for supplemental irrigation and the amounts of recreational activity in the area. The four time periods selected were: (1) June, July, August and September; (2) October and November; (3) December and January; and (4) February, March, April and May.

Two basic types of data were required to determine the economic consequences of alternative water management policies. First, the various activities that use the water within the Kissimmee River Basin must be identified. The quantities demanded by each use must be determined with respect to the temporal and spatial distribution of the demands. In addition, the value of water in each use during each time period and at each location must be determined and in some cases, the values of water associated with different quantities for each category must also be determined.

The second major type of data required is the amount of water available to be allocated among the various water using activities. This type of data includes the quantity of water from rainfall and runoff which is available in each sub-basin in each time period and the quantity of storage in each sub-basin. In addition, maximum and minimum storage capacities and flood damages associated with various storage levels must be determined and various other physical and institutional aspects of the water management system, such as water release requirements, must be determined.

After the data were obtained, they were aggregated and summarized into forms useable in the modeling algorithms. Since in this study two different types of models were used, the data were analyzed and summarized in two different ways. For example, the linear programming algorithm needed the amounts of water required for each water using activity and the physical and institutional constraints to be expressed as linear functions. However, these functional relationships were not required to be linear in the simulation model.

Chapter II discusses water management modeling and the basic types of data used in this study. The analysis and summarization of each type of data necessary for, and peculiar to, each of the two different types of models, however, are discussed in the chapter in which each model is described. Chapter III is devoted to the description of the development and application of the linear programming model, and Chapter IV presents the simulation model. The fifth and final chapter contains a summary of the results and the implications of the study. In addition, three appendices are presented. A considerable amount of time and resources were required to develop the technique for estimating the value of water used for recreation and data collection for this purpose. Appendix A is devoted to the description of these efforts in estimating the value of recreation. The other two appendices present the detailed descriptions of models that were used in the simulation portion of the study. Appendix B presents the surface water management model and Appendix C contains the water use activities model.

CHAPTER II

MODELING AND DATA SOURCES

Water Management Modeling

The process of making and implementing water management decisions involves physical, economic and institutional considerations. These three considerations should be evaluated and integrated into any water management decision or policy.

The physical considerations are concerned with what is physically possible. It involves determining the range and limits of the system. For example, if a given amount of rainfall occurs in a specified period of time, how much runoff will occur and what will be the streamflow response and the water elevation in water storage areas? By modeling the physical system, these types of effects on the system can be estimated and a new state of the system determined.

Water management alternatives should also be evaluated in terms of what is economically desirable. The economic considerations involve an economic evaluation of the physical possibilities of the system. The water management decisions are concerned with how to meet the current objectives in the most efficient manner given the physical system. In this case, the development costs for the system are sunk costs and already given. The economic evaluation now deals with the net benefits of each of the management alternatives within the given system.

Both the physical and economic considerations are dependent upon what is institutionally permissible. Institutions are the group and social actions that influence and control individual behavior [1]. Water rights is an example of formal control over decisions, and customary practices are formal controls. The Central and Southern Florida Flood Control District is an example of an institution established for water management purposes. Water management alternatives must be evaluated to determine if they are legally permissible and politically acceptable.

The physical, economic and institutional considerations are all important components of any operational water management model. Figure 2 depicts the major components that comprise the development and ultimate selection of an operational water management policy.

A long-term operational water management policy is developed in the following manner:

(a) A proposed long-term regulation policy is specified. This could be in the form of a gate regulation schedule (rule curve), water use regulation, land use change or any other modification.

(b) This policy affects the form of the surface water management model or the institutional constraint model.

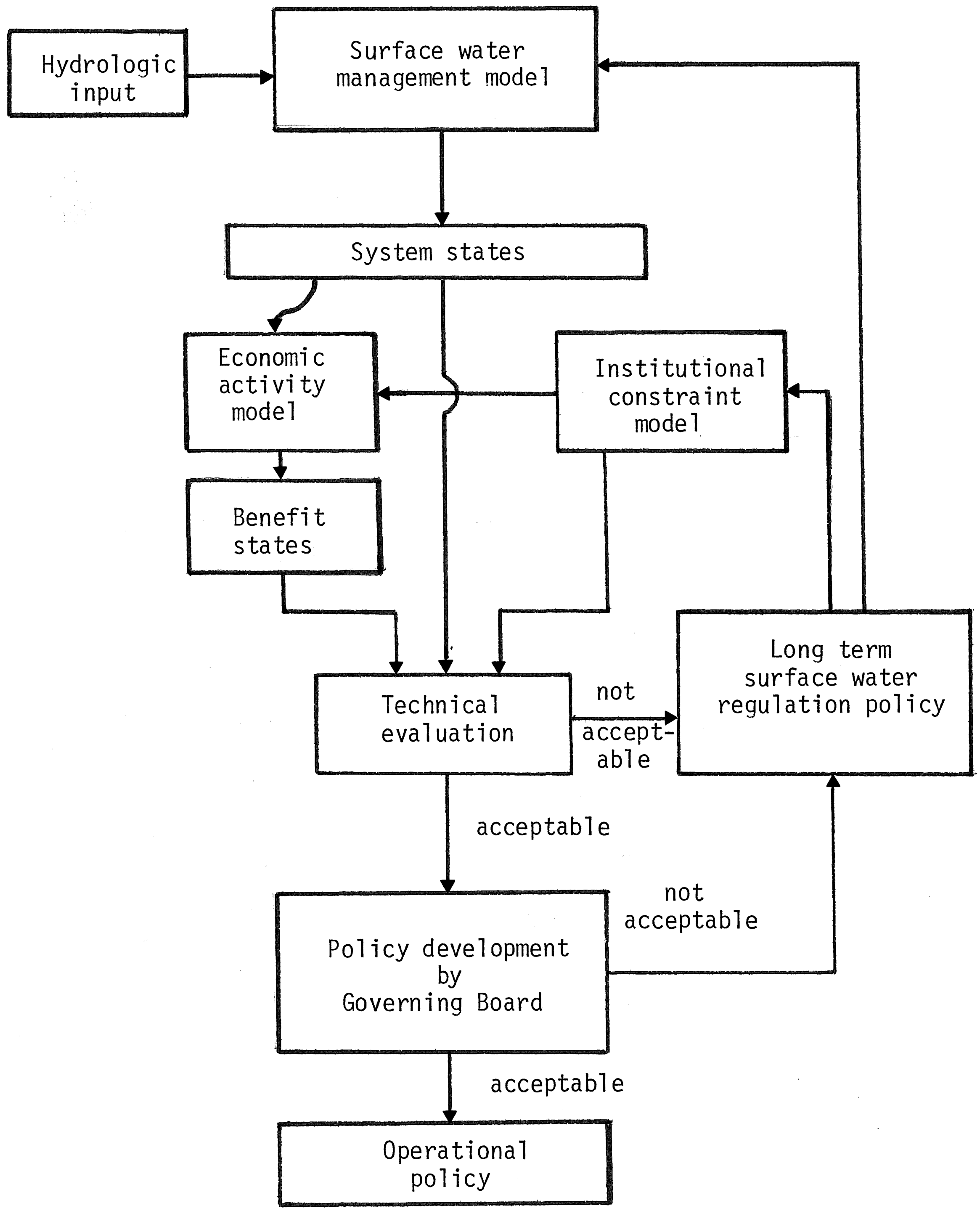

Figure 2. -- Development of operational water management policy.

(c) Hydrologic data are the primary inputs to the surface water management model, and the output is a set of lake surface elevations, the lake system states.

(d) The lake system states are inputs to the economic activities model, which gives as output the levels to the various water use activities and the net dollar benefits accruing to various activities as a result of the regulation policy.

(e) The lake states, benefit states and institutional constraints provide information on the reasonableness of the proposed regulation policy. If not accepted, the policy is modified in light of the evaluation results and another run is made.

(f) If the policy is accepted, it is next evaluated by the governing board in the light of considerations that cannot be quantified. If rejected, modifications and a new series of runs are made until the policy is acceptable at the first level.

When the long-term operational water management policy is satisfactorily developed, a short-term execution policy is formulated. Figure 3 illustrates the execution of the short-term operational policy. The policy execution model functions in the following manner:

(a) Actual rainfall is continuously monitored and the data transmitted to the operations center via the telemetry system.

(b) The rainfall data provide input to the streamflow simulator, which produces as output runoff into the lakes.

(c) A set of gate operations is specified by the gate operations model.

(d) The gate operations and runoff values are the inputs to the lake surface elevations model, which gives as output a set of lake surface elevations or the lake system states.

(e) These states are evaluated in terms of what the short-term operational policy specifies. In addition, governing board and staff judgement can be used to establish evaluation criteria. If rejected, a new set of gate operations is specified.

(f) If accepted, the set of gate operations becomes the short-term operations schedule.

Within this operational water management framework, two analytical techniques were used to assess the economic consequences of operational policy alternatives. A linear programming model was developed to assess the economic consequences of broad policy alternatives and the relative trade-offs based on the economic returns from allocations of water among different users, locations and time periods. A simulation model of the hydrologic-economic aspects of the system was developed to assess the operational policies which are more specific, such as water level regulation schedules. Both of these analytical techniques require a considerable amount of hydrologic and economic data.

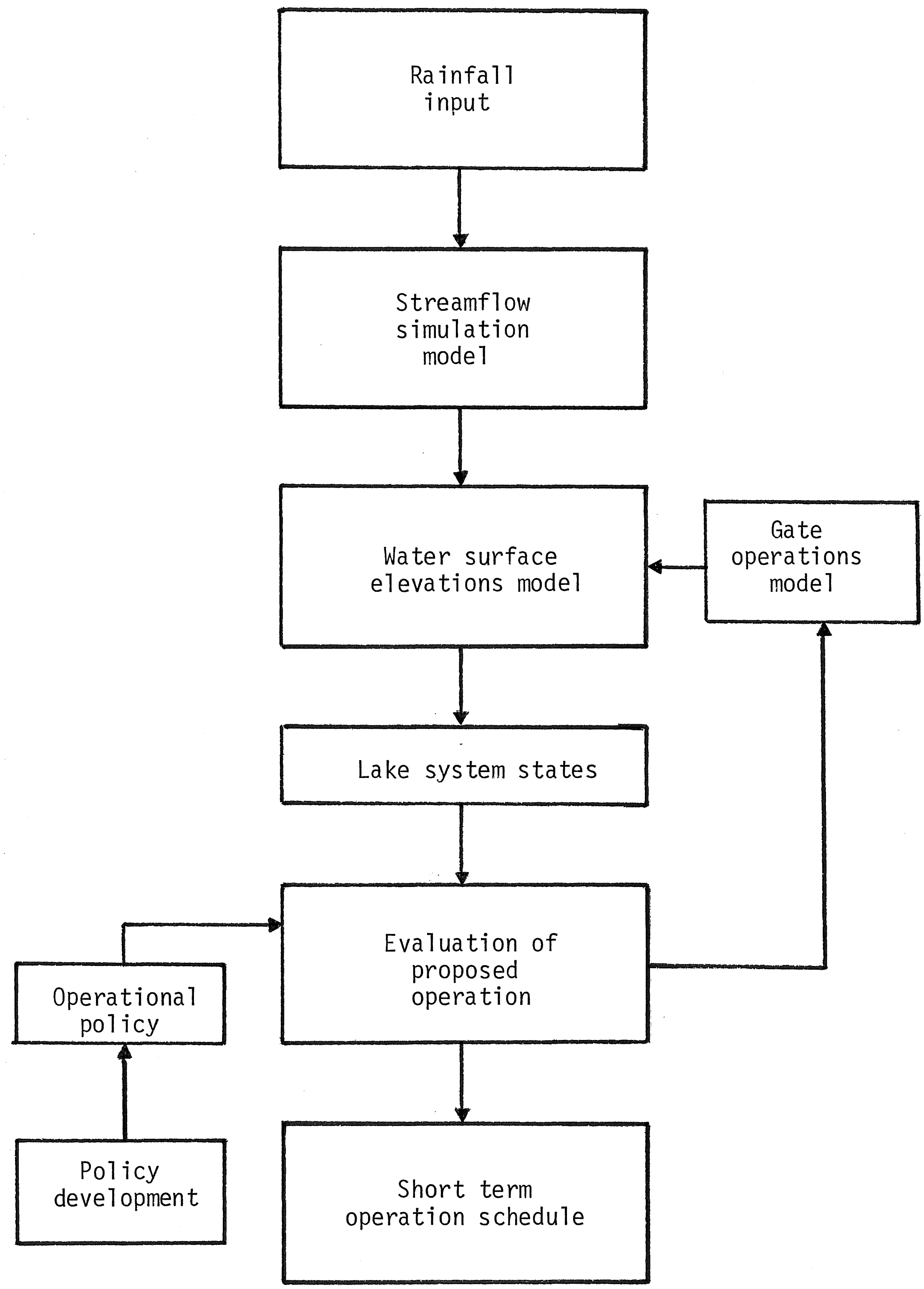

Figure 3. -- Execution of the short-term operational policy.

Hydrologic and Economic Data

Value of Water in Alternative Uses

The increased demand for water in relation to a relatively stable supply of water has focused attention on the importance of proper management and allocation of water. Problems relating to the allocation of water among alternative uses arise when water becomes scarce and there is competition for it. As long as water is abundant (not in excess), competition among users and potential users of water does not arise since everyone has sufficient amounts for his need. However, as water becomes scarce, users compete for its use and control.

The scarcity of water implies an allocation among competing uses and users. In an economic context, efficiency in the allocation of water among competing uses requires the determination of the value of water in alternative uses. Therefore, the management of existing supplies of water and the allocation among users calls for up-to-date and reliable estimates of the value of water in agricultural, municipal, industrial, recreational and other uses. Economics provides criteria for determining the allocation among competing uses and users of water [27]. If the quantity of water is not restricted, an individual should use water to the point that the cost of an additional unit of water is just equal to its return. In economic terminology, a firm or individual should allocate water to a particular use until the marginal value product (MVP) equals the price (cost) of water (P_w).

$$MVP = P_w \tag{1}$$

The MVP indicates the rate at which a firm's revenue would increase if the input (water) were increased by a small amount. If there is a limited supply of water available and the firm has competing uses for the water, the firm should use each unit of water where the net contribution to profits is the greatest. It can be shown that the firms should allocate the given supply of water between the two uses (A and B) so that the marginal value product from the last unit of water applied to A will be equal to the marginal value product of the last unit of water applied to B [27]. That is, it should be allocated in such a manner that the marginal value products are equated for all uses.

$$MVP_A = MVP_B \tag{2}$$

This economic criterion can be extended to determine the allocation of water among users, S and R. It can be shown that for economic efficiency water should be allocated so that the marginal value productivity will be equated for all uses and users.

$$MVP_{AR} = MVP_{BR} = MVP_{AS} = MVP_{BS} \tag{3}$$

Likewise, it can be shown that the optimum allocation of water over time would occur when the marginal value product from the use of water in one time period is equal to the discounted marginal value product from the use of water in some future time period. The value of water in alternative uses is needed so that rational economic decisions can be made concerning allocations among competing uses of water.

Agricultural Use of Water

In central and southern Florida, agriculture uses a large portion of available surface water and will continue to demand a large quantity for many years to come. Between 1959 and 1964, irrigated farm acreage in Florida increased 194 percent to over one million acres [35, p. 149]. It has been estimated that if this trend continues, by 1980 two million acres will be under irrigation. This move toward capital-intensive irrigation in humid Florida is due to the desire of producers to maximize profits, reduce the risk of temporary plant stress due to short-term drought and replace or upgrade present irrigation systems which are labor-intensive.

To determine the value of water used for the irrigation of crops in the Kissimmee River Basin it was necessary to first determine (a) the types of crops and acreages of each crop irrigated, and (b) the acres of irrigated crops that used surface water as the source of irrigation water. These data were available for the year 1968 from a recent survey of the Kissimmee River Basin by the Soil Conservation Service (SCS).[1] In addition, projections of total irrigated acres for the year 1980 for the Kissimmee River Basin were supplied by the SCS. Crop acreages were not broken down with regard to different soil types. The level of aggregation into crop types was sufficient to introduce considerable variation in net returns per acre within each crop type. The cross-sectional data and SCS data reveal that a large majority of the crops were produced on the same or very similar soil types.

The next step in determining the value of water used to irrigate crops was to determine the increase in yields forthcoming from the use of irrigation water over the yields that could be obtained without its use. Two approaches were taken to obtain this data. First, an extensive search of reported research was conducted to gather as much information as possible on the relationships between water consumption and level of crop yield for the three types of crops. The second major effort consisted of an extensive survey of farmers, ranchers and scientists engaged in the production of or research on the production of crops in the Kissimmee River Basin. The survey of farmers and ranchers was designed to obtain information needed to estimate the value of water for agricultural uses, such as current irrigation practices and costs and returns of producing various crops.

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[1]The data on crop acreages was obtained from the River Basin-Watershed Planning Staff, Soil Conservation Service, U. S. Department of Agriculture, Gainesville, Florida.

The primary source of data regarding the additional yields of citrus from application of various levels of irrigation water was supplied by the work of Koo, Sites, Reuss and Harrison of the University of Florida [17, 18, 25, 26]. The value of water used for irrigating citrus was estimated from these data by Wilder [36].

While the data on the response of citrus yields to irrigation water were quite sufficient for determining differences in yields resulting from differing levels of irrigation, similar data for pastures and vegetable crops were not available. Most vegetables produced in the area were irrigated, and many farmers and researchers stated that for the most part, production would not be possible without both drainage and supplemental irrigation. On the other hand, comparatively little of the total pasture in the Kissimmee River Basin was irrigated at the time this study was conducted. Thus response to irrigation water for vegetables and other crops and pasture was obtained from interviews with University of Florida scientists familiar with the production practices and physiology of the crops.

After the yield responses of the crops were obtained, it was necessary to determine the difference in net returns to irrigated crops and the net returns from the crops if produced without irrigation. The net returns from irrigated and non-irrigated citrus were determined from data supplied by Koo, Sites, Reuss, Harrison and Wilder [17, 18, 25, 26, 36] and data obtained from Brooke [4]. Costs and returns used in the determination of the net returns to water were computed on the basis of 1969 prices.

The determination of net returns to irrigated pasture was complicated because the pasture plants were not sold directly but were utilized by cattle. Thus, it was necessary to determine the additional amount of beef that could be produced by irrigated pasture over that which could be produced by non-irrigated pasture. Thus, using information obtained from animal scientists at the University of Florida, and farmers and ranchers in the Kissimmee River Basin, cost and return budgets were computed (using 1969 prices) for three levels of pasture irrigation. These budgets are presented in Table 1.

Net returns to vegetables and other crops were extremely variable, not only between different types of crops but also for the same crop from year to year. For this reason, plus the fact that little secondary information was available on the response of the various crops to irrigation water, an average of irrigation water requirements and net returns to water for several crops was used in this study. This estimate is representative only of an aggregate of several crops including field corn, sweet corn, tomatoes and cut flowers. Thus, it would not be representative of the net returns to water which could be expected from any one crop in any one year.

The specific form of data on the agricultural use of water utilized in the linear programming and the simulation models are quite different. The reasons for this difference are several, but the basic differences relate to the functional forms in which the data are utilized in each model and the differences in the amount of detail with which the models are designed

Table 1.--Net returns to water from irrigated pasture in the Kissimmee River Basin

Budget item	Unit	Time irrigation applied		
		Spring	Winter-Spring	Fall-Winter-Spring
Annual net gain	lb. beef/acre	132.7	176.8	206.3
Gross irrigation water used	acre-inches	14.8	16.4	18.0
Annual repayment costs of irrigation system	$/acre	8.76	8.76	8.76
Annual irrigation operation costs	$/acre	.62	.68	.75
Total annual irrigation costs	$/acre	9.38	9.44	9.51
Gross returns on net gain	$/acre	33.18	44.20	51.58
Net costs of beef produced	$/acre	13.27	17.68	20.63
Annual returns to irrigation	$/acre	10.53	17.08	21.44

to simulate the Kissimmee River Basin water management system. Thus, the presentation of the specific input data used in each model is presented in the chapter in which each model is discussed.

Recreational Use of Water

It is widely recognized that outdoor recreation is an important segment of our economy. This is particularly true of the Kissimmee River Basin in Florida. This area contains more than thirty lakes of varying sizes plus canals, creeks and rivers, all of which are nationally renowned for the quality of sport fishing which they provide on a year-round basis.

Agencies involved in water resources planning, development and management have come to accept recreational use as a major factor to be considered in water resource development projects. However, the process of determining the economic value of such use has been the subject of much controversy. It was the intent of this portion of the study to estimate total recreational values of water in the Kissimmee River Basin and relate these values to the amount of water in storage within the system.

Two types of recreationists utilize the water in the Kissimmee River Basin. These are (1) recreationists living on waterfront property (permanently or during vacation and holidays); and (2) those traveling to the area primarily to engage in recreational activities from publicly accessible facilities. For both types of recreationists the primary water-based activities include fishing, waterskiing, boating and swimming. Visiting recreationists also enjoy camping. The procedures used in this study to estimate the annual value of recreation included interviews with both types of recreationists.

To evaluate the economic significance of water to recreational visitors, a demand curve showing willingness of users of the area to pay measurable sums for specified amounts of recreation was estimated. The number of days per visit was considered the quantity variable in a demand relationship and the daily on-site costs a price variable. The aggregate demand for recreation was derived by expanding this average demand relationship for individuals according to the number of visits. That is, total recreational usage of an area was defined as the product of the number of days a recreationist uses a recreational site per visit and the number of visits to a recreational site. It was assumed that the impact of water level on recreational values is reflected in the number of visits rather than the length of stay per visit. Therefore, the value per visit was estimated and then the relationship between water level and visits was estimated to relate water level to recreational value. The annual average value per visit was estimated to be:

$$\text{Value per visit} = \int_{3.23}^{17.77} (e^{1.929 - .051\,c})\,dc \qquad (4)$$

$$= \$59.91$$

where c is the daily on-site costs per person. The total number of visits (V_T) was estimated to be a function of water level (W_L):

$$V_T = -3,962,699.23 + 81,219.81\ W_L \qquad (5)$$

The estimated value to recreationists was estimated by combining the analyses of days per visit and number of visits. The value of recreation needed to be expressed as a function of water level for use in the allocation models. Combining Equations (4) and (5) gives an estimate of economic value relating to water level:

$$\text{Annual Economic Value} = (\$59.91)\ (-3,962,699.23 + 81,219.81\ W_L) \qquad (6)$$

where $59.91 is the estimated value per visit.

Waterfront residents in the Kissimmee River Basin benefit from participation in recreational activities and higher land values for waterfront property. Waterfront residents were interviewed to obtain information regarding property values and participation in and expenditures on recreational activities.

The benefits accruing to waterfront residents, in terms of actual expenditures and increased property values, are not additive with those estimated for visiting recreationists. For this reason and the fact that values for waterfront residents were not correlated with water levels, only the values estimated for visiting recreationists were used in the allocation models.

Since the recreational use of the water within the Kissimmee River Basin was so important relative to the total value of water in the basin and because essentially no data were available with regard to the value of this particular use, a large portion of the total effort expended in this study was devoted to developing primary data and methods of analyzing this data in order to determine the value of water for recreational purposes. The procedures used and the results obtained from this effort are reported as Appendix A. In addition, the specific uses of recreational data which are peculiar to the linear programming and simulation models, respectively, are presented in the chapters in which these two models are discussed.

Municipal and Industrial Use of Water

Within the Kissimmee River Basin there are currently very few municipalities and only two with populations over 1,000 which adjoin the lakes or streams within the river basin. Thus, current municipal and industrial uses of water within the basin are of little importance, especially since the two largest municipalities within the basin use ground water as their primary source of municipal and industrial water. In the future, however, it is quite possible that the industrial and municipal uses of surface water will become more important relative to the other uses of surface water within the basin. For this reason, these types of uses are considered as a part of the total economic use of water within the basin in the simulation model. Therefore, the specific details of the municipal use of water in the basin as used in the simulation model will be presented in the chapter in which the simulation model is discussed.

Hydrologic and Water Control Data

A basic assumption underlining any attempt to allocate water is that the amount of water available for allocation and the physical capabilities for controlling the available water be known. As was stated earlier, the Central and Southern Florida Flood Control District has developed extensive hydrologic data as well as data relative to the storage capacities and physical capabilities of the water management system within the Kissimmee River Basin. Thus, they were able to furnish extensive and detailed data relative to the quantities of rainfall and its distribution through time and space, the amount of water runoff resulting from this rainfall, storage capacities of each lake and stream, the rates at which water could be released through the various control structures and the relationship between water elevations in the storage facilities and the quantities of water in storage for each lake and stream within the basin. In addition, they were able to furnish some data on the relationships between water level elevations and damages due to flooding for each lake within the system.

Because of the basic differences in the linear programming and simulation models which have been discussed previously, the types of hydrologic and water control information utilized by each model were considerably different. Therefore, discussion of a specific type of hydrologic and water control data utilized in each model will be discussed in the respective chapter in which each model is presented.

CHAPTER III

A LINEAR PROGRAMMING WATER ALLOCATION MODEL

Basic Data Inputs for the Model

For the purpose of developing the linear programming water allocation model, the Kissimmee River Basin was broken down into four sub-basins (see Figure 1). Sub-basin I is at the head of the Kissimmee River, sub-basin II and sub-basin III complete the stem of the river, and Lake Istokpoga in the southwest portion of the study area is located in sub-basin IV and is actually hydrologically independent of the other three sub-basins.

The time periods established for use in this model are:

1 = June - September

2 = October - November

3 = December - January

4 = February - May

The selection of these periods was based on the precipitation patterns in the area and on the seasonal aspects of demands for water for crop irrigation and recreation.

To determine the optimal allocation of water within the Kissimmee River Basin using a linear programming model requires that data be obtained on the amounts of water available and the methods by which it can be controlled, the uses which can be made of the water and the value of water in each use. The specific data used in the linear programming model will now be discussed.

Hydrologic Data

In order to determine the amount of available surface water to be controlled by the water management facilities in the Kissimmee River Basin during a specified period of time it is necessary to determine the water "yield" for each sub-basin. Yield is determined by two major factors, (a) rainfall and its distribution, and (b) the resulting amount of runoff or streamflow generated by the rainfall. The water yield estimates used in the study were developed for the four sub-basins by the FCD.[2] For all

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[2]The FCD staff primarily responsible for the development of the hydrologic data used here were R. L. Hamrick and N. N. Khanal. The techniques used and the results obtained from their application to the Kissimmee River Basin are reported in [14 and 15].

four sub-basins, there was considerable variation in yields for each time period from year to year (Table 2). Also total annual yield for all four sub-basins varied considerably from year to year with the years 1961, 1967 and 1970 being the driest, while exceptionally large yields occurred in the years 1966 and 1969.

Storage capacities for the lakes in each sub-basin at various water level elevations and U.S.G.S. data on daily elevations for each lake were used to compute lake storage at different frequency levels for the years 1961-1970 (Table 3). From those storage-frequency relationships minimum and mean storage levels for each sub-basin were derived. The minimum storage level was set at the level which the lakes were observed to equal or exceed 90 percent of the time. Likewise, the mean storage levels were set at the level which the lakes were observed to equal or exceed 50 percent of the time. These storage levels for each sub-basin are shown in Table 4.

Storage levels for sub-basin III were established independently by FCD personnel.[3] It should be noted that since sub-basin III does not contain any lakes, the minimum and mean storage levels were equal.

The maximum storage levels were determined by the average elevations for all lakes in each sub-basin at which flood damages were first incurred. As can be seen by comparing the maximum storage levels in Table 4 with the storage frequency relationships in Table 3, the maximum storages were equaled or exceeded at least 10 percent of the time between 1961 and 1970.

For levels of storage above the maximum regulated storage, flood damages were incurred. The FCD staff[4] estimated the replacement cost of crops and structures damaged or destroyed by flood waters at one foot intervals for water level elevations above the maximum allowable levels. These were converted to storage levels for each sub-basin and linear relationships between flood damages and storage above regulated levels were estimated. The flood damages per acre-foot of water above the maximum regulated storage levels were estimated to be $15.00, $2.00, $4.30 and $4.30 for sub-basins I through IV, respectively.

In addition to establishing realistic storage levels for each of the sub-basins, it was felt that acceptable levels of water released from the Kissimmee River Basin should be considered since the Kissimmee River and its tributaries have historically furnished much of the surface water for Lake Okeechobee and southeast Florida. In order to accomplish this, the FCD furnished monthly discharges of water through structures S-65E (water released from sub-basin III) and S-68 (water released from sub-basin IV) for the period 1961-1970. Since water released from sub-basin I

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[3]From conversations with R. L. Hamrick.

[4]Data obtained from N. N. Khanal was used to estimate the flood damage relationships.

Table 2. -- Water yield by time period and sub-basin, Kissimmee River Basin, 1961-1970

Year	Sub-basin I Time periods				Sub-basin II Time periods				Sub-basin III Time periods				Sub-basin IV Time periods			
	1	2	3	4	1	2	33	4	1	2	3	4	1	2	3	4
	J-S	O-N	D-J	F-M	J-S	O-N	D-J	F-M	J-S	O-N	D-J	F-M	J-S	O-N	D-J	F-M
	1,000 acre-feet															
1961	38	20	5	14	57	24	52	111	31	21	20	11	81	9	51	72
1962	87	149	26	3	129	115	30	10	270	124	33	105	305	65	13	17
1963	23	96	46	99	13	79	54	104	136	61	43	52	104	44	27	157
1964	246	22	78	70	225	49	82	120	189	44	39	58	176	27	41	87
1965	53	86	19	28	217	131	30	46	95	132	26	30	237	80	20	50
1966	191	58	40	139	148	81	43	178	131	13	30	94	334	49	69	141
1967	115	17	2	30	209	61	23	30	50	37	7	17	156	42	19	23
1968	162	72	8	6	162	92	30	8	86	120	21	2	296	74	14	46
1969	131	193	97	46	162	222	87	75	98	259	61	51	315	217	70	119
1970	29	25	70	72	67	43	67	90	10	33	59	65	146	10	78	126
Avg.	107.5	73.8	39.1	50.7	144.9	89.7	49.8	66.2	109.6	90.4	33.9	38.0	215.0	61.7	40.2	83.8
Std. dev.	75.5	59.6	33.3	44.1	62.8	56.8	22.8	57.7	77.3	71.8	17.1	30.9	93.9	59.8	25.2	50.0
Per month avg.	26.9	36.9	19.5	12.7	36.2	44.8	24.9	16.6	27.4	45.2	17.0	9.5	53.8	30.8	20.1	21.0

Table 3. -- Lake storage at different frequency levels for the Kissimmee River Basin for the years 1961-1970

Lake	Proportion of time that water in storage equals or exceeds the amount shown in 1,000 acre feet					
	Percent					
	1	5	10	25	50	90
Sub-basin I						
Tohopekaliga	222	182	160	130	108	65
East Tohopekaliga	172	154	140	123	104	80
Hart	7	7	7	7	7	7
Mary Jane	13	10	7	6	6	6
Myrtle	4	3	3	3	2	2
Alligator	47	40	38	35	32	25
Gentry	17	15	15	14	12	9
Total	482	411	370	318	271	194
Sub-basin II						
Kissimmee, Hatchineha, Cypress, Tiger	700	560	484	400	328	184
Marian	27	26	24	23	23	21
Marian	65	64	63	63	60	48
Jackson	8	7	6	5	4	4
Rosalie	66	58	58	56	47	45
Weohyakapka	73	70	68	67	64	52
Total	939	785	703	613	526	354
Sub-basin IV[a]						
Istokpoga	250	217	185	155	150	102

[a]Frequencies for storage levels for sub-basin III (the Kissimmee River) were not established.

flowed into sub-basin II and releases from sub-basin II flowed into sub-basin III, releases from the first two sub-basins were not considered in establishing discharge levels. From these data three discharge levels were established and are presented in Table 5. The minimum release requirement for each time period is simply the sum of the average of the lowest monthly discharges for each month in the time period for the years 1961-1970. The mean release requirements are the sum of the monthly mean discharges for each month in the time periods. Finally, the proposed release requirement is the same as the minimum release requirement for

Table 4. -- Minimum, mean and maximum storage levels by sub-basin for the Kissimmee River Basin

Type of storage	Sub-basin I	Sub-basin II	Sub-basin III	Sub-basin IV
	1,000 acre-feet			
Minimum storage	194,000	354,000	15,000	102,000
Mean storage	271,000	526,000	15,000	150,000
Maximum regulated storage	350,000	640,000	30,000	180,000

Table 5. -- Alternative release requirements by time period from the Kissimmee River Basin

	Time periods			
	June-Sept. 1	Oct.-Nov. 2	Dec.-Jan. 3	Feb.-May 4
	1,000 acre-feet			
Minimum				
IV	15,000	9,000	5,000	17,000
III	70,000	45,000	30,000	40,000
Mean				
IV	94,000	39,000	21,000	67,000
III	278,000	171,000	99,000	237,000
Proposed requirement				
IV	15,000	9,000	25,000	85,000
III	70,000	45,000	150,000	200,000

time periods 1 and 2 and five times the minimum for time periods 3 and 4. The reason for proposing this release requirement was to insure an ample supply of water to the southeast Florida area during the drier months of winter and spring.

Agricultural Use of Water

Data on the types of crops and acreages of each which were irrigated and the acres of irrigated crops that used surface water as the source of irrigation water were necessary in order to determine the value of water used for the irrigation of crops. These data were available for the year 1968 from a recent survey of the Kissimmee River Basin by the Soil Conservation Service (SCS).[5] In addition, projections of total irrigated acres for the year 1980 for the Kissimmee River Basin were supplied by the SCS. These data were summarized into three main types of crops by the SCS and are shown in Table 6.

Table 6. -- Irrigated crops by sub-basin in the Kissimmee River Basin

Crops	Sub-basins			
	I	II	III	IV
	Acres			
Total irrigated acreage -- 1968				
Citrus	6,240	6,580	1,540	10,230
Irrigated pasture	1,100	1,320	6,756	19,230
Vegetables & other crops	200	0	1,300	1,320
Surface water irrigation -- 1968				
Citrus	2,190	2,150	350	5,030
Irrigated pasture	0	1,000	820	11,670
Vegetables & other crops	200	0	0	1,400
Total irrigated acreage -- 1980				
Citrus	3,900	11,600	1,900	11,200
Irrigated pasture	3,800	3,500	10,600	32,800
Vegetables & other crops	1,700	400	1,100	6,700

Source: Based on data provided by River Basin-Watershed Planning Staff, Soil Conservation Service, U. S. Department of Agriculture, Gainesville, Florida.

[5]The data on crop acreages was obtained from the River Basin-Watershed Planning Staff, Soil Conservation Service, U. S. Department of Agriculture, Gainesville, Florida.

The next step in determining the value of water used to irrigate crops was to determine the increase in yields from irrigation. Once the yield responses of the crops were obtained the net returns from irrigation could be established. These data were summarized into two irrigated citrus, three irrigated pasture and one irrigated vegetable crop production practices and are shown in Table 7. Costs and returns used in the determination of the net returns to water were computed on the basis of prices prevailing in 1969.

Table 7. -- Net returns to irrigation water and the acre-feet of irrigation water applied by time period for irrigated crops in the Kissimmee River Basin

Crop	Net returns per acre	Irrigation water applied by time period			
		1 June-Sept.	2 Oct.-Nov.	3 Dec.-Jan.	4 Feb.-May
	- Dollars -	Acre-feet			
Spring irrigated citrus	52.11				.500
Spring & summer irrigated citrus	108.19	.170			.500
Pasture--irrigated in fall, winter & spring	10.53		.417	.167	.916
Pasture--irrigated in winter & spring	17.08			.367	1.000
Pasture--irrigated in spring only	21.44				1.233
Irrigated vegetables & crops	25.00				.333

Recreational Uses of Water

The value of the recreational use of water in the Kissimmee River Basin is summarized by sub-basin and time period in Table 8. It was assumed that maximum recreational values could be obtained if the amount of water in storage were at optimal levels. Research by Behar indicated that the number of recreational visits per time period to Lake Tohopekaliga decreased as the amount of water in storage fell below the mean storage level [2]. Based on this information, recreational benefits to the

Table 8. -- Value of water to recreational visitors by sub-basins and time period for the Kissimmee River Basin, 1970

Sub-basin	Time period 1	2	3	4
	$1,000			
I	5,345	1,386	1,241	5,215
II	6,458	1,358	1,533	4,720
III	353	217	646	641
IV	1,425	189	241	674
Total	13,581	3,150	3,661	11,250

management of the water in the sub-basins were assumed to reach a maximum at the mean storage level; decrease by one-third as the water level fell from the mean to the minimum level; and two-thirds of the benefits thus accumulated at a constant rate between a zero lake level and the minimum storage level (see Figure 4). Recreational benefits were assumed to decline when the level of water in storage exceeded the maximum free storage. Using this concept of the relationship between storage levels and the value of water to recreational visitors the benefits in dollars per acre-foot of storage were determined as two linear functions. The recreational returns per acre-foot of water are presented in Table 9.

The total value of water used for recreational purposes for the Kissimmee River Basin is the sum of its value to recreational visitors and its value to lakefront residents. In addition, part of the value of the water for recreational uses is capitalized into the value of lakefront property. For purposes of the linear programming model, however, only the values of water to the recreational visitors were included in the application of this model. This value was used because it was by far the largest component of the recreational values and because sufficient information on the values of the other components was not available.

Algebraic Representation of the Model

A linear programming model of an existing water management system may take many forms. That is, given any particular physical system and set of objectives recognized by the system management authority, it is conceivable that several different objective functions, each with their specific set of water using activities and physical and institutional constraints, would be relevant to the operational policy formulation. Since such water management systems are usually managed for the benefit of the "public" an objective which seeks to maximize the economic benefits

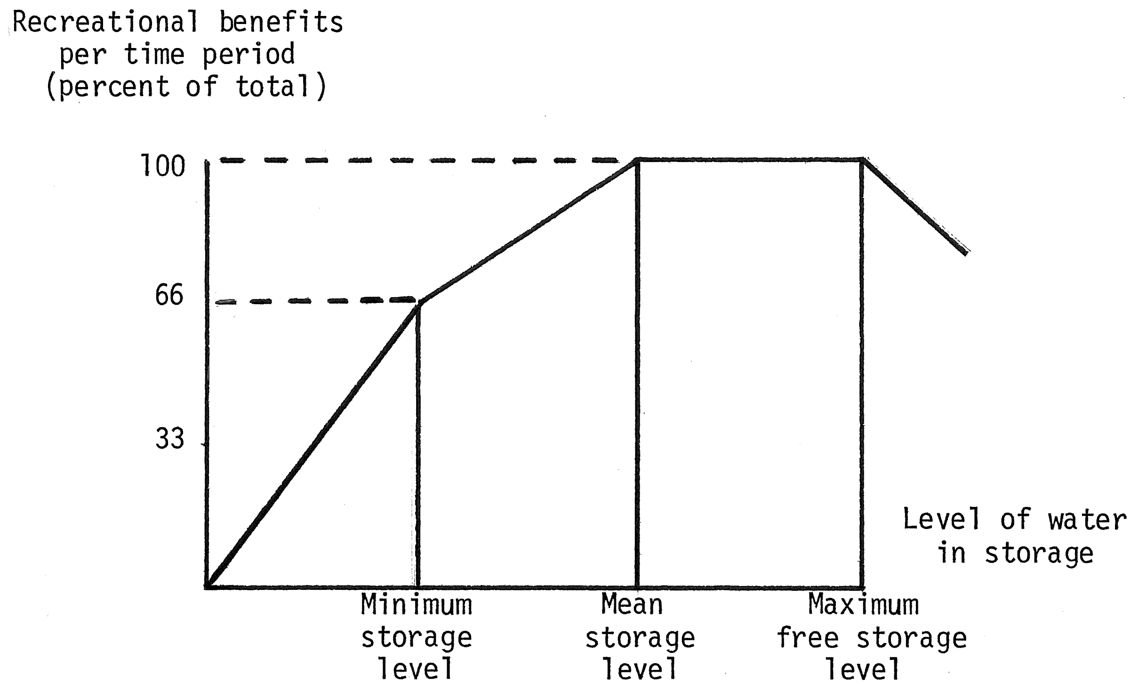

Figure 4. -- Accumulation of recreational benefits in relation to storage levels, Kissimmee River Basin, Florida.

Table 9. -- Recreation returns to water in storage in the Kissimmee River Basin

Sub-basin	Time periods			
	1 Jun.-Sept.	2 Oct.-Nov.	3 Dec.-Jan.	4 Feb.-May
	Dollars per acre-foot			
Zero to required minimum storage level				
I	18.37	4.76	4.27	17.92
II	12.16	2.56	2.89	8.89
III	23.52	14.49	43.08	42.71
IV	9.31	1.24	1.57	4.41
Minimum to mean storage level				
I	23.14	6.00	5.37	22.58
II	12.52	2.63	2.97	9.15
III	-	-	-	-
IV	9.89	1.31	1.67	4.68

occurring to the public would be one of primary importance for most types of systems.

The linear programming model developed for the Kissimmee River Basin water management system had as its objective the maximization of net economic benefits to the public. The various institutional, physical and hydrologic constraints and characteristics of the system were described previously. It was anticipated that this model would be useful as an information generating tool for the selection and formulation of operational policies by the FCD personnel.

The linear programming model of the Kissimmee River Basin can be represented algebraically by:

Maximize:

$$\text{Total Net Returns (TNR)} = \sum_i \sum_k \left[\sum_j a_{jki}\, C_{jki} + \sum_n a_{nki}\, S_{nki} \right] \tag{7}$$

Subject to:

$$C_{jki} \leq A_{jk}$$

$$S_{1ki} = ML_{ki}$$

$$S_{nki} \leq RLM_{nki},\ n = 2, 3, \ldots$$

$$MXR_{ki} \geq REL_{ki}$$

$$MRL_i \leq REL_{ki}$$

$$Y_{ki} + \sum_n b_{nki}\, S_{nk(i-1)} + REL_{(k-1)} =$$

$$\sum_j b_{jki}\, C_{jki} + \sum_n S_{nki} + REL_{ki}$$

Where:

a_{jki}, a_{nki} = the per unit net returns to society from water using activities (may be $\gtrless 0$)

C_{jki} = the level of activity (e.g., acres for citrus) of each of j water consumptive activities in each of k sub-basins, in each of i time periods

S_{nki} = the acre-feet of water stored, thus available for recreational and future consumptive uses, for each of n levels of storage, in each of k sub-basins, in each of i time periods

Y_{ki}	=	the acre-feet of water yield (net runoff water) available in each of k sub-basins and each of i time periods
b_{jki}, b_{nki}	=	the acre-feet of water used for each unit of the various consumption and storage activities
A_{jki}	=	the maximum number of units of each water consumption activity available in each sub-basin
ML_{ki}	=	the acre-feet of water required to be stored for each sub-basin in each time period
RLM_{nki}	=	the acre-feet of water in each storage level for each sub-basin in each time period
MRL_i	=	the acre-feet of water required to be released from the system for each time period
MXR_{ki}	=	the maximum acre-feet of water allowed to be released from each sub-basin for each time period
REL_{ki}	=	the acre-feet of water released from each sub-basin for each time period

The model described above would allocate the available water over i time periods and k sub-basins such that the total net returns (TNR) to society would be maximized. TNR would be provided by the net returns (a_j, a_n) to water used in the various consumptive (C_j) and non-consumptive (S_n) uses. The per unit net returns to water might be either positive (for uses beneficial to society), zero (for uses neither beneficial nor detrimental) or negative (for uses detrimental to society). The TNR would be maximized subject to constraints on the water management system such as the storage capacities within each sub-basin (RLM_k), the minimum amounts of water required to be released from the system during each time period (MRL_i) and the minimum acre-feet of water required to be held in storage in each sub-basin (ML_k).

The minimum storage requirements (ML_k) for each sub-basin and the acre-feet in each storage level (RLM_k) for each sub-basin were presented in Table 4. The alternative release requirements (MRL_i) for sub-basins III and IV were presented in Table 5. The acre-feet of water yields for each sub-basin and each time period (Y_{ki}) are shown in Table 2 with the mean yield for the 10-year period being used in the initial solutions of the model. Maximum releases were not specified for the sub-basins in the Kissimmee River Basin because the time periods were long enough to preclude the possibility of the physical system being over-taxed by extraordinarily large releases.

The only consumptive uses of water (C_j) in the Kissimmee River Basin were the irrigated crops. The six different crop-irrigation practice activities, the net returns per acre from each (a_{jki}) and the acre-feet of water required by each (b_{jki}) for each time period were presented in Table 7. The acreages of each crop in each of the sub-basins were given in Table 6.

There were two non-consumptive uses of water or water related activities (S_{nk}) in the Kissimmee River Basin: recreational use of water in storage and flood damages from excessive amounts of water in storage. The net returns from the recreational use of the water in storage in each sub-basin for each time period were presented in Table 9. The net costs of flood damages per acre-foot of water above the regulated storage level for each sub-basin were estimated. To these flood damages were added the losses in recreational benefits equal to the net returns to water from recreation for storage between the mean and minimum required levels. Thus, the net cost of excessive quantities of water in storage was equal to the flood damages plus the losses in net returns to recreation. These total net costs are shown in Table 10.

Table 10. -- The total net costs per acre-foot of water in storage above the regulated storage levels for each sub-basin in the Kissimmee River Basin

Time period	Sub-basin			
	I	II	III	IV
	Dollars			
1	33.37	14.16	27.82	13.61
2	19.76	4.56	18.79	5.54
3	19.17	4.89	47.38	5.87
4	32.92	10.89	47.01	8.71

It should be noted that water released from sub-basin I is available in sub-basin II in the same time period. Similarly, releases from sub-basin II are available in sub-basin III in the same time period. Water stored in any time period in any sub-basin is available in the same sub-basin in the next time period. Thus, the amount of water yield (Y_{ki}) in any sub-basin in any previous time period plus the amount of water stored in that sub-basin in the previous time period [$S_{nk(i - 1)}$] less evaporation losses (b_{nki}) plus the amount of water released in the same time period from a previous sub-basin [$REL_{(k - 1)i}$] must equal the amount of water consumed in that sub-basin in that time period (b_{jki}, C_{jki}) plus the water stored in that sub-basin in that time period (S_{nki}) plus the water released from that sub-basin in that time period (REL_{ki}). The releases for sub-basins I and IV from previous sub-basins were always zero. Also, for the first time period, the amount of water in storage in each sub-basin had to be exogenously determined. In all cases it was set at the mean storage level for the sub-basin as presented in Table 4.

Capabilities of the Model

The types of information provided by a linear programming water allocation model and the manner in which this information could be used in the operational policies selection process of a governing authority of a water management system can be classified as follows:

1. Optimal (in terms of economic benefits) allocation of water over time and space and among economic activities is calculated within the hydrologic and institutional (policy) constraints specified.
2. Changes in "optimal" benefits from alternative hydrologic and/or institutional constraints can be compared.
3. Changes in benefits from alternative "optimal" allocations induced by changes in the levels of various water using activities can be evaluated.
4. The model provides only very limited information regarding the physical control of the water necessary to achieve the optimal allocations due to the necessity of aggregating hydrologic data into runoff or streamflows over relatively large periods of time.

An inherent limitation in linear programming water allocation models such as the one presented here is the inability to relate economic costs and returns from each of the water using activities to periods of time sufficiently small to reflect significant fluctuations in water yield. That is, because of the nature of the water using activities, and the necessity that they be related to water in the form of linear coefficients, the units of time are usually required to be no shorter than one month or, at best, two weeks if exceptionally specific production data were available. More often, as is the case here, time periods of one month or longer are used in such models.

Another built-in limitation of linear programming when used to model a decision-allocation system such as this is the inability to model the incremental aspects of the decisions making process with respect to time. In the model depicted here, for example, the hydrologic yields for each time period are required as input data. Thus, the optimal allocation of water for the year is based on this knowledge which, of course, is never available to a decision maker in a realistic situation.

This model can, however, provide useful guidelines and initial indications as to the most efficient spatial and temporal allocations of the water managed by the system. More importantly, it can provide very useful indications of the relative sensitivities of the various hydrologic and economic aspects of the system to proposed policy changes. Such information can then be used to guide the development of more sophisticated information generating techniques such as simulation models of the system.

Application of the Model: Selected Results

The linear programming model was applied to data from the Kissimmee River Basin. Optimal allocations were obtained using the three alternative release requirements (MRL_i) presented in Table 5 and the three levels of irrigated crop acreages (A_{jk}) presented in Table 6. Solutions for all nine combinations (3 x 3) of these acreages and release requirements were obtained using the 10-year average water yields (Y_{ik}) for each time period and sub-basin as presented in Table 2. For ease of reference when making comparisons the following notation will be used:

Levels of irrigated acreages:	Code
1968 - Surface water source	68 SW
1968 - Total irrigated acres	68 IR
1980 - Projected total irrigated acres	80 IR
Alternative release requirements:	
Minimum (10-year average)	MIN
Proposed	PRO
Mean (10-year average)	MEAN

Typical results obtained from these optimal allocations are exemplified by the results from using release requirement "MIN" and irrigated acreage "68 SW" as shown in Table 11. Note that the release requirements only apply directly to sub-basins III and IV. Sub-basin II, however, releases its water into sub-basin III. Likewise, water released from sub-basin I flows into sub-basin II.

In all of the sub-basins, most of the benefits come from the recreational use of the water. The magnitude of these benefits is further illustrated by comparing the total benefits from sub-basins I and II with those from sub-basins III and IV. It should be noted that the primary cause of this difference is due to the amount of water in storage (small number of lakes and streams) in sub-basins III and IV compared to sub-basins I and II.

These results, plus similar results from the allocations based on the remaining eight other combinations of irrigated acreage and release requirements, are summarized with respect to the total benefits generated in Table 12. It should be noted that little difference in total benefits

Table 11.-- Allocation of water and benefits obtained from the linear programming model of the Kissimmee River Basin using minimum release requirements, 1968 surface water irrigated crop acreages, and 10-year mean water yields

	Unit	Time period				Annual total
		1	2	3	4	
Sub-basin I						
Net yield	1,000 a.f.	107.5	73.8	39.1	50.7	271.1
Water in storage at end of period	1,000 a.f.	350.0	271.0	293.8	328.7	
Water released	1,000 a.f.	28.1	68.8	0.0	0.0	96.9
Benefits from irrigated citrus	$1,000	-	-	-	-	236.9
Benefits from irrigated pasture	$1,000	-	-	-	-	0.0
Benefits from irrigated veg. crops	$1,000	-	-	-	-	5.0
Benefits from recreation	$1,000	5,345.5	1,385.9	1,241.1	5,214.9	13,187.4
Costs from flooding	$1,000	0.0	0.0	0.0	0.0	0.0
Net benefits	$1,000					13,429.3
Sub-basin II						
Net yield	1,000 a.f.	144.9	89.7	49.8	66.2	350.6
Water in storage at end of period	1,000 a.f.	640.0	526.0	526.0	526.0	
Water released	1,000 a.f.	58.7	118.5	18.1	37.9	233.2
Benefits from irrigated citrus	$1,000	-	-	-	-	232.6
Benefits from irrigated pasture	$1,000	-	-	-	-	21.4
Benefits from irrigated veg. crops	$1,000	-	-	-	-	0.0
Benefits from recreation	$1,000	6,458.0	1,357.5	1,533.2	4,720.4	14,069.0
Costs from flooding	$1,000	0.0	0.0	0.0	0.0	0.0
Net benefits	$1,000					14,323.1

Continued

Table 11.-- Allocation of water and benefits obtained from the linear programming model of the Kissimmee River Basin using minimum release requirements, 1968 surface water irrigated crop acreages, and 10-year mean water yields (Continued)

	Unit	Time period				Annual total
		1	2	3	4	
Sub-basin III						
Net yield	1,000 a.f.	109.6	90.4	33.9	83.8	271.9
Water in storage at end of period	1,000 a.f.	30.0	15.0	30.0	150.0	
Water released	1,000 a.f.	153.2	228.1	60.1	62.7	514.8
Benefits from irrigated citrus	$1,000	-	-	-	-	37.9
Benefits from irrigated pasture	$1,000	-	-	-	-	17.6
Benefits from irrigated veg. crops	$1,000	-	-	-	-	0.0
Benefits from recreation	$1,000	352.8	217.3	646.1	674.4	1,856.8
Costs from flooding	$1,000	0.0	0.0	0.0	0.0	0.0
Net benefits	$1,000					1,912.3
Sub-basin IV						
Net yield	1,000 a.f.	215.0	61.7	40.2	83.8	400.7
Water in storage at end of period	1,000 a.f.	150.0	150.0	150.0	150.0	
Water released	1,000 a.f.	214.1	20.8	29.2	62.7	326.8
Benefits from irrigated citrus	$1,000	-	-	-	-	544.2
Benefits from irrigated pasture	$1,000	-	-	-	-	250.2
Benefits from irrigated veg. crops	$1,000	-	-	-	-	26.0
Benefits from recreation	$1,000	1,424.6	189.0	240.9	674.4	2,528.9
Costs from flooding	$1,000	0.0	0.0	0.0	0.0	0.0
Net benefits	$1,000					3,349.3
Net benefits to total basin	$1,000					33,014.0

Table 12. -- Total benefits from allocation of water by linear programming model of the Kissimmee River Basin for three alternative release requirements and levels of irrigated acreage by sub-basin

Irrigated acres	Release requirement		
	MIN	PRO	MEAN
		$1,000	
Sub-basin I			
68 SW	13,429.3	13,429.3	12,970.8
68 IR	13,888.9	13,888.9	13,265.0
80 IR	13,975.2	13,975.2	12,994.4
Sub-basin II			
68 SW	14,323.1	13,930.1	12,291.9
68 IR	14,809.2	14,219.8	12,864.4
80 IR	15,409.0	14,768.1	13,415.4
Sub-basin III			
68 SW	1,912.3	1,912.3	1,894.7
68 IR	2,200.7	2,200.7	2,055.9
80 IR	2,317.2	2,317.2	2,089.9
Sub-basin IV			
68 SW	3,349.3	3,349.3	3,349.3
68 IR	4,081.0	4,065.0	4,052.6
80 IR	4,611.3	4,503.1	4,474.6
Total Kissimmee River Basin			
68 SW	33,014.0	32,621.0	30,606.7
68 IR	34,979.8	34,446.4	32,237.9
80 IR	36,070.8	35,563.6	32,974.3

for the basin is found between the combination of "68 SW" irrigated acreage and release requirements "MIN" with that for "80 IR" irrigated acreage and release requirements "MEAN." On the other hand, a difference in total benefits of approximately 16 percent is found between combinations "68 SW, MEAN" and "80 IR, MIN." These comparisons demonstrate that for the total basin, there exist possibilities for trade-offs between release requirements and acres of crops to be irrigated while maintaining total benefits at a relatively constant level. It should also be noted that these same combinations of irrigated acres and release requirements often do not produce patterns of differences in net benefits for each sub-basin which are similar to the difference between combinations for the total basin: e.g., sub-basin I.

In Table 13 the annual quantities of water released from sub-basin III and the total releases per year from the Kissimmee River Basin (sub-basin III plus sub-basin IV) are shown for each of the nine combinations of release requirements and irrigated acreages. As can be seen, the differences in the total amounts of water released per year between release requirement MIN and PRO are not as great as the differences between release requirements PRO and MEAN. If release requirement MIN is used as a standard, the additional quantities of water released each year using release requirement PRO and MEAN can be determined. Likewise, from the information in Table 12 the reductions in total benefits from release requirements PRO and MEAN can be determined for each of the three levels of irrigated acreage. By dividing the reduction in total benefits by the additional acre-feet of water released, an indication of the cost per acre-foot of the water released (in terms of benefits foregone) can be obtained. These comparisons, for the total releases from the Kissimmee River Basin, in dollars per acre-foot and using release requirement MIN as the base are presented in Table 14.

Table 13. -- Water released from sub-basin III and total water released from the Kissimmee River Basin using three levels of release requirements and irrigated acreage

Irrigated acres	Release requirement		
	MIN	PRO	MEAN
	Acre-feet		
68 surface water			
Sub-basin III	514,800	589,700	785,000
Sub-basins III & IV	841,600	911,400	1,105,900
68 irrigated acres			
Sub-basin III	510,200	585,600	785,000
Sub-basins III & IV	822,100	890,500	1,095,300
80 irrigated acres			
Sub-basin III	485,800	579,700	785,000
Sub-basins III & IV	754,700	881,800	1,095,100

Table 14. -- Cost of additional water releases above the minimum[a]

Irrigation level	Release requirement: Proposed	Release requirement: Mean
	------- Dollars/acre-foot ------	
1968 surface water irrigated	5.63	9.11
1968 total irrigated acreage	7.80	10.04
1980 total irrigated acreage	3.99	9.10

[a]Minimum release requirements were based on ten-year averages.

These values indicate that for each acre-foot of water that is released using release requirement PRO over that which would be released using release requirement MIN costs between $3.99 and $7.80 per acre-foot in benefits foregone. Similarly, each acre-foot of water that is released using release requirement MEAN over that which would be released using release requirement MIN costs between $9.10 and $10.04 per acre-foot in benefits foregone.

It should be noted, however, that these cost indicators are based on 10-year water yields for each sub-basin in each time period and many other assumptions and constraints built into the model. They do indicate, however, that the costs, in terms of benefits foregone, of water released from the Kissimmee River Basin in addition to that which is released using the minimum release requirement tends to be quite responsive to changes in the amount released. This relationship exists both for the annual total releases and the releases for each time period. The cost of water releases is also quite sensitive to the amount of water used for the irrigation of crops in the Kissimmee River Basin.

Further insights into the differences in the optimal allocations of water obtained from the nine combinations of the levels of these two release requirements and irrigation acreages can be seen by examining the sources of benefits for each combination. In Table 15 the benefits for each combination of the three levels of irrigated acreage and release requirement are displayed as those from irrigated crops and those from recreation. As would be expected, the percent of the total benefits made up of benefits from irrigated crops increases as the level of irrigated acres increases. Note, however, that there are slight increases in the percent of total benefits made up of benefits from irrigated crops as the level of release requirements increases. These later changes are due to the decreases in storage below the mean levels which in turn cause decreases in the amount of benefits from the recreational use of the water.

Table 15. -- Benefits from crop irrigation and recreation obtained from the optimal allocation of water in the Kissimmee River Basin by level of release requirement and irrigated acreage

Irrigated acres	Release requirement					
	MIN		PRO		MEAN	
	$1,000	Percent of total	$1,000	Percent of total	$1,000	Percent of total
68 surface water						
Crops	1,371.8	4.2	1,371.8	4.2	1,332.8	4.4
Recreation	31,642.1		31,249.2		29,273.9	
68 irrigated acres						
Crops	3,337.7	9.5	3 337.7	9.7	3,143.2	9.8
Recreation	31,642.1		31,108.7		29,094.7	
80 irrigated acres						
Crops	4,428.7	12.5	4,428.7	12.5	4,044.9	12.3
Recreation	31,642.1		31,134.9		28,929.4	

The optimal allocations of water from the nine combinations of levels of release requirements and irrigated acreage were obtained using the 10-year water yields (Y_{ik}) for each sub-basin and time period as shown in Table 2. In order to understand better the effects of variations in yield on the optimal allocations, the model was run 10 times in succession using the actual yields for each time period and sub-basin for the 10-year period 1961-1970. The release requirements were set at the minimum level (MIN) and the irrigated acres from surface water sources for 1968 (68 SW) were used for all 10 runs. For the first run, the water in storage in each sub-basin at the beginning of time period 1 was assumed to be the mean storage level, but for each of the successive runs, the water in storage at the end of time period 4 from the previous run was used as the initial amount of water in storage.

In Figure 5 the amount of water in storage at the end of each time period for the 10-year period is shown for each sub-basin. It should be noted that 1961, 1967 and 1970 were the only years in which the storage level in any of the sub-basins was drawn below the mean level. Also, considerable differences in storage levels for each time period can be seen between the 10 years when actual yields were used as compared to the storage levels using the 10-year average yields.

The releases of water from each sub-basin for the same 10 optimal allocations are similarly displayed in Figure 6. It should be noted that particularly for sub-basins III and IV the patterns of releases per time period for most of the 10 years are quite similar to the pattern of releases from the allocation using the 10-year average yields.

The results from the 10 optimal allocations should not be interpreted as being representative of an optimal allocation of water over a 10-year period. Due to the design of the model, only the data from one year at a time was considered in the optimization process. Thus, the optimal allocation would no doubt be different if data from all 10 years had been considered at once.

Interpretation of Results and Implications

In all of the optimal allocations that were obtained in this study, not one included as part of its optimal allocation the storage of water above the regulated levels; thus, no flood damages were incurred. This is probably due to a combination of several factors, all of which could be summarized by saying that the costs of flooding in any one time period in order to provide more water for use in another time period exceeded the benefits that could be gained from having the water available.

The results obtained from the application of the linear programming allocation model to the Kissimmee River Basin provide the following conclusions concerning possible operating policy alternatives:

1. If mandatory release requirements are maintained at their minimum levels, the model indicates that for most years, irrigated acreage

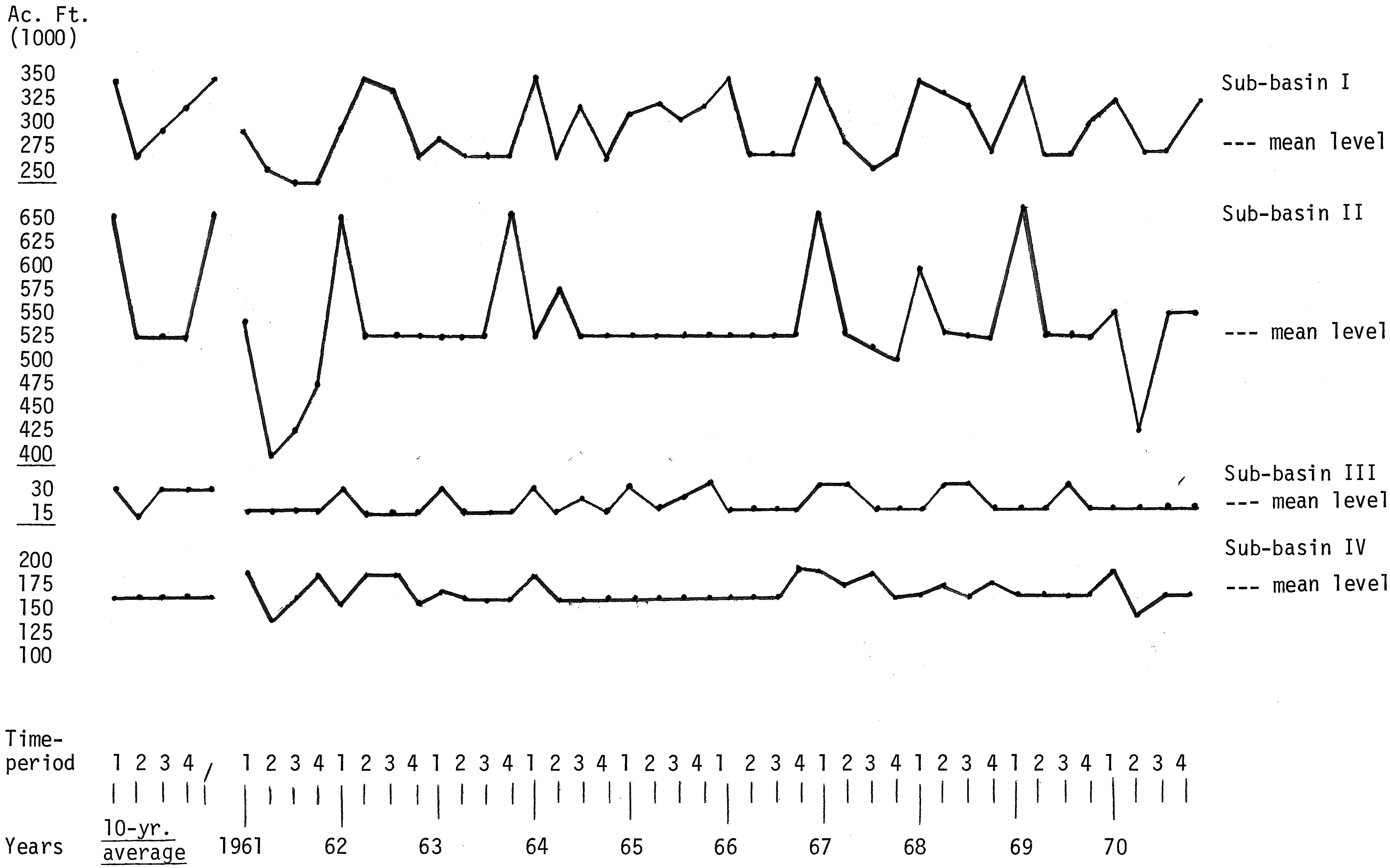

Figure 5. -- Quantities of water in storage at the end of each time period for each of 10 optimal allocations of water using 10 successive years of water yields for the Kissimmee River Basin.

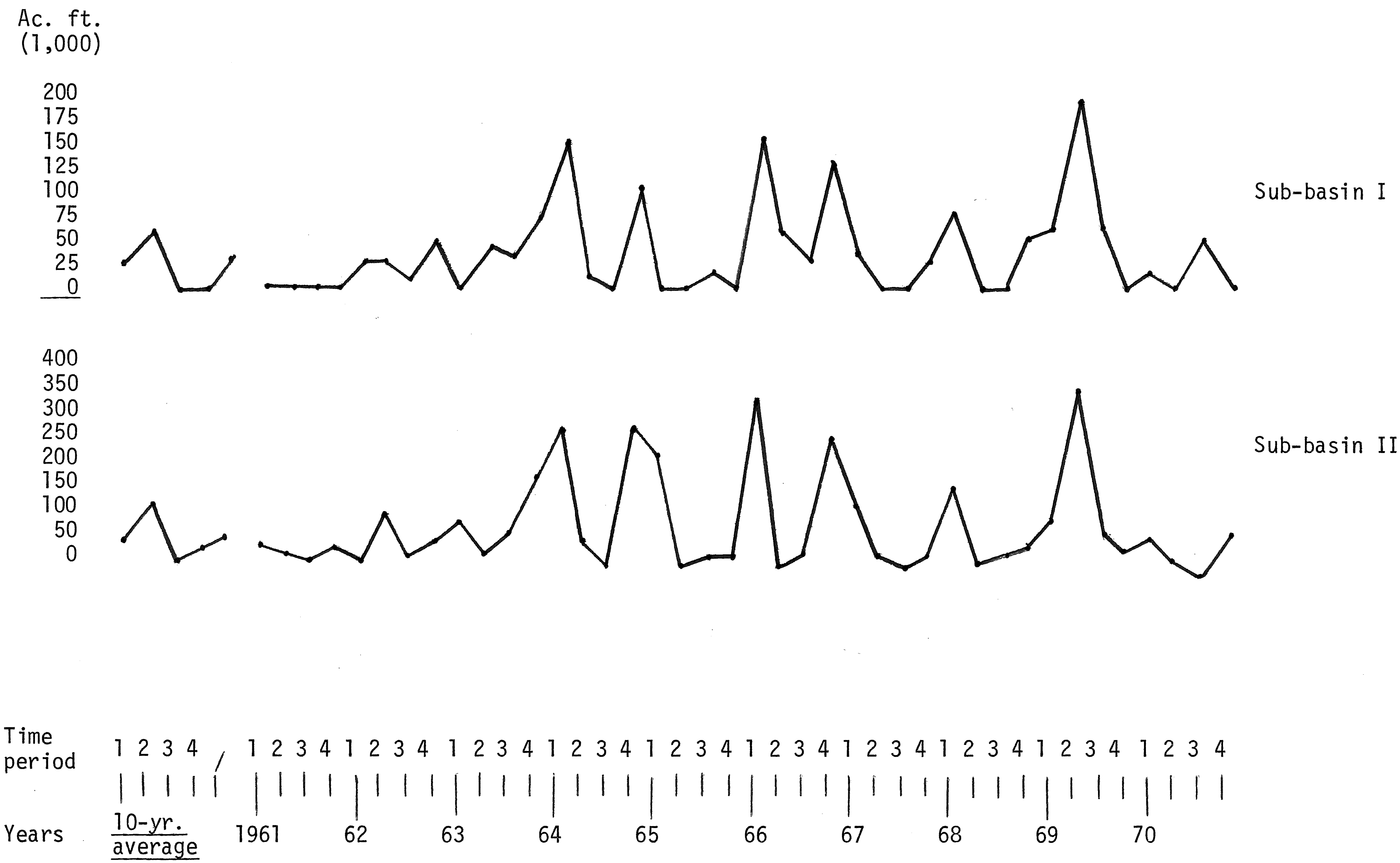

Figure 6. -- Quantities of water released from each sub-basin in each time period for each of 10 optimal allocations of water using 10 successive years of water yields for the Kissimmee River Basin.

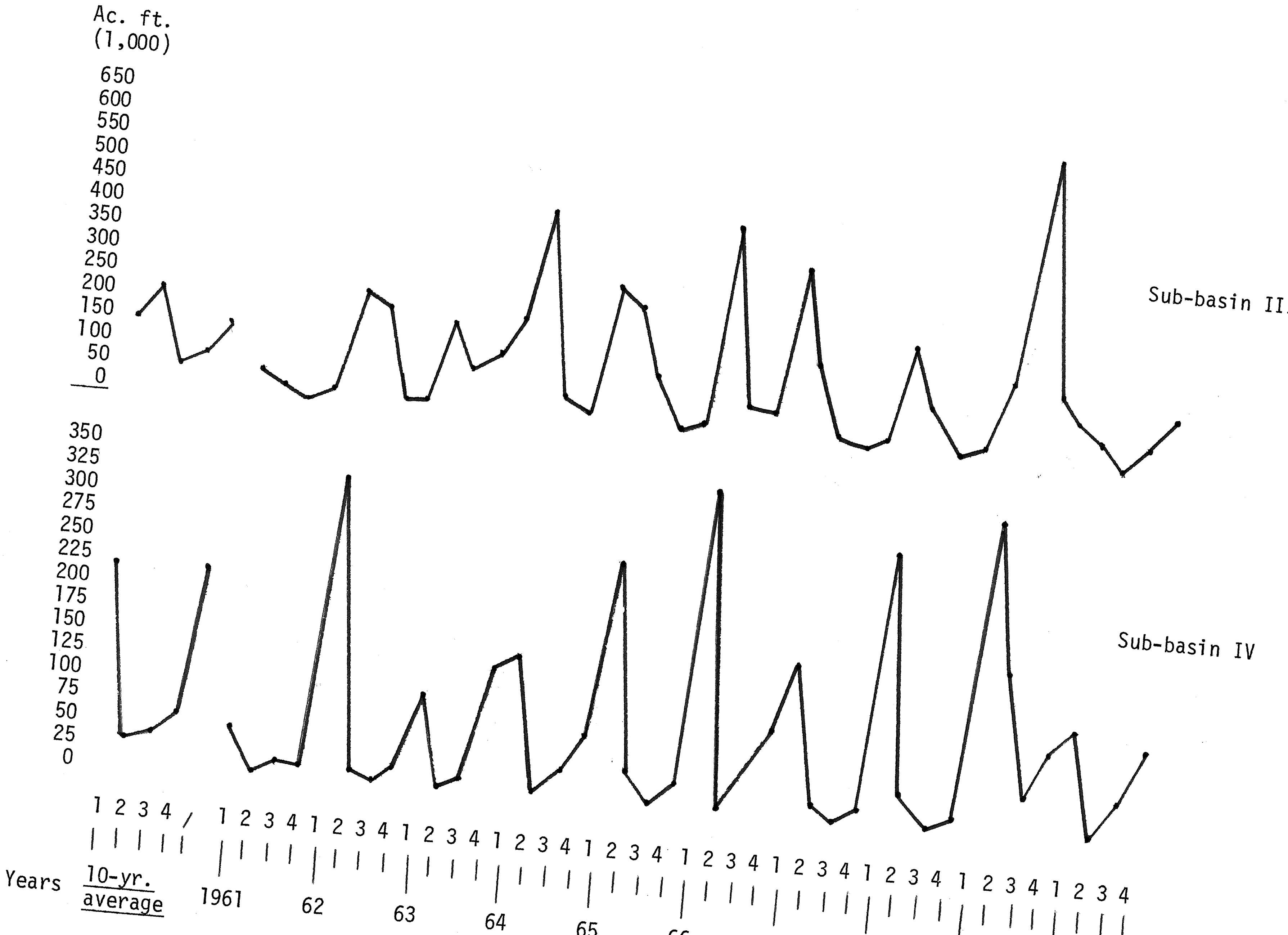

Figure 6. -- Continued.

could be expanded considerably without decreasing recreational benefits derived from the water in the Kissimmee River Basin.

2. The benefits to society from the use of water in the Kissimmee River Basin accrue mainly from its use as a recreational resource.

3. The cost, in terms of benefits foregone, for additional water released above minimum release requirements is quite sensitive to (a) the quantities per year of additional releases, (b) the time period in which water is released, and (c) the acres of each type of irrigated crops in the sub-basin.

These conclusions, for the most part, could possibly have been predicted by someone familiar with the water management system in the Kissimmee River Basin operated by the FCD and with the uses being made of the water in the Kissimmee River Basin. The provision of new or unexpected information by the use of this model was, however, not an objective of the study. The model has been demonstrated to be adaptable to the provision of optimal (with respect to economic benefits) allocation of water in the Kissimmee River Basin. More importantly, as stated in the previous paragraph, it has been demonstrated that the model can provide useful indications of the relative sensitivities of the various hydrologic and economic aspects of the system to proposed policy changes. This particular demonstration could be made to yield yet more information by making additional allocations using more alternative release requirements, levels of different types of irrigated crop acreages in each sub-basin, and different levels of water yield for each sub-basin and each time period.

The type of model, which in this study was adapted to the four sub-basins of the Kissimmee River Basin, could be expanded to include more sub-basins without taxing the capacity of the type of computer (IBM 370-165) used in this study. The complexity of the model would be increased only slightly by the addition of more sub-basins as long as the types of uses of water and the direction of movement of water between sub-basins was similar to those of the Kissimmee River Basin. Obtaining the necessary data would, however, require a significant amount of time and effort as was explained in Chapter II. If additional uses of water were incurred, the problem of obtaining reliable estimates of the value of water in particular uses in different locations with respect to both time and space could be costly. For example, if navigation or prevention of salt water intrusion into fresh water aquifers were among the beneficial uses of the water, extensive studies would be required in order to determine the quantities of water used for these purposes and the value of water in these uses.

In terms of computer cost, the linear programming model used in this study to allocate water in the Kissimmee River Basin proved to be very efficient. When solved using the IBM 370-165 computer at the University of Florida, the nineteen optimal solutions discussed in this report were obtained at an average cost of $4.13 each. The size of the activities matrix for the model in the simplex algorithm was only 120 x 120 with a density of only 1.92. The cost would, however, be expected to increase as the size and/or density of the matrix increased; one or both of which would be necessary if the model were adapted to a larger geographic area.

CHAPTER IV

SIMULATION MODEL OF THE KISSIMMEE RIVER WATER MANAGEMENT SYSTEM

The Simulation Model

Conceptual Aspects

The FCD, in developing an approach to study operational policy alternatives, must find one which will include the essence of the complexities involved in surface water management. The influence of the natural hydrology, the existing water management system, the water use activities and the formal and informal institutions must be reflected. Inclusion of these is difficult because of the diversity in each but is essential if reasonable policy alternatives are to be found. This study suggested simulation as a means of considering various interactions. It was believed that many characteristics could be mathematically modeled, and quantitative parameters defined, to assist in policy evaluation. This, tied with the governing board's reflection of subtle nonquantifiable factors, would provide a means of evaluating policy alternatives. Figure 7 illustrates an information flow model, which is an expansion of the policy development model shown in Figure 2 and provides a framework for a simulation approach.

This study, more specifically, develops this conceptual model into an integral operational model. The geographic area to which this model was adapted is shown in Figure 8.[6] Rainfall data for the basin are either synthesized or obtained from historic records, then distributed over watersheds and runoff determined. The generated runoff in turn flows into the lakes and is stored or released through management of gate-type structures. Management criteria are specified by the long-term policies of the water management authority. Lake surface elevations are generated, providing information on the availability of water for various activities and the level of these is determined. The quantified economic benefits along with the system states and the institutional considerations provide the input into the policy evaluation. This evaluation is a technical weighing of various parameters by the staff and is not itself modeled. It does, however, provide a feedback into long-term policy and suggests modifications.

The approach allows the water management authority to take initial hydrologic information on very short intervals and assess on the basis of long-term results the acceptability of the operational policy. This is accomplished by inputing rainfall at 12-minute intervals, thereby

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[6]The geographic area to which the simulation model was applied is comprised of 14 sub-areas. This geographic area is equivalent to sub-basins I and II in Figure 1.

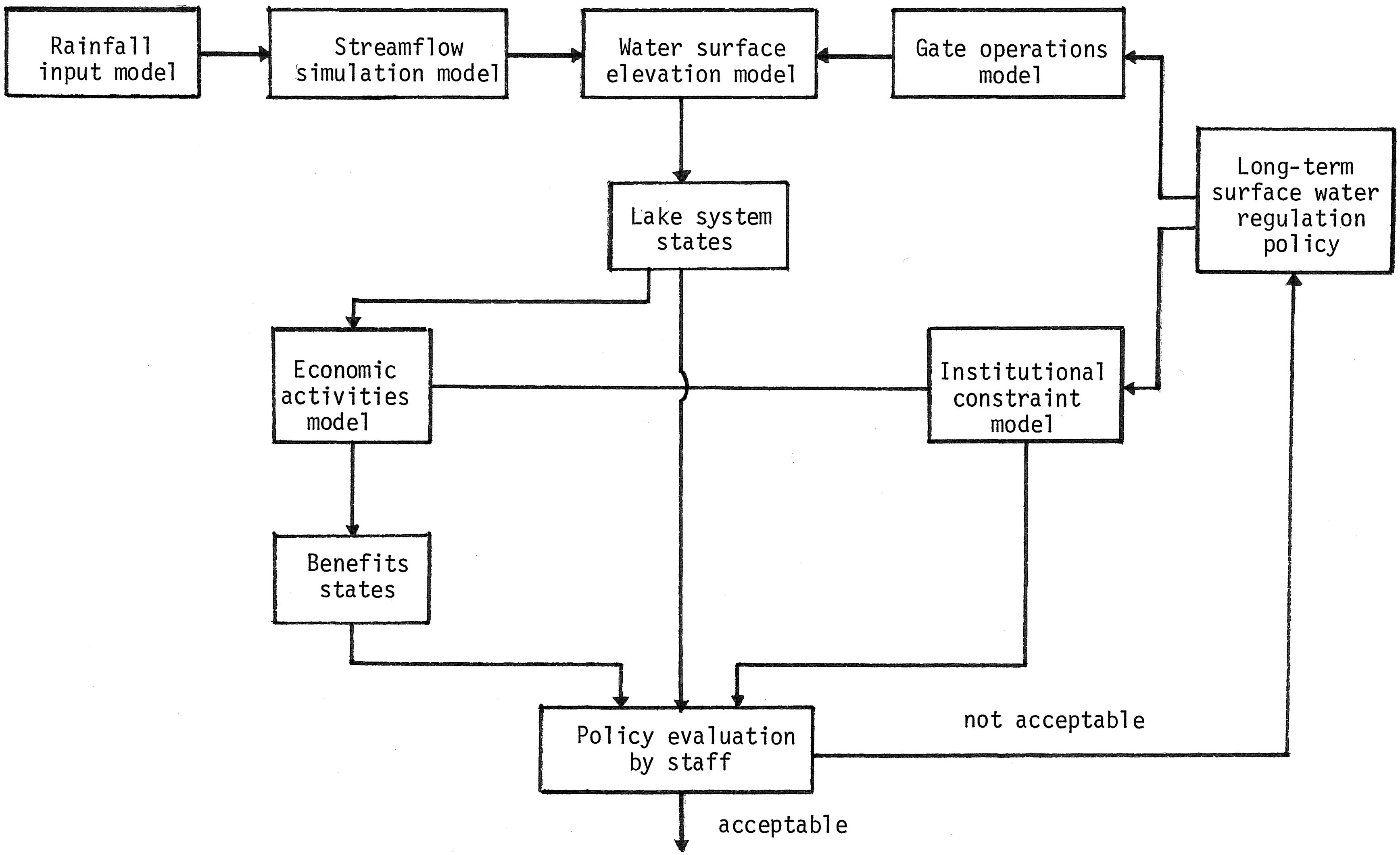
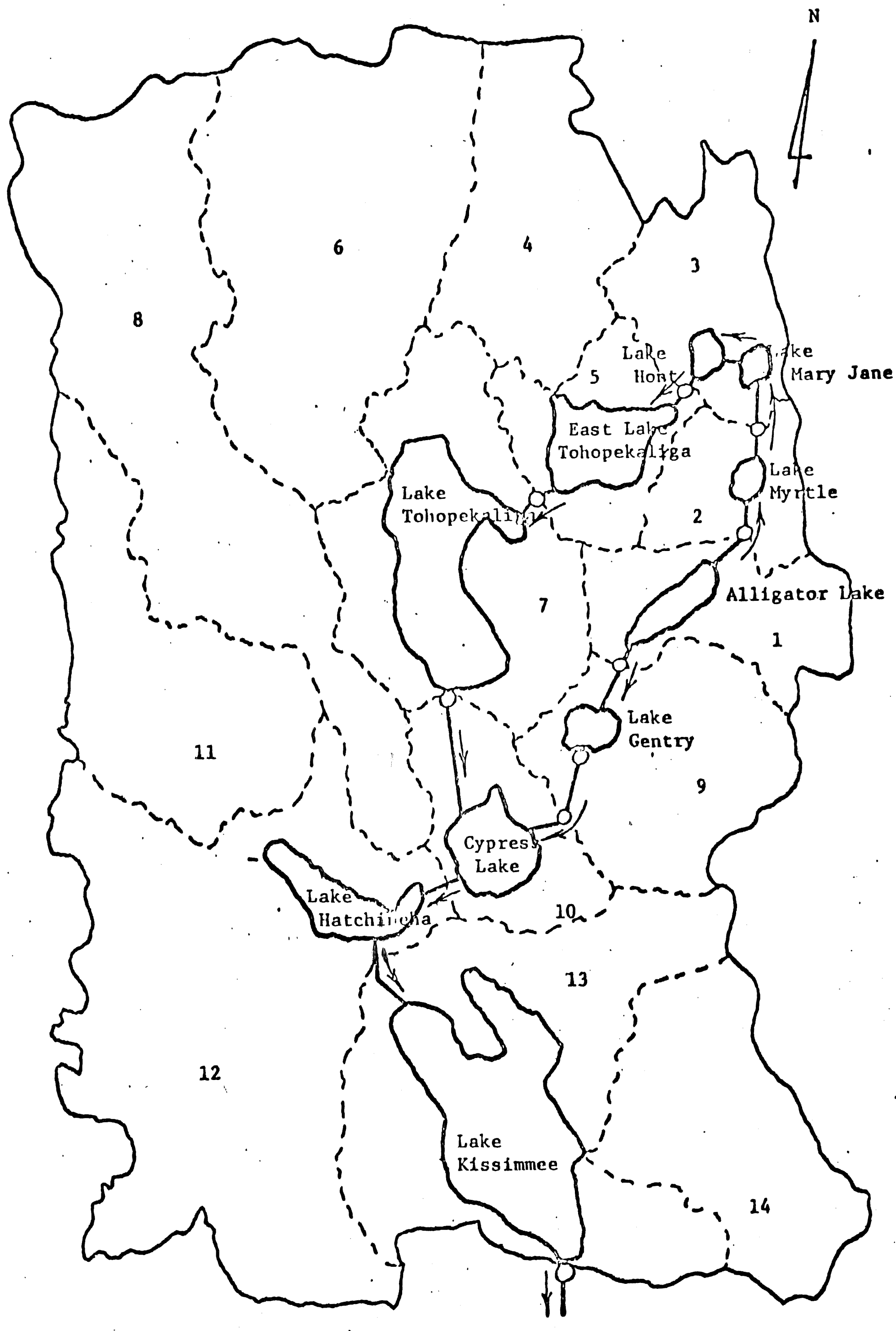


Figure 7. -- Water management information flow diagram.



Legend

Upper Kissimmee River Boundary
Watershed boundary
Lake outline
Canal and control structure
Water flow

Figure 8. -- Upper Kissimmee River Basin as used in the Simulation Model.

reflecting the natural variability. Runoff is determined at three-hour intervals and lake surface elevations at six-hour intervals. Economic activity levels are determined at varying intervals depending on the activity, and net benefits are totaled annually. Therefore, by operating the simulation model, given a specific operational procedure for an extended period of time, hydrologic and economic information is produced which is used in the policy evaluation.

The specific components or models making up the simulation are illustrated in Figure 7. Each of these, the rainfall model, the streamflow model, the water surface elevation model, the gate operation model and the economic activities model will be described in the following sections. The institutional constraint model is incorporated in the other models.

The types of data and functions used in the working model are described in Appendices B and C. In this study some of the data were quite accurate, while others were only approximations. An early working model was desired, so the usefulness of an integrated approach could be demonstrated.[7]

Rainfall Models

The rainfall input can be provided from either of two sources. The first, which is used in the present study, employs historic data from rain-gauging stations in the basin to determine the rainfall over each of the sub-basins. This is accomplished in two steps. Step one distributes daily rainfall values at a geographic point into 24 hourly values and then divides each hourly rainfall value into five equal parts, thereby obtaining rainfall values at two-tenths-of-an-hour intervals. The development of the relationships is based primarily upon the work of Pattison [21], which considers a well acknowledged characteristic of persistency in daily rainfall values. Step two estimates the two-tenths-of-an-hour-interval rainfall values at grid points between the widely separated rain-gauging stations. This approach is based essentially upon a square grid system where the rainfall at any grid point or node is computed by applying an appropriate weighting factor. These factors for each node are based on the relative distances from the rain gauges which are within a specified distance of the node of interest. From these two-tenths-of-an-hour values a single rainfall value for an entire sub-area is computed by averaging the weighted values over the sub-basin. Sinha and Khanal [30] have described the two steps in detail and presented values for the Kissimmee River Basin.

The second source utilizes a stochastic model to synthesize daily rainfall input data. Rainfall at a point is a continuous hydrologic process which can be transformed into a discrete process with a given time interval. Rainfall amounts observed during different, short time intervals (hours, days) are not independent events, and conditional probabilities for these

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[7] The computer program written in Fortran IV and the complete set of data used in this study are available from Kiker [16] or Mr. William V. Storch, Director, Department of Engineering, Central and Southern Florida Flood Control District.

events can be estimated. The daily rainfall process is similar to a Markov process. Due to these similarities, a first-order Markov chain has been used to simulate the daily rainfall process in the Kissimmee River Basin. Khanal and Hamrick [15] have reported the details of this approach and the results for the basin. Data from this source replaces the historic daily rainfall values obtained from the twelve gauging stations.

Streamflow Model

The sub-model for simulating streamflow from rainfall events involves using mathematical relationships for determining four broad activities of the hydrologic cycle. These are (a) infiltration, (b) water losses due to evaporation, transpiration and deep ground percolation, (c) recovery of water into the stream channel from soil reservoir and overland flow, and (d) routing the water from channel to watershed outlet. The mathematical functions used in the Kissimmee River Basin model have been developed by several researchers and are presented by Sinha and Lindahl [29].

The volume of water moving into the soil profile is found by empirical infiltration equations, which are primarily functions of soil moisture. These are evaluated at the beginning and end of a time interval. Water loss, water that reaches the ground surface but never appears at the watershed outlet, is the total of these activities. An empirical expression that reflects the fluctuations in depth to the water table is used to specify the evaporation loss. The rate of loss is assumed to never exceed the pan evaporation rate. Transpiration losses are assumed to be primarily a function of pan evaporation and an overall growth index for the existing vegetation. Deep percolation is a function of the rate that gravitational water moves through the soil. Recovery of water into stream channels is from two sources, sub-surface flow and overland flow. The mathematical relationships used to estimate the net surface discharge are based on the continuity equation and a storage/outflow expression developed empirically. These are solved in an iterative procedure. With the sub-surface discharge available, total storage is obtained from a balance equation. Overland flow is the difference between the precipitation and infiltration when surface depression storage is full. A time distribution of water at the watershed outlet was generated with a routing equation. It used an empirical time constant associated with the source of the water -- surface or sub-surface flow -- along with the average inflow and discharge at the beginning of the time interval. The streamflow model used rainfall input on a 12-minute interval and provided watershed discharge on a three-hour interval. This in turn was used as input into the water surface elevation management model.

Surface Water Management Model

The water surface elevation management model is the first point at which management decisions can be made and water output affected. Figure 8 shows the relationship of the actual watersheds, lakes, canals and structures in the upper Kissimmee Basin. The fourteen sub-areas empty into the ten major lakes as presented in Table 16. Water in Alligator Lake can move

Table 16. -- Relationships of sub-areas, lakes, and control structures

Sub-area	Area	Drains into lake	Controlled by structure
	Sq. mi.		
1	60.50	Alligator	S-58 and S-60
2	37.91	Myrtle	S-57
3	57.68	Mary Jane and Hart	S-62
4	89.67	East Tohopekaliga	S-59
5	52.93	East Tohopekaliga	S-59
6	185.66	Tohopekaliga	S-61
7	132.77	Tohopekaliga	S-61
8	198.75	Tohopekaliga	S-61
9	89.22	Gentry	S-63 and S-63A
10	119.63	Cypress	S-65
11	109.85	Hatchineha	S-65
12	197.78	Hatchineha	S-65
13	197.78	Kissimmee	S-65
14	94.70	Kissimmee	S-65

north through Lake Myrtle and around the western chain, or south through Lake Gentry and into Cypress Lake, where the western and eastern flows come together. The water movement is then southward through Lake Kissimmee and down the Kissimmee River to Lake Okeechobee. This series of lakes, canals and structures provides the management capability. By controlling the lake levels with nine control gates, water can be retained or released.

The management components of the upper Kissimmee Basin can be generalized as shown schematically in Figure 9. Table 17 presents the nomenclature that is used for each component. Water can be retained in lakes 1 - 7 by management of structures 1 - 9. The discharged water moves down one of the canals 1 - 13 and into the next lake. All runoff from the sub-area entering the management system and all water withdrawals are assumed to occur only at the lakes. Lake Tohopekaliga is shown schematically in Figure 10 to illustrate typical water flows into and out of a lake. No return flows from consumptive uses are assumed.

The mathematical representation of water flow and management in this generalized system can best be handled by considering several fundamental activities. The major purpose of the model is to determine lake surface elevations at regular intervals. The lake surface elevation at the end of a given time interval is a function of the water stored in the lake at

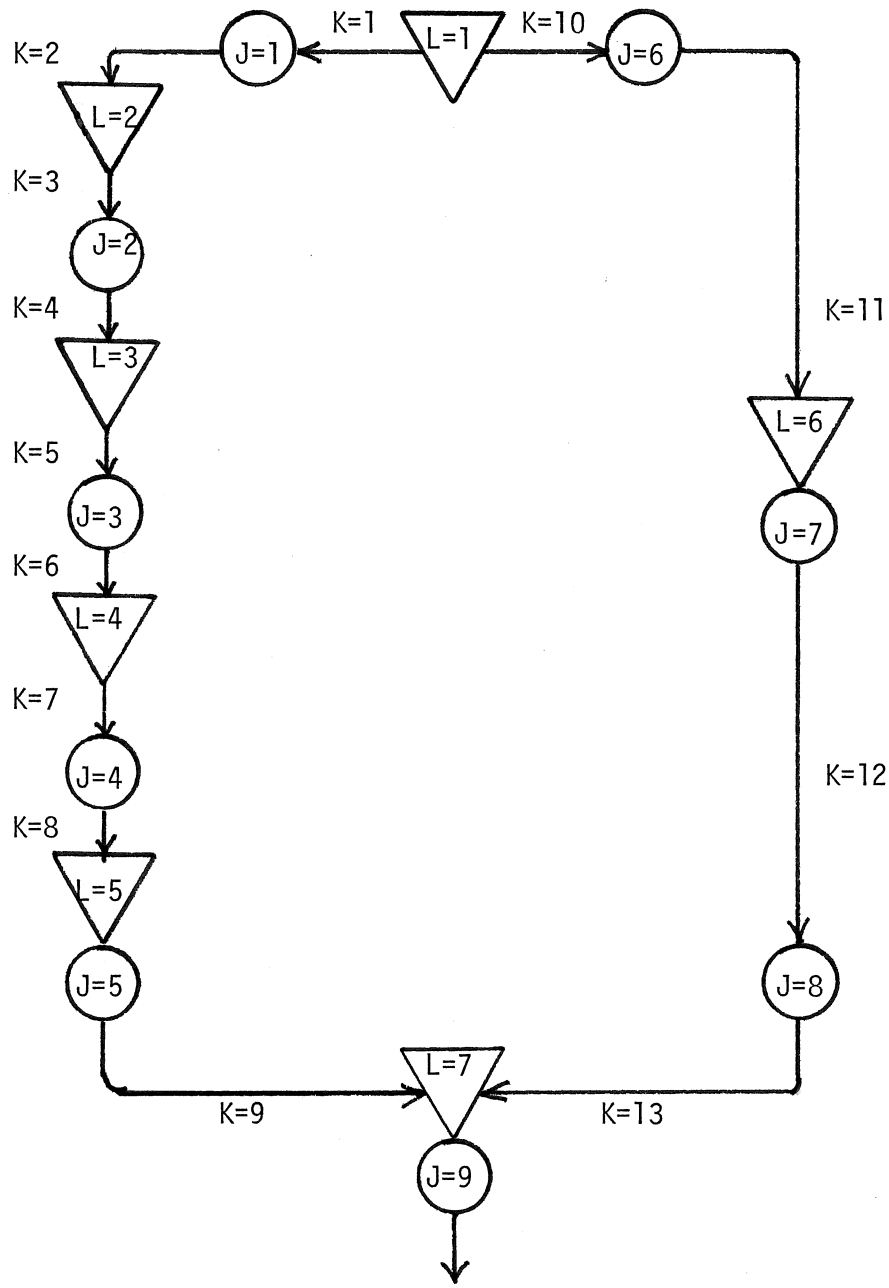


Figure 9. -- Schematic diagram of the Upper Kissimmee River Basin water management system.

Table 17. -- Symbols used to represent lakes, structures, and canals

Symbol	Represents
L	Lake
1	Alligator
2	Myrtle
3	Mary Jane and Hart
4	East Tohopekaliga
5	Tohopekaliga
6	Gentry
7	Cypress, Hatchineha, and Kissimmee
J	Structure
1	S-58
2	S-57
3	S-62
4	S-59
5	S-61
6	S-60
7	S-63
8	S-63A
9	S-65
K	Canal
1	C-32 above S-58
2	C-32 below S-58
3	C-30 above S-57
4	C-30 below S-57
5	C-29 above S-62
6	C-29 below S-62
7	C-31 above S-59
8	C-31 below S-59
9	C-35 below S-61
10	C-33 above S-60
11	C-33 below S-60
12	C-34 above S-63A
13	C-34 below S-63A

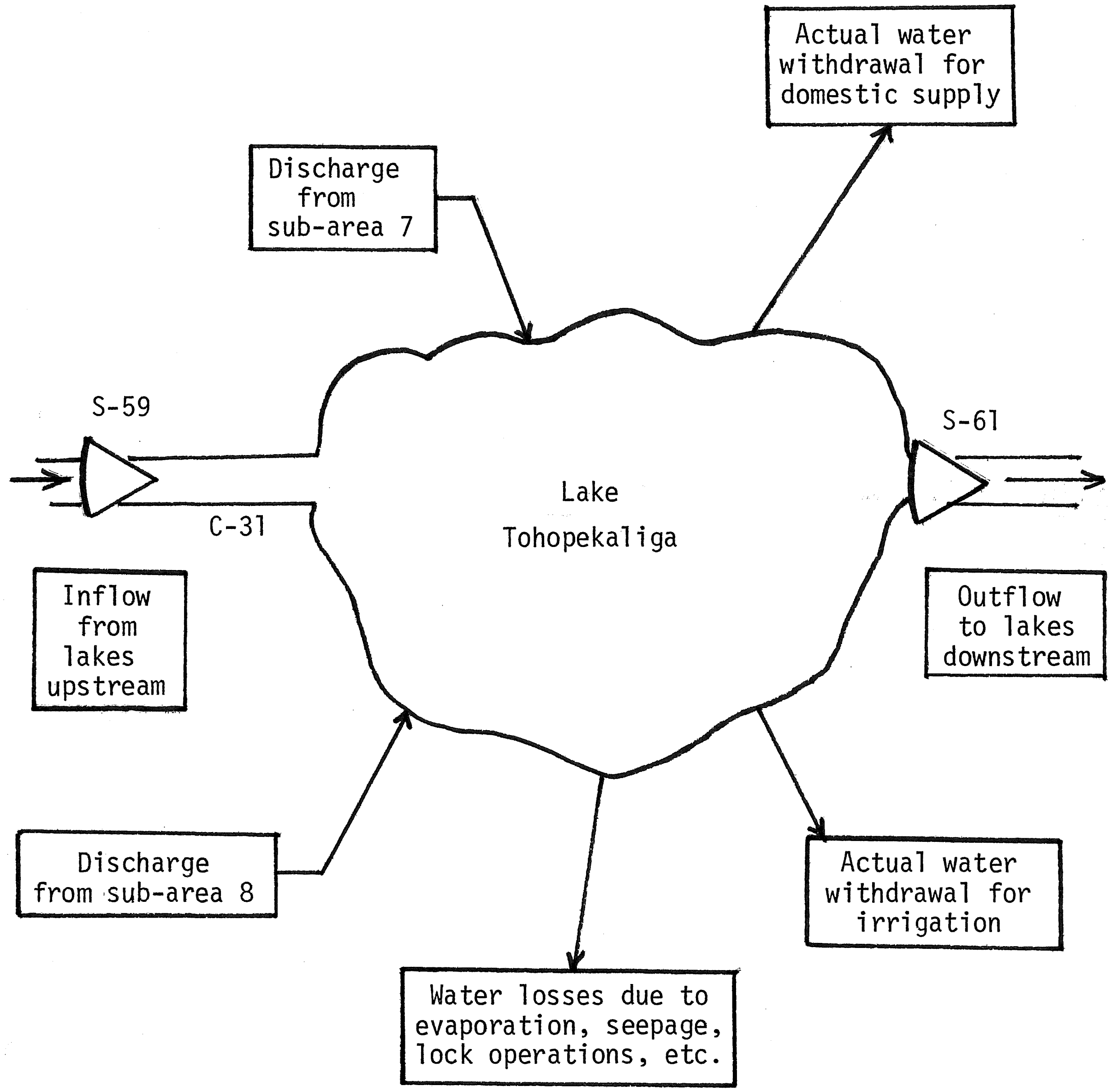


Figure 10.-- Water inflows and outflows for Lake Tohopekaliga.

the end of the previous time interval and the net flow rate into or out of the lake during the time interval of interest. The net flow rate for a lake is the sum of the flows illustrated in Figure 10, or the total runoff flow rate into the lake, the flow rate into the lake from the upstream structure, the flow rate out of the lake through the downstream structure and the flow rate of consumptive withdrawals from the lake. The runoff flow rate is determined by the streamflow model. The flow rate through a structure during a given time interval is a function of the gate opening (operation) and the headwater and tailwater elevations at the end of the previous time interval. The lake surface elevation at the end of the previous time interval is compared with an institutionally established desired lake surface elevation and the manner in which these compare specifies the gate operation for the next time interval. The consumptive withdrawal flow rate is an institutionally established function of the lake surface elevation and consumptive needs, in this case irrigation and domestic consumption.

The sequence of calculations is shown in Figure 11. Initially, sub-area runoff values are provided as input data from the streamflow simulation model and a set of system states -- headwater, tailwater and lake surface elevations -- are available from the previous time interval. The consumptive water withdrawals are determined from the irrigation and domestic consumption needs found in the water use model and the institutionally established withdrawal functions. In this study, linear segmented functions specify the percentage of water needs that can be met using surface water. These are illustrated in Figure 12 for irrigation and domestic consumption.

The desired lake level is specified on any given day by an institutionally established linear segmented function, generally called the lake regulation schedule or rule curve. A typical one, in this case for Lake Tohopekaliga, is shown in Figure 13. The gate operation, the number of feet a given gate is opened, is a function of the difference between the actual lake level at the end of the previous time interval and the desired lake level for the present interval. The function used is illustrated in Figure 14. The percent of the maximum gate operation is determined and then multiplied by the maximum gate opening.

The flow rate through a given structure during the time interval can be obtained from the gate operation and the effective head across the structure. It is assumed that the difference between the headwater elevation and the tailwater elevation at the end of the previous time interval represents the effective head during the present interval. The net flow rates for each of the lakes during the time interval can be found from these values. And this, along with the stored water, is used to determine the lake surface elevation at the end of the present time interval. The set of lake surface elevations is the basic input into the water use models.

Headwater and tailwater elevations occurring at the end of the present time interval must be calculated as they are needed for determining the effective head in the next time interval. A technique developed by Prasad [23] and suggested by Sinha [28] was used to compute the water surface

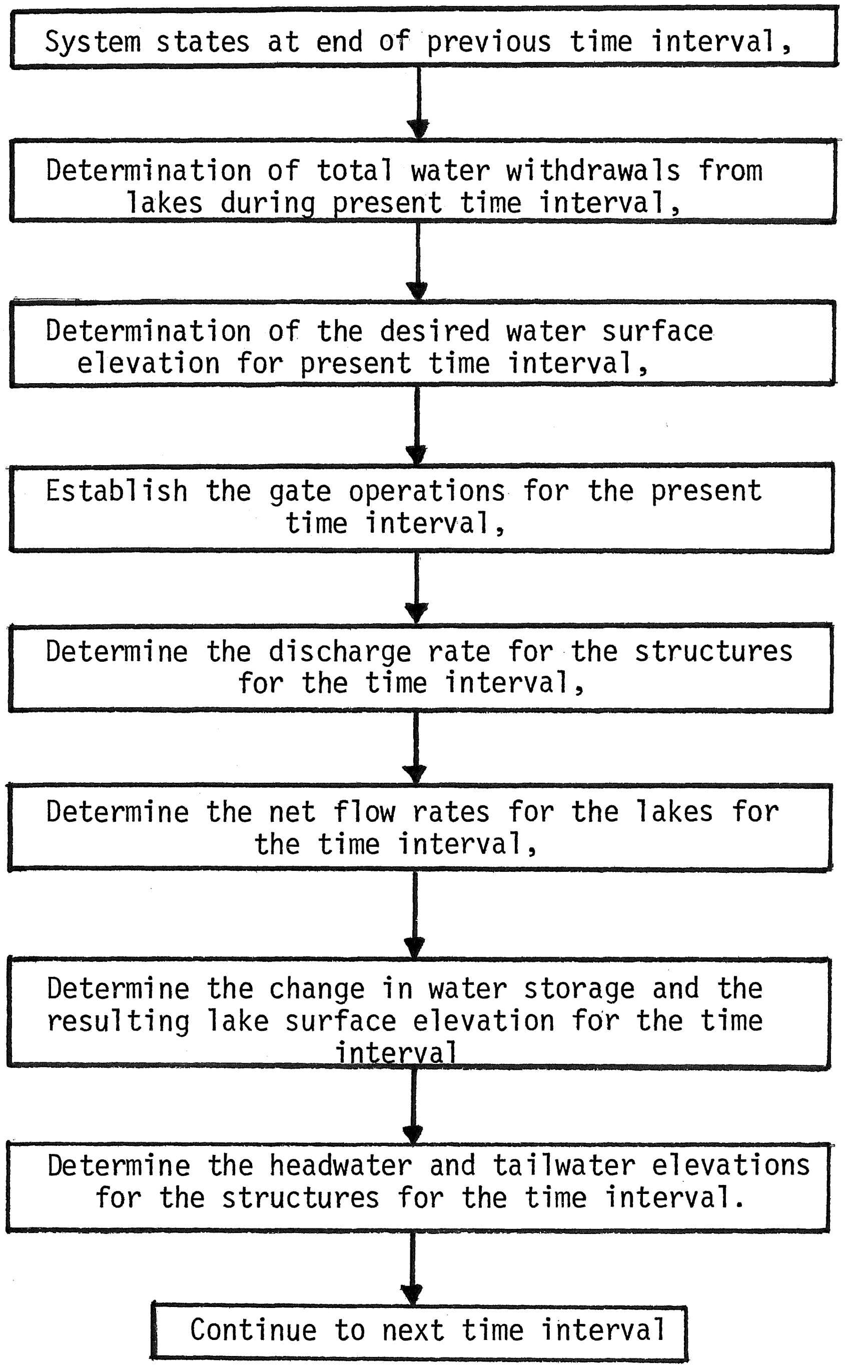
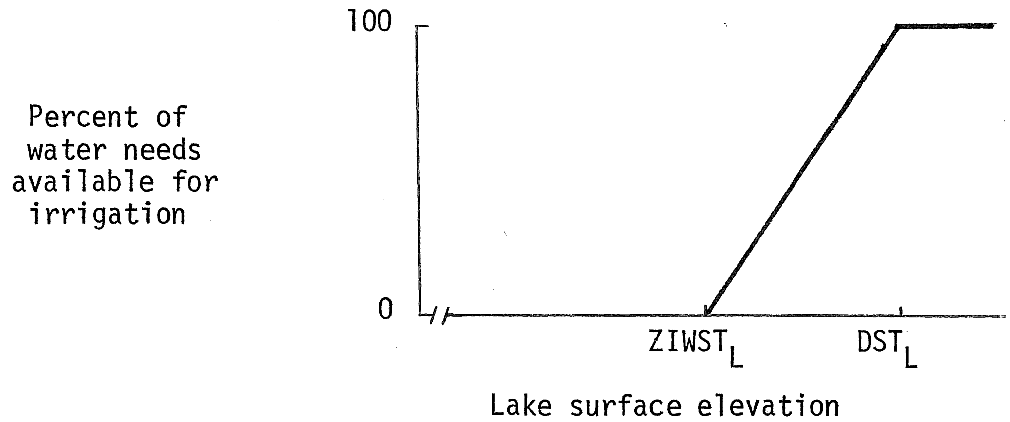
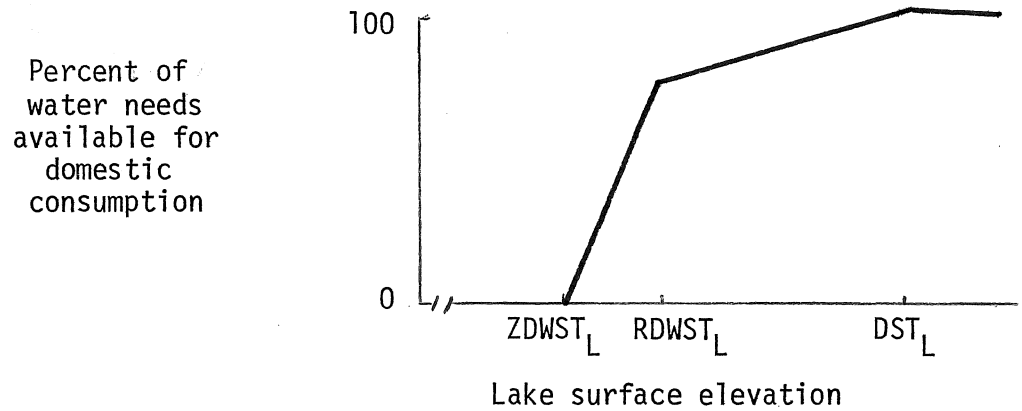


Figure 11.-- Sequence of calculations in the water surface elevation management model.



(a) Irrigation withdrawal function.



(b) Domestic consumption function.

Figure 12. -- Consumptive withdrawal function.

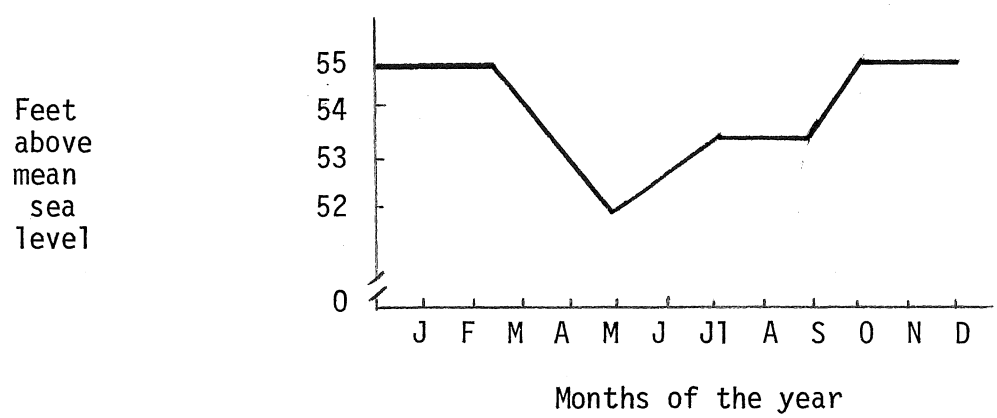


Figure 13. -- A typical regulation schedule.

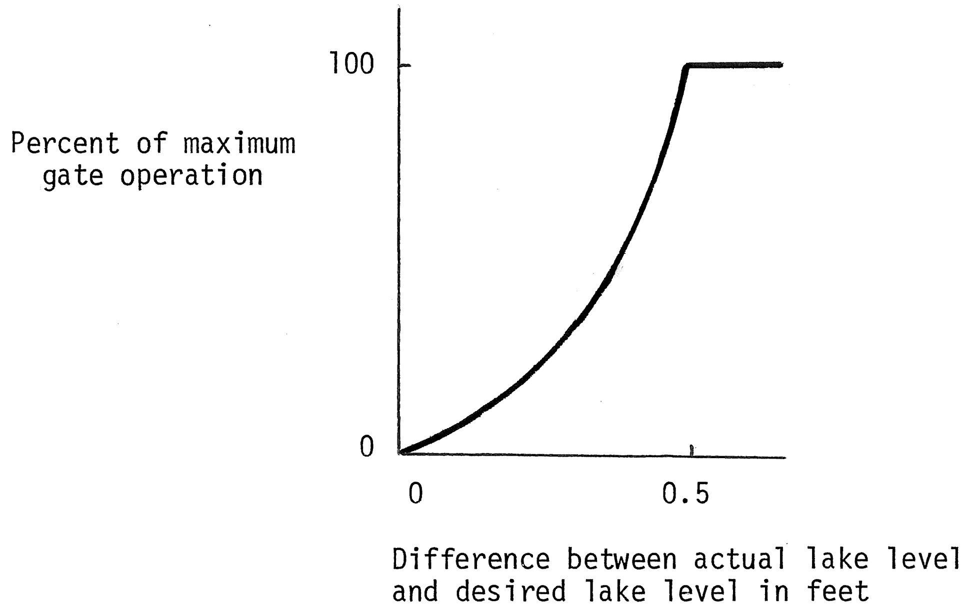


Figure 14. -- The gate operation function.

profile along the canals. The gradually varied flow equation provides the relationship between water depth and distance along the canal. Since the differential equation is a nonlinear function of water depth and not readily solved analytically, a digital algorithm developed by Prasad was used. The technique readily handles non-uniform channels and allows water surface profiles to be computed moving upstream or downstream.

Headwater elevations are thus found by starting at the lake outlet where the water surface elevation is the same as the lake surface elevation. The water surface profile is then determined by moving downstream to the structure. The intersection of the water surface profile and the structure gives the headwater elevation. The tailwater elevation is found in a like manner except the profile is calculated moving upstream from the lower lake. The headwater and tailwater elevations at the end of the present time interval are now available for use in determining the flow rate through the structure during the next time interval. (Appendix B presents a complete analysis of this model.)

The time interval used in this portion of the simulation is six hours. The sub-area runoff values are aggregated to six hours. The results from the water surface elevation management model are, therefore, lake surface elevations for all lakes every six hours.

The institutional constraint model is not a distinct entity as are the other models but is a series of constraint functions incorporated in the others. The institutionally established regulation schedules for the lakes (see Figure 13) are built into the water surface elevation model. Each specifies the lake surface elevation for every day of the year. The schedule in this way reflects the attitudes of the people of south Florida, through the FCD, as to how water in the lakes should be managed. Attitudes about the discharge or export of water from one basin to another are handled likewise. Minimum flows through outlet structures are handled in the water surface model thus satisfying the institutionally established water export requirements. The water withdrawal functions (see Figure 12) are built into the water use activities models in a similar manner. They indicate how the water should be allocated when the water availability is at certain levels. Attitudes about distribution of a scarce water supply are again reflected through the FCD.

The present study assumes four economic activities related to surface water. The net benefits accruing to these for spatial and temporal control of water are the primary indices of the management system's performance. Crop irrigation and domestic water supply are consumptive uses while recreation simply uses stored water. Property flooding is a result of excess surface water. All of these are functions of the amount of water in storage. The potential for flood damages increases with greater quantities of stored water and decreases with lesser quantities. Recreational use is influenced primarily at the extreme high and low water levels. The determination of the benefits accruing to each of the activities from a given management procedure are considered in the next four sections.

Crop Irrigation Model[8]

Surface water available for irrigation is a function of the amount of water available, and, as mentioned above, the function is institutionally established. With the lake levels known, the percentage of the irrigation water needs that can be furnished can be determined. During the growing season the water needs for a crop are based on the irrigation water required to bring the soil to field capacity. Irrigation water is not applied until the soil moisture is depleted to one-third of the soil moisture available between the permanent wilting point and field capacity. When rainfall occurs the total moisture available to the crops during a given time interval is the sum of the moisture at the end of the previous time period and the water entering the soil profile from irrigation and rainfall.

Plant water use is based on the evapotranspiration equation proposed by Blaney and Criddle [3]. A modified form proposed by Phelan [22] was

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[8]This model is presented in more detail in Appendix C.

used to estimate monthly potential evapotranspiration rates. The potential evapotranspiration for a given time interval is obtained by dividing the monthly potential evapotranspiration by the number of time intervals in the month. The actual evapotranspiration occurring is assumed to be a function of soil moisture. Studies at the United States Salinity Laboratory in California [8] indicate transpiration occurs at the full potential rate until a critical point in the available soil moisture is reached; thereafter the actual evapotranspiration lags the potential. This critical point was assumed to be one-third of the available soil moisture between the permanent wilting point and field capacity for the sandy soils of the Kissimmee River Basin. It was assumed that deep percolation occurs only when available soil moisture is at its capacity level. The soil moisture is used in the next time period to determine if irrigation water should be applied and the rate at which evapotranspiration will occur.

The actual evapotranspiration occurring during each time interval is accumulated through the entire growing season to obtain the total water used by the crop. This is done for each crop, first, with both rainfall and irrigation water as the total water available, and second, with just rainfall as the total water available. At the end of the growing season there are two effective water inputs for each crop, the actual total evapotranspiration when irrigation as well as rainfall is available and the actual total evapotranspiration when only rainfall is used.

The availability of effective water on crop yields can be translated into benefits accruing to the users of water and used along with the benefits accruing to other uses of water as an index of water management effectiveness. To do this, the concept of producer's surplus was used, and the surplus assumed to be benefits accruing to society from irrigation water. Producer's surplus can be demonstrated by using traditional neoclassical production theory and assuming perfect competition in all markets. A crop production function is used which translates available effective water to crop yields when all other production factors are held constant.

The crop yields with and without irrigation water are obtained by solving the production function with the effective water available from both rainfall and irrigation, and rainfall alone, respectively. The price of the crop is assumed to be independent of activities in the river basin and constant. The producer's surplus due to the availability of irrigation water is shown as the shaded area in Figure 15.

The present study considered two crops, irrigated pasture and citrus. Irrigation water is assumed to be available only in sub-areas in which lakes are located. The growing season is the entire year, so actual evapotranspiration is determined daily and accumulated for the entire year. The management of water in each lake causes the available water to vary so that the actual evapotranspiration varies. The resulting producer's surplus for each crop provides the benefits due to irrigation water being available for each crop grown near each of the lakes.

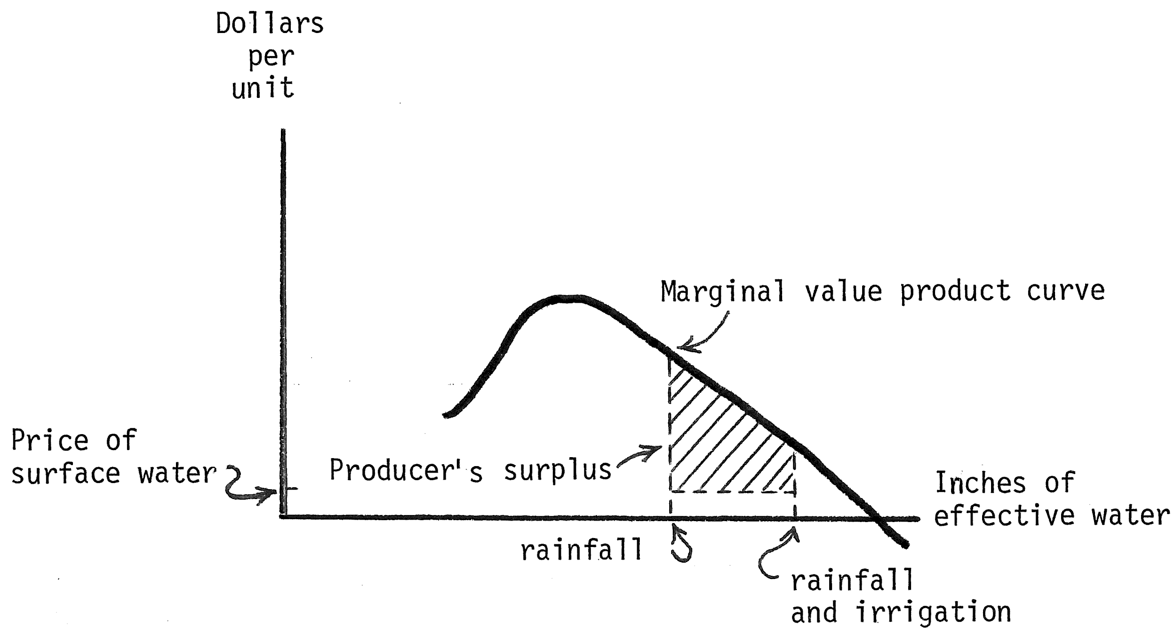

Figure 15. -- Producer's surplus from the availability of irrigation water.

Residential Water Consumption Model

Surface water available for residential consumption is a function of the amount of water stored. The amount of water that can be removed from a lake is given as a percentage of the water needed. To obtain the maximum amount of water needed, an average consumer is assumed and his needs determined.[9] Howe and Linaweaver [13] in an extensive study have formulated residential water demand models and estimated the relevant parameters from cross-sectional data.

The quantity demanded for domestic purposes per dwelling was found to be a function of the average market value of the dwellings, the average irrigation water needs for lawn grass and total water price at the block rate applicable to the average domestic use. The equation was used to obtain the maximum daily water desired by each dwelling. The actual daily water provided from surface water is the product of this desired quantity and the percent of needs allowed.

The consumer's surplus for domestic water consumption is assumed to be the benefits accruing to the actual available water for residential use.

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[9]The quantity of water demanded for residential use is assumed to be relatively constant in the very short run because of fixed price schedules.

The shaded area of Figure 16 illustrates the consumer's surplus for surface water available for residential use. Or, the consumer's surplus for surface water is the benefits accruing to the availability of surface water for residential use. The actual quantity of water used by residents from each lake is determined daily, and these quantities are accumulated for the entire year. This quantity is then used to calculate the consumer's surplus for the yearly consumption of surface water from each lake. (This model is presented in Appendix C.)

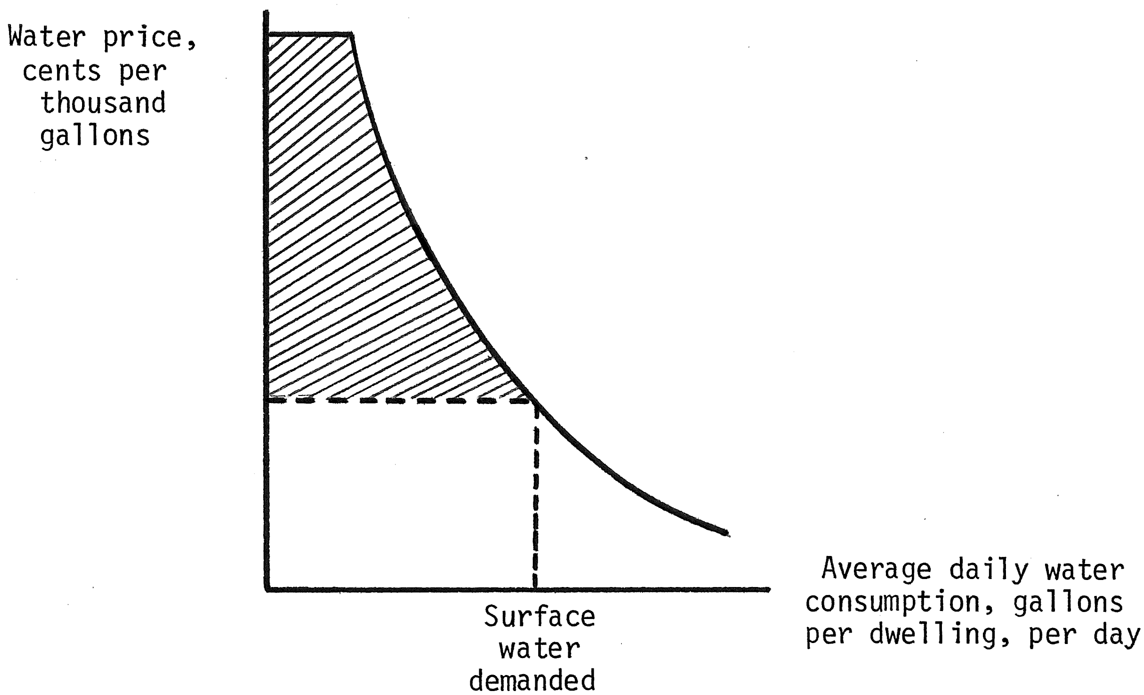


Figure 16. -- Residential water demand function.

Water Recreation Model

The lakes of the basin are used extensively for recreation, and the level of use is influenced by the depth of water. This is true because the lakes are quite shallow, and several feet of fluctuation drastically affects boating. When the water surface elevation is low, large areas of the bottom are covered with only a foot or two of water, and when the lake surface is high, access is limited and boat launching is difficult. Recreational use, therefore, is assumed to be a function of water surface elevation as well as other variables. The calculation of benefits accruing to recreational use of the lakes due to water management is presented in Appendix C.

Flood Damage Model

Benefits are higher in the first three water use activities when great quantities of water are conserved. But, in the case of flood prevention, the lower the lake surface elevation and conserved water, the lower the probability of floods occurring. The higher the level, the higher the probability of flooding and the resulting flood damages. So, when flood protection becomes a concern in lake water management, there are conflicting operational objectives. The stochastic nature of rainfall aggravates the situation and makes the findings of a reasonably balanced policy difficult.

Flood damages are a function of the lake level and the activities at various elevations. In the case of agricultural crops, the duration of the floods is also a factor. Damage to crops increases with the time of exposure to saturated soil conditions until finally the crop is killed. The tolerance of crops to wet conditions varies; some crops can survive adverse conditions for long periods. Urban property and rural structures are considered to be damaged immediately; duration of flooding is not a factor. Momentary wetting of structures and machinery causes maximum damages.

The lack of demand functions for flood protection makes it impossible to use the surplus concept to determine benefits as was used for the other water use activities. The only avenue open for placing an economic value on the flooding phenomenon is to use the market value of replacing the damaged property. Lost net revenue to productive activities should also be considered. Flood damages resulting from lake water management policy are thus considered negative benefits (for more detail see Appendix C).

Policy Evaluation Capabilities of the Model

Simulation models, by their very nature, allow easy modification of function specification. This provides a ready means of considering policy changes and the resulting effect on the overall management system. The proposed changes, however, must come from an understanding of the nature of the management and not a haphazard altering of variables and functions. The suggested policy changes will come from the technical staff after thorough study of the problems facing the water management authority.

The simulation model can readily handle investigations of policy concerned with spatial and temporal allocation of surface water as well as changes in surface water demand by specific economic activities. The water stored in the system of lakes is a function of the management of the control gates. The actual day-to-day operation of the gates is specified by the regulation schedules or rule curves for each structure. These rule curves are the long-term management policy. Briefly, they indicate that on a given day the water surface elevation for a given lake should be at a certain level. The schedule is given for an entire year.

It is by varying the shape of these rule curves that alternative spatial and temporal allocations can be considered. In this case, the information flow in Figure 7 is from the long-term surface regulation policy model to the gate operation model.

A typical investigative simulation would be as follows: Basic input into the water management sub-model is a generated set of sub-basin runoffs from the rainfall and streamflow sub-models. The gate openings during the run are determined by the specified rule curves. The resulting set of lake states is submitted to the economic activities model, and the net benefits accruing to this management procedure determined. The run would be made over a sufficient period of time to allow the stochastic character of the hydrology to be reflected in the sets of lake states and benefit states. Alternative regulation schedules would be examined in a similar manner using the same input data set.

Variation of the regulation schedules for structures within the basin allows study of spatial and temporal allocation within the study basin. In a similar manner, the effect of water exported from the basin on the benefits accruing to the basin can be investigated. To accomplish this, specific flow rates through the outlet structure are set, and the effect on the lakes determined.

The effects of land and water use changes on net benefits accruing to the basin can also be readily explored. Particular changes in land use, the resulting change in water demand and the regulations allowing surface water withdrawal are considered. In the land use case the particular changes are entered by modifying the appropriate variables in the water use activities model. When the water withdrawal regulations are altered, the function changes are made in the institutional constraint model. In both cases, a set of runoff values is used, and a set of lake states determined. The net benefits to this set of states and water uses are calculated and provide an indication of the effects of use changes.

The use of the simulation for each of these policy considerations and activity changes was demonstrated. A complete study of each was not performed; but rather, the type of information resulting from a study and used in the policy evaluation by the staff was generated.

Policy Evaluation Demonstrations

Policy evaluation capabilities of a water management organization can be expanded with simulation model use. The basis for the broadened capabilities lies in the ability to change formulations, parameters and variables, while using the model as an apparatus to give insight into the complex interactions occurring in the real system. The simulation of the Kissimmee River Basin is intended to demonstrate this usefulness in dealing with difficult water management problems in south Florida. Demonstrations illustrating the potential of the model in four policy areas, (a) temporal and spatial water storage, (b) consumptive withdrawals, (c) minimum outflows, and (d) land and water use patterns, have been performed.

Simulation analysis can provide information such as the flow through each structure, lake levels, flood damages, amount of irrigation water applied, evapotranspiration, soil moisture levels, crop yields, domestic consumption, recreational use and the benefits resulting from each use. These outputs can be aggregated, used to calculate standard statistics or put into any form useful in the staff and governing board evaluation. It should be noted that the dollar benefits can be used to compare the distributional effects of a policy as well as its overall economic efficiency. That is, the dollar benefits accruing to a particular water use associated with a particular lake can be obtained and compared to another use on another lake, and a policy selected on this comparison. Or, in the case of the efficiency criteria, a policy which produces the highest net benefits to the entire basin can be selected. The staff and governing board have a number of physical and economic indicators with which to compare policy alternatives.

Only a few of these indicators of policy performance are presented for the policy demonstrations discussed below. The availability of water for each water use activity, the floods occurring and certain aggregated dollar benefits are mentioned. The purpose of these was to give the reader a feel for the relative change in indicators when a change was made in certain parameters of formulations. The purpose was not to give an exhaustive study of each policy.

Two computers were used to perform the demonstrations. The rainfall and runoff calculations were performed on the Flood Control District's CDC 3100 computer. The University of Florida's IBM 370, model 165 computer was used to run the water management model, the water use activities model and the institutional constraint model. No cost figures were available on the operation of the rainfall and runoff models. The cost of running the other three models in the policy demonstrations was nine dollars for a one-year run.

Rainfall occurring over the basin during the period June 1, 1968 to May 31, 1971 was used as the basic input. A set of runoff values was generated using the FCD rainfall and streamflow models. This set of runoff values for the three years was used for each policy demonstration run.

This was an interesting time period because the first two years had typical rainfalls, while the third was very dry. The rainfall means for the fourteen sub-areas were approximately 53 inches and 57 inches for years 1 and 2, respectively. The third year mean was approximately 37.5 inches. This year was the beginning of the worst drought in the recorded history of south Florida. The results of this change in rainfall were seen in policy demonstrations. For example, in simulation 1 using the present regulation schedule, group 1 crop acreages and proportional withdrawal functions, recreation benefits dropped \$440,000 while irrigation benefits rose \$694,000 between year 1 and year 3.

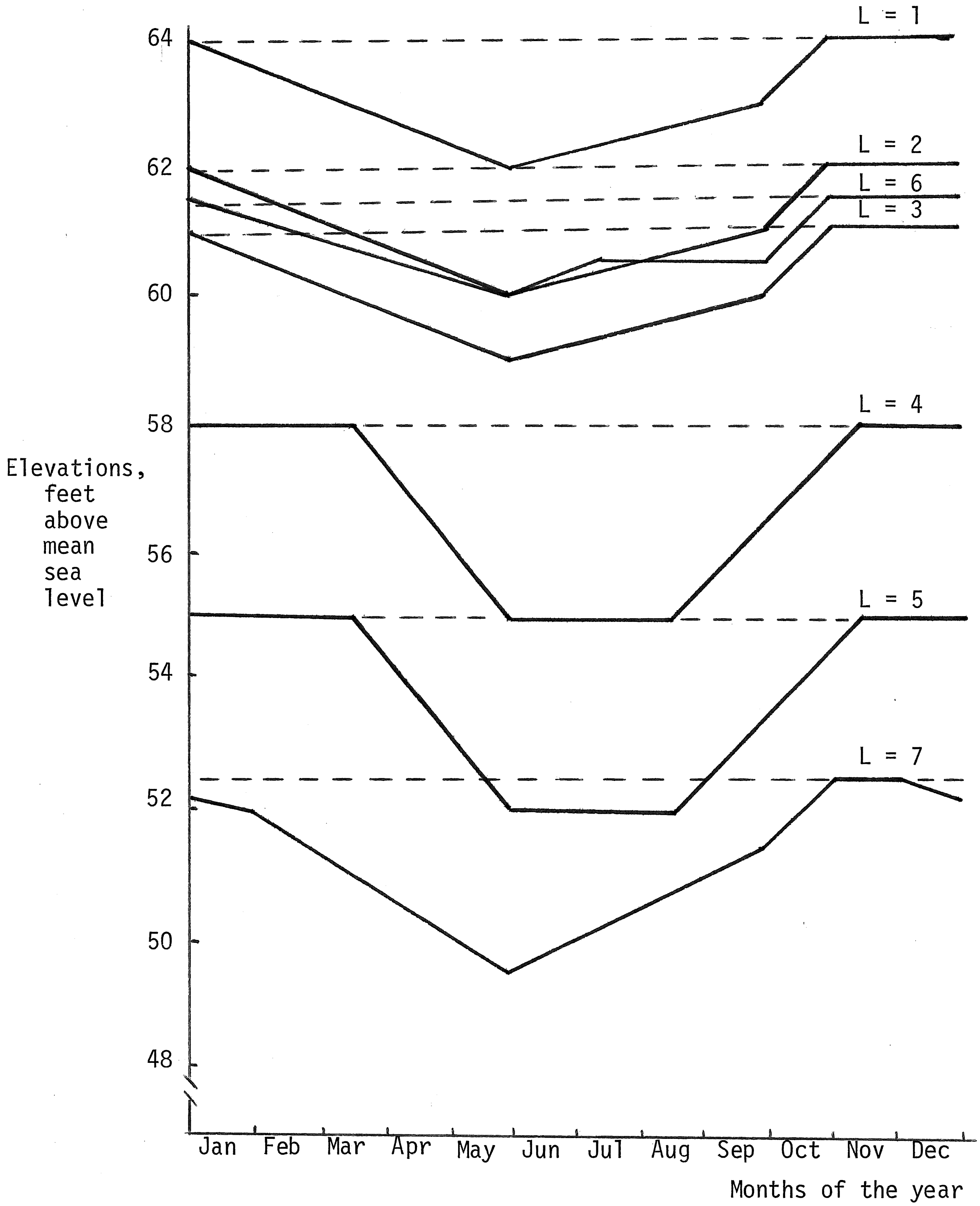
Temporal and Spatial Water Storage

Temporal and spatial water storage is controlled by regulating the gates at the outlets of the lakes. The gates are opened and closed so as to maintain a certain lake elevation. The FCD specifies the lake elevation for a given day with the lake regulation schedule. Ideally, the storage policy given by each of these will provide the maximum net benefits to the area. It is in the development of these schedules that the FCD will use the simulation model to study the effects of alternative storage policies.

The regulation schedules are best illustrated by linear segmented functions as shown in Figure 17. Here, each of the presently used schedules is shown. Generally, the lakes are allowed to reach a maximum elevation in the late fall and then decrease through the winter and spring to a minimum at the beginning of the summer. This corresponds to the periods of light rainfall in winter and spring and heavy in the summer, although there is great variation.

Three configurations of regulation schedules were used in the demonstrations. The first consisted of three variations of the present regulation schedules. Simulation runs were made with (a) the present schedules for each lake, (b) the shape of the present schedules but with all elevations for a given day lowered one foot, and (c) the present schedules but with the maximum elevation raised one-half foot. The second configuration is a set of changes being proposed by the FCD. The proposed schedules for lakes 1, 2, 4 and 5 are given in Figure 18. The last configuration, constant lake elevations set at the highest elevation on the present schedules, is desired by many people with property fronting on the lakes.

Output from the model gives sufficient information to allow comparison of regulation schedules with respect to physical as well as economic states. Simulation 1 (using the present schedules and group 1 acreages) resulted in all irrigation needs being met except on lakes 1, 2 and 3 during the dry period of 1971. (Table 18 presents the three-year total benefits and damages for the regulation schedule demonstrations.) A small amount of agricultural flooding occurred in October, 1969. The net benefits accruing to the availability of water during the three years was $71,118,689. Simulation 2, using the present schedule dropped one foot, resulted in flood damages being reduced to $8,685 but also decreased the net benefits by $2,762,055. Both recreation and irrigation benefits dropped substantially. There was a very definite shortage of water in lakes 1, 2 and 3 during the dry period. The proposed schedules(simulation 3) resulted in the same flooding as the present schedule. Recreation benefits rose, but irrigation benefits dropped, and net benefits were $73,129 lower than in simulation 1. The constant lake levels (simulation 4), on the other hand, caused a $949,871 increase in net benefits over simulation 1. There was an increase in recreation and irrigation benefits but a rise in flood damages to $468,138, with the majority occurring in urban areas on Lake Tohopekaliga. The water was 1.07 feet above the flood level and remained above flood level for 37 days. When the maximum elevations on the present schedules were raised one-half foot, there was very little change in the benefit levels, but there was an increase in flood damages. A number of small floods occurred in the late fall and winter because the desired lake level was the same as the point where flood damages begin. The outcome was a decrease in net benefits.



Legend: _ _ _ _ Constant elevation schedule
_______ Present schedule used by FCD

Figure 17. -- Regulation schedules for lakes in the Upper Kissimmee River Basin.

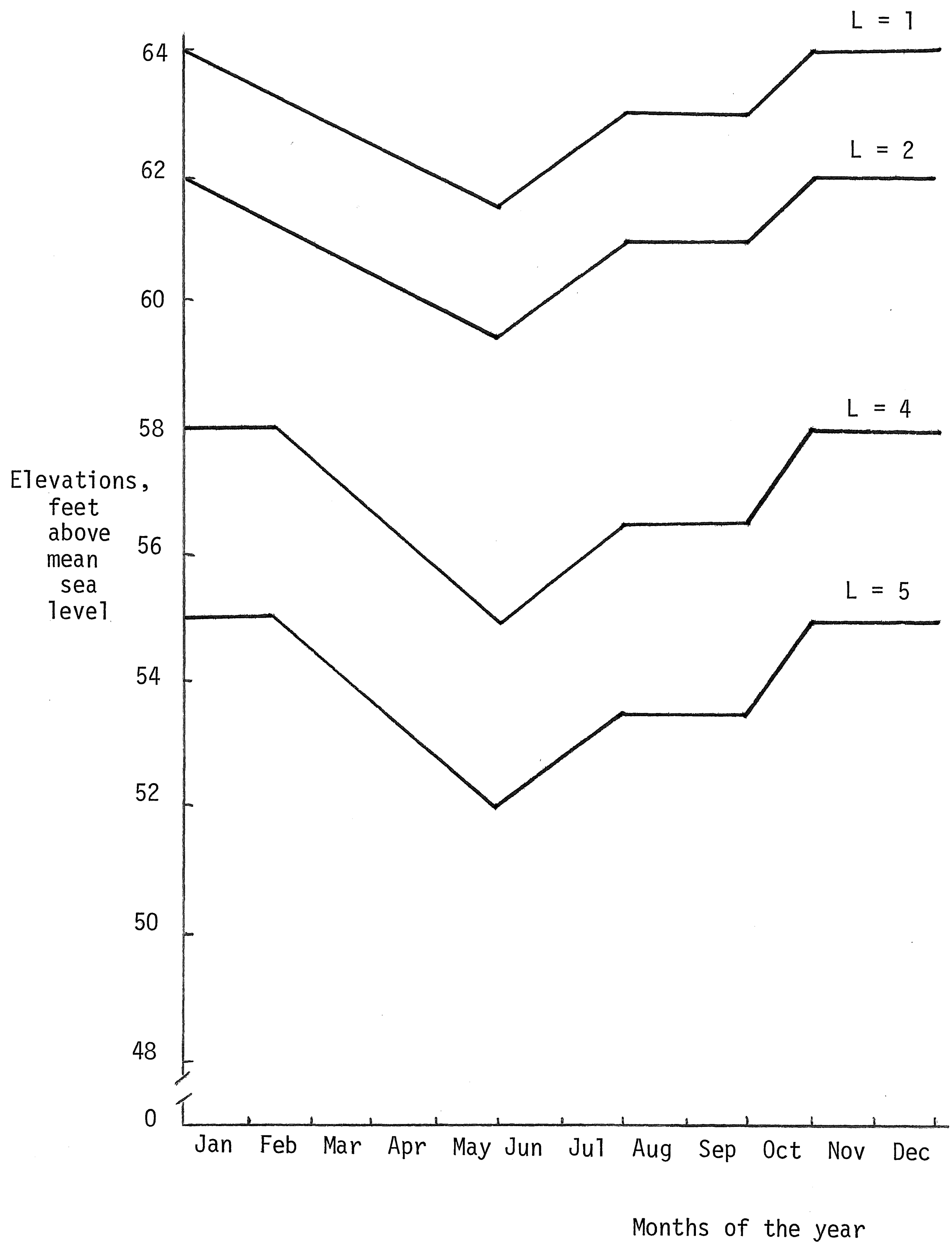


Figure 18. -- Proposed regulation schedules.

Table 18. -- Three-year total dollar benefits and damages resulting from various regulation schedules

Simulation	Regulation schedule	Recreation benefits	Irrigation benefits	Domestic water benefits	Flood damages	Net benefits
		Dollars				
1	Present regulation schedules[a]	62,705,102	8,103,188	336,029	25,621	71,118,689
2	Present regulation schedules, but one foot lower[a]	60,502,697	7,531,818	330,804	8,685	68,356,634
3	Proposed regulation schedules for L = 1, 2, 4 & 5, while L = 3, 6, & 7 are the present schedules[a]	62,847,766	7,889,376	334,039	25,621	71,045,560
4	Constant elevation schedules[a]	63,829,826	8,345,516	361,356	468,138	72,068,560
5	Constant elevation schedules[b]	63,780,420	12,381,731	358,561	515,764	76,004,948
6	Constant elevation schedules except for L = 5 which has the present schedule[c]	63,467,358	12,365,288	349,417	98,546	76,083,517

[a]Group 1 crop acreages and proportional withdrawal functions were used.

[b]Group 2 crop acreages and "all or nothing" withdrawal functions were used.

[c]Group 2 crop acreages and proportional withdrawal functions were used.

It is possible to vary only one lake's regulation schedule to gain greater insight into the effects of one lake on the entire system. To demonstrate this, simulation 6 was made identical to 5, except lake 5 had the present schedule rather than the constant schedule, as did the others. Flood damages dropped by $417,218 while the increase in net benefits was only $78,569.

The demonstration runs have shown the model to be effective in analyzing specific segments of proposed regulation schedules as well as comparing different proposed schedules. The daily values for lake levels and soil moisture help pinpoint time periods when greater quantities of water need to be available from storage. These lake levels, also, help in identifying periods in which less water should be stored to prevent undue flooding.

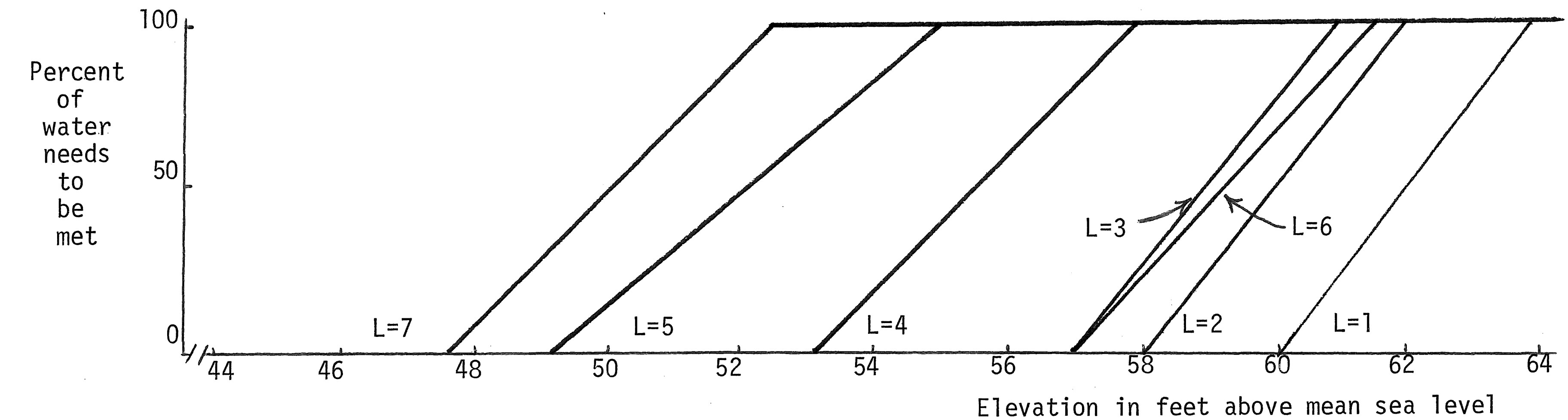
Consumptive Withdrawals

The FCD has the responsibility of providing surface water to consumptive users and also to protect the water resources in times of serious drought. Under the Florida Water Resources Act of 1972, surface water to be used consumptively is to be controlled by withdrawal permits. To protect the lakes from undue lowering, the water allowed to be withdrawn could be a function of water in storage or the lake surface elevation.

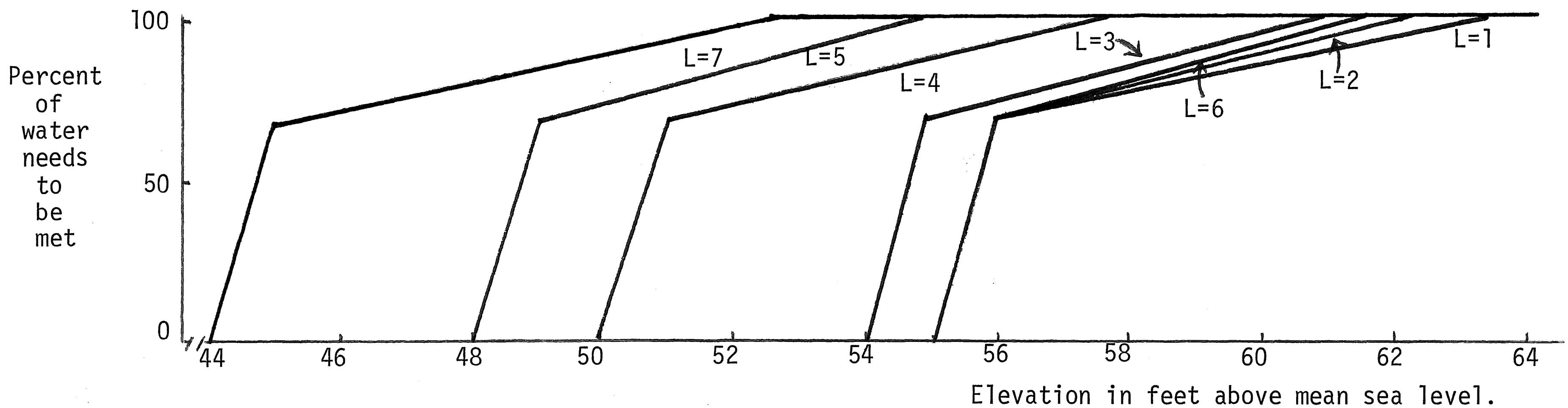
Different consumptive water use policies can be investigated because the simulation model allows ready change of the withdrawal functions. The functions -- irrigation and domestic withdrawal -- are linear segmented functions which specify a percentage of water needs to be met when the lake surface is at a given elevation (illustrated in Figure 12). These allow 100 percent of the needs to be met when the lake surface elevation is equal to or above the level specified by the regulation schedule. And, when the lake is below this level, the percentage of needs which can be met drops off and reaches zero at certain elevations.

Two simulation runs were performed to demonstrate the use of the model in studying withdrawal policies. The first used the irrigation and domestic withdrawal functions described above and presented in Figure 19. The second used an "all or nothing" approach for irrigation needs and the above proportional approach for domestic use. One hundred percent of irrigation needs would be met until the lake elevation reached the zero withdrawal elevation (given in Figure 19a) and below this no withdrawal was possible. The domestic withdrawal functions were as given in Figure 19b. Group 2 crop acreages were used in both runs. There is little difference in the two policies as indicated in Table 19. Irrigation benefits differed by $196,947, and net benefits by $366,615. In both runs, the majority of water needs were met in the first two years. In the third year again the needs were met for lakes 4, 5, 6 and 7, but lakes 1, 2 and 3 were quite low and water needs were not met.

The irrigation routine in the simulation model is structured so irrigation cannot occur more than once every eight days. When the



(a) Irrigation withdrawal functions for lakes.



(b) Domestic consumption withdrawal function for lakes.

Figure 19. -- Proportional consumption withdrawal functions.

Table 19. -- Three-year total benefits and damages resulting from irrigation withdrawal demonstrations

Simulation	Function	Recreation benefits	Irrigation benefits	Domestic consumption benefits	Flood damages	Net benefits
		Dollars				
7	Proportional withdrawals	62,369,083	12,108,788	325,042	25,367	74,777,546
8	"All or nothing" withdrawals	62,200,981	11,911,841	323,476	25,476	74,410,931

proportional withdrawal functions are used and the lakes are low, only a small percentage of the water needs can be met. This causes soil moisture to remain low, and at the end of the eight-day cycle irrigation is required again. The result is a large number of small irrigations in dry periods. If the irrigation cycle were greater, the amount of water provided under the proportional withdrawal function would decrease, and the "all or nothing" withdrawal function would provide more irrigation water. In the present demonstration, however, the proportional withdrawal had higher irrigation benefits. This resulted because lakes 1, 2 and 3 dropped to near the zero irrigation withdrawal elevations. The proportional withdrawal function provided some water without dropping the lake a large amount. This allowed irrigation eight days later. The "all or nothing" function dropped the lake and the lake did not recover enough to allow irrigation in the next several weeks.

A proportional irrigation withdrawal function, made up of several linear segments similar to the domestic consumption withdrawal function, would provide greater quantities of water for surface elevations near the desired level. The probability of the lakes being near this elevation is high. When the lakes drop to a low elevation with a low probability of occurring, the percent of water needs to be met would be sharply reduced. This would allow adequate water to users during normal times, but provide some protection before the lake level becomes very low.

Minimum Outflows

Establishment of minimum outflows from the lakes and basin can be a means of meeting operational criteria that cannot be placed in an economic framework. Often minimum flows are established for pollution abatement, for natural environment maintenance and to meet water needs in regions downstream. The Kissimmee River Basin presently exports water to

Lake Okeechobee and south Florida for all three reasons. The size of the minimum flows will affect the level of benefits accruing to the basin because in dry periods water will be released when it is needed in the basin.

The simulation model was set up to provide for minimum flows through structure 9 (S-65). The specified flow would always be met unless lake 7 reached a dangerously low level. Runs were made with three flows, 0, 250 and 750 cubic feet per second (cfs), and the three-year total benefits and damages are given in Table 20. The same flooding occurred in all three simulations. Likewise, the benefits accruing to the use of water in a certain lake were the same except for lake 7. All the decreases in benefits shown in Table 20 were caused by lowering of lake 7. There was little decrease when the flow rate was 250 cfs, but when it was raised to 750 cfs, there was a drop of nearly $2 million in benefits to the lake 7 area.

Table 20. -- Three-year benefits and damages resulting from minimum flow simulations

Simulation	Minimum flow rate through structure 9, in cfs	Recreation benefits	Irrigation benefits	Domestic consumption benefits	Flood damages	Net benefits
		Dollars				
1	0	62,705,102	8,103,188	336,029	25,621	71,118,689
9	250	62,695,209	8,102,248	335,496	25,621	71,107,332
10	750	60,899,313	7,902,552	335,661	25,621	69,111,905

The loss of $2 million in benefits to the water users on lake 7 points up the equity problems that arise when various policies are implemented. In the above case all the water sent down the Kissimmee River was taken from lake 7. Minimum flows could be set for each lake so that the outflow from lake 7 would be partly offset by the inflow from the other lakes. A more involved alternative to meet this downstream flow would be to proportion the flow to all the lakes on the basis of their present storage level. In both situations, each lake area would experience some benefit decrease in dry periods. In general the simulation provides the means for investigating the loss in benefits to the whole area and the distribution of the loss when water export is required.

Land and Water Use Patterns

Changes in land and water use affect the management of a system. The present water management procedures were developed to fit existing use patterns. Over time, patterns change and new procedures are needed. A new land development may be proposed and a permit to withdraw water requested. Or, a proposed urban development may be announced for a flood prone area. The success or failure of the development depends on the quantity of water granted in the permit or the availability of flood protection. The managers of the water system need information on the effects of such developments to make intelligent decisions. The simulation model can assist in evaluating the interactions occurring due to land and water use changes.

Simulation runs were made to demonstrate the effect of crop acreage increases. In these, the land use changes were assumed not to substantially affect the runoff from the sub-area. The FCD streamflow model was not changed. Two groups of crop acreages were used and are given in Table 21. There was sufficient water available to meet the increased irrigation needs in every year except the dry third year. The increased acreages boosted irrigation benefits by $4,005,600 and net benefits by $3,658,857 (Table 22) when present regulation schedules were used. An additional run was made using the constant elevations schedule except for lake 5 which used the present schedule. This was done to provide additional stored water to meet needs during the dry period. There was a slight increase in irrigation benefits along with increases in recreational benefits. A small amount of flooding occurred on lakes 3, 4, 5, 6 and 7, and flood damages jumped. There was, however, a total increase in net benefits of $1.3 million.

Table 21. -- Crop acreages used in alternative simulations

Lake	Group 1		Group 2	
	Pasture	Citrus	Pasture	Citrus
	Acres			
1	1,000	2,110	1,000	2,110
2	1,000	600	1,000	600
3	1,000	240	1,000	240
4	1,000	760	3,000	1,500
5	1,000	1,580	3,000	2,500
6	1,000	180	1,500	360
7	1,000	360	4,000	1,000

Note: The acreages are not the acres of crops presently irrigated with surface water but were selected only for demonstration purposes.

Table 22. -- Three-year benefits and damages resulting from land and water use change demonstrations

Simulation	Acreage	Recreation benefits	Irrigation benefits	Domestic consumption benefits	Flood damages	Net benefits
		-----------------------	-----------------------	Dollars	-----------------------	-----------------------
1	Group 1	62,705,102	8,103,188	336,029	25,621	71,118,689
7	Group 2	62,369,083	12,108,788	325,042	25,367	74,777,546
6	Group 2	63,467,358	12,365,288	349,417	98,546	76,083,517

Note: All three simulations used the proportional withdrawal function. Simulations 1 and 7 used the present schedule, while 6 used the constant elevation schedules except for lake 5 which used the present schedule.

The ability to investigate proposed changes will be important in years to come as the area continues to grow. There will be greater pressures on both ground and surface water in the basin, and demands to export more water downstream will increase. The FCD must have accurate information on the effects to arrive at policies which will provide high economic and noneconomic benefits to the Kissimmee area and all of south Florida.

Policy Implications

It is important to point out the above demonstrations were performed for purely illustrative purposes and no specific policy implications should be made. This is due to several aspects of the demonstrations. First, there is currently very little consumptive use of surface water in the upper Kissimmee Basin. Few of the crop acreages given in group 1 acreages use surface water for irrigation. The majority of citrus growers use ground water, and much of the pasture is not irrigated. The group 2 acreages were simply assumed increases. Presently, all residential water is ground water. These activities were used in the demonstrations because in the near future surface water will be used in conjunction with ground water. Other areas of Florida experiencing rapid growth have demonstrated the problems that can arise if proper planning is not involved.

A second aspect that presents some distortion is the data on flood damages. Few data were available, and those which were did not reflect the characteristics needed to evaluate good water management. The data were aggregated into urban and agricultural damages for each lake. The flood duration assumed was thirty days. This provides no information on floods that do not destroy crops but retard their production. Flood stage/damage data are needed for each crop and several flood durations.

Managed flooding of low damage crops could be evaluated with respect to the overall water management objectives. It may be that, in the long run, occasional flooding of certain grasslands would increase the net benefits to the area. This flood plain management alternative needs studying.

The sub-area runoff values being generated by the FCD with the rainfall and streamflow models have some error. The parameters used in the streamflow model were obtained by "tuning" the model using runoff data from Boggy Creek in sub-area 4. This sub-area was assumed to be representative of the others, and the parameters were used for all fourteen sub-areas. The effect of this was seen in the flooding that the simulation indicated did not occur. Study of the simulation output revealed the rapid increase in lake elevation could only be caused by runoff from sub-area 9. Having a model available which allows constant monitoring of individual lake surface elevations will make it possible for the FCD to "tune" the streamflow model for each sub-area.

The use of only a three-year period is another shortcoming of the present demonstrations. Three years is not a sufficient time period to have the random variation occurring in the rainfall and other hydrologic characteristics to be reflected in the stream states and economic benefits. The three-year period was an unusual one and incorporated an extremely dry year. Actual policy studies, however, should be performed over a period that is statistically sound.

A rigorous validation of the entire simulation model has not been performed. Each of the sub-models, however, has been tested and responds to changes as anticipated. The results of early testing of the rainfall and runoff models are presented in references [15, 29, and 30]. The FCD is presently continuing development and testing of these. The lake surface elevation model was checked by simulating the conditions of Lake Tohopekaliga and the results presented in Sinha [28]. The entire water surface elevation model, in which all lakes, canals and structures were included, has not been thoroughly checked. However, when operated with the present regulation schedules and no consumptive withdrawals from the lakes, the model produced lake surface elevations within inches of the historic values in all but flooding situations. In periods of high water the model occasionally gave higher lake surface elevations than actually existed, although these were not more than approximately one foot higher. It is believed that this was caused by the input of runoff values which were too large (as mentioned above) and not by the water surface elevation management model. The model does reflect transition points from rising to falling lake surfaces.

Comparison of the output from the water use activities sub-models to historic data was not possible because very little surface water is used consumptively in the study basin. The water use models did react to changes in lake surface elevations as expected. Yields, and therefore irrigation benefits, dropped when irrigation water was not available. Domestic consumption of surface water, and the resulting benefits, dropped when surface water was not available for this use. Recreational use of the lakes dropped when the lake surface elevations were unusually low or when flooding occurred. Flood damages did not exist when the lake surfaces were within the normal range but increased when the water rose above this range. In all cases the simulation model when operated as an entire unit did respond as was foreseen, and the magnitude of the physical and economic output was as anticipated.

These inadequacies in no way invalidate the simulation methodology. It is important to get a first model operational so these weaknesses can be studied in the context of the whole. With the relative importance of each component in mind, further development of the model can be undertaken more efficiently.

Applicability of the Model in Policy Selection

The policy decision makers are appointed to represent the people of the region in matters concerning water management. They are to reflect subtle, nonquantifiable, subjective views of many people. This is often accomplished by conducting hearings and other public meetings to determine the general attitude of the people toward a specific policy. But in addition to this, they need accurate information on the physical, technical and economic consequences of several policy alternatives. High speed computers have greatly extended man's analytical capabilities and can assist in analyzing the complex interactions found in water policy selection.

The simulation model of the upper Kissimmee River Basin presented in this study can be used to illustrate the type of information available to the decision makers. A specific policy, concerned with one aspect of the management of the control system, is programmed into the model. Then, the time series rainfall data are used, and the model operated through the time period. The following information is generated and available for use by the decision makers in the evaluation of this policy:

1. The water management model provides the flow through each control structure along with the volume of water in storage and the surface elevation for each lake at six-hour intervals.
2. Output from the irrigation model includes the inches of water applied at each irrigation and the daily total amount of irrigation water withdrawn from each lake. Daily evapotranspiration and soil moisture for each crop are also available. Evapotranspiration for the entire growing season is determined and used to obtain the yields for each crop grown around each lake. These are used, in turn, to obtain the benefits accruing to the availability of water from each lake for each crop.
3. The domestic consumption model provides the daily volume of water withdrawn from the individual lakes for residential use in addition to the benefits accruing to this use.
4. Recreational visits to each lake and the accompanying benefits are determined monthly and yearly.
5. The lake states furnish information on floods and their duration. Damages to urban areas, rural structures and individual crops are determined for each flood.

These data can be put in other forms to provide useful information to the decision makers.

The series of runs reported in this study were made to demonstrate the use of the models and the resulting data for several specific policy problems. The resulting water shortages, floods and damages, crop yields, recreation visits and benefit levels were readily available from the model output. Comparison of policy alternatives pointed out the relative ease of finding the effect of the change on (a) the water stored in the entire basin, (b) the water stored in individual lakes, (c) the different water users in the entire basin, (d) the different water users on each lake, and (e) the distribution of benefits to the various water users on the various lakes.

This methodology, because of its detailed approach, lends itself to the refinement of operational policy for individual basins. It is the authors' opinion that the method could be extended to cover an area as large as the entire FCD. But, rather than construct one large model of the entire region with as much detail as the one above, it would be wise to work on individual basins. Each could then be tied together by a large, much less detailed model of the entire FCD. This large model could be a linear programming model or a more aggregated simulation model and would be used to consider broad policy alternatives. The reduced number of alternatives could then be submitted to the individual basin models and shaped into final operational policy for each unique basin.

Each of the individual basins will have different characteristics. Some regions, like the Kissimmee River Basin, will be primarily storage areas and water exporters. Recreation will be an important activity. Other regions will have no storage capacity and will be consumers of imported water, which may be irrigation or residential consumers, as in the case of the east coast area. In some basins, man will have little control over water flow, while in others the present complex of canals and structures will give nearly complete control. Each basin will have to be studied and the essence of its hydrology, water use and economy gleaned and incorporated into a model.

The availability of data varies with the basins. Much of the hydrologic needs for some basins could be met from existing sources. Secondary sources would provide information on water use. In other basins, hydrologic and water management data are not available and would have to be collected. It is important to keep in mind, however, that a first-generation model can be developed with very rough data. These can be used, in turn, to indicate which data are sufficient and which need to be more accurate.

One final point should be made. The results of a simulation investigation do not prescribe optimal policies for dealing with water management problems. The investigation, rather, provides answers to the specific problems fed into the model and the model consists of only the quantified aspects of the management problem. The simulation results can provide insights and information to the decision makers concerning a specific policy. The final selection is theirs.

CHAPTER V

SUMMARY, CONCLUSIONS, AND IMPLICATIONS

This study was divided into four primary parts. First, the problem was identified and delineated. Second, data collection and analyses were performed while the third and fourth parts were development and empirical evaluation of the linear programming allocation model and the simulation model.

Like many water management districts, the Central and Southern Florida Flood Control District was designed and developed primarily to provide relief from flooding. Additional water management responsibilities have become important to the public and have been recognized by the Flood Control District. The fixed rule curves by which they have been operating were not satisfactory to meet the changing demands on the system. Consequently, the Flood Control District was interested in water management models that would provide them with information regarding alternative allocations of water among the various uses and users of water. The problem was to determine how to meet the present water management responsibilities given an existing water management system.

One criterion used was the allocation of water to uses where the economic value was the highest. This does not mean that other criteria are less important, but that this criterion represents one aspect that the decision makers must consider. In the allocation models developed, other criteria are combined with economic criteria. Systems-management models which yield information on the economic consequences of alternative allocations resulting from alternative management policies were investigated. These models provide information on the institutional and social consequences of policies as well as the hydrologic (and other physical water management) aspects of the system.

In order to determine the economic consequences of alternative water management policies, the value of water used to meet the alternative demands must be known. The alternative demands for the water controlled by the FCD as well as the temporal, qualitative and quantitative aspects of these demands must be known in order to determine the value of water.

The primary uses of water (or allocation alternatives) were flood control, recreation and agriculture (irrigation). Additional potential uses include municipal and industrial water supplies. Data on agricultural uses were available while data on recreational uses were almost non-existent. Because recreation was a significant user of the water managed by the FCD, an extensive effort was made in this study to generate data relating to the value of water in recreational uses in the study area. Available data were less than adequate for the value of flood prevention and for the value of water used to supply municipalities and industrial uses.

In addition to data concerning the economic consequences of alternative water management policies, it was necessary to obtain information on the basic hydrology of the water management system. These data included historical and simulated records on rainfall, runoff, streamflow evaporation, storage capacities and water control structure capabilities. These data were provided by the FCD and in most cases were more than adequate for the water management systems models used in this study.

Decision makers need information relative to the outcome of various policy alternatives with respect to the hydrologic, economic and institutional aspects of the system, in order to decide upon the optimal policy or policies to meet the multi-objectives of the district. Two analytical techniques seemed to be appropriate: linear programming and simulation.

A linear programming model of the hydrologic-economic system was developed to determine the economic consequences of broad operational policy alternatives and the relative trade-offs based on economic returns from water allocations among different users, locations and time periods. For analyzing the operational policies which are more specific, such as water level regulation schedules, a simulation model of the hydrologic-economic aspects of the system was developed.

The basin was divided geographically into four sub-basins and the year was divided into four time periods. Hydrologic data, including water yields for each time period and sub-basin, minimum, mean and maximum regulated storage levels for each sub-basin and three alternative water release requirements for each time period were obtained from the FCD. The value of water used in the irrigation of various agricultural crops, the quantities of water required by each crop activity and the acres of the various crops that could be irrigated in each sub-basin were determined from information obtained from the SCS, farmers and ranchers in the area and agricultural scientists. The value of water for recreation was determined by extensive surveys of the recreationists in the Kissimmee River Basin. These values were then related to the amount of water in storage in each sub-basin. Estimates of the flood damages incurred from excessive amounts of water in storage were obtained from the FCD. These estimates were then combined with estimates of the amount of recreational value lost when water was stored at levels above the maximum regulated levels to obtain total net costs of excessive quantities of water in storage.

A linear programming model was designed to allocate the available water over the four time periods and four sub-basins such that total net returns to society would be maximized. Total net returns would accrue from the net returns to water used in the various consumptive and non-consumptive uses. The per unit net return to water might be either positive, zero or negative. Total net returns were maximized subject to constraints on the water management system such as the storage capacities of each sub-basin, the minimum quantity of water required to be released each time period and the minimum quantity of water required in storage in each sub-basin.

Optimal allocations were computed using three levels of release requirements and three levels of irrigated crop acreages. These nine optimal allocations were obtained using the 10-year average water yields for each time period and sub-basin. The recreational use of water was the primary source of benefits in all of these allocations. Comparison of the net benefits obtained from these nine different allocations illustrate that for the total basin some possibilities exist for trade-offs between release requirements and acres of irrigated crops while maintaining total benefits at a relatively constant level. The results also illustrated that the net benefits of each sub-basin were affected directly by the different allocations.

In addition to the nine optimal allocations discussed in the preceding paragraph, 10 more optimal allocations were obtained using water yields for each sub-basin and time period from 10 successive years (1961 - 1970). These solutions were obtained using the 10-year average minimum water release requirement and the acres of crops irrigated with surface water in 1968. In only three of the 10 years, 1961, 1967 and 1970 did the storage level in any of the sub-basins fall below the mean levels. Also, considerable differences were found in the storage levels for each time period for the 10 allocations using actual yields as compared to the storage levels using the 10-year average yields.

In all of the allocations, none included as part of its optimal allocation the storage of water above the regulated level. Therefore, no flood damages were incurred. If mandatory release requirements are maintained at their minimum levels, the model indicates that for most years, irrigated acreage could be expanded considerably without decreasing recreational benefits. The estimated cost, in terms of benefits foregone, for water released in addition to that released using minimal release requirements ranged from \$3.99 to \$10.04 per acre-foot. These costs were quite sensitive to (a) the quantities per year of additional releases, (b) the time period in which water is released, and (c) the acres of each type of irrigated crop in the sub-basin.

A simulation model was developed for the upper portion of the Kissimmee River Basin. The part of the basin modeled corresponds to sub-basins I and II described in the linear programming model. The complexities of the system were, however, developed to a much greater extent in this model than in the linear programming model.

The simulation model included eight control structures and seven lakes, each with its own water level regulation schedule (rule curve) specifying desired water levels on a daily basis throughout the year. Each of the seven lakes had one or more drainage sub-areas from which it received runoff water. The hydrologic aspects of the model consisted of rainfall for each drainage area being calculated on twelve minute intervals. These rainfall data were then used as input to the runoff model which calculated amounts of water inflow to each lake for each six-hour period. The runoff data, along with the lake elevations and daily water level regulation schedules were used to compute the eight control structure gate settings on six-hour intervals. From the hydrologic part of the model, average daily lake levels for each of the seven lakes were used to compute allowable irrigation water withdrawals for irrigation and municipal water uses, recreational use levels and flood damages for high water. These daily data were then used to calculate the annual levels of each activity and annual benefits and costs accruing to the management of water.

The simulation model was run using hydrologic input data for three consecutive years starting June 1, 1968 running through May 31, 1971. The simulation model was run using the present operating schedules for each lake. The annual economic benefits and costs were generated for each lake. As in the linear programming model, the largest source of benefits was from recreational uses of water, with irrigation benefits being the next largest. The benefits from domestic demand were insignificant in terms of dollar benefits as were the flood damages. There were, however, relatively large amounts of variation from year to year in all of the benefits.

In order to examine a proposed change in the policy regarding regulation schedules the same three years were simulated using a regulation schedule which called for a one foot lower elevation in each lake each day. The results showed a significant decrease in both benefits and flood damages for all three years, but the reduction in benefits during the third year (which was abnormally dry) were quite significant. Very definite water shortages occurred in three of the lakes. A third water level regulation schedule with proposed changes in the regulation schedules for four lakes and the other lakes with their present schedules was evaluated. This schedule has been considered by the Central and Southern Florida Flood Control District. The only changes of any consequence were in the recreation and irrigation benefits. For the three-year period the recreation benefits increased over those obtained when the original rule curve was used, and the irrigation returns decreased. Total benefit changes were, however, less than $100,000 for the three years. The effects of a regulation schedule specifying constant lake levels set at the highest elevation on the present schedule was also evaluated. Irrigation and recreation benefits increased substantially, but there was also a substantial rise in flood damages. The net benefits increased appreciably.

Different policies regarding consumptive water use withdrawals and minimum outflows were also investigated. The consumptive use withdrawal policies that were studied did not yield substantially different results in terms of net benefits. However, net benefits were found to be sensitive to the minimum outflows.

The two types of water management models demonstrated in this study can serve different purposes. The simulation model is best suited for developing and evaluating specific operational policies. The linear programming model is better suited for assessing effects of broad operational policy alternatives and for determining optimal choices.

The linear programming water allocation model has the advantage of determining optimum allocation solutions with respect to uses, time and location subject to physical and institutional constraints. The input data requirements for such a model are relatively simple, and in addition, if one chooses as the objective function the maximization of economic benefits, the costs of trade-offs between water uses in time and space can be obtained in the results. This model also provides a relatively easy comparison of changes in economic benefits from alternative optimal allocation due to changes in physical or institutional constraints or changes in the level of water using activities.

One of the limitations of the linear programming type of models is the inability to relate economic costs and returns to each of the water using activities to periods of time sufficiently small to reflect fluctuations in water yield and runoff. The unit of time used in this type of model is usually one month (or at best 2 weeks) or longer. This type of model is also restricted to linear coefficients. Another limitation is the inability of the model to capture the incremental aspects of the decision making process with respect to time. For example, the hydrologic yields for each time period are required as input data and these data are never available to the decision maker in a realistic situation. The linear programming model provides only limited information regarding specific operational policies for managing the water to achieve optimal allocations.

The complexities of the water management system were developed to a much greater extent in the simulation model. Specific rainfall, runoff and lake state relationships were included in the model. One of the advantages of the simulation model is that these relationships do not have to be specified in linear form. The simulation model also has the advantage that it can be adapted to provide specific operational water management information. The effects of a change in the water regulation schedule can be easily determined. The simulation model was interfaced with the Flood Control District's physical model while the accumulation of output from the FCD's physical model for each time period was used in the linear programming model. The simulation model also has the advantage that short time intervals can be used. In this study rainfall input data was based on 12-minute time intervals.

The greater detail that was built into the simulation model does provide more specific operational information, but more specific data and data relationships are needed as input to the model. The advantages of specifying changes in operational policy are also offset by the fact that the simulation model does not choose the optimal solution. Other techniques must be used with the simulation model to determine the optimal allocation.

This study has demonstrated the feasibility and usefulness of water management system modeling as a method to provide information for selecting water management policy alternatives for existing water management institutions. In addition, the concepts of the system modeling approach for obtaining policy decision making information is far-reaching in its ability to provide detailed and timely information.

The simulation model, because of its detailed approach, lends itself to the refinement of operational policy for individual basins. An area as large as the entire FCD could be modeled. But, rather than construct one large model of the entire region with as much detail as the simulation model in this study, it seems better to work on individual basins. Each basin model could then be tied together by a larger, much less detailed model of the entire FCD. This large model could be a linear programming model or a more aggregated simulation model and would be used to consider broad policy alternatives. The reduced number of alternatives could then be submitted to the individual basin models and shaped into final operational policy for each of the basins.

With respect to the management of the water system controlled by the Central and Southern Florida Flood Control District, this study has provided adequate indications that efficient operational policies within the FCD may not be possible without integrating at least part of the modeling techniques developed in this study into their water management policy selection process. Such alterations in the policy selection process would require (a) collecting, analyzing and augmenting necessary data, (b) developing, running and modifying system models on large, high-speed computers, and (c) analyzing and interpreting the results for decision makers.

This study has pointed out some critical data shortages which should be corrected regardless of the future use of the modeling techniques. Of critical importance is the lack of data regarding the use and value of the publicly owned lakes and streams in this state by recreationists. Accurate data regarding the demand for flood protection and the costs associated with various flood-stage levels are also seriously inadequate. Likewise, better data on the demand for and the value of water used by municipalities and industries are needed.

This study has also illustrated the need for more generally applicable techniques for determining the value of water in alternative uses. Further, the techniques which do exist are inconsistent in the standards of value used for measuring the net benefits from the different uses of water. For example, replacement costs were used to measure flood damages, while the value of the recreational use of water was measured in the amount of consumer's surplus accruing to recreationists.

The refinement of techniques for determining the value of water in alternative uses and the collection of additional data would enhance the usefulness of water management system modeling for decision makers.

APPENDIX A

THE RECREATIONAL USE OF WATER

Two types of recreationists utilize the water in the Kissimmee River Basin. These are (1) recreationists living on waterfront property (permanently or during vacation and holidays), and (2) those traveling to the area primarily to engage in recreational activities from publicly accessible facilities. For both types of recreationists the primary water-based activities include fishing, waterskiing, boating and swimming. Visiting recreationists also enjoy camping.

Procedures used in this study to estimate the annual value of recreation included interviews with both types of recreationists. To maintain as much homogeneity as possible, recreational activities were analyzed for each of the four time periods: (1) June-September, (2) October-November, (3) December-January, and (4) February-May.

The procedures for estimating recreational value will be discussed first for visitors utilizing public facilities and then for waterfront residents. Many recreationists visit the Kissimmee River Basin from nearby residences, other parts of Florida and from locations outside the state. To evaluate the economic significance of water to recreational visitors, a demand curve showing willingness of users of the area to pay measurable sums for specified amounts of recreation will be estimated. Before presenting the model used in this study to estimate the demand for recreation, it may be helpful to review the fundamental concepts of demand analysis.

Demand Analysis

The objective of the consumer is to maximize his satisfaction, subject to a constraint -- the amount of money that he has available to purchase the goods and services that he desired in a given time period. It is also assumed that the consumer prefers to have as much of the goods and services as possible. A demand curve is a schedule that shows the various quantities that the consumer will purchase at various prices. A good explanation of the derivation of the consumer's demand curve is presented by Reiling, Gibbs and Stoevener [24].

An individual's demand curve for a commodity, Q_1, is illustrated in Figure A-1. When the price of Q_1 is 2, the consumer will purchase 5 units of the commodity. When the price of Q_1 increases to 4 and 6, the individual will purchase only 3 and 1 units, respectively. Thus, as the price of Q_1 increases, the consumer purchases less of the commodity. The market demand curve for a good or service is obtained by horizontally adding the demand curves for all individuals in the market.

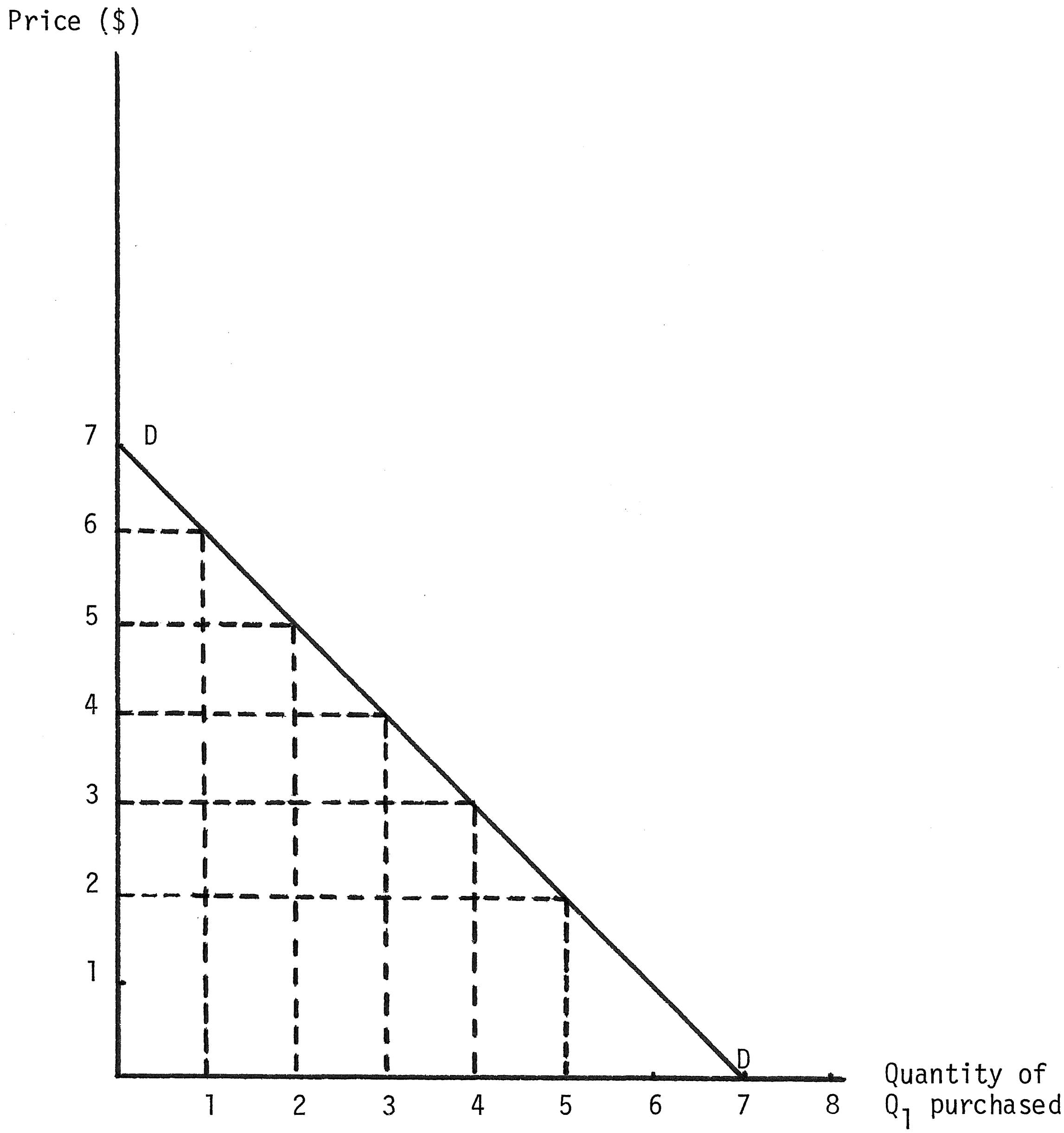


Figure A-1. -- The consumer's demand curve for commodity Q_1.

The concept of consumer's surplus needs to be discussed before introducing the demand model for recreation. Assume that the consumer pays a price for a commodity that is less than or equal to the benefits he receives from that commodity. This can be illustrated by an individual's demand curve DD, as shown in Figure A-1. Assume that the market price for the commodity is two dollars. At that price, the consumer demands five units of the commodity. He pays two dollars for each of the five units of the commodity. However, the consumer's demand curve shows that he would be willing to pay more than two dollars for the first unit of the commodity. In fact, the consumer would be willing to pay six dollars. However, since the first unit, like all other units, is sold at the market price of two dollars, the consumer receives six dollars worth of satisfaction for only two dollars. Thus, he enjoys a "surplus" by receiving excess benefits from the first unit. The same situation exists for the second, third and fourth units of the commodity. The consumer is paying less, and those units of the commodity result in a surplus to the consumer. The difference between the price the consumer is willing to pay for the units of the commodity and the price he actually has to pay for them is called "consumer's surplus." Consumer's surplus is used in this study to estimate some of the values associated with the demand for outdoor recreation.

Value of Water to Recreational Visitors

Demand for recreation, in the absence of an efficient market, has been estimated in two ways: the direct and indirect methods. In the direct method, the recreationist is asked how much he would be willing to pay for a specified amount of recreation. The indirect method (utilized in this study) involves estimates of willingness to pay for recreation by observing the amount a recreationist actually spends in order to participate in a recreational experience.

Total recreational usage of an area was defined as the product of the number of days a recreationist uses a recreational site per visit and the number of visits to a recreational site:[1]

$$\frac{\text{days}}{\text{visit}} \cdot \frac{\text{visit}}{\text{time period}} = \frac{\text{total recreational usage}}{\text{time period}}$$

[1]Recreation "visitor-days" and recreation "visits" are defined by the U.S. Forest Service as follows: (1) "A recreation visitor-day consists of 12 visitor-hours, which may be aggregated continuously, intermittently or simultaneously by one or more persons. The visitor-hours contained therein must be spent by persons in any activities, except those which are a part of or incidental to the pursuit of a gainful occupation;" (2) "A recreation visit is the entry of any person upon a site, or area of land or water, generally recognized as an element in the recreation population. Visits must be made in order to engage in any activities, except those which are a part of, or incidental to, the pursuit of a gainful occupation." [10]

The number of days per visit can be considered the quantity variable in a demand relationship and the daily on-site costs a price variable. The aggregate demand for recreation can then be derived by expanding this average demand relationship for individuals according to the number of visits.[2] For purposes of this study, it was assumed that the impact of water level on recreational values can be measured by the number of visits rather than the length of stay per visit. Thus, a value per visit was estimated and the relationship between water level and visits was utilized to relate water level to recreational value.

Theoretical Model

The theoretical model for the length of visit relationship is based on traditional concepts of consumer behavior theory. In order to participate in an outdoor recreational experience, the recreationist will incur two types of costs. A recreationist will pay a certain cost (on-site costs), C, while consuming recreation and he will incur travel costs (fixed cost), T, in order to get to the recreation site. It is assumed that it is necessary to pay a certain charge, T, before consumption of recreation, Y, is possible, The charge, T, is not dependent on the quantity of Y purchased. It can be considered a payment for the privilege of purchasing Y.

The travel cost includes transportation costs, the cost of food and lodging enroute to the recreation site and other costs. The cost of travel to the recreation site, T, competes with the cost of recreation and all other goods consumed. Therefore, the budget constraint faced by the consumer is:

$$m = CY + T + Pq \qquad m, C, P \geq 0 \qquad Y, T > 0 \tag{1}$$

Where m is income of the recreationist, C is on-site costs, Y is number of days per visit at the site, T is travel cost, q is all other goods consumed and P is price of all other goods.

By rearranging Equation (1) as follows:

$$m - T = CY + Pq \tag{2}$$

the budget constraint shows how the travel cost, T, affects income. By consuming Y, the recreationist will have less income available than if he only consumed q. The travel cost, T, will be zero if no recreation is consumed since any amount of recreation will generate some travel cost.[3]

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[2]An alternative method of deriving aggregate demand would be to relate the number of visits to price and other relevant variables and then to solve simultaneously with the days per visit relation. This method was not used because of inadequate data.

[3]This is true even if an individual walks to a recreation site. His travel cost, in this case, is very small but is still positive.

On-Site Costs

A change in the on-site recreation costs, C, and the cost of other nonrecreational commodities, P, will have an effect on the quantity of recreation days per visit. A change in C or P will result in a change in the slope of the budget constraint line since the slope of this line is equal to the ratio of the two prices.

Figure A-2 illustrates the effect on on-site costs on the quantity of recreation demanded. U_0, U_1 and U_2 are indifference curves. They reflect different combinations of recreation, Y, and nonrecreation, q, that yield equal satisfaction (utility) to the recreationist. That is, the recreationist is indifferent between combinations of Y and q that lie on the same indifference curve. The recreationist's utility function defines his indifference curves [24]. U_0, U_1 and U_2 are only a portion of the indifference curves that are defined by the utility function.

In Figure A-2, travel costs, T, the level of income, m, and the price of other commodities, P, are held constant at T^o, m^o and P^o, respectively. Only C is variable so that the effect on C on the quantity of recreation days per visit demanded can be seen.

On budget line, BC^o, the recreationist would prefer not to consume any recreation since he could achieve a higher level of utility, U_1, by foregoing recreation and consuming m^o/p^o units of nonrecreation. The recreationist could achieve this higher level rather than the point $\frac{m^o - T^o}{p^o}$ since any recreation involves a cost T^o that must be incurred before any recreational activities can occur. If no recreation is consumed then the potential recreationist has T^o more dollars of income to spend on nonrecreation units. This causes a discontinuity in the budget constraint. A decrease in C from C^o to C' is represented by the budget line BC'. After the price decrease, the utility level of U_1 can be obtained in two ways. First, the recreationist can consume no recreation and be at the point m^o/p^o or he can consume $Y = Y^c$, $q = q^c$. The recreationist would be indifferent between the two choices since he would remain at the same utility level regardless of his decision.

Decreasing on-site costs further gives the budget line BC". This will change the optimal budget to $Y = Y^d$, $q = q^d$. Thus, as the price of recreation (on-site costs) decreases, the quantity of recreation (days per visit) demanded increases. At any value of C where $C < C'$, the recreationist will prefer to consume a combination of recreation and nonrecreation commodities rather than solely nonrecreation commodities. For any value of C where $C > C'$, the consumption of recreation would be excluded from the budget, i.e., any budget line to the left of BC'. The price of a recreation unit

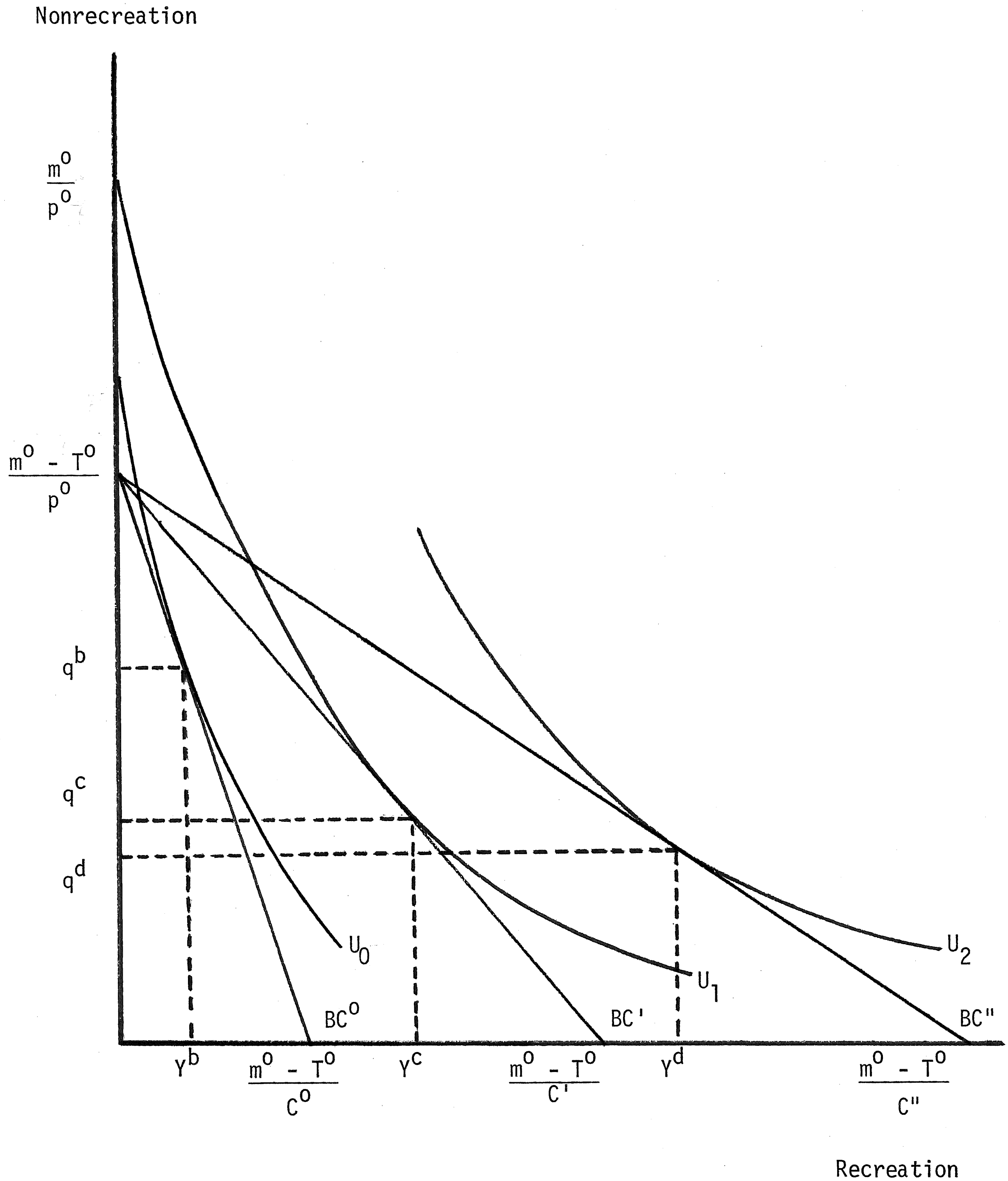

Figure A-2. -- Optimal combinations of recreation and nonrecreation commodities for a consumer faced with various on-site costs.

at the point where a recreationist is indifferent between recreation and nonrecreation, C', in this case, is defined as the "critical" on-site cost (C^*). The effect of a change in C on the amount of recreation will depend on the magnitude of the difference between C and the critical price (C^*). The critical value of the on-site recreation cost, C^*, depends on the level of income, m, the price of other commodities, P, the cost of travel, T, and the utility function, U.[4]

$$C^* = C^* (T, P, m, U) \tag{3}$$

Travel Costs

A change in the cost of travel will be viewed in a different manner than a change in on-site recreation costs due to the fact that a travel cost must be incurred before any recreation is consumed. By varying the travel cost, T, a different budget constraint is imposed for each value of T. Equation (2) indicates that high levels of T leave less income to be spent on recreation, Y, and all other quantities, q, whereas lower levels of T will make more income available.

It can be hypothesized that as travel costs decrease the amount of recreation (and nonrecreation goods) will increase within a certain range due to the effect of more income being available for the consumption of Y and q. This is because a decrease in travel costs can be looked upon as an increase in income.

At a certain level of T, the potential recreationist is indifferent between consuming recreation and not consuming recreation. This level of travel cost has been labeled the critical travel cost, T^*. It is so designated since at a level of travel cost below T^*, the recreationist will consume some level of recreation in order to maximize his utility while at a level above this cost, he will not consume any recreation.

The value of T^* is expressed as a function of four independent variables:

$$T^* = T^* (C, P, m, U) \tag{4}$$

That is, the critical travel cost, T^*, depends on the variable on-site recreation costs, C, the cost of a unit of other commodities, P, the income of the recreation group, m, and the utility function, U.

The theoretical model can now be written as three equations: the quantity of recreation demanded per visit, the critical travel costs and the critical on-site recreation cost.

$$Y = Y [(T^* - T), (C^* - C)] \qquad \text{for } (T^* - T) \geq 0, \ (C^* - C) \geq 0 \tag{5}$$

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[4]The recreationist's preference between recreation and other goods is specified by his utility function.

$$T^* = T^* (C, P, m, U) \tag{6}$$

$$C^* = C^* (T, P, m, U) \tag{7}$$

Data collected from recreationists using the Kissimmee River Basin in 1970 were used to estimate these relationships. These data were collected via questionnaire and used to derive the variables and estimate the coefficients in Equations (5), (6) and (7). A discussion of the sampling procedure used to secure a representative sample of recreationists and activities is presented in the following section.

Selection of the Sample

The Kissimmee River Basin was divided into the upper, central and lower sub-basins corresponding to their geographical location from north to south. Within each sub-basin, lakes were chosen to collect data on the water-oriented outdoor recreation activities. Lakes to be included in the sample were chosen to represent a cross-section of all outdoor recreation activities that take place within the basin. Proportional sampling was used to select the recreational sites. Recreationists were then randomly selected to obtain the information needed to estimate the equations of the theoretical model. Based on information from our studies in other areas it was estimated that the sample size would need to be approximately 1,000. It was then necessary to divide the sample according to time periods and recreation sites.

The number of boats which passed through navigational locks on the Kissimmee River were used to estimate the percent of use by time period. Independent estimates by the Florida Game and Fresh Water Fish Commission Wildlife officers confirmed the data. The percent and use by time period was estimated as: June-September, 25 percent; October-November, 26 percent; December-January, 14 percent; and February-May, 35 percent.

Some measure of the intensity of use for each selected lake and site was needed to properly allocate the sample. Information provided by the Florida Game and Fresh Water Fish Commission was used to estimate the intensity of use at selected sites and public access points on the selected lakes. From this data the number of interviews to be collected at access points for each time period was computed. The allocation of interviews by access point and time period is presented in Table A-1.

The use of these sites is likely to be different on weekends and holidays than on weekdays. Data from Moss Park indicated that approximately three times as many people used the park on weekends than on weekdays.[5] Therefore, weekends and holidays were weighted by three in allocating the number of interviews for a particular site according to weekends and holidays versus weekdays. This resulted in an estimated

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[5]Moss Park, a park owned and operated by Orange County and located at Lakes Hart and Mary Jane, has kept daily records of visits for several years. From these records the number of weekday and weekend visitors was obtained.

Table A-1. -- Number of interviews for each lake grouping by time periods for each access point, Kissimmee River Basin

Lake group	Access point	Interviews per time period 1	2	3	4	Yearly total
		---------- Number ----------				
Kissimmee, Hatchineha, and Tiger	Mack	34	36	19	48	137
	Lester	28	30	16	40	114
	Oasis	14	15	8	20	57
	Port Hatchineha	24	25	14	34	97
	Marie	14	15	8	20	57
	S-65	14	15	8	20	57
	Tiger Fish Camp	4	5	2	6	17
	Pennington	3	3	1	4	11
	Grape Hammock	1	1	1	2	5
	Kissimmee Park	3	3	1	4	11
	Shady Oak	2	2	1	2	7
	Subtotal	141	150	79	200	570
Lake Tohopekaliga	Scotties	15	16	8	21	60
	County Ramp	10	10	6	14	40
	Red's	6	7	4	9	26
	Jannis	8	8	4	10	30
	Bank fishing	1	1	1	1	4
	2-lane ramp	2	3	1	4	10
	3-lane ramp	5	5	3	7	20
	Yacht Club	2	3	1	4	10
	Subtotal	49	53	28	70	200
Mary Jane and Hart	Moss Park	18	18	10	24	70
Kissimmee River	Joe and Wanda's	16	17	9	22	64
	O'Kissimmee	12	13	6	17	48
	FCD Camp (North)	8	9	4	11	32
	FCD Boat Ramp	4	4	2	6	16
	Subtotal	40	43	21	56	160
Total		248	264	138	350	1,000

56 percent of the use of the area occurring during weekends and holidays and 44 percent of the use occurring during the weekdays.

This sampling procedure was used to accurately estimate the outdoor recreational activities on a proportional basis. The proportional sampling procedure was designed by determining the percentage of total use by time periods, lake groupings, interview sites and finally, by weekends and holidays or weekdays. By determining the proportion of use for these various areas, it was felt that a better cross section of all activities that occur along with the intensities of the activities were accurately reflected by the sample.

Explanation of the Variables

The data from the interviews were used to calculate economic and sociological variables that are necessary to estimate economic value. A large number of variables could be developed from the questionnaire data. However, only the following variables were utilized in this portion of the study:

Y = length of recreationist's visit (days)

T = travel costs

C = on-site costs

m = income

n = size of recreation group

s = site characteristics

Length of recreationist's visit (Y)

The number of recreation days per visit was determined by asking the recreational group when they arrived and when they planned to leave. The time of arrival and departure was used to determine the total number of days and hours the recreational group planned to stay at the site. To avoid a problem in terminology a recreation day was defined as a 12-hour period. For example, if a group of 5 recreationists visited a site from 6:00 a.m. until 6:00 p.m. on the same day, this would constitute 5 recreation days.

Recreationists were also asked the minimum amount of time they would spend at the site considering the cost and distance traveled getting to the recreation site and the time involved. In a very few instances due to unforeseen circumstances some recreationists actually spent less time at the recreation site than they stated as a minimum. Where this occurred the questionnaire was not used or the minimum number of days was set equal to the actual days spent at the site. Some of the circumstances which created these few situations were severe weather conditions, accidents and other unforeseen events.

In preliminary analysis of the data there appeared to be two separate sample groups. These two groups were those recreationists that spend more than 90 days at the recreation site and those that spend less than 90 days.

The group that spent over 90 days was removed from the analysis since it was felt that they did not fit the definition of a visiting recreationist for purposes of this study. This group contained observations which were characterized by low incomes and retirement ages and thus fit more closely the definition of a seasonal resident than a recreationist. With these observations removed, the total usable observations from the sample were reduced to 950.

Travel costs (T)

The cost of travel to get to and from the recreation site included food and lodging enroute and the cost of operation of vehicles that transported the recreation group to the site. The amount of food brought from their homes for consumption enroute, food purchased while enroute, the length of trip in days or hours and the cost of lodging enroute whether in the form of camping or motel fees were used in determining the cost of food and lodging enroute. To calculate vehicle cost the point of origin of the trip was determined so that a distance from the point of origin to the recreation site could be ascertained. The cost of operating the vehicle was estimated to be seven cents per mile.[6] Transportation costs plus the total costs of the group for lodging, meals and other miscellaneous items in travelling to and from the site were added to calculate travel costs for the group, T. In order to be more accurate in determining the cost of food enroute, the cost of food that would have been consumed at home was subtracted.[7] In some cases the cost of food eaten at home exceeded the cost of food enroute. This, of course, would give a negative travel cost if it were the only component. On perhaps a dozen interviews where vehicle costs were nonexistent and food costs at home exceeded food consumed enroute, a negative travel cost ensued. In no case did the costs amount to less than minus seven cents per person. Negative travel costs were not used in the study. For purposes of computation negative costs were set equal to $.01.

On-site costs (C)

On-site costs included the cost of food consumed at the site for all members of the group minus the estimated cost of food that would have been consumed at home. Camping fees, cabin rentals and motel costs were also

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[6]The seven cents per mile includes the cost of gas and oil for the trip plus minor maintenance. It does not include depreciation, taxes or insurance which would be incurred regardless of the decision to participate in a recreational experience or not [12].

[7]Cost of meals eaten at home was based on USDA estimates for various income levels [32, 33].

included in on-site costs. In addition any cost that was directly attributable to participation in the recreation experience was considered an on-site cost. This includes costs such as: launching fees for boats, rental of boat slips or dockage, rental of such items as skis, cushions, motors, boats and other articles. Also included in on-site costs was the cost of operating a boat. This was determined by asking the recreation group how many outboard motors they had and how many gallons of gas would be used per day. Multiplying the number of gallons of gas used per day by 42 cents yields the cost per day of operating the boat.[8] All of these costs were added and where applicable divided by the number of days at the site to give C, the on-site cost per day.

Income (m)

The recreationist's income was estimated by determining an income category that most closely corresponds to the family income of the respondent. The family income includes all working members of the family. It was felt that the total income of the recreationist's family would be more of a factor in recreation decisions than the income of the primary wage earner alone. Before tax incomes were used.

The actual income used in the analysis was the midpoint of the income ranges. As an example, $9,500 was used as the income for the $9,000-$9,999 range. The incomes given by the respondents were also used in determining the cost of food consumed at home since USDA estimates of the cost of food per day is given by income level of the consumer.

Size of recreation group (n)

The determination of the number of people in the group was by a direct question. In most cases the recreation group was a family group consisting of a father, mother and one or more children. In other cases the group consisted of scouts and similar groups. No distinction was made as to the composition of the group, however.

Site characteristics (s)

The utility variable in the critical travel cost equation, T*, and the critical on-site recreation cost equation, C*, may be represented by several other variables. Among surrogate variables that have been used in past studies are: the amount of recreational equipment owned by a recreationist, personal characteristics of the recreationist and the characteristics of a recreation site.

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[8]The average price of a gallon of gas plus the required oil for mixing outboard fuel amounted to 42 cents per gallon. This estimate was obtained from a range of costs given by marina operators and boat owners.

In this study the characteristics of a recreation site were utilized as a measure of a recreationist's utility. Some site characteristics that enter into consideration are the accessibility of the site, the facilities available at the site, the general climate of the area and the location of the site. These characteristics are fixed for each site but are variable when many sites are considered. The characteristics of a site determine whether the recreationists will consume recreation at the site and will determine in part the number of days spent at the site.

In this study many characteristics of the individual recreation site were determined, including the incidence of restaurants, cabins and campsites. Recreation sites were divided into three groups. Those with a high incidence of the characteristics that determine a site's desirability were placed in Group I. Group II contained those sites that had a medium level of desirable site characteristics while Group III had a low level of desirable characteristics. Sites that occurred in Group II perhaps had only a boat ramp or at most simple picnic facilities while those of Group I were characterized by restaurants, motel accomodations and other such amenities.

Application of the Model

The theoretical model can now be written as:

$$Y = Y\,[(T^* - T),\ (C^* - C)] \qquad \text{for } (T^* - T) \geq 0,\ (C^* - C) \geq 0 \tag{8}$$

$$T^* = T^*\,(C, m, s) \tag{9}$$

$$C^* = C^*\,(T, m, s) \tag{10}$$

Where s is the site characteristic and is used as a surrogate for utility, U. The three equations can be solved simultaneously to obtain a relationship between the independent variables in the T* and C* equations and the dependent variable Y.

The dependent variable (Y) is defined as the number of visitor days a recreational group spends at the recreation site per trip. Thus $Y = ny$, where y is the number of days per person per visit and n is the size of the recreation group. Since Y varies by two separate variables, a per capita equation to utilize a single dependent variable is:

$$y = y\,(t, c, m, s, n) \qquad \text{for } c \leq c^* \tag{11}$$

Where,

c = daily on-site costs per person

t = travel costs per person

m = income of the recreationist

s = site characteristics

n = number of persons in the recreation group

The impact of n on y was hypothesized to be of a curvilinear nature. Thus, $\frac{1}{n}$ was used as an independent variable rather than n. Due to prior evidence [10] that the demand function may not be linear, a semi-logarithmic regression equation was estimated where the dependent variable, y, was in natural log form and the independent variables were non-logarithmic. The estimated demand relationship is given as:[9]

$$\ln y = \underset{}{2.183} + \underset{(.0014)}{.0260^{**}}\, t - \underset{(.010)}{.051^{**}}\, c + \underset{(.000005)}{.00001^{*}}\, m \qquad (12)$$

$$- \underset{(.172)}{1.399^{**}}\, \frac{1}{n} + \underset{(.114)}{.229^{**}}\, D_1 - \underset{(.120)}{.258^{*}}\, D_2 - \underset{(.129)}{.368^{**}}\, D_3$$

$R^2 = .351$ Degrees of freedom = 942

The D_1, D_2 and D_3 variables represent zero-one variables to account for the differences among time periods. For example, D_1, helps explain how the demand relationship would be different between time periods one and four. The coefficient on D_1 indicates that one could expect recreationists to spend an additional 1.3 days (derived by taking the anilog of .229) recreating per visit in time period one (June-September) over time period four (February-May). Similarly, the length of stay would decrease in both periods two and three compared to four.

Equation (12) is applicable to all types of recreation sites in the Kissimmee River Basin. Due to the lack of a significant effect of site characteristics in the model, s was not used in the final formulation of Equation (12). It was concluded, from other estimated equations in this study that the recreationist paid little attention to the specific site characteristics in deciding the number of days he would spend at a recreation site in the Kissimmee River Basin.

Equation (12) contains on-site costs, travel costs, income, number of recreationists in the group and the effect of time periods. In this equation the sign of the coefficient of travel cost, t, is positive. This coefficient indicates that as travel costs increase $10.00 the recreationist will increase his stay at the site by 1.2 days (derived by taking the anilog of the product of (10) and (.026)). The negative sign of the coefficient of on-site costs, c, indicates that as the price of a day of recreation increases the number of days spent at the recreation site will decrease. An increase of $1.00 in on-site costs will result in a decrease in the number of days spent at the site of approximately 1.1 days. Both the coefficients of travel cost and on-site cost are significant at the 1 percent level.

The sign of the coefficient of m, the recreationist's income, is positive. This indicates that as income goes up, the number of days a recreationist will spend at the site increases. For example, a $1,000

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[9]Standard errors are presented in parentheses under the coefficients. ** indicates significance at the 1 percent level and * indicates significance at the 5 percent level.

increase in income would result in a one day increase in the time spent at the recreation site per visit. The coefficient of the variable $\frac{1}{n}$ is negative. The negative sign of the coefficient indicates that as the group size increases the number of days spent at the recreation site per visit increases. This can perhaps be explained by the fact that larger groups are usually family groups who are vacationing while individual recreationists usually spend only a few hours.

Equation (12) was simplified to illustrate the relationship between the quantity of recreation consumed (days at a site per person per visit, y) and various prices of recreation (on-site costs per person per day, c) with all other variables held constant. The demand curve for an average individual was determined by holding all independent variables in Equation (12), except c, at their means.

By using the mean values of t, m, n, D_1, D_2 and D_3 in Equation (12) and solving for the ln y in terms of c the demand function becomes:

$$\ln y = 1.929 - .051\ c \qquad (13)$$

The means of the dependent and independent variables are summarized in Table A-2.

Table A-2. -- Average values of variables estimated for outdoor recreationists in the Kissimmee River Basin, 1970

Time period	Days per visit (y)[a]	Travel cost (t)	Daily on-site cost (c)	Income (m)	Group size (n)	Minimum days per visit[a]
Feb.-May	7.95	20.16	3.25	11,782	3.07	4.01
June-Sep.	5.16	7.80	2.41	10,079	3.27	2.08
Oct.-Nov.	3.75	7.16	3.38	10,048	2.77	1.98
Dec.-Jan.	4.38	17.31	3.66	11,997	3.06	2.58
All periods	5.64	13.38	3.23	10,964	3.06	2.78

[a]Measured in terms of 12-hour periods.

Another component of the demand function for outdoor recreation is the critical on-site cost, c*. Critical on-site cost was estimated by obtaining the minimum numbers of days recreationists were willing to recreate, *ceteris paribus*. This corresponds to the maximum price they would be willing to pay on a demand curve. The minimum number of days, y*, was substituted into Equation (13) and solved for c. The minimum number of days, y*, was calculated to be 2.78 days for all time periods. The critical on-site cost, c*, was calculated to be $17.77. This is the maximum amount of on-site costs a recreationist would pay to engage in outdoor recreation given his travel and time commitment.

The demand function for recreation can be written as:

$$y = e^{1.929 - .051c} \qquad \text{for } c \leq \$17.77 \tag{14}$$

Equation (14) is derived with all independent variables held at their mean (except on-site cost). This includes D_1, D_2 and D_3. Thus, this relation is based on the average recreationist over time periods. If, however, the demand relation for a particular time period were desired, for time period four all D variables equal zero. The demand relation for time period four holding all other variables at a means appropriate to time period four, is:

$$y = e^{2.198 - .051c} \tag{15}$$

For period one, D_1 is set equal to one and D_2 and D_3 are zero. Similarly, for periods two and three, D_2 is one and D_3 is one, respectively. If an analysis of recreational values called for a particular time period, then it is preferable to use values of variables associated with that period.

By utilizing the mean values obtained in the demand function a graphical representation can be derived. The demand function for the average individual recreationist, on a per visit basis, in the Kissimmee River Basin during 1970 is presented in Figure A-3.

The value per visit is based on the theory of consumer's surplus and is the shaded portion in Figure A-3. Consumer's surplus is based on the concept that the price a rational person pays for something can never exceed the price he would be willing to pay rather than do without. In many cases the actual price he pays is less than what he would have paid. The satisfaction that he derives over and above what he gives up is surplus satisfaction. The measure of this satisfaction is the excess of the price which he would be willing to pay (measured by a demand curve) over what he actually paid. This concept of consumer's surplus was used in estimating the value of recreation.

The annual value per visit for the average recreationist can be calculated as:

$$\text{Value per visit} = \int_{3.23}^{17.77} (e^{1.929 - .051c})\, dc \tag{16}$$

$$= \$59.91$$

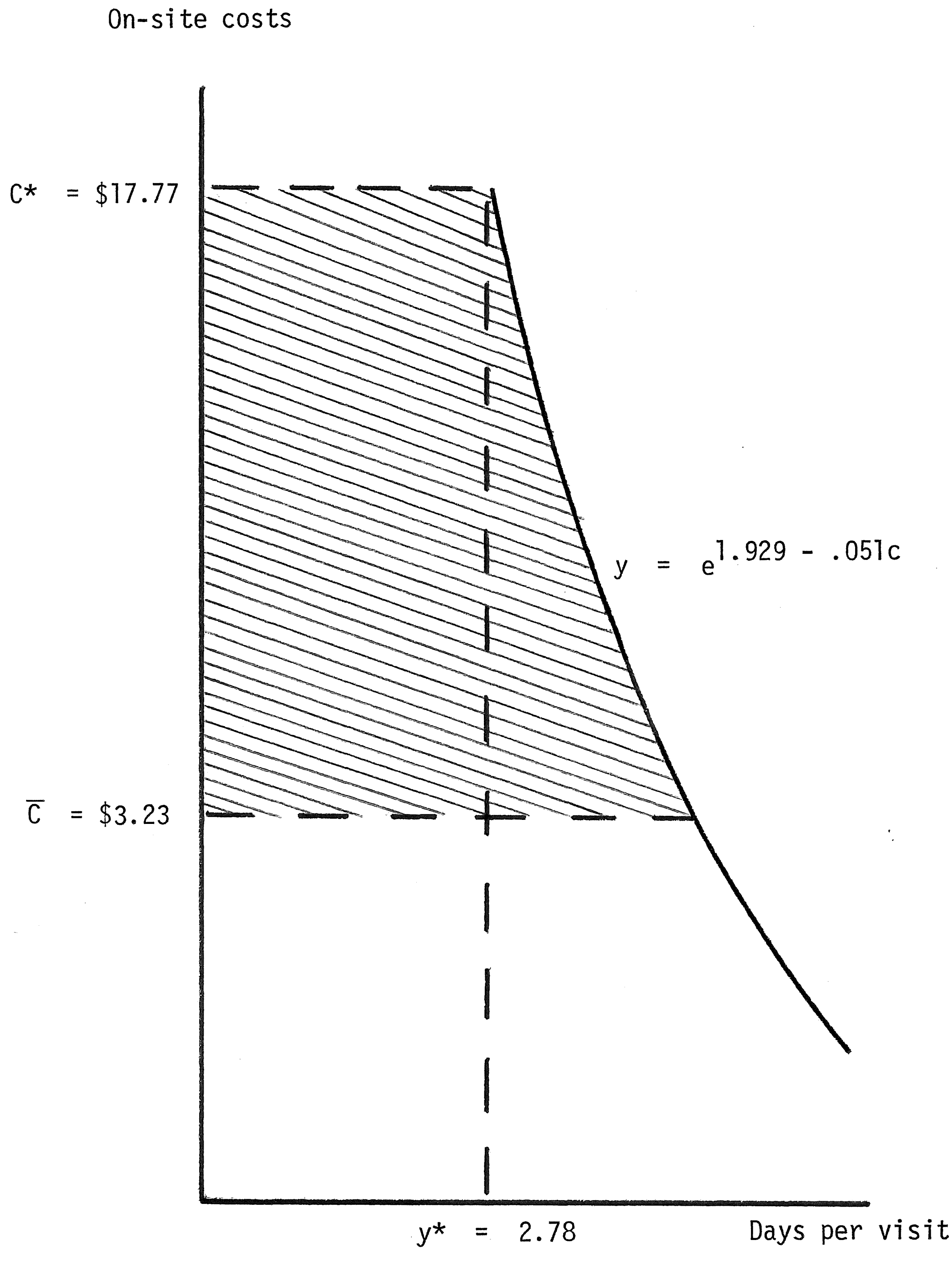

Figure A-3. -- Estimated demand function and consumer's surplus for an individual recreationist, Kissimmee River Basin, 1970.

The entire shaded area under the demand curve is included in consumer's surplus even though no recreation is consumed until the minimum number of days spent at the site is reached. If there were not a discontinuity due to the minimum number of days, the demand curve would intersect the on-site cost axis and the entire area would be included in consumer's surplus. Due to the discontinuity the curve is truncated.

The average annual economic value of a recreation visit in the Kissimmee River Basin was estimated to be $59.91. Travel cost, income and group size have influence on this value in that they jointly determine the position of the demand function. If incomes were to increase, for example, then the curve would lie further from the origin; thus the value estimates would increase. The exact impact of increased incomes can be estimated by utilizing the coefficient on the income variable in Equation (12). Similar effects can be estimated for the other independent variables.

The estimated consumer surplus per visit for each time period was:

Time period	Consumer surplus
1 (June-Sep.)	$100.42
2 (Oct.-Nov.)	$34.59
3 (Dec.-Jan.)	$38.29
4 (Feb.-May)	$71.03

As previously discussed, the demand estimate of interest for visiting recreationists is the aggregate demand for the total number of visitor-days per year. The preceding model is appropriate for explaining the number of visitor-days per visit. That is, it pertains to an individual, not to the population of users. The total number of visitor-days, and analogously the total economic value, can be obtained by multiplying Equation (11) by the estimated number of visits (V) to the basin during the year (or by each time period). The appropriate aggregate model can be specified as:

$$Vy = f\ (t, c, m, s, n) \qquad \text{for } c \leq c^* \tag{17}$$

The estimated number of visits will be discussed in the next section.

Visits Relationship

A procedure was developed to estimate the number of visits. In addition, the relationship between the number of visits and other factors, primarily water level, was estimated.

A multiple linear regression model was used to explain the relationship between the number of recreational visits to the Kissimmee River Basin and selected physical variables. The model was formulated as follows:

$$V = \alpha_0 + \alpha_1 W_L + \alpha_2 W_V + \alpha_3 R_a + \alpha_4 T + \alpha_5 D_1 + \alpha_6 D_2 + E \tag{18}$$

Where:

V = number of visitors per time period

W_L = water level

W_V = wind velocity

R_a = rainfall

T = temperature

$D_1 = \begin{cases} 1 \text{ for each observation in season I}^{10} \\ 0 \text{ for all other seasons} \end{cases}$

$D_2 = \begin{cases} 1 \text{ for each observation in season II} \\ 0 \text{ in all other seasons} \end{cases}$

α_i = regression coefficients

E = error term

It was also of interest to estimate a relationship between the total number of people visiting the area (V) and the actual number of people using the water for recreational purposes (X). It was hypothesized that the variables are positively correlated. The estimated equation can be used to predict the total number of recreationists during a set time period based upon the number of visitors observed recreating during one instant in time. The equation hypothesized in this study was:

$$V = B_0 + B_1X + E \tag{19}$$

Where:

V = number of visitors per time period

X = number of recreationists as observed by an overflight[11]

B_i = regression coefficients

E = error term

The observations for each variable in both models were accumulated into two week totals.

It was believed that three lakes could be chosen to adequately represent the river basin. The degree of usage and size of the lakes were used as the criteria for choosing the sampled lakes. Lake Gentry is representative of small lakes, Lake Marian medium-sized lakes and Lake Tohopekaliga large lakes.

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[10]Only three time periods were recognized in estimating the visits relationship due to the nature of the data. Time periods 2 and 3 were combined. Thus, season II now refers to October - January.

[11]An overflight consisted of observing the number of people recreating on each lake during an instant in time from a small airplane. This data was collected for each lake in the river basin at different times of the day on selected days over a period of one year.

Definition of Variables

The following sections will briefly discuss each variable used in the analysis. The empirical results from estimating Equations (18) and (19) will be presented following the discussion of the variables.

Number of visitors (V)

The dependent variable (V) is the estimated number of people using the lake facilities for recreational purposes. The use of a lake facility includes such activities as launching a boat from a ramp, waterskiing, swimming, hiking, fishing or just "passing the time of day" along the shoreline. Therefore, the variable V is an estimate of the total number of visitors (or visits) that attend the lake or its immediate surroundings to participate in a type of recreational activity, during a set time period.

The data to calculate the number of people utilizing the facilities of a sampled lake (V) were collected from a traffic survey. Traffic survey counters were placed at the eight public access points to fish camps and county boat ramps on Lakes Tohopekaliga, Gentry and Marian. Data from these traffic counters were used to calculate the number of visitors per time period [9].

Water level (W_L)

It was assumed that recreationists do react to variations in the water level of a particular lake, which is the main variable of interest. If the water level of a lake were too low or too high, it may be difficult or impossible for the recreationist to launch his boat. The Flood Control District is interested in how recreation activity varies with the level of water. If these relationships are determined, the FCD can use this information in the allocation of water. The nature of the relationship between recreational visits and water level is presented in Figure A-4. It was hypothesized that the number of visits would increase as water level increased from low water levels up to W_{L_1}; from W_{L_1} to W_{L_2}, the number of visits would not fluctuate with water level; and above W_{L_2}, which represents the maximum free storage level, the number of visits would decrease as the water level increases. It was only possible to test the first part of the hypothesis due to the lack of data furing flood conditions. It was possible to obtain from the Central and Southern Florida Flood Control District daily measurements in feet above sea level of water at the nearest lock of each of the three sampled lakes (see Figure 1).

Temperature (T)

Most recreationists become less interested in recreating whenever the temperature increases to the point where it is uncomfortable. Therefore, it was hypothesized that as the maximum daily temperature increases, the

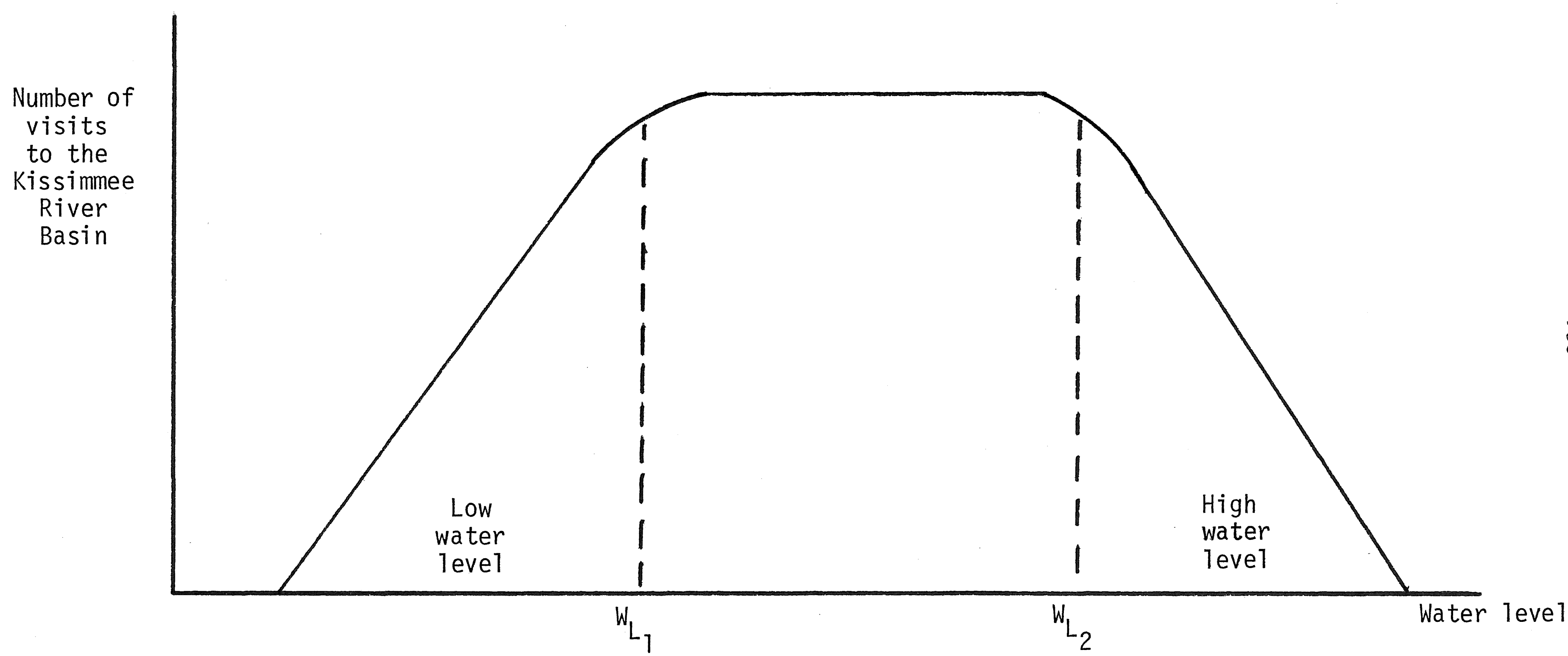

Figure A-4. -- Hypothesized relationship of water level to recreation-visits, Kissimmee River Basin.

number of visits to the river basin will decrease. It was impossible to attain an accurate temperature reading at each lake. The only data available concerning daily temperature was obtained from the U.S. Department of Commerce -- National Oceanic and Atmospheric Administration. The nearest location for gathering the highest daily temperature reading for Lake Gentry and Lake Tohopekaliga was at the Kissimmee Climatological Station; while for Lake Marian, the nearest was the Indian Lake Estates Climatological Station [34]. It was assumed that maximum temperature readings were the only readings that would influence recreational usage of the river basin. The other extreme point, the lowest daily temperature, was not considered relevant due to the general climate in this part of Florida and the type of recreational activities predominating.

Rainfall (R_a)

In most cases, rainfall has an influence on outdoor recreational activities. As rainfall increases only a few "enthusiastic" outdoor recreationists continue to engage in activities. Such recreational activities as picnicking and sports are usually disrupted by thunderstorms. Thus, it is hypothesized that as the amount of rainfall increases, the number of visits to the Kissimmee River Basin will decrease.

The measurement of rainfall at each individual sampled lake was desired but not available. Instead, a daily rainfall count at the nearest lock for each sampled lake was the measurement obtained. Rainfall was measured by two different methods. The first procedure to account for rainfall entailed measuring rainfall in inches per day during each time period, at each of the three locks. The second method consisted of determining the total number of days that rain occurred within the time period, at each lock. It is believed that the first method of measuring rainfall would prove to be more significant in the regression equation since recreationists are affected by the amount of rainfall rather than the mere presence of rainfall. In the Kissimmee River Basin rainfall occurs most frequently during season I but not for long durations. The water level data and all rainfall data were collected at the same locations.

Wind velocity (W_V)

As W_V increases beyond a certain point, it imposes restrictions on the maneuverability of soil boats and fishing lines and generally makes recreation less desirable. Therefore, it was hypothesized that as wind velocity increases, the number of visits to the river basin will decrease.

The data available at each lake concerning wind velocity was nonexistent. The only attainable data for the entire river basin came from Herndon Airport in Orlando, Florida [34]. It recorded the highest mile per hour reading, for each day, in the Orlando area. Thus, the same measurement had to be used for each of the three lakes.

Overflight counts (X)

The method for determining the number of visitors actually utilizing the water in the river basin for recreation was to employ overflight counts of the lakes during a particular time of day. There were a total of 48 flights during a period of one year. These data will be referred to as "overflight counts." It was assumed that the overflight counts should vary directly with V. Therefore, the more people visiting the facilities adjacent to the water, the more people there will be using the water for recreation.

While the overflight data were available for all lakes in the river basin, only the three sampled lakes were utilized in this portion of the study. The raw data actually consisted of a count of the number of people sighted on boats and shorelines of each lake in the basin. In order to sum the individual overflights to obtain an estimate of the use over a period of time, the data were adjusted [9]. The adjustment was necessary since there are more weekdays than weekends or holidays in a given time period. This adjustment was not applied to the traffic count data since it was collected over several weeks rather than at one point in time.

Statistical Models and Empirical Results

A recreational use equation was estimated for the three lakes. Also, a predictive equation was computed to estimate recreational use of a lake based upon the overflight counts. The selection of the final equations was based upon the extent to which it was believed to describe observed conditions and upon statistical indicators of significance. The statistical criteria included "t" values for individual variables, R^2, and "F" values for the function.

A zero-one dummy variable was used in the model to differentiate among the different types of lakes. Variable L_1 possesses a value of "1" whenever the data were collected from Lake Marian and a zero at all other times. Variable L_2 is the dummy variable for Lake Gentry. When estimating recreational usage of lakes, other than those sampled by the traffic survey, such characteristics as size of the lake, distance from population centers and depth of water should be considered in determining the proper value for L_i.

The estimated regression equation for recreational use was:[12]

$$V = \underset{}{-766.2} + \underset{(3.737)}{22.07^{***}} W_L - \underset{(54.35)}{85.98} R_a - \underset{(0.865)}{1.80^{**}} T \tag{20}$$

$$- \underset{(14.39)}{43.08^{**}} D_2 - \underset{(14.37)}{82.80^{***}} L_1 - \underset{(35.56)}{314.28^{***}} L_2$$

$$R^2 = .687 \qquad d.f. = 77 \qquad F = 28.14$$

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[12]Standard errors are presented in parentheses under the coefficients. ***, ** and * indicate significance at the 1 percent, 5 percent and 10 percent levels, respectively.

The statistical results support the hypothesis that recreational use of the lake varies directly with the water level and inversely with the physical variables temperature and rainfall. As water level (W_L) increases by one foot, recreational use of the lake is estimated to increase by 22.07 visitors. Recreational usage of the lake will decrease by 43.08 visitors between season II and the other seasons. The daily number of visitors decreases from Lake Tohopekaliga to Lake Marian to Lake Gentry by 82.81 and 314.28 visitors, respectively.

Overflight predictive model

This equation was derived to estimate the total number of visitors at a lake by the use of overflight counts. Data from all sampled lakes were utilized. The regression equation was estimated as follows:[13]

$$V = 98.73 + \underset{(.129)}{1.189^{***}} X - \underset{(15.32)}{27.594^{*}} D_1 - \underset{(16.69)}{33.968^{**}} D_2 \qquad (21)$$

$$R^2 = .554 \qquad d.f. = 80 \qquad F = 33.05$$

The coefficients for variables D_1 and D_2 indicate that recreational use decreases during season I to II. For each person observed by the overflight, it is estimated that 1.2 recreationists would utilize the facilities. The relationship established in this equation enables the estimation of recreational use by engaging an overflight. For example, in season III ($D_1 = D_2 = 0$) if 30,000 people were observed by the overflights, an estimate of total usage (based on this relationship) of 35,769 is obtained. To estimate the number of visitors from overflight data, it is only necessary to substitute a zero or one for the appropriate season into Equation (21).

Estimating Total Recreational Usage of the Kissimmee River Basin

The preceding models were applied to the total number of people using the sampled lakes. These relationships were developed to estimate the total number of people using the entire river basin during a particular time period. Traffic meter data were available only for three lakes. Therefore, these data could not be used to estimate the number of recreationists for the entire river basin. The relationship between the number of people using the three lakes and the total number of people using the river basin was established. The percentage of people using the three sampled lakes (P) was estimated from overflight counts.

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[13] Standard errors are presented in parentheses under the coefficients. ***, ** and * indicate significance at the 1 percent, 5 percent and 10 percent levels, respectively.

The total number of people using the river basin (V_T) was calculated by multiplying the number of people using the three lakes (V_i) by the factor $\frac{1}{P}$.

Thus:

$$V_T = \left[\sum_{i=1}^{3} V_i \right] \cdot \left[\frac{1}{P} \right] \qquad (22)$$

where i refers to the number of the lake. The estimated number of visitors to the Kissimmee River Basin is presented in Table A-3.[14]

Table A-3. -- Seasonal estimates of the total number of visitors to the Kissimmee River Basin in 1970

Season	Lake	Visitors at sampled lakes	Visitors in the river basin
		------------ Number	-------------
June-Sep.	Gentry	11,896	
	Tohopekaliga	23,592	
	Marian	8,508	
	Subtotal	43,996	134,957
Oct.-Jan.	Gentry	5,090	
	Tohopekaliga	27,568	
	Marian	10,351	
	Subtotal	43,009	186,186
Feb.-May	Gentry	11,488	
	Tohopekaliga	34,526	
	Marian	13,280	
	Subtotal	59,294	158,117
Total visits (V_T)			479,260

[14]Other methods could be utilized to estimate the number of visits for the entire river basin. For example, the proportion of access points on the three sampled lakes to the basin could be used. This was applied in [2].

The relationship between total recreational visits and water level can be formulated by combining Equations (20) and (22). Total visits (V_T) can be expressed as a function of daily visitation at each sampled lake (V_i), proportion of visits on sampled lakes to entire basin (P_j) and the number of days in each of the three time periods. By allowing L_1 and L_2 to be zero or one depending on which lake is being considered, D_2 equal to one during season II and holding the rainfall and temperature variables at their means, total visitations on a yearly basis can be expressed as a function of water level:

$$V_T = -3{,}962{,}699.23 + 81{,}219.81\ W_L \qquad (23)$$

If, for example the water were at a mean value (for the time over which data were obtained in this study) of 54.058 feet, one would expect approximately 428,000 visits annually. If the water level were at the maximum observed (61.57), about one million visits could be expected.

Estimates of Value to Visiting Recreationists

The value was estimated by combining the analyses of days per visit and number of visits.

$$\text{Total (Annual) Economic Value} = \begin{matrix}\text{Value}\\ \text{per}\\ \text{Visit}\end{matrix} \times \begin{matrix}\text{Number}\\ \text{of}\\ \text{Visits}\end{matrix}$$

where the number of visits was expressed as a function of water level. The value of recreation needed to be expressed as a function of water level for use in the allocation models. Combining Equations (16) and (23) gives an estimate of economic value relating to water level:

$$\begin{matrix}\text{Annual}\\ \text{Economic}\\ \text{Value}\end{matrix} = (\$59.91)\ (-3{,}962{,}699.23 + 81{,}219.81\ W_L) \qquad (24)$$

where $59.91 is the estimated value per visit. The annual economic value for a water level of 54.058 feet is estimated at $25.6 million, while at 61.57 feet it is approximately $62.2 million. The estimated relationship indicates that no economic value would be forthcoming, due to zero visits, at a water level as low as 48.79 feet above sea level. The lowest water level observed on Lake Tohopekaliga during an extreme drawdown was 47.74 feet. The above estimate, therefore, seemed reasonable.

To obtain estimates of value for each time period it would be necessary to utilize the demand curve and visit relationship for the particular time period. If the only estimates of interest are economic values, then the relationship of water level could be ignored; data in Table A-3 could be applied directly to values per visit from the demand relationship. The total annual value to visiting recreationists for 1970 were estimated to be $28.7 million [($59.91)(479,260)].

Value of Water to Waterfront Residents

This portion of the study was concerned with recreational data gathered from a sample of waterfront residents in the Kissimmee River Basin. The survey was designed to obtain information regarding property values, recreational activities of the residents, effects of different water levels on participation in different recreational activities and opinions of the residents regarding the value of lakefront property as compared to other types of property [6].

The survey results indicated that there were a total of about 984 lakefront dwellings in the Kissimmee River Basin, of which 800 were vacation homes or permanent homes and not part of commercial enterprises. Of these 800 residences, 56 percent were represented in this survey. Of the survey respondents, 25 percent were retired. Average age of the household head was 52 years, while the average income per household was $10,930. It was also found that 73 percent of the residences were permanent homes while the remaining 27 percent were seasonal or weekend homes.

The respondents indicated that the quality of water in the lakes was of primary importance and a source of much concern. In addition, they indicated that their primary reason for buying and/or wanting to live on a lake was for recreational purposes; the primary activity, as hypothesized, was fishing. Two other factors which concerned lakefront residents were the fluctuation of water level and the elevation and topography of residential sites.

In addition, data on the actual activities in which the respondents participated were obtained. The objective was to determine which activities (fishing, waterskiing, swimming and boating) were most popular, how often the residents participated and the variable expenditures associated with their use of the lake.[15] The survey respondents were asked to report the number of times they participated in various recreational activities during four time periods of the year. These activities included only those which originated from their waterfront property. The variable expenses involved in each activity during each time period were also obtained. These data are presented in Table A-4.

The average number of activity days per participating family was computed. This includes only those families that stated they participated at least once in the given activity in any of the four time periods.

The expenditures were for such things as gas, oil, bait and picnic lunches that were associated directly with recreational activities on the lake. It is assumed that the residents were willing to pay at least as much as the various expenses incurred. This represents an estimate of the

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[15] Ideally, it would be desirable to obtain enough information to derive a demand curve for recreational use of the water by waterfront residents. Due to the limited scope of this portion of the study, only actual expenditures were obtained.

Table A-4. -- Activities and expenditures on water-based recreational activities by waterfront residents, Kissimmee River Basin, Florida, 1970

	Activity	Time periods: June-Sep.	Oct.-Nov.	Dec.-Jan.	Feb.-May	Annual totals	Avg. expenditure per day (std. dev.)	Participating[a]
		Number						Percent
Days per participating family	Fishing (avg.)	44.42	21.42	19.90	44.22	129.96		89
	(std. dev.)	36.77	13.25	19.19	26.65	110.56		
	Boating (avg.)	24.06	9.60	8.78	19.41	61.84		57
	(std. dev.)	27.28	8.16	11.76	20.65	70.76		
	Swimming (avg.)	58.15	8.45	2.15	29.00	97.74		48
	(std. dev.)	46.61	12.73	10.77	25.94	86.77		
	Waterskiing (avg.)	32.87	5.66	2.93	14.86	56.33		29
	(std. dev.)	26.51	7.03	6.45	16.71	58.76		
		Dollars						
Expenditures per participating family[b,c]	Fishing (avg.)	175.90	84.83	78.80	175.11	514.64	3.96 (3.08)	
	Boating (avg.)	91.67	36.58	33.45	73.95	235.61	3.81 (3.17)	
	Waterskiing (avg.)	175.20	30.16	15.62	79.21	300.24	5.33 (2.96)	

Continued

Table A-4. -- Activities and expenditures on water-based recreational activities by waterfront residents, Kissimmee River Basin, Florida, 1970 (Continued)

Activity		Time periods: June-Sep.	Time periods: Oct.-Nov.	Time periods: Dec.-Jan.	Time periods: Feb.-May	Annual totals	Avg. expenditure per day (std. dev.)	Participating[a]
		-----	-----	Dollars	-----	-----		
Average aggregate expenditure	Per participating family[c]	442.77	151.57	127.87	328.27	1,050.49		
	Per interviewed family	286.37	98.04	82.70	212.31	679.40		

[a]The total respondents who reported that their family engaged in an activity at least once during one of the time periods.

[b]No expenditures were reported for swimming by survey respondents.

[c]These expenditures refer only to that segment of the respondents whose families actually engaged in an activity at least once during a particular time period.

value of water use privileges to the resident. The average expense was $679.40 per year for all interviewed families. Expenses for equipment and traveling to the waterfront residence, in those cases where the waterfront residence was not the permanent home, were not included. The average monthly expenditures were lowest in December and January and highest during the months of June through September.

By expanding the average expenditure of the residents surveyed in this study to the total population of all lakefront residents in the Kissimmee River Basin, an estimate of the total expenditure in the waterfront population can be obtained. It was estimated that there were approximately 800 lakefront residences in the Kissimmee River Basin. The recreational activities associated with waterfront residences in the Kissimmee River Basin amounts to an annual total expenditure of approximately $544,000 [11].

Lake Level Fluctuation

It was hypothesized that the fluctuation of the lake level was of primary concern to lakefront residents. In the survey, the effects on recreational activities of a fluctuation in the water level were obtained. The residents were asked to estimate how much the lake on which they lived fluctuated within a year. The average response was a fluctuation of 3.6 feet. This average figure varied considerably between sub-basins.

The perceived effect of a three-foot fluctuation in the water level on activities of lakeshore residents was obtained. Sixty-six percent of these respondents indicated that if the lake level dropped three feet below its minimum level for the past year they could not use the lake for recreation during that time. An additional 13 percent indicated that lowering the lake level three feet would reduce their activities but would not stop them completely. On the other hand, the remaining 21 percent indicated that the lake level falling three feet below its minimum would not affect their use of the lake at all. The variation in responses was due to factors such as the depth of the lake and the depth of canals through which the residents obtained access to the lake. The conclusion is that approximately 79 percent of the lakeshore residents would be significantly affected if the lake level were to drop three feet below its minimum.

Lakefront Property Values

Two methods of estimating the value of water frontage to residential property are presented. The first method uses multiple regression to analyze the effect of several independent variables, including water frontage on vacant residential lot sales. The second attempts to estimate the value attributed to water frontage from owners' estimates of the value of their property with and without water frontage. The survey of waterfront residents was conducted on the 30 lakes and streams of the Kissimmee River Basin. The data for the analysis of the sales of vacant residential lots, however, was obtained from only 9 of the lakes in the northern portion of the Kissimmee River Basin [7].

The two methods are not used in this study to estimate the same values. The real estate sales method was used to estimate the value of water frontage to vacant residential lots. Available market sales data were not adequate to estimate by this method the value of water frontage to property with residences. The resident survey method is only used for property currently occupied on a permanent or part time basis and thus includes the value of houses and other structures on the residential lot. Both methods were, however, designed to estimate the value of a typical property with and without water frontage.

Real Estate Sales Method

The objectives of this portion of the study were two-fold: first, to determine the portion of a typical vacant residential lot value (by actual sales of real estate) attributable to water frontage in the river basin; and second, to determine the significance of additional factors influencing the market for this type of residential property. Multiple linear regression techniques were used to analyze sales of vacant residential lots.

Factors affecting sales price

The sales price of a residential lot is influenced by many factors. The hypothesized model can be represented as:

$$Y = b_o + \sum_{i=1}^{11} b_i x_i \qquad (25)$$

Where:

Y = total sales price of vacant residential lots

x_1 = year in which the sale occurred (1966 = 1, . . ., 1970 = 5)

x_2 = lot size in number of acres

x_3 = presence (x_3 = 1) or absence (x_3 = 0) of lake frontage

x_4 = presence (x_4 = 1) or absence (x_4 = 0) of canal frontage

x_5 = miles to the nearest paved road from the lot

x_6 = number of utilities available in the subdivision

x_7 = percent of wood homes in the subdivision in which the sale occurred

x_8 = number of community services in the subdivision

x_9 = presence (x_9 = 1) or absence (x_9 = 0) of a boat ramp in the subdivision

x_{10} = presence (x_{10} = 1) or absence (x_{10} = 0) of a sand bottom in the lake adjacent to the subdivision

x_{11} = linear feet of the canal installed by the subdivision developer

A total of 316 actual sales were recorded in portions of Osceola and Orange Counties, Florida.[16] These observations were recorded only on vacant residential lots from actual sales during 1966-70. Only lot sales data from planned subdivisions with at least one waterfront lot, or other means of access to a canal or natural lake -- such as a subdivision boat ramp -- were considered. However, almost all subdivisions from which lot sales were recorded contained both waterfront and nonwaterfront lots. The sample included 197 lots with no water frontage (62%), 83 lots with only lake frontage (26%), 30 lots with only canal frontage (9%) and 6 lots with lake and canal frontage (2%). The other variables were measured by either personal observations or interviews of real estate personnel and/or owners of subdivisions.

In estimating the equations by means of multiple linear regression analysis, some of the independent variables were deleted from the equations. Examinations of the simple correlation coefficients indicated multicollinearity (a coefficient of .83) between the number of community services (x_8) and the occurrence of boat ramps (x_9). Due to this problem and the lack of statistical significance (together or separately) both variables were deleted. In addition, the occurrence of a sand bottom lake adjacent to the subdivision (x_{10}) and the length of canal (x_{11}) variables exhibited very low significance to sales value. These two variables were deleted from the final estimated equations.

The final estimated equation using total sales value of the residential lot as the dependent variables is:[17]

$$\begin{aligned} Y = \; & 863.85 + \underset{(2.65)}{102.75^{*}}\, x_1 + \underset{(33.88)}{342.89^{***}}\, x_2 + \underset{(183.71)}{3231.51^{***}}\, x_3 \\ & + \underset{(256.69)}{808.59^{***}}\, x_4 - \underset{(84.18)}{143.95^{*}}\, x_5 + \underset{(82.36)}{370.60^{***}}\, x_6 - \underset{(2.93)}{4.04^{*}}\, x_7 \end{aligned} \tag{26}$$

$$R^2 = .631 \qquad \text{d.f.} = 308 \qquad F = 75.23$$

Four of the seven independent variables possess coefficients significant at least at the 1 percent level. The coefficient for the number of acres (x_2) was positive as expected and indicates that for every additional acre, the total sales price would be expected to increase by \$342.89. The coefficient for x_6 indicates that each utility available in the subdivision, in addition to electricity, adds \$370.60 to the sales price.

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[16]In the vicinity of Lakes Mary Jane, Tohopekaliga, East Tohopekaliga, Alligator and Lizzy.

[17]Standard errors are presented under the coefficients. ***, **, and * indicate statistical significance at the 1 percent, 5 percent and 10 percent levels, respectively.

The year in which sales of residential lots occurred was significant only at the 10 percent level. The year of the sale was expected to exhibit more influence on the sales price. A steady upward trend in real estate prices has existed over the past several years; however, due to only five years in which sales were recorded for this study, the trend was not as significant as originally expected.

The coefficient of the distance to paved roads variable was negative as expected, but was significant at only the 10 percent level. It is believed that this is a relevant variable to include in a model of this type even though it is less significant than desired in this particular case. The small degree of significance may be due to the fact that only vacant lot sales were recorded. If residential structures had been present, a higher correlation would be expected between the distances to paved roads and property values. In addition, due to weather conditions and the fact that non-paved roads in this part of Florida are sand roads, it is not as important to have paved roads as in other parts of the country.

The percent of wood homes in the subdivision coefficient was significant at the 10 percent level. The fact that few houses were already constructed in the subdivisions when sales of vacant lots occurred may be an important determinant of the relative significance of this variable. If an area was extensively developed, with few vacant lots, the value of the housing surrounding the lots would perhaps play a more important role in determining the price of the lot.

The contribution to the sales price of property by each of the independent variables can be interpreted directly from the coefficients in Equation (26). By utilizing the coefficients of lake frontage (x_3) and canal frontage (x_4), the increase in the value of property resulting from these factors can be estimated. In Table A-5 the total sales price of a residential lot was estimated for four circumstances, for the year 1970 ($x_1 = 5$): (1) the presence of only canal frontage ($x_4 = 1$); (2) the presence of only lake frontage ($x_3 = 1$); (3) the presence of both lake and canal frontage ($x_3 = x_4 = 1$); and (4) neither canal nor lake frontage ($x_3 = x_4 = 0$). The difference in the estimated price with and without water frontage can be inferred to be due to the presence of water frontage. All other variables are held constant at their means so the influence of water frontage can be estimated.

It can be concluded, from this portion of the study, that in 1970, the presence of water frontage added an estimated $4,040 to the total value of residential lots. The effect of lake frontage only was estimated to be $3,232 while canal frontage alone added $809.

The most significant factors contributing to property value, found in this study, were the size of the lot in acres, the presence of lake frontage, the presence of canal frontage, the number of utilities available and the percent of wood homes in the subdivision. The variables in Equation (26) explained 63 percent of the variation in the total sales price.

Table A-5. -- Estimated sales price of residential lots with and without the presence of water frontage, 1970

Type of lot	Estimated total sales price	Value added by water frontage	
	--- Dollars ---	- Dollars -	- Percent -
Non-waterfront	1,797.23		
Lakefront only	5,028.74	3,231.51	64.3
Canal front only	2,605.82	808.59	31.0
Canal and lakefront	5,837.33	4,040.10	69.2

Resident Survey Method

Waterfront residents' estimates of their property values are presented in Table A-6.[18] When the residents were asked what they would sell their property for if it were put on the market today and what they would pay for their property if they were going to purchase it today, the difference in the average values reported was $4,660.

The source of this difference may be explained as follows: When the respondents were asked to name a price for which they would be willing to sell their property, the question was not meant to imply that most of the respondents wished to sell their property, for most indicated that they were not interested in selling. Thus, the average selling price of $27,370 probably represents a figure substantially above the market price for the property. That is, the respondents in answering this question indicated more of what if would take to get them to leave their property at the time of the interview than an estimate of market price. On the other hand, the response to the question relating to their willingness to pay for the property if they did not own it could be interpreted as a more realistic indicator of the true market value of the property at the time of the interview.

To get an indication of the value of the property that could be attributed to the presence of the lake, the respondents were asked to estimate their selling price if the lake were permanently drained and they were to sell the property today. The interviewers were instructed to probe the respondents on this question. The purpose of the probing was to make sure that the respondents had thought of the consequences of not

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[18]It should be noted that all of the arithmetic means of the estimated waterfront property values have relatively large standard deviations. Thus, these estimates as well as the differences between estimates may not be significantly different from zero in a statistical sense. The large standard deviations are the result of an unusually large amount of variation in the estimated property value, which ranged from 0 to $99,000.

Table A-6. -- Arithmetic means of lakefront property values reported by survey respondents, Kissimmee River Basin, Florida, 1970[a]

Situation	Average value	Standard deviation
	---------- Dollars	----------
Average selling price today	27,370	23,070
Average buying price today	22,710	18,670
Average selling price if the lake were permanently drained	14,250	13,710
Average selling price if the lake were permanently lowered three feet	19,140	19,790
Average buying price if the lake were permanently lowered three feet	15,710	18,970
Average selling price if the lake were subject to fluctuations	20,650	19,350
Average buying price if the lake were subject to fluctuations	17,000	18,780

[a]Buying price was not estimated for permanently drained lake, because information obtained in prior pilot surveys indicated that the estimated purchasing price would be zero in a large majority of interviews. That is, the residents indicated that they would not buy the property if it did not have lake frontage.

having the lake border their property. In response to this question, the respondents felt that they would be willing to sell their property for an average of $14,250. This figure represents 52 percent of the average selling price with the lake present, which indicates that the presence of the lake (in the opinion of the lakefront residents) contributes about 48 percent of the selling price of the property.

In order to ascertain the impacts of a substantially reduced lake level on property values, the respondents were asked to estimate the price at which they would be willing to buy their property if they did not own it and if the lake were permanently lowered three feet below the minimum lake level for the past year. The average of the responses was $15,710.[19] When the buying price, if the lake were lowered, is compared with the buying price of the property as it now exists, we find that the percent

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[19]Since the differences in the buying and selling prices were approximately 82 percent for each of the remaining questions, only the buying price will be discussed.

of the buying price after the lake is lowered would be only 69 percent of the reported present buying price.

Finally, the respondents were asked to name the lowest price they would pay for their property if the lake level were to be subject to fluctuations of up to three feet below its minimum level for the past year, one or two times per year for a duration of one or two months. This question was asked in order to ascertain the significance of the fluctuations of the water to extremely low levels but on a less than permanent basis. It was thought that since fluctuations of this magnitude would restrict activities during parts of the year and would present an unstable waterline for beaches and boat docks, that the residents should be able to estimate the effects of this type of water level fluctuations on their property values. The data indicated that under these conditions, the residents' estimated buying price would average $17,000. As indicated by the differences in the buying prices, the fluctuations of the water level to three feet below its minimum would reduce the value of the property to 75 percent of its current value. This figure compares with the reduction of about 69 percent of its current value if the lake were permanently lowered three feet.

The lakefront property owners believe that the property would be more valuable to them if the lake level were to fluctuate during the year rather than if it were permanently lowered. These results were somewhat as expected and indicate that any lowering of the lake either on a permanent or a variable basis would reduce the current value of the lakefront property (at least in the opinion of its current residents).

Comparisions of the Two Approaches

As was noted earlier the two techniques for estimating the value of residential property contributed by the presence of lake frontage are not measures of the same value, at least as they are used in this study. That is, multiple regression analysis was used only to analyze sales of vacant residential lots, while the survey of lakefront residents estimated only values of occupied lakefront property. It appears, however, that the two techniques could be used to estimate the same values.

Before making a decision as to which of the two methods to use in a given situation, several factors should be considered. A primary consideration should be the type of information desired. That is, from the resident survey method no information would be available on the magnitude and significance of the many other factors which contribute to the value of the property other than the ones which the respondents are asked to estimate. On the other hand, if the only information requested is, for example, the percent of value attributed to the presence of lake frontage, then the regression model is not needed to obtain this estimate. The percent of value added by the presence of lake frontage is 66 percent when estimated from the differences in the average of the observed sales prices of the lakefront and non-lakefront lots. This estimate is quite close to the estimate of 65 percent obtained from the regression model.

Another factor to consider when using the resident survey method is that when interviews are taken, one deals with a "personal value" of property which incorporates the attitude of an unwilling seller (since he holds the property) who is being offered a hypothetical price to induce him to sell his property. Personal value is determined by attitude which incorporates, among other things, a sentimental attachment factor to his property. Other factors (such as home and community) are included in his evaluation.

Other factors which should be considered before making a decision to use one of these two methods include the relative cost and availability of the data required by the two techniques. Also, the amount and number of sources of variation in the values of the property to be estimated should be considered. Generally, as the number of sources and amount of variation in the dependent variable increase, the amount of variation explained by multiple regression techniques decreases.

Regardless of the dissimilarities in the two techniques, it may be of interest to consider the differences in the estimates of the percent of the property values attributable to the presence of lake frontage. The real estate sales analysis shows that vacant lakefront residential lots would be worth only 35 percent of their current value if they were without lake frontage. The lakefront residents, however, estimated their property would be worth only 52 percent of its current value if it did not have lake frontage. The difference in these estimates may be attributable to the fact that the lakefront residents were reporting property with structures. That is, usually a large percentage of the total value of a house and lot is contributed by the house. Thus, the percentage of the total value that lake frontage contributes to a vacant residential lot would be expected to be larger than the percentage of total value that lake frontage contributes to a residential house and lot.

APPENDIX B

SURFACE WATER MANAGEMENT MODEL AND DATA

The surface water management model consists of a series of components describing the lakes, gate structures and canals and the manner in which they are used. Water surface elevation is a function of the quantity of stored water and the lake configuration. The relationships for the seven lakes were obtained using one-foot interval contour maps. The gate structure relationships were obtained empirically by the FCD. The canals, although actually having somewhat irregular bottom slopes and cross-sections, were assumed to have constant bottom slopes and uniform cross-sections throughout the length of each reach. Data providing cross-section characteristics at 200-foot intervals are available but would be expensive to use. The model for calculating the water surface elevations along the canal can easily accept these data if needed for greater accuracy.

Surface water available for irrigation and domestic consumption is controlled by the FCD. Very little surface water is presently used for either of these activities, and this is managed through permits. When large quantities of surface water are needed in the future, the amount allowed will have to be controlled, so the present study suggests the amount be a function of lake surface elevations or available storage. The functions used were given in Figure 19. The actual shape of these will be varied to determine the effect of different consumptive withdrawal policies.

In discussing the surface water management model, the lakes were designated L = 1-7, the structures J = 1-9 and the canals K = 1-13. The time interval is designated i. The following equations and data were used for each component.

Lakes

The lake surface elevation at the end of a time interval, $ST_{L,i}$, is a function of the water stored in the lake at the end of the previous time interval, $STOR_{L,i-1}$, and the net flow rate into or out of the lake during the time interval, or:

$$ST_{L,i} = s(STOR_{L,i-1}, QN_{L,i})$$

The net flow rate is found by using the general flow equation:

$$QN_{L,i} = SUBQ_{L,i} + QJ_{up},i - QJ_{down},i - ACWS_{L,i}$$

Where:

$QN_{L,i}$ = net flow rate for lake L in the time interval

$SUBQ_{L,i}$ = total runoff flow rate into lake L

$Q_{Jup,i}$ = flow rate into lake L from the upstream structure

$Q_{Jdown,i}$ = flow rate out of lake L through the downstream structure

$ACWS_{L,i}$ = flow rate of consumptive withdrawals for lake L

Water entering the lake from rainfall and water leaving the lake by evaporation is included in $SUBQ_L$.

The relationship between the water surface levels and lake storage is given in Table B-1.

Water Control Structures

The flow rate for a structure, $Q_{J,i}$, is:

$$Q_{J,i} = q(GO_{J,i}, HWS_{J,i-1}, TWS_{J,i-1})$$

Where:

$GO_{J,i}$ = gate operation of opening height for structure J during the time interval

$HWS_{J,i-1}$ = headwater elevation for structure J at the end of the previous time interval

$TWS_{J,i-1}$ = tailwater elevation for structure J at the end of the previous time interval

Note the effective head across a structure is:

$$EH_{J,i-1} = HWS_{J,i-1} - TWS_{J,i-1}$$

The gate operation is given by:

$$GO_{J,i} = g(ST_{L,i-1}, DST_{L,i})$$

Where:

$DST_{L,i}$ = institutionally established desired lake surface elevation

The relationship used in this study is shown in Figure 14, Chapter IV, and is:

$$PGOM_J = 0, \; DDA_L \leq 0$$

$$PGOM_J = 400 \cdot (DDA_L)^2, \; 0 < DDA_L < 0.5$$

$$PGOM_J = 100, \; 0.5 \leq DDA_L$$

Where:

$PGOM_J$ = percent of maximum gate operation

DDA_L = difference between $ST_{L,i-1}$ and $DST_{L,i}$

The chatacteristics of the various control structures are given in Table B-2.

Table B-1. -- Relationships between water storage levels and lake storage

Lake surface elevations, ft. above mean sea level	Lake 1	2	3	4	5	6	7
	Storage in acre-feet						
42	1,050		72				64,000
43	1,105		111				81,000
44	1,160		160				103,800
45	1,955		226				130,530
46	2,750		318		8,000		179,030
47	3,390		444		17,000		217,630
48	4,025		653	24,900	26,000		259,700
49	4,745		955	33,400	40,500		306,100
50	5,478		1,381	42,400	55,300		357,300
51	6,400		1,989	51,900	69,000		414,100
52	7,365	165	2,890	61,800	84,000		475,900
53	9,482	602	4,032	81,800	101,200		541,800
54	12,659	1,137	5,151	82,700	122,600	5,600	625,200
55	15,010	1,679	6,520	94,200	144,200	6,700	727,900
56	17,970	2,436	8,105	106,000	170,500	8,000	851,200
57	21,387	3,296	9,827	118,300	194,700	9,300	986,000
58	25,296	4,286	11,739	130,000	222,600	10,800	1,181,500
59	29,545	5,446	14,000	143,700	250,000	12,300	
60	34,440	6,805	16,248	158,600	280,500	13,900	
61	38,518	8,077	17,480	176,400	306,000	15,500	
62	44,950	9,632	20,900	194,300	335,000	17,200	
63	50,555	11,421	23,940	210,500	360,000	20,000	
64	57,430	13,611	27,200	227,500	390,000	23,700	
65	66,966	16,456	33,400	250,000	420,000	29,000	
66	80,615					35,600	
67	98,434					42,000	
68	120,348					48,300	

Table B-2.-- Gate structure characteristics

Structure no.	Structure type	Max. gate opening, ft.	Max. discharge, cubic feet per second	Discharge equation
1	Double culverts with gates	4.0	160	Submerged flow: $Q = 15.92\ F\ \left(\frac{EH}{0.03921\ F^2 + 0.0078}\right)^{0.5}$ for $GO \leq 1$ ft., $P = 0.143\ (GO)^{1.14}$ for $GO > 1$ ft., $P = 0.1828\ GO - 0.0398$ for $P \leq 0.5$, $F = \frac{1}{\pi}\ [\pi - \arctan\left(\left\lvert\frac{\sqrt{p-p^2}}{1-2p}\right\rvert\right) - 2(1-2p)\sqrt{p-p^2}\ ]$ for $P > 0.5$, $F = \frac{1}{\pi}\ [\arctan\left(\left\lvert\frac{2\sqrt{p-p^2}}{1-2p}\right\rvert\right) - 2(1-2p)\sqrt{p-p^2}\ ]$ Non-submerged flow: $Q = 78\ (EH)^{0.495}$
2	Double culverts with gates	4.5	170	Same as structure no. 1

Continued

Table B-2. -- Gate structure characteristics (Continued)

Structure no.	Structure type	Max. gate opening, ft.	Max. discharge, cubic feet per second	Discharge equation
3	Gate structure	6.0	640	Submerged flow: $Q = 10.5 \ GO \ [2g(EH)]^{1/2}$ Free controlled flow: $Q = 95.2 \ (GO)^{0.956} \ (HWS - 55.3 - 0.5 \ GO)^{0.353}$ Free uncontrolled flow: $Q = 85.5 \ (HWS - 55.3)^{1.315}$
4	Gate structure	8.9	820	$Q = 125.21 \ (GO)^{1.10} \ (EH)^{0.255}$
5	Gate structure	18.1	2,300	$Q = 122.6 \ (GO)^{1.142} \ (EH)^{0.519}$
6	Gate structure	9.2	450	$Q = 86.11 \ (GO)^{1.156} \ (EH)^{0.2411}$
7	Gate structure	7.8	715	$Q = 114.09 \ (GO)^{1.1044} \ (EH)^{0.2108}$
8	2-gate structure	11.1	2,000	$Q = 116.40 \ (GO)^{1.1} \ (EH)^{0.24}$
9	3-gate structure	13.2	11,000	$Q = 391.7998 \ (GO)^{0.9630} \ (EH)^{0.466}$

Note: Q = water flow through a gate in cubic feet per minute; GO = gate operation in feet; g = gravitational constraint; EH = effective head across a gate in feet; and HWS = headwater elevation in feet above MSL.

Canals

Flow in the canals must be modeled because headwater and tailwater elevations occurring at the end of a time interval are needed for determining the flow through the structure during the next interval. In the study area two situations occur which can be illustrated by using East Lake Tohopekaliga (L=4) and Lake Tohopekaliga (L=5). These are shown schematically in Figure B-1. In the first case, structure (J=4) has a canal (K=7) leading to it and a canal (K=8) leading from it. When structure 4 is open, the headwater elevation for it will be different from the water surface elevation for lake 4. Likewise, the tailwater elevation will differ from the water surface elevation for lake 5. The second case has the structure at the lake exit so there is no upstream canal. The headwater elevation for structure 5 will be the same as the water surface elevation for lake 5. The tailwater will be different from the downstream lake.

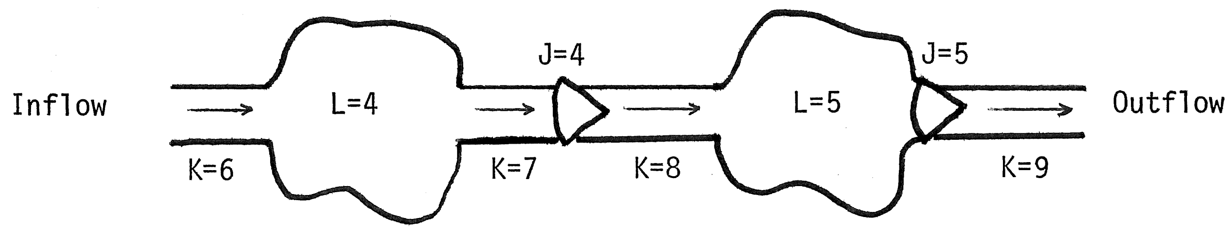


Figure B-1. -- Schematic diagram of the lake, canal and control structure relationship.

A technique developed by Prasad [23] and suggested by Sinha [28] was used to compute water surface profile along the canals. A change in water surface elevation, WSE, with respect to space can be represented by:

$$\frac{d(WSE)}{dx} = \frac{dB}{dx} + \frac{dy}{dx} \qquad \text{where } B = C + z$$

Integrating we get:

$$WSE = B + y = C + z + y$$

Where:

- WSE = water surface elevation
- B = streambed elevation from mean sea level at upstream point of the reach
- C = streambed elevation from mean sea level at downstream point of the reach
- x = distance along the streambed
- z = change in bed elevation between upstream point and downstream point of the reach
- y = depth of water

The differential equation of gradually varied flow provides the relationship between water depth and distance and can be expressed:

$$\frac{dy}{dx} = \frac{SO - SE}{1 - \frac{\alpha Q^2 T}{gA^3}}$$

Where:

SO = slope along the streambed

SE = energy gradient

α = velocity head coefficient

Q = discharge through a given control structure

T = top width of the channel cross-section

g = acceleration due to gravity

A = cross-sectional area of the channel

Manning's formula can be used for the energy gradient:

$$SE = \frac{(RN)^2 \; V^2}{2.22 \; (HR)^{4/3}}$$

Or substituting:

$$V = \frac{Q}{A} \quad \text{and} \quad HR = \frac{A}{P}$$

$$SE = \frac{(RN)^2 \; Q^2 \; P^{4/3}}{2.22 \; A^{10/3}}$$

Where:

V = velocity of flow

RN = Manning's roughness coefficient

HR = hydraulic radius

P = wetted perimeter

Substituting the energy gradient expression into the gradually varied flow equation, the result is:

$$\frac{dy}{dx} = \frac{SO - \frac{(RN)^2 \; Q^2 \; P^{4/3}}{2.22 \; A^{10/3}}}{1 - \frac{\alpha Q^2 T}{gA^3}}$$

This differential equation is a nonlinear function of y and is not readily solved analytically. Prasad [23] has developed a digital algorithm for solving the equation. The technique readily handles non-uniform channels and allows water surface profiles to be computed moving upstream or downstream.

Headwater elevations are found by starting at the lake outlet where:

$$WSE = ST_L$$

And the water surface profile is determined by moving downstream to the structure. The tailwater elevation is found in a like manner except the profile is calculated moving upstream from the lower lake.

The canal characteristics are given in Table B-3.

Table B-3. -- Canal characteristics

Canal no.	Bottom width, ft.	Side slope	Manning's roughness coefficient	Upper end elevation, ft.MSL	Bottom slope	Length of reach, ft.
1	5	1/2	0.168	52.80	$5.8x10^{-6}$	4,751
2	5	1/2	0.168	51.50	$5.8x10^{-6}$	6,200
3	5	1/2	0.168	51.25	$7.0x10^{-5}$	7,245
4	5	1/2	0.168	59.90	$1.21x10^{-4}$	5,762
5	10	1/2	0.168	58.60	$1.11x10^{-4}$	898
6	10	1/2	0.168	57.00	$1.43x10^{-4}$	6,912
7	20	1/2	0.168	46.60	$1.48x10^{-4}$	2,425
8	20	1/2	0.168	45.00	$1.26x10^{-4}$	18,280
9	20	1/2	0.168	34.00	$5.6x10^{-5}$	23,200
10	10	1/2	0.168	53.45	$2.47x10^{-4}$	4,016
11	10	1/2	0.168	51.00	$5.2x10^{-5}$	9,602
12	40	1/2	0.168	46.70	$4.22x10^{-4}$	15,080
13	60	1/2	0.168	40.50	$9.6x10^{-5}$	15,461

APPENDIX C

WATER USE ACTIVITIES MODELS AND DATA

Crop Irrigation Model

The irrigation simulation estimates the crop yield possible with the water available and the net revenue for the crop. Surface water and rainfall provide the available water. 60 percent of the rainfall and 70 percent of the applied irrigation water are assumed to be available in the root zone. The evapotranspiration by the crop is utilized in a production function, and variations in this cause different crop yields. The potential monthly evapotranspiration values for pasture grass and citrus in the Kissimmee River Basin were obtained from the Soil Conservation Service and presented in Table C-1.

A modified form of the Blaney-Criddle equation proposed by Phelan [22] was used to estimate monthly potential evapotranspiration rates. It is given by:

$$ET_p = k_c k_t \frac{T_a P_d}{100}$$

Where:

ET_p = monthly potential evapotranspiration rate in inches of water

k_c = monthly crop coefficient which is a function of physiology and stage of growth of the crop

k_t = temperature coefficient which is given by:

$$k_t = 0.0173\ T_a - 0.314$$

T_a = mean monthly temperature in °F

P_d = monthly percentage of daylight hours of the year

The actual evapotranspiration is a function of soil moisture, and daily calculations of both are made. The moisture retention capacity of the soils is important, and the sandy soil of the Kissimmee Basin was assumed to be predominantly Leon fine sand.

Figure C-1 illustrates the function used to obtain the proportion of the potential that gives the actual evapotranspiration in a given time interval. Therefore,

$$AET_i = ET_{p,i}, \quad SMCR \leq SMA_i$$

$$AET_i = PET\ (ET_{p,i}), \quad SMPW < SMA_i < SMCR$$

$$AET_i = 0, \quad SMA \leq SMPW$$

Table C-1. -- Evapotranspiration information

Crop	Month	Avg. Temp., °F T_a	% daylight hours P_d	Temperature coefficient, k_t	Crop coefficient, k_c	Potential evapotranspiration ET_p
Pasture	Jan.	62.4	7.44	.76	.48	1.67
	Feb.	63.8	7.10	.79	.57	2.04
	Mar.	67.1	8.38	.85	.74	3.54
	Apr.	71.8	8.66	.93	.86	4.98
	May	76.8	9.41	1.02	.90	6.65
	Jun.	80.4	9.34	1.08	.92	7.43
	Jul.	81.7	9.53	1.10	.92	7.87
	Aug.	82.1	9.14	1.11	.91	7.58
	Sep.	80.6	8.32	1.08	.87	6.31
	Oct.	75.3	8.04	.99	.80	4.78
	Nov.	68.0	7.32	.86	.67	2.89
	Dec.	63.5	7.32	.78	.52	1.91
						57.65
Citrus	Jan.	62.2	7.40	.76	.63	2.20
	Feb.	63.8	7.07	.79	.66	2.35
	Mar.	67.3	8.37	.85	.68	3.25
	Apr.	72.0	8.67	.93	.70	4.06
	May	77.0	9.46	1.02	.71	5.27
	Jun.	80.6	9.39	1.08	.71	5.81
	Jul.	81.9	9.58	1.11	.71	6.19
	Aug.	82.2	9.17	1.11	.71	5.94
	Sep.	80.6	8.32	1.08	.70	5.07
	Oct.	75.1	8.02	.98	.69	4.07
	Nov.	67.8	7.28	.86	.67	2.85
	Dec.	63.2	7.27	.79	.64	2.30
						49.36

Note: These data were provided by the Soil Conservation Service, United States Department of Agriculture.

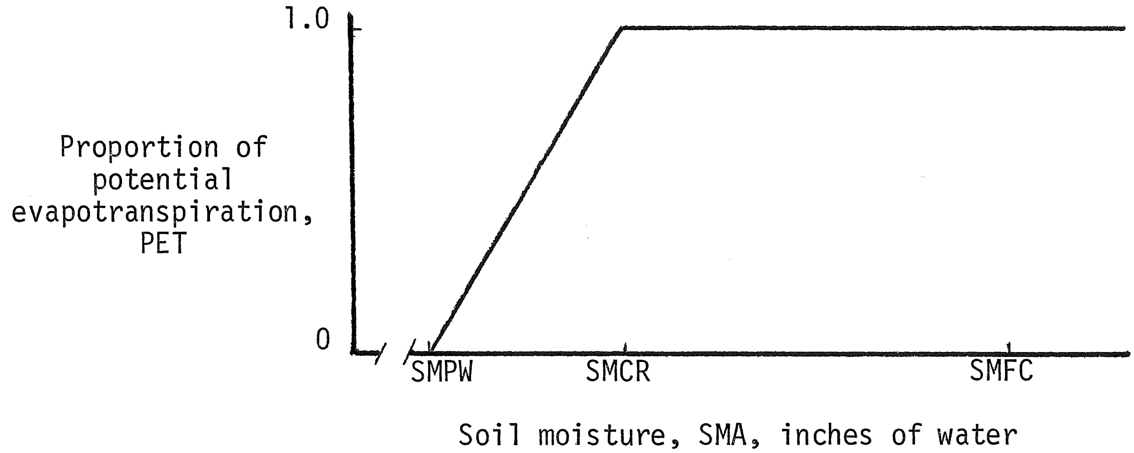


Figure C-1. -- Potential evapotranspiration function.

Where:

$ET_{p,i}$ = potential evapotranspiration during time interval i

AET_i = actual evapotranspiration during time interval i

PET = percent of potential evapotranspiration actually occurring

SMA_i = soil moisture during time interval i

SMFC = soil moisture at field capacity

SMPW = soil moisture at permanent wilting point

SMCR = soil moisture at critical point

The soil profile moisture at the end of a time interval is:

$$SMA_i = SMA_{i-1} + WESI_i + WESR_i - AET_i$$

Where:

$WESI_i$ = water entering soil profile from irrigation during time interval i

$WESR_i$ = water entering soil profile from rainfall during time interval i

The data used are given in Table C-2.

The actual evapotranspiration during each time interval, AET_i, is accumulated through the entire growing season to obtain the total evapotranspiration. ET_{total} is the total actual evapotranspiration when only rainfall is available.

The crop yields and production costs were obtained from data described in Chapters II and III. For this first generation simulation simple linear

Table C-2. -- Soil information

Soil characteristics	Crop	
	Pasture	Citrus
Field capacity (0.1 atm.), inches of water per foot of soil	1.50	1.50
Permanent wilting point (15 atm.), inches of water per foot of soil	0.55	0.55
Root zone, inches of soil	36.00	60.00
Available moisture at field capacity, SMFC, inches of water	4.50	7.50
Available moisture at permanent wilting point, SMPW, inches of water	1.65	2.75
Available moisture at point where ET begins to decrease, SMCR, inches of water	2.60	4.33

production functions are used, and are assumed to approximate Stage II production with all other factors held constant (see Table C-3). Prices of all goods were average prices for the period 1968 through 1970 and were assumed not to be affected by the activities in the basin. Perfect competition in all models was assumed. Since the production function is linear and prices perfectly elastic, the marginal value product line is horizontal, and the producer's surplus for a crop with irrigation is the net income when irrigation water is available minus the net income when irrigation water is not available.

The producer's surplus is assumed to reflect the benefits accruing to society as a result of irrigation water being available. Neoclassical production theory is used to demonstrate this concept. The traditional idealized production function is, implicitly:

$$\text{YIELD} = f(\text{ET, all other factors held constant})$$

and is illustrated along with the marginal physical product curve, MPP, and the average physical product curve, APP, in Figure C-2. The crop yields with and without irrigation water, YIELD_{total} and YIELD_{rain}, respectively, are obtained by solving the production function with ET_{total} and ET_{rain}, respectively. Multiplying the marginal physical product by the price of the crop, P_y, the marginal value product, MVP,, is obtained. Mathematically:

Table C-3. -- Crop yields, production costs and prices

Crop Yield Functions

a. Beef yields in pounds/acre

$$YIELD_{B,L} = -200 + 14(ET_{B,L}), \quad 20 \leq ET_{B,L} \leq 70$$

b. Mixed citrus yields in boxes per acre

$$YIELD_{C,L} = -300 + 17(ET_{C,L}), \quad 20 \leq ET_{C,L} \leq 70$$

Cost Functions

a. Beef production costs in dollars per acre

$$COST_{B,L} = 8.76 + 0.1(YIELD_{B,L}) + 0.056(ET_{total,B,L} - ET_{rain,B,L})$$

b. Citrus production costs

$$COST_{C,L} = 172.02 + 0.145(YIELD_{C,L}) + 2.40(ET_{total,C,L} - ET_{rain,C,L})$$

Crop Prices

a. Beef price in dollars per pound

$$PRI_B = 0.25^a$$

b. Mixed citrus price in dollars per 90 pound box

$$PRI_C = 1.40^a$$

[a]Average prices for period 1968 through 1970.

$$MPP = \frac{\partial\,(TPP)}{\partial\,(ET)}$$

$$MVP = P_y \frac{\partial\,(TPP)}{\partial\,(ET)}$$

And, graphically, Figure C-3. The price of the crop is assumed to be independent of activities in the river basin and constant, and is therefore the marginal revenue. First, substituting ET_{total}, and

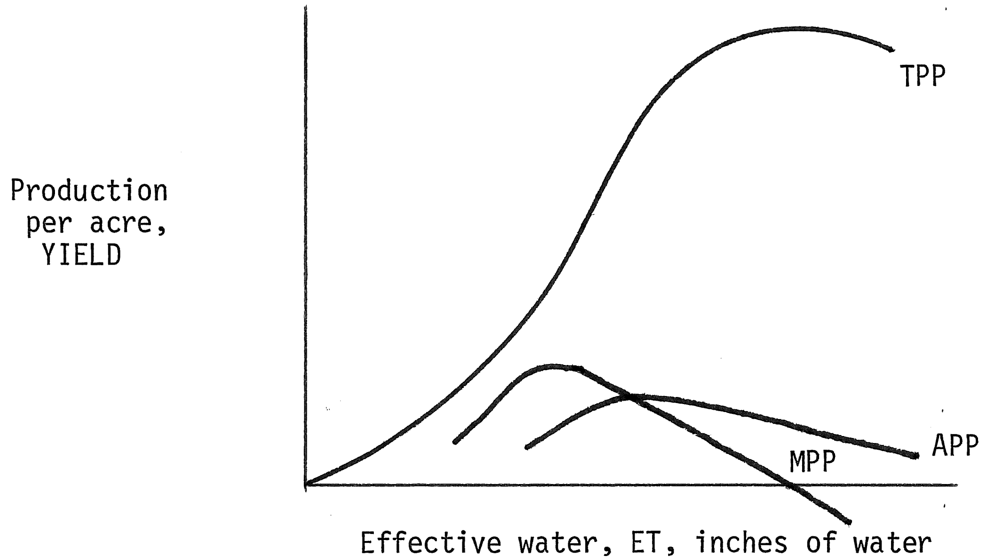


Figure C-2. -- Typical production, average physical product, and marginal physical product curves.

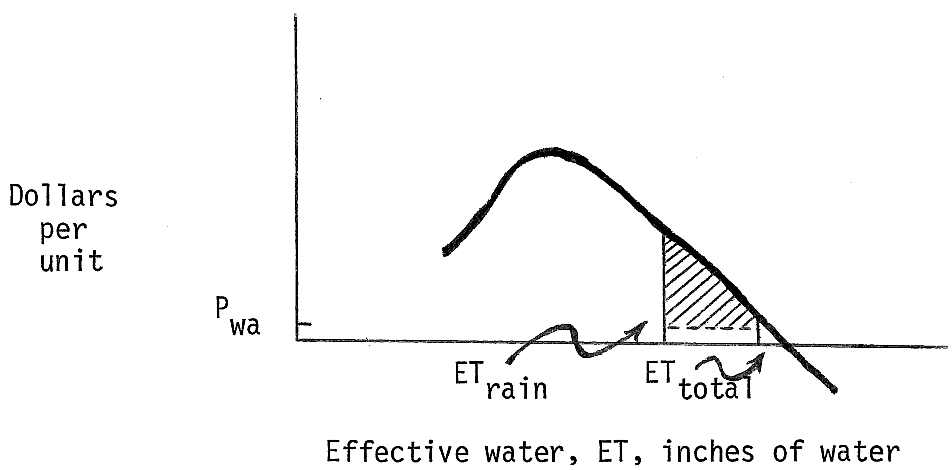


Figure C-3. -- Typical marginal value product curve.

integrating, the total revenue for the irrigated crop, TR_{total}, is obtained:

$$TR_{total} = \int_{0}^{ET_{total}} P_y \frac{\partial\,(TPP)}{\partial\,(ET)}\, d(ET)$$

doing likewise with ET_{rain}, the total revenue for the crop without irrigation water, TR_{rain}, is obtained:

$$TR_{rain} = \int_{0}^{ER_{rain}} P_y \frac{\partial\,(TPP)}{\partial\,(ET)}\, d(ET)$$

The producer's surplus, PS, for each of these cases is the total revenue minus the price times the quantity. In the case of rainfall, no price was paid so the total revenue due to the effective water is the producer's surplus. In the case of rainfall and irrigation, there is a price paid for just the irrigation water, so:

$$P_w = 0, \qquad 0 \leq ET \leq ET_{rain}$$

and

$$P_w = P_{wa}, \qquad ET_{rain} \leq ET \leq ET_{total}$$

Where:

P_w = price of water

P_{wa} = price of irrigation water actually paid

The producer's surplus for this case is:

$$PS_{total} = TR_{total} - P_{wa}\,(ET_{total} - ET_{rain})$$

This is the producer's surplus (PS) accruing to all the effective water without regard to its source. Only the irrigation water is available as a result of the water management system. Therefore, only the producer's surplus associated with the irrigation water is an appropriate indication of benefits due to the system management. The producer's surplus for effective water from the rainfall is subtracted from the producer's surplus for the total effective water. Mathematically, this is:

$$PS = \int_{0}^{ET_{total}} P_y \frac{\partial\,(TPP)}{\partial\,(ET)}\, d(ET) - P_{wa}\,(ET_{total} - ET_{rain}) - \int_{0}^{ET_{rain}} P_y \frac{\partial\,(TPP)}{\partial\,(ET)}\, d(ET)$$

and graphically, the shaded area in Figure C-3.

Since linear crop production functions were used and prices were assumed perfectly elastic, the marginal value product is constant, and the producer's surplus for a crop with irrigation is:

$$PS_{total,L} = P_y (YIELD_{total,L}) - COST_{total,L}$$

and without irrigation:

$$PS_{rain,L} = P_y (YIELD_{rain,L}) - COST_{rain,L}$$

The producer's surplus indicating the level of benefits due to the availability of surface water from a given lake for irrigation is:

$$PS_L = PS_{total,L} - PS_{rain,L}$$

Residential Water Consumption Model

The calculation of consumer's surplus for residential use of surface water requires the total amount of water on average household uses. This is obtained with the Howe and Linaweaver demand function which requires information on the water price rate schedule, the market value of the dwellings and the water needs for lawn irrigation in the Kissimmee River Basin. The proportion of this total water demand that can be removed from the lakes is specified by the institutionally established withdrawal functions. As mentioned, surface water is not presently used for residential purposes, so the data used were collected from available information on ground water use in the basin.

The residential water demand equation used in this study and presented by Howe and Linaweaver [13] is:

$$q_a = 86.3\, v^{0.474} (w_s - 0.6r_s)^{0.626}\, P_a^{-0.405}$$

Where:

q_a = average annual quantity demanded for domestic purposes in gallons per dwelling unit per day

v = market value of the dwelling unit in thousands of dollars

$(w_s - 0.6r_s)$ = lawn irrigation water needs in inches of water

P_a = the sum of water and sewer charges that vary with water evaluated at the block rate applicable to the average domestic use in cents per thousand gallons

The consumer's surplus for domestic water consumption is assumed to be the benefits accruing to the actual available water for residential use. The total residential water demand equation above is assumed to represent the demand for water up to a specific price, PRIU. At this point the demand function becomes perfectly elastic and is, therefore, a horizontal line to the origin (see Figure C-4). It is assumed that at this price other sources of water become feasible. If 100 percent of the residential demand were met, the consumer surplus would be:

$$\text{CSURP} = \int_{\text{PRIL}}^{\text{PRIU}} q_a\,(p_a)\,dp_a - (\text{PRIL} \cdot \text{WCPD})$$

The portion of consumer surplus gained when less than 100 percent is available is:

$$\int_{\text{PRIL}}^{\text{PRIU}} q_a\,(p_a)\,dp_a - \int_{\text{PRIL}}^{\text{PRIW}} q_a\,(p_a)\,dp_a + (\text{PRIW} - \text{PRIL})\,\text{GPD}$$

Or simply:

$$\int_{\text{PRIW}}^{\text{PRIU}} q_a\,(p_a)\,dp_a + (\text{PRIW} - \text{PRIL}) \cdot \text{GPD}$$

Where:

CSURP	=	the consumer's surplus for residential use of surface water in cents
$q_a(p_a)$	=	the demand function for residential water
p_a	=	price of residential water
PRIU	=	highest price consumers will pay for water, in cents per thousand gallons
PRIW	=	price consumers would pay for the actual quantity of surface water they received, in cents per thousand gallons
PRIL	=	the price the consumer must actually pay for water, in cents per thousand gallons
GPD	=	quantity of surface water actually received in gallons per day
WCPD	=	the maximum quantity of water residences would demand at the price p_a, in gallons per day

Several assumptions pertaining to information needed were made based on questioning of employees of the utility departments of the Cities of Kissimmee and St. Cloud. It was assumed that dwellings had an average market value of $20,000 and an average lawn required fifteen inches of irrigation water per year. The demand equation simplifies to:

$$q_a = 1930.669\,(p_a)^{-0.405}$$

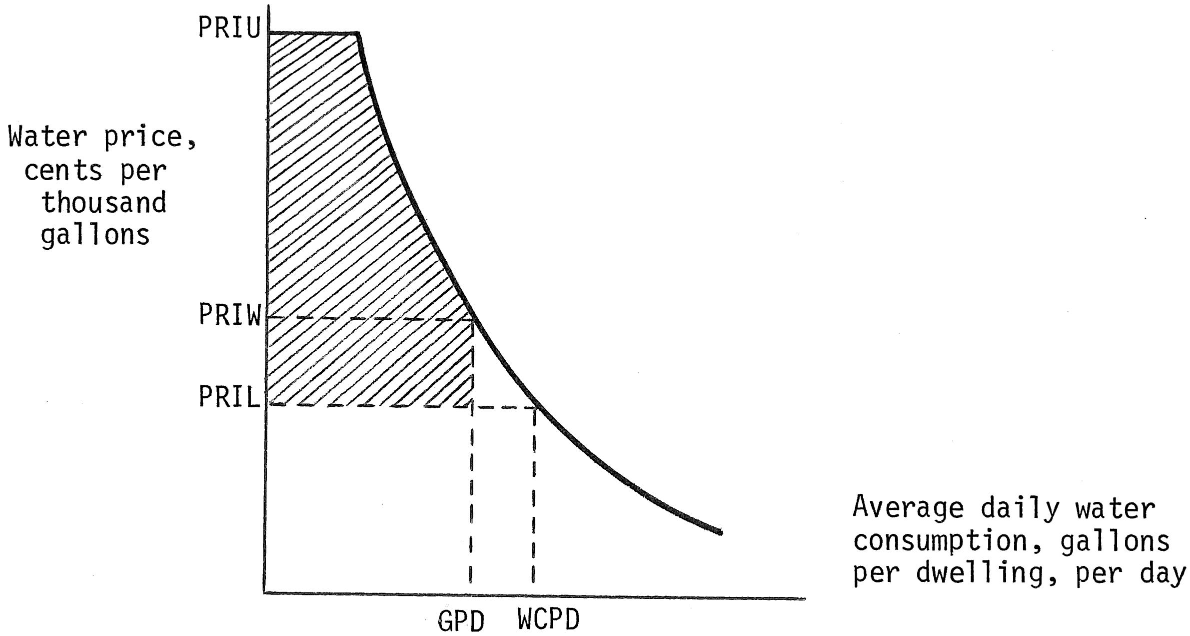


Figure C-4. -- Residential water demand function.

A combined water and sewer charge of 60 cents per thousand gallons gives a maximum water demand, WCPD, of 370 gallons per day. The proportion of daily water needs that can be removed from the lakes is specified by the institutionally established withdrawal functions. This proportion and the total water needs, WCPD, give the quantity of water removed from the lake, GPD_L. Substituting GPD_L into the demand equation gives $PRIW_L$. PRIU was set at 120 cents per thousand gallons and PRIL 60 cents per thousand gallons. With this information the consumer's surplus for each dwelling was calculated. Only lakes 4 and 5 were assumed to have residents using surface water. Lake 4 had 1,580 dwellings in the surrounding area and lake 5 had 4,750. Using the consumer's surplus equation the benefits accruing to the use of surface water were found.

Water Recreation Model

The effect of water surface elevation on recreational visits to lakes in the Kissimmee Basin was demonstrated in Appendix A.

Recreational use was assumed to be a function of water surface elevation as illustrated in Figure C-5. Implicitly, this may be written [2]:

$$V = f(W_L, T, D_2, R_d, W_v)$$

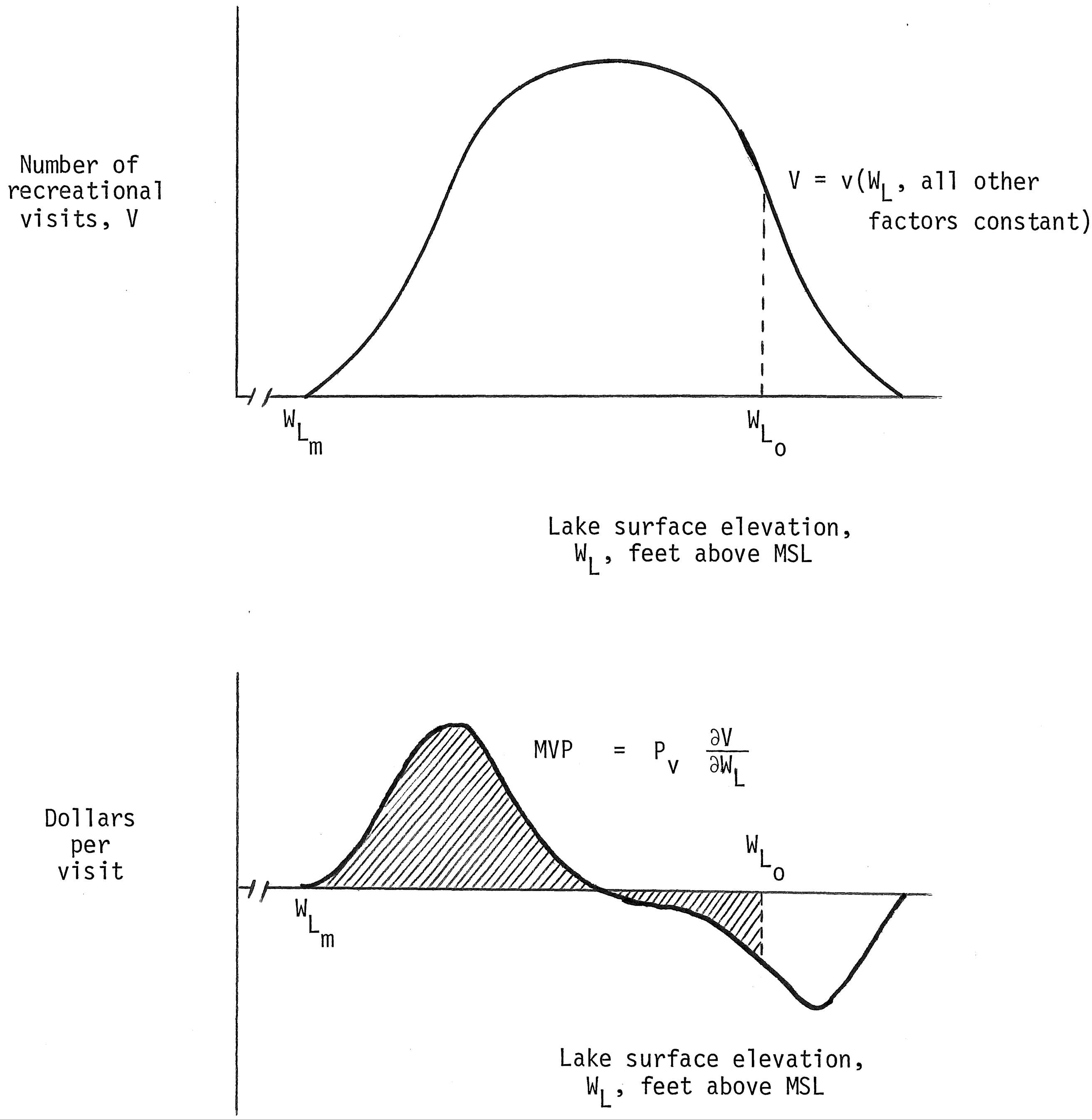


Figure C-5.-- Recreational visit functions.

Where:

V = number of visitors to lake per day

W_L = lake surface elevation in feet above MSL

T = daily temperature in °F

W_v = highest daily wind velocity in mph

R_d = number of days of rain

D_2 = season of the year

By taking the first partial derivative with respect to water level, the additional visits associated with an incremental change in water level are expressed as $\frac{\partial V}{\partial W_L}$. The value of additional visits associated with a change in water level is obtained by multiplying $\frac{\partial V}{\partial W_L}$ by the value of a visit, P_v. The price of a visit is assumed to be independent of the number of visits and is used as the marginal revenue of a visit. Benefits to recreational use of water can then be written:

$$\int_{W_{L_m}}^{W_{L_0}} P_v \frac{\partial V}{\partial W_L} \, dW_L$$

Where:

W_{L_0} = the actual lake surface elevation

W_{L_m} = the elevation of the bottom of the lake in feet above MSL

There is no price for water level management; therefore, the benefits are the entire area under the marginal value product (MVP) curve. It should be noted that the water surface elevation may be at any level and that recreational visits will be made. This results in the situation shown in Figure C-5 where the water surface elevation is above the point of highest use. The benefits accruing to this water level are shown by the shaded area above the axis minus the shaded area below.

A reduction of 25.63 visits per foot decrease in water level below the minimum desired level was estimated for Lake Tohopekaliga. This represents 11.5 percent of the 223.32 visits per day average, and implies for each foot of drop there is an 11.5 percent drop in the number of visits. Or, in a range of 8.7 feet, there will be a 100 percent drop in visits. There are no data to support a decrease in visits for surface elevations above the desired level, but it is reasonable to assume this is the case. Lake Tohopekaliga was assumed to be typical of the lakes in the basin, and the 11.5 percent decrease in the number of visits per foot of lake surface drop was used when the lake surfaces were below the desired level. A 20 percent decrease in visits per foot of water surface increase was used when the lake surface was above the desired level. (The elevations for each lake are given in Table C-4.) Since the relationship between water surface elevations and number of visits is a linear segmented function, the pseudo-marginal product and the marginal value product curves (Figure C-5) are step functions. The benefit from recreational use of the lakes is found by simply multiplying the number of visits per month by the value of an average visit.

Table C-4. -- Elevations for the percent of maximum monthly recreational visits functions

L	$ZRLST_L$	$DRUST_L$	$FMIN_L$	$ZRHST_L$
	-------------------	Feet above sea level	---------------------	
1	53.28	62.0	64.5	69.5
2	51.28	60.0	62.5	67.5
3	50.28	59.0	61.5	66.5
4	47.28	56.0	58.5	63.5
5	44.28	53.0	55.5	60.0
6	51.28	60.0	62.0	67.0
7	40.28	49.0	53.0	58.0

Note: $ZRLST_L$ = the lower lake surface elevation at which there are no recreational visits
$DRUST_L$ = the lake surface elevation at which maximum recreational visits occur
$FMIN_L$ = the lake surface elevation at which the recreational visits begin to drop from the maximum
$ZRHST_L$ = the higher lake surface elevation at which there are no recreational visits

The value of a visit, P_v, is not readily attainable, because there is no true market for recreational visits to the lakes of the Kissimmee Basin. In Appendix A a demand function for recreation on these lakes by an average individual was estimated. In doing this, it was assumed that the average individual's demand for recreation on the lake is not affected by the lake level. Some marginal users stop using the lake, but the average individual's demand remains the same. Since this is the case, the consumer's surplus for an average individual making an average visit remains constant for varying water levels. The value of a visit to be used in the benefit function is the consumer's surplus for an average individual making an average visit to the lake. In the simulation portion of the study \$58.88[1] for an average visit of 5.64 days was used.

Using the consumer's surplus and the number of visits to a particular lake during a month, the benefits accruing to the availability of surface water for recreation are found.

The number of monthly visits to each lake when the lake is at the desired level is given in Table C-5.

Table C-5. -- Estimated monthly visits to each lake

Month	Lake						
	1	2	3	4	5	6	7
	Number						
Jan.	1,984	110	1,600	5,433	5,886	1,419	17,610
Feb.	1,369	153	721	4,450	10,872	272	13,351
Mar.	1,369	153	721	4,450	10,872	272	13,351
Apr.	1,369	153	720	4,450	10,871	271	13,351
May	1,369	152	720	4,450	10,871	271	13,350
Jun.	388	71	663	2,085	8,652	81	13,395
Jul.	387	71	664	2,085	8,652	81	13,395
Aug.	387	71	664	2,085	8,652	81	13,394
Sep.	388	72	664	2,085	8,652	81	13,394
Oct.	1,682	126	892	6,257	8,121	824	16,159
Nov.	1,683	126	893	6,258	8,120	825	16,160
Dec.	1,985	109	1,600	5,434	5,886	1,420	17,611

Flood Damage Model

Flood damages for each of the lakes was found by investigating the activities at various elevations around the lake. The FCD gathered the

[1] This value was estimated from a preliminary version of the demand curve for recreation in the Kissimmee River Basin. The final estimate used to obtain consumer's surplus was \$59.91.

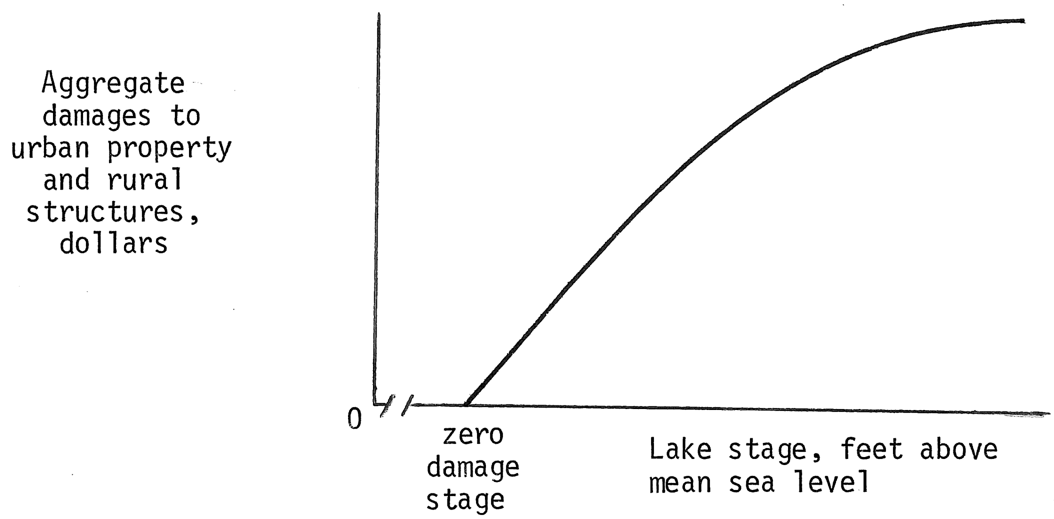
data which were used to construct the functions. Urban and rural structure damages are expressed by the linear functions in Table C-6. The land around the lakes slopes away from the lakes at a very flat angle and the area flooded increases linearly; therefore, linear functions provide a reasonable approximation. It is assumed that thirty days are required to repair damages, so property previously damaged cannot be redamaged until thirty days have elapsed. Figure C-6a illustrates the function for a typical lake.

Table C-6. -- Urban and rural structures flood damage functions

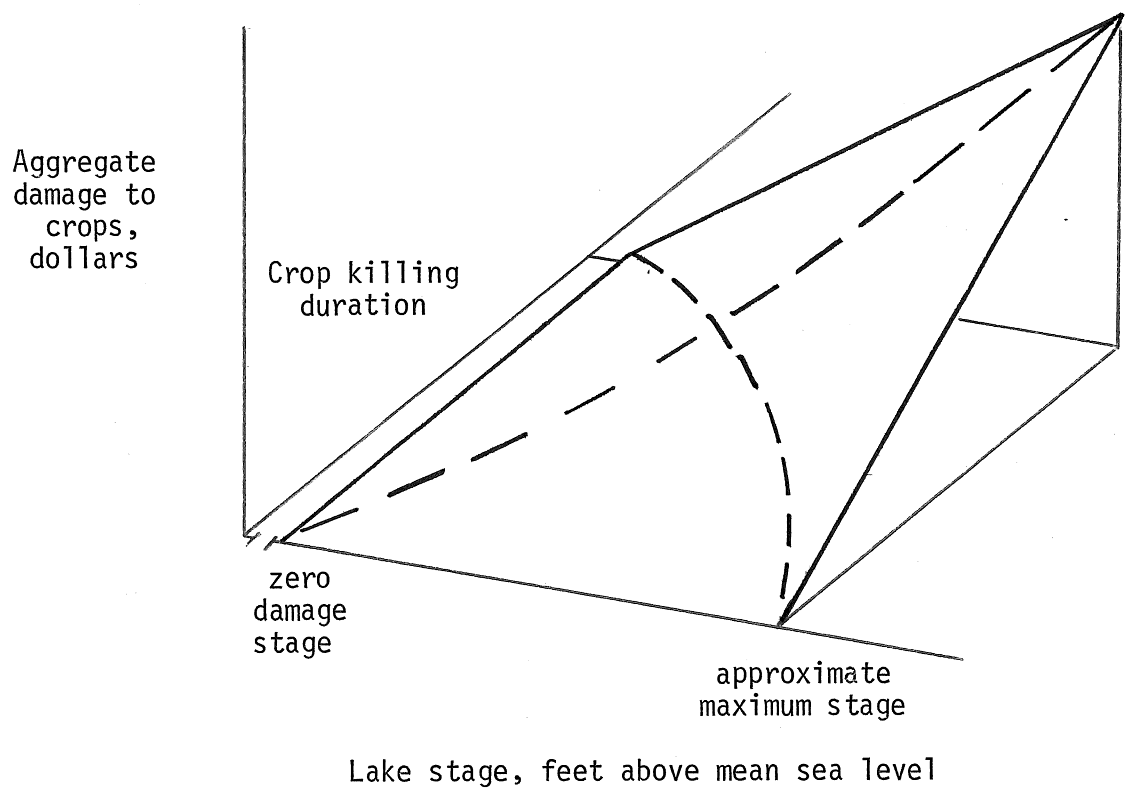
Lake	Urban	Rural structures & miscellaneous
1	$FUD_1 = 29,931,850 + 45,455\ ST_1$	$FRD_1 = -3,933,600 + 59,600\ ST_1$
2	$FUD_2 = 0$	$FRD_2 = 0$
3	$FUD_3 = 5,990,310 + 96,774\ ST_3$	$FRD_3 = 226,795 + 3,658\ ST_3$
4	$FUD_4 = 21,636,340 + 363,636\ ST_4$	$FRD_4 = -4,845,144 + 81,431\ ST_4$
5	$FUD_5 = 9,866,680 + 177,778\ ST_5$	$FRD_5 = -4,018,977 + 72,414\ ST_5$
6	$FUD_6 = 0$	$FRD_6 = -1,333,680 + 21,390\ ST_6$
7	$FUD_7 = -14,840,000 + 280,000\ ST_7$	$FRD_7 = 0$

Note: FUD_L = urban flood damages in dollars
FRD_L = rural structures and miscellaneous damages in dollars
ST_L = lake surface elevation in feet above mean sea level

Crop damages are a function of the mean flood stage and the duration of the flood. The area flooded increases linearly, and if the crops are assumed to be uniformly distributed with respect to land elevation, a linear increase in damages associated with flood stage is reasonable. A hyperbolic paraboloid of the general form $z = cxy$, where c is a constant and x, y and z are Cartesian coordinates, was used. This function has the property, that, when cut in the x-z or y-z plane, a straight line results. This allows a function to be obtained with very little data. This was appropriate for the data available, since the FCD was only able to provide damage values for pasture and citrus when the crops were



(a) An urban property and rural structures damage function.



(b) A crop damage function.

Figure C-6.-- Flood damage functions for a typical lake.

completely destroyed. This is identified as the filling flood duration, and was assumed to be fifteen days for pasture and five days for citrus. Figure C-6b illustrates a crop damage function. The functions obtained for each crop adjacent to each of the lakes are shown in Table C-7.

Table C-7. -- Crop flood damage functions

Lake	Pasture	Citrus
1	$FPD_1 = 141(ST_1 - 64.5)\ DOF_1$	$FCD_1 = 5{,}455\ (ST_1 - 64.5)\ DOF_1$
2	$FPD_2 = 0(ST_2 - 62.5)\ DOF_2$	$FCD_2 = 0(ST_2 - 62.5)\ DOF_2$
3	$FPD_3 = 524(ST_3 - 61.5)\ DOF_3$	$FCD_3 = 658(ST_3 - 61.5)\ DOF_3$
4	$FPD_4 = 452(ST_4 - 58.5)\ DOF_4$	$FCD_4 = 248(ST_4 - 58.5)\ DOF_4$
5	$FPD_5 = 587(ST_5 - 55.5)\ DOF_5$	$FCD_5 = 1{,}534(ST_5 - 55.5)\ DOF_5$
6	$FPD_6 = 434(ST_6 - 62.0)\ DOF_6$	$FCD_6 = 920(ST_6 - 62.0)\ DOF_6$
7	$FPD_7 = 2{,}750(ST_7 - 54.0)\ DOF_7$	$FCD_7 = 0(ST_7 - 54.0)\ DOF_7$

Note: FPD_L = pasture flood damages in dollars

FCD_L = citrus flood damages in dollars

ST_L = lake surface elevation in feet above mean sea level

DOF_L = duration of flood in days and has maximum values of 15 and 5 days for pasture and citrus, respectively

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