EXAMINING RESERVOIR MANAGEMENT PRACTICES: THE OPTIMAL PROVISION OF WATER RESOURCES UNDER ALTERNATE MANAGEMENT SCENARIOS

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ALTERNATE MANAGEMENT

SCENARIOS

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INTRODUCTION

In recent years, there has been increasing interest and concern focused on the use of our natural resources. As the population of the planet expands, the strains placed on the earth's natural resources also increase. Even though technological advances have allowed us to use our resources more efficiently, the demands placed on our natural resource base increase with population and output. The concept of sustainability suggests that in response to this increase in demand, our use of these precious resources should be reviewed. One particular area that is the subject of much concern is the use of water resources.

Background

The adequate availability and quality of water is vital to virtually every organism living on the planet. The most basic use, that of consumption, fulfills life-sustaining requirements of plants, animals, and humans, as well as millions of other organisms. Through this, water serves to regulate population growth, influences the health and living conditions of the earth's inhabitants, and contributes significantly to its biodiversity (Newson, 1992). In addition to water's most fundamental use, today's society has become even more dependent on water for other uses. One of the most important uses of water in today's society is for its role in industrial and commercial enterprises. As world population increases, the output of goods and services required to maintain a given standard of living must also increase. Most production processes rely on the availability of water for various reasons. With increasing world production, the demands placed on our water resources for use in industrial and commercial processes increase as well. In addition to these uses, water serves other roles in today's society. Households use water for many non-consumptive purposes. Electric energy producers use the force of moving water to generate electricity. The large bodies of surface water that cover three-fourths of the earth are used as a means of transportation. Finally, these bodies of water, including oceans, lakes, rivers, and streams, provide a natural playground for sporting and recreation activities. Clearly, water serves many important roles in today's society. With its direct and indirect impacts on virtually every aspect of human life, it is not surprising that water is among the most precious and coveted of all natural resources. The result is an increasing strain on the available water resources due to increasing competition in the market for the use of these resources.

Special Concerns

An interesting aspect of the consumption and other uses of water resources is that the dynamics of providing water to consumers is quite different than that for other natural resources. This is due to the nature of the associated supply and demand forces. Unlike many other goods and natural resources, the supply of and demand for water resources have both a spatial and a temporal dimension. That is, demand and supply are not matched in time or across space. The spatial mismatch arises because, even though water may be available somewhere, it is not always available exactly where we want it. This type of mismatch occurs in the consumption of most goods and services, and is a problem dealt with on a daily basis. Over time, society has developed a system of facilities and vehicles to accommodate the transportation of goods and services to their places of consumption. To deal with the spatial mismatch concerning water resource use, society faces the same obstacles. In response, we build networks of pumping stations and pipelines to transport and distribute water to those places where they are to be consumed.

The main point of departure from the nature of most goods and services and other natural resources is that water supply and demand also face a temporal mismatch. This temporal mismatch arises due to the fact that both water supply and water demand fluctuate over time, independently of each other. Quite often it seems that the demand for water is highest during time periods in which water supplies are their lowest. To address the temporal mismatch, society has been faced with the task of bridging the time between water demand and its availability. To achieve this feat, we create impoundments or reservoirs to store water by constructing dams. These reservoirs collect water during times of abundance, and store it until periods of shortage require its use. This function of reservoirs, in effect, transports water resources through time.

Water Resource Management Issues

The process of delivering water resources to consumers at the appropriate time and place for consumption is an important, but not singular, aspect of water resource management. In fact, effective water resource management requires a multidisciplined approach to overseeing the use of our available water resources. Among the most important aspects of managing the world's water are concerns about conservation and the efficient allocation of the current supply of water.

Water is often thought of as a completely renewable natural resource. That is, as water is consumed, nature replenishes the stock with more water in such a manner that we will never deplete the earth's stock. While this faith in nature and the hydrologic cycle may be founded on some truths, it is possible to deplete the earth's usable water supply. Even abstracting from the idea of water quality and the possibility of water pollution, our current use patterns could, in the not so distant future, result in severe water shortages around the world. To clarify this, a distinction must be made between the two major sources of useable water supply.

Our available water supplies are derived from two major sources – groundwater and surface water. Groundwater refers to that water supply that is drawn from beneath the earth's surface. It is water that collects in the porous layers of rock, sand, and gravel known as aquifers. Surface water is that water that flows and collects on the surface of the earth, in the form of fresh water reservoirs, lakes, rivers, and streams. Due to its salinity, the water contained in the world's oceans is not considered to contribute directly to our usable water supply. The water that we consume is either drawn from groundwater or surface water stocks.

Groundwater stocks can be considered either renewable or nonrenewable, depending on the time horizon. It is regenerated through the normal hydrologic cycle, but at a very slow rate. It is estimated that only 2.5 percent of the groundwater available for extraction in the United States is available on a renewable basis (CEQ 1978). This means that, for the most part, the groundwater supply can be viewed as being a depletable, nonrenewable resource. As such, its efficient use generates the same conservation concerns as do other fixed resources.

The supply of surface water faces a somewhat different set of issues. Surface water supplies are rather rapidly renewed by the earth's hydrologic cycle. Again abstracting from pollution, nature replenishes the earth's surface water supply at a faster rate than it is consumed. On a worldwide basis, the total annual consumption of water amounts to only about 10 percent of the world's surface water stock (Tietenberg, pg.208). However, due to the geographic and temporal distribution of water resources and water demands, there are water shortages occurring around the world today. Also, areas with abundant water supplies today may begin to experience shortages in the near future. This situation imposes two requirements on an effective water resource management policy (Hartwick and Olewiler, pg. 76). First, water resources should be allocated in an efficient manner among competing users, with very different needs and demands. Secondly, an effective management policy should accommodate variability in surface water supplies. Addressing these two issues is the constant focus of water resource management groups and personnel at every level of aggregation. These concerns are faced by agencies from the global level down to the smallest grass roots level. The most noticeable outgrowth of these concerns is the increasing focus on reservoir management and resource allocation.

Current Practices

Efficient management of the nation's reservoirs has become a vital part of the efforts to develop sustainable resource policy concerning water resources. In the past, this idea of efficiency in water resource use was viewed to mean *engineering* efficiency, or the ability to ensure water supply (Spulber and Sabbaghi, pg. 55). In this context, efficiency has nothing to do with allocating water based on the benefits of alternative uses. It simply refers to the ability and cost-effectiveness of delivering a given quantity of water for a given use. In times past this may have been sufficient, as water supplies were not under the strains seen today. Although movements are being made to exercise greater diligence in practicing efficient management of the nation's water resources, much more needs to be done.

In evaluating the alternative uses of a given water resource, the most common practice today is the use of benefit-cost analysis. This process compares the benefits and costs of a proposed management strategy to evaluate the desirability of the option. While this process does identify those options that are economically feasible, it does not identify economically optimal alternatives. In pursuit of sustainable resource policies, it is those economically optimal outcomes that should be the goal.

The largest participant in the management of fresh water resources in the United States is the Corps of Engineers. The practices of the Corps of Engineers, therefore, set the stage for all other water management parties. For this reason, the practices of the Corps should be fully investigated to identify opportunities for improvement. This investigation indicates that the current policies of water resource managers in general may be inferior to alternative approaches that are employed in other aspects of resource policy management.

Problem Statement

Three main concerns arise from the investigation into the current practices of the Corps of Engineers regarding water resource management. First, the Corps views the problem as a storage capacity issue. The basic approach of the Corps is to investigate issues in terms of storage capacity, rather than water usage. This is accomplished by a distinction between the reservoir and the water occupying the reservoir. The Corps exerts control over the capacity of the reservoir, but not the water taking up that capacity. This view is based on the fact that the Corps has ownership over the reservoir, but not the water. The water is owned by the State of Oklahoma. To this end the Corps allocates storage capacity between alternative users, who must seek approval from the State for the use of the water. This separate treatment of the water and the reservoir places unnecessary burdens on the effective management of the resource.

A second concern discovered through the investigation into the Corps' practices is in regards to the rigidity of the current allocation process. The process of allocating reservoir capacity to different uses is quite complex and burdensome. Various studies indicate that the process of choosing an allocation can take up to three years. In addition, when conditions change, necessitating a change in allocations, the process must be repeated. The concern with this process is that water usage, as determined by reservoir allocations, cannot be altered in a timely manner to adjust to changing demands and water conditions. Economic efficiency in reservoir management requires the ability to make timely adjustments in water usage. The goal envisioned by the author is the ability to correct inferior allocations on an annual basis.

The third concern with current practices is that economic values of some reservoir services are not adequately addressed within the scope of reallocation studies. While most activities are examined, the values of these activities are not consistently considered in a systematic way within the economic analysis phase of these studies. For an economic assessment to yield valid results, all feasible benefits must be measured.

Proposed Approach

With the increasing demands being placed on our natural resources, the efficient use of these resources is becoming more important everyday. To ensure dependable access to water resources for future generations, reservoir management practices should be chosen with the guidance of the most effective tools available. To further this proposition, the current research examines the current practices of water resource management, as conducted by the Corps of Engineers to identify opportunities for improvement. This examination is conducted, at first, at an institutional policy level. Then the examination advances to the level of an individual site, to evaluate the practices actually employed at Broken Bow Lake, in southeastern Oklahoma. This process provides a view of the benefits generated under the current management policies.

This study then posits a systematic approach to evaluate alternative management options for the reservoir in question. The absence from current practices of meaningful economic integration of multiple activities is addressed through the implementation of this multiple-use management decision tool. The major contribution of this research is the incorporation of multiple activities into an approach to reservoir management, which identifies the policies that generate the greatest benefits. While current practices address the economic feasibility of a *proposed* management scenario, the model developed herein addresses the search for the most efficient of *all* possible scenarios. Another significant aspect of the research at hand is the incorporation of activities impacted by reservoir management, but beyond the boundaries of the lake.

Results from alternative management scenarios and inflow conditions are generated through multiple model estimations. These results provide a measure of the benefits generated by the reservoir system, both in total, and for each reservoir activity examined. Benefits from each of these scenarios are compared to benefits from other possible alternatives, including the current strategy. Management practices are then evaluated based on the total and individual benefits resulting from these estimations.

While the application of this type of modeling is not unique to water resource management, the scope and breadth of the study are somewhat original. Numerous studies evaluate the potential benefits of proposed alternative management scenarios. Other studies employ the optimization procedures presented in this research, but evaluate only two or three reservoir activities. This research seeks to combine these two approaches by incorporating the most inclusive measure of reservoir benefits feasibly possible, and utilizing optimization procedures to identify the best management policy.

This process defines the most economically efficient management scenarios for different reservoir conditions. The acceptability of these alternatives, however, is mitigated by other concerns. As is the case under current practices, economic analysis is only one part of the decision process. Reservoir managers must also consider the political, social, and environmental concerns regarding possible alternatives. Outcomes dictated by the economic analysis may be reinforced, or more often, contradicted by these other concerns. While the existence of these other issues is recognized by this research, the focus remains on the economic outcomes.

CHAPTER II

RESERVOIR DESIGN AND MANAGEMENT

The primary function of reservoirs is the storage of water from one period to another, in order to smooth the fluctuations of water supplies across time. In addition, reservoirs provide a source from which many users may draw water for various uses. Each of these functions serves to better match the demands that we place on our limited resources and their supplies.

The construction of these reservoirs gives rise to an interesting set of policy decisions concerning the management of the resource. Each of these decisions relates to the degree of efficiency with which we utilize our water resources. The first decision to be made, taking place before the impoundment is constructed, is to determine the appropriate size of the facility to be constructed. As with any investment project, there is a specific capacity that is most consistent with the efficient provision of the output generated. The second major decision that must be addressed is the efficient operation of the facility. Specifically, how access to and use of the resource is allocated among alternative uses influences the efficiency of the facility.

Sizing of Facilities

Because the primary function of a reservoir is to provide for the storage of water, the most important physical characteristic of a reservoir is its storage capacity (Linsley and Franzini 1979). Once the decision is made to pursue efforts for the construction of a reservoir, it must be determined what storage capacity is appropriate. This decision depends on the designated purpose of the reservoir and the amount of water required to satisfy the demands for which the facility is being constructed. The most common approach to reservoir sizing utilizes the relationship between reservoir storage capacity and the yield.

Unlike the volume of a regular shape, which can be determined through standard volumetric calculations, determining the storage capacity of a reservoir generally requires the application of topographic techniques. This is due to the irregular contour of the earth's surface. An elevation survey of the area encompassing the proposed reservoir produces a family of contour lines, representing points of equal elevations. Each elevation is represented as a single plane in space. The area of each elevation is then determined through planimetering, a method of determining the area of an irregular shape. The relationship between elevation and area is summarized by the area-elevation curve. The integral of this area-elevation curve yields the elevation-capacity curve. This relationship shows the volume of storage available at each water surface elevation level (Linsley and Franzini, 1979, p.147).

Yield is the amount of water that can be supplied by a reservoir during a specified time period, in order to meet the demands of the designated uses. The time interval can be as short as a single day, and as long as a year or more. Generally, the shorter interval models are applied to reservoir management problems. For reservoir planning, the appropriate time horizon is generally one year, with the yield expressed in monthly intervals. The yield in a given time period is determined by the amount of water flowing into the reservoir (Linsley and Franzini, 1979, p.150). However, it is also influenced by the amount of water that is lost due to insufficient capacity and evaporation, among other things. That is, the yield is determined by the amount of water available throughout the time interval. Through a series of mathematical equations, representing the relevant hydrological factors, and using historical inflow data, we can determine the storage capacity required to satisfy a steady yield. Thus the appropriate reservoir size is the minimum size that fulfills our yield requirements.

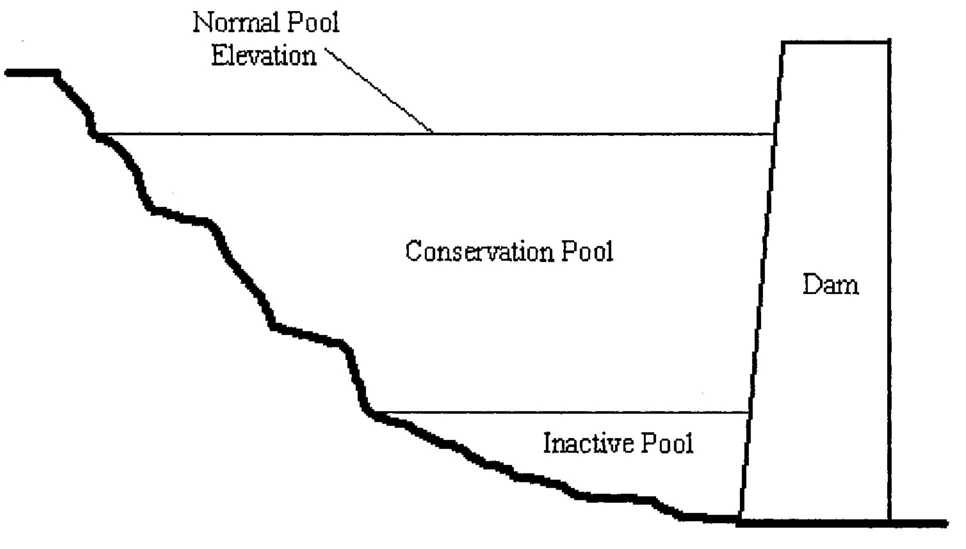
This storage-yield relationship reflects the dual nature of the basic reservoir problem. Not only does this relationship aid in determining the appropriate reservoir size for a given steady yield, but it also represents the yield that can be derived from a given reservoir. Because demands are often highest during the periods of low flow, water resource managers are most concerned with yield during these low flow periods. That is, what is the largest sustainable yield that can be supplied through the worst drought on record? Answering this question provides managers with an historical reference on which to base future projections. The time period encompassing the worst drought on record is commonly referred to as the "critical period." More specifically, the critical period is a series of consecutive time intervals, usually more than a year in length, during which the historic flows are significantly lower than normal. The largest sustainable yield that is available during this critical period is known as the "safe yield" or the "historical yield" (ReVelle, pg. 4-7). Using this critical period data for sizing a reservoir allows water resource managers to determine the appropriate size of a facility in order to satisfy yield requirements during the worst drought on record. This provides some assurances that the desired yield will likely be safe in the future, provided that future droughts are no more severe than that of the critical period. Since it is possible that future droughts may be more severe, these safe yields are not safe at all. Based on this possibility, researchers have begun to study the reliability of the standard reservoir models. The reliability of a reservoir is defined as the probability of delivering the expected yield throughout the economic life of the reservoir, with no periods of deficiency (Linsley and Franzini, 1979, p.157). Currently, two prominent approaches to dealing with reservoir reliability include reliability constrained optimization models and reliability estimation of alternative storage capacities.

Allocation of Storage Capacity

As was stated earlier, one of the main functions of reservoirs is to transport water across time, in order to smooth the discrepancies between supply and demand. However, this is not the only function of most reservoirs. In fact, many reservoirs serve several functions concurrently. It is these varying uses of reservoir storage capacity that is the topic of much discussion among those who reap, or would reap, the benefits associated with competing uses. The designated purposes of reservoirs can be broken down into two main classifications: single purpose and multiple purpose.

Single purpose reservoirs are designed and operated to serve a single purpose. The designated purpose may be different for each reservoir, and generally fall into one of two broad designations: 1) flood control, and 2) conservation (Johnson et al. 1990). Flood control capacity is generally unoccupied storage volume maintained for the purpose of collecting potential floodwaters during periods of heavy rainfall or runoff. These floodwaters are then released gradually, and in a manner that prevents or minimizes down-stream flooding. Conservation storage is a broad designation for which there can be several specified uses. These uses may include hydroelectric power generation, municipal and industrial water supply, environmental protection, and recreation, among others. Conservation pools are maintained at certain levels, or with certain volumes, to satisfy their designated uses. In addition to flood control and conservation capacity, reservoirs generally maintain a storage capacity for the purpose of accommodating sedimentation. This is storage capacity known as dead storage or the inactive pool. Dead storage is occupied, but unused capacity that allows for the natural sedimentation to occur, without impacting the capacity assigned to other uses. Figure 1 illustrates a common depiction of a single purpose reservoir's storage capacity. The reservoir illustrated in Figure 2-1 is operated solely for conservation purposes.

FIGURE 2-1[1]: SINGLE PURPOSE RESERVOIRS



Multiple purpose reservoirs are those reservoirs that have as their designated use more than a single purpose. These facilities are generally operated to satisfy some combination of flood control and conservation purposes, with the storage capacity

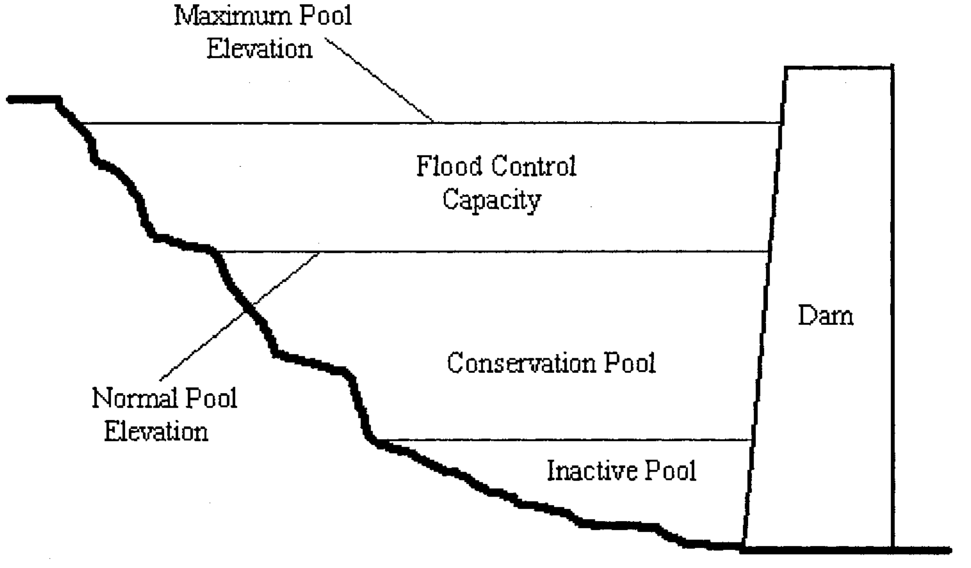
[1] Adapted from Johnson et al., 1990.

allocated to each expressed in terms of elevation or a volume measure. Operating a reservoir as a multiple purpose facility generates some interesting interactions between different uses and users. Demands for alternative uses of storage capacity can be either complementary or conflicting, depending on the nature of the two uses. Considering a facility operated jointly for hydroelectric generation and municipal water supply, this interaction should be evident. Water used for electric generation purposes flows through the generating facility and into the stream below the reservoir. This water cannot also be used for municipal water supply, as it must be released in order to generate electricity. Therefore, these two uses conflict with each other. However, if we consider a reservoir for which the designated uses are fish and wildlife maintenance and recreation, the two purposes do not compete with each other. Regardless of the designated uses for a reservoir's storage capacity, each use must be assigned a discrete storage volume for its use. The allocation of capacity between alternative designated uses is generally measured in terms of elevation. The reservoir depicted by Figure 2-2 has been designated as a multiple use facility. Flood control and municipal water supply, a conservation purpose, are the two uses authorized for this reservoir.

Role of the Corps of Engineers

One of the best sources of information regarding the operations and functioning of reservoirs in the United States is the United States Army Corps of Engineers. The Corps of Engineers is the main vehicle through which federal water resources interests are exercised. The Corps maintains a network of facilities and extensive data libraries, which provide an opportunity to examine data on many reservoirs of different sizes and with

FIGURE 2-2[2]: MULTIPLE PURPOSE RESERVOIR



different uses. Therefore, to examine the alternative functional arrangements of existing reservoirs, a survey of the operations of reservoirs owned by the U. S. Army Corps of Engineers is in order.

The Corps is a division of the U.S. Army, through which the federal government's water program objectives are pursued. Historically, the main objective of the federal government was to provide a means to prevent or minimize floods and the resulting flood damages. The result of this program was the construction of a network of reservoirs, owned and operated by the Corps. While these facilities were viewed locally as a source of solutions for municipal water supply woes, domestic water supply was not a federal responsibility. The passage of the Water Supply Act of 1958 (WSA) ushered in a new era in federal involvement in domestic water supply (IWR 1998). The significance of the WSA was to advocate the inclusion of municipal and industrial water supply in Corps

[2] Adapted from Johnson et al., 1990.

reservoirs, and to do so under a uniform policy. Although municipal water supply remained a non-federal responsibility, the 1958 act stated that the federal government should cooperate with local governments in addressing water supply concerns. Because municipal water supply remained a non-federal responsibility, the inclusion of water supply in a Corps reservoir required a non-federal sponsor. This sponsor is required to repay the costs of providing this water supply, as a proportion of the total project costs, plus interest, during the life of the project. The life of a Corps reservoir project was generally expected to be 50 years.

Little changed, concerning the role of the Corps in municipal water supply, between 1958 and 1986. However, the passage of the Water Resources Development Act of 1986 (WRDA'86) significantly altered the federal role. Among the provisions of the WRDA'86 were a reduction of the repayment period from 50 years to 30 years, mandatory annual operations and maintenance cost reimbursements, and updated interest rate calculations. The results of this act were to alter the emphasis and operations of the Corps. Today, non-federal water supply sponsors are expected to repay construction costs before or during construction. Also, single purpose facilities are no longer considered feasible. These changes have shifted the focus of the Corps from construction of new water resource facilities to more appropriate management of existing facilities. That is, a new emphasis is placed on more efficient operations, water conservation measures, and reallocation of existing supplies (IWR, 1998). For this reason, the focus of current research seems to be shifting from determining the appropriate sizing of facilities to determining more appropriate uses for existing facilities.

While the Corps' mission is multidimensional, encompassing many different types of projects and efforts, the projects and operations of most interest for the current research endeavor are those of water resource development and management. The Corps of Engineers designs, constructs, and operates water resource facilities for various different purposes. Three main purposes for these facilities are for mitigation of flood damages, navigation, and environmental restoration (NRC, pg.33).

Nationwide, the Corps currently owns and operates approximately 600 reservoirs, including navigation locks and dams. Contained within these facilities is approximately 216 million acre-feet of storage capacity. Of this, approximately 107 million acre-feet of storage is designated as single-purpose storage. That is, the purpose of each facility represented in this total is singular. The remaining 109 million acre-feet of storage in the Corps of Engineers system is designated as multiple-purpose storage (Johnson et al., 1990).

The state of Oklahoma falls entirely within the boundaries of the Southwestern Division in general, and within the Tulsa District specifically. Through the Tulsa District, the Corps currently owns and operates 32 flood control facilities, with 9 of these serving as multiple purpose water resource projects including hydropower production.

Need for Reallocation

During the design and construction phases of a reservoir project, a specific purpose or use is authorized for the impoundment. This purpose may be singular in nature, or it may encompass several authorized uses of the facility. Based on current needs and the projected needs of future users, an appropriate size is determined and authorized. If the facility is authorized for multiple purposes, each use is assigned an amount of storage capacity deemed appropriate at the time of construction. The sum of these authorized storage volumes contributes to the determination of the size of the facility to be constructed. The ultimate determining factor in sizing a reservoir has traditionally been the hydrologic factors involved. The optimal size is determined to be the smallest size that will provide the yield required to satisfy the authorized use or uses.

This hydrologic approach of determining the minimum size necessary to meet the reservoir's purposes has, in addition, the effect of minimizing the total costs associated with the project. This is due to the fact that the relationship between the size of the facility and the associated total costs is positive. The only variable cost associated with construction of a given facility depends on the capacity of the facility to be built. Therefore, costs increase monotonically with capacity. Thus, the approach to reservoir sizing that determines the smallest size that satisfies the authorized purposes yields the optimal size for the facility, both in terms of hydrology and economic efficiency (ReVelle pg.5).

Changing Needs and Uses

Although the sizing of the impoundment and the allocation between uses may be efficient at the time of construction, it may not remain so. Over time, the factors influencing the original design may change. The sources of these changes are numerous. Factors such as sedimentation may alter the storage-yield relationship, altering the yield for a given, predetermined impoundment size. New demands may be placed on existing authorized uses. Existing designated uses may become unnecessary. Demands for alternative uses of the existing storage capacity may develop. Finally, the values assigned to different outputs may change, altering the economics of the various allocations. To accommodate these types of changes, it may be desirable to alter either the designated uses of the existing storage capacity, the storage volumes authorized for each use, the operating policies of the reservoir, or any combination of these measures. In some cases, it may even be appropriate to alter the size of the impoundment.

Accommodating Changes

For single purpose reservoirs, the changes may be limited to altering either the operating policies or the size of the facility. That is, if a reservoir of a given size is faced with changing demand for water, the options are limited. The most common response is for water resource managers to alter the way in which water is regulated. This is often accomplished by changing the release patterns and flows. The other option is a bit more extreme. Reservoir managers may choose to increase the capacity of the impoundment by raising the height of the dam. The appropriate response is determined by the amount of change in the water supply necessary to meet the new demands.

For multiple purpose reservoirs, there are more options available for addressing changing needs or demands. These include the options available to single purpose reservoirs, but also include many more possibilities. The most promising and widely applied approach to dealing with these changing needs is the use of storage capacity designated for one use to satisfy another use. This reallocation may be either permanent or temporary, depending on the nature of the new demand environment. If the new demands placed on the reservoir are of a seasonal nature, the changes made to accommodate this may also follow a similar seasonal pattern. However, if the new demands are relatively constant throughout the year, and projected to be permanent, then the changes made to the reservoir's water resource allocations should also be permanent.

Opportunities for Reallocation

The designated uses from which water resources are shifted, and any new sources of water are in no way predetermined. It is the goal of the reallocation to provide for the new or increased demand from some source. Determining the source is often a point of contention. When one user gains access to a limited resource, some other user often looses. The choice facing water resource managers is how to determine which user gains access and which looses. They must choose how to reallocate the resource in order to accommodate the new or increased use. In the broadest sense, these reallocations of storage space generally occur between the flood control and conservation pools. It is also common to shift water resources among authorized uses of the conservation pool. However, these are not the only options available. Johnson et al (1990), reviewing existing reallocation studies, identified eight general cases of opportunities for reallocation of storage capacity involving Corps of Engineers' reservoirs. These cases are listed below.

1. Use of water supply storage not under contract
2. Temporary use of storage allocated for future conservation and sedimentation
3. Use of storage made available by changes in conservation demands or purpose
4. Seasonal use of flood control capacity during dry seasons
5. Reallocation of flood control space for conservation purposes

6. Modification of reservoir water control plan and method of regulation
7. Increasing total storage capacity by raising the elevation of the existing dam
8. System regulation of corps and non-corps reservoirs

In developing these generalized cases of opportunities, the authors reviewed sixteen studies that examined water storage capacity reallocations. Of these sixteen, reallocations were implemented at eight of the facilities.

Logistics of Reallocation

In order to investigate the outcomes of a reallocation, one must first understand how those outcomes were chosen. That is, we must understand the process that is employed in arriving at a particular decision. In the case of water resource issues, this process usually involves various agencies at different levels of government, as well as those individuals and businesses impacted by the water resource problem or its solution. Each of the participants in this process has an important role to play. The role and influence of each of these participants is important in determining the outcome of a particular water resource problem.

Investigation of water supply and other water resource issues by the Corps is occasionally initiated on behalf of the Corps itself, subsequent to identifying a water resource problem or opportunity. However, these studies are generally initiated through the request of an interested party, usually a local government agency, with a water resource problem beyond its scope of abilities. In addition, studies may be facilitated by the efforts of a congressional member through a direct request for authority to study a specific water resource problem (NRC, pg. 34).

Reallocation Process

In the case of a reallocation of storage capacity, the process is generally begun with the request of an interested user or potential new user of the water. For example, if a local municipal water district determines that its current water supply is insufficient to meet current or future needs, it may request additional water from a Corps facility. However, this is not the first stop for a request of this nature. This request is generally presented to the state's water resources management agency before being brought to the attention of the local Corps office. Even though the Corps owns the facility that stores the water, the water itself is generally the property of the state. Therefore, it is the state that determines who has the right to use the water. Depending on the proposed use of the water requested, the state water resource agency may either approve or deny the request. Once the new user establishes a right to the use of a given quantity of water, the next step is to determine the most feasible source of satisfying that demand.

The decision of which source to use to satisfy the new demand usually requires the comparison of alternatives. These alternatives may include various existing Corps and non-Corps facilities, the construction of new facilities, and groundwater sources. Once a set of alternatives is identified, each of these is evaluated in terms of financial feasibility and environmental impacts. Based on the evaluations of the alternative plans, the new user decides which one is the most feasible solution to the existing water resource problem. If it is determined that the best source of water is an existing Corps reservoir, the new user then contacts the Corps regarding the request for water.

The role of the Corps is to determine the most economically feasible and socially and environmentally acceptable method of providing the desired water supply, if one exists. This can only be determined through an investigation of the impacts of the changes required to satisfy the new demand. The scope of the investigation by the Corps depends on the necessary changes. If the facility in question has unused capacity authorized for the use for which the water is being requested, the required changes may be minimal and the impacts insignificant. Thus, the scope of the investigation may be narrow and pointed. However, if the facility is not authorized for the desired purpose, or has no excess capacity, a more detailed investigation is warranted and required. The nature of an investigation into most water resource issues by the Corps, including reallocation studies is a relatively detailed and time-consuming process, following relatively strict guidelines.

Corps Policies and Procedures

The evaluation of a water resource problem by the Corps usually must adhere to a relatively structured process. Regardless of the source of the request for the study, the Corps must have both the authorization and the funding to conduct the study. Each of these is at the discretion of the U.S. Congress. Each year, the Congress acts upon legislative bills and amendments that grant the authority to the Corps to conduct specific water resource studies. Once the Corps has the authority to conduct a study, it must get funding for the project. Funding for these types of projects is generally provided through the annual appropriations act passed by the Congress. With the authority and the funding to conduct a study, the Corps can now embark on the initial areas of the investigation. At this point, it should be noted that not all Corps projects are subject to congressional approval and funding. The case for these exceptions is presented in a later section.

Not unlike many other federally administered public works and other programs, decisions concerning water resource use are often the subject of a lengthy bureaucratic process. According to the National Research Council (NRC pg. 35), the average time required to complete the initial planning stages of any Corps' project is approximately six years. Studies investigating the possibilities of reallocating storage capacity may be concluded more quickly, but construction related projects are often extremely time consuming. This six-year average does not include the planning of any physical structures to be built. The design and engineering of the planned facilities come later.

According to Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G), the guidelines that direct research by the Corps, the initial planning stages of any project study, including reallocation studies are broken into two distinct phases. Each of these phases has its own limited scope and objectives, as well as funding sources. While the P&G suggestions are not mandatory, they do represent the recommended and generally applied process of conducting water resource studies. The phases of a study conducted by the Corps generally include the reconnaissance phase and the feasibility phase. For each phase, the P&G outlines a six-step planning process that should be followed to guide the study (NRC, pg.34). These six steps include:

1. Specify problems and opportunities
2. Inventory and forecast conditions
3. Formulate alternative plans
4. Evaluate effects of alternative plans.
5. Compare alternative plans.

6. Select recommended plan.

If the subject of a study is the reallocation of storage capacity among potential uses and users, a reallocation report must be prepared to guide the decision process. The content and detail of the reallocation report should be commensurate with the extensiveness of the proposed reallocation, and the impacts on all affected uses (WSH, pg.4-8). That is, the report should cover all of the basic concerns related to the proposed changes. The Institute for Water Resources (IWR) has identified five objectives that any reallocation report should address. These objectives include the following:

1. Identify and quantify the new use and user.
2. Evaluate the impacts on other project uses and users.
3. Determine the environmental effects.
4. Determine the price to be charged the new user.
5. Determine the appropriate compensation to existing users.

A reallocation report should address any of these objectives that are relevant to the study at hand. While the simple and relatively minor projects may not include some of the concerns listed above, more extensive projects will generally include all of the issues. Ultimately, the findings of the reallocation report are the basis for either implementing or terminating the project. Thus, the accuracy and reliability of the analysis contained within the report is of major concern. This report is the product of the entire investigation, including reconnaissance and feasibility phases. Therefore, a discussion of these two planning phases is in order.

Reconnaissance Phase

The reconnaissance phase of a Corps reallocation study is a somewhat detailed assessment of the water resource problem and its possible and likely solutions. This phase of the study is conducted, and is sufficiently detailed to determine if the project warrants further investigation and funding. During this phase of the investigation, an assessment of all relevant issues is conducted. These are the same issues suggested for the reallocation report, but carried out in a less formal and detailed manner. The issues of most concern during the reconnaissance phase of a study often include the scale of the proposed reallocation, the possible environmental impacts, and the impacts on other uses and users. The determinations made relative to each of these issues greatly impact the future actions regarding the study. If investigators believe that the proposed reallocation will have severe detrimental effects on either the environmental conditions or other uses and users, the study will likely be terminated without further consideration.

The other major concern, the scale of the proposed reallocation, influences the authorization and funding required for continued research on the issue. This relates to the exceptions noted earlier, regarding the requirement of congressional approval for authorization and funding. Based on section 301(b) of the Water Supply Act of 1958, any changes in the allocations or operations of a Corps facility that would significantly impact the designated purposes of the storage capacity, or that would require major structural changes must receive congressional approval. As a general rule of thumb, the threshold applied by the Corps is the lesser of 50,000 acre-feet or 15 percent of the total storage capacity of the facility in question. Provided a proposed plan does not violate the criteria above, any reallocation of storage volume less than the applied threshold may be undertaken at the discretion of the Corps. Reallocations that either violate the criteria, or exceed the threshold must be approved by the U.S. Congress.

This approach is also extended to the funding of both the feasibility phase of the study and the reallocation itself. Generally, the reconnaissance phase of a study is funded through the Corps' Operations and Maintenance (O&M) funds, although use of alternative funds is also an option (WSH, pg.4-8). This phase of a study is limited both in time and funding. The current allowances are for one year and a maximum of $100,000 (NRC, pg.35). Specific findings of the reconnaissance phase may signal the need for congressional involvement. If it is determined that the reallocation warrants further investigation, or the feasibility phase of the study, authorization and funding for continued research are sought from Congress. If the reallocation is found to be acceptable, and no further investigation or congressional approval is needed, then the Corps may implement the reallocation using O&M funds (WSH, pg.4-8). Upon completion of the reconnaissance phase of the study, a recommendation is made to either continue with the feasibility phase of the project, or implement the reallocation with no further investigations, or terminate the study entirely.

If the decision is made to pursue the proposed project through additional research, the first step is to seek authorization and funding from Congress. As with most federal actions, the time required to acquire the necessary legislative approval is significant. This is true with the funding aspects of a project as well. The lead-time for funding a project or study is often in the range of one to two years. Therefore, it is common for the Corps to evaluate the need for additional funding at the outset of the reconnaissance phase, and initiate the process if it is believed that congressional approval and funding will be required. This approach should tend to shorten the overall time required to complete the project or study. In addition, a project or study that is likely to require congressional approval and funding may also require local, non-federal sponsorship. If the purpose of the study is non-federal in nature, such as municipal water supply, a cost-sharing arrangement should be negotiated during the reconnaissance phase. This cost-sharing agreement generally addresses project scheduling, cost allocation, and other concerns of the Corps and the non-federal sponsor.

Feasibility Phase

Once authorization and funding for the feasibility phase is approved, the focus and detail of the project evaluation intensifies. During this phase, the issues to be addressed in the reallocation report are investigated in detail. Also, public meetings to inform local interests are held during this phase. In the early stages of this phase, alternative plans to address the problems or opportunities are formulated. There may be several alternative plans formulated. However, the *P&G* only requires that one alternative plan be developed. This required alternative is the National Economic Development (NED) plan. The NED plan is the water resource development alternative that maximizes the project's marginal social benefits, while protecting the nation's environment, in accordance with federal environmental statutes and related laws (NRC, pg.34). These alternative plans are then compared to the proposed plan in regards to their associated impacts. The formulation of these alternative plans is extremely time and resource consuming. Therefore, the number of alternative plans formulated for comparison is limited by the intensity of the analysis.

In evaluating the feasibility of a reallocation, many factors must be considered. These include technical and hydrologic considerations, legal concerns, environmental impacts, cost reimbursement, and economic assessments, among others. Each of these is evaluated with regard to the issues and concerns to be addressed in the reallocation report. One area of specific concern is the effect on the environment of the proposed changes.

With the passage of the Water Resource Development Act of 1990 (WRDA'90), the Corps was assigned an additional mission. The WRDA'90 requires the Corps to include environmental protection as a primary mission in its planning, implementation, and operation of water resource projects. In addition, the Water Resource Development Act of 1996 (WRDA'96) extended this mission to include not only environmental protection, but also environmental restoration. In response to these changes, the focus on environmental impacts of proposed reallocations has intensified. One result of this attention on the environment is the implementation of environmental impact assessments, which may be included in the final reallocation report. This Environmental Assessment (EA) reports the findings of simulation models for the proposed changes. Areas of interest include the impacts on endangered species, habitat, and fisheries. This may apply to those environmental impacts within the reservoir, as well as downstream effects. Common findings of an EA are that there are detrimental impacts, beneficial impacts, or no significant impacts on the environment of the alternative plans. The report generally outlines the source and degree of expected impacts. The findings of the EA may significantly influence the likelihood of implementing the proposed plan. If a proposed reallocation is found to likely have significant detrimental environmental impacts, proceeding with the plan is inconsistent with the mission of the Corps, regarding environmental protection. Thus, the proposed reallocation plan will likely be altered or abandoned. If a proposed reallocation will likely have no significant environmental impacts, then investigations into other aspects of the proposed change continue.

Economic Assessment

While there has been increasing attention focused on the environmental impacts of water resource development projects, this is generally not the determining factor. As with most decisions that we face, the choice often reduces to a question of economics. For alternative plans with similar impacts on non-economic concerns, the logical decision variable is the economic feasibility of the plans. Therefore, it should not be surprising that the determining factor in most reallocation projects is the economic impact generated by the change. A reasonable justification for this approach is offered by Lesser et al (1997 pg.614): Although the sustainability of our natural resources cannot be accomplished through the application of economic principles alone, it cannot be accomplished without the insight of economic analysis.

A common approach to this economic problem and to reallocation projects in general is to apply benefit-cost analysis to a discrete change in the storage allocations associated with alternative uses. That is, to compare the changes in benefits and costs to society of operating the facility according to the proposed plan versus the status quo. This approach requires determining the costs and benefits associated with each alternative, and then deriving the difference between the two. These costs and benefits are determined relative to each authorized use of the facility. This means that benefits for one use may increase as a result of the reallocation, while benefits associated with another use declines. In the final analysis, the changes in benefits are compared to the changes in costs, yielding a measure of the net benefits of the proposed reallocation. It is this net benefit measure that determines the economic acceptability of a specific alternative. A reallocation effort would be judged economically feasible only if the present value of the stream of net benefits is positive. This means that only those alternatives for which benefits exceed costs will be deemed economically feasible. When comparing alternative plans, the decision becomes one of determining that plan that generates the greatest positive net benefits. However, if the proposed project is specifically oriented toward environmental protection or restoration, the criteria may be somewhat different. For these projects, the decision is one of choosing the alternative that achieves the desired goal at the lowest cost. This is due to the fact that some environmental projects are desirable, even if they are not economically sound. An approach to resource development that does not use traditional benefit-cost analysis is not entirely unusual. In fact, many federal agencies are legally barred from considering economic values in some decision-making processes. The viewpoint taken for this benefit-cost analysis is from the perspective of the taxpayers. That is, the costs and benefits used are those that accrue to society in general.

Embedded in this approach is the problem of determining the values to use for the benefits and costs associated with an alternative. The determination of some of these values may be difficult, depending on the nature of the alternative uses. The values used to represent benefits refer to the value of the output of the facility. These values are often difficult to ascertain. The output of a facility refers not only to the value of those outputs that are relatively easily measured, such as water supply and hydropower, but also to the output of those non-market goods that are not easily valued. These non-market goods include recreation, flood control, and fisheries. For example, the hydropower benefits of a given facility can be determined by evaluating the amount of electricity generated at the current market value. If a reallocation of water supply storage from the flood control pool to the hydropower pool were implemented, one would expect to see increased benefits associated with the hydroelectric generation function of the facility. The increase in benefits associated with this change could be captured by determining the increase in electricity generated under the new allocation, and evaluating this output at the market price. Likewise, a reallocation to the water supply pool can be valued by utilizing the market value of municipal water supplies. The common thread between these two examples is that both uses have market values. Therefore, determining the benefits of a reallocation to one of these purposes can be achieved using these market values.

The benefits of a facility allocated to a purpose that is not exchanged in a normal market setting are more difficult to ascertain. The value of flood control space in a reservoir can be determined using estimates of damages that would occur in the event of a flood. The value of increasing or decreasing the flood control capacity can be estimated as the difference between the damages prevented under the two allocations. To address the benefits of uses such as recreation and fisheries, there are several methods of estimating an appropriate value. These methods can be classified into two main groups: proxies and preference evaluation. Proxy methods of valuing non-market goods use information concerning goods that are related to the non-market good in question to estimate a value. Prominent proxy methods include hedonic pricing and travel cost approaches. Preference evaluation techniques seek to elicit responses from individuals that reveal their willingness-to-pay, and thus the value placed on a non-market good. The most prominent of these techniques is the contingent valuation method. An emerging approach for addressing the problem is the benefit-transfer process. While this process has promise, it has not yet been widely applied to the reservoir problem. The basic idea here is to apply the valuations derived at similar facilities, through one of the above approaches, to the facility in question. One reason for the development of this approach is to reduce the time and costs associated with the valuation of non-market goods. While each of these techniques has its uses and limitations, the travel cost method seems to be the most widely used method of valuing the non-market goods associated with reservoirs.

The costs associated with a reallocation are the losses to society that arise due to the proposed change. These costs are more appropriately defined as benefits foregone. If a proposed reallocation from hydropower to water supply yields reduced electric generation, the value of this reduction, or the benefits foregone, represents a cost of the reallocation. Likewise, if a proposed reallocation is expected to result in a decline in the value of recreation activities at the facility, this decline represents a cost of the proposed plan. That is, any negative benefits that arise as a result of a proposed reallocation of storage capacity are the costs of that reallocation.

The economic feasibility of a proposed reallocation depends on the relationship between the associated costs and benefits of the plan. If a proposed plan generates costs in excess of the benefits generated, the plan would be judged economically infeasible. If a plan generates benefits greater than the associated costs, it would be judged economically feasible. All other things constant, those plans that generate negative or smaller net benefits would be passed over in favor of a plan that generates positive or greater net benefits.

This economic analysis is not the overriding factor in determining the fate of a proposed reallocation. While it is possibly the most important in most cases, the economic feasibility must be considered within the context of the broader social, political, and natural environments. That is, just because a plan generates the greatest economic benefits, does not necessarily mean that it is the best alternative for the given situation. A plan that generates small or negative net benefits may be preferred to a plan that generates larger net benefits if the former arouses less social conflict than the latter. Likewise, the political environment may make a project that yields smaller economic benefits more preferable. The Corps' use of this holistic approach in evaluating these types of projects generally results in the best-proposed alternative being adopted.

Cost Allocation

In addition to the economic feasibility and political, social, and environmental concerns associated with a proposed reallocation, the Corps is also concerned with the allocation of costs to the new user. Because all non-federal purposes require a non-federal sponsor, someone must pay the Corps for the storage space provided. In determining the appropriate amount to be charged for the reallocated storage, the Corps is primarily concerned with recovering the costs associated with the initial capital investment. To address this issue, the Corps employs one of three methods to determine the appropriate share of the project costs to be assigned to the user of the reallocated storage. These three approaches are 1) benefits or revenues forgone, 2) replacement costs for lost storage capacity, and 3) updated cost of storage capacity. In general, the actual price charged for the reallocated storage is the highest of these three formulations. However, Johnson et al. (1990) states that the third approach is generally applied more often than the first two. For the first two of these methods, the determination of the appropriate value depends of the purpose from which the storage volume is reassigned.

If the reallocated capacity is taken from a use such as hydropower generation, then benefits or revenues forgone can be obtained from in-house valuations of electricity produced. The use of a smaller pool results in less production of electricity, and reduced revenues. These lost revenues can be used to value the reallocated storage. Replacement costs for water taken from electric generation can be estimated as the cost of replacing the electricity lost due to the reallocation. If the electricity-marketing agency were to purchase power to fulfill its existing contracts, the price paid, using its least cost alternative, would represent the value of the reallocated storage.

Similarly, if the reallocated capacity were taken from a use such as flood control, the benefits or revenues forgone are determined by the loss in capacity for preventing flood damages. Flood capacity is valued for the amount of flood damages it can prevent. Reducing the size of the flood control pool reduces the damages that can be prevented. The value of these previously preventable damages can then be interpreted as the value of the reallocated storage. Replacement costs for storage capacity taken from flood control are the costs associated with providing an equivalent amount of protection through other means. These other means include construction of additional facilities, altering management policies, and structural changes for the existing facility. The least costly of these options would represent the replacement cost for the reallocated storage capacity.

For the final method of valuing the reallocated storage, the Corps assigns a proportionate amount of the initial construction costs to the new use. This is accomplished through a three-step procedure. The first step is determining the cost of the reallocated capacity at the time of construction. The total cost of the project is allocated to the new use based on its proportion of total usable storage capacity. The second step is to determine the midpoint of the physical construction period. This requires identifying the month halfway between initiation and completion of the project. This point in time is interpreted as the time at which the cost is incurred. The final step is to update the original cost to its current equivalent. This is accomplished with the use of a construction cost index. By multiplying the initial construction cost assigned to the reallocated storage volume by the ratio of current to previous prices in the construction industry, we derive a cost for the storage volume at current prices. In addition to the updated cost of storage, the non-federal sponsor is also responsible for any specific costs associated with the actual reallocation, including necessary construction and relocation costs. Also the new user will be responsible for a proportionate share of the facility's operation and maintenance costs. Once the appropriate cost of storage and other associated costs are determined, the required payment from the non-federal sponsor can be assigned.

Concerns with Current Practices

The approach of the Corps in addressing reservoir problems in general and reallocations specifically has evolved over several decades. The assessment of these problems is a result of years of practical application and burdensome federal restrictions and mandates. At the same time, the body of theory concerning the solutions to various water resource problems has grown. However, according to Simonovic (1992), there is a gap between the theory and practice applied in solving many of these water resource problems. Simonovic states that the main focus of research over the past several decades has been the application of a systems approach to dealing with water resource problems. This approach takes a much broader view of the reservoir problem than traditional methods, such as benefit-cost analysis. The application of benefit-cost analysis and the general approach to the problem employed by the Corps may not be keeping up with technological and analytical advancements in the field of resource allocation. There also appears to be an opportunity to address additional issues, within the scope of a reallocation study that are not analytically incorporated into the Corps' approach.

Efficiency Concerns

The application of benefit-cost analysis to water resource development projects is not a new approach. In fact, it has a long history in the U.S. and elsewhere. For evaluating the economic feasibility of alternative plans, benefit-cost analysis has been used for decades. This approach, however, is subject to some major complications and limitations. The major issue facing benefit-cost analysis is concern about the efficiency aspects of the approach.

In general, the concept of benefit-cost analysis is an acceptable tool for evaluating the economic feasibility of a potential project. However, in practice, the approach becomes more controversial. A major point of concern is the decision rules that are applied. There are generally three decision rules used in benefit-cost analysis. These include 1) benefit-cost ratio, 2) positive net-present-value, and 3) maximum net-present-value. The first of these suggests that a project should be implemented only if the ratio of benefits to costs exceeds unity. The second suggests that a project should be implemented only if the stream of net benefits is greater that zero. The third suggests that a project should be implemented only if it generates a higher net-present-value than all other alternatives evaluated. Although all three are acceptable rules for evaluating alternatives in terms of economic feasibility, none identify an efficient option. The maximum net-present-value rule identifies the most efficient option, but only among those alternatives that were evaluated.

Regardless of the decision rule that is applied, the most that can be hoped for is to identify those options that are economically acceptable, or preferable to the other proposed alternatives. While this approach does identify those storage volume allocations that are economically feasible, it does nothing for ensuring that a given allocation results in the optimal use of the storage capacity. It only identifies those allocations that are acceptable. This approach is deficient, in that, it would require that an infinite number of possibilities be examined in order to approach a reasonable chance of identifying an optimal outcome. Even if the objective is to achieve a given water supply storage capacity, for a specified use, the benefit-cost approach does not identify the most efficient method of achieving the goal.

Neglected Impacts

Another source of deficiency in the approach applied by the Corps is the omission of some impacts from the benefit-cost analysis. The traditional benefit-cost analysis generally includes only those impacts that occur within the facility. Impacts on purposes such as recreation and fisheries within the reservoir are usually included in the analysis. However, the traditional benefit-cost analysis does not incorporate the impacts on downstream activities, such as in-stream fisheries. Most studies address this concern through the EA in an ad hoc manner, if at all. Changes in reservoir operations and policies may have significant impacts on these types of activities, and should be done in a manner that minimizes negative downstream effects. A common approach to managing downstream effects is generally limited to adherence to low flow regulations. While these regulations establish a minimum discharge necessary to preserve the stream's ecosystem, they do nothing to account for changes in benefits due to altered reservoir management policies. An environmentally and socially responsible evaluation process should incorporate these impacts into the decision-making process.

Although the planning and evaluation process practiced by the Corps provides valuable insight into the issues involved in resource development, the shortcomings discussed above indicate that an alternative approach may be needed. This does not imply that the current approach needs to be abandoned. Benefit-cost analysis continues to be helpful in determining the economic feasibility and desirability of proposed projects, and is useful in comparing alternative plans. Instead of abandoning the benefit-cost approach, it should be amended. The approach implemented here to expand the scope and focus of the response to the reallocation problem will address each of the deficiencies outlined above.

CHAPTER III

GENERAL APPROACH AND SITE OF APPLICATION

There are several aspects of this study that set it apart from the current approach to reservoir allocations, as practiced by the Corps, and the existing literature on this type of problem. The main departure from the current practices of the Corps is the way in which water and reservoirs are viewed. The typical focus of the Corps is on the reservoir capacity, while this study focuses on the water in the reservoir. From the current literature, this study is distinguished by the scope of the problem addressed. Numerous studies analyze multiple-use reservoirs. However, these studies generally limit the scope of the study to two or three uses. This study attempts to capture as complete a measure of benefits arising from the reservoir as possible, by identifying and incorporating all of the major sources of benefits associated with reservoir resources. Due to many potential complications, this approach required careful selection of the site of application.

Study Area

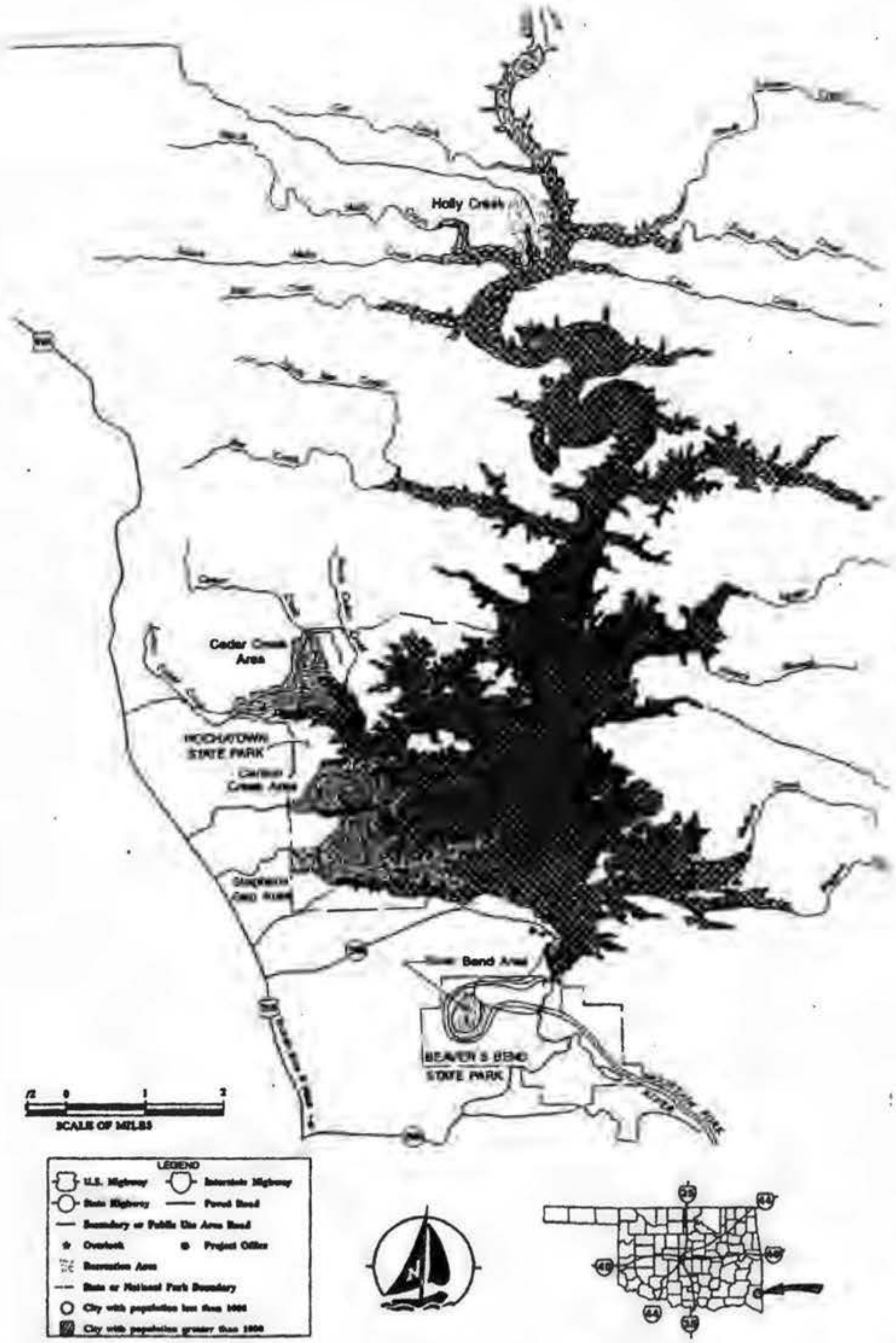
In preparation for this report, several sites were considered for study. The proposition that the process of reallocation needs to be revised requires a site at which the process can be applied and evaluated. The site chosen needed to provide the opportunity for reallocation, free of as many obstacles as possible. The obstacles of most concern were those of the legal, political and environmental nature. These types of issues cannot be effectively addressed within an economic analysis of the type proposed. In addition, political and legal issues concerning a particular site often supersede any economic evaluations presented. Increasingly, environmental concerns are a major source of conflict for reservoir problems. For this reason, the site chosen for this study should face as few of these challenges as possible.

Broken Bow Lake

The facility chosen for the application of this research project is the Broken Bow Lake, in southeastern Oklahoma. Broken Bow Lake is located on the Mountain Fork River in McCurtain County, approximately nine miles north of the town of Broken Bow. A dam totaling 4,026 feet in length, and rising 225 feet above the streambed forms the reservoir. The reservoir extends about 22 miles upstream from the dam, and yields approximately 180 miles of shoreline at normal pool. Constructed by the Corps, the facility was completed in June of 1970, at a total cost of $41,222,000. Figure 3-1 provides an illustration of the reservoir and its location.

The reservoir is designated as a multiple-purpose facility, serving flood control, water supply, recreation, fish and wildlife, and hydroelectric generation. Flood control is achieved through eight 40-foot by 40-foot gates along the spillway, with a designed capacity of 443,000 cfs. In addition, there are two diversion tunnels for emergency use. These measure 17 feet and 2 feet in diameter. Under normal flood control operations the releases are routed through the generating facility, and are limited to 8,000 cfs, the rated capacity of the channel below the dam (Uwakonye, 1990). Total flood control storage capacity is approximately 450,000 acre-feet, which on average provides flood prevention for 11,000 acres annually. Water supply is provided to the Broken Bow area through a 4-foot by 4-foot supply line with a 2-foot pressure conduit. These serve to satisfy the

Figure 3-1: Broken Bow Lake



Source: Oklahoma Water Atlas

estimated 173 mgd water supply needs of the Broken Bow area. Recreation at the reservoir is supported by numerous facilities surrounding the lake, and also along the Mountain Fork River below the dam. A principle form of recreation in the area is sport fishing, both in the reservoir and in downstream fisheries. Electric generation is accomplished with two 50,000-kilowatt generators, fed by a penstock measuring 25 feet in diameter and approximately 1,800 feet long. The intake for the penstock is located at an elevation of 530 feet msl. The average annual electricity generated is over 129 million kilowatt hours. Other pertinent reservoir data are presented in Table 3-1.

Table 3-1: Broken Bow Lake Data

Feature	Elevation (feet above MSL)	Surface Area (acres)	Volume (acre-feet)
Top of Dam	645.0	-	-
Maximum Pool	639.7	20,500	1,598,950
Top of Flood Control Pool and Spillway Gates	627.5	18,000	1,368,230
Flood Control Capacity(1)	599.5 - 627.5	-	450,160
Top of Conservation Pool(1)	599.5	14,200	918,070
Conservation Capacity(1)	559.0 - 599.5	-	469,820(2)
Spillway Crest	587.5	12,600	757,420
Top of Inactive Pool	559.0	9,200	448,250

(1) Reflects normal pool from November through March, which increases to 602.5 from June through September.
(2) Includes 152,500 acre-feet of water supply storage.

Source: U.S. Army Corps of Engineers

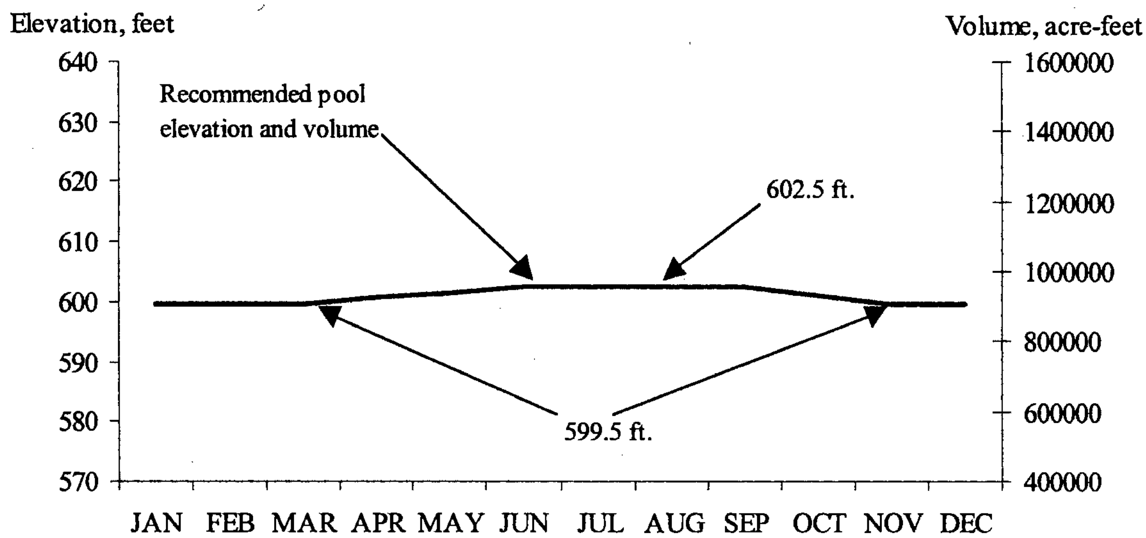
Reallocation Opportunities at Broken Bow Lake

Broken Bow Lake offers an interesting opportunity for this type of analysis due to several features. First, there is storage capacity at the facility that is not officially designated for any specific use. While the total storage capacity of Broken Bow Lake is approximately 1.6 million acre-feet, the amount allocated for specific purposes is less than 1.1 million acre-feet. Although this capacity has no official, contracted use, its existence is a source of benefits to both recreation and hydropower. This excess capacity provides an opportunity for reallocation of the storage capacity that puts the unallocated capacity to a use that may have a higher value than its current use.

In addition, Broken Bow Lake currently operates under the practice of maintaining a seasonal conservation pool. This operation scheme generally allows the normal pool elevation to fluctuate throughout the year. In dry periods, when there is little threat of flooding, the conservation pool is increased, providing additional water supplies for the various uses. While this practice provides increased water storage capacity, it also reduces the flood control capacity, as the increased conservation storage is borrowed from the flood pool. During wet periods, when the threat of flooding is greater, the conservation pool is reduced to accommodate more flood control capacity.

The current seasonal pool guide for Broken Bow Lake calls for a normal pool elevation of 599.5 feet msl from November through March. This gradually increases to 602.5 feet in June, where it is maintained through September. During October the reservoir is again drawn down to an elevation of 599.5 feet. A diagram of the pool guide for Broken Bow Lake is presented in Figure 3-2. Manipulation of this seasonal conservation pool schedule provides an opportunity for increased benefits from reservoir operations. While the current schedule was undoubtedly devised based on hydrologic principles, it is possible that an economic analysis of the situation could suggest a more beneficial pool elevation schedule.

Figure 3-2: Broken Bow Lake Seasonal Pool Guide

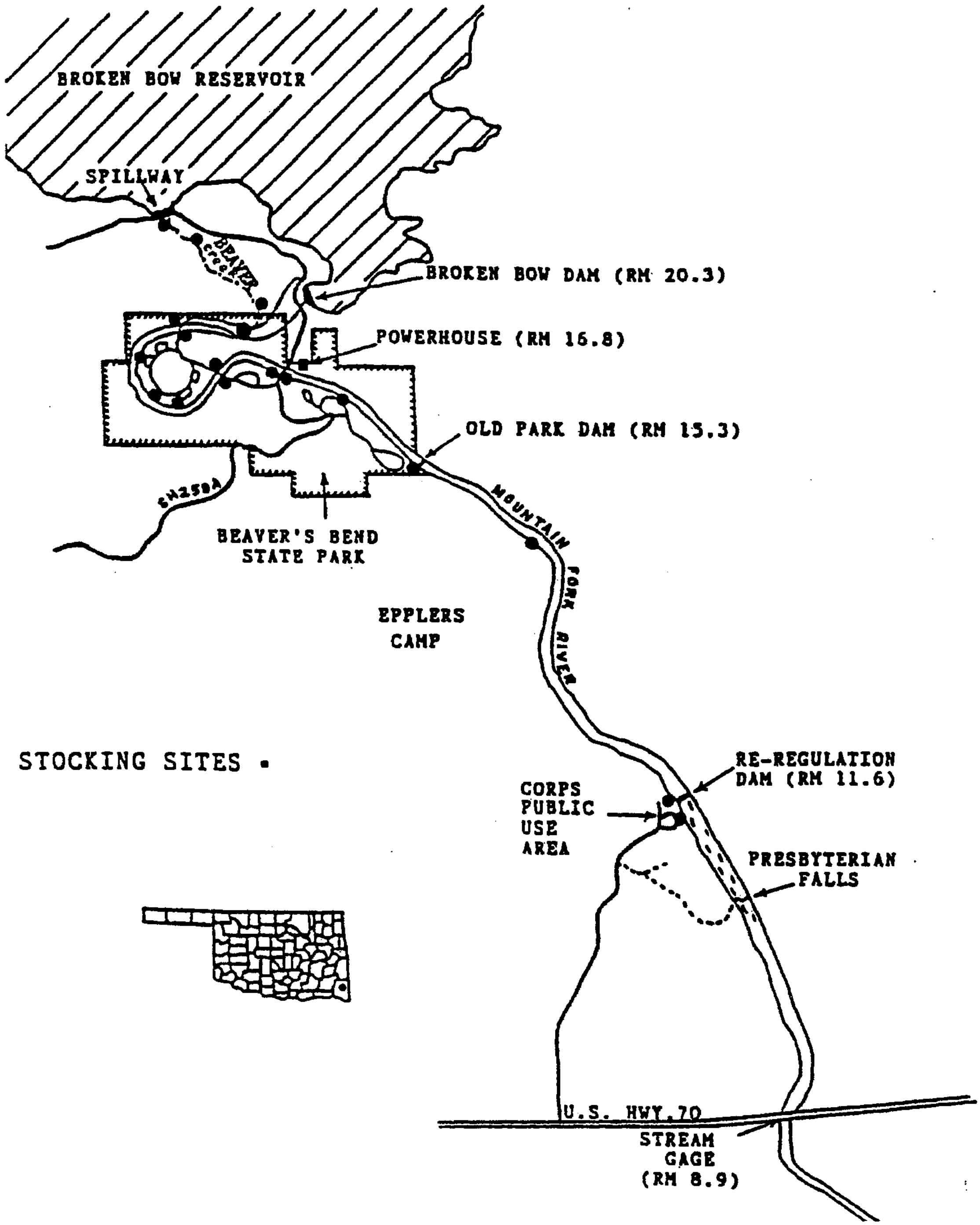


An additional attraction of the Broken Bow Lake is the existence of a year-round trout fishery in the Mountain Fork River below the lake's dam. Initiated by the Oklahoma Department of Wildlife Conservation (ODWC), the fishery was established in January of 1989. The ODWC designated a twelve-mile stretch of the Mountain Fork River from the Broken Bow dam downstream to the U.S. Highway 70 bridge as a year-round put-and-take trout fishery area. Periodic stocking of the river began in 1990 at numerous locations along the span of the fishery. The location of the fishery and the stocking sites are presented in Figure 3-3. To ensure a suitable environment for the fish, the ODWC has negotiated with the Corps for the release of water from the Broken Bow Lake to the downstream area at appropriate intervals and in appropriate quantities.

The existence of this fishery, and the required in-stream flows for suitable habitat provides an opportunity to examine the effects of reservoir operations on downstream activities. While there are water quality issues that are of significant importance to sustaining a year-round fishery, these are beyond the scope of this study. Factors such as the temperature and oxygen content of the releases are vital to the existence of the fishery. However, these are issues best left for another study. The issue addressed herein deals only with the patterns and quantities of releases to the stream. Although the Corps has agreed to release water according to a specified arrangement with the ODWC, this agreement may leave room for improvement. An economic analysis of reservoir operations, incorporating the benefits accruing to the downstream fishery may produce an alternate pattern of releases that yields greater benefits to all involved.

A final attraction of the Broken Bow Lake is the possibility of significantly increased municipal and industrial water demand. Currently, only residents and businesses in the Broken Bow and McCurtain County area receive water drawn from the Broken Bow Lake. However, there exists the possibility for increased water supply withdrawals to support proposed interstate water transfers. This type of potential transfer presents the possibility for analysis of alternative water supply quantities. The benefits of these alternative transfer quantities may significantly impact the outcomes of the model, and may be useful in directing the negotiations concerning pending actions.

Figure 3-3: Mountain Fork Trout Fishery



Source: Harper, 1990

Application of Approach to Broken Bow Lake

The methodology for dealing with the reallocation problem posited herein calls for a broader approach to the basic reservoir problem, as advocated by Simonovic (1990). This approach involves the design and implementation of a computer-assisted mathematical model to identify the optimal use of a given storage volume and pattern of inflows. The purpose of this optimization model is to identify the most economically efficient allocation of reservoir volume, and thus, a preferred water resources management policy, considering the alternative designated uses. This idea of efficient use relates to the benefits accruing to all parties impacted by the allocation scheme. Thus, the general viewpoint taken is that the most efficient allocation is that which yields the greatest total benefits to all parties involved. It should be noted that even though an economic analysis is not capable of capturing all impacts associated with a reallocation project, one can make the process more valuable by representing as many of the impacts as possible. This means that although this type of economic approach may not capture the social, political and environmental aspects of the project, it is more useful than an approach that ignores things that can be captured.

While the issues of water allocation and storage allocation are generally considered to be completely separate problems, for the current endeavor they are treated as one. The motivation for this singular treatment of reservoir resources is the idea that without the other, each resource is severely diminished. This approach requires that an assumption be made regarding the resolution of conflicts between the alternative approaches to water resource problems. The approach taken herein treats the management of the water and the management of the reservoir as a single resource management issue. This requires that both the state and the Corps be fully accommodating. That is, these two agencies, in effect, act as a single entity in pursuit of the maximum benefits from the public good. Although this assumption may not be entirely realistic, it should not diminish the value of the outcomes of the model.

In addition, the inclusion of non-consumptive uses such as recreation in the reservoir makes an explicit division of the water storage capacity, as practiced by the Corps, somewhat meaningless. This is due to the fact that water enjoyed for recreation purposes may be included in water supply or hydropower allocations. Likewise, water for downstream recreation may be first used for electric generation. Due to these complications, the approach taken in this study is to evaluate reservoir resources in terms of releases and total volume, rather than individual storage allocations. This approach requires that, in order to maximize the benefits of the reservoir and its resources, the allocation and management practices be integrated into a single management strategy.

Simulation of Current Operations

The first step in the analysis is to establish a baseline to which alternative outcomes can be compared. This is accomplished by developing a model that reflects the current operation and management policies of the Broken Bow Lake, and captures the associated benefits. This simulation exercise is based on the historical record of inflows and releases, electric power generated, recreation activity levels, flood damages prevented, stream fishing activities, and municipal and industrial water supply withdrawals. From this information, an estimate of the benefits accruing to all parties affected by the reservoir can be generated. This estimate will serve as the baseline for the comparison of all other outcomes. Simulation models of this type have been applied to water resource problems since the early 1950's, used to estimate benefits of virtually every use of water resources. These simulation models permit detailed and realistic representations of the complex physical and economic characteristics of a reservoir system (Simonovic, 1992), and should serve the current needs well.

An integral part of this simulation and the optimization exercises to follow is the determination of the relationships between the different water storage volumes or releases and the benefits of various uses of the water. These relationships can be estimated by applying statistical procedures to the historical records of activity levels or benefits and water storage or release values. For example, it is widely accepted that recreation benefits increase with reservoir volume. Given historical records of water levels and recreation benefit measures, one can estimated the relationship between the two. Other benefits, such as electric generation, can be estimated based on the reported releases and the physical characteristics of the generation facility. This approach to estimating the relationship between variables to be used in a mathematical model is relatively widespread, and is an accepted practice. Once estimated, these relationships are used in the simulation exercise to generate the baseline total benefits measure, given the past operations of the facility. These same relationships form the basis for the optimization exercises to follow.

Optimization Under Existing Constraints

The second step in this process is to employ an optimization procedure to determine the optimal use of the water resources, based on the relationships estimated earlier. The water uses considered in this exercise are the same as those of the simulation exercise, and based on the same set of constraints. The constraints on the model serve to reflect economic, physical and hydrologic conditions and limitations of the reservoir and its services. The outcome of this exercise will provide a measure of the potential gains that can be experienced by simply employing a model of this type. These gains are determined by comparing total benefits of reservoir services, as well as benefits accruing to each individual activity examined to those benefits estimated under the current management practices in the simulation exercise. In addition, this estimate of benefits derived from the initial optimization procedure will serve as a basis for examining alternative reservoir management scenarios.

Optimization of Alternative Scenarios

The final step in the analysis involves the evaluation of several different policy scenarios. For each scenario, the appropriate constraints will be changed, and the optimization procedure performed. Possible alternative scenarios, discussed fully in later chapters, include increased pool constraint levels, water supply sales, price changes and changes in streamflow requirements. These scenarios reflect potential policy changes that may alter the benefits arising from reservoir services.

The benefits arising from each of these alternative policies will be compared to the benefits arising from the current set of model constraints. Increases and decreases in benefits, for both individual activities and in total, provide a measure of the potential gains and losses from each scenario. These gains and losses will then be compared to each other, to identify those management alternatives that provide the greatest benefit.

CHAPTER IV

METHOD OF ANALYSIS AND DATA REQUIREMENTS

Model Design

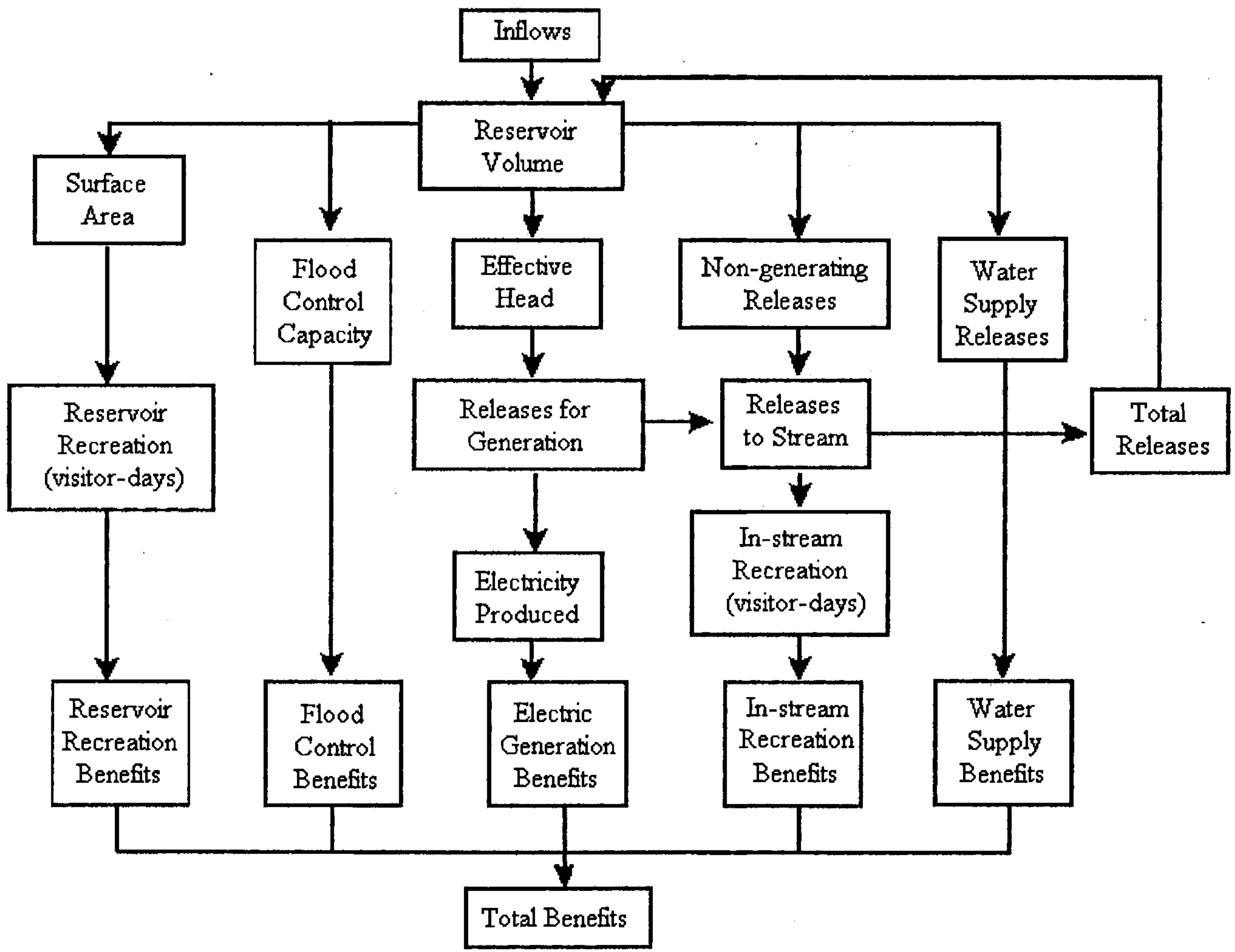
The basis for this model is the typical mass-balance approach to determining changes in reservoir storage volume. The model uses inflows and outflows to determine the reservoir volumes in each period. The volume in storage and the amount released for various uses determines the benefits to each specified use. Total benefits over a single period are defined as the sum of benefits accruing to all uses. The simulation exercise uses historic inflows and outflows to estimate the baseline total benefits. The optimization exercise uses historic inflows, but endogenously determines the monthly releases to each activity. This process identifies that allocation and pattern of uses that maximizes total benefits. A flowchart illustrating the integration of the economic and hydrologic characteristics in the model is presented in Figure 4-1. While the scope and detail of the model applied here is broader, the basic model formulation is adapted from the Ward and Lynch (1996) model.

The time horizon of the model consists of twelve consecutive months, from January through December. Each variable is expressed in terms of monthly averages or monthly totals, depending on the variable in question. The objective of the model is to determine that allocation and management scenario that maximizes the sum of the benefits accruing to all specified uses over this twelve-month period. This is accomplished through the integration of the hydrologic and economic characteristics associated with the reservoir itself and each use specified by the model.

The dimensions of the model include the Broken Bow Lake, with its adjacent recreation facilities, and the Mountain Fork River, including the trout fishery areas. The reservoir resources and management policies are viewed as having direct impacts on each of the stated uses in the area. Each stated use of the reservoir or its release derives benefits in different ways. Inflows to the reservoir increase the volume of water available for the various uses. How this volume is allocated among the different uses determines the distribution and level of benefits derived. If this additional volume is allocated and released to municipal and industrial water supply, the associated benefits accrue to the water supply contractors. If allocated and released to hydroelectric generation, that use enjoys the benefits. In these cases, benefits can accrue to only one of the competing uses.

However, the uses are not always in conflict with each other. In fact, alternative uses are often complementary. In some cases, water used for one purpose generates benefits for another. In both examples above, holding the water to be used for generation or water supply increases the pool level. To a certain degree, this increased pool level is desirable for recreation uses within the reservoir. Thus benefits are generated in lake recreation in addition to the benefits accruing to the designated uses. Also, releases to hydropower generation eventually find their way into the stream. This means that in addition to the hydropower benefits, the downstream fishery enjoys increased flows and the resulting benefits.

Figure 4-1: Integration of Economic and Hydrologic Characteristics



Mathematical Formulation

This modeling approach is carried out in a three-step process. First, benefits accruing under the current operating policies are estimated for each of three conditions. The alternative conditions examined are for different average annual water input levels. An average water year is defined by the historical data to be the average monthly inflows over the period of record. The wet and dry years are then defined as a 50 percent increase and decrease, respectively. For each of these conditions, the current operating policies are evaluated. Second, an estimate of the benefits generated under a policy of managing the resource in order to optimize the total reservoir benefits is derived. Thirdly, the benefits generated under each approach for each condition are compared to determine the gains or losses incurred. Each of the modeling tasks is accomplished with variations on the same basic model formulation. That is a method of calculating the total benefits derived under alternative sets of assumptions. This calculation takes the following general form:

$$(4\text{-}1) \qquad TB = \sum_{m=1}^{12} \left(BK_m + BM_m + BC_m + BL_m + BS_m \right)$$

where TB = total annual benefits accruing to the reservoir resources,

BK_m = benefits accruing to hydropower generation in month m,

BM_m = benefits accruing to municipal and industrial water supply in month m,

BC_m = benefits accruing to flood control in month m,

BL_m = benefits accruing to lake recreation in month m, and

BS_m = benefits accruing to stream recreation in month m.

Each of the right-hand-side variables varies with the allocation and management strategy employed. Each allocation and release pattern generates a specific level of benefits to each use and in total. As water is shifted from one purpose to another, benefits to one set of uses may increase while benefits to another set decrease. To explain the relationships between the allocation and release patterns and the benefits accruing to each use, each benefit function needs to be examined further.

Hydropower Benefits

The operating mechanics of a hydroelectric generating facility follows a relatively standard set of hydrologic and mechanical principles. These principles are basically the same as those that applied to the water mills used throughout history. A generator attached to a wheel is turned when falling water is allowed to act upon the wheel. In today's hydroelectric power plants the wheel has been replaced with a turbine, and a conduit called a penstock has harnessed the energy of falling water more efficiently. Hydropower is generated when water is released through the conduit, turning the turbine and thus the generator.

The amount of electricity that a specific facility can generate in a given time period is viewed to be a function of two variables, the amount of water released through the turbines and the effective head of the reservoir. Thus the hydropower function takes the form of equation 4-2:

$$(4\text{-}2) \qquad K_m = f(g_m, \overline{H}_m)$$

where K_m = amount of electricity produced in month m.

$\overline{H}_m$ = effective head of the reservoir in month m, and

g_m = amount of water released for generation in month m,

The head is the linear distance between the turbines and the surface of the reservoir. This distance determines the amount of force applied to the turbines. The greater is the head, the more force that is applied to the turbines, and the more electricity that is produced per unit of water released. Often head is simply calculated as a difference in elevation between the turbines and the surface. This would require the estimation of surface elevation relative to volume. Again to reduce the number of transformations and relationships estimated, an alternative method is employed. The approach used here is to simply estimate the relationship between the effective head and the average volume of water in the reservoir. This should effectively capture the relationship between volume and surface elevation including the difference to calculate the head. This relationship is given by equation 4-3:

$$\text{(4-3)} \qquad \overline{H} = f(\overline{V})$$

where $\overline{V}$ = average volume of water in the reservoir, in acre-feet.

Water released through the turbines is subtracted from the existing stock. Therefore, the amount of water in the reservoir is constantly changing. This causes the elevation of the reservoir surface to change, which alters the head. To minimize the effects of this changing stock, the effective head is defined as the average head during each month, as given by equation 4-4; and the average volume is given by equation 4-5:

$$(4\text{-}4) \qquad \overline{H}_m = \frac{(H_m + H_{m+1})}{2}$$

$$(4\text{-}5) \qquad \overline{V}_m = \frac{(V_m + V_{m+1})}{2}$$

where H_m = head at generator at beginning of month m,

H_{m+1} = head at generator at end of month m,

V_m = reservoir volume at beginning of month m, and

V_{m+1} = reservoir volume at end of month m.

The benefits derived from the production of electricity in each month are determined as the value of the electricity produced in that month, evaluated at the current wholesale market price in that month. Following this, the hydropower benefit function takes the form of equation 4-6:

$$(4\text{-}6) \qquad BK_m = P_{km} * K_m$$

where K_m = amount of electricity produced in month m, and

P_{km} = prevailing market price per kilowatt-hour of electricity in month m.

Water Supply Benefits

The water supply needs of the surrounding communities and businesses are drawn from supplies allocated to this use. In addition, there is the potential for exports of water to surrounding states. These withdrawals come directly from the reservoir's storage volume. The benefits accruing from municipal and industrial water supply is determined by the prevailing wholesale market price, which is assumed constant. This assumption is made to reflect the nature of municipal and industrial water supply contracts at the wholesale level. The total value of water made available for these consumptive uses is determined by the amount withdrawn by the water supply managers, and is expressed by equation 4-7:

$$(4\text{-}7) \qquad BM_m = P_w * w_m$$

where P_w = constant price of municipal and industrial water supply, and

w_m = amount of water released for M&I use in month m.

<u>Flood Control Benefits</u>

Unlike other uses of a reservoir's storage capacity, flood control benefits accrue due to the existence of empty or unused capacity. The more unused capacity that is available, the more potential floodwaters a reservoir will be able to absorb. The greater a reservoir's capacity to accommodate unusually large flows, the greater will be the flood control benefits. These benefits can also be expressed as a function of the volume of water in the reservoir. The latter approach is taken herein. In this formulation, one would expect flood control benefits to increase with decreased water storage volumes. However, the volume of water in the reservoir is constantly changing as water is released to the various uses. To smooth the effects of large releases of water during the month, an alternative measure of water storage is employed. That is to use the average water volume during each month. In addition, the amount of water flowing into the reservoir influences the level of flood control benefits. For a given water storage volume, or flood control capacity, flood control benefits would be expected to increase with larger inflows.

This means that the value of a given flood capacity will increase as inflows increase. Lastly, most flood control benefits accrue during periods in which there is a risk of flood damages. Holding storage capacity vacant in the name of flood control during times that have historically seen little or no flooding will likely yield very few benefits. So these benefits are reflective of those months where flooding is more likely. These relationships are presented below. The volume to average volume conversion is presented in equation 4-8, and the benefits of flood control in equation 4-9:

$$\overline{V}_m = \frac{V_m + V_{m+1}}{2} \quad (4\text{-}8)$$

$$BC_m = f(\overline{V}_m, I_m) \quad (4\text{-}9)$$

where $\overline{V}_m$ = average water storage volume in month m,

V_m = volume of water in reservoir at beginning of month m,

V_{m+1} = volume of water in reservoir at end of month m, and

I_m = total water inflows to reservoir in month m.

Lake Recreation Benefits

The benefits accruing to lake recreation are typically expressed as a function of the surface area of the reservoir. As the lake's surface area increases, all things being equal, one would expect that the benefits of recreation would also increase (Ward and Lynch, 1996; Cordell and Bergstrom, 1993). Alternative measures have also been employed to serve as proxies for surface area. ReVelle (1999) uses surface elevation, and also states that recreation benefits from a relatively constant elevation. Surface area, and for that matter elevation, is a function of the reservoir's storage volume. With volume as the standard unit of measure in this model, lake recreation will also be presented as a function of volume. This should reduce the transformations needed, without negatively impacting the validity of the argument.

As the amount of water stored in the reservoir increases, the amount of surface area and elevation will also increase. This relationship being implicit in the model, recreation expressed as a function of reservoir volume should capture the effects desired. Again, to smooth fluctuations in reservoir volume during each month due to large releases, monthly averages are used. Equation 4-10 presents the formulation for the benefits of lake recreation:

$$(4\text{-}10) \qquad BL_m = f(\overline{V}_m)$$

<u>Stream Recreation Benefits</u>

Benefits from stream recreation for this study are limited to in-stream fishing, and are expressed as a function of the streamflow and the average number of visitors per month. While this approach will certainly underestimate the total actual benefits accrued, it will perform the function desired. Following the approach of Daubert and Young (1981), and the premise of Ward (1985) and others, total individual benefits derived from in-stream fishing are estimated as a function of the average streamflow. The initial valuations can be estimated using various methods. Ward (1985) uses the Travel Cost Method to derive initial estimates of individual benefits on the Rio Chama River. Daubert and Young (1981) use the Contingent Valuation Method to value per-day recreation benefits at the Poudre River. The authors then estimate the individual total and marginal value of streamflow in terms of dollars per acre-foot per day. Most studies of the value of water for in-streamflow, including Ward (1985) and Daubert et al. (1981), estimate a value in the range between $14 and $27 per acre-foot. With a separate CVM study beyond the scope of this effort, it seems prudent to incorporate these estimates through the benefit transfer process. The findings of the latter provide the most adaptable measures, and are used in this research.

The main caveat to using this type of benefit transfer process is that the sites applied should have somewhat similar characteristics for the study to yield valid results. In terms of demographics, there is little significant difference between the two study areas. The only significant difference is the average annual flow and average low flow in the two rivers. These differ by approximately 400 cubic feet per second (cfs). However, this will be addressed by a slight adjustment in flows prior to estimation of the benefit equation. The resulting values will reflect streamflows relative to the size of the stream, and will exhibit the same pattern as the original study. In addition, as a check of the resulting values, value estimates will be compared with an existing study of benefit valuation at the site in question produced by Choi (1993).

This streamflow is the sum of all water released from the reservoir during the period. That is, all hydropower releases and all non-generating releases combine to provide streamflow. As the streamflows increase, the benefits derived from in-stream recreation will increase. At some point, however, further increases will diminish recreation benefits in the stream. In addition, water in the reservoir is a stock variable, while streamflow is a flow variable. If the assumption that releases are steady throughout the month is continued, the streamflows can be converted to a volume measure. Thus stream recreation benefits can be expressed as a function of the volume of water released to the stream. The relationship between releases and monthly streamflow volume is presented in equation 4-11, and the stream recreation benefits in equation 4-12:

(4-11) $F_m = g_m + r_m$

(4-12) $BS_m = f(F_m)$

where F_m = total releases to the stream in month m,

g_m = water releases for hydropower generation in month m,

r_m = water releases other than for hydropower generation in month m, and

Mass-Balance

The backbone of the model, the component that makes the model operational, is the mass-balance constraint. This equation and its associated constraints represent the physical characteristics of the reservoir. Together, they ensure that the model behaves according to the laws of physics. Determining the volume of water in the reservoir during each month and changes in storage from month to month is accomplished through this mass-balance equation. The volume of water in the reservoir in a given period is determined by the beginning volume, the inflows, and the outflows in the previous month. Two elements of reservoir volume are purposefully omitted from this formulation. Precipitation and evaporation are often included in these types of models. However, the net monthly effect of these two factors was determined to be insignificant in determining the volume of the reservoir in question. This is likely due to the relatively humid climate of southeastern Oklahoma, where precipitation and evaporation totals are somewhat equal. Inclusion would simply add to the bulkiness of the model. The resulting formulation is presented in the following equations:

(4-13) $$V_{m+1} = V_m + I_m - O_m$$

(4-14) $$O_m = r_m + g_m + w_m$$

(4-15) $$V_m \leq R$$

(4-16) $$V_{13} \geq V_1$$

(4-17) $$r_m, g_m, w_m \geq 0$$

(4-18) $$V_m, O_m, I_m \geq 0$$

where R = usable storage capacity in the reservoir,

O_m = total outflows from reservoir in month m, and

all other variables are as previously defined.

Equation 4-13 states that the volume of water in the reservoir in month m+1 is equal to the previous month's initial stock plus inflows minus outflows. Equation 4-14 provides a method of accounting for total releases and withdrawals from the reservoir. Equation 4-15 requires that the storage volume in any month not exceed the reservoir's physical capacity. Equation 4-16 states that the storage volume in the last period must not be less than the volume in the first period. This constraint prevents the borrowing of water from future periods. Without this constraint, the model would drain the reservoir in the last period, as there are no additional benefits to be derived from future storage. Equations 4-17 and 4-18 are non-negativity constraints.

Modeling Approach

The purpose of this research is to design and implement a modeling framework to analyze reservoir benefits and determine the optimal use of reservoir resources. These types of problems can be approached from several different angles. Reservoir analysis problems are usually broken down into two categories: simulation and optimization. Simulation models utilize historical data to predict values for user-specified variables. Optimization models compute optimal values for a set of decision variables. In application, the distinction between the two is somewhat blurred. Each approach contains elements of the other (Wurbs, 1994). In this research, both are employed. The simulation approach is used to establish a baseline benefits measure, and the optimization to determine the strategy that yields the maximum benefits.

In addition, optimization models may be approached in various ways. Optimization models are usually classified as 1) linear programming, 2) dynamic programming, or 3) non-linear programming. Each approach has its strengths and weaknesses. According to Simonovic (1992), linear programming (LP) is the technique employed most often in water resource analysis, for various reasons. Not the least of which is its relative ease of use and moderate computational requirements. LP models are also well suited for reservoir problems, according to Wurbs (1994). However, LP models are somewhat restrictive. The application of linear programming requires that the objective function and all constraints be expressed as linear functions. While these relationships may be better represented by non-linear functions, there are methods for fitting linear approximations that are generally acceptable.

Non-linear programming methods offer the ability to utilize non-linear functions. However, these methods are generally slow and cumbersome (Simonovic, 1992). While these methods are also well suited for reservoir analysis problems, their level of difficulty has hindered their wide application. However, this research uses non-linear programming due to the nature of many of the relationships. While methods for fitting linear approximations exist, where possible, relationships will be expressed on a best-fit criterion. Often many of the relationships associated with water resources research are non-linear in nature. Thus the use of non-linear techniques seems most appropriate.

Data Requirements

This modeling formulation is somewhat data-intensive. However, most of the data needed is relatively easily obtained through various sources. The most basic data needs are for reservoir storage measures. In addition, this approach requires data reflecting the flows into and out of the reservoir on a regular interval. These data elements are obtained from the Corps of Engineers. The Corps publishes monthly figures for each of these. Another set of data needed concerns the production of electricity and per-unit prices for electricity. These were obtained from Southwestern Power Administration, the firm that markets the electricity produced at Broken Bow Lake. These data series were obtained on a daily basis from January 1995 through December 2000. The data were then compiled to represent monthly totals and averages for the entire period.

Data concerning water supply flows and prices were obtained from the Oklahoma Water Resources Board and various municipal water districts. Streamflow measures were gathered from the Oklahoma Department of Wildlife Conservation, and values will be adapted from existing studies of in-stream fisheries. Finally, lake recreation and flood control data were collected from the Corps of Engineers' studies, and values adapted from various independent studies.

CHAPTER V

MODEL IMPLEMENTATION

In calculating or estimating each of the components of the model, various procedures are used. The methods applied are designed to conform to the nature of the problem or existing literature examining each part of the model. In the following sections, the procedure applied to each of the components of the model will be explained. In the last section, all individual parts will be brought together to form the model outlined in Chapter IV.

Hydropower Benefits

In the previous chapter, hydropower benefits were defined by equation 2 as being a function of the effective head and the releases through the turbines. This basic formulation reflects the work of Chatterjee et al. (1998), although others follow similar procedures. There are several steps leading to this formulation. The first step in this process is to calculate the effective head from the time-specific head provided by the data. This is accomplished be simply averaging the head at the beginning and end of each month. Next, the same procedure was applied to determining the average storage volume in the reservoir in each month as the average of the beginning and ending volumes. Then the relationship between the average volume of water in the reservoir in a given month, measured in acre-feet, and the resulting average head, measured in linear feet, is estimated. This relationship is needed due to the model's dependence on volume rather than elevation as the underlying measure of water in the reservoir. Following the basic approach of ReVelle (1999), Ward and Lynch (1996), and others, head was viewed as an increasing function of volume, but at a decreasing rate. The form estimated and the resulting coefficients are as follows, with t-statistics in parentheses:

(5-1)

$$\overline{H} = B_1 * \overline{V}^{B_2}$$

$$\underset{(2.55)}{\overline{H} = 1.7279} * \underset{(12.03)}{\overline{V}^{0.3382}} \qquad R^2 = .9455$$

where $\overline{V}$ = average volume of water in the reservoir, measured in acre-feet, and

$\overline{H}$ = effective head of the reservoir, measured in linear feet.

With this relationship estimated, the hydropower function itself can now be addressed. The data provide historic measures of releases and volume, which can now be represented as the effective head. Theory suggests that hydropower generated will increase with increases in either of these. More specifically, as the product of these two variables increases, generation will also increase. Again, this approach is specifically supported by ReVelle (1999), as well as generally supported by numerous others. Still other studies calculate this relationship based on standard principles of hydraulics and physics, where the hydropower output is proportional to the product of releases and effective head. While the latter depicts theoretical output relative to releases and head, the former can depict the relationship between output and the actual releases and head. For this reason, and the availability of data, this research relies on the estimated relationship between actual occurrences. Also, due to the proportional nature of the engineering-based determination of the relationship, the estimated relationship is assumed to be linear in nature as well. The form estimated and the resulting coefficients are presented as follows, with t-statistics in parentheses:

$$K_m = B_1 + B_2 * \left(\overline{H}_m * g_m\right) \tag{5-2}$$

$$K_m = \underset{(0.21)}{179.38} + \underset{(19.84)}{0.001058} * \left(\overline{H}_m * g_m\right) \qquad R^2 = .9471$$

where K_m = electricity produced in month m, measured in megawatt hours, and

g_m = amount of water released for generation in month m, measured in acre-feet.

The last component of the hydropower benefit function is the price used to evaluate the output in each month. The objective of this component is to evaluate the value of the water resources used in the production of the electricity. Therefore, the use of retail prices would not be appropriate, as they would reflect the value of the entire electric generation and transmission process. A more appropriate measure would be wholesale electricity prices, or the cost to the distributor of replacing any electricity losses at the generating facility in question with production from an alternative facility (Gibbons, 1986).

Electricity prices are structured along a two-tiered format, with the distinction based on the type of electricity generated. Electricity is generally generated to satisfy either peak-load demand or off-peak (base-load) demand. Off -peak electricity is generated to satisfy the continuous demands placed on an electric distribution system. According to the U.S. Department of Energy, roughly 40 percent of the demand is continuous, or base-load. The facilities used to satisfy this portion of the demand must run, for the most part, on a continuous basis.

Peak-load electricity is generated to satisfy that part of electricity demand that fluctuates seasonally and on a daily basis. Therefore, the facilities used to satisfy this type of demand need only operate during times of increased demand. In general, hydropower facilities are used to satisfy peak-load energy demand. The main reason for this use of hydropower facilities is the quick startup and flexibility these plants offer. Other production methods, such as fossil fuel and nuclear-fired steam generation are best suited for base-load production, due to the continuous nature of demand and the rigidity of these production processes. Output in these facilities cannot be started or stopped, and production levels altered as quickly and easily as with hydropower plants (Gibbons, 1986). So hydropower facilities in general, and the Broken Bow Lake facility specifically, are used for peak-load electricity generation.

This distinction in types of electricity produced leads to a different pricing structure depending on the type of demand the electricity is designed to satisfy. In general, the value or price of peak-load electricity in the wholesale market exceeds that of base-load electricity. This is somewhat intuitive, in that one would expect the price of any good to increase as demand increases. Furthermore, peak-load electricity demand reflects those periods during which demand exceeds that of continuous (base-load) demand. In addition, these prices fluctuate significantly across time. Not only are these prices seasonal, but there are also substantial fluctuations even on a daily basis. For this reason a definitive wholesale price in a given month is difficult to assign. The approach taken herein is to utilize information about peak-load electricity pricing obtained from multiple sources. Wholesale prices used in this model component are based on a compilation of averages obtained from the Southwest Power Pool, Megawatt Daily, and the U.S. Energy Information Administration, and are presented in Table 5-1.

Table 5-1: Average Wholesale Electric Prices by Month

Month	Price[a]
January	$26
February	$28
March	$30
April	$31
May	$32
June	$37
July	$37
August	$34
September	$31
October	$30
November	$29
December	$28

(a)-prices in 2000 US$ per MWH

With each of the components of the hydropower benefits defined and established, the method of accounting for the value of water used for electric generation is complete. The average volume of water in the reservoir determines the head applied to the generators. Along with this head, the water released through the turbines determines the amount of electricity generated. This electricity is evaluated at the prevailing wholesale price for the current month to determine the total value of the electricity produced. This value represents the benefits accruing to the system through hydroelectric generation. The final formulation is expressed as equation 5-3:

$$(5\text{-}3) \qquad BK_m = [179.38 + 0.001058 * (\overline{H}_m * g_m)] * \mathrm{P_{km}}$$

where BK_m = benefits accruing to hydropower in month m, measured in dollars, and

P_{km} = average wholesale price of electricity in month m, in dollars.

Water Supply Benefits

The benefits accruing from municipal and industrial water supply are determined as the water supplies withdrawn, evaluated at the prevailing price. The amount of water withdrawn for these uses is itself a decision variable, and is determined with in the model. Thus, the only issue at hand presently is the pricing of the resource. The first issue to be resolved is whether to use retail or wholesale prices. The second issue is the determination of an appropriate measure of these prices.

Not unlike the problem associated with the pricing of electricity, the pricing of water supplies delivered to municipal and industrial users reflects the value of the entire water supply process. The desire in the research at hand is to capture the value of the water as drawn from the reservoir. Thus, the most appropriate measure to use as a value of this raw water would be wholesale prices.

The second issue to address is obtaining an accurate measure of these wholesale prices. As with wholesale electric markets, a definitive market price is difficult to obtain due to wide variations in disclosed prices across regions and water supply districts. However, examining water supplies from Broken Bow Lake affords an interesting opportunity. That is, there are currently negotiations regarding the sale of water from Broken Bow Lake to the state of Texas. One component of these negotiations is the determination of an appropriate price for the transfer of water to take place. Although the Oklahoma State Legislature must approve the sale of water before any transfers may begin, there has been interest expressed by the North Texas Water Alliance. This coalition of five Northern Texas water districts seeks to purchase from the Broken Bow Lake up to 600,000 acre-feet of water annually, for an estimated eight cents per 1000 gallons (Planet Ark, 2001). Seven municipal water districts in the region that publish their water costs were comparable to this price. If the value to water supply districts of the water in Broken Bow Lake is the goal, then this proposed sale is an appropriate measure. Converting this price into a price per acre-foot measure is needed for compatibility with the model. The resulting value is roughly $25 per acre-foot.

An additional topic that needs addressing is the constant nature of this pricing scheme. While there is certainly a seasonal nature for retail prices in municipal and industrial water markets, wholesale markets are generally satisfied by long-term contracts based on fixed or average per unit pricing. Although this pricing scheme does not capture the seasonal nature of water demands, it does reflect the average value of the water resources in question. To reflect seasonal changes in water values, demand at the wholesale level would need to be estimated. Based on the traditional long-term nature of these contracts, seasonal demands may be difficult to construct. Therefore, the price at which the water in question can be sold is deemed to be the most appropriate value, despite its shortcomings.

Flood Control Benefits

As presented in the previous chapter, flood control benefits are viewed to be function of the average storage volume in a given month and the total inflows to the reservoir in the same month. It is assumed that flood control benefits accrue during those months in which it is most likely that a flood event could occur. In this approach, flood control benefits are measured as the value of the damages prevented by the flood control function of the reservoir. The benefits used in this procedure are flood control benefits estimated by the Corps of Engineers. The underlying assumptions are as follows: 1) for a given rate of reservoir inflows, the benefits accrued increase with vacant capacity, and 2) for a given flood control capacity, benefits increase as inflows increase.

While this approach to valuing flood control benefits may be over-simplified, it has some advantages over traditional methods of estimating flood control benefits. The most valued of these advantages is its simplicity. Traditional approaches often evaluate the existence value of a flood control facility, while considering the value of a fixed pool level. To investigate the value of alternative pool levels, multiple evaluations are conducted at various levels. These studies are generally performed in the context of a benefit-cost analysis. Flood control studies by the Corps of Engineers generally rely on surveys or land-use maps to ascertain the type of land uses that may be inundated by a potential event. Then for each type of land-use, damage-elevation (or depth-damage) curves are applied to estimate the potential damages from flooding. In addition to the damages that would be incurred, the probability of various flood events in a given year must be determined. Using these relationships, potential damages in a given time period can be estimated. The benefits of flood protection are then determined as the net of damages with and without the flood control structure (Thompson, et al., 1983). If the capacity of the facility is such that a given flood event does not exceed the absorption abilities of the flood pool, then the facility yields benefits equal to the damages that would have been incurred in the absence of the facility. For flood events that exceed the absorption abilities of the facility, the flood control benefits equal the difference between with and without scenarios.

The complication associated with these models is that they rely on river stage data. That is, the stage of the river below the impoundment, which requires the introduction of additional stream characteristics. An additional concern is the time horizon of many traditional flood control valuation techniques. While river stages are tied to reservoir releases, a monthly average release may not adequately reflect the nature of stream flows. These extreme flows are most appropriately associated with peak releases, which are not compatible with the approach taken herein. This traditional type of approach is appropriate for a flood-control-only study. However, the current research focuses on the tradeoffs in benefits associated with alternative reservoir volumes. To introduce an additional measure of system flows, and incorporate inconsistent timing of events would add undue complexity to the model structure. To avoid these complexities, the simple approach of estimating values based on volume and inflows is chosen.

An interesting aspect of the flood control component of this model is the timing of flood control benefits. The Corps of Engineers publishes flood control data for its projects. However, until recently this data has not been compiled on a monthly basis for Broken Bow Lake. Prior to the current year, benefits were estimated only during periods when there was a significant potential for a flood event. These events do not correspond with the monthly planning periods used in this model. The approach employed in this research utilizes these flood control benefits for the years 1995 through 2000, as estimated by the Corps of Engineers. During this period, there were 22 events for which the Corps estimated flood control benefits. The timing of these events is defined by the days of the month on which benefits accrued. These event-specific benefits are allocated to the corresponding months based on the recorded timing of the events. If an event falls completely within the month of April, then all benefits are attributed to that month. If an event is defined to cover equal days in consecutive months, then the benefits are distributed equally over the two months. Other events are prorated and distributed based on the relative duration within each month. This process yields a total of 43 observations of months in which there were flood control benefits.

Using the monthly volume and inflow data for the period 1995 through 2000 corresponding to the defined flood events, a relationship is estimated that presents these benefits as a function of monthly average volume and total inflows. The results of this procedure are captured by equation 5-4, with t-statistics in parentheses:

(5-4)

$$BC_m = B_1 * (I_m) + B_2 * (\overline{V}_m)$$

$$BC_m = \underset{(6.11)}{2.95} * (I_m) - \underset{(2.77)}{0.1297} * (\overline{V}_m) \qquad R^2 = .6511$$

where BC_m = flood control benefits in month m, in U.S. dollars,

$\overline{V}_m$ = average volume of water in the reservoir in month m, in acre-feet, and

I_m = stream inflows to the reservoir in month m, measured in second-day-feet.

Although there is no reason to expect this relationship to be linear in nature, alternative structural relationships were estimated with no significant improvement in results. In the interest of a more durable model structure, linear relationships are employed when acceptable.

Lake Recreation Benefits

The literature is replete with models and methods for estimating recreational benefits accruing to water resources. Most of these studies rely on one of two methods for measuring these benefits. Boyle et al. (1993) uses the contingent valuation method (CVM) to evaluate the effects of altering the flow in the Colorado River on recreational boating. Likewise, Cordell and Bergstrom (1993) use the CVM to evaluate the effects on recreational benefits of changes is lake levels in North Carolina. Ward (1987), Ward et al. (1996), and Ward and Lynch (1996) use variations on the travel cost method (TCM) to estimate the benefits of lake recreation in the U.S. Southwest. Most of these recreation models are designed as stand-alone evaluations of recreation benefits, or as part of benefit-cost analyses, and do not present values as a function of the amount of water in the lake. Additionally, due to the complexity and research requirements, these approaches are beyond the scope of the research at hand.

A method of estimating lake recreation is needed that is compatible with the current model structure. Furthermore, the aspect of interest is how recreation benefits respond to changes in the volume of water in the reservoir. To this end, one study in particular provides a method of estimating these recreation benefits. Ward et al. (1996) estimates recreation benefits at ten Corps of Engineers reservoirs in the Southwest using a regional travel cost model. These values are expressed as a function of the amount of water in the reservoir. The most useful aspect of this study is that fluctuations in lake levels are expressed in terms of percentages. That is, rather than using quantity measurements in representing the storage volume, the authors present the various lake levels as a percentage of the facility's capacity. Furthermore, the authors provide a method of adapting the marginal and total benefits estimated at these facilities to other study areas. This approach is followed in the current research.

The benefits estimated by Ward et al. (1996) are aggregate marginal benefits per acre-foot of water held. The first step in utilizing these measures for the current study is to convert to individual marginal benefits. This is accomplished by dividing by the average number of visitors to the sites in their study. While these benefits fall into a relatively narrow range, using the estimates from one particular lake may be questionable without the incorporation of substantial data addressing demographics and lake characteristics for the two regions. To avoid this pitfall, an average of the facilities studied is employed. This procedure yields average measures of the marginal benefits associated with an acre-foot of water at various lake levels. As expected, these marginal benefits increase with the percentage of lake capacity occupied. At lake levels above the designed capacity one would expect these values to decline, and become negative. However, because the constraints on the model prevent this occurrence, evaluation of the benefits is limited to 100 percent of capacity.

To adapt these benefit measures to Broken Bow Lake, the volume of water in the reservoir associated with incremental percentage measures are calculated. A percent full measure of 100 percent yields a volume of 1.599 million acre-feet, the total capacity of the facility. A percent full measure of 90 percent yields a volume of 1.439 million acre-feet. This process is repeated for 10 percent increments across the range of zero to 100 percent. The marginal benefits associated with various lake levels according to this process are presented in Table 5-2. This data represents aggregate marginal values for an average of the monthly visitation levels, determined to be 95,649 visits.

Table 5-2: Marginal Benefits of Recreation per Acre-Foot

Volume	MB
1599000	\$9.50
1439100	\$6.89
1279200	\$6.56
1119300	\$5.51
959400	\$4.80
799500	\$4.56
639600	\$4.82
479700	\$3.69
319800	\$1.75
159900	\$1.09

Next, a marginal benefit function for Broken Bow Lake is estimated using the marginal benefit values presented by Ward et al. (1996) and the various lake levels generated. The results of this are presented in equation 5-5, with the coefficients expressed in scientific notation, and t-statistics in parentheses:

$$(5\text{-}5) \qquad MB = f(V)$$

$$MB = \underset{(1.27)}{[6.69E\text{-}06]} + \underset{(9.54)}{[5.09E\text{-}11]} * V \qquad R^2 = .9193$$

where MB = individual marginal benefits of lake recreation, in U.S. dollars, and

V = volume of water in the reservoir.

This equation represents the individual marginal benefits per acre-foot of water at Broken Bow Lake. However, the formulation of the model requires the use of the total benefit function. This is achieved by integrating equation 5-5, which yields:

(5-6) $$TB = \int MBdv = \int [6.69E-06] + [5.09E-11] * Vdv$$

$$TB = [6.69E\text{-}06] * V + [2.545E\text{-}11] * V^2 + C$$

where TB = individual total benefits accruing from lake recreation, in dollars, and

C = the constant term arising from the integration, representing the intercept.

Equation 5-6 represents the total individual benefits accruing to each visitor to the facility for the purpose of lake recreation. As there would be no lake recreation benefits without water in the reservoir, the constant is assumed to be zero. The last step required to capture the total recreation benefits arising from lake operations is to aggregate across the estimated number of visitors in each month. Lake visitation estimates were obtained from the Corps of Engineers as monthly totals for the year 2001. These estimates are presented in Table 5-3.

Table 5-3: Monthly Lake Visitation Estimates for 2001

Month	Visitors
January	15,125
February	17,809
March	21,588
April	60,640
May	182,345
June	183,747
July	200,135
August	174,436
September	105,822
October	98,832
November	71,295
December	16,008
average	95,649

To account for the impact of releases from the reservoir during the month, the static measure of volume is replaced with the average volume as discussed earlier. This process yields a formulation that represents the total recreation benefits in each month as a function of the average volume of water held in the reservoir during that month, and is given by equation 5-7:

$$(5\text{-}7) \qquad BL_m = [6.69E\text{-}06] * \overline{V}_m + [2.545E\text{-}11] * \overline{V}_m{}^2 * X_m$$

where BL_m = total benefits accruing to lake recreation in dollars,

X_m = estimated number of lake recreation visits in month m, and

$\overline{V}_m$ = average volume of water in the reservoir in month m, in acre-feet.

Implicit in this formulation is the assumption that changes in the volume of water in storage, and thus the surface area, will alter the benefits accruing to recreation visitors. However, these changes will not, in the short run, alter the visitation numbers. As recreation trends develop somewhat slowly over time, it is reasonable to assume that changes in lake attributes will similarly take time to impact visitation trends.

Stream Recreation Benefits

The function of this component of the model is to capture the benefits accruing from the state-sponsored fishery, which lies below Broken Bow Lake on the Mountain Fork River. While the exclusion of other activities on the stream will certainly underestimate the benefits arising from releases to the stream, it will allow for a simple examination of stream flow values. That is, how stream flow impacts the benefits derived from certain activities. Numerous studies indicate that stream flow levels and fluctuations have significant impacts on recreation benefits. This relationship is utilized in this study, where the benefit accruing to trout fishing is a function of total streamflows.

One study by Bishop et al. (1989) uses the CVM to estimate benefits accruing to anglers of a portion of the Colorado River below Glen Canyon Dam. Their study estimates values of $51 per visitor day, and shows significant reductions associated with stream flow fluctuations. Flows above and below a constant 10,000 cfs, reduce the benefits derived from fishing that stream. Richards and Wood (1985), at a nearby site on the Colorado River, use the TCM to estimate a benefit measure of $170 per visitor day, with similar reductions arising from fluctuations. While each of these evaluates the benefits for a given scenario, they do not generate demand curves or total benefit functions for in-stream flow.

A study by Daubert and Young (1981) investigates the same type of activities, but generates total benefit functions for in-stream flows. The study uses the CVM to impute shadow prices for this stream flow on the Cache la Poudre River in Colorado. These prices are then compared to the marginal values of the water used in alternative activities. The usefulness of this study in the current research is the construction of a Bradford bid curve (Bradford, 1970). This curve represents a survey respondent's the total willingness to pay (WTP) for alternative stream flow levels. This bid curve can also be interpreted as a total benefit function for in-stream flows. This analysis is the foundation for the stream recreation benefits component of this study.

Adapting the marginal and total benefits functions produced by Daubert and Young to the study at hand follows a process similar to the lake recreation component. Using the estimated individual total value measures from Daubert and Young, the first step in the process is to convert the stream flow measures from cubic feet per second to acre-feet. This conversion requires the assumption of a constant rate of release from the reservoir to the stream. Because the quest at hand is not the construction of a management model, this assumption is required.

The next task is to adjust the stream flow data to reflect the Mountain Fork River. Flows in the Cache la Poudre River are consistently lower than those of the Mountain Fork River. Therefore, using marginal and total benefit values for one stream to estimate values at the other without some adjustment would provide unacceptable values. The key to this process lies in the indexing of these adjustments. That is, determining the appropriate degree to which flows must be adjusted. One approach would be to follow the format of the reservoir study by Ward et al. (1996), in which volume is expressed in terms of percentages of capacity. This would require that flows in each of the two streams be converted to percentage measures for the estimation process, and then back to volume measures for incorporation into the model.

An alternative approach is to simply adjust the streamflows to reflect some average for each of the two streams. Several studies provide a basis for this method of adjusting the stream flow measures. Among others, Walsh et al. (1980) and Amirfathi et al. (1984) produce estimates of the levels of stream flow at which total willingness-to-pay is the highest. While the benefit estimates published by these and many others cover a wide range, their estimates of the point at which benefits are maximized are somewhat consistent. Walsh et al. (1980) found that benefits were maximized at flow levels near 35 percent of stream maximum. Amirfathi et al. (1984) found that this benefit maximizing flow was 20-25 percent of stream maximum. In addition, they found that the value of additional flows above 50 percent of stream capacity was zero. This indicates that streamflows in the range between 0 and 50 percent of stream maximum is where most fishing benefits arise. To this end, flows in the estimation of a total benefit function are adjusted to reflect the size and capacity of the Mountain Fork River. The resulting benefit function is thus adjusted and scaled to match the current stream.

With this adjustment to flows completed, the next task is to estimate the individual total benefit function for the Mountain Fork River. Following the lead of Daubert and Young, and numerous similar studies, this relationship is estimated as a second-degree polynomial function of streamflows. Again, these streamflows are assumed constant throughout each individual month, and are expressed in terms of average daily acre-feet of releases from the reservoir. The result of this estimation is given by equation 5-8:

$$\text{(5-8)} \qquad TB = \underset{(3.55)}{0.0164 * F} - \underset{(5.28)}{0.00000221 * F^2}$$

where TB = total individual benefits arising from stream fishing, and

F = average daily stream flow measured in acre-feet.

As equation 5-8 was estimated using values generated by Daubert and Young's original total benefit function, the resulting estimation statistics are invalid. The adjustment of flows did not alter the relationship from the original estimation as presented by Daubert and Young. The only change resulting from the adjustment is a shift in the benefit function. The t-statistics reported are from the original study, and the R^2 omitted, as it was not published.

Equation 5-8 gives the total willingness-to-pay, or total benefits per day, of each visitor to the Mountain Fork River fishery, expressed as a function of the average daily stream flow. To represent the total value of a given stream flow level for each month this total individual benefit function must be aggregated across all visitors in each month. Initial visitation numbers were obtained from Choi (1993). These data were estimated on a quarterly basis, which is not compatible with the monthly basis used in the current research. To address this problem, quarterly averages for the years 1990 and 1991 were decomposed into monthly averages that reflect the seasonal trends exhibited in the source data. Additionally, although a formal study of fishery visitation has not been conducted since 1992, discussions with the resident stream biologist for the Oklahoma Department of Wildlife Conservation yielded more current estimates. While ad hoc in nature, these estimates are based on first-hand experience. These estimates are presented in Table 5-4.

Table 5-4: Monthly Fishery Visitation Estimates for 2001

Month	Visitors
January	1,852
February	1,852
March	1,852
April	2,925
May	2,925
June	2,925
July	2,625
August	2,625
September	2,625
October	964
November	964
December	964
average	2,092

With the estimated total benefit function and monthly visitation numbers, an expression of the total stream benefits based on streamflows can be constructed. This formulation is given by equation 5-9.

$$(5\text{-}9) \qquad BS_m = [0.0164 * F_m - 0.00000221 * F_m^2] * Y_m$$

where BS_m = total benefits accruing to stream fishing activities in month m,

F_m = average daily stream flow in month m, and

Y_m = estimated number of person trips to the fishery in month m.

Combined Model Elements

With each of the individual components of the model addressed, the final task in completion of the model structure is to incorporate each of the elements into the theoretical model described in the previous chapter. In addition, various constraints to the system need to be introduced and explained. Below is the mathematical presentation of the model in its completed form. While some adjustments are made to facilitate the completion of various exercises, the major components are rigid.

Objective function:

$$(5\text{-}10) \qquad TB = \sum_{m=1}^{12} \left(BK_m + BM_m + BC_m + BL_m + BS_m\right)$$

where

$$(5\text{-}11) \qquad BK_m = [179.38 + 0.001058 * (\overline{H}_m * g_m)] * P_{km}$$

$$(5\text{-}12) \qquad BM_m = P_w * w_m$$

$$(5\text{-}13) \qquad BC_m = 2.95 * I_m - 0.1297 * \overline{V}_m$$

(5-14) $BL_m = [(6.69E\text{-}06) * V + (2.545E\text{-}11) * V^2] * Xm$

(5-15) $BS_m = [0.0164 * F_m - 0.00000221 * F_m^{\ 2}] * Y_m$

Constraints:

(5-16) $V_{m+1} = V_m + I_m - O_m$

(5-17) $O_m = r_m + g_m + w_m$

(5-18) $V_m \leq R$

(5-19) R = 1,598,950 acre-feet

(5-20) $V_{13} \geq V_1$

(5-21) $g_m \leq$ 404,600 acre-feet

(5-22) $F_m = g_m + r_m$

(5-23) $F_m \leq$ 476,000 acre-feet

(5-24) $F_m \geq$10,000 acre-feet

(5-25) $\Sigma w_m = W \leq$ 600,000 acre-feet

(5-26) $w_m \geq 0.0625 * W$

(5-27) $r_m, g_m, w_m \geq 0$

(5-28) $V_m, O_m, I_m \geq 0$

Although the model considers five alternative activities, there are only three decision variables. These are water releases for municipal and industrial water supply (w_m), water releases for hydropower generation (g_m), and water releases for the purpose of stream maintenance (r_m). Recreation and flood control benefits arise without the consumption or release of water. Therefore, there are no explicit volumes assigned to these two components. Equation 5-19 limits water storage to the physical capacity of the reservoir, 1,598,950 acre-feet. Equation 5-21 states that hydropower releases may not exceed 404,600 acre-feet per month, the designed capacity of the generating facility. Equation 5-22 defines the monthly total stream flow as the sum of releases for hydropower generation and gate releases. Equation 5-23 limits the total releases to the stream each month to its estimated capacity of 476,000 acre-feet. Equation 5-24 imposes a minimum stream flow requirement on the system to protect habitat. This requirement of 10,000 acre-feet per month corresponds to the minimum average flow during the period of record of approximately 160 cubic-feet per second. Equation 5-26 requires that water supply withdrawals in any given month be at least 75 percent of the average monthly withdrawal. Because water supply prices are assumed constant, there is no tendency for these withdrawals to follow any specific pattern. This constraint forces these water supply withdrawals to be somewhat evenly distributed across the year.

This set of model equations is the basis for the analysis that is presented in the following chapters. To arrive at each solution, modifications in the applicable constraints are required. These will be discussed as necessary. However, the bulk of the model remains unchanged for each situation. The only change required for most analyses is the introduction of alternative inputs to the system. These inputs are the beginning reservoir volume and the record of inflows.

CHAPTER VI

ANALYSIS AND RESULTS

The analysis in this research is conducted in a series of steps to evaluate the benefits of different management scenarios. In each set of evaluations, benefits generated from the optimization of the model are compared to the benefits derived from the analysis of current management practices or other proposed scenarios. The benefits generated under current management practices are estimated with the use of historic records of inflows and outflows. These flows are incorporated into the model as predetermined values. This process does not require endogenous decision-making, as the variables enter the model as known historic values. Under these inflows and outflows, benefit measures for each of the model components are calculated from the relationships incorporated into the model. The optimization of the model requires the use of historic inflows, but endogenously determines the optimal release pattern. That is, based on a given pattern of inflows, the model determines the pattern of outflows that maximizes the annual benefits across all activities. This process is repeated for each alternative management scenario. The benefits generated under the optimization for each of these alternatives can then be compared to each other, and to the baseline benefits arising from current management practices.

Each set of benefits is impacted by the water conditions that are used in the modeling of the system. That is, the inflows used in the model may reflect different conditions relative to the average inflows to the reservoir. The primary condition, under which these benefits are estimated, is that of an average year. This is conducted by using the average inflows to the reservoir, during the period of record, as the inflows in the model. This record of inflows is generated by averaging the monthly inflows across the period of record. In addition, for each management scenario, the analysis is repeated using generated records of flows representing years of above average flows, and below average flows. The dry year is represented by a fifty percent reduction in monthly inflows, while the wet year is represented by a fifty percent increase in monthly inflows. These inflow levels were chosen, in part, because they are relatively close to actual conditions at Broken Bow Lake during the period of record. In fact, the maximum flows and minimum flows deviate more than this on a monthly basis, from year to year. On an annual basis these flows deviate 35%-40% from average. The fifty percent deviation was chosen mostly to impose a strain on the model, greater than that which may be experienced using actual flows.

For the baseline analysis, not only are the records of inflows needed, but also needed are the resulting outflow patterns. These are constructed using the historical releases and outflows from the period of record. For the average year, the data provide a record of the releases and withdrawals. However, for the wet and dry years, the release and withdrawal patterns must be constructed based on actual releases. Analysis of the data indicates that hydropower releases fluctuate proportionately with changes in the water conditions in a given year. Water supply withdrawals, on the other hand, fluctuate inversely with changes in the conditions. For a dry year, characterized by a fifty percent reduction in flows, water supply withdrawals increase by twenty-five percent. The fifty percent increase of the wet year results in a twenty-five percent reduction in water supply withdrawals. For each of these conditions, hydropower and water supply releases were calculated, based on historical patterns. With total releases given by the data, the third decision variable, releases to the stream, were calculated as a residual. These were then checked against stream flow data obtained from the Oklahoma Department of Wildlife Conservation, and found to be consistent. The historical average and synthesized wet and dry year inflows and releases are presented in Table 6-1.

Each management scenario is evaluated under each of the conditions discussed above. The following sections detail the calculation of the baseline benefits for each of the water conditions. In addition, benefits are estimated under various sets of assumptions, designed to reflect alternative management scenarios. A comparison of these benefits, both in aggregate and for each activity, provides a measure of the value of this type of approach to reservoir management.

TABLE 6-1

BASELINE INFLOWS AND RELEASES

	AVERAGE YEAR				DRY YEAR				WET YEAR			
	Inflows	Power	M&I	Gate	Inflows	Power	M&I	Gate	Inflows	Power	M&I	Gate
January	49,484	92,968	368	4,043	24,742	45,989	460	2,240	74,226	137,966	276	7,826
February	50,889	73,678	412	1,295	25,445	35,304	515	1,873	76,334	111,853	309	915
March	57,913	122,942	530	4,050	28,956	59,887	662	3,212	86,869	179,660	397	11,226
April	46,795	72,648	421	783	23,398	35,730	526	670	70,193	108,180	316	2,282
May	44,530	73,043	457	11,603	22,265	34,542	571	7,439	66,795	103,625	342	23,687
June	42,440	64,924	460	6,589	21,220	32,734	574	2,678	63,660	98,201	345	9,414
July	10,159	71,411	453	13,056	5,080	33,439	566	8,456	15,239	100,316	340	26,725
August	2,027	46,199	435	11,031	1,013	21,624	543	6,664	3,040	64,873	326	21,297
September	7,969	30,243	418	9,726	3,985	13,927	523	5,743	11,954	41,782	314	18,483
October	33,975	30,899	464	2,629	16,988	15,944	580	472	50,963	47,833	348	2,807
November	68,190	48,603	321	3,071	34,095	23,212	401	2,384	102,285	69,637	241	8,114
December	55,413	117,435	387	12,396	27,707	54,738	484	12,862	83,120	164,214	290	39,746

Average Year

The average year analysis is based on a record of monthly inflows and releases over the period of record, 1995 through 2000. While there are substantial fluctuations among these observations, this record of average inflows and releases captures the actual pattern of inflows and releases for Broken Bow Lake over this period. Although all scenarios are modeled for each water condition, the average year is addressed first, and in the greatest detail. The calculation of the baseline benefits is outlined first. Then the various optimization exercises are presented.

Baseline Benefits

The baseline or benchmark benefits are the set of benefits to which other management scenario benefits are compared. As discussed earlier, these benefits are computed based on historic inflows and outflows. Since the decision variables of the model are forced to take on predetermined historic values, there are no endogenous decisions. Due to these imposed values, model constraints are of little significance. However, there are some notable characteristics and assumptions to be pointed out.

The physical capacity of the reservoir is divided into segments as discussed in Chapter II. Capacity is allocated based on use of the water. There are allocations for dead storage, conservation, and flood control. Because data for the reservoir reflects only usable storage, the inactive pool can be ignored without consequences. The conservation pool is the segment from which all releases are obtained. That is, those activities that take water from the reservoir reduce the quantity of water in the conservation pool. Flood control capacity reflects vacant storage capacity in the reservoir, designed to absorb potential flood waters. In effect, adherence to this designated flood pool capacity imposes an artificial maximum capacity on the reservoir.

In addition, Broken Bow Lake operates under the influence of a seasonal pool guide. This seasonal pool guide suggests different maximum storage volumes for different months during the year. The purpose of changing the storage capacity throughout the year is to increase the flood control capacity during months of likely flood events. During the summer months of June through September, when flooding is unlikely, the conservation pool is constrained to an elevation of 602.5 feet. This translated into a volume of 950,976 acre-feet. During the flood-prone months of November through March, the conservation pool is limited to an elevation of 599.5 feet, which translates into a capacity of 917,360 acre-feet. The months of April, May, and October are transition periods between the recommended pool levels. This seasonal pool guide is reflected in the capacity constraints in Table 6-2, where the constraints are presented in both elevation and volume.

Table 6-2: Seasonal Pool Guide for Broken Bow Lake

Month	Elevation[(a)]	Volume[(b)]
January	599.50	917,360
February	599.50	917,360
March	599.50	917,360
April	600.50	928,566
May	601.50	939,771
June	602.50	950,976
July	602.50	950,976
August	602.50	950,976
September	602.50	950,976
October	601.00	934,168
November	599.50	917,360
December	599.50	917,360

(a) - feet above mean sea level (msl)

(b) - measured in acre-feet

The Broken Bow municipal water supply facility, which withdraws water from Broken Bow Lake, is constrained by its existing capacity. The capacity of this facility is six million gallons per day (mgd). On a monthly basis this means the facility can withdraw and process a maximum of 551 acre-feet of water. While there are discussions involving the sale of water to other interested parties, this possibility will be addressed later in the chapter.

Likewise, hydropower production is limited by the capacity of the existing facility. Southwest Power Administration operates the hydroelectric generating facility located at Broken Bow Lake, with an installed capacity of 100 megawatts. This rating reflects continuous use output. With a standard 30-day month, there are 720 hours per month. This means that the monthly output of electricity for the facility is limited to 72,000 megawatt hours (mwh). In addition to the generation constraints, the facility is also limited by hydrologic constraints. These physical characteristics limit the amount of water that can be released through the facility during a specified time period. The design of the existing hydropower facility limits releases to a maximum of 404,600 acre-feet per month.

The hydropower facility at Broken Bow Lake is just one component of a network of 22 generating facilities operated by Southwest Power Administration. While there is a contracted aggregate output for the network, there is no individual requirement for the Broken Bow Lake facility. If this facility cannot, in a given time period, adequately supply the necessary output, other facilities in the network can augment production. As such, there is no minimum electricity production constraint placed on the model.

Streamflow is an important component of the reservoir management strategy, as it provides for recreation activities within the stream. As discussed in previous chapters, the volume of releases to the stream influences the benefits accruing to the down-stream fishery. In support of these releases, a minimum rate of flow within the stream is necessary to maintain the aquatic habitat. This has long been a major issue of concern for managers of the fishery. While there is no formal agreement between the managers of the fishery and the reservoir, there is a certain amount of cooperation regarding this issue. That is, when necessary, reservoir managers work to accommodate the needs of the downstream fishery in terms of flow maintenance. To capture this effort to maintain a certain minimum level of streamflow, the model imposes a lower bound of 10,000 acre-feet per month. This constraint corresponds to the lowest level of flows during the period of record. In subsequent optimization exercises, this constraint will be altered to measure the impact of its imposition on benefits accruing to all uses, individually and in total.

Using the aforementioned characteristics and the relationships presented in previous chapters, baseline benefits measure can be calculated. These benefits represent the total benefits accruing to each individual activity and in total. The results of this procedure and the following analyses are presented in Table 6-3.

Table 6-3

Average Year Annual Benefits By Activity

Scenario	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
Baseline Benefits	$4,831,674	$128,104	$276,352	$648,909	$9,428,735	$15,313,774
Optimization with existing facilities and seasonal pool guide	$5,162,729	$165,300	$273,606	$542,673	$9,798,824	$15,943,132
Optimization with seasonal pool guide and water supply of 300,000	$3,518,699	$7,500,000	$284,199	$463,877	$9,589,727	$21,356,502
Optimization with seasonal pool guide and water supply of 600,000	$1,870,630	$15,000,000	$312,185	$315,258	$9,225,864	$26,723,937
Optimization without seasonal pool and with existing facilities	$5,631,977	$165,300	$177,091	$277,700	$14,982,583	$21,234,651
Optimization without seasonal pool and with water supply of 300,000	$3,689,474	$7,500,000	$159,183	$134,686	$13,652,782	$25,136,125
Optimization without seasonal pool and with water supply of 600,000	$1,958,117	$15,000,000	$236,139	$263,577	$11,292,646	$28,750,479
Optimization with a 5 foot pool increase and existing facilities	$5,281,151	$165,300	$232,782	$518,642	$10,508,648	$16,706,523
Optimization with a 5 foot pool increase, water supply of 300,000	$3,602,420	$7,500,000	$244,223	$436,119	$10,305,754	$22,088,516

Table 6-3 (continued)

Scenario	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
Optimization with a 5 foot pool increase, water supply of 600,000	$1,916,056	$15,000,000	$258,057	$288,664	$10,056,908	$27,519,685
Optimization with 50% streamflow reduction, no seasonal pool, and water supply of 300,000	$3,766,282	$7,500,000	$199,235	$286,894	$13,478,224	$25,230,635
Optimization with 50% streamflow reduction, no seasonal pool, and water supply of 600,000	$1,886,419	$15,000,000	$195,319	$111,724	$11,967,091	$29,160,553
Optimization with a 10% electricity price increase, no seasonal pool, and water supply of 300,000	$4,141,001	$7,500,000	$205,922	$332,961	$13,085,627	$25,265,511
Optimization with a 10% electricity price increase, no seasonal pool, and water supply of 600,000	$2,090,485	$15,000,000	$210,157	$177,225	$11,547,841	$29,025,708

Notes: 1 - all benefits are expressed in 2000 U. S. dollars
2 - baseline benefits are calculated based on historical inflow and release patterns
3 - existing facilities refers to installed hydropower and water supply infrastructure
4 - 300,000 water supply constraint reflects a maximum installed capacity of 25,000 acre-feet per month
5 - 600,000 water supply constraint reflects a maximum installed capacity of 50,000 acre-feet per month
6 - no seasonal pool means reservoir volume constrained only by physical capacity of reservoir
7 - 5 foot increase is above the existing pool constraint

Total benefits arising from the current management practices equals $15,313,774. This includes $4.8 million for hydropower, $128,104 for water supply, $276,352 for flood control, $648,909 for fishery benefits, and $9.4 million for lake recreation activities. Initial inspection of these benefit measures indicates that, of the five activities examined, lake recreation provides the greatest level of benefits. An examination of the details of this calculation, provided in Table A-1 of Appendix A, seems to support this observation. Based on the pattern of releases, it appears that the current management practice seeks a balance between each of the five activities. This is evidenced by the distribution of hydropower releases being weighted toward the flood-prone months of January through March and December. This increases electricity production and generates increased flood control benefits during these times. During the traditional vacation season of May through August, releases for hydropower are reduced. This has the effect of raising the conservation pool during those months, which contributes to lake recreation benefits. In addition, releases to the stream seem to be weighted toward those same vacation months, which gives rise to greater benefits from the downstream fishery. Water supply releases remain relatively constant throughout the year. This is likely due to the demand driven nature of water supply withdrawals. That is, the managers of the water supply systems, not the reservoir managers, make water supply withdrawal decisions. All other release decisions are made by the reservoir managers. Even the decision to release water for electric generation is made by the reservoir managers. Despite the apparent effort to balance the distribution of releases between activities, lake recreation emerges as the single largest source of benefits, accounting for nearly two-thirds of total benefits.

Optimization with Existing Facilities and Parameters

The next issue addressed is the potential for increased benefits by utilizing the optimization process presented in earlier chapters. To evaluate this issue, an initial optimization is performed which is bound by the same constraints as the baseline benefits calculation. That is, the output and capacity of all facilities remain unchanged, and institutional constraints such as the seasonal pool guide are also maintained. Using the same pattern of inflows, the model determines the optimal size and pattern of releases across activities, based on the principle of equal marginal benefits.

This optimization procedure yields total benefits of $15,943,132, which represents an increase of $629,358. While the increase in benefits is relatively small, it is an improvement over current practices. This increase in total benefits is the result of increases in benefits for three activities, and losses in benefits for the remaining two activities. The activities for which benefits increase are hydropower, water supply, and lake recreation. Flood control and fishery benefits decrease. Among the winners, both hydropower and lake recreation increase by approximately $350,000, while water supply benefits increase by about $37,000. The decreases in flood control and fishery benefits are approximately $3,000 and $106,000, respectively. An examination of the details in Table A-2 reveals some interesting information concerning the marginal values of the competing activities.

In all months, the water supply constraint is binding. This indicates that the marginal benefit of water supply exceeds that of competing uses in each month. Likewise the seasonal pool constraint is binding throughout the year. The benefits of increasing the volume of water in the reservoir accrue mostly to lake recreation, while diminishing flood control benefits. Thus, the binding pool constraint indicates that the marginal benefit of lake recreation, less reductions in flood control benefits, exceeds those of hydropower and fishery benefits combined. Finally, the minimum flow constraint is binding in August and September. Without the constraint, releases would fall below the constrained minimum. This shows that the combined marginal benefits of hydropower, flood control, and fishery activities are less than the benefits of lake recreation.

Water Supply Issues

The discussions involving the sale of water resources to neighboring counties in Texas raises the issue of the effects this type of transfer would have on total benefits arising from the reservoir system. To address this issue, the water supply constraint is relaxed in a two-step process, to evaluate the change in benefits from alternative transactions. The first step assumes an annual transfer of 300,000 acre-feet of raw water to these counties. To accommodate this quantity annually would require the construction of facilities capable of handling 25,000 acre-feet per month. Thus the existing water supply constraint of 551 acre-feet per month is replaced with the 25,000 acre-feet constraint. The model is then optimized based on this set of parameters to measure the change in total and individual benefits. General results are presented in Table 6-3, while detailed results are presented in Table A-3 in Appendix A.

This scenario yields substantial increases in total benefits, with the vast majority accruing to water supply. Total benefits under this set of parameters equal $21.36 million, an increase of over $5.4 million. Water supply benefits increase from $165,300 to $7,500,000, which reflects the sale of 300,000 acre-feet of water at a price of $25 per acre-foot. In addition, flood control benefits increase by $10,600, to $284,199. All other activities suffer reductions in benefits. Hydropower benefits decline more than $1.6 million due to the redistribution. The fishery and lake recreation components also suffer reduced benefits of roughly $80,000 and $200,000, respectively.

The second step of this investigation of water supply issues assumes an even larger transfer of water to the Texas counties. With the proposed sale under consideration involving up to 600,000 acre-feet annually, it seems appropriate to examine that possibility within the context of the model at hand. Transferring this volume of water on an annual basis would require facilities capable of handling up to 50,000 acre-feet of water each month. Thus the water supply constraint in the model is increased to match this volume. Based on earlier discussions of the marginal values, the results of this process are somewhat predictable.

Total benefits increase substantially, to an estimated $26,723,937. Again, the vast majority of the benefits accrue to water supply, with flood control also experiencing a slight increase. Hydropower, fishery and lake recreation benefits each decline. As more water is allocated to water supply, those benefits increase at a constant rate equal to the fixed price incorporated into the model. Flood control benefits increase due to the reduced storage volume in the reservoir. Although the value of each acre-foot of storage decreases, the total value of flood control capacity increases due to the ability to absorb a much larger flow. Hydropower and fishery benefits decrease due to reduced releases through the generators and into the stream, while lake recreation benefits decline due to the reduced reservoir pool. Despite the significant reductions in benefits accruing to the three latter uses, the increase in total benefits suggests that the allocation of more reservoir capacity to water supply should be considered.

Pool Guide Constraints

Another important aspect of the reservoir at Broken Bow is the imposition of a seasonal pool guide. This pool guide suggests different pool levels for each month of the year. This pool guide is driven by the threat of potential flood events at different times during the year, and the rise in tourism during the summer months. A direct consequence of pool guides in general is the creation of a designated flood pool. This is vacant capacity, held for the capture of potential floodwaters. In effect, a pool guide that creates this type of flood pool imposes an artificial capacity constraint on the reservoir. If the flood pool is to remain vacant, volume in the reservoir cannot exceed the levels recommended by the pool guide. Despite a larger physical capacity, the usable capacity for activities other than flood control is reduced.

The use of a seasonal pool guide is an improvement over a fixed pool guide in that reservoir volume is allowed to increase in the summer months when the threat of flooding is reduced. This increase in summer volumes supports lake recreation by increasing the surface area, and improving access to the water by existing facilities, such as boat ramps. In addition, lake levels are reduced during the months when the threat of flooding is the greatest. This accommodates the flood protection function of the reservoir. However, this raises the issue of the costs associated with this type of artificial capacity constraint.

To investigate the potential for increases in total benefits by altering the pool constraints, a series of alternative capacity constraints are imposed. Each of these sets of constraints is designed to provide a measure of the benefits or costs of alternative management scenarios.

The first optimization exercise to address the issue of capacity constraints completely eliminates the seasonal pool guide, and relies solely on the physical capacity of the reservoir to provide a constraint on the volume of water in the reservoir at any point in time. This scenario assumes that other parameters of the reservoir remain unchanged. That is, the capacity of the hydropower and water supply facilities are held constant. This exercise provides a measure of the costs, in terms of loss of benefits, associated with the imposition of the current pool guide. It can also be interpreted as the potential benefits gained by relaxing the pool constraints.

The results of this exercise show total benefits of over $21 million. This is a marked increase as compared to the original optimization results of $15.9 million, with the seasonal pool guide in effect. Most of the increase in total benefits accrues to lake recreation, with benefits increasing from $9.8 million to $15 million. This increase is due to the increase in pool levels, especially during the summer months.

Hydropower also gains from this increase in pool levels. Although the releases for hydropower are basically unchanged, the increased pool increases the head applied to the generators. This in turn generates more electricity per unit of water released. Even though releases are approximately the same, hydropower benefits are greater without the artificial pool capacity constraint. These benefits increase from $5,162,729 to $5,631,977, an increase of $469,248.

Flood control and fishery benefits each decline as a result of this policy. The magnitudes of these reductions are $96,515 and $264,973, respectively. Lastly, water supply benefits remain unchanged, as the constraints on this component of the model are binding in both scenarios.

This set of parameters is also applied to the water supply sales scenarios discussed earlier, to evaluate the potential benefits from eliminating the seasonal pool guide and following through on the water transfers. This is done for both the 300,000 acre-feet level and the proposed transfer of 600,000 acre-feet.

For a transfer of 300,000 acre-feet, total benefits equal slightly more than $25 million. This is significantly larger than the $21 million for the same transfer under the existing seasonal pool guide. A transfer of 600,000 acre-feet yields total benefits of $28.75 million, again larger than the $26.7 million under the seasonal pool constraint. In each of these scenarios, both lake recreation and hydropower experience increases in benefits as compared to the benefits under the seasonal pool guide. While the increase in hydropower benefits is relatively small, the majority of the increase in total benefits arises as a result of significantly larger recreation benefits. The downstream fishery and flood control suffer the only reductions in benefits, while water supply benefits remain unchanged.

As a final evaluation of the institutional pool constraints at Broken Bow Lake, an intermediate scenario was developed. Rather than completely abolish the existing pool guide, which seems somewhat extreme, this scenario simply alters the constraint. This evaluation incorporates a pool guide that follows the pattern and logic of the original guide, but raises the maximum conservation pool level by five feet in each month. This translates into an increase of roughly 56,000 acre-feet of capacity in the reservoir.

While the increases in benefits are not as substantial as in the previous scenarios, the distribution of these increases are similar. Total benefits under the assumptions of a five-foot pool increase and existing hydropower and water supply facilities equal $16.7 million. This shows an increase in benefits of $763,391 over the existing pool guide scenario. The largest gain in benefits come from lake recreation, with hydropower also showing small gains. Flood control and fishery benefits each decline slightly, while water supply benefits remain unchanged.

Comparing these results to the baseline scenario yields an even clearer picture of the increases in benefits. That is, by employing an optimization model of the type developed in this research, and increasing the pool guide by five feet, total benefits increase from $15.3 million to $16.7 million. Lake recreation benefits increase by almost $1.5 million, while hydropower and water supply benefits increase by $450,000 and $37,000, respectively. These gains are only slightly offset by reductions in flood control and fishery benefits of $44,000 and $130,000, respectively.

The 300,000 and 600,000 acre-feet transfer scenarios under a five-foot pool increase show similar results when compared to the baseline benefits and those under the original pool guide. Lake recreation and hydropower each increase, while flood control and fishery benefits decline. Also, as the water supply constraint is increased, those individual benefits increase substantially. As a result, the net effects show substantial increases in total benefits across each of the scenarios.

Streamflow Constraints

Another issue that emerged as a point of contention between the stakeholders of Broken Bow Lake activities involves the imposition of minimum flow constraints on the Mountain Fork River below the lake. While no formal agreement has been forged, reservoir managers cooperate with wildlife authorities to maintain a minimum rate of flow in the stream. This flow is seen as the minimum streamflow necessary to maintain the habitat of the stream. In previous model scenarios, this stream minimum was represented by a monthly minimum release to the stream of 10,000 acre-feet. This measure corresponds to the smallest monthly flow during the period of record.

To address claims that this "agreement" to maintain some minimum stream releases creates substantial net losses, an alternative constraint is employed to measure the losses or potential gains associated with eliminating this type of release. Since both hydropower and gate releases find their way into the stream, the constraint is placed on the sum of these two releases. With benefits of the original constraint of 10,000 acre-feet per month already estimated, the alternative scenario assumes a reduction in the streamflow minimum to 5,000 acre-feet per month. This represents a fifty-percent reduction in the constraint. An increase in total benefits will indicate that there are net costs associated with the imposition of this agreement.

Referring again to the results presented in Table 6-3, benefits are shown for this scenario under both the 300,000 and 600,000 acre-foot water transfer assumptions, with no artificial pool constraint. The results of these exercises are somewhat mixed. In each case, the total benefits to the reservoir increase. However, the source of the increase is different for each scenario.

Under the 300,000 acre-foot transfer, total benefits increase by $94,510, from $25.14 million to $25.23 million. These gains come from several sources. Hydropower benefits increase by $76,808, which is consistent with the freedom to choose the most beneficial pattern of releases. Although the magnitude could not have been predicted, the direction of change was expected. Flood control benefits increased by $40,052, which is not alarming, because the prediction for this activity was ambiguous. Water supply benefits remained constant, as the constraint in both scenarios is binding. The other activities produced benefit measures that were unexpected. Although lake recreation benefits were expected to rise as a result of this new, less restrictive constraint, they in fact decreased by $174,558. An examination of the details in Appendix A reveals that in the first eight months of the year, benefits behaved as expected – they rose. However, in the last four months, benefits fell short of the previous scenario's results. Further examination reveals the reason for this shift. In the latter scenario, with a reduced flow minimum, reservoir volume in the summer months was larger than for the original scenario. This increased volume was facilitated by the smaller monthly release requirement, and desirable for the sake of increased recreation benefits. To fully utilize this volume for hydropower production before the end of the year, heavy releases began during the ninth month. This reduced reservoir volume and recreation benefits in those last four months. In the earlier scenario, heavy releases for hydropower did not begin until the eleventh month.

The timing of these releases also explains the approximate $152,000 increase in fishery benefits under the reduced flow constraint. One would expect that mandating a minimum flow constraint would not only protect the habitat for future benefits, but also increase the contemporaneous benefits of the fishery. However, this is not the case. Reducing the constraint actually increased these benefits. Under the initial constraint, releases to the stream were driven by the constraint until the ninth month. In the last two months of the year, releases through the generators and into the stream were very heavy. These releases were large enough to reduce fishery benefits to zero. Under the latter constraint, large releases began earlier, but were smaller in volume. This produced positive benefits for the fishery in all months, resulting in a larger annual benefit.

Under the 600,000 acre-foot transfer, results were likewise mixed. While total benefits increased by $410,074, the sources of this increase were somewhat unexpected. Compared to the previous exercise, individual benefits moved in opposite directions for each activity. Hydropower, fishery and flood control benefits were reduced under the alternative flow constraint, while lake recreation benefits increased. The reason for these results lies in the timing of the releases, not the quantities. The releases for electric generation and water supply are the same in each scenario. In addition, gate releases to the stream are zero in both cases. The effects of alternative timing of releases for each activity are briefly examined below.

The main reason for the decline in hydropower is reduced releases early in the year. Under each scenario, the minimum flow constraint is binding throughout the first part of the year. While the constraint is binding for the first seven months under the original assumption, the reduced constraint is binding for all but the last two months. The original constraint calls for minimum releases of 10,000 acre-feet per month, while the alternative calls for only 5,000 acre-feet per month. The smaller minimum release constraint and the extended period of influence yield significant reductions in electricity production. This, in turn, reduces the benefits accruing to hydropower.

Lake recreation and flood control benefits are each products, at least in part, of the volume of water in the reservoir at any given time. While lake recreation benefits increase with storage volume, flood control capacity and benefits decrease with increased volume. Under the reduced minimum flow constraint, the reservoir volume increases earlier in the year, because less water is released to the stream. Although this benefits recreation, flood control is diminished. Flood control is also diminished by the fact that this increased volume is held later in the year, which increases recreation benefits. Another result of holding this larger volume of water until late in the year is that fishery benefits are reduced. Only after the tenth month does the stream experience flows above the required minimum flow. Although the flows in months eleven and twelve are large enough to generate substantial benefits, they are not large enough to offset the reductions earlier in the year. As with the previous exercise, water supply benefits remain unchanged due to the fixed price and equivalent releases.

Sensitivity to Price Changes

Recreation and fishery benefits and the value of flood control services are not determined by standard market prices, and therefore are not subject to the fluctuations in prices experienced by goods traded in formal markets. This does not suggest that values for these activities are constant or fixed, simply that routine fluctuations are difficult to capture due to the methods employed in calculating these benefits. Those goods traded in market settings, on the other hand, are subject to frequent price changes, and these price changes are easily measured. In addition, fluctuations in the price of reservoir services may have significant impacts on the management practices employed. For this reason, it may be beneficial to examine the impact of altering the price structure for those market-traded reservoir services.

The activity that is most likely to experience fluctuations in prices is hydropower production. While water supply values may fluctuate at the consumer level, raw water prices at the wholesale level are generally set by long-term contracts. Therefore, the only activity remaining, for which to evaluate the effects of price fluctuations is that of hydropower. Electricity prices used in this study represent an average of three published price measures. Between these measures there are significant differences as to the definitive price of electricity at any given time. To address the possibility that the price measure used in this study is not representative of the wholesale electricity market's price, and to examine the effects of an increase in this price, an alternate price measure is imposed. The new price represents a ten percent increase over the original price structure used. That is, the price used in each month is increased by ten percent, but the structure and pattern of prices across time is unchanged.

This scenario is examined under both the 300,000 and 600,000 acre-foot water supply assumptions. Under each set of assumptions, total benefits increased, with the majority of the gains accruing to hydropower. For water supply of 300,000 acre-feet, hydropower benefits increased by $451,527 while electric production declined slightly. For water supply of 600,000 acre-feet, hydropower benefits increased by $132,367, but with increased production. Benefits from other activities were mixed in both cases, with the changes being relatively small. One key point concerning hydropower production in both cases is that the increased price level does not alter the amount of water released for electricity production. Only the timing changes, and these changes are somewhat minor.

Dry Year

The dry and wet years present more of a challenge to this type of optimization model than does the average year. When flows deviate substantially from the average flows, the constraints generally become more pressing. The dry year assumptions applied to this set of exercises include inflows that are reduced to fifty-percent of average year flows. In addition, historic outflows are altered to reflect actual withdrawals during historic dry years. The purpose of this group of exercises, and those for the wet year, is to evaluate the performance of the model developed within under other than average conditions. That is, to see if benefit gains estimated under the average year conditions carry-over to other conditions.

Baseline Benefits

The parameters of the baseline benefits estimation are the same as those used in the previous section. The only point of departure from earlier discussions is in the historic flows used for the analysis. For the average year baseline benefits, historic inflows and outflows were used. However, for the dry year analysis, these flows must be synthesized. The level of inflows chosen exceeds the lowest level of annual flows during the period of record, although some months experienced flows equaling those of the synthesized record. Outflows for this analysis are also generated from information contained in the record of flows. Examination of this data reveals that hydropower releases fluctuate proportionately with inflow conditions. That is, if inflows decline by fifty-percent, hydropower releases also decline by fifty-percent. Water supply releases, however, move inversely with water conditions. If inflows decline by fifty-percent, water supply withdrawals increase by twenty-five-percent. The remaining decision variable, gate releases, is calculated as a residual. The resulting record of flows provides a basis for estimating the baseline benefits measure.

Imposing this record of flows on the model yields an estimate of benefits for current management practices under dry year conditions. The general results of this estimation, and the various optimization exercises are presented in Table 6-4. Detailed results are presented in Appendix B. Several notable points from this baseline solution should be emphasized. Hydropower benefits are substantially less than those for an average year, as hydropower releases are less. In addition, flood control benefits are reduced to $0 for this baseline estimation, and for all subsequent exercises under dry year conditions. This is not a surprising outcome. If inflows in every month fall short of those needed to create the potential for flooding, then flood control services are of no value. Other reservoir services accrue benefits as expected.

Table 6-4

Dry Year Annual Benefits By Activity

Scenario	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
Baseline Benefits	$2,357,936	$160,128	$0	$420,886	$9,431,671	$12,370,621
Optimization with existing facilities and seasonal pool guide	$2,588,705	$165,300	$0	$358,320	$9,782,988	$12,895,313
Optimization with seasonal pool guide and water supply of 300,000	$993,159	$7,456,593	$0	$170,537	$9,497,785	$18,118,074
Optimization with seasonal pool guide and water supply of 600,000	$897,941	$7,930,548	$0	$154,961	$9,488,119	$18,471,569
Optimization without seasonal pool and with existing facilities	$2,713,090	$165,300	$0	$302,722	$11,713,122	$14,894,234
Optimization without seasonal pool and with water supply of 300,000	$1,003,159	$7,500,000	$0	$162,780	$10,029,947	$18,695,886
Optimization without seasonal pool and with water supply of 600,000	$754,370	$8,627,151	$0	$131,037	$9,906,304	$19,418,862
Optimization with a 5 foot pool increase and existing facilities	$2,652,725	$165,300	$0	$329,612	$10,493,708	$13,641,345
Optimization with a 5 foot pool increase, water supply of 300,000	$1,003,289	$7,500,000	$0	$162,900	$10,029,509	$18,695,698

Table 6-4 (continued)

Scenario	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
Optimization with a 5 foot pool increase, water supply of 600,000	$754,598	$8,627,151	$0	$131,037	$9,914,963	$19,427,749
Optimization with 50% streamflow reduction, no seasonal pool, and water supply of 300,000	$997,504	$7,500,000	$0	$143,616	$10,357,203	$18,998,323
Optimization with 50% streamflow reduction, no seasonal pool, and water supply of 600,000	$409,709	$10,127,155	$0	$67,059	$9,926,965	$20,530,888
Optimization with a 10% electricity price increase, no seasonal pool, and water supply of 300,000	$1,089,976	$7,500,000	$0	$149,601	$10,074,742	$18,814,319
Optimization with a 10% electricity price increase, no seasonal pool, and water supply of 600,000	$829,806	$8,627,151	$0	$131,037	$9,906,304	$19,494,298

Notes: 1 - all benefits are expressed in 2000 U. S. dollars
2 - baseline benefits are calculated based on historical inflow and release patterns
3 - existing facilities refers to installed hydropower and water supply infrastructure
4 - 300,000 water supply constraint reflects a maximum installed capacity of 25,000 acre-feet per month
5 - 600,000 water supply constraint reflects a maximum installed capacity of 50,000 acre-feet per month
6 - no seasonal pool means reservoir volume constrained only by physical capacity of reservoir
7 - 5 foot increase is above the existing pool constraint

Total benefits under the baseline assumptions equal $12,370,621, roughly $3 million less than those for an average year. Most of this difference arises from the $2.5 million reduction in hydropower benefits. Fishery benefits are also reduced by the decline in inflows, with the reduction totaling more than $264,000. Lake recreation and water supply benefits each increase slightly under reduced flows.

Optimization with Existing Facilities and Parameters

Employing the optimization process generates gains in benefits similar to those under the average year conditions. Total benefits estimated through the optimization of the system's resources equal $12,895,313, a gain of roughly $525,000. Hydropower, water supply, and lake recreation each experience relatively small gains in benefits, while fishery benefits decline slightly. Lake recreation benefits totaling $9.8 million represent an increase of approximately $351,000. As in earlier scenarios, lake recreation is the source of greatest gains from the optimization process. With the existing facilities as a constraint on the system, water supply benefits increase only slightly. Again, flood control services yield no benefits.

Water Supply Issues

A major concern for many of those involved with water supply sales to the counties in Texas, especially during low volume years, is the impact the transfer would have on local consumers of the reservoir's services. While local usage may consist of consumption by local residents of all reservoir services, for the purpose of this research it is limited to flood control, fishery and lake recreation benefits. Furthermore, flood control capacity during times of below average flow is determined to have no value. For this reason, only lake and fishery recreation benefits are considered representative of local benefits derived from the reservoir. Water supply for local residents may also be a point of interest and concern. However, the local municipal water consumption quantity is extremely small, and is assumed to be met with little consequence. Therefore, this activity is not allocated to the local usage classification. A final point to be made concerning recreation activities being designated as local is that not all recreation participants reside in the local area. The designation of recreation activities as local stems from the fact that many of the benefits of recreation filter down to local businesses and workers through spending and the multiplier effect.

The main issue of concern is the possibility of contractual obligations to these counties dominating water supply usage during times of shortage. This issue is best illustrated through an examination of the results from the dry year analysis with alternative water supply constraints. Again, the analysis considers transfers of 300,000 and 600,000 acre-feet of water, and evaluates the changes in total and individual benefits.

Under the assumption of transferring 300,000 acre-feet, total benefits are just over \$18.1 million. This represents an increase in benefits of more than \$5 million. However, all benefits accrue to water supply, with all other activities suffering reductions in benefits. The largest reduction in benefits comes in hydropower, with benefits falling from \$2.6 million to under \$1 million. Fishery and lake recreation benefits also decline, with reductions totaling \$188,000 and \$285,000, respectively. These are the reductions that opponents of the transfer fear. However, if the local community enjoys the revenues from the transfer, these reductions can be more than offset.

Under the 600,000 acre-foot transfer assumption, the results are quite similar. In fact, benefits increase only slightly. This is due to the fact that the reservoir is unable to meet the water supply constraint under the given set of assumptions. Although the water supply constraint is raised to 50,000 acre-feet per month, the reservoir is only capable of delivering a maximum of approximately 33,000 acre-feet. This is due to the reduced inflows and constraints preventing borrowing and mandating minimum flows in the stream. Also restricting the reservoir's ability to meet the water supply maximum is the artificial capacity constraint imposed by the seasonal pool guide. Despite these issues, water supply benefits manage to increase, while benefits accruing to all other activities decline. Total benefits increase to $18.47 million, an increase of approximately $350,000 above the 300,000 acre-foot scenario.

Pool Guide Constraints

The pool constraint imposed on the Broken Bow Lake is less restrictive during dry years. Thus the gains in benefits from removing it are somewhat limited. The largest gain is experienced through the comparison of the optimization exercises with and without the seasonal pool constraint, and with the existing facilities. The gains here total $2 million, with most of the increase accruing to lake recreation. Under the water supply alternatives, gains from eliminating the pool constraint are significantly less. For a transfer of 300,000 acre-feet, the gains equal $578,000. For a transfer of 600,000 acre-feet, the gains are $947,000. While these are sizeable gains, they do not compare to the gains experienced under the average year conditions.

Increasing the pool constraint by five feet produced similar gains in benefits. With existing facilities, raising the pool constraint by five feet produced gains of $746,000 over the original optimization exercise. These gains arise from increases in lake recreation of $711,000, and hydropower of $64,000, and a decline of $29,000 in fishery benefits. Water supply benefits remain unchanged, and flood control benefits remain zero.

For the two alternative water supply transfers, gains in benefits were likewise consistent. Increases in total benefits are $577,000 for the 300,000 acre-foot transfer, and $956,000 for the 600,000 acre-foot transfer. In each case, lake recreation is the source of most of the gains, while benefits from other activities were relatively small and mixed.

Streamflow Constraints

Of the three conditions examined, the dry year is expected to be the condition under which the minimum flow constraint is most binding. In addition, the greater the water supply capacity, the more binding this constraint is likely to be. This assertion can be tested by reducing the value of this constraint and examining the benefits generated. The greater are the gains, the more costly is the imposition of this constraint.

In both cases, total benefits increase. For the 300,000 acre-foot transfer, total benefits increase by $302,000, with all of the gains accruing to lake recreation. Fishery and hydropower benefits decline, while water supply and flood control benefits remain unchanged. Under the 600,000 acre-foot transfer assumption, total benefits rise by $1.1 million. While lake recreation benefits increase slightly, substantial gains are seen in water supply benefits. With the original minimum flow constraint, the reservoir is unable to satisfy the water supply capacity of 50,000 acre-feet per month. When the constraint is reduced, the total difference in flows is allocated to water supply. This raises water supply releases by 60,000 acre-feet, and benefits by $1.5 million. Hydropower and fishery benefits decline as a result of this shift in water resources.

Sensitivity to Price Changes

In response to a ten-percent increase in the wholesale electricity price, there were very minor changes in the decision variables. Under the intermediate water transfer assumption, hydropower increased by $87,000. This increase was due mainly to the increase in price for electricity produced. However, there was a very slight increase in hydropower production. Total benefits for this scenario increased by $118,000, with a small increase in lake recreation and small decrease in fishery benefits comprising the balance. Under the 600,000 acre-foot transfer, there was no impact on the decision variables. Release patterns were unchanged. Total benefits increased by $75,436, which equals the increase in hydropower benefits. All other benefits remain the same.

Wet Year

The wet year analysis places strains on the model different than those of the dry year. In the dry year, minimum flow constraints and satisfying water supply capacity are the main interests. That is, how to best allocate water during times of shortage. In wet years, it is likely that the major concern involves what to do with surplus water. Although the mechanics of the problem are identical, the perception of the problem is quite different. Instead of minimum flow constraints placing restrictions on the model, it is likely that maximum capacities will be the limiting factors.

The wet year analysis assumes inflows fifty-percent greater than those for an average year. Using data from the period of record, a record of outflows is generated to correspond with this record of inflows. Together, these flows are used to estimate the baseline benefits measure. Using the inflows only, the series of optimization procedures conducted for the previous conditions will be repeated. General results of these exercises are presented in Table 6-5, with detailed solutions presented in Appendix C.

Table 6-5

Wet Year Annual Benefits By Activity

Scenario	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
Baseline Benefits	$6,997,607	$96,078	$936,526	$673,296	$9,431,100	$18,134,607
Optimization with existing facilities and seasonal pool guide	$8,512,000	$165,300	$915,940	$547,311	$9,788,820	$19,929,371
Optimization with seasonal pool guide and water supply of 300,000	$6,063,690	$7,500,000	$928,579	$549,336	$9,658,596	$24,700,201
Optimization with seasonal pool guide and water supply of 600,000	$4,385,607	$15,000,000	$993,153	$561,225	$9,153,208	$30,093,193
Optimization without seasonal pool and with existing facilities	$8,891,103	$165,300	$614,707	$228,326	$17,373,253	$27,272,689
Optimization without seasonal pool and with water supply of 300,000	$6,708,809	$7,500,000	$646,246	$226,741	$16,681,765	$31,763,561
Optimization without seasonal pool and with water supply of 600,000	$4,696,163	$15,000,000	$691,665	$216,871	$14,893,812	$35,498,511
Optimization with a 5 foot pool increase and existing facilities	$8,720,616	$165,300	$856,539	$543,587	$10,562,774	$20,848,816
Optimization with a 5 foot pool increase, water supply of 300,000	$6,200,066	$7,500,000	$875,391	$528,320	$10,379,472	$25,483,249

Table 6-5 (continued)

Scenario	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
Optimization with a 5 foot pool increase, water supply of 600,000	$4,503,542	$15,000,000	$897,362	$502,137	$10,128,247	$31,031,288
Optimization with 50% streamflow reduction, no seasonal pool, and water supply of 300,000	$6,417,209	$7,500,000	$620,455	$103,195	$17,420,608	$32,061,467
Optimization with 50% streamflow reduction, no seasonal pool, and water supply of 600,000	$4,632,661	$15,000,000	$676,936	$151,129	$15,334,796	$35,795,522
Optimization with a 10% electricity price increase, no seasonal pool, and water supply of 300,000	$7,381,506	$7,500,000	$646,246	$229,068	$16,677,703	$32,434,523
Optimization with a 10% electricity price increase, no seasonal pool, and water supply of 600,000	$5,165,780	$15,000,000	$691,665	$216,871	$14,892,812	$35,967,128

Notes: 1 - all benefits are expressed in 2000 U. S. dollars
2 - baseline benefits are calculated based on historical inflow and release patterns
3 - existing facilities refers to installed hydropower and water supply infrastructure
4 - 300,000 water supply constraint reflects a maximum installed capacity of 25,000 acre-feet per month
5 - 600,000 water supply constraint reflects a maximum installed capacity of 50,000 acre-feet per month
6 - no seasonal pool means reservoir volume constrained only by physical capacity of reservoir
7 - 5 foot increase is above the existing pool constraint

Baseline Benefits

Baseline benefits for the wet year analysis are substantially larger than those for dry and average years. As with earlier baseline benefits estimates, the current management strategy for wet years appears to seek a balance in water allocation between the various activities. The initial estimate of total benefits equals $18.1 million, with individual benefits for all activities significantly larger than for the other conditions. One source for the increased total benefits is the existence of substantial flood control benefits. These flood control benefits are more a product of higher inflows than of conservation pool strategies. This point is made when the alternative strategies are analyzed. Hydropower also becomes more of a contributor under the wet year condition than for the other conditions, with benefits totaling almost $7 million. Water supply, fishery, and lake recreation benefits are relatively close to the average year estimates.

Optimization with Existing Facilities and Parameters

The optimization process for the wet year condition, considering the existing facilities and parameters yields an estimate of total benefits significantly larger than those of the baseline scenario. Where the baseline benefits measure totals $18.1 million, the optimization process produces total benefits of $19.9 million, an increase of $1.8 million. Further examination of the results provides an explanation for such large gains.

The largest source of the gains seen in the optimization is hydropower production. Hydropower benefits under the two scenarios increased by $1.5 million. Two factors influence the amount of electricity produced – releases to the generators and the elevation of the reservoir. Under the optimization process, an additional 160,000 acre-feet of water is released to the generators. This is water that, under the historical management practice, was released through the spillway gates. While this does generate benefits for the fishery, it produces no electricity. Released through the generators, the water generates benefits for both activities.

In addition, the optimization results call for maintaining a larger volume in the reservoir through most of the year, especially during the latter part of the year. This increased volume translates into a larger effective head during those months. As discussed earlier, the greater the head, the greater will be the electricity production per unit of water released. This combination of larger releases and a greater effective head results in significant increases in hydropower benefits.

Another main source of gains under these scenarios is lake recreation, with these benefits rising by more than $350,000. The reason for these gains is the same increased pool that contributed to the increase in hydropower benefits. For the other activities, the changes in benefits arising from the optimization were mixed and relatively small. Flood control and fishery activities were the losers, with reductions of $21,000 and $126,000, respectively. Water supply benefits increased by roughly $70,000, due to completely satisfied transfer capacity.

Water Supply Issues

An examination of the alternative water supply transfers provides results similar to those of the average year. Under the assumption of a 300,000 acre-foot transfer, total benefits increase from $19.9 million to $24.7 million, with the source of the gains somewhat predictable. Due to the increase in the water supply constraint from the current 551 acre-feet per month to 25,000 acre-feet, these benefits increase from $165,000 to $7.5 million. The only major reduction in benefits came from hydropower, with a decline of $2.45 million. This decline is due to a shift of 290,000 acre-feet of releases from hydropower to municipal and industrial water supply. Benefits accruing to the other activities were mixed, with flood control and fishery benefits increasing slightly and lake recreation benefits decreasing slightly.

As compared to the average year analysis, the gains in total benefits from increased water supply are quite similar. However, the measure of total benefits is much larger. The reason for the larger wet year benefits is that the problem of scarcity is diminished with the larger inflows. Two main points of difference, hydropower and flood control benefits, arise from the presence of these larger inflows throughout the year.

The increased inflows create the possibility for fully satisfying the water supply capacity and generating relatively large amounts of electricity simultaneously. In previous cases, it was a matter of choosing which activity would receive the water. Because water supply yielded higher marginal benefits at all levels, water was first allocated to that activity. Only after the water supply constraint became binding did releases through the generators rise above the required minimum streamflow level. The situation is exactly the same in this case, except the remaining volume of water is substantial, allowing for greater hydropower benefits.

The second point of difference between wet year and average year conditions is the benefits accruing to flood control. Flood control benefits of $929,000 far outstrip those of the average year analysis. However, as pointed out earlier, these benefits are likely due to the increased flows rather than increased flood control capacity. Even those scenarios, in which reservoir volume is the largest, produce flood control benefits greater than any of the average year scenarios.

For a transfer of 600,000 acre-feet, the results are likewise predictable. Total benefits increase by an additional $5.4 million. The greatest source of this increase is a rise of $7.5 million in water supply benefits, resulting from the doubling of the applicable constraint. Hydropower benefits suffer the largest reduction, with benefits declining from $6 million to $4.4 million. Lake recreation benefits also decline by $500,000, due to reduced pool levels. Fishery and flood control benefits each increase slightly.

Pool Guide Constraints

Examination of the benefits generated under alternative pool constraints provides some evidence of the potential for large gains in benefits during years of above average flows. During wet years, these artificial capacity constraints are more restrictive, and more costly in terms of benefits foregone than in other years. By completely removing the pool guide, and solving the model under the assumption of existing facilities, these potential benefits become evident.

This exercise produces an estimate of total benefits of $27.3 million. Compared to the $19.9 million under the existing pool guide, this is a substantial gain. As expected, the main source of this gain is lake recreation. Benefits of recreation increase from $9.8 million to $17.4 million. This increase is due to the increased pool volume throughout the year, but especially during the summer months. Hydropower benefits increase slightly, while flood control and fishery benefits decline under this set of assumptions. Water supply benefits are unchanged, as the constraint is binding in both scenarios.

Raising the water supply constraints to represent the transfer of water to interested parties increases total benefits even more. With the assumption of a 300,000 acre-foot transfer, in addition to the removal of the pool constraint, total benefits increase to $31.8 million. For a transfer of 600,000 acre-feet, total benefits equal $35.5 million. Compared to the same transfer levels under the existing pool constraint, these estimates represent increases of $7.1 million and $5.4 million, respectively. Again, the main source of the gains is lake recreation, with hydropower increasing moderately.

Increasing the pool guide rather than eliminating it also produces increases in total benefits, but, as expected, the increases are much smaller. Under the assumption of existing water supply facilities, total benefits increase to $20.8 million, an increase of $920,000. For the intermediate water supply transfer level, benefits increase by $783,000, while the 600,000 acre-foot transfer yields gains of $938,000. In each case, the sources of the increases are lake recreation and hydropower. Also, under the increased pool guide curve, the reductions in flood control benefits are much smaller.

Streamflow Constraints

Concerns over maintaining a minimum level of flows in the stream are somewhat diminished in years of above average inflows. However, altering this constraint continues to exert influence on the outcome of the model. For a water supply level of 300,000 acre-feet, reducing the minimum flow constraint increases total benefits by $297,000. The beneficiary of this reduction is lake recreation, with benefits increasing by $738,000. While water supply benefits remain unchanged, all other activities suffer losses. Benefit estimates under the 600,000 acre-foot constraint are similar, with total benefits increasing by $297,000, due to increases in lake recreation.

Sensitivity to Price Changes

The effects of the increase in electricity prices in the wet year are similar to the effects under the other conditions. For the 300,000 and 600,000 acre-foot water supply constraints, total benefits increased by $671,000 and $469,000, respectively. For both scenarios, the increases are attributable solely to an increase in benefits for the electricity produced. Allocations and timing of releases were unchanged.

Conclusions

This research makes no claim of capturing all elements of the decision process as related to the management of Broken Bow Lake. There are surely social, political, and environmental concerns that are not represented by the analysis in this study. However, as an important part of the process, the economic analysis presented herein does suggest some avenues of approach to improving economic efficiency in the use of the reservoir's resources. Predictably, these options include approval of the pending water supply transfer at some level, increasing the pool level, and reducing the minimum flow constraints. The value, in terms of increased benefits, for each of these alternatives is dependent on the inflow conditions in a given year. However, these changes can be implemented in a way that allows revisions as conditions vary from year to year.

The analysis of alternative water supply constraints provides evidence of the most noticeable gains of all management options. For each inflow condition, increasing the water supply capacity produces significant increases in total benefits. Most of these increases accrue to water supply, with relatively small decreases in benefits to the other activities. While the increase in water supply benefits is somewhat uniform across water conditions, the offsetting reductions in other activities are not. Generally, the greater the level of inflows, the less is the reduction in these other benefits. The wet year analysis produces the greatest gains from increasing the water supply constraint. This is due to the relatively small reductions in other benefits necessary to meet the water supply capacity. Increasing the water supply constraint in dry years results in relatively large reductions in other individual benefits, due to a shortage of water. Thus, the gains in total benefits are smaller in dry years than in wet years.

Increasing the pool level for the reservoir also produces significant gains in total benefits. While the greatest gains are experienced with the total elimination of this artificial capacity constraint, factors other than economic concerns will likely render this option unrealistic. However, even the relatively small increase in the pool guide analyzed in this study yielded significant increases in total benefits, with lake recreation being the main source of the gains. These gains in total benefits are greatest during the years of above average flows.

Finally, reducing the minimum flow constraint placed on the model produces gains in total benefits, but on a smaller scale than the other alternatives. Also, unlike the other alternatives, these benefits will likely be the greatest during dry years. While this is likely to be the most contentious of the alternatives, for environmental reasons, the economic analysis presented in this study is quite straightforward and remarkably consistent.

CHAPTER VII

SUMMARY

The major objectives of this study are to examine the current management practices regarding the resources of the Broken Bow Lake, and posit an alternative approach to the decision-making process. A major premise was that the methods applied to reservoir allocation and water usage allowances could be improved upon. The approach taken in this research required the development and implementation of a mathematical model, designed to represent the various services provided by the reservoir.

Motives for Study

An examination of the policies of the Corps of Engineers regarding the allocation of reservoir capacity, and thus water volume, provided an insight into the methods generally applied to this type of problem. The most notable of these is the rigidity of the allocations, once developed. Corps reports indicate that the time required to implement a change in the allocation could exceed two years. In the case of Broken Bow Lake, there is current evidence of this time consuming process. At the outset of this research, a reallocation study was begun for the reservoir. As of completion of the study at hand, the reallocation study is yet to be finished. The time needed to conduct a reallocation study is a major motive for the type of management approach posited in this research. A management approach that requires more than two years for an adjustment in reservoir allocation could be seen as a rigid approach.

A second interesting aspect of the current approach is the distinction made between the reservoir and the water in the reservoir. From the perspective of the Corps, the facility is an asset, to be managed in a way that recovers the initial investment in the project. This is accomplished by allocating storage capacity to various non-Federal parties who are willing to pay for that capacity. The amount to be paid depends on the amount of capacity allocated. In terms of asset management, given the cost recovery-only motive of the Corps, this seems to be a reasonable approach. However, in terms of resource management, this approach seems to leave room for improvement.

In the process of the reallocation study, the Corps conducts various assessments, including hydrologic, environmental and economic analyses. The focus of these assessments is on the viability of one or more proposed allocation schemes, with the results indicating whether or not each proposal is acceptable. While all of these concerns are incorporated into the reallocation decision, it appears that the main focus remains on recovery of the Corps investment.

Method of Analysis

The current research takes a different approach to the process of allocating reservoir resources to various activities. The first major difference between current practices and this study is that there is made no distinction between capacity and volume. This study views the reservoir and its contents as a single resource, which can be allocated to several different uses. While this approach requires that the existing agencies involved with management of different aspects of the reservoir fully cooperate with one another, it relieves the political constraints on the resource. This freedom from political wrangling affords timely adjustments in allocations. The means for identifying the needed adjustments is the economic model of the reservoir developed in this research.

The mathematical model developed herein provides a certain degree of flexibility in reservoir management decisions and their timing. It can identify the most economically efficient management decisions, given an existing set of constraints. The model can also identify alternative avenues of increased benefits by relaxing certain constraints on the system. In this study, several different scenarios were examined, to identify the optimal allocations for each set of constraints. In addition, these scenarios were examined within the context of different inflow conditions. This analysis is important because inflows, for the most part, determine the volume of water in the reservoir in a given time period.

Five alternative activities associated with the use of reservoir resources were incorporated into the model. These activities included hydropower generation, flood control, municipal and industrial water supply and lake recreation. In addition, fishing activities along the Mountain Fork River below the dam were also included in the analysis. A benefit measure for each of these activities was developed, and used to represent the trade-offs associated with allocation of water to each activity. For lake recreation and fishery activity, benefit functions were adapted from existing studies. For flood control, historic benefit measures and hydrologic data provided the information necessary to capture the desired benefits. Prevailing wholesale prices were used to represent benefits for the two activities having market prices – hydropower and water supply. All of these benefit functions were incorporated into the model to represent the trade-offs associated with various water allocation schemes.

Study Results

The outcome of the analysis revealed several interesting observations. The first, and possibly most supportive of the general approach taken in this research, is the fact that under each inflow condition, total benefits were increased by the employment of the optimization model. For an average year, this result can be seen in the illustration of pool levels and the associated benefits presented in Figure D-1 in Appendix D. In this graph, the pool levels suggested by the seasonal pool guide is accompanied by the historical baseline and optimization pool curves. For each of the curves, a total benefit value is given. This indicates that a stricter adherence to the seasonal pool guide, as followed by the optimization model, yields slight increases in total benefits. Figures D-2 and D-3 illustrate similar results for the dry and wet years, respectively. In each case, total benefits are increased under the optimization model's suggested allocations and release patterns.

Another interesting outcome is the change in benefits arising from an increase in the volume of water held in the reservoir. The premise of this exercise was that increasing the capacity for water storage in the reservoir would yield increased total benefits. While one exercise evaluated the benefits of increasing this capacity to match the reservoir's physical capacity, another looked at simply increasing the existing institutional pool constraint. Due to the unlikelihood of implementing the former scenario, only the latter scenario is presented here. The increase in the pool constraint used in this exercise was an elevation increase of five feet. This translates into an increase in volume of approximately 56,000 acre-feet. In Figure D-4, the average year optimizations for both the original and the alternative pool constraints are presented. For clarity, the pool guides themselves are omitted from this illustration. This graph shows that the relatively small increase in pool levels yields significant increases in total benefits. Figures D-5 and D-6 show similar outcomes for dry and wet years, respectively. In all cases, increased pool levels generate significant increases in benefits.

A final observation is that municipal water supply dominates the management decision process. The constant wholesale price of municipal water withdrawals is greater than the sum of benefits of the alternative activities. This can be seen by looking at the shadow prices of the alternative uses, which were analyzed for several scenarios. However, this can be inferred from the fact that in almost every scenario, the water supply constraint is binding. The only case in which this maximum constraint is not binding is in dry years, when meeting the water supply constraint would violate the non-borrowing constraint placed on the model.

The result of this influence by the water supply activity is predictable. Total benefits consistently increase with increases in the amount of water allocated to water supply. Although hydropower and lake recreation suffer significant losses in benefits under increased water supply scenarios, these reductions are far less than the gains in water supply benefits. Changes in benefits to other activities are minimal.

Along with other less significant results, the three observations pointed out here indicate that there are several possible avenues of approach to extracting increased benefits from the Broken Bow Lake. The most basic of these is simply the implementation of a model of reservoir benefits similar to the one developed in this research. In addition, there are various management scenarios that, if implemented, could produce significant increases in total benefits. The approaches most likely to be received favorably are small increases in pool levels and approval of pending water supply transfers to Texas. The magnitude of each of these alternatives most desirable must be evaluated in terms of the other concerns and interests. However, the economic analysis provided by this study should provide a starting point for such decisions.

Concluding Remarks

The research presented in this study provides a relatively complete picture of the economics of various management decisions at the Broken Bow Lake. While there are admittedly some neglected aspects, such as rafting on the Mountain Fork River and recreation activities at Beaver's Bend State Park, this research is a step in the right direction. The more activities that can be captured, the more valid will be the results. This study is an attempt to capture more of these benefits than previous studies of this type, and to present as complete a picture as possible.

In all that this research claims to provide, there is one major thing it does not provide - a stand-alone decision tool. While the economic analysis should be a major component of reservoir management decisions, other aspects of the reservoir problem continue to exist. Concerns about environmental consequences should always play an important role in reservoir decisions. Likewise, social and political environments must be considered when proposing changes in reservoir services. These factors cannot be easily incorporated into a mathematical model as presented in this research, but significantly impact the acceptability of economically efficient outcomes.

In practice, this study suggests rearranging the hierarchy of analysis when conducting reallocation studies. Current practices include an economic analysis as a component of a decision process driven by cost-recovery motives. Along with the economic analysis, other considerations are those environmental, social and political concerns discussed earlier. This study suggests employing the economic analysis as the centerpiece of the decision process, with other concerns, including cost-recovery, filling the role of decision parameters.

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APPENDIXES

APPENDIX A

AVERAGE YEAR TABLES

TABLE A-1

AVERAGE YEAR BASELINE

	RELEASES (ac-ft)					Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	92,968	368	4,043	97,379	49,484	912,358	17,794	444,850	9,206	28,284	55,418	124,360	662,118
February	73,678	412	1,295	75,385	50,889	912,958	14,142	381,841	10,300	32,352	50,342	146,549	621,384
March	122,942	530	4,050	127,522	57,913	938,334	23,695	687,169	13,242	49,797	55,230	183,892	989,330
April	72,648	421	783	73,852	46,795	925,478	14,011	420,321	10,525	18,659	78,687	507,634	1,035,826
May	73,043	457	11,603	85,103	44,530	944,280	14,181	439,605	11,415	9,551	83,887	1,565,709	2,110,167
June	64,924	460	6,589	71,973	42,440	947,347	12,638	454,973	11,489	2,990	77,617	1,584,230	2,131,299
July	71,411	453	13,056	84,920	10,159	959,405	13,942	501,903	11,317	0	75,221	1,752,380	2,340,821
August	46,199	435	11,031	57,665	2,027	894,600	8,875	292,864	10,864	0	61,013	1,399,266	1,764,007
September	30,243	418	9,726	40,387	7,969	840,949	5,754	172,610	10,450	0	47,057	785,808	1,015,925
October	30,899	464	2,629	33,992	33,975	816,341	5,818	168,715	11,600	0	15,008	707,375	902,698
November	48,603	321	3,071	51,995	68,190	849,620	9,169	256,731	8,025	91,560	20,911	536,215	913,442
December	117,435	387	12,396	130,218	55,413	932,641	22,596	610,092	9,671	43,159	28,518	135,317	826,757
annual	844,993	5,126	80,272	930,391	469,784	912,141	162,615	4,831,674	128,104	276,352	648,909	9,428,735	**$15,313,774**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE A-2

AVERAGE YEAR OPTIMIZATION WITH EXISTING FACILITIES AND SEASONAL POOL

	RELEASES (ac-ft)							BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Reservoir Volume (ac-ft)	Hydropower Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	92,425	551	0	92,976	49,484	912,358	17,691	442,281	13,775	28,284	54,725	124,360	663,425
February	100,210	551	0	100,761	50,889	917,360	19,201	518,435	13,775	31,784	55,787	147,439	767,220
March	114,116	551	0	114,667	57,913	917,360	21,841	633,388	13,775	52,502	56,312	178,725	934,702
April	80,898	551	0	81,449	46,795	917,360	15,536	466,066	13,775	19,706	82,350	502,032	1,083,929
May	76,413	551	0	76,964	44,530	928,566	14,744	457,061	13,775	11,579	80,246	1,532,881	2,095,542
June	72,275	551	0	72,826	42,440	939,771	14,011	504,401	13,775	3,968	78,049	1,568,231	2,168,424
July	19,564	551	0	20,115	10,159	950,976	3,939	141,788	13,775	0	25,607	1,733,892	1,915,062
August	10,000	551	0	10,551	2,027	950,976	2,101	69,328	13,775	0	13,705	1,511,246	1,608,054
September	10,000	551	0	10,551	7,969	944,437	2,096	62,891	13,775	0	13,705	908,834	999,205
October	82,217	551	0	82,768	33,975	949,665	15,970	463,118	13,775	0	27,326	854,749	1,358,968
November	151,273	551	0	151,824	68,190	934,168	29,071	813,989	13,775	80,653	25,550	603,907	1,537,874
December	114,170	551	0	114,721	55,413	917,360	21,851	589,983	13,775	45,130	29,311	132,528	810,727
annual	923,561	6,612	0	930,173	469,784	9,123,580	178,052	5,162,729	165,300	273,606	542,673	9,798,824	**$15,943,132**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE A-3

AVERAGE YEAR OPTIMIZATION WITH SEASONAL POOL AND M & I OF 300,000

	RELEASES (ac-ft)				Inflows (dsf)	Reservoir Volume (ac-ft)	Hydropower Generation (mwh)	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total				Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	67,976	25,000	0	92,976	49,484	912,358	13,059	326,472	625,000	28,284	47,807	124,360	1,151,923
February	75,761	25,000	0	100,761	50,889	917,360	14,560	393,129	625,000	31,784	50,600	147,439	1,247,952
March	89,667	25,000	0	114,667	57,913	917,360	17,200	498,801	625,000	52,502	54,217	178,725	1,409,245
April	56,449	25,000	0	81,449	46,795	917,360	10,895	326,837	625,000	19,706	67,375	502,032	1,540,950
May	51,964	25,000	0	76,964	44,530	928,556	10,084	312,600	625,000	11,579	63,696	1,532,881	2,545,756
June	47,826	25,000	0	72,826	42,440	939,771	9,332	335,958	625,000	3,968	60,045	1,568,231	2,593,202
July	10,000	25,000	0	35,000	10,159	950,976	2,101	75,630	625,000	0	13,705	1,733,892	2,448,227
August	10,000	25,000	0	35,000	2,027	936,091	2,091	68,990	625,000	0	13,705	1,481,406	2,189,101
September	13,215	25,000	0	38,215	7,969	905,104	2,676	80,292	625,000	0	17,837	861,395	1,584,524
October	57,848	25,000	0	82,848	33,975	882,668	11,018	319,518	625,000	0	22,564	779,573	1,746,655
November	74,784	25,000	0	99,784	68,190	867,091	14,107	394,998	625,000	89,306	26,172	549,990	1,685,466
December	74,683	25,000	0	99,683	55,413	902,323	14,277	385,474	625,000	47,070	26,154	129,803	1,213,501
annual	630,173	300,000	0	930,173	469,784	912,358	121,400	3,518,699	7,500,000	284,199	463,877	9,589,727	**$21,356,502**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE A-4

AVERAGE YEAR OPTIMIZATION
WITH SEASONAL POOL
AND M & I OF 600,000

	RELEASES (ac-ft)							BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Reservoir Volume (ac-ft)	Hydropowe Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	103,887	50,000	0	153,887	49,484	912,358	19,863	496,571	1,250,000	28,284	59,097	124,360	1,958,312
February	26,738	50,000	0	76,738	50,889	856,450	5,138	138,731	1,250,000	39,641	23,819	135,285	1,587,476
March	27,779	50,000	0	77,779	57,913	880,473	5,380	156,014	1,250,000	57,261	24,615	169,754	1,657,644
April	31,449	50,000	0	81,449	46,795	917,360	6,149	184,471	1,250,000	19,706	43,183	502,032	1,999,392
May	26,964	50,000	0	76,964	44,530	928,566	5,319	164,883	1,250,000	11,579	37,894	1,532,881	2,997,237
June	22,826	50,000	0	72,826	42,440	939,771	4,548	163,719	1,250,000	3,968	32,757	1,568,231	3,018,675
July	24,630	50,000	0	74,630	10,159	950,976	4,912	176,832	1,250,000	0	31,434	1,733,892	3,192,158
August	17,595	50,000	0	67,595	2,027	896,461	3,493	115,280	1,250,000	0	23,253	1,402,918	2,791,451
September	18,305	50,000	0	68,305	7,969	832,878	3,542	106,268	1,250,000	0	24,107	776,457	2,156,832
October	10,000	50,000	0	60,000	33,975	780,353	1,977	57,320	1,250,000	0	5,033	669,126	1,981,479
November	10,000	50,000	0	60,000	68,190	787,623	1,982	55,501	1,250,000	99,557	5,033	488,228	1,898,319
December	10,000	50,000	0	60,000	55,413	862,640	2,039	55,040	1,250,000	52,189	5,033	122,700	1,484,962
annual	330,173	600,000	0	930,173	469,784	912,358	64,342	1,870,630	15,000,000	312,185	315,258	9,225,864	**$26,723,937**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE A-5

AVERAGE YEAR OPTIMIZATION WITH NO SEASONAL POOL AND EXISTING FACILITIES

	RELEASES (ac-ft)				Inflows	Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	(dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	551	0	10,551	49,484	912,358	2,074	51,852	13,775	28,284	9,669	124,360	227,940
February	10,000	551	0	10,551	50,889	999,786	2,134	57,608	13,775	21,151	9,669	164,421	266,624
March	10,000	551	0	10,551	57,913	1,089,995	2,192	63,555	13,775	30,232	9,669	222,697	339,928
April	10,000	551	0	10,551	46,795	1,194,111	2,255	67,638	13,775	0	15,272	704,486	801,171
May	10,000	551	0	10,551	44,530	1,276,214	2,302	71,356	13,775	0	15,272	2,312,676	2,413,079
June	10,000	551	0	10,551	42,440	1,353,832	2,345	84,406	13,775	0	15,272	2,521,335	2,634,788
July	10,000	551	0	10,551	10,159	1,427,313	2,384	85,811	13,775	0	13,705	2,948,679	3,061,970
August	126,193	551	0	126,744	2,027	1,436,877	28,059	925,939	13,775	0	78,439	2,593,366	3,611,519
September	149,697	551	0	150,248	7,969	1,314,145	32,268	968,028	13,775	0	70,369	1,395,452	2,447,624
October	178,005	551	0	178,556	33,975	1,179,676	36,968	1,072,071	13,775	0	18,801	1,130,020	2,234,667
November	199,882	551	0	200,433	68,190	1,068,390	40,128	1,123,584	13,775	63,338	10,761	716,696	1,928,154
December	199,783	551	0	200,334	55,413	1,002,973	39,264	1,060,129	13,775	34,086	10,802	148,395	1,267,187
annual	923,560	6,612	0	930,172	469,784	912,358	192,373	5,631,977	165,300	177,091	277,700	14,982,583	**$21,234,651**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE A-6

AVERAGE YEAR OPTIMIZATION
NO SEASONAL POOL
M & I OF 300,000

	RELEASES (ac-ft)					Reservoir	Hydropov	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	25,000	0	35,000	49,484	912,358	2,074	51,852	625,000	28,284	9,669	124,360	839,165
February	10,000	25,000	0	35,000	50,889	975,337	2,117	57,168	625,000	24,305	9,669	159,320	875,462
March	10,000	25,000	0	35,000	57,913	1,041,097	2,161	62,657	625,000	36,540	9,669	209,909	943,775
April	10,000	25,000	0	35,000	46,795	1,120,764	2,211	66,318	625,000	0	15,272	648,528	1,355,118
May	10,000	25,000	0	35,000	44,530	1,178,418	2,245	69,606	625,000	0	15,272	2,081,975	2,791,853
June	10,000	25,000	0	35,000	42,440	1,231,587	2,276	81,951	625,000	0	15,272	2,223,264	2,945,487
July	10,000	25,000	0	35,000	10,159	1,280,619	2,304	82,954	625,000	0	13,705	2,549,940	3,271,599
August	10,000	25,000	0	35,000	2,027	1,265,734	2,296	75,764	625,000	0	13,705	2,188,310	2,902,779
September	10,000	25,000	0	35,000	7,969	1,234,746	2,278	68,347	625,000	0	13,705	1,284,738	1,991,790
October	44,451	25,000	0	69,451	33,975	1,215,525	9,460	274,328	625,000	0	18,748	1,175,321	2,093,397
November	253,175	25,000	0	278,175	68,190	1,213,345	53,004	1,484,102	625,000	44,639	0	845,847	2,999,588
December	242,547	25,000	0	267,547	55,413	1,070,186	48,682	1,314,427	625,000	25,415	0	161,270	2,126,112
annual	630,173	300,000	0	930,173	469,784	912,358	131,108	3,689,474	7,500,000	159,183	134,686	13,652,782	**$25,136,125**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE A-7

AVERAGE YEAR OPTIMIZATION
NO SEASONAL POOL
M & I OF 600,000

	RELEASES (ac-ft)					Reservoir	Hydropow	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	50,000	0	60,000	49,484	912,358	2,074	51,852	1,250,000	28,284	9,669	124,360	1,464,165
February	10,000	50,000	0	60,000	50,889	950,337	2,100	56,711	1,250,000	27,530	9,669	154,159	1,498,069
March	10,000	50,000	0	60,000	57,913	991,097	2,128	61,708	1,250,000	42,990	9,669	197,105	1,561,472
April	10,000	50,000	0	60,000	46,795	1,045,764	2,164	64,907	1,250,000	3,142	15,272	593,025	1,926,346
May	10,000	50,000	0	60,000	44,530	1,078,418	2,184	67,714	1,250,000	0	15,272	1,855,254	3,188,240
June	10,000	50,000	0	60,000	42,440	1,106,587	2,202	79,267	1,250,000	0	15,272	1,932,929	3,277,468
July	10,000	50,000	0	60,000	10,159	1,130,619	2,217	79,798	1,250,000	0	13,705	2,164,882	3,508,385
August	51,424	50,000	0	101,424	2,027	1,090,734	10,529	347,463	1,250,000	0	56,748	1,801,016	3,455,227
September	47,988	50,000	0	97,988	7,969	993,322	9,537	286,105	1,250,000	0	54,019	968,954	2,559,078
October	50,046	50,000	0	100,046	33,975	911,114	9,657	280,062	1,250,000	0	20,445	811,216	2,361,723
November	55,360	50,000	0	105,360	68,190	878,338	10,535	294,969	1,250,000	87,855	21,919	558,917	2,213,660
December	55,354	50,000	0	105,354	55,413	907,994	10,650	287,561	1,250,000	46,338	21,918	130,829	1,736,646
annual	330,172	600,000	0	930,172	469,784	912,358	65,977	1,958,117	15,000,000	236,139	263,577	11,292,646	**$28,750,479**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE A-8

AVERAGE YEAR OPTIMIZATION WITH A 5 FOOT POOL INCREASE AND EXISTING FACILITIES

	RELEASES (ac-ft)					Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	36,399	551	0	36,950	49,484	912,358	7,076	176,899	13,775	28,284	30,826	124,360	374,144
February	100,210	551	0	100,761	50,889	973,386	19,586	528,834	13,775	24,556	55,787	158,915	781,867
March	114,116	551	0	114,667	57,913	973,386	22,280	646,108	13,775	45,275	56,312	192,636	954,106
April	80,898	551	0	81,449	46,795	973,386	15,846	475,394	13,775	12,478	82,350	541,109	1,125,106
May	76,413	551	0	76,964	44,530	984,592	15,035	466,095	13,775	4,351	80,246	1,650,969	2,215,436
June	72,275	551	0	72,826	42,440	995,797	14,285	514,248	13,775	0	78,049	1,687,814	2,293,886
July	19,564	551	0	20,115	10,159	1,007,002	4,012	144,433	13,775	0	25,607	1,864,780	2,048,595
August	10,000	551	0	10,551	2,027	1,007,002	2,138	70,567	13,775	0	13,705	1,625,326	1,723,373
September	10,000	551	0	10,551	7,969	1,000,463	2,134	64,022	13,775	0	13,705	977,844	1,069,346
October	110,291	551	0	110,842	33,975	1,005,691	21,776	631,505	13,775	0	29,328	919,348	1,593,956
November	145,590	551	0	146,141	68,190	962,120	28,264	791,399	13,775	77,047	26,549	626,856	1,535,626
December	147,804	551	0	148,355	55,413	950,995	28,580	771,647	13,775	40,791	26,178	138,691	991,082
annual	923,560	6,612	0	930,172	469,784	912,358	181,012	5,281,151	165,300	232,782	518,642	10,508,648	**$16,706,523**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE A-9

AVERAGE YEAR OPTIMIZATION WITH 5 FOOT POOL INCREASE AND M & I OF 300,000

	RELEASES (ac-ft)					Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	19,465	25,000	0	44,465	49,484	912,358	3,867	96,685	625,000	28,284	17,984	124,360	892,313
February	68,246	25,000	0	93,246	50,889	965,872	13,362	360,764	625,000	25,526	47,913	157,359	1,216,562
March	89,667	25,000	0	114,667	57,913	973,386	17,545	508,796	625,000	45,275	54,217	192,636	1,425,924
April	56,449	25,000	0	81,449	46,795	973,386	11,112	333,347	625,000	12,478	67,375	541,109	1,579,309
May	51,964	25,000	0	76,964	44,530	984,592	10,282	318,744	625,000	4,351	63,696	1,650,969	2,662,760
June	47,826	25,000	0	72,826	42,440	995,797	9,513	342,474	625,000	0	60,045	1,687,814	2,715,333
July	10,000	25,000	0	35,000	10,159	1,007,002	2,138	76,982	625,000	0	13,705	1,864,780	2,580,467
August	10,000	25,000	0	35,000	2,027	992,117	2,129	70,242	625,000	0	13,705	1,594,746	2,303,693
Septembe	10,000	25,000	0	35,000	7,969	961,130	2,108	63,232	625,000	0	13,705	929,218	1,631,155
October	75,496	25,000	0	100,496	33,975	941,909	14,639	424,519	625,000	0	26,293	845,930	1,921,742
Novembe	95,439	25,000	0	120,439	68,190	908,684	18,238	510,652	625,000	83,940	28,734	583,230	1,831,556
Decembe	95,621	25,000	0	120,621	55,413	923,261	18,370	495,983	625,000	44,369	28,747	133,603	1,327,702
annual	630,173	300,000	0	930,173	469,784	912,358	123,303	3,602,420	7,500,000	244,223	436,119	10,305,754	**$22,088,516**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE A-10

AVERAGE YEAR OPTIMIZATION WITH A 5 FOOT POOL INCREASE AND M & I OF 600,000

	RELEASES (ac-ft)					Reservoir	Hydropowe	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	50,000	0	60,000	49,484	912,358	2,074	51,852	1,250,000	28,284	9,669	124,360	1,464,165
February	39,243	50,000	0	89,243	50,889	950,337	7,718	208,385	1,250,000	27,530	32,727	154,159	1,672,801
March	53,135	50,000	0	103,135	57,913	961,855	10,428	302,423	1,250,000	46,763	40,956	189,744	1,829,886
April	31,449	50,000	0	81,449	46,795	973,386	6,270	188,098	1,250,000	12,478	43,183	541,109	2,034,868
May	26,964	50,000	0	76,964	44,530	984,592	5,422	168,071	1,250,000	4,351	37,894	1,650,969	3,111,285
June	22,826	50,000	0	72,826	42,440	995,797	4,634	166,829	1,250,000	0	32,757	1,687,814	3,137,400
July	10,000	50,000	0	60,000	10,159	1,007,002	2,138	76,982	1,250,000	0	13,705	1,864,780	3,205,467
August	10,000	50,000	0	60,000	2,027	967,117	2,112	69,689	1,250,000	0	13,705	1,543,827	2,877,221
September	10,000	50,000	0	60,000	7,969	911,130	2,073	62,197	1,250,000	0	13,705	868,609	2,194,511
October	29,059	50,000	0	79,059	33,975	866,909	5,591	162,138	1,250,000	0	13,315	762,218	2,187,671
November	43,485	50,000	0	93,485	68,190	855,120	8,240	230,721	1,250,000	90,850	18,440	540,539	2,130,550
December	44,011	50,000	0	94,011	55,413	896,650	8,469	228,671	1,250,000	47,801	18,608	128,780	1,673,860
annual	330,172	600,000	0	930,172	469,784	912,358	65,169	1,916,056	15,000,000	258,057	288,664	10,056,908	**$27,519,685**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE A-11

AVERAGE YEAR OPTIMIZATION
WITH A 50% STREAMFLOW REDUCTION
NO SEASONAL POOL
AND M & I OF 300,000

	RELEASES (ac-ft)				Inflows	Reservoir Volume	Hydropower Generation	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	(dsf)	(ac-ft)	(mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	5,000	25,000	0	30,000	49,484	912,358	1,127	28,168	625,000	28,284	4,948	124,360	810,760
February	5,000	25,000	0	30,000	50,889	380,337	1,150	31,051	625,000	23,660	4,948	160,358	845,017
March	5,000	25,000	0	30,000	57,913	1,051,097	1,173	34,022	625,000	35,250	4,948	212,503	911,723
April	5,000	25,000	0	30,000	46,795	1,134,764	1,200	35,987	625,000	0	7,815	659,836	1,328,638
May	5,000	25,000	0	30,000	44,530	1,198,418	1,218	37,766	625,000	0	7,815	2,128,433	2,799,014
June	5,000	25,000	0	30,000	42,440	1,256,587	1,235	44,462	625,000	0	7,815	2,283,085	2,960,362
July	5,000	25,000	0	30,000	10,159	1,310,619	1,250	45,007	625,000	0	7,014	2,629,702	3,306,723
August	90,527	25,000	0	115,527	2,027	1,300,734	19,517	644,067	625,000	0	77,082	2,269,031	3,615,180
September	110,250	25,000	0	135,250	7,969	1,189,219	23,027	690,811	625,000	0	79,859	1,222,786	2,618,456
October	120,313	25,000	0	145,313	33,975	1,069,748	24,236	702,832	625,000	0	29,138	995,140	2,352,110
November	135,366	25,000	0	160,366	68,190	991,705	26,561	743,705	625,000	73,231	27,960	651,455	2,121,351
December	138,715	25,000	0	163,715	55,413	966,355	26,978	728,404	625,000	38,810	27,552	141,535	1,561,301
annual	630,171	300,000	0	930,171	469,784	912,385	128,672	3,766,282	7,500,000	199,235	286,894	13,478,224	**$25,230,635**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE A-12

AVERAGE YEAR OPTIMIZATION
WITH A 50% STREAMFLOW REDUCTION
NO SEASONAL POOL
AND M & I OF 600,000

	RELEASES (ac-ft)				Inflows	Reservoir	Hydropowe	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	5,000	50,000	0	55,000	49,484	912,358	1,127	28,168	1,250,000	28,284	4,948	124,360	1,435,760
February	5,000	50,000	0	55,000	50,889	955,337	1,142	30,823	1,250,000	26,885	4,948	155,187	1,467,843
March	5,000	50,000	0	55,000	57,913	1,001,097	1,157	33,551	1,250,000	41,700	4,948	199,644	1,529,843
April	5,000	50,000	0	55,000	46,795	1,060,764	1,176	35,288	1,250,000	1,207	7,815	603,986	1,898,296
May	5,000	50,000	0	55,000	44,530	1,098,418	1,188	36,831	1,250,000	0	7,815	1,899,855	3,194,501
June	5,000	50,000	0	55,000	42,440	1,131,587	1,198	43,139	1,250,000	0	7,815	1,989,827	3,290,781
July	5,000	50,000	0	55,000	10,159	1,160,619	1,207	43,454	1,250,000	0	7,014	2,240,060	3,540,528
August	5,000	50,000	0	55,000	2,027	1,125,734	1,197	39,485	1,250,000	0	7,014	1,876,300	3,172,799
September	5,000	50,000	0	55,000	7,969	1,074,746	1,181	35,421	1,250,000	0	7,014	1,071,948	2,364,383
October	5,000	50,000	0	55,000	33,975	1,035,525	1,168	33,877	1,250,000	0	2,576	954,391	2,240,844
November	107,840	50,000	0	157,840	68,190	1,047,796	21,591	604,547	1,250,000	65,995	29,301	698,965	2,648,808
December	172,332	50,000	0	222,332	55,413	1,024,972	34,142	921,835	1,250,000	31,248	20,516	152,568	2,376,167
annual	330,172	600,000	0	930,172	469,784	912,358	67,474	1,886,419	15,000,000	195,319	111,724	11,967,091	**$29,160,553**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE A-13

AVERAGE YEAR OPTIMIZATION WITH A 10% ELECTRICITY PRICE INCREASE NO SEASONAL POOL AND M & I OF 300,000

	RELEASES (ac-ft)				Inflows	Reservoir Volume	Hydropower Generation	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	(dsf)	(ac-ft)	(mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	25,000	0	35,000	49,484	912,358	2,074	57,037	625,000	28,284	9,669	124,360	844,350
February	10,000	25,000	0	35,000	50,889	975,337	2,117	62,885	625,000	24,305	9,669	159,320	881,179
March	10,000	25,000	0	35,000	57,913	1,041,097	2,161	68,922	625,000	36,540	9,669	209,909	950,040
April	10,000	25,000	0	35,000	46,795	1,120,764	2,211	73,950	625,000	0	15,272	648,528	1,362,750
May	10,000	25,000	0	35,000	44,530	1,178,418	2,245	76,566	625,000	0	15,272	2,081,975	2,798,813
June	10,000	25,000	0	35,000	42,440	1,231,587	2,276	90,146	625,000	0	15,272	2,223,264	2,953,682
July	10,000	25,000	0	35,000	10,159	1,280,619	2,304	91,249	625,000	0	13,705	2,549,940	3,279,894
August	93,870	25,000	0	118,870	2,027	1,265,734	20,047	727,711	625,000	0	77,906	2,188,310	3,618,927
September	103,253	25,000	0	128,253	7,969	1,150,876	21,341	704,260	625,000	0	79,448	1,171,476	2,580,184
October	112,778	25,000	0	137,778	33,975	1,038,402	22,503	717,859	625,000	0	29,325	957,793	2,329,977
November	124,589	25,000	0	149,589	68,190	967,894	24,262	747,262	625,000	76,302	28,913	631,632	2,109,109
December	125,681	25,000	0	150,681	55,413	953,321	24,349	723,154	625,000	40,491	28,841	139,120	1,556,606
annual	630,171	300,000	0	930,171	469,784	912,358	127,890	4,141,001	7,500,000	205,922	332,961	13,085,627	**$25,265,511**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE A-14

AVERAGE YEAR OPTIMIZATION
WITH A 10% ELECTRICITY PRICE INCREASE
NO SEASONAL POOL
AND M & I OF 600,000

	RELEASES (ac-ft)					Reservoir	Hydropov	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generatior (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	50,000	0	60,000	49,484	912,358	2,074	57,037	1,250,000	28,284	9,669	124,360	1,469,350
February	10,000	50,000	0	60,000	50,889	950,337	2,100	62,382	1,250,000	27,530	9,669	154,159	1,503,740
March	10,000	50,000	0	60,000	57,913	991,097	2,128	67,879	1,250,000	42,990	9,669	197,105	1,567,643
April	10,000	50,000	0	60,000	46,795	1,045,764	2,164	71,398	1,250,000	3,142	15,272	593,025	1,932,837
May	10,000	50,000	0	60,000	44,530	1,078,418	2,184	74,485	1,250,000	0	15,272	1,855,254	3,195,011
June	10,000	50,000	0	60,000	42,440	1,106,587	2,202	87,194	1,250,000	0	15,272	1,932,929	3,285,395
July	10,000	50,000	0	60,000	10,159	1,130,619	2,217	87,778	1,250,000	0	13,705	2,164,882	3,516,365
August	10,000	50,000	0	60,000	2,027	1,090,734	2,192	79,571	1,250,000	0	13,705	1,801,016	3,144,292
September	10,000	50,000	0	60,000	7,969	1,034,746	2,156	71,164	1,250,000	0	13,705	1,020,905	2,355,774
October	10,000	50,000	0	60,000	33,975	990,525	2,127	67,867	1,250,000	0	5,033	901,705	2,224,605
November	92,865	50,000	0	142,865	68,190	997,796	18,315	564,112	1,250,000	72,445	28,524	656,559	2,571,640
December	137,307	50,000	0	187,307	55,413	989,947	26,923	799,618	1,250,000	35,766	27,730	145,942	2,259,056
annual	330,172	600,000	0	930,172	469,784	912,358	66,782	2,090,485	15,000,000	210,157	177,225	11,547,841	**$29,025,708**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

APPENDIX B

DRY YEAR TABLES

TABLE B-1

DRY YEAR
BASELINE BENEFITS

	RELEASES (ac-ft)					Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	45,989	460	2,240	48,689	24,742	912,358	8,893	222,323	11,507	0	38,250	124,360	396,440
February	35,304	515	1,873	37,692	25,445	912,658	6,869	185,469	12,876	0	31,354	146,488	376,187
March	59,887	662	3,212	63,761	28,956	925,346	11,580	335,834	16,552	0	45,777	180,686	578,849
April	35,730	526	670	36,926	23,398	918,918	6,966	208,968	13,156	0	48,687	503,105	773,916
May	34,542	571	7,439	42,552	22,265	928,319	6,762	209,637	14,268	0	54,469	1,532,268	1,810,642
June	32,734	574	2,678	35,986	21,220	929,852	6,421	231,170	14,361	0	47,617	1,547,367	1,840,515
July	33,439	566	8,456	42,461	5,080	935,882	6,570	236,512	14,147	0	48,805	1,699,176	1,998,640
August	21,624	543	6,664	28,831	1,013	903,479	4,263	140,679	13,579	0	35,436	1,416,716	1,606,410
September	13,927	523	5,743	20,193	3,985	876,653	2,783	83,485	13,063	0	25,733	827,602	949,883
October	15,944	580	472	16,996	16,988	864,350	3,146	91,224	14,500	0	8,013	759,412	873,149
November	23,212	401	2,384	25,997	34,095	880,989	4,526	126,720	10,031	0	11,938	561,027	709,716
December	54,738	484	12,862	68,084	27,707	922,500	10,589	285,915	12,088	0	24,807	133,464	456,274
annual	407,070	6,405	54,693	468,168	234,894	909,275	79,368	2,357,936	160,128	0	420,886	9,431,671	**$12,370,621**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE B-2

DRY YEAR OPTIMIZATION WITH EXISTING FACILITIES AND SEASONAL POOL

	RELEASES (ac-ft)				Inflows	Reservoir Volume	Hydropower Generation	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	(dsf)	(ac-ft)	(mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	43,436	551	0	43,987	24,742	912,358	8,409	210,230	13,775	0	35,396	124,360	383,761
February	49,829	551	0	50,380	25,445	917,360	9,638	260,227	13,775	0	39,157	147,439	460,598
March	56,782	551	0	57,333	28,956	917,360	10,958	317,779	13,775	0	42,825	178,725	553,104
April	34,571	551	0	35,122	23,398	917,360	6,742	202,250	13,775	0	46,695	502,032	764,752
May	32,328	551	0	32,879	22,265	928,566	6,341	196,579	13,775	0	44,187	1,532,881	1,787,422
June	30,259	551	0	30,810	21,220	939,771	5,970	214,932	13,775	0	41,808	1,568,231	1,838,746
July	10,000	551	0	10,551	5,080	950,976	2,101	75,630	13,775	0	13,705	1,733,892	1,837,002
August	10,000	551	0	10,551	1,013	950,483	2,100	69,316	13,775	0	13,705	1,510,254	1,607,050
September	10,000	551	0	10,551	3,985	941,938	2,095	62,839	13,775	0	13,705	905,795	996,114
October	38,192	551	0	38,743	16,988	939,276	7,487	217,129	13,775	0	16,674	842,944	1,090,522
November	83,765	551	0	84,316	34,095	934,168	16,178	452,974	13,775	0	27,534	603,907	1,098,190
December	59,311	551	0	59,862	27,707	917,360	11,438	308,820	13,775	0	22,929	132,528	478,052
annual	458,473	6,612	0	465,085	234,894	912,358	89,457	2,588,705	165,300	0	358,320	9,782,988	**$12,895,313**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE B-3

DRY YEAR OPTIMIZATION WITH SEASONAL POOL AND M & I OF 300,000

	RELEASES (ac-ft)				Inflows	Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	(dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	18,987	25,000	0	43,987	24,742	912,358	3,777	94,421	625,000	0	17,583	124,360	861,364
February	25,380	25,000	0	50,380	25,445	917,360	4,997	134,922	625,000	0	22,766	147,439	930,127
March	32,333	25,000	0	57,333	28,956	917,360	6,317	183,191	625,000	0	27,981	178,725	1,014,897
April	10,122	25,000	0	35,122	23,398	917,360	2,101	63,022	625,000	0	15,449	502,032	1,205,503
May	10,000	23,649	0	33,649	22,265	928,566	2,085	64,647	591,224	0	15,272	1,532,881	2,204,024
June	10,000	24,615	0	34,615	21,220	939,001	2,093	75,334	615,369	0	15,272	1,566,609	2,272,584
July	10,000	25,000	0	35,000	5,080	946,402	2,098	75,517	625,000	0	13,705	1,723,348	2,437,570
August	10,000	25,000	0	35,000	1,013	921,460	2,080	68,655	625,000	0	13,705	1,452,266	2,159,626
September	10,000	25,000	0	35,000	3,985	888,466	2,057	61,715	625,000	0	13,705	841,580	1,542,000
October	10,000	25,000	0	35,000	16,988	861,355	2,038	59,090	625,000	0	5,033	756,133	1,445,256
November	10,000	25,000	0	35,000	34,095	859,991	2,037	57,024	625,000	0	5,033	544,379	1,231,436
December	10,000	25,000	0	35,000	27,707	892,499	2,060	55,621	625,000	0	5,033	128,033	813,687
annual	166,822	298,264	0	465,086	234,894	912,358	33,740	993,159	7,456,593	0	170,537	9,497,785	**$18,118,074**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE B-4

DRY YEAR OPTIMIZATION WITH SEASONAL POOL AND M & I OF 600,000

	RELEASES (ac-ft)				Inflows	Reservoir Volume	Hydropower Generation	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	(dsf)	(ac-ft)	(mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,943	33,044	0	43,987	24,742	912,358	2,253	56,319	826,099	0	10,534	124,360	1,017,312
February	17,336	33,044	0	50,380	25,445	917,360	3,470	93,695	826,099	0	16,185	147,439	1,083,418
March	29,246	28,087	0	57,333	28,956	917,360	5,731	166,196	702,184	0	25,720	178,725	1,072,825
April	10,339	24,783	0	35,122	23,398	917,360	2,142	64,258	619,574	0	15,764	502,032	1,201,628
May	10,000	24,783	0	34,783	22,265	928,566	2,085	64,647	619,574	0	15,272	1,532,881	2,232,374
June	10,000	24,783	0	34,783	21,220	937,867	2,092	75,306	619,574	0	15,272	1,564,220	2,274,372
July	10,000	24,783	0	34,783	5,080	945,100	2,097	75,485	619,574	0	13,705	1,720,350	2,429,114
August	10,000	24,783	0	34,783	1,013	920,375	2,080	68,630	619,574	0	13,705	1,450,112	2,152,021
September	10,000	24,783	0	34,783	3,985	887,598	2,057	61,696	619,574	0	13,705	840,550	1,535,525
October	10,000	24,783	0	34,783	16,988	860,704	2,037	59,076	619,574	0	5,033	755,420	1,439,103
November	10,000	24,783	0	34,783	34,095	859,557	2,036	57,016	619,574	0	5,033	544,036	1,225,659
December	10,000	24,783	0	34,783	27,707	892,282	2,060	55,617	619,574	0	5,033	127,994	808,218
annual	147,864	317,222	0	465,086	234,894	912,358	30,140	897,941	7,930,548	0	154,961	9,488,119	**$18,471,569**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE B-5

DRY YEAR OPTIMIZATION WITH NO SEASONAL POOL AND EXISTING FACILITIES

	RELEASES (ac-ft)				Inflows	Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	(dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	551	0	10,551	24,742	912,358	2,074	51,852	13,775	0	9,669	124,360	199,656
February	10,000	551	0	10,551	25,445	950,796	2,101	56,719	13,775	0	9,669	154,253	234,416
March	10,000	551	0	10,551	28,956	990,626	2,128	61,699	13,775	0	9,669	196,986	282,129
April	10,000	551	0	10,551	23,398	1,037,408	2,158	64,746	13,775	0	15,272	586,948	680,741
May	10,000	551	0	10,551	22,265	1,073,184	2,181	67,612	13,775	0	15,272	1,843,643	1,940,302
June	10,000	551	0	10,551	21,220	1,106,718	2,202	79,270	13,775	0	15,272	1,933,224	2,041,541
July	10,000	551	0	10,551	5,080	1,138,182	2,221	79,964	13,775	0	13,705	2,183,750	2,291,194
August	57,640	551	0	58,191	1,013	1,137,689	11,947	394,246	13,775	0	61,298	1,902,264	2,371,583
September	71,219	551	0	71,770	3,985	1,081,504	14,472	434,166	13,775	0	69,505	1,080,657	1,598,103
October	78,358	551	0	78,909	16,988	1,017,623	15,584	451,949	13,775	0	26,759	933,309	1,425,792
November	89,871	551	0	90,422	34,095	972,349	17,578	492,181	13,775	0	28,242	635,325	1,169,523
December	91,386	551	0	91,937	27,707	949,435	17,729	478,686	13,775	0	28,390	138,403	659,254
annual	458,474	6,612	0	465,086	234,894	912,358	92,375	2,713,090	165,300	0	302,722	11,713,122	**$14,894,234**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE B-6

DRY YEAR OPTIMIZATION WITH NO SEASONAL POOL AND M & I OF 300,000

	RELEASES (ac-ft)				Inflows (dsf)	Reservoir Volume (ac-ft)	Hydropower Generation (mwh)	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total				Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	25,000	0	35,000	24,742	912,358	2,074	51,852	625,000	0	9,669	124,360	810,881
February	10,000	25,000	0	35,000	25,445	926,347	2,084	56,264	625,000	0	9,669	149,260	840,193
March	10,000	25,000	0	35,000	28,956	941,728	2,094	60,740	625,000	0	9,669	184,733	880,142
April	10,000	25,000	0	35,000	23,398	964,061	2,110	63,292	625,000	0	15,272	534,537	1,238,101
May	10,000	25,000	0	35,000	22,265	975,388	2,117	65,639	625,000	0	15,272	1,631,370	2,337,281
June	10,000	25,000	0	35,000	21,220	984,473	2,123	76,445	625,000	0	15,272	1,663,407	2,380,124
July	10,000	25,000	0	35,000	5,080	991,488	2,128	76,613	625,000	0	13,705	1,828,217	2,543,535
August	15,806	25,000	0	40,806	1,013	966,546	3,233	106,696	625,000	0	21,072	1,542,670	2,295,438
Septembei	18,156	25,000	0	43,156	3,985	927,746	3,639	109,167	625,000	0	23,929	888,601	1,646,697
October	18,578	25,000	0	43,578	16,988	892,480	3,673	106,523	625,000	0	8,973	790,442	1,530,938
Novembei	21,139	25,000	0	46,139	34,095	882,537	4,140	115,917	625,000	0	10,082	562,261	1,313,260
December	21,407	25,000	0	46,407	27,707	903,906	4,223	114,011	625,000	0	10,196	130,089	879,296
annual	165,086	300,000	0	465,086	234,894	912,358	33,638	1,003,159	7,500,000	0	162,780	10,029,947	**$18,695,886**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE B-7

DRY YEAR OPTIMIZATION WITH NO SEASONAL POOL AND M & I OF 600,000

	RELEASES (ac-ft)				Inflows	Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	(dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	26,960	0	36,960	24,742	912,358	2,074	51,852	673,996	0	9,669	124,360	859,877
February	10,000	26,960	0	36,960	25,445	924,387	2,082	56,227	673,996	0	9,669	148,862	888,754
March	10,000	26,960	0	36,960	28,956	937,808	2,092	60,662	673,996	0	9,669	183,762	928,089
April	10,000	26,960	0	36,960	23,398	958,181	2,106	63,172	673,996	0	15,272	530,408	1,282,848
May	10,000	26,960	0	36,960	22,265	967,549	2,112	65,475	673,996	0	15,272	1,614,738	2,369,481
June	10,000	26,960	0	36,960	21,220	974,673	2,117	76,208	673,996	0	15,272	1,642,383	2,407,859
July	10,000	26,960	0	36,960	5,080	979,729	2,120	76,330	673,996	0	13,705	1,800,666	2,564,697
August	10,000	26,960	0	36,960	1,013	952,827	2,102	69,369	673,996	0	13,705	1,514,970	2,272,040
September	10,000	30,623	0	40,623	3,985	917,873	2,078	62,339	765,584	0	13,705	876,705	1,718,333
October	10,000	32,112	0	42,112	16,988	885,139	2,055	59,589	802,809	0	5,033	782,307	1,649,738
November	10,000	33,197	0	43,197	34,095	876,662	2,049	57,363	829,936	0	5,033	557,584	1,449,916
December	10,000	33,474	0	43,474	27,707	900,973	2,066	55,784	836,854	0	5,033	129,559	1,027,230
annual	120,000	345,086	0	465,086	234,894	912,358	25,053	754,370	8,627,151	0	131,037	9,906,304	**$19,418,862**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE B-8

DRY YEAR OPTIMIZATION WITH A 5 FOOT POOL INCREASE AND EXISTING FACILITIES

	RELEASES (ac-ft)					Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	551	0	10,551	24,742	912,358	2,074	51,852	13,775	0	9,669	124,360	199,656
February	27,239	551	0	27,790	25,445	950,796	5,413	146,149	13,775	0	24,203	154,253	338,380
March	56,782	551	0	57,333	28,956	973,386	11,176	324,108	13,775	0	42,825	192,636	573,344
April	34,571	551	0	35,122	23,398	973,386	6,875	206,236	13,775	0	46,695	541,109	807,815
May	32,328	551	0	32,879	22,265	984,592	6,465	200,401	13,775	0	44,187	1,650,969	1,909,332
June	30,259	551	0	30,810	21,220	995,797	6,085	219,054	13,775	0	41,808	1,687,814	1,962,451
July	10,000	551	0	10,551	5,080	1,007,002	2,138	76,982	13,775	0	13,705	1,864,780	1,969,242
August	10,000	551	0	10,551	1,013	1,006,509	2,138	70,556	13,775	0	13,705	1,624,309	1,722,345
September	10,000	551	0	10,551	3,985	997,964	2,132	63,973	13,775	0	13,705	974,729	1,066,182
October	58,504	551	0	59,055	16,988	995,302	11,595	336,261	13,775	0	22,729	907,250	1,280,015
November	88,395	551	0	88,946	34,095	969,882	17,277	483,770	13,775	0	28,087	633,279	1,158,911
December	90,395	551	0	90,946	27,707	948,445	17,533	473,383	13,775	0	28,294	138,220	653,672
annual	458,473	6,612	0	465,085	234,894	912,358	90,901	2,652,725	165,300	0	329,612	10,493,708	**$13,641,345**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE B-9

DRY YEAR OPTIMIZATION
WITH A 5 FOOT POOL INCREASE
AND M & I OF 300,000

	RELEASES (ac-ft)				Inflows	Reservoir Volume	Hydropower Generation	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	(dsf)	(ac-ft)	(mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	25,000	0	35,000	24,742	912,358	2,074	51,852	625,000	0	9,669	124,360	810,881
February	10,000	25,000	0	35,000	25,445	926,347	2,084	56,264	625,000	0	9,669	149,260	840,193
March	10,000	25,000	0	35,000	28,956	941,728	2,094	60,740	625,000	0	9,669	184,733	880,142
April	10,000	25,000	0	35,000	23,398	964,061	2,110	63,292	625,000	0	15,272	534,537	1,238,101
May	10,000	25,000	0	35,000	22,265	975,388	2,117	65,639	625,000	0	15,272	1,631,370	2,337,281
June	10,000	25,000	0	35,000	21,220	984,473	2,123	76,445	625,000	0	15,272	1,663,407	2,380,124
July	10,000	25,000	0	35,000	5,080	991,488	2,128	76,613	625,000	0	13,705	1,828,217	2,543,535
August	15,900	25,000	0	40,900	1,013	966,546	3,251	107,297	625,000	0	21,188	1,542,670	2,296,155
September	18,211	25,000	0	43,211	3,985	927,652	3,649	109,476	625,000	0	23,995	888,488	1,646,959
October	18,609	25,000	0	43,609	16,988	892,330	3,679	106,685	625,000	0	8,987	790,276	1,530,948
November	21,050	25,000	0	46,050	34,095	882,357	4,123	115,441	625,000	0	10,044	562,118	1,312,603
December	21,316	25,000	0	46,316	27,707	903,815	4,205	113,545	625,000	0	10,158	130,073	878,776
annual	165,086	300,000	0	465,086	234,894	912,358	33,637	1,003,289	7,500,000	0	162,900	10,029,509	**$18,695,698**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE B-10

DRY YEAR OPTIMIZATION
WITH A 5 FOOT POOL INCREASE
AND M & I OF 600,000

	RELEASES (ac-ft)				Inflows	Reservoir Volume	Hydropower Generation	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	(dsf)	(ac-ft)	(mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	26,960	0	36,960	24,742	912,358	2,074	51,852	673,996	0	9,669	124,360	859,877
February	10,000	26,960	0	36,960	25,445	924,387	2,082	56,227	673,996	0	9,669	148,862	888,754
March	10,000	26,960	0	36,960	28,956	937,808	2,092	60,662	673,996	0	9,669	183,762	928,089
April	10,000	26,960	0	36,960	23,398	958,181	2,106	63,172	673,996	0	15,272	530,408	1,282,848
May	10,000	26,960	0	36,960	22,265	967,549	2,112	65,475	673,996	0	15,272	1,614,738	2,369,481
June	10,000	26,960	0	36,960	21,220	974,673	2,117	76,208	673,996	0	15,272	1,642,383	2,407,859
July	10,000	26,960	0	36,960	5,080	979,729	2,120	76,330	673,996	0	13,705	1,800,666	2,564,697
August	10,000	26,960	0	36,960	1,013	952,827	2,102	69,369	673,996	0	13,705	1,514,970	2,272,040
September	10,000	26,960	0	36,960	3,985	917,873	2,078	62,339	673,996	0	13,705	876,705	1,626,745
October	10,000	30,555	0	40,555	16,988	888,803	2,057	59,665	763,863	0	5,033	786,363	1,614,924
November	10,000	35,946	0	45,946	34,095	881,884	2,052	57,468	898,662	0	5,033	561,740	1,522,903
December	10,000	35,946	0	45,946	27,707	903,445	2,068	55,831	898,662	0	5,033	130,006	1,089,532
annual	120,000	345,087	0	465,087	234,894	912,358	25,060	754,598	8,627,151	0	131,037	9,914,963	**$19,427,749**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE B-11

DRY YEAR OPTIMIZATION
WITH A 50% STREAM FLOW REDUCTION
NO SEASONAL POOL
AND M & I OF 300,000

	RELEASES (ac-ft)				Inflows	Reservoir Volume	Hydropower Generation	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	(dsf)	(ac-ft)	(mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	5,000	25,000	0	30,000	24,742	912,358	1,127	28,168	625,000	0	4,948	124,360	782,476
February	5,000	25,000	0	30,000	25,445	931,347	1,133	30,601	625,000	0	4,948	150,277	810,826
March	5,000	25,000	0	30,000	28,956	951,728	1,140	33,071	625,000	0	4,948	187,217	850,236
April	5,000	25,000	0	30,000	23,398	979,061	1,150	34,488	625,000	0	7,815	545,120	1,212,423
May	5,000	25,000	0	30,000	22,265	995,388	1,155	35,807	625,000	0	7,815	1,674,059	2,342,681
June	5,000	25,000	0	30,000	21,220	1,009,473	1,160	41,749	625,000	0	7,815	1,717,450	2,392,014
July	5,000	25,000	0	30,000	5,080	1,021,488	1,164	41,891	625,000	0	7,014	1,899,143	2,573,048
August	21,747	25,000	0	46,747	1,013	1,001,546	4,432	146,252	625,000	0	28,159	1,614,094	2,413,505
September	24,846	25,000	0	49,846	3,985	956,805	4,963	148,900	625,000	0	31,675	923,922	1,729,497
October	25,447	25,000	0	50,447	16,988	914,848	5,005	145,156	625,000	0	11,878	815,400	1,597,434
November	28,847	25,000	0	53,847	34,095	898,036	5,616	157,246	625,000	0	13,232	574,661	1,370,139
December	29,198	25,000	0	54,198	27,707	911,697	5,710	154,175	625,000	0	13,369	131,500	924,044
annual	165,085	300,000	0	465,085	234,894	912,358	33,755	997,504	7,500,000	0	143,616	10,357,203	**$18,998,323**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE B-12

DRY YEAR OPTIMIZATION
WITH A 50% REDUCTION IN STREAM FLOW
NO SEASONAL POOL
AND M & I OF 600,000

	RELEASES (ac-ft)				Inflows	Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	(dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	5,000	31,647	0	36,647	24,742	912,358	1,127	28,168	791,184	0	4,948	124,360	948,660
February	5,000	31,647	0	36,647	25,445	924,700	1,131	30,538	791,184	0	4,948	148,926	975,596
March	5,000	31,647	0	36,647	28,956	938,433	1,136	32,938	791,184	0	4,948	183,917	1,012,987
April	5,000	31,647	0	36,647	23,398	959,119	1,143	34,286	791,184	0	7,815	531,065	1,364,350
May	5,000	31,647	0	36,647	22,265	968,799	1,146	35,531	791,184	0	7,815	1,617,386	2,451,916
June	5,000	31,647	0	36,647	21,220	976,236	1,149	41,352	791,184	0	7,815	1,645,729	2,486,080
July	5,000	31,647	0	36,647	5,080	981,604	1,150	41,417	791,184	0	7,014	1,805,049	2,644,664
August	5,000	31,647	0	36,647	1,013	955,014	1,141	37,669	791,184	0	7,014	1,519,376	2,355,243
September	5,000	36,802	0	41,802	3,985	920,373	1,130	33,886	920,052	0	7,014	879,712	1,840,664
October	5,000	37,821	0	42,821	16,988	886,461	1,118	32,409	945,525	0	2,576	783,769	1,764,279
November	5,000	38,556	0	43,556	34,095	877,275	1,114	31,199	963,896	0	2,576	558,071	1,555,742
December	5,000	38,728	0	43,728	27,707	901,227	1,123	30,316	968,210	0	2,576	129,605	1,130,707
annual	60,000	405,083	0	465,083	234,894	912,358	13,608	409,709	10,127,155	0	67,059	9,926,965	**$20,530,888**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE B-13

DRY YEAR OPTIMIZATION
WITH A 10% ELECTRICITY PRICE INCREASE
NO SEASONAL POOL
AND M & I OF 300,000

	RELEASES (ac-ft)				Inflows	Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	(dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	25,000	0	35,000	24,742	912,358	2,074	57,037	625,000	0	9,669	124,360	816,066
February	10,000	25,000	0	35,000	25,445	926,347	2,084	61,891	625,000	0	9,669	149,260	845,820
March	10,000	25,000	0	35,000	28,956	941,728	2,094	66,814	625,000	0	9,669	184,733	886,216
April	10,000	25,000	0	35,000	23,398	964,061	2,110	69,621	625,000	0	15,272	534,537	1,244,430
May	10,000	25,000	0	35,000	22,265	975,388	2,117	72,202	625,000	0	15,272	1,631,370	2,343,844
June	10,000	25,000	0	35,000	21,220	984,473	2,123	84,089	625,000	0	15,272	1,663,407	2,387,768
July	10,000	25,000	0	35,000	5,080	991,488	2,128	84,274	625,000	0	13,705	1,828,217	2,551,196
August	10,000	25,000	0	35,000	1,013	966,546	2,111	76,644	625,000	0	13,705	1,542,670	2,258,019
Septembe	10,000	25,000	0	35,000	3,985	933,552	2,089	68,932	625,000	0	13,705	895,623	1,603,260
October	10,000	25,000	0	35,000	16,988	906,442	2,070	66,031	625,000	0	5,033	805,991	1,502,055
Novembe	20,773	25,000	0	45,773	34,095	905,077	4,105	126,425	625,000	0	9,926	580,323	1,341,674
Decembe	44,313	25,000	0	69,313	27,707	926,811	8,620	256,016	625,000	0	18,704	134,251	1,033,971
annual	165,086	300,000	0	465,086	234,894	912,358	33,725	1,089,976	7,500,000	0	149,601	10,074,742	**$18,814,319**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE B-14

DRY YEAR OPTIMIZATION
WITH A 10% ELECTRICITY PRICE INCREASE
NO SEASONAL POOL
AND M & I OF 600,000

	RELEASES (ac-ft)				Inflows	Reservoir Volume	Hydropower Generation	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	(dsf)	(ac-ft)	(mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	26,960	0	36,960	24,742	912,358	2,074	57,037	673,996	0	9,669	124,360	865,062
February	10,000	26,960	0	36,960	25,445	924,387	2,082	61,850	673,996	0	9,669	148,862	894,377
March	10,000	26,960	0	36,960	28,956	937,808	2,092	66,728	673,996	0	9,669	183,762	934,155
April	10,000	26,960	0	36,960	23,398	958,181	2,106	69,490	673,996	0	15,272	530,408	1,289,166
May	10,000	26,960	0	36,960	22,265	967,549	2,112	72,022	673,996	0	15,272	1,614,738	2,376,028
June	10,000	26,960	0	36,960	21,220	974,673	2,117	83,829	673,996	0	15,272	1,642,383	2,415,480
July	10,000	26,960	0	36,960	5,080	979,729	2,120	83,963	673,996	0	13,705	1,800,666	2,572,330
August	10,000	26,960	0	36,960	1,013	952,827	2,102	76,306	673,996	0	13,705	1,514,970	2,278,977
Septembei	10,000	30,623	0	40,623	3,985	917,873	2,078	68,572	765,584	0	13,705	876,705	1,724,566
October	10,000	32,112	0	42,112	16,988	885,139	2,055	65,547	802,809	0	5,033	782,307	1,655,696
Novembei	10,000	33,197	0	43,197	34,095	876,662	2,049	63,100	829,936	0	5,033	557,584	1,455,653
December	10,000	33,474	0	43,474	27,707	900,973	2,066	61,362	836,854	0	5,033	129,559	1,032,808
annual	120,000	345,086	0	465,086	234,894	912,358	25,053	829,806	8,627,151	0	131,037	9,906,304	**$19,494,298**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

APPENDIX C

WET YEAR TABLES

TABLE C-1

WET YEAR
BASELINE BENEFITS

	RELEASES (ac-ft)					Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	137,966	276	7,826	146,068	74,226	912,358	26,320	657,999	6,904	101,273	50,941	124,360	941,477
February	111,853	309	915	113,077	76,334	913,258	21,379	577,239	7,725	107,374	56,338	146,609	895,285
March	179,660	397	11,226	191,283	86,869	951,321	34,704	1,006,428	9,931	133,542	27,552	187,116	1,364,569
April	108,180	316	2,282	110,778	70,193	932,039	20,825	624,745	7,894	86,835	88,989	512,176	1,320,639
May	103,625	342	23,687	127,654	66,795	960,241	20,156	624,830	8,561	73,174	87,155	1,599,287	2,393,007
June	98,201	345	9,414	107,960	63,660	964,841	19,141	689,067	8,617	63,333	88,896	1,621,379	2,471,292
July	100,316	340	26,725	127,381	15,239	982,929	19,671	708,164	8,488	0	78,272	1,808,149	2,603,073
August	64,873	326	21,297	86,496	3,040	885,721	12,348	407,494	8,148	0	75,792	1,381,887	1,873,321
September	41,782	314	18,483	60,579	11,954	805,244	7,769	233,057	7,838	0	63,070	744,702	1,048,667
October	47,833	348	2,807	50,988	50,963	768,333	8,731	253,194	8,700	51,224	20,616	656,497	990,231
November	69,637	241	8,114	77,992	102,285	818,250	12,897	361,107	6,019	196,186	26,664	511,760	1,101,736
December	164,214	290	39,746	204,250	83,120	942,783	31,640	854,283	7,253	123,585	9,011	137,178	1,131,310
annual	1,228,140	3,844	172,522	1,404,506	704,678	903,110	235,581	6,997,607	96,078	936,526	673,296	9,431,100	**$18,134,607**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE C-2

WET YEAR OPTIMIZATION
WITH EXISTING FACILITIES
AND SEASONAL POOL

	RELEASES (ac-ft)				Inflows	Reservoir Volume	Hydropower Generation	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	(dsf)	(ac-ft)	(mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	141,415	551	0	141,966	74,226	912,358	26,973	741,765	13,775	101,273	52,227	124,360	1,033,400
February	150,590	551	0	151,141	76,334	917,360	28,765	854,306	13,775	106,845	49,332	147,439	1,171,697
March	171,449	551	0	172,000	86,869	917,360	32,724	1,043,898	13,775	137,923	39,901	178,725	1,414,222
April	127,225	551	0	127,776	70,193	917,360	24,329	802,869	13,775	88,728	87,175	502,032	1,494,579
May	120,498	551	0	121,049	66,795	928,566	23,147	789,297	13,775	77,260	88,388	1,532,881	2,501,601
June	114,291	551	0	114,842	63,660	939,771	22,052	873,257	13,775	66,567	88,930	1,568,231	2,610,760
July	29,622	551	0	30,173	15,239	950,976	5,871	232,494	13,775	0	36,851	1,733,892	2,017,012
August	10,000	551	0	10,551	3,040	950,976	2,102	76,260	13,775	0	13,705	1,511,246	1,614,986
September	30,850	551	0	31,401	11,954	946,444	6,098	201,218	13,775	0	38,135	911,276	1,164,404
October	104,898	551	0	105,449	50,963	938,711	20,247	645,870	13,775	29,246	29,233	842,303	1,560,427
November	218,781	551	0	219,332	102,285	934,168	41,964	1,292,505	13,775	181,233	1,990	603,907	2,093,410
December	169,029	551	0	169,580	83,120	917,360	32,265	958,261	13,775	126,865	21,444	132,528	1,252,873
annual	1,388,648	6,612	0	1,395,260	704,678	912,358	266,537	8,512,000	165,300	915,940	547,311	9,788,820	**$19,929,371**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE C-3

WET YEAR OPTIMIZATION WITH SEASONAL POOL AND M & I OF 300,000

	RELEASES (ac-ft)					Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	116,966	25,000	0	141,966	74,226	912,358	22,341	558,523	625,000	101,273	56,202	124,360	1,465,358
February	133,855	25,000	0	158,855	76,334	917,360	25,588	690,875	625,000	106,845	54,037	147,439	1,624,196
March	139,286	25,000	0	164,286	86,869	909,646	26,543	769,757	625,000	138,918	52,789	176,836	1,763,300
April	102,776	25,000	0	127,776	70,193	917,360	19,688	590,653	625,000	88,728	88,471	502,032	1,894,884
May	96,049	25,000	0	121,049	66,795	928,566	18,487	573,082	625,000	77,260	87,321	1,532,881	2,895,544
June	89,842	25,000	0	114,842	63,660	939,771	17,373	625,427	625,000	66,567	85,683	1,568,231	2,970,908
July	10,000	25,000	0	35,000	15,239	950,976	2,101	75,630	625,000	0	13,705	1,733,892	2,448,227
August	10,000	25,000	0	35,000	3,040	946,149	2,098	69,219	625,000	0	13,705	1,501,547	2,209,471
September	10,000	25,000	0	35,000	11,954	917,167	2,077	62,324	625,000	0	13,705	875,856	1,576,885
October	104,959	25,000	0	129,959	50,963	905,836	20,018	580,516	625,000	33,487	29,234	805,314	2,073,551
November	136,947	25,000	0	161,947	102,285	876,783	25,780	721,843	625,000	188,636	27,774	557,680	2,120,933
December	144,580	25,000	0	169,580	83,120	917,360	27,624	745,841	625,000	126,865	26,710	132,528	1,656,944
annual	1,095,260	300,000	0	1,395,260	704,678	912,358	209,718	6,063,690	7,500,000	928,579	549,336	9,658,596	**$24,700,201**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE C-4

WET YEAR OPTIMIZATION
WITH SEASONAL POOL
AND M & I OF 600,000

	RELEASES (ac-ft)					Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	178,090	50,000	0	228,090	74,226	912,358	33,922	848,052	1,250,000	101,273	36,069	124,360	2,359,754
February	68,540	50,000	0	118,540	76,334	831,236	12,763	344,607	1,250,000	117,955	48,028	130,352	1,890,942
March	68,477	50,000	0	118,477	86,869	863,837	12,916	374,567	1,250,000	144,828	48,003	165,757	1,983,155
April	77,776	50,000	0	127,776	70,193	917,360	14,943	448,287	1,250,000	88,728	80,916	502,032	2,369,963
May	71,049	50,000	0	121,049	66,795	928,566	13,721	425,365	1,250,000	77,260	77,350	1,532,881	3,362,856
June	64,842	50,000	0	114,842	63,660	939,771	12,589	453,188	1,250,000	66,567	73,483	1,568,231	3,411,469
July	19,511	50,000	0	69,511	15,239	950,976	3,928	141,422	1,250,000	0	25,545	1,733,892	3,150,859
August	49,325	50,000	0	99,325	3,040	911,637	9,522	314,240	1,250,000	0	55,099	1,432,810	3,052,149
September	51,017	50,000	0	101,017	11,954	818,332	9,496	284,894	1,250,000	0	56,432	759,690	2,351,016
October	47,797	50,000	0	97,797	50,963	740,983	8,620	249,989	1,250,000	54,753	19,781	628,031	2,202,554
November	50,351	50,000	0	100,351	102,285	744,092	9,084	254,348	1,250,000	205,753	20,533	455,366	2,186,000
December	48,485	50,000	0	98,485	83,120	846,265	9,135	246,648	1,250,000	136,036	19,986	119,806	1,772,476
annual	795,260	600,000	0	1,395,260	704,678	912,358	150,639	4,385,607	15,000,000	993,153	561,225	9,153,208	**$30,093,193**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE C-5

WET YEAR OPTIMIZATION WITH NO SEASONAL POOL AND EXISTING FACILITIES

	RELEASES (ac-ft)					Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	551	0	10,551	74,226	912,358	2,074	51,852	13,775	101,273	9,669	124,360	300,929
February	10,000	551	0	10,551	76,334	1,048,775	2,166	58,469	13,775	89,893	9,669	174,806	346,612
March	10,000	551	0	10,551	86,869	1,189,365	2,252	65,303	13,775	102,835	9,669	249,492	441,074
April	10,000	551	0	10,551	70,193	1,350,814	2,343	70,289	13,775	32,813	15,272	829,604	961,753
May	11,997	551	0	12,548	66,795	1,479,244	2,856	88,537	13,775	6,223	18,150	2,819,969	2,946,654
June	125,496	551	0	126,047	63,660	1,598,950	28,925	1,041,299	13,775	0	87,549	3,161,115	4,303,738
July	29,622	551	0	30,173	15,239	1,598,950	6,964	250,719	13,775	0	36,851	3,443,048	3,744,393
August	188,707	551	0	189,258	3,040	1,598,950	43,404	1,432,332	13,775	0	41,256	3,000,932	4,488,295
September	226,127	551	0	226,678	11,954	1,415,710	49,887	1,496,599	13,775	0	241	1,542,026	3,052,641
October	253,700	551	0	254,251	50,963	1,212,700	53,104	1,540,007	13,775	0	0	1,171,727	2,725,509
November	264,288	551	0	264,839	102,285	1,059,355	52,849	1,479,763	13,775	165,084	0	708,898	2,367,520
December	248,709	551	0	249,260	83,120	997,041	48,738	1,315,934	13,775	116,586	0	147,276	1,593,571
annual	1,388,646	6,612	0	1,395,258	704,678	912,358	295,562	8,891,103	165,300	614,707	228,326	17,373,253	**$27,272,689**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE C-6

WET YEAR OPTIMIZATION
WITH NO SEASONAL POOL
AND M & I OF 300,000

	RELEASES (ac-ft)					Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	25,000	0	35,000	74,226	912,358	2,074	51,852	625,000	101,273	9,669	124,360	912,154
February	10,000	25,000	0	35,000	76,334	1,024,326	2,150	58,043	625,000	93,047	9,669	169,596	955,355
March	10,000	25,000	0	35,000	86,869	1,140,467	2,223	64,455	625,000	109,143	9,669	236,171	1,044,438
April	10,000	25,000	0	35,000	70,193	1,277,467	2,303	69,075	625,000	42,275	15,272	770,097	1,521,719
May	10,000	25,000	0	35,000	66,795	1,381,488	2,359	73,143	625,000	18,838	15,272	2,570,839	3,303,092
June	10,000	25,000	0	35,000	63,660	1,478,702	2,410	86,766	625,000	0	15,272	2,840,235	3,567,273
July	10,000	25,000	0	35,000	15,239	1,569,749	2,456	88,406	625,000	0	13,705	3,356,821	4,083,932
August	98,926	25,000	0	123,926	3,040	1,564,922	22,675	748,267	625,000	0	78,878	2,913,427	4,365,572
September	167,751	25,000	0	192,751	11,954	1,447,014	37,328	1,119,839	625,000	0	59,335	1,588,322	3,392,496
October	294,483	25,000	0	319,483	50,963	1,277,932	62,710	1,818,578	625,000	0	0	1,255,723	3,699,301
November	239,839	25,000	0	264,839	102,285	1,059,355	47,976	1,343,336	625,000	165,084	0	708,898	2,842,318
December	224,260	25,000	0	249,260	83,120	997,041	43,965	1,187,049	625,000	116,586	0	147,276	2,075,911
annual	1,095,259	300,000	0	1,395,259	704,678	912,358	230,629	6,708,809	7,500,000	646,246	226,741	16,681,765	**$31,763,561**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE C-7

WET YEAR OPTIMIZATION
NO SEASONAL POOL
M & I OF 600,000

	RELEASES (ac-ft)				Inflows (dsf)	Reservoir Volume (ac-ft)	Hydropower Generation (mwh)	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total				Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	50,000	0	60,000	74,226	912,358	2,074	51,852	1,250,000	101,273	9,669	124,360	1,537,154
February	10,000	50,000	0	60,000	76,334	999,326	2,133	57,600	1,250,000	96,272	9,669	164,325	1,577,866
March	10,000	50,000	0	60,000	86,869	1,090,467	2,192	63,564	1,250,000	115,593	9,669	222,821	1,661,647
April	10,000	50,000	0	60,000	70,193	1,202,467	2,260	67,785	1,250,000	51,950	15,272	710,967	2,095,974
May	10,000	50,000	0	60,000	66,795	1,281,448	2,305	71,447	1,250,000	31,738	15,272	2,325,274	3,693,731
June	10,000	50,000	0	60,000	63,660	1,353,702	2,345	84,403	1,250,000	13,169	15,272	2,521,010	3,883,854
July	10,000	50,000	0	60,000	15,239	1,419,749	2,380	85,669	1,250,000	0	13,705	2,927,584	4,276,958
August	11,160	50,000	0	61,160	3,040	1,389,922	2,617	86,375	1,250,000	0	15,212	2,479,646	3,831,233
September	123,320	50,000	0	173,320	11,954	1,334,780	26,753	802,596	1,250,000	0	78,937	1,424,782	3,556,315
October	176,680	50,000	0	226,680	50,963	1,185,129	36,751	1,065,778	1,250,000	0	19,215	1,136,869	3,471,862
November	214,839	50,000	0	264,839	102,285	1,059,355	42,994	1,203,835	1,250,000	165,084	3,959	708,898	3,331,776
December	199,260	50,000	0	249,260	83,120	997,041	39,084	1,055,259	1,250,000	116,586	11,020	147,276	2,580,141
annual	795,259	600,000	0	1,395,259	704,678	912,358	163,888	4,696,163	15,000,000	691,665	216,871	14,893,812	**$35,498,511**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE C-8

WET YEAR OPTIMIZATION
WITH A 5 FOOT POOL INCREASE
AND EXISTING FACILITIES

	RELEASES (ac-ft)					Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	85,389	551	0	85,940	74,226	912,358	16,358	449,845	13,775	101,273	53,292	124,360	742,545
February	150,590	551	0	151,141	76,334	973,386	29,343	871,497	13,775	99,618	49,332	158,915	1,193,137
March	160,244	551	0	160,795	86,869	973,386	31,213	995,695	13,775	130,696	45,459	192,636	1,378,261
April	127,225	551	0	127,776	70,193	984,592	24,914	822,160	13,775	80,056	87,175	549,040	1,552,206
May	120,498	551	0	121,049	66,795	995,797	23,696	808,031	13,775	68,587	88,388	1,674,936	2,653,717
June	125,496	551	0	126,047	63,660	1,007,002	24,764	980,661	13,775	57,894	87,549	1,712,083	2,851,962
July	29,622	551	0	30,173	15,239	1,007,002	5,982	236,900	13,775	0	36,851	1,864,780	2,152,306
August	10,000	551	0	10,551	3,040	1,007,002	2,138	77,624	13,775	0	13,705	1,625,326	1,730,430
September	35,393	551	0	35,944	11,954	1,002,470	7,102	234,377	13,775	0	42,714	980,347	1,271,213
October	117,163	551	0	117,714	50,963	990,194	23,001	733,745	13,775	22,604	29,249	901,321	1,700,694
November	201,973	551	0	202,524	102,285	973,386	39295	1,210,271	13,775	176,174	9,873	636186	2,046,279
December	225,055	551	0	225,606	83,120	973,386	43765	1,299,810	13,775	119,637	0	142844	1,576,066
annual	1,388,648	6,612	0	1,395,260	704,678	912,358	271,571	8,720,616	165,300	856,539	543,587	10,562,774	**$20,848,816**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE C-9

WET YEAR OPTIMIZATION
WITH A 5 FOOT POOL INCRESE
AND M & I OF 300,000

	RELEASES (ac-ft)				Inflows	Reservoir Volume	Hydropower Generation	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	(dsf)	(ac-ft)	(mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	60,940	250,000	0	310,940	74,226	912,358	11,726	293,141	625,000	101,273	44,808	124,360	1,188,582
February	126,141	250,000	0	376,141	76,334	973,386	24,608	664,428	625,000	99,618	55,348	158,915	1,603,309
March	147,000	250,000	0	397,000	86,869	973,386	28,648	830,796	625,000	130,696	50,556	192,636	1,829,684
April	102,776	250,000	0	352,776	70,193	973,386	20,083	602,504	625,000	81,501	88,471	541,109	1,938,585
May	96,049	250,000	0	346,049	66,795	984,592	18,853	584,437	625,000	70,033	87,321	1,650,969	3,017,760
June	89,842	250,000	0	339,842	63,660	995,797	17,713	637,668	625,000	59,339	85,683	1,687,814	3,095,504
July	10,000	250,000	0	260,000	15,239	1,007,002	2,138	76,982	625,000	0	13,705	1,864,780	2,580,467
August	10,000	250,000	0	260,000	3,040	1,002,175	2,135	70,462	625,000	0	13,705	1,615,387	2,324,554
September	10,000	250,000	0	260,000	11,954	973,193	2,116	63,477	625,000	0	13,705	944,043	1,646,225
October	115,761	250,000	0	365,761	50,963	961,862	22,508	652,736	625,000	26,259	29,283	868,677	2,201,955
November	158,956	250,000	0	408,956	102,285	922,007	30,404	851,315	625,000	182,802	23,957	594,010	2,277,084
December	167,795	250,000	0	417,795	83,120	940,575	32,301	872,120	625,000	123,870	21,778	136,772	1,779,540
annual	1,095,260	3,000,000	0	4,095,260	704,678	912,358	213,233	6,200,066	7,500,000	875,391	528,320	10,379,472	**$25,483,249**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE C-10

WET YEAR OPTIMIZATION
WITH A 5 FOOT POOL INCREASE
AND M & I OF 600,000

	RELEASES (ac-ft)				Inflows (dsf)	Reservoir Volume (ac-ft)	Hydropower Generation (mwh)	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total				Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	39,733	50,000	0	89,733	74,226	912,358	7,708	192,688	1,250,000	101,273	33,047	124,360	1,701,368
February	97,348	50,000	0	147,348	76,334	969,593	19,007	513,199	1,250,000	100,107	55,461	158,129	2,076,896
March	122,000	50,000	0	172,000	86,869	973,386	23,807	690,389	1,250,000	130,696	55,828	192,636	2,319,549
April	77,776	50,000	0	127,776	70,193	973,386	15,242	457,256	1,250,000	81,501	80,916	541,109	2,410,782
May	71,049	50,000	0	121,049	66,795	984,592	13,992	433,765	1,250,000	70,033	77,350	1,650,969	3,482,117
June	64,842	50,000	0	114,842	63,660	995,797	12,834	462,022	1,250,000	59,339	73,483	1,687,814	3,532,658
July	10,000	50,000	0	60,000	15,239	1,007,002	2,138	76,982	1,250,000	0	13,705	1,864,780	3,205,467
August	10,000	50,000	0	60,000	3,040	977,175	2,119	69,913	1,250,000	0	13,705	1,564,245	2,897,863
September	10,000	50,000	0	60,000	11,954	923,193	2,082	62,450	1,250,000	0	13,705	883,109	2,209,264
October	75,935	50,000	0	125,935	50,963	886,862	14,430	418,457	1,250,000	35,934	26,367	784,213	2,514,971
November	105,143	50,000	0	155,143	102,285	861,833	19,721	552,182	1,250,000	190,564	29,240	545,833	2,567,819
December	111,434	50,000	0	161,434	83,120	909,214	21,268	574,239	1,250,000	127,915	29,330	131,050	2,112,534
annual	795,260	600,000	0	1,395,260	704,678	912,358	154,348	4,503,542	15,000,000	897,362	502,137	10,128,247	**$31,031,288**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE C-11

WET YEAR OPTIMIZATION WITH REDUCED STREAMFLOW NO SEASONAL POOL AND M & I OF 300,000

	RELEASES (ac-ft)					Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	5,000	25,000	0	30,000	74,226	912,358	1,127	28,168	625,000	101,273	4,948	124,360	883,749
February	5,000	25,000	0	30,000	76,334	1,029,326	1,166	31,487	625,000	92,402	4,948	170,657	924,494
March	5,000	25,000	0	30,000	86,869	1,150,467	1,204	34,916	625,000	107,853	4,948	238,874	1,011,591
April	5,000	25,000	0	30,000	70,193	1,292,467	1,245	37,354	625,000	40,340	7,815	782,132	1,492,641
May	5,000	25,000	0	30,000	66,795	1,401,448	1,275	39,516	625,000	16,258	7,815	2,621,066	3,309,655
June	5,799	25,000	0	30,799	63,660	1,503,702	1,480	53,293	625,000	0	9,031	2,905,833	3,593,157
July	5,173	25,000	0	30,173	15,239	1,598,950	1,364	49,112	625,000	0	7,250	3,443,048	4,124,410
August	5,569	25,000	0	30,569	3,040	1,598,950	1,455	48,011	625,000	0	7,791	3,000,932	3,681,734
September	180,904	25,000	0	205,904	11,954	1,574,400	41,400	1,242,011	625,000	0	48,649	1,782,161	3,697,821
October	323,041	25,000	0	348,041	50,963	1,392,164	70,789	2,052,868	625,000	0	0	1,407,970	4,085,838
November	261,257	25,000	0	286,257	102,285	1,145,029	53,632	1,501,701	625,000	154,032	0	784,029	3,064,762
December	240,324	25,000	0	265,324	83,120	1,061,296	48,103	1,298,772	625,000	108,297	0	159,546	2,191,615
annual	1,047,067	300,000	0	1,347,067	704,678	960,550	224,240	6,417,209	7,500,000	620,455	103,195	17,420,608	**$32,061,467**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE C-12

WET YEAR OPTIMIZATION WITH REDUCED STREAMFLOW NO SEASONAL POOL AND M & I OF 600,000

	RELEASES (ac-ft)					Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	5,000	50,000	0	55,000	74,226	912,358	1,127	28,168	1,250,000	101,273	4,948	124,360	1,508,749
February	5,000	50,000	0	55,000	76,334	1,004,326	1,158	31,266	1,250,000	95,627	4,948	165,375	1,547,216
March	5,000	50,000	0	55,000	86,869	1,100,467	1,189	34,473	1,250,000	114,303	4,948	225,469	1,629,193
April	5,000	50,000	0	55,000	70,193	1,217,467	1,224	36,714	1,250,000	50,015	7,815	722,654	2,067,198
May	5,000	50,000	0	55,000	66,795	1,301,448	1,248	38,677	1,250,000	29,158	7,815	2,373,644	3,699,294
June	5,000	50,000	0	55,000	63,660	1,378,702	1,269	45,672	1,250,000	9,944	7,815	2,583,686	3,897,117
July	5,000	50,000	0	55,000	15,239	1,449,749	1,287	46,344	1,250,000	0	7,014	3,011,598	4,314,956
August	5,000	50,000	0	55,000	3,040	1,424,922	1,281	42,269	1,250,000	0	7,014	2,564,226	3,863,509
September	113,915	50,000	0	163,915	11,954	1,375,940	24,980	749,401	1,250,000	0	79,823	1,483,970	3,563,194
October	204,857	50,000	0	254,857	50,963	1,235,694	43,187	1,252,420	1,250,000	0	8,616	1,201,091	3,712,127
November	220,436	50,000	0	270,436	102,285	1,081,742	44,421	1,243,795	1,250,000	162,196	1,142	728,273	3,385,406
December	203,458	50,000	0	253,458	83,120	1,013,831	40,128	1,083,462	1,250,000	114,420	9,231	150,450	2,607,563
annual	782,666	600,000	0	1,382,666	704,678	924,951	162,499	4,632,661	15,000,000	676,936	151,129	15,334,796	**$35,795,522**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE C-13

WET YEAR OPTIMIZATION
WTH A 10% ELECTRICITY PRICE INCREASE
NO SEASONAL POOL
AND M & I OF 300,000

	RELEASES (ac-ft)				Inflows	Reservoir Volume	Hydropower Generation	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	(dsf)	(ac-ft)	(mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	25,000	0	35,000	74,226	912,358	2,074	57,037	625,000	101,273	9,669	124,360	917,339
February	10,000	25,000	0	35,000	76,334	1,024,326	2,150	63,847	625,000	93,047	9,669	169,596	961,159
March	10,000	25,000	0	35,000	86,869	1,140,467	2,223	70,901	625,000	109,143	9,669	236,171	1,050,884
April	10,000	25,000	0	35,000	70,193	1,277,467	2,303	75,983	625,000	42,275	15,272	770,097	1,528,627
May	10,000	25,000	0	35,000	66,795	1,381,448	2,359	80,457	625,000	18,838	15,272	2,570,839	3,310,406
June	10,000	25,000	0	35,000	63,660	1,478,702	2,410	95,443	625,000	0	15,272	2,840,235	3,575,950
July	10,000	25,000	0	35,000	15,239	1,569,749	2,456	97,246	625,000	0	13,705	3,356,821	4,092,772
August	101,658	25,000	0	126,658	3,040	1,564,922	23,296	845,645	625,000	0	79,266	2,913,426	4,463,337
September	165,018	25,000	0	190,018	11,954	1,444,282	36,700	1,211,087	625,000	0	61,274	1,584,261	3,481,622
October	294,483	25,000	0	319,483	50,963	1,277,932	62,710	2,000,436	625,000	0	0	1,255,723	3,881,159
November	239,839	25,000	0	264,839	102,285	1,059,355	47,976	1,477,670	625,000	165,084	0	708,898	2,976,652
December	224,260	25,000	0	249,260	83,120	997,041	43,965	1,305,754	625,000	116,586	0	147,276	2,194,616
annual	1,095,258	300,000	0	1,395,258	704,678	912,358	230,622	7,381,506	7,500,000	646,246	229,068	16,677,703	**$32,434,523**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

TABLE C-14

WET YEAR OPTIMIZATION
WITH A 10% ELECTRICITY PRICE INCREASE
NO SEASONAL POOL
AND M & I OF 600,000

	RELEASES (ac-ft)					Reservoir	Hydropower	BENEFITS[1]					
	Hydro-power	Water Supply	Gate	Total	Inflows (dsf)	Volume (ac-ft)	Generation (mwh)	Hydro-power	Water Supply	Flood Control	Fishery	Lake Recreation	Total
January	10,000	50,000	0	60,000	74,226	912,358	2,074	57,037	1,250,000	101,273	9,669	124,360	1,542,339
February	10,000	50,000	0	60,000	76,334	999,326	2,133	63,360	1,250,000	96,272	9,669	164,325	1,583,626
March	10,000	50,000	0	60,000	86,869	1,090,467	2,192	69,920	1,250,000	115,593	9,669	222,821	1,668,003
April	10,000	50,000	0	60,000	70,193	1,202,467	2,260	74,564	1,250,000	51,950	15,272	710,967	2,102,753
May	10,000	50,000	0	60,000	66,795	1,281,448	2,305	78,592	1,250,000	31,738	15,272	2,325,274	3,700,876
June	10,000	50,000	0	60,000	63,660	1,353,702	2,345	92,844	1,250,000	13,169	15,272	2,520,010	3,891,295
July	10,000	50,000	0	60,000	15,239	1,419,749	2,380	94,236	1,250,000	0	13,705	2,927,584	4,285,525
August	11,160	50,000	0	61,160	3,040	1,389,922	2,617	95,012	1,250,000	0	15,212	2,479,646	3,839,870
September	123,320	50,000	0	173,320	11,954	1,224,780	26,753	882,856	1,250,000	0	78,937	1,424,782	3,636,575
October	176,680	50,000	0	226,680	50,963	1,185,129	36,751	1,172,356	1,250,000	0	19,215	1,136,869	3,578,440
November	214,839	50,000	0	264,839	102,285	1,059,355	42,994	1,324,218	1,250,000	165,084	3,959	708,898	3,452,159
December	199,260	50,000	0	249,260	83,120	997,041	39,084	1,160,785	1,250,000	116,586	11,020	147,276	2,685,667
annual	795,259	600,000	0	1,395,259	704,678	912,358	163,888	5,165,780	15,000,000	691,665	216,871	14,892,812	**$35,967,128**

Notes: 1 - all benefits are expressed in 2000 U.S. dollars

APPENDIX D

POOL ELEVATION CURVES

Figure D-1

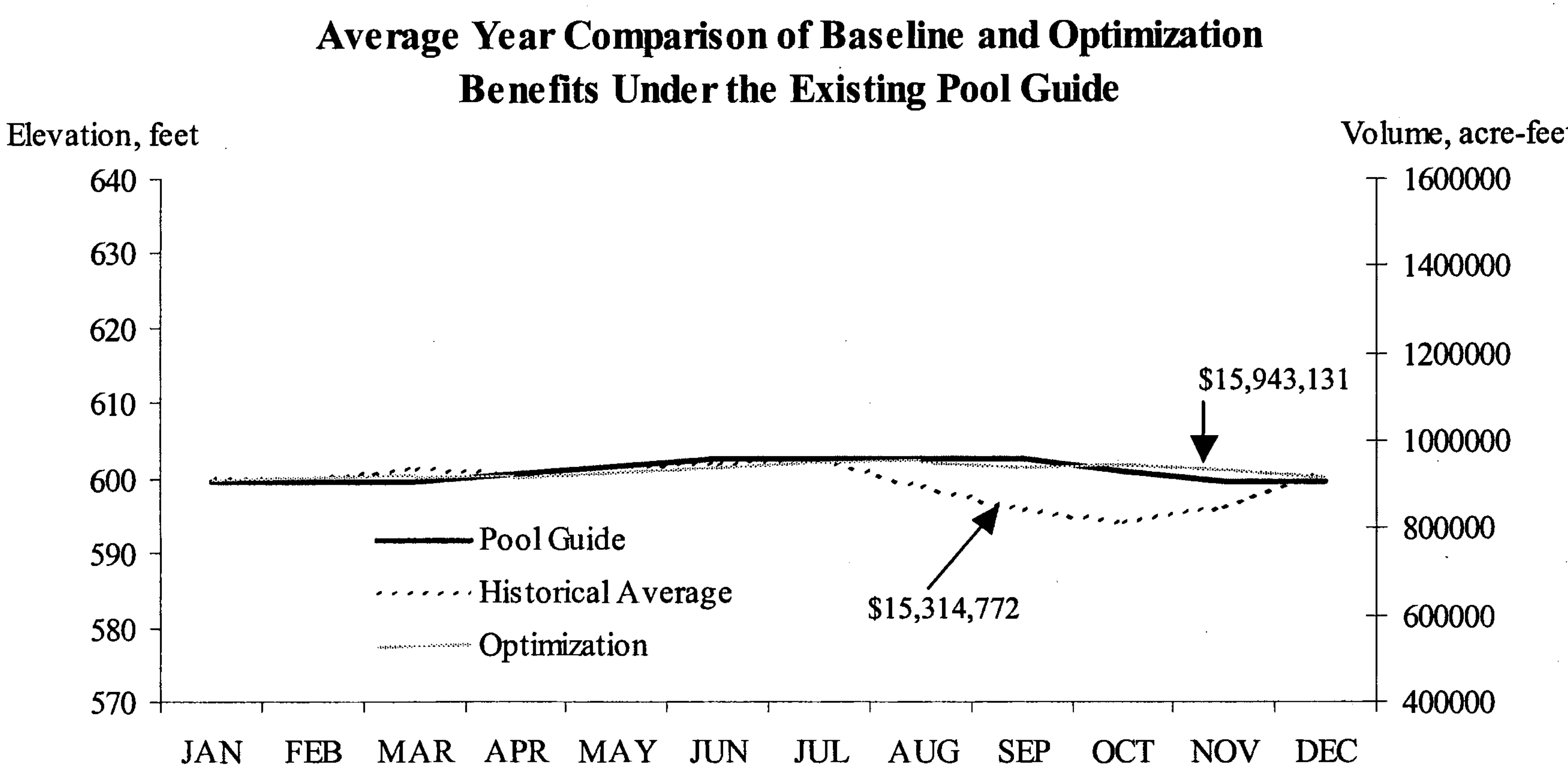

Average Year Comparison of Baseline and Optimization
Benefits Under the Existing Pool Guide
Elevation, feet
Volume, acre-feet
640
630
620
610
600
590
580
570
1600000
1400000
1200000
1000000
800000
600000
400000
$15,943,131
$15,314,772
Pool Guide
Historical Average
Optimization
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Figure D-2

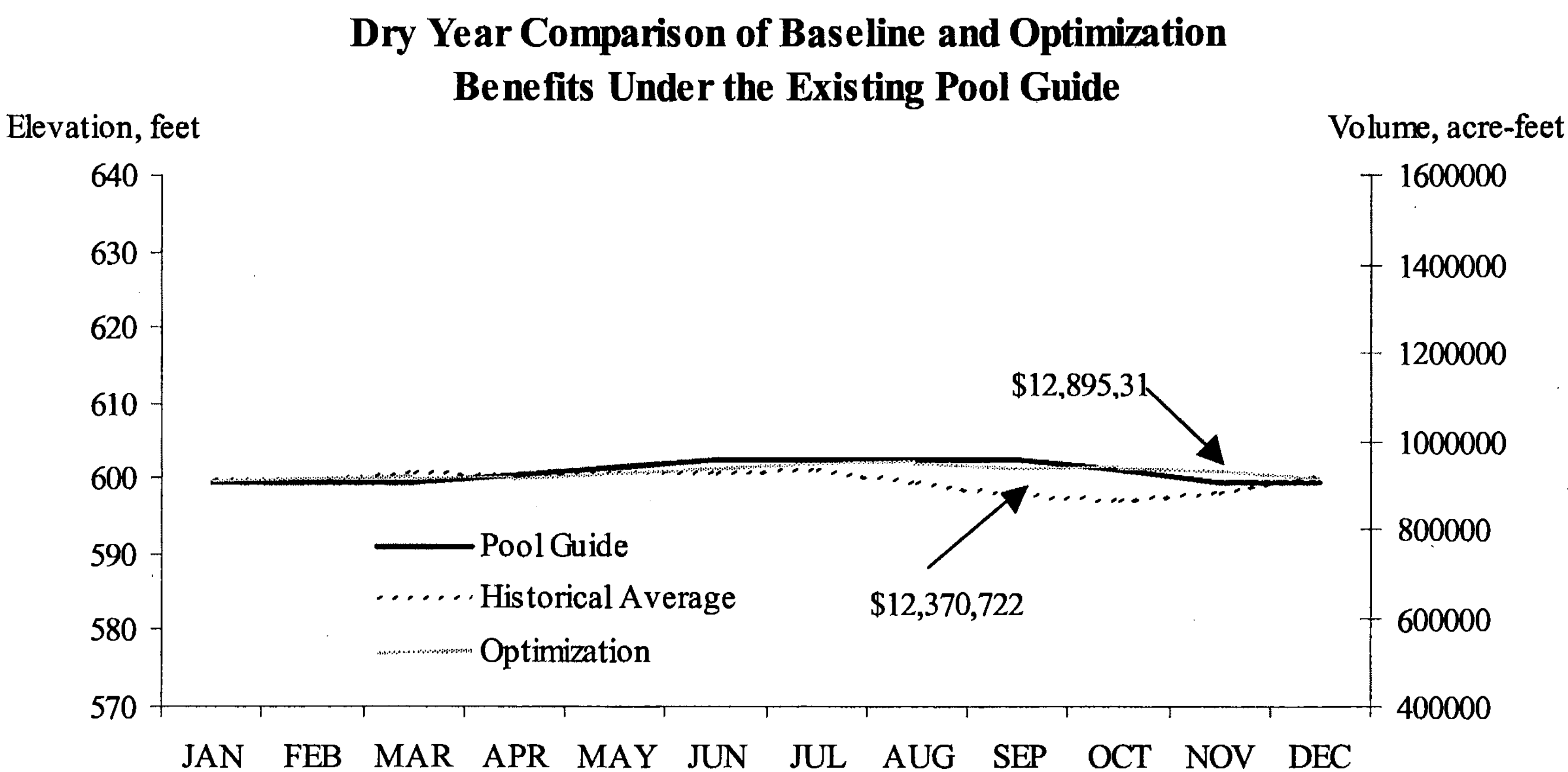

Dry Year Comparison of Baseline and Optimization
Benefits Under the Existing Pool Guide
Elevation, feet
Volume, acre-feet
640
630
620
610
600
590
580
570
1600000
1400000
1200000
1000000
800000
600000
400000
$12,895,31
$12,370,722
Pool Guide
Historical Average
Optimization
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Figure D-3

Wet Year Comparison of Baseline and Optimization Benefits Under the Existing Pool Guide

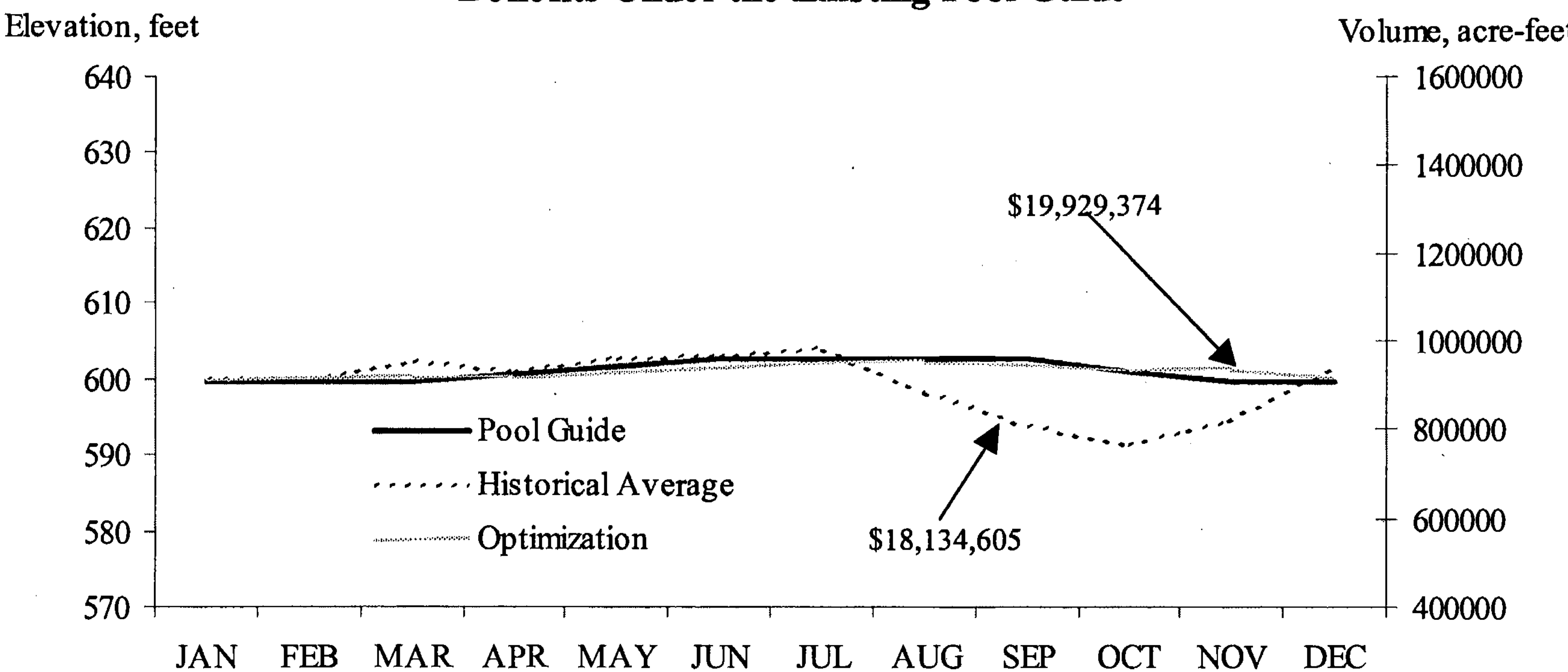
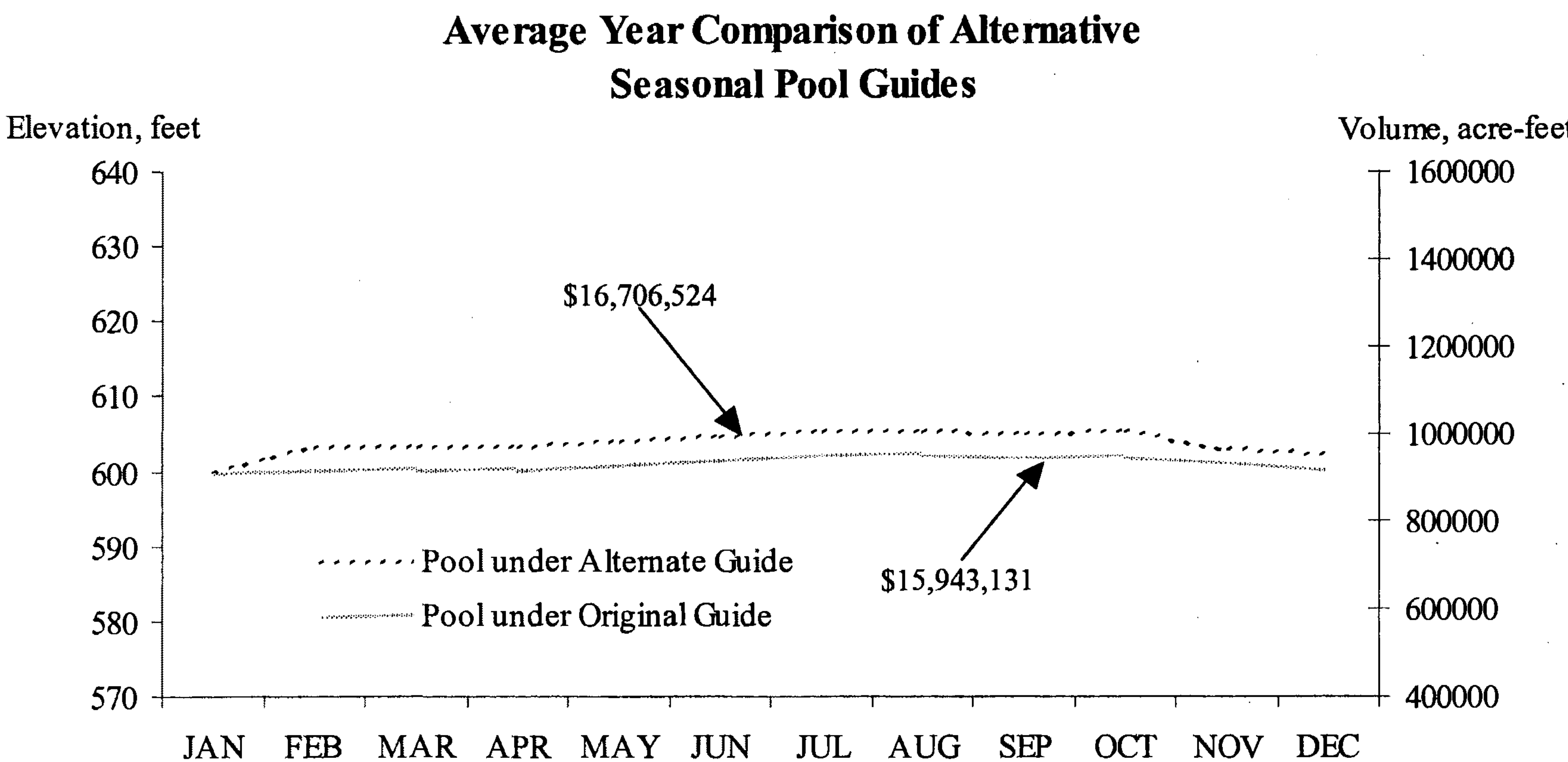


Figure D-4



Average Year Comparison of Alternative Seasonal Pool Guides
Elevation, feet
Volume, acre-feet
640
630
620
610
600
590
580
570
1600000
1400000
1200000
1000000
800000
600000
400000
$16,706,524
$15,943,131
Pool under Alternate Guide
Pool under Original Guide
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Figure D-5

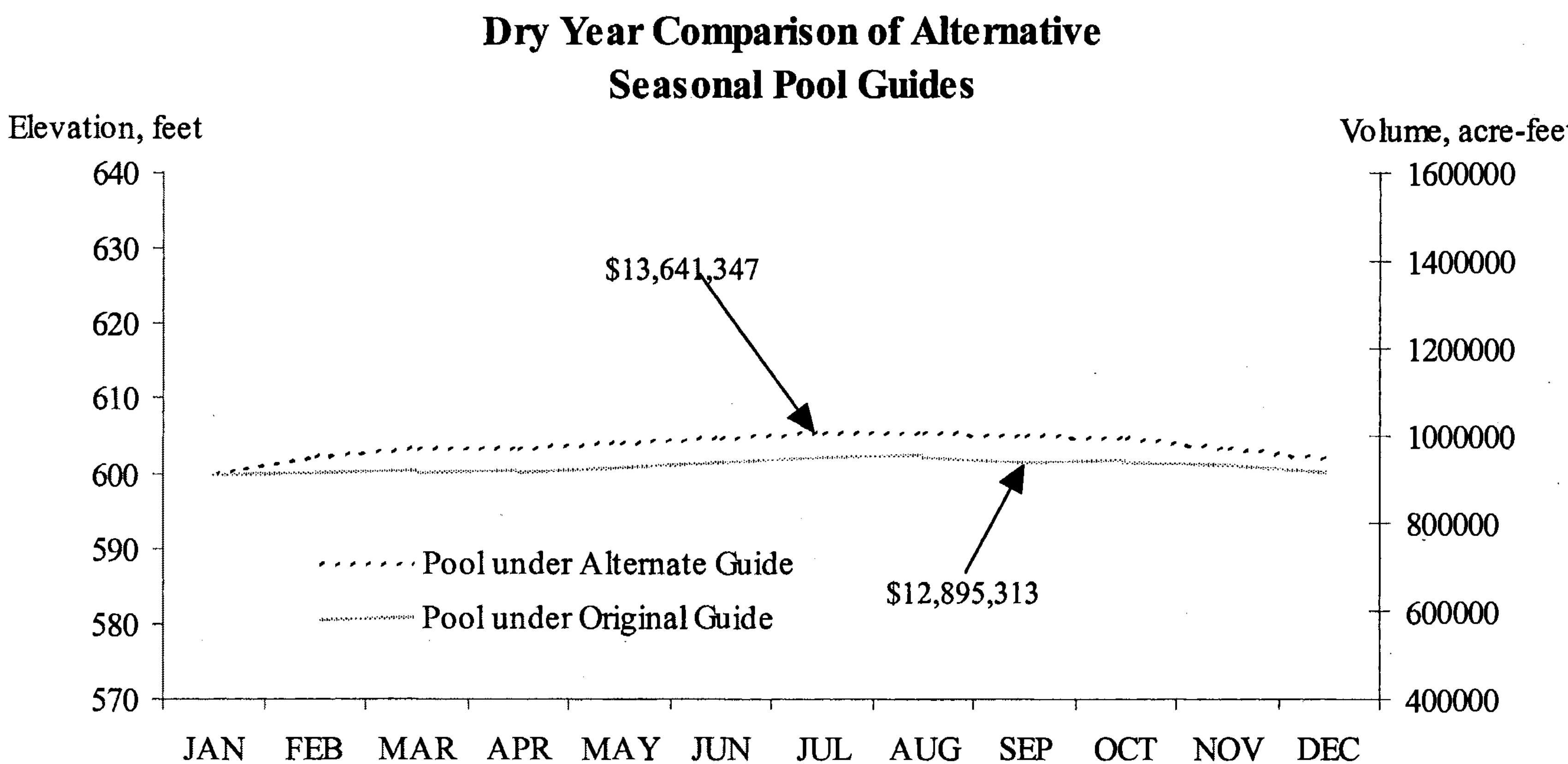
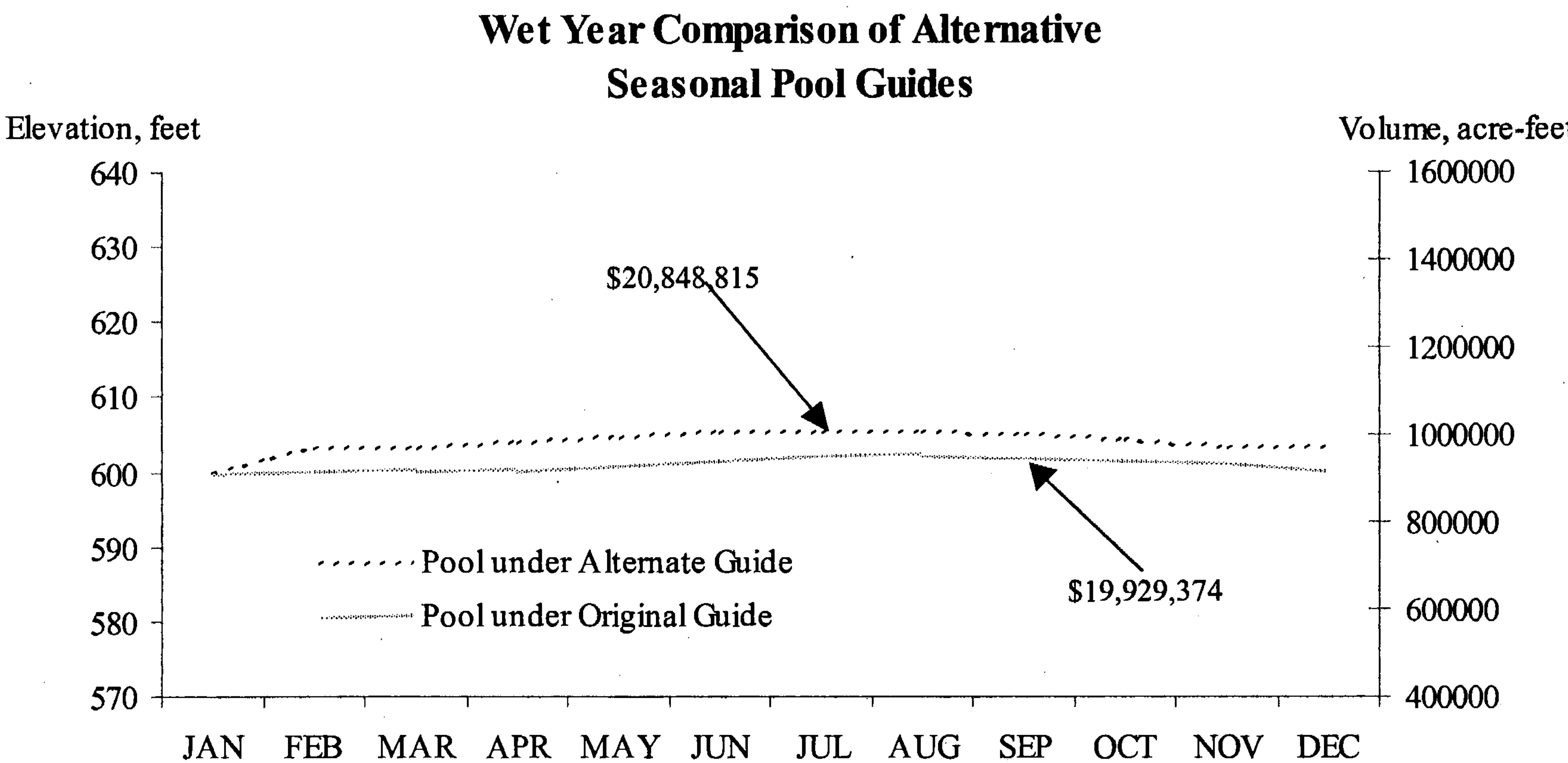

Dry Year Comparison of Alternative
Seasonal Pool Guides
Elevation, feet
Volume, acre-feet
640
630
620
610
600
590
580
570
1600000
1400000
1200000
1000000
800000
600000
400000
$13,641,347
$12,895,313
Pool under Alternate Guide
Pool under Original Guide
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Figure D-6



Wet Year Comparison of Alternative
Seasonal Pool Guides
Elevation, feet
Volume, acre-feet
640
630
620
610
600
590
580
570
1600000
1400000
1200000
1000000
800000
600000
400000
$20,848,815
$19,929,374
Pool under Alternate Guide
Pool under Original Guide
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

VITA 2

Russell W. McKenzie

Candidate for the Degree of

Doctor of Philosophy

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