University of Nevada
Reno

Optimizing Flood Control Allocation
For A Multipurpose Reservoir

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Hydrology

by

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June 1970
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ABSTRACT

Much research has been devoted to applying systems analysis to multipurpose reservoir design and operation. By computer analysis, a single multipurpose reservoir's operation can be simulated and the economic benefits from this operation can be computed. Incorporation of an optimizing technique into the program can lead to an economic optimization of the reservoir flood control diagram. This optimized diagram should be developed for a period of time during which stable economic conditions exist at the reservoir. The complete program which computes the optimized diagram can be re-used with minimal amount of change to re-compute optimized diagrams for the same reservoir for succeeding periods of stable economic conditions or to compute optimized diagrams for other reservoirs. The most economic flood control diagram should be considered in the development of the operating rules for a multipurpose reservoir.
CHAPTER I

INTRODUCTION

With the advent of computer technology, many of the problems which had earlier been considered too tedious for solution became solvable with the computer. This was especially true in the field of water resources. Prior to the computer era, design and operation of a multipurpose reservoir from a systems analysis viewpoint was not attempted because of the prohibitive amount of computations involved. Now, after more than a decade of computer application, the systems approach has been used with varying degrees of success to solve problems of reservoir design and operation.

However, the continuing research time which is being devoted to multipurpose reservoir design and operation evidences the fact that as yet a generally acceptable procedure for determining the best plan of design or operation has not been developed. This lack of total success is due in a large part to the great variety of factors that come to bear upon a multipurpose reservoir. These factors have made, in some instances, even computer solution prohibitive. For this reason the application of systems approach methods to multipurpose reservoir design and operation has
been limited, in most cases, to problems which have been reduced in scope.

I. GOAL OF STUDY

In this study the systems approach method was applied to a single multipurpose reservoir in an attempt to develop a technique which could be applied to a great many such reservoirs to determine their optimum operating policies. The procedure used was to develop an optimum operating policy as defined by the optimum reservoir flood control diagram. In other words, the optimum flood control diagram for a multipurpose reservoir defined its optimum operating policy. By using this definition for the optimum operating policy, the scope of the problem is being limited since the number of variables which are to be optimized is being limited. The emphasis was on optimizing only the flood control diagram; however, this approach was deemed satisfactory for producing a useful optimum operating policy since the introduction of additional variables (e.g., power benefits, water supply benefits, etc.) very likely would not result in a sufficient improvement in the operating policy to warrant the added complexity that would result from their inclusion in the problem.
The procedure employed to select this optimum diagram involved an iterative process in which the gross benefits were computed from the operation of the reservoir based upon various flood control diagrams. With the help of a mathematical optimization technique the one flood control diagram which showed the greatest gross benefits was determined. Since this procedure requires that all reservoir benefits are to be computed as a function of the flood control diagram, the flood control diagram is the only independent variable. Because the iterative technique required recomputation of reservoir benefits for each of many different flood control diagrams, the problem was ideally suited to computer application; and consequently, a reservoir model as developed by the U. S. Army Corps of Engineers, Hydrologic Engineering Center (Beard, 1966), was used to simulate the operation of a representative multipurpose reservoir. The computer program was modified to include an economic analysis calculation, and the resultant model was used to compute the reservoir benefits corresponding to the various flood control diagrams.

There is one facet of the approach used in this study which is in opposition to the general use of flood control diagrams today. The difference lies in the time period for
which the optimum operating policy is used to operate a reservoir. In many cases the flood control diagrams which are used to operate multipurpose reservoirs are static operational guides. That is to say, the diagrams, which were developed early in the project life of the reservoir, are in some cases being used relatively unchanged from their original form. Since the economics of a multipurpose reservoir are usually very dynamic, the concept of a static flood control diagram (i.e., one used in its original form for the entire project life) should be avoided because, as economic conditions change, so should a rule which is based on these economic conditions change.

An example which would illustrate the dynamic nature of the economics at a multipurpose reservoir is that of a reservoir where the maximum recreation use has not been reached. At such a reservoir the recreation use, hence the recreation demand, may be expected to increase each year up to the point in time when the maximum or saturation use is attained. At this point, on the basis of the market area population and the recreation availability, the reservoir theoretically will support no additional use. During the time preceding attainment of maximum use, the increasing recreation use at the reservoir introduces a dynamic element
into the economic situation since the yearly recreation demands are dynamic. A similar case could also be made for other conservation purposes; and hence, dynamic economic conditions at a multipurpose reservoir could likewise be attributed to conservation purposes other than recreation.

The uneconomical situation which could result from the use of a static diagram becomes evident in the following example. Consider the case of a flood control diagram that was developed for the fifty-year life span of a reservoir showing a dynamic conservation demand. For this particular reservoir the fifty-year flood control diagram would produce a non-optimum operation of the reservoir for each individual year because the economic analysis included years other than the current year (i.e., the one particular year for which the reservoir is being operated). In other words, the operating policy as defined by the fifty-year flood control diagram would be partly based on economic conditions which are not expected to exist for the current year. To further illustrate this aspect, once again consider the situation of the multipurpose reservoir where recreation use is expected to increase yearly up to a certain saturation point. If the recreation use at the reservoir is expected to be 100,000 visitor days for the current year of operation, but the operating policy is based on the expected recreation
use for all the years of reservoir operation which, for instance, might vary from 50,000 visitor days to a saturation use of 700,000 visitor days, the reservoir operation for the current year will be uneconomical because the operation is not being based on the economic conditions expected for the current year (i.e., a recreation demand of 100,000 visitor days). Instead, the economic conditions expected for all fifty years of operation are being used as a basis for operation for each individual year. Clearly, this is not an economical approach to operating a facility at which an increase in efficiency of ten per cent can mean an increase in benefits in the hundreds of thousands of dollars.

In light of the preceding reasoning, it was decided that it would be much more useful to develop an optimum flood control diagram for a time period during which the demands for conservation purposes were nearly constant. A time span of one year was both practical to work with and also short enough so that the conservation demands could be considered nearly constant; and hence, in this study the goal was to develop the optimum one-year flood control diagram for a multipurpose reservoir. By restricting the time base to one year, substantial increases in benefits should
be realized over those derived from a flood control diagram with a fifty-year time base.

It should be emphasized here that by reducing the time span for which the operating rule is developed it will be necessary to recalculate another optimum flood control diagram for succeeding periods of constant economic conditions. Recalculation of succeeding diagrams will be identical to the first calculation except for the necessary modification to account for the new economic conditions. Because recalculation of optimum diagrams will be necessary, emphasis was placed on developing a technique which would allow easy recomputation of succeeding flood control diagrams. It should also be mentioned at this point that the time span should not be restricted to one-year operations only. The time span selected should be the one which is most meaningful and practical, and this depends upon the particular situation at the reservoir being analyzed. However, in the majority of cases, a one-year time period would be the most readily applicable time base for which stable economic conditions could be assumed.

In summary, the objective sought in this study was the development of a technique which would select the one flood control diagram for a single multipurpose reservoir
which when used to operate the reservoir for one particular year would result in the greatest expected dollar return from the reservoir's operation for conservation and flood control purposes for that one year of operation. The approach was to vary the flood control diagram in a logical manner and to compute the gross benefits corresponding to the various diagrams. Selection of the one flood control diagram showing the greatest dollar return was made by a mathematical optimization technique which was programmed into a high-speed digital computer.

II. USE OF STUDY RESULTS

It is not intended for the economically optimum flood control diagram as ultimately selected in this study to be incorporated directly into a reservoir operation manual. This economically optimum diagram should be used only as an aid or guide in the selection of the final optimum diagram for the particular reservoir being analyzed because many factors other than economics should be considered in the selection of the final operating policy. Legal, social, and political factors sometimes have a great effect upon the operation of a multipurpose reservoir; and therefore, the final operating policy must not only be based on economic considerations but also must include these other factors as
well. Hence, to develop the final operating policy, one should have at his disposal the economically optimum flood control diagram plus a feeling for the importance of these other noneconomic factors. The final operating policy should be selected by deviating from the economically optimum policy as necessary to account for the influence of these noneconomic factors on the reservoir operation. If an understanding of the assumptions and constraints which were used to develop the technique in this study can be acquired, then it is likely that the economically optimum flood control diagram will be properly used in conjunction with these other factors to select the final diagram.

III. PREVIOUS WORK

In the development of an approach for this study, several similar studies were reviewed. Particular attention was given to the chapters of *Derivation of Reservoir Operating Rules by Economic Analysis* (Dowell, 1967) where the determination of conservation benefits was described. The objective of that study was similar to the one of this study; however, there was a considerable difference in the approaches of the two. Another source (Douglas, 1968), also concerned with the study mentioned above, stated that "total expected flood control and water supply benefits should be
periodically reevaluated to reallocate storage space in response to the changing conditions." Here the concept of developing optimum operating policies for periods of constant economic conditions is found.

The two sources listed above are two of the latest sources which are directly related to the subject of this study. Much prior work has been done in attempting to apply systems analysis to water resources; however, it would be senseless to attempt to mention them all. It has been assumed that most of these works are somewhat familiar to the reader; and therefore, only a few of them are listed in the bibliography.
CHAPTER II

MODEL RESERVOIR

I. GEOGRAPHY

The procedure employed in this study to find the economically optimum flood control diagram involved calculation of a reservoir's operational benefits for each of many flood control diagrams. In other words, it was necessary to know exactly what were the benefits from operating a multipurpose reservoir on the basis of each of these various diagrams. Hence, one of the first steps was to select one particular reservoir which could be used as a model, upon which all calculations would be based. For this purpose, Folsom Reservoir, located on the American River about 15 miles northeast of Sacramento, California, was chosen. The choice of Folsom should not be taken to mean that the goal of this thesis was to replace the existing flood control diagram with the one developed herein. Folsom was simply used as a model with which the technique would be developed.

Location. A glance at Figures 1 and 2 will indicate the location and dimensions of the almost 1,900 square miles of watershed drained by the reservoir. As can be seen from
Figure 1. Major drainage systems in Northern California.
Figure 2. American River Drainage Above Folsom Reservoir
Figure 2, the main surface flow network is composed of the three forks of the American River. The Middle Fork joins the North Fork just a few miles northeast of Auburn, and the South and North Forks are joined at the reservoir. The drainage area of the Middle Fork covers nearly 620 square miles; the South Fork and North Fork drainage area cover approximately 700 and 1,200 square miles, respectively.

Climate and topography. The Folsom watershed is characterized by great variety in both topography and climate. The Sierra Nevada mountain range, whose summit forms the easternmost boundary of the watershed, accounts for this great variety in that the drainage area, which extends from the Sierra foothills up into the high country, exhibits the vertical zonation of climate and vegetation typical of the windward slope of a middle latitude mountain range.

At the lower elevations of the watershed, the relief is gentle and the climate is characterized by hot summers and mild winters. Vegetation here consists predominantly of grasses with scattered patches of hardwoods. Progressing farther up the Sierras toward the sources of the watershed, relief becomes much greater and the climate comes under the influence of the greater elevations. The climate in this area of elevation from 4000 to 6000 feet is characterized
by mild summers and cold winters. Here evergreens are found mixed with hardwoods; and dense, thick timber stands replace the grasses except in the valleys where the grasses still predominate. In the highest areas of the watershed at elevations extending up to 10,000 feet, the relief is extremely rugged and the climate is characterized by cool summers and severe winters. Evergreens have completely replaced the hardwoods, and they blanket the area except where bare exposures of granite prohibit their growth.

II. HYDROLOGY

Precipitation. Because of the orographic effect of the Sierras, a great range in annual precipitation exists between lower elevation stations and those in the high country. Average annual basin precipitation is approximately fifty-three inches, ranging from eighteen to twenty inches in the lower areas to about seventy inches in the highest areas (U. S. Army Corps of Engineers, 1956).

The presence of the Sierra Nevada also explains the difference in the precipitation forms which occur throughout the basin. During all seasons the precipitation comes as rain at lower elevations, while during winter, snow is the predominant form of precipitation at higher elevations.
However, instances of winter rain have been noted at all but the highest elevations. In summer, rain is the predominant form of precipitation at all points in the watershed; however, rare occurrences of snow showers have been reported in the summit area during the summer season.

The distribution of precipitation is controlled by large scale climatic factors; and hence, a similar precipitation distribution occurs throughout the watershed. January is reported as the wettest month. Over 20 per cent of the average annual precipitation may occur at some stations during this month. The next wettest months are usually February, December, and March, in that order. Approximately 70 per cent of the average annual basin precipitation occurs within this four-month time span, and 97.5 per cent occurs within the period of October through May.

Runoff. There are two principal precipitation patterns which account for all the flood-producing flows into Folsom Reservoir. One pattern occurs as rainstorms at lower elevations in the winter. The second pattern occurs as warm late winter or spring rains falling at lower and higher elevations. In this second case, runoff from the higher elevations is usually enhanced by snowmelt from deep snow packs upon which the warm rains may fall.
The greatest historical inflow to Folsom Reservoir occurred on December 23, 1964, when a peak flow of 280,000 cfs was recorded. However, the peak inflow from this flood was directly attributable to the failure of Hell Hole Dam which was located approximately 45 miles upstream of the reservoir on the Rubicon River (see Figure 2). Without the failure of Hell Hole, the peak inflow from this flood would have been 214,000 cfs. Before the 1964 December flood occurred, the peak historical inflow had been 219,000 cfs of the 1955 December flood.

**Upstream regulation.** The drainage area above Folsom Reservoir is dotted with many storage and diversion facilities. However, the total number of these facilities can be misleading because it may appear that they exert a considerable influence upon the natural inflow to the reservoir. (A glance at Figure 2, page 16, which gives the location of the more significant of these regulatory structures, will familiarize the reader with the various storage and diversion facilities.) However, the three major storage facilities, which account for more than 76 per cent of the total upstream storage capacity, drain only 245 of the 1,900 square miles of watershed. Hence, only 13 per cent of the watershed is controlled by these structures; and since the amount of
control exerted by these structures on the flow from their watersheds is small, the effect of their control upon the natural flow into Folsom is virtually insignificant. Similarly, the control exerted by the diversion facilities is very minor. Since it can be concluded that the operation of the upstream regulatory structures has an insignificant effect upon the natural flow into Folsom, it was possible to classify the reservoir as a single multipurpose reservoir (i.e., the reservoir was not part of a system of reservoirs). Hence, the technique developed in this study is applicable to single multipurpose reservoirs.

III. RESERVOIR DATA

Folsom Dam is of concrete gravity construction with adjoining rolled earth dams extending from both sides. Nimbus Dam, located seven miles downstream from Folsom, serves as an afterbay for releases from Folsom. Nimbus also is a concrete gravity dam. Pertinent data for all the reservoir components are given in Table I. The project purposes for Folsom Reservoir are flood prevention, power generation, recreation, and water supply. Data describing the use of the facilities for these various purposes will be given later in the chapters which deal with each purpose individually.
# TABLE I

## PERTINENT DATA - FOLSOM DAM AND RESERVOIR

### Elevation

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<th>Pool Type</th>
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<tr>
<td>Minimum power pool</td>
<td>327.0 feet</td>
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<tr>
<td>Flood control pool</td>
<td>427.0 feet</td>
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<tr>
<td>Gross pool</td>
<td>466.0 feet</td>
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<td>Spillway design flood pool</td>
<td>475.4 feet</td>
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### Area

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<td>Minimum power pool</td>
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<td>Flood control pool</td>
<td>9,040</td>
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<td>Gross pool</td>
<td>11,450</td>
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<td>Spillway design flood pool</td>
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### Storage capacity

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<tr>
<td>Flood control pool</td>
<td>610,000 A.F.</td>
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<td>Gross pool</td>
<td>1,010,000 A.F.</td>
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<tr>
<td>Spillway design flood pool</td>
<td>1,120,000 A.F.</td>
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### Spillway

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<td>Crest elevation</td>
<td>418.0 feet</td>
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<td>Capacity</td>
<td>567,000 cfs</td>
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### Main Dam

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<td>Elevation, top of parapet</td>
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<td>Max. height, foundation to roadway crown</td>
<td>340.0 feet</td>
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<tr>
<td>Crest length</td>
<td>1,400.0 feet</td>
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CHAPTER III

OBJECTIVE FUNCTION AND OPTIMIZATION TECHNIQUE

I. OBJECTIVE FUNCTION

One of the most important steps in any study is to formulate a precise definition of the problem that is to be attacked. A qualitative definition of the problem was given in Chapter I; however, because the procedure employed to investigate this particular problem required a quantitative value for various trial solutions, it was necessary to attach a quantitative value to the definition. Hence, an objective function was introduced to quantitatively define the total gross benefits derived from each reservoir operation plan. An objective function is simply a criterion that is used to compare the merits of various solutions to a problem; and in this particular study, the objective function was the criterion which indicated whether one flood control diagram was better economically than another diagram.

Since the objective functions of most economic optimization studies are concerned with net benefits, the use of gross benefits in this study might require some justification. Net benefits are used in economic optimization studies because the economically optimum solution
of a problem is the one which results in the greatest net benefits. In this particular study, net benefits would be computed by subtracting the operating, maintenance, and replacement costs (OM&R costs) from the gross benefits. However, in the case of a one-year operation of an existent reservoir, the OM&R costs would be nearly constant regardless of what flood control diagram is used to operate the reservoir. In other words, the OM&R costs associated with a one-year operation of an existent multipurpose reservoir are not a function of the flood control diagram. Hence, for this particular situation, use of gross benefits in the objective function was equivalent to using net benefits since the net benefits are equal to the gross benefits minus a constant (i.e., the OM&R costs). In other words, the optimum flood control diagram would be the one which showed the greatest gross benefits as well as the greatest net benefits.

Since the objective function was set equal to the total gross benefits of each reservoir operation, the objective function (or benefit function), \( B(d) \), was simply the total of the gross benefits from each of the project purposes:
\[ B(d) = \sum_{i = r, p, ws, f} b_i (d) \quad (3.1) \]

where,
- \( d \) = flood control diagram
- \( B(d) \) = total gross benefits
- \( b_r \) = gross benefits from recreation
- \( b_p \) = gross benefits from power
- \( b_{ws} \) = gross benefits from water supply, and
- \( b_f \) = gross benefits from flood control.

To find the best operation of the reservoir, it was necessary to find the one flood control diagram which produced the greatest value of \( B(d) \). This required the calculation of \( B(d) \)'s for many possible \( d \)'s (flood control diagrams); and as mentioned earlier in this report, a problem such as this was ideally suited to computer application.

II. COMPUTER APPLICATION

The problem of computing \( B(d) \) for each of many various flood control diagrams was ideal for computer solution because it involved performing the same computations repeatedly. In this instance, the repeated calculations which the computer would perform were simulation of the reservoir's operation and computation of the resultant
gross benefits. A routing program, Reservoir Yield, developed at the U. S. Army Corps of Engineers, Hydrologic Engineering Center (Beard, 1966), was already designed to perform the routing portion of the computation; and this program was used after addition of the economic analysis portion of the computation to compute the gross benefits resulting from each flood control diagram.

**Conservation benefits.** The problem of computing benefits for each of the four project purposes (power generation, recreation, water supply and flood control) was divided into two distinct computational procedures. In one procedure the conservation benefits (power generation, recreation, and water supply) were computed; and in the other procedure, the flood control benefits were computed.

In order to calculate the gross benefits from the conservation purposes, three variables had to be known. The first variable was the amount of resources available for each project purpose. For example, the amount of water available for fulfilling water supply demands, for power generation, and for recreation use. All of the data necessary to determine this variable was generated in the Reservoir Yield program, previously described. Second, the demand for each of these functions had to be known
so that the amount of use could be determined. Economic demands for each of the conservation purposes for 1970 were determined from data of past use. The third variable was the economic worth of a unit use of each project purpose. A unit value for the project purpose of power generation could be given in terms of dollars per kilowatt-hour of electrical energy generated. From analysis of the economic situation at Folsom Reservoir the economic value of a unit use for all three conservation project purposes for 1970 was determined. The economic data was input into the Reservoir Yield program, and the necessary calculations for computation of the gross benefits for each of the conservation purposes was also added. Thus in its final form the routing program was capable of routing a series of inflows and computing from the routing the gross benefits from conservation benefits. These benefits were added to the flood control benefits, described below, to determine the total gross benefits derived from one particular flood control diagram.

**Flood control benefits.** The second benefit computation was the calculation of the flood control benefits. A completely separate procedure developed on the basis of flood occurrence probabilities was used to compute these
benefits. In this procedure the probability of a flood occurring and the probability of that flood producing a particular damage were used to compute expected flood damages. In order to perform these computations, another HEC program, Flood Hydrograph Package, (U. S. Army Corps of Engineers, 1969) was used with slight modification to develop a generalized function of flood damages versus flood-control and supplementary space for each calendar month.

The flood control benefits were determined by subtracting the flood damages from the pre-project flood damages (the damages which would occur without the reservoir), and these benefits were added to the conservation purposes' gross benefits to determine the total gross benefits of using each particular flood control diagram to operate the reservoir.

III. OPTIMIZATION TECHNIQUE

As already explained in this report, the mathematical technique employed to select the economically optimum flood control diagram involved recomputation of the gross benefits for many different flood control diagrams. In the preceding sections, a brief discussion was given on the method of
computing these benefits. The following discussion is concerned with the optimization technique that was used to select the economically optimum flood control diagram.

For the purposes of this study, it was decided that a gradient technique, in particular the univariate technique, would be well suited to the problem of selecting the economically optimum flood control diagram. The univariate optimization technique was chosen because of its easy application to the particular problem at hand.

The search process by which the univariate technique seeks out the optimum solution is simple in theory. This process first requires a value of the objective function with all the variables (in this case, the variables which describe the flood control diagram) at their initial or starting value. For the second step, the first variable is changed a pre-determined amount, holding the other variables constant; and the value of the objective function is recomputed. As previously mentioned, this recomputation was handled by the computer. It would involve another complete routing and benefit analysis based on the modified flood control diagram. In the third step, the same variable is changed once again; and another value of the objective function is computed for the third time. At this point
the three values of the objective function are examined, and the variable is optimized by changing it in the direction and by the amount indicated as optimum by the three values of the objective function. With this new value of the first variable, the second variable is optimized as was the first. Once again optimization of the variable is accomplished by changing the second variable as indicated by three new values of the objective function. This process is repeated for the remaining variables; and after optimizing the last variable, the first cycle of optimization is completed. The optimization may run for as many cycles as desired. In this study three cycles were run at which point the variable which last caused the greatest change in the objective function is optimized again. This process is repeated until negligible improvement is attained.

The univariate technique was programmed into the Reservoir Routing program using a univariate subroutine developed by Leo R. Beard at the Hydrologic Engineering Center. This optimization technique, together with the conservation benefit and flood benefit additions to the Reservoir Routing program, enabled the entire computation leading to the economically optimum flood control diagram to be accomplished in one computer run. In other words,
starting with the initial values of the variables (i.e., the initial flood control diagram) as input, the modified program would output the economically optimum flood control diagram.

In summary, the objective function defined total gross benefits from the reservoir as operated on the basis of a particular flood control diagram. This benefit function was computed by the Reservoir Yield program, as modified to include the economic benefit analysis. The univariate optimization technique, which is a search process that optimizes one variable at a time, was used to select the economically optimum flood control diagram because of its direct application to the problem. This technique was added to the Reservoir Yield program, and the resulting modified program was a complete package sufficient for computing the economically optimum flood control diagram.
CHAPTER IV

CONSERVATION BENEFIT ANALYSIS

I. INTRODUCTION

In Chapter III there was a very brief discussion on the methodology of computing the conservation benefits that would be derived from operating a multipurpose reservoir with a particular flood control diagram. This chapter is devoted to expanding and detailing the brief discussion of the preceding chapter. Each of the three conservation purposes is the subject of a chapter subsection, and in each subsection there is an explanation of the technique developed to compute the conservation benefits. Preceding this, however, is a discussion of the more general aspects of the conservation benefit analysis.

II. METHODOLOGY OF CONSERVATION BENEFIT ANALYSIS

As previously mentioned, the approach used in this study was to simulate the operation of a single multipurpose reservoir to determine the operational benefits of various flood control diagrams. The model which was used to simulate the reservoir's operation was a modified version of a
computer program developed by the U. S. Army Corps of Engineers. This model will take a series of monthly inflows, operate the reservoir on the basis of these inflows, and compute the total gross benefits that would result. The routing was done on a monthly basis, and the benefits were likewise computed on a monthly basis. A monthly benefit analysis was necessary to account for monthly variations in the economic demands of the conservation purposes.

Monthly inflows. Since the goal of this study was to develop a flood control diagram for a future year (1970) of reservoir operation, the first requirement for determining the 1970 conservation benefits was to select a set of inflows which would be representative of the flows which would occur during 1970. Because of the difficulty of making exact predictions of river discharge, it was decided to route twenty years of representative monthly inflows with the model, compute the average annual conservation benefits of these twenty years of flow, and use this average benefit value as the expected annual conservation benefit for 1970. For this study, the twenty-year inflow period of 1915 through 1934 was used; and the total conservation benefits from this twenty-year period were averaged to determine the conservation benefits which were expected for 1970.
This twenty-year period of representative inflows included a wet period followed by a six-year dry period followed by a more normal three-year period. This sequence of inflows included the two types of flows that would be critical in the determination of conservation benefits, and because of this the twenty-year flow period was a representative sequence for determining the expected conservation benefits for the one year of reservoir operation.

An alternative method available for computing the expected conservation benefits was generation of many years of synthetic inflows and computation of an average annual conservation benefit from these flows. However, it was doubtful that this alternative method would have produced a substantial improvement in the estimate of the annual conservation benefits computed from that of a carefully chosen twenty-year period of inflows. The additional computational time required by the computer to route the many years of synthetic flows made the alternative method less desirable than the shorter twenty-year period. Because the hand-chosen period of inflows offered a good estimate of the expected conservation benefits with a reasonable amount of computation time, this method was chosen over the alternative of generating a long sequence of synthetic flows.
Projected economic conditions. The second requirement for determining the expected conservation benefits for the year of operation was an estimate of the economic conditions which would occur during this one-year period. This additional estimate was required so that a dollar value could be attached to the various conservation benefits. Through the routing of the monthly inflows, the amount of resource available for each conservation purpose was determined. In other words, for example, the routing computed how much power would be generated in the twenty years of operation. In addition to the amount of resource available, the economic demand and unit value of each conservation purpose were needed to determine how much of the resource was required and what would be the economic worth of each unit of this resource. Once again using power generation for an example, the demand for power in 1970 and the unit value of each unit of power generated during 1970 had to be known to attach a dollar value to the 1970 power benefits. Because 1970 was the year for which the optimum flood control diagram was developed, the unit economic values for all conservation benefits were projected for 1970 economic conditions.

With an estimate of the amount of resource available, the unit economic value, and the amount of resource required
for each conservation purpose for 1970, a dollar value of the total 1970 conservation benefits was computed. The following chapter subsections deal with how the 1970 economic demands and unit economic values of the three conservation purposes at Folsom Reservoir were determined.

III. RECREATION BENEFITS

Of the three conservation purposes at Folsom Reservoir, recreation was the most difficult to quantify. Recreation use at a multipurpose reservoir depends on many diverse, and as yet, not completely understood factors. Some of the more important factors which are known to influence the amount of recreation use at a reservoir include the distance of travel to the reservoir, the degree of development of the recreation facilities, the availability of equivalent recreation facilities elsewhere, the season of the year, and the reservoir stage. (Des Jardins, 1968.) However, even if a reliable method for determining the amount of recreation use can be developed, there still remains the problem of assessing a value to a unit of recreation use. Hence, there were two obstacles to estimating the 1970 recreation benefits at Folsom. First, a relation between the amount of recreation use and the factors listed above had to be developed. Second, the unit economic value of
recreation use was necessary to compute the dollar value of benefits after the amount of recreation use had been determined.

Estimating recreation use. An expression which accurately estimates the amount of recreation use at a reservoir should take account of as many of the previously mentioned factors as possible. On the basis of data of past recreation use at Folsom, a relation expressing recreation use as a function of many of these factors was developed. However, as is the case with most analyses of recreation use at a multipurpose reservoir, finding usable recreation data was a major problem in itself. For Folsom two sources of data existed. The State of California, Department of Parks and Recreation, which is the agency responsible for operating and maintaining the recreation facilities at Folsom, and the Bureau of Reclamation, which receives recreation-use data from the Department of Parks and Recreation, both were able to furnish five years of data; but there was a large discrepancy between these two sets of data. After considerable time was spent unsuccessfully trying to resolve the difference in the data sets, it was decided to use the data supplied by the Department of Parks and Recreation since it was the agency responsible for taking the recreation-use data at the reservoir.
From the recreation-use data of the Department of Parks and Recreation, a trend in the monthly distribution of the recreation use was evident. For the five years for which data was available, July or August was always the month of greatest use while the month of least use was always either November, December, or January. Because July and August are two of the warmest summer months and conversely November, December, and January are some of the coldest winter months, this trend was not unexpected.

Through analysis of the recreation-use data, an expression relating recreation use directly to reservoir surface area was developed. This relation was preferable because of the computational technique employed in the routing program. The routing program computed average monthly storages internally for routing purposes; and therefore, an expression relating recreation use to reservoir surface area, which may be computed directly from reservoir storage, was a very workable relation.

The unit of recreation use used in this study was the recreation day, which was defined as "a visit to the project for recreation purposes by one person for a period of one day or less." (Gomez and Crane, 1968). Therefore, the ultimate objective of this phase of the recreational-use analysis was to relate the number of recreation days
to the reservoir surface area. It would then be a simple matter to compute the number of recreation days to be expected for a particular reservoir storage since surface areas could be easily computed from the reservoir storages.

From the recreation-use data and historical average monthly reservoir surface areas found in Folsom's operational record, recreation densities (i.e., the number of recreation days per acre of average monthly reservoir surface area), as shown in Table II, were computed for each month for which recreation-use data was available. These recreation densities were averaged, and the average values were used for the 1970 recreation-use computations. Table III indicates the monthly recreation-density values that were used in the computation of monthly recreation use at Folsom.

Using these anticipated 1970 recreation densities, the expected monthly recreation attendances at Folsom Reservoir were calculated in the routing program. For example, the twenty values of average January storage, one for each of the twenty years of routing, were used to compute the corresponding twenty average January reservoir surface areas. Each of these surface areas was multiplied by 19.8, the 1970 January recreation density, and each of these
**TABLE II**

<table>
<thead>
<tr>
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<td>23.3</td>
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<td>37.1</td>
<td>25.6</td>
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<td>27.0</td>
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<td>60.6</td>
<td>44.8</td>
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<td>54.7</td>
<td>33.3</td>
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<td>54.3</td>
<td>58.0</td>
<td>45.0</td>
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<td>49.4</td>
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<td>35.2</td>
<td>37.0</td>
<td>24.4</td>
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<td>25.8</td>
<td>22.8</td>
<td>30.8</td>
<td>34.1</td>
<td>21.7</td>
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<td>16.0</td>
<td>23.4</td>
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<tr>
<td>Dec</td>
<td>15.7</td>
<td>24.5</td>
<td>17.5</td>
<td>25.3</td>
<td>10.4</td>
<td></td>
</tr>
</tbody>
</table>

* Number of recreation days per average monthly surface area in acres.

**TABLE III**

**ANTICIPATED 1970 RECREATION DENSITIES***

<table>
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<tr>
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<tbody>
<tr>
<td>Jan</td>
<td>19.8</td>
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<td>29.5</td>
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<td></td>
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<tr>
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<td>33.6</td>
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<td>47.8</td>
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<td>Jun</td>
<td>43.6</td>
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<td></td>
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<tr>
<td>Dec</td>
<td>18.7</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

* Number of recreation days per average monthly surface area in acres.
products was an expected recreation use for January. The average of the twenty January values was used as the expected January recreation use for 1970. Every other monthly recreation-use value was computed in the same way as described for January; and the expected monthly recreation use in recreation days was multiplied by the unit value of a recreation day, to be described later, to determine the dollar value of the gross recreation benefits for 1970.

**Unit value of recreation day.** The objective of the second phase of the recreation analysis was to determine the unit value of the recreation day. The U.S. Army Corps of Engineers uses a point system for evaluating the unit value of a recreation day at its reservoirs; and for the purposes of this study, this approach was considered adequate. A summary of this point system is presented in Table IV (Bernard, 1968).

The unit value of a recreation day at Folsom Reservoir was determined to be one dollar, as indicated by the total of sixty-seven points which were accumulated. Hence, dollar values of the monthly gross recreation benefits were computed by multiplying the expected monthly recreation uses in recreation days by one dollar.
<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>RANGE OF POINT VALUES</th>
<th>FOLSOM VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Quality of project access &amp; recreational facilities provided.</td>
<td>3 to 20</td>
<td>18</td>
</tr>
<tr>
<td>b. Number of project recreational activities available.</td>
<td>1 to 10</td>
<td>10</td>
</tr>
<tr>
<td>c. Aesthetic conditions of project and project area.</td>
<td>5 to 25</td>
<td>17</td>
</tr>
<tr>
<td>d. Competitive water-oriented recreation areas within vicinity.</td>
<td>3 to 15</td>
<td>6</td>
</tr>
<tr>
<td>e. Relationship of project area to demand area population.</td>
<td>10 to 30</td>
<td>16</td>
</tr>
<tr>
<td>Range of Points (Total)</td>
<td>23-36</td>
<td>67</td>
</tr>
<tr>
<td>Dollar value assigned per recreation day.</td>
<td>$0.50</td>
<td>$0.75</td>
</tr>
<tr>
<td></td>
<td>$1.00</td>
<td>$1.25</td>
</tr>
<tr>
<td></td>
<td>$1.50</td>
<td>$1.50</td>
</tr>
</tbody>
</table>
The gross recreation benefits computed in the manner described above were a function of many of the factors which were earlier indicated as influencing the recreation use. The average recreation densities were a function of the month and the reservoir stage or surface area; and because they were based on data of past use, the recreation densities also included the effect of the degree of development of recreation facilities at Folsom, the distance of travel, and the availability of other equivalent recreation facilities. Hence, the gross benefits from recreation took into account many of the factors that determine the amount of recreation use at a multipurpose reservoir.

Since recreation was only one of the three conservation purposes at Folsom, there still remained two other economic analyses to be made. Economic relations for the water supply and power purposes are developed in the next two chapter subsections.

IV. WATER SUPPLY BENEFITS

Because of the nature of the water supply demand, the water supply benefit analysis was handled in a different manner than that for recreation. In this analysis, target values of monthly water supply were determined on the basis
of past water purchases. The water supply demands for 1970 were projected linearly from the three years of data of past use which was supplied by the Bureau of Reclamation, the agency responsible for the operation of the reservoir.

The three water customers at Folsom with their projected demands and average unit rates are shown in Table V. The average 1970 unit rates were calculated on the basis of the percentages of M&I (municipal and industrial) water and irrigation water included in the 1970 projected demands of each customer. The last two customers shown in Table V contracted for M&I water only, for which the unit rate was $9 per acre foot; hence, the average rate for both was simply $9 per acre foot. The San Juan Suburban Water District had contracted for both M&I and irrigation water which is sold at $2.50 per acre foot, and so it was necessary to determine the percentage of each type of water usage. The average percentages of M&I water and irrigation water purchases by San Juan S.W.D. for the three years of past use was used for the 1970 percentages. Using the two unit rates for the two classes of purchased water, the 1970 average unit price for the San Juan Suburban Water District was $4.99 per acre foot.
The projected water supply unit rates of the three water customers were then used to compute an average unit rate for all water to be sold during 1970. This average rate, which was computed by taking a weighted average for all the 1970 water, was $6.07 per acre foot.

### TABLE V

**PROJECTED 1970 WATER SUPPLY DEMANDS AND UNIT RATES**

<table>
<thead>
<tr>
<th>Customer</th>
<th>1970 Demands (Acre Feet)</th>
<th>1970 Rate ($ per Acre Foot)</th>
</tr>
</thead>
<tbody>
<tr>
<td>San Juan Suburban Water District</td>
<td>2,680</td>
<td>4.99</td>
</tr>
<tr>
<td>El Dorado Hills County Water District</td>
<td>885</td>
<td>9.00</td>
</tr>
<tr>
<td>County of El Dorado (Lake Hills Estates)</td>
<td>100</td>
<td>9.00</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>3,665</strong></td>
<td></td>
</tr>
</tbody>
</table>

As shown in Table V, the target value for water supply for 1970 was 3,665 acre feet. This meant that with an average unit rate of $6.07 per acre foot and with no water supply shortages the 1970 gross benefits from water supply would be $22,247 ($6.07 x 3,665). Distribution of the annual demand among the months was done by using the average distribution of past use as the 1970 monthly
distribution. In the routing program, monthly shortages to water supply were computed; and the monthly water supply deficits were computed as the shortage in acre feet multiplied by the unit rate ($6.07). Deficits were subtracted from the monthly target values of gross benefits to determine the monthly gross benefits from water supply.

The unit value for an acre foot of water supply was chosen as that which the customer pays for the water. However, it is likely that the total economic worth of an acre foot of this water is much greater since loss of even a small part of a community water supply can have serious repercussions on the economy of the community. In the absence of a method for including these effects in the unit value, the value of a unit of water supply was chosen as that which the customers pay for the water.

V. POWER BENEFITS

The problem of developing a relation for computation of the gross benefits from power generation was handled in a similar manner to that for recreation benefits. Output from the unmodified Reservoir Yield program indicated the total monthly energy generated at the dam. To determine the economic value of this power a unit rate for each
kilowatt-hour of energy was determined, and the monthly gross benefits from power were calculated by multiplying the amount of energy generated each month by the unit rate.

The power generated at a multipurpose reservoir can be divided into firm power, which is purchased by power suppliers to fill a definite space in their load curve, and dump power, which is power generated in addition to that purchased for firm power. The Bureau of Reclamation furnished monthly demands for firm energy and unit values for both firm and dump energy. The monthly gross benefits from generation of firm energy were calculated by multiplying the amount of firm energy generated by the firm energy rate. Any excess of monthly energy generated over the firm energy demand was multiplied by the dump energy rate, and this product was the monthly dump energy benefits. The sum of the firm energy and dump energy monthly gross benefits was the monthly gross benefits from power generation.

VI. COMPUTER ANALYSIS

The computation of all the monthly conservation gross benefits was done with the computer. The modified computer program, as it routed the monthly inflows, performed the monthly benefit analysis. Hence, at the end of each twenty-year routing (one routing for each flood control
diagram), the monthly gross benefits from the conservation purposes were totaled and averaged to give the expected gross benefits from the conservation purposes for 1970. The economic analysis of the one remaining reservoir purpose, flood control, will be the subject of the following chapter.
CHAPTER V

FLOOD CONTROL BENEFIT ANALYSIS

I. INTRODUCTION

Using the procedures of the preceding chapter, conservation benefits for each conservation purpose were calculated; and this left flood control benefits as the only unknown quantity in the objective function. The flood control benefit analysis was accomplished in an entirely separate analysis because of the contrasting nature of flood control and conservation purposes. In this analysis the concepts of flood probabilities and reservoir stage probabilities were combined to develop a table of expected flood damages for various reservoir stages. This damage table was subsequently added to the modified routing program, in which the flood benefits were computed as a function of average monthly storages concurrent with the routing process.

Because of the great potential for flood damage in the Sacramento area from high releases from Folsom Reservoir, the reservoir was designed and is operated to provide flood prevention (i.e., complete flood control) for downstream areas. This requirement was deleted in this study because the purpose here was to develop the economically
optimum reservoir operation, and it was possible for flood damages to be incurred with this operation.

The enormous amount of computational work required by the probability analysis of flood control benefits was handled by another Corps of Engineers' program, Flood Hydrograph Package (U. S. Army Corps of Engineers, 1969). With modifications, the Hydrograph Package program computed the entries of the damage table and output the damage table on computer cards for subsequent use in the routing program.

II. DAMAGE TABLE

The release from a reservoir is dependent upon several factors. The inflow flood hydrograph, the rules by which the reservoir is operated, and the reservoir stage at the beginning of the inflow flood hydrograph are the independent variables that determine what the flood releases from the reservoir will be. As is the usual case for a multipurpose reservoir, the rules that are used to operate the reservoir are fixed; and consequently, this reduces the number of variables to two. Proceeding on the basis that only these two variables determine the flood release from a particular reservoir, a model was developed for computing flood benefits on the basis that flood releases
from Folsom were a function of only the inflow flood hydrograph and the reservoir stage at the start of the inflow flood hydrograph.

The first step in the development of the flood benefit analysis was to account for the effect of the inflow hydrograph upon flood releases. The result of this step was the flood damage table. The second step was to account for the effect of the reservoir stage, and this was accomplished partly in the damage table and partly in the routing program. This second step will be examined in a later chapter subsection.

Integration of frequency curve.

To develop a benefit analysis based upon flood probabilities, only those probability floods which can cause downstream damages need be considered. This can be determined from the damage-flow curve by picking from the curve the greatest discharge which had zero flood damage. From analysis of the flow frequency curve (U. S. Army Corps of Engineers, File 11-4465) only those floods with an exceedance frequency of 3 per cent or less were considered as flood producing for Folsom Reservoir. In other words, a flood with a probability of occurrence greater than 3 per cent was not a damage-producing flood because levee
protection below the reservoir would prevent damage from occurring from any flood with a smaller occurrence interval.

To compute the damages from all floods with an exceedance frequency of 3 percent or less, it was necessary to integrate the damage-producing range (3 per cent to 0 per cent exceedance frequencies) of the flow-frequency curve for damages. The frequency curve was divided into four intervals for the damage integration. The following breakdown in the frequency curve was selected:

<table>
<thead>
<tr>
<th>Exceedance Frequency Interval (%)</th>
<th>Midpoint of Interval (%)</th>
<th>Range of Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0.2</td>
<td>0.1</td>
<td>0.002</td>
</tr>
<tr>
<td>0.2 - 0.4</td>
<td>0.3</td>
<td>0.002</td>
</tr>
<tr>
<td>0.4 - 1.0</td>
<td>0.7</td>
<td>0.006</td>
</tr>
<tr>
<td>1.0 - 3.0</td>
<td>2.0</td>
<td>0.020</td>
</tr>
</tbody>
</table>

The integration was accomplished by first routing each of the four representative floods, which are those with an exceedance frequency corresponding to each of the midpoint frequencies, and selecting the peak reservoir release from each flood. To complete the integration the damage corresponding to each of those four peak releases was determined and multiplied by the respective probability range. The sum of the four products (flood damage x interval range) was the expected annual flood damage.
Hence, the damage from the flood with an 0.1 percent exceedance frequency was calculated and multiplied by 0.002, the corresponding probability range. This product indicated the expected annual flood damage from the first flow frequency interval. Repeating this process for the other three representative floods resulted in three additional expected annual damages, which when summed with the first expected damage value, gave the expected annual damage from all damage-producing floods into Folsom Reservoir.

**Flood damage computation.** In the preceding paragraphs, little information was given on the technique that was used to compute the damages from each of the four representative floods or on how the concept of reservoir stage probabilities was included in the analysis. This chapter subsection is concerned with developing these two aspects as they relate to the flood damage computations of the four representative floods. In general, a table of expected flood damages for each calendar month as a function of initial reservoir stage and amount of required flood control space was constructed for direct use in the monthly operation computation. This precluded the necessity of considering individual flooding events in every twenty-year routing.
To determine the damages that would result from making high releases from Folsom Reservoir, a damage-flow curve was obtained from the Sacramento District, Corps of Engineers. A damage-flow curve indicates what the downstream damages will be if the flow at a reference point in a river is known. The curve supplied by the Corps of Engineers gave damages downstream of Folsom Dam for known releases from Folsom. Since this curve was based on 1962 conditions, it was necessary to update it to 1970 conditions; and this was accomplished by increasing all the damages on the curve by 30 per cent. Figure 3 shows both the 1962 curve and the updated curve for 1970 conditions.

The damage which would result from a certain inflow flood hydrograph could now be determined by routing the hydrograph through the reservoir and using the reservoir release as indicated by this routing procedure to pick the corresponding damage from the damage-flow curve. The expected annual damage could be determined, as mentioned above, by routing the four representative floods and integrating their damages. However, the expected annual damage value that would result from such a calculation would be dependent upon the reservoir stage at the time the inflow flood hydrograph first reached the reservoir. For example,
Primary damages in million dollars
(January 1962 conditions)

Figure 3. Damage-Flow Curve.
if the 0.3 per cent flood was routed through the reservoir when the reservoir was half full, the release would be less than if the reservoir had been three-quarters full; and therefore, the damages for the release from the half-full reservoir would be less than from the three-quarters-full reservoir. To account for the effect of reservoir stage on the expected annual damages, a damage value was computed for many different reservoir storages.

At the time a flood first enters the reservoir, there is an infinite number of possible storages which the reservoir may have. It is possible for the reservoir stage to be below the bottom of flood control pool, at flood control pool, or in the flood control pool. Because the release capacity at Folsom was great in comparison to the amount of flood control space, it would always be possible to get the reservoir stage down to bottom of flood control pool at the end of each month regardless of the amount of flooding which occurred during the month. Since a monthly routing was used, the possibility of getting an end of the month storage in the flood control pool was eliminated. Hence, in this study only two possible situations could exist with respect to reservoir stage at the beginning of the flood hydrograph - the reservoir stage could be at or below flood control pool.
Two terms were used which would describe these two possible initial reservoir stages. The term flood control reservation referred to the amount of flood control space required by the flood control diagram for the particular month of routing. Any storage space that exists in the reservoir in addition to the flood control reservation was termed supplemental storage. Hence, any possible reservoir stage could be described by a flood control reservation and a supplemental storage.

Figure 4 shows the current flood control diagram for Folsom. It shows that for the month of November with a parameter value of twenty-one, the maximum storage is 610,000 acre feet; and the flood control reservation is 400,000 acre feet. The parameter values shown in Figure 4 are indicative of the ground wetness of the drainage basin. However, they are somewhat redundant since for a small parameter value to be in effect the antecedent runoff would be likewise small. In effect then, it would be very improbable that the higher storage value allowed by a smaller parameter value could be attained because the small amount of antecedent runoff would most likely prohibit filling the reservoir. For this reason, only the outside curve, or the curve indicated by the maximum parameter value, was considered in this study.
Parameters are preceding 60-day basin mean precipitation in inches.

Figure 4. Flood control diagram - Folsom Reservoir.
(From Leo R. Beard, "Flood Control Operation of Multiple Purpose Reservoirs")
To construct a table which shows the effect of reservoir stage on flood releases from the reservoir, the routing of the four flood hydrographs to determine expected annual flood damages was done for every possible 100,000 acre foot combination of flood control reservation and supplemental storage. Since the reservoir's gross pool was 1,010,000 acre feet, any combination of the two totaling more than 1,010,000 acre feet was not possible. Thus, for each of the possible combinations, an expected annual damage value was computed. These values were arranged into a table as shown in Figure 5.

**Computer Application.** All the computations leading to the damage table were completed with the Flood Hydrograph Package, as modified to perform the necessary damage calculations. This program is explained in greater detail in Appendix A; however, the basic computations made by the program will be explained here.

To compute the damage table, several distinct operations had to be performed. First, the four representative floods had to be developed and formed into an inflow hydrograph which had a shape similar to flood hydrographs on the American River at Folsom. The Hydrograph Package program was equipped to construct a balanced hydrograph from a
<table>
<thead>
<tr>
<th>Flood Control Reservation (100,000 A.F.)</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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<td></td>
<td></td>
<td></td>
<td>$1,010,702</td>
</tr>
<tr>
<td>2</td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
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</tr>
</tbody>
</table>

Nodal points represent expected annual damages for indicated storage combinations of supplemental space and flood control reservation.

(Example: Expected annual damages for 100,000 A.F. supplemental storage and 200,000 A.F. flood control reservation is $1,010,702.)

Figure 5. Annual Damage Table Format
given set of volumes and a given hydrograph shape. The volumes corresponding to the four floods were taken from the flow frequency curve, and a flood hydrograph shape was selected from the Reservoir Regulation Manual (U. S. Army Corps of Engineers, 1956). The Hydrograph Package program computed four balanced inflow hydrographs with the particular shape characteristic of that reach of the American River.

The next operation was to route each of these four balanced inflow hydrographs through the reservoir. The program was modified to simulate the operation of Folsom Reservoir since the routing procedure employed in the Hydrograph Package was a Modified Puls method which would not account for dams with gated spillways. The routing was done on an hourly basis, and the peak hourly reservoir release from each representative flood was selected and used to determine the downstream flood damages.

The final operation was to integrate the four floods for damages. This operation was performed subsequent to the routing operation. The maximum hourly release was selected from the routing, and the damage for this particular release was obtained by interpolation from the damage-flow curve. Immediately following determination of the downstream damages, the damage was multiplied by the proper factor for
integration (see page 52). For each possible reservoir storage combination of flood control reservation and supplemental storage, the four integrated damage values were totaled to give the expected annual damage for that particular combination of flood control reservation and supplemental storage. There were sixty-five possible storage combinations; hence, the four representative floods were routed and totaled sixty-five times with the Flood Hydrograph Package. After the 260 routings (sixty-five storage combinations times four routings for each combination) and the summations, the damage table was output onto computer cards for use in the modified Reservoir Routing program.

The damage table derived here was constant as long as the flow-frequency curve remained unchanged. Thus, to repeat the derivation of the optimum flood control diagram to account for changed economic conditions, the damage table used in earlier derivations could be re-used.

The preceding discussion has described the computation of the expected damages, but there still remains the application and use of the damage table in the modified routing program. The following chapter subsection is concerned with this aspect.
III. DAMAGES IN ROUTING PROGRAM

Conversion to monthly damages.

The nodal points of the damage table represent expected annual damages for particular storage combinations. Since all benefits were calculated on a monthly basis, the expected annual damages had to be converted to expected monthly damages. In a study of Pacific Coast stream characteristics (U. S. Army Corps of Engineers, 1960) it was found that a consistent trend was evident in the monthly distribution of flood flows. A tabulation of the percentage of annual flooding which occurred in each month was presented by latitude, and the factors which were applicable to Folsom were selected. The annual expected damage values on the damage table were multiplied by each monthly flood factor, and in this way twelve monthly damage tables were constructed. The monthly flood factors for the particular latitude at Folsom are shown in Table VI.

| TABLE VI |
|------------------|---|---|---|
| MONTHLY FLOOD FACTORS |   |   |   |
| Jan   | .23 | Jul | .00 |
| Feb   | .24 | Aug | .00 |
| Mar   | .19 | Sep | .00 |
| Apr   | .06 | Oct | .03 |
| May   | .01 | Nov | .08 |
| Jun   | .00 | Dec | .16 |
Average monthly storages.

The monthly expected damage tables indicated damage values for particular reservoir storages; hence, to compute the expected flood damage for a particular month in 1970 the monthly storage had to be known. By knowing the average storage for a month, the expected damage could be taken from the monthly damage table. If for example, the average monthly storage for October was 590,000 acre feet, the expected monthly flood damage table could be interpolated for the October flood damage simply by knowing the October flood control reservation. The October flood damage table would be entered at the level of appropriate flood control reservation (400,000 acre feet for the case of the current flood diagram), and the expected damage would be calculated by interpolating between the 0 and 100,000 acre feet supplemental storage levels (see calculations below).

\[
\begin{align*}
1,010,000 \text{ A.F. gross pool storage} \\
- 400,000 \text{ A.F. flood control reservation} \\
610,000 \text{ A.F. bottom of flood control pool} \\
610,000 \text{ A.F.} \\
-590,000 \text{ A.F. average monthly storage} \\
20,000 \text{ A.F. average monthly supplemental storage}
\end{align*}
\]

\[\therefore \text{ necessary to interpolate for a supplemental storage of 20,000 A.F.}\]
Stage duration analysis.

To compute the expected monthly flood damages from the damage table, it was necessary to know what the chances were of getting certain average monthly storages. In other words, if there was a 10 per cent chance that the average monthly storage for October would be 590,000 acre feet, the part of the total expected monthly flood damage that would be contributed from this average monthly storage would be 10 per cent times the damage value obtained by the interpolation previously discussed. All other possible average monthly storages would likewise be used to determine expected damages from the damage table, and these damage values would also be multiplied by their corresponding probabilities of occurrence to determine the remaining parts of the total expected damage. The sum of all the products of expected damages and corresponding probabilities of occurrence would be equal to the total expected flood damage for October.

Mathematically,

\[
F.D._{\text{Oct}} = \sum_{i=1}^{n} (fd_i \times p_i) \tag{5.1}
\]

where,

- \(F.D._{\text{Oct}}\) = total expected October flood damages
- \(fd_i\) = flood damage for the \(i^{\text{th}}\) possible average monthly storage
\[ \pi_i = \text{probability of occurrence of } i^{th} \text{ possible average monthly storage, and} \]

\[ n = \text{number of possible average monthly storages.} \]

In actuality, there were an infinite number of possible average storages for each month. To handle the computation of equation 5.1, the number of possible average monthly storages and their corresponding probabilities of occurrence were determined in the routing program. This program was modified to calculate a monthly stage duration curve of average monthly storages. Hence, for the twenty-year routing period, average monthly storages were tabulated and at the completion of the routing, twelve monthly stage-duration curves had been determined, one for each month. The total expected flood damage for each month was then computed by determining the flood damages corresponding to the midpoints of the intervals of the stage-duration curve and multiplying these damage values by their respective probabilities of occurrence, as indicated by the stage-duration curve.

\[ F.D. j = \sum_{i=1}^{k} (f_{d_i} \times p_i) \quad (5.2) \]

where,

\[ F.D. j = \text{total expected flood damages for the } j^{th} \text{ month} \]

\[ f_{d_i} = \text{flood damage for the storage corresponding to the midpoint of the } i^{th} \text{ interval of the monthly stage duration curve} \]
\[ p_i \] = probability of occurrence of an average monthly storage falling in the \( i \)th interval of the monthly stage-duration curve, and

\[ k \] = number of intervals in the monthly stage-duration curve.

**Stage duration intervals.** The size and position of the storage intervals in the stage-duration analysis have a significant influence on the value of the total expected monthly flood damages. Ideally, the intervals should be small where there may be clusters of average monthly storage values and large where there is a random distribution or scattering of storage values. In the process of routing twenty years of flows, it was expected that a cluster of average monthly storages would occur just below the bottom of flood control storage (or maximum conservation pool). To account for the clustering effect, varied storage intervals were used for each month depending on the monthly flood control reservation. The intervals were set so as to have a small storage interval of 4,000 acre feet centered around the bottom of flood control pool, 25,000 acre feet intervals beneath this first interval for 200,000 acre feet, and 100,000 acre feet storage intervals below this. Hence, the first interval on each month's stage-duration curve had an upper boundary of 2,000 acre feet above bottom of flood control pool and lower boundary of 2,000 acre feet below...
the bottom of flood control pool. The second interval was bounded by an upper limit corresponding to the lower boundary of the first interval and a lower limit of 25,000 acre feet below the upper limit. The number of average monthly storages which fell within the first interval determined the probability of the average monthly storage being within this interval. This probability was then multiplied by the flood damage which would occur for a storage combination indicated by the middle of the interval (i.e., zero supplemental storage) to determine the part of the expected damages contributed by this interval.

IV. FLOOD CONTROL BENEFITS

All the necessary computations for performing the monthly stage-duration analysis and computing the expected monthly flood damages were accomplished in the modified routing program. At the conclusion of the twenty-year routing period, the expected monthly flood control benefits were determined by subtracting the expected monthly flood damages from the monthly pre-project flood damages (the monthly damages that would occur without the reservoir). The pre-project flood damages were calculated similarly to the expected damages on the damage table by integrating the
flow-frequency curve for damages at zero flood control reservation. The summation of the monthly flood control benefits was the total annual expected flood control benefits for 1970.

Thus, the last quantity in the objective function was determined; and the total gross benefits from one particular flood control diagram was then known. The next step in the analysis was to vary the flood control diagram and recompute the operation benefits derived from the second flood control diagram. This step, along with a detailed explanation of the use of the optimization technique, will be discussed in the following chapter.
CHAPTER VI

OPTIMIZATION

I. STARTING BASE

Diagram variables. As mentioned previously, a set of initial or starting variables were required by the univariate technique to begin the search for the optimum flood control diagram. The current flood control diagram shown in Figure 4, page 58, was used as the starting base of the search process; however, because the univariate technique would subsequently modify the initial diagram in its search for the optimum, the flood control diagram had to be expressed in terms of distinct variables. For this purpose, the flood control diagram was defined by two volume variables and five time variables. Table VII lists and defines the seven variables, and a graphic representation of the flood control diagram is given in Figure 6.

TABLE VII

FLOOD CONTROL DIAGRAM VARIABLES

<table>
<thead>
<tr>
<th>VARIABLE NAME</th>
<th>DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAR(1)</td>
<td>Maximum flood control reservation (f.c.r.)</td>
</tr>
<tr>
<td>VAR(2)</td>
<td>f.c.r. at breakpoint in ascending limb</td>
</tr>
<tr>
<td>VAR(3)</td>
<td>Time in days past midnight August 31 (t₀) at which f.c.r. is first reduced</td>
</tr>
</tbody>
</table>
TABLE VII (continued)

<table>
<thead>
<tr>
<th>VARIABLE NAME</th>
<th>DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAR(4)</td>
<td>Time in days past $t_0$ to breakpoint</td>
</tr>
<tr>
<td>VAR(5)</td>
<td>Time in days past $t_0$ to zero f.c.r.</td>
</tr>
<tr>
<td>VAR(6)</td>
<td>Time in days past $t_0$ at which f.c.r. is first increased from zero</td>
</tr>
<tr>
<td>VAR(7)</td>
<td>Time in days past $t_0$ to start of maximum f.c.r.</td>
</tr>
</tbody>
</table>

The ranking of the variables was based on the effect the variables had on the objective function. The variable designated as VAR(1) was the first variable to be optimized in the optimization process; hence, the variable which was thought to have the greatest effect on the objective function was designated VAR(1). By similar reasoning the variable thought to have the least effect was designated VAR(7). In effect, the optimization process is speeded by arranging the variables in this fashion.

The particular selection of variables used to define the flood control diagram restricted the optimum flood control diagram to a basic shape similar to the initial or current flood control diagram. This fact is evident upon a close look at the variable definitions in Table VII, page 70. The flood control diagram is restricted to having a horizontal bottom line at the maximum flood control reservation because VAR(1) is a constant value between VAR(7) and VAR(3). Also, linear descending and ascending limbs are forced upon the
Figure 6. Variables of Flood Control Diagram
(Refer to Table VII, p. 70)
optimum diagram because of the particular selection of the variables. Such a restraint should not significantly affect the validity of the optimum flood control diagram because the shape of the initial diagram also was based on flood probabilities. Hence, this particular shape should be reasonably close to the optimum; and therefore, restricting the optimum flood control diagram to this shape was not an invalidating restraint.

**Alternative starting bases.** The univariate technique is designed so that it will start at the one point defined by the initial values of the variables and proceed from this point to the point at which the greatest value of the objective function occurs. It is possible that the optimum as indicated by the technique could be a relative maximum, and this depends upon the starting base used. To reduce the chances of arriving at a relative maximum value of the objective function instead of the optimum, several different starting bases should be used. If different optimums are indicated by different starting bases, then it can be inferred that some of these optimum values are really only relative maximums. For this reason, many different initial flood control diagrams were used. The optimum diagrams arrived at from each starting base will be discussed in the following chapter.
CHAPTER VII

OPTIMIZATION RESULTS

I. OPTIMIZED FLOOD CONTROL DIAGRAMS

The results of the optimization of the various starting bases brought to light several interesting features. The most significant result was the lack of any of the optimized flood control diagrams re-occurring from different starting bases. Each starting base produced an optimized flood control diagram which was different from the optimized diagrams of all of the other starting bases. However, even though no clear-cut optimum flood control diagram was produced, certain worthwhile conclusions can still be drawn as to what the optimum flood control diagram should look like. Figures 7-11 depict the starting bases and their corresponding optimized flood control diagrams.

In each optimized diagram, the position of the rising limb was at an earlier date than was the rising limb of the current flood control diagram. In other words, regardless of what starting base was used all the various optimized diagrams indicated that a more economical reservoir operation would be to start filling up the reservoir at an earlier date in the spring than the current flood control diagram allows.
Flood Control Reservation
(1,000 Acre Feet)

LEGEND

--- initial diagram
--- Δ optimized diagram
gross benefits in parentheses

Figure 7. Optimization - Current Diagram
Figure 8. Two Optimizations - Modified Diagram No. 1

LEGEND

- initial diagram
- first optimized diagram
- second optimized diagram

gross benefits in parentheses
Figure 9. Optimization - Modified Diagram No. 2

LEGEND

- initial diagram
- triangle optimized diagram

gross benefits in parentheses

Flood Control Reservation (1,000 Acre Feet)

<table>
<thead>
<tr>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
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<td>212</td>
<td>242</td>
<td>273</td>
<td>303</td>
<td>334</td>
</tr>
</tbody>
</table>

($9,057,124)$

($8,811,365)$
Figure 10. Optimization - Modified Diagram No. 3
**Flood Control Reservation (1,000 Acre Feet)**

**LEGEND**

- O — initial diagram
- △ — optimized diagram

Gross benefits in parentheses

Figure 11. Optimization - Modified Diagram No. 4
A second consistent feature found in all the optimized diagrams was the shortened time duration for which the maximum flood control reservation was in effect. As can be seen in Figure 7, page 75, the duration of maximum flood control reservation was no longer than approximately 140 days while the current flood control diagram was 151 days in duration. Thus the duration of the time period for which the flood control reservation is at its maximum value should be shortened in order to achieve a more economical operation.

No firm conclusion could be drawn concerning the value of the maximum flood control reservation. In two of the cases, the optimized flood control diagrams showed maximum reservations greater than the 400,000 acre feet of the current diagram. In the other four cases, the maximum reservation was less than the value of the current diagram. However, the greatest variation in maximum reservation from the current diagram was only 90,000 acre feet, a 23 per cent variation. This would seem to indicate that the current flood control diagram is close to the optimum value for the maximum flood control reservation.

The gross benefits derived from each of the optimized diagrams are shown in the appropriate figures. In all cases, the optimized diagram showed a considerable increase in total
gross benefits. The general increase in benefits over those of the starting base was approximately 4 per cent. This increase represents a significant improvement in reservoir operation since a 4 per cent increase is on the order of $350,000 per year. It should also be pointed out here that each optimized flood control diagram showed an increase in gross benefits over that for the current diagram. Hence, even though diverse starting bases were used, some of which showed as much as a 6 per cent reduction in gross benefits from the current flood control diagram, the operations indicated by all the optimized diagrams represent an improvement over the current flood control diagram.

The starting bases, as shown in Figures 7-11, pages 75 through 79, respectively, were devised to cover all areas around the current diagram. In addition, the current flood control diagram was also used as a starting base. For one of the starting bases, the optimization process was run twice. The optimized flood control diagram was input back into the program as an initial diagram, and the optimization procedure was run again. For this particular case, the improvement in gross benefits was 4 per cent for the first optimization and 2 per cent for the second optimization. The gross benefits from the second optimization were the largest of the optimized diagrams. However, this was the
only case in which the optimization technique was re-run; and thus the optimized flood control diagrams for the other starting bases probably could have been improved if more time was allowed for optimization. Discounting the case in which the second optimization was run, the starting base of the existing flood control diagram showed the greatest gross benefits in the optimized diagram.

Usefulness of results. As described earlier in this chapter, even though no one flood control diagram was conclusively shown to be the one optimum diagram, several useful conclusions could be drawn from the results of this study. Several characteristics of the optimum flood control diagram were indicated by the optimized diagrams. The most important characteristic was concerned with the position of the rising limb of the flood control diagram. All the optimized diagrams had a rising limb which occurred earlier than the rising limb of the current flood control diagram. The conclusion which can be drawn from this occurrence is that the optimum flood control diagram would have an earlier rising limb than the current flood control diagram. This is a very significant finding since the position of the rising limb is the main factor which determines whether or not the summer conservation demands are met. Since the summer period is the most critical conservation benefit period, the significance of an earlier rising limb becomes evident.
A second useful result was the shortened time duration for which the maximum flood control diagram was in effect. Since, once again, all optimized diagrams showed this characteristic, the optimum flood control diagram should also have a shorter time duration than the current diagram.

The fact that none of the maximum flood control reservations of the optimized diagrams varied more than 23 per cent from that of the current diagram indicated that the maximum reservation of the current flood control diagram was close to the optimum value. Hence, the optimum flood control diagram should have a maximum flood control reservation in the vicinity of 400,000 acre feet, a rising limb which occurs earlier than the current diagram, and a shorter time duration for which the maximum flood control diagram is in effect.

The fact that no one specific diagram was arrived at from different starting bases could indicate that the response surface of the objective function is a very complex surface with many peaks. It could also be the result of an inter-dependence among the variables. The univariate technique requires that all the independent variables be independent of each other; and if this condition is not met, the adjustment of one variable can counteract
an earlier adjustment causing the resultant optimized solutions to wander. However, the variables in this study appear to be independent; and so that above explanation probably does not apply here. A third explanation could be the order in which the variables were optimized. As mentioned earlier, the order of the variables has a bearing on the speed at which the optimized solution is reached. A poor choice in ordering the variables could require more than three cycles for the univariate technique to reach the optimum.

II. ADDITIONAL WORK

The possible explanations given above to account for the lack of a consistent optimized flood control diagram point out the possibilities for further experimentation with the response surface. On the basis of these explanations, several new approaches could be taken to generate the optimum diagram. If the problem is a many-peaked response surface, using many more starting bases would point this fact out since a common optimum diagram would eventually appear. If the problem is a dependency among the variables, the problem could be circumvented by changing the variables. Finally, if a poor order of variables is the cause, a re-ordering would correct this. Thus, it would be possible to devote a considerable
research effort simply to an examination of the results of this study.

III. APPLICABILITY

**Succeeding diagrams.** As mentioned at an earlier stage in this report, the technique for selecting the optimum flood control diagram was developed with the intention of making recomputation of succeeding diagrams as easy task. An entire recomputation for Folsom Reservoir can be made by simply changing the economic input to reflect the changed economic conditions. This would involve at most changing the recreation densities, the power demand and unit rates, and the water supply demand and average rate. It should not be unreasonable to expect that a new flood control diagram could be produced with only two days of economic legwork. The computer time spent in calculating each of the optimized diagrams in this study was approximately four minutes on a CDC 6600, a third generation computer.

**Other reservoirs.** The modifications necessary to adapt this technique to another single multipurpose reservoir would entail changing the reservoir parameters and recomputing the damage table, in addition to deriving new economic relationships. The damage table for another stream location may be computed with the modified Flood Hydrograph
Package as changed to account for the flow characteristics and reservoir operating rules which would apply. The modified Reservoir Yield program could be used to derive the optimum flood control diagram by inputting the necessary reservoir parameters, economic relationships, and the damage table as computed in the modified package program.

There are two parameters which are needed to apply this technique to another reservoir which could necessitate some additional considerations. First, the monthly flood factors which were used to distribute the annual flood damages among the months have not been calculated for all streams. Hence, to apply the technique to another reservoir would most likely require that a similar monthly analysis of the annual flooding be made. Second, the release capacity at Folsom is great in comparison to the flood control storage; and hence, it was concluded that it would always be possible to start each month with a reservoir storage no greater than the bottom of flood control pool. However, a great many reservoirs are operated in the flood pool for long periods of time, and the same conclusion could not be reached for these reservoirs. A slight modification in the Flood Hydrograph Package to include negative supplemental storages in the damage table would be the only change necessary
to account for this possibility. In this way, the occurrence of a flood at a time when the reservoir was in flood control pool could be accounted for.

IV. SUMMARY

The technique developed in this study, although not producing a clear-cut optimum flood control diagram, did however, provide some useful results. Certain characteristics of the optimum flood control diagram became apparent in the optimized diagrams that were produced with the technique. Thus, the technique as herein developed will provide meaningful information concerning the optimum operating policy of a single multipurpose reservoir.
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APPENDIX

APPENDIX

II. FLOOD HYDROGRAPH PACKAGE

Of the two computer programs used in this study, the first was the Flood Hydrograph Package. In essence this program, before modification, was designed to handle "all ordinary flood hydrograph computations associated with a single reservoir or pump-controlled system, including routing through channels and through open-choke storage in a function of storage and inflow." (J. C. Avery Cripps, Engineer, 1959.) The particular limitations that the modified program served in this study were computation of four balanced inflow hydrographs and the routing of each of these hydrographs through Poison Reservoir. However, to route these four hydrographs a modification was required to enable the routing to be done with the variably-gated valve structure that is found at Poison Dam.

To construct the design table from these routings, it was necessary to make several additions to the program. The first concern was the addition of a design-flow curve from which the design corresponding to the peak release could be calculated. In addition to integrate the flow-frequency curve for design, we also wanted to include the damage values at the four representative floods would be used to determine the expected damage for all flood-producing flows. Finally, the inclusion of a "DO LOOP" to repeat this damage integration for all possible 100,000 cases and calculations of flood control, reservoir, and supplemental storage was made, and this enabled the comparison of all values for the damage table. The output from this program, in the form of punched cards with the damage table values, was read in the reservoir yield package.

II. RESERVOIR YIELD PACKAGE

The principal purpose in this study was the Reservoir Yield program as modified to include the benefit analyses.
APPENDIX A

COMPUTER PROGRAMS

I. FLOOD HYDROGRAPH PACKAGE

Of the two computer programs used in this study, the first was the Flood Hydrograph Package. In essence this program, before modification, was designed to handle "All ordinary flood hydrograph computations associated with a single recorded or hypothetical storm, including routing through channels and reservoirs where outflow is a function of storage and inflow." (U. S. Army Corps of Engineers, 1969.) The particular functions that the unmodified program served in this study were computation of four balanced inflow hydrographs and the routing of each of these hydrographs through Folsom Reservoir. However, to route these four hydrographs a modification was required to enable the routing to be done with the variable-gated release structures that is found at Folsom Dam.

To construct the damage table from these routings, it was necessary to make several additions to the program. The first concern was the addition of a damage-flow curve from which the damage corresponding to the peak release could be calculated. An addition to integrate the flow-frequency curve for damages was also input so that the damage values of the four representative floods could be used to determine the expected damage for all flood-producing flows. Finally, the addition of a "DO LOOP" to repeat this damage integration for all possible 100,000 acre feet combinations of flood control reservation and supplemental storage was made, and this enabled the computation of all values for the damage table. The output from this program, in the form of punched cards with the damage table values, was used in the Reservoir Yield program.

II. RESERVOIR YIELD PROGRAM

The principal program in this study was the Reservoir Yield program as modified to include the benefit analysis
and optimization routine. In its unmodified form, this program "... performs any number of multipurpose routings under identical conditions for a single reservoir with optional delivery to pipe line (sic) or river or both and with maximum and minimum flood controls at the reservoir and, if desired, at one downstream control point." (Beard, 1966.)

Additions to this program were necessary to compute the gross benefits from conservation purposes, tabulate a stage-duration curve, compute flood control benefits, and optimize the objective function.

Optimizing technique. A univariate subroutine as developed by Leo R. Beard was the optimizing technique added to the routing program. This subroutine was used with only minor changes in the output to select the optimum flood control diagram.

III. NEW VARIABLE NAMES

Below is a list of some of the variable names which were added to the Flood Hydrograph Package and Reservoir Yield programs. Definitions are given opposite the variable name.

**Flood Hydrograph Package.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAM(KK)</td>
<td>KK(^{th}) damage point on the damage-flow curve in $1,000,000.</td>
</tr>
<tr>
<td>FLDM(IJ,JX,IB)</td>
<td>flood damage in $1,000,000 from IB(^{th}) flood with flood control reservation of (IJ-1) x 10(^6) acre feet and supplemental storage space of (JX-1) x 10(^6) acre feet</td>
</tr>
<tr>
<td>IBAL</td>
<td>number of floods to be routed</td>
</tr>
<tr>
<td>ICAP(IJ,JX)</td>
<td>initial storage in acre feet before routing begins (equal to (IJ-1) x 10(^6) acre feet flood control reservation and (JX-1) x 10(^6) acre feet supplemental space).</td>
</tr>
</tbody>
</table>
NPF
PEKFLO(KK)
PFLDM(IJ,KX)
QHI(I,IB)
STORA
TMAX(IJ,JX,IB)

- number of points on damage-flow curve
- KKth peak flow in 1,000 cfs on the damage-flow curve
- entries in annual damage table; expected annual damage for (IJ-1) x 10^6 acre feet flood control reservation and (JX-1) x 10^6 acre feet supplemental space
- Ith balanced ordinate of IBth hydrograph in cfs
- total storage at bottom of flood control pool in acre feet
- (subsequent to statement 1757) total storage in reservoir at beginning of flood routing in acre feet
- maximum release in cfs for the IBth flood with (IJ-1) x 10^6 acre feet of flood control reservation and (JX-1) x 10^6 acre feet of supplemental space.

The above variables represent the important variables which were added to the Package program. Additional variables were added but they were unique to the particular routing used for Folsom, and hence, they will not be defined here.

Reservoir Yield Program.

UVRD
PR
DPR
RD(I)
PWSB(I)
AVR
TOD
VAR(JJ)
FCR(I)

- unit value of recreation day ($X.XX)
- power rate; the price of 1,000 KW-HR of firm power as charged to power purchasers
- dump power rate; the price of 1,000 KW-HR of dump power as charged to power purchasers
- recreation density in rec-days/acre of reservoir surface area; one value for each month
- periods water supply benefit (a target value in $X.XX; one value for each month
- Average loss rate for shortages in projected water supply volumes ($X.XX/AF)
- storage in reservoir (AF) at point just where dam is being overcrested; storage when stage is at top of dam
- variables which described the flood control diagram
- average monthly flood control reservations in 100,000 AF; determine from input flood control diagram
STRMXX(I) - average monthly conservation storage in AF corresponding to the average monthly FCR(I); (ex: STRMXX(I) = 1010000 - FCR(I) * 100,000) (Note gross pool = 1,010,000 acre feet).

IV. REQUIRED INPUT

Flood Hydrograph Package. Since this program would have to be substantially altered to reproduce an expected annual damage table for another location, the necessary input will not be listed here. For the input for the unmodified program, the reader should contact The Hydrologic Engineering Center in Davis, California. The source deck for the program used in this study is on file at the Center also.

Reservoir Yield. Table VIII gives the additional input required for the Reservoir Yield program. For the intervening input cards, contact the Hydrologic Engineering Center for a description of the Reservoir Yield program.

V. COMPUTER LISTINGS

On the following pages are the modifications to both the programs. Some of the statements on these pages are identical to the ones in the unmodified program, but they have been included herein to give a point of reference for the additions. Both source decks are on file at the Hydrologic Engineering Center, 609 Second Street, Suite I, Davis, California 95616.
### TABLE VIII
New and Amended Input Cards
(Reservoir Yield)

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>STRMXX(I)</td>
<td>NPER Values</td>
</tr>
<tr>
<td>FCR(I)</td>
<td>NPER Values</td>
</tr>
<tr>
<td>PWSB(I)</td>
<td>NPER Values</td>
</tr>
<tr>
<td>RD(I)</td>
<td>NPER Values</td>
</tr>
<tr>
<td>VAR(JJ)</td>
<td>(No. of Diagram) Values</td>
</tr>
</tbody>
</table>

**Legend:**
- VARIABLE NAME = New variable
- VARIABLE NAME = old variable
- X = new card
- X = old card

**The # of blank cards shown between the cards above should be replaced by the correct # of input cards. Blank cards simply indicate a break between the cards shown above.**
MODIFICATIONS TO FLOOD HYDROGRAPH
PACKAGE PROGRAM

DIMENSION PPFD(12), WTF(12,16), MFLDM(12), 
    1FLBENS(12), FCR(12), SSTOR(27), EL(27)
DIMENSION STRMX(12), WTF(12)
DIMENSION DFHCR(11), SS(18), FIFD(18), TFLDM(12)

Intervening Statements - Refer to Source Deck

DO 70 J=1,12
    TFLDM(I)=0.
    MFLDM(I)=0.
    70 CONTINUE
DO 80 JX=1,11
    DO 80 I=1,6
        PFLDM(I,JX)=0.
        80 CONTINUE
90 CONTINUE
NPF=0
READ2, (EL(I), I=1,NSTOR)
READ2, (SSTOR(I), I=1,NSTOR)
C READ ELH-ELV VS O TABLE, TICGA
READ 14, XPT, YOT
NPT=XPT+.1
NOT=YOT+.1
PRINT 15, NPT, NOT
INC=NOT+1
DO 91 I=1,NPT
    J=1+2*INC* (I-1)

(next statement on following page)
(continued from preceding page)

C ENTER HAMMOND ELEV PARAMETER
READ 14, U(J)
JUS=J+INC
U(JUS)=U(J)
PRINT 16, U(J)
C 91 K=1, NOT
L=J+K
READ 14, U(L), U(L+INC)
C PRINT RATING TABLE
91 PRINT 17, U(L), U(L+INC)

Intervening Statements - Refer to Source Deck

READ 2, STORM, SPEE, DMS, TPSOC, TPSDA, STRTL, CNSTL, RTIMP, ORCSN, STOR,
ISTRTO, ENERGY, TPAPS, RATIO, TEMP, HP, CP, ALAT, ELEV, TENNP
PRINT 185, STORM, SPEE, DMS, TPSOC, TPSDA, STRTL, CNSTL, RTIMP, ORCSN, RTIOP
185 FORMAT (/B9H, STORM, SPEE, DMS, TPSOC, TPSDA, STRTL, CNSTL, RTIMP, ORCSN, RTIOP
1T L RTIMP, ORCSN, RTIOP/4F8.2, FR.7, 3F8.2, FR.0, FR.2)

Intervening Statements - Refer to Source Deck

C * * ** ** READ HYDROGRAPH SUPPLIED * * ** ** ** ** ** ** ** ** **
1112 READ 2, ((OHT(I, IB), I=1, NC), IB=1, 3)
DA(IH)=TPSDA
VOL=TPSDA%645./TPH
IF (IDERY.GT.9) GO TO 1200
IF (ISTM.GT.1) PRINT 985, ISTM, TRDA(ISTM)

Intervening Statements - Refer to Source Deck
93
1250 IF(AVG.GT.0.) GO TO 1270

CALCULATING AVG BALANCED HYDR ORDINATES FOR IR HYDROGRAPHS

DO 1262 IR=1,3
DO 1250 I=2,NO
JX=NO+1+2
OH(JX)=(OH(I,JX,IR)+OH(I,JX-1,IR))*0.5
OH(JX,IR)=OH(JX)
1260 CONTINUE

OH(1,IR)=OH(1,IR)
1262 CONTINUE

DO 1270
1265 IF(AVG.LE.0.) GO TO 1270
TM=NO-1
DO 1268 I=1,TM
OH(I)=(OH(I)+OH(I+1))*0.5
1268 OH(1,IR)=OH(1)

Intervening Statements - Refer to Source Deck

1730 AK=(Q(J)-QTEL(I-1))/(QTEL(I)-QTEL(I-1))
IF (AK.LT.0.) AK=0.
STOR=AK*STOR(I-1)+(1.-AK)*STOR(I)
GO TO 1750
1740 DO 1743 JX=1,11
1742 JJ=1,6
TCP=M(1,JX)=100000-100000*(IJ-1)-100000*(JX-1)
1742 CONTINUE

1743 CONTINUE

IF=1.0
DO 1780 IR=1,3
DO 1770 JX=1,11
DO 1778 JJ=1,6
TCP=M(I,JX,TM)=0.
IF (TCP(J,JX,LT.10000) GO TO 1778
STOR=TCP(J,JX)
STOR=STOR+12.1/TMP+(1776/2.)
C ROUTING COMPUTATION
1750 TM=3770.
PRINT 1751,STOR,STRI,TMP,IJ,JX,IR
1751 FORMAT (3F20.0,3I3)
SUM=0.
IND=0
IND=0
DO 1776 I=1,NO
IF (IND.GE.1) GO TO 1773
DIF=0.
SIFE=0.
STRA=(STRI-TMP)*5)/TPH+12.1
STRI=STRI-TMP+OH(I,IR)
DO 1753 K=2,10
IF (STRI.LT.STOR(I-1)) GO TO 1754
1752 IF (STRI.LE.STOR(I)) GO TO 1755
1753 CONTINUE

(next statement on following page)
(continued from preceding page)

\[ k = 10 \]
\[ \text{GO TO 1755} \]

1754 \[ k = k - 1 \]
\[ \text{IF (} k \geq 0 \text{, GO TO 1756} \]

1755 \[ \text{IF (} \text{STOP}(k) \text{, GT, STOP}(k-1) \text{, GO TO 1757} \]

1756 \[ \text{TOTTEL} = \text{OUTTEL}(k) \]
\[ \text{GO TO 1758} \]

1757 \[ \text{IF (} k = \text{STOP}(k-1)/(\text{STOP}(k)-\text{STOP}(k-1)) \text{, AK = 0,} \]
\[ \text{TOTTEL} = \text{OUTTEL}(k) \times \text{AK} \text{, GTTEL}(k-1) \times (1-\text{AK}) \]

1758 \[ \text{STOP} = 1000000 \times (1 - 1000000 \times (I - 1)) \]
\[ \text{IF (} \text{STOP}, \text{GT}, 1191718 \text{, GO TO 1759} \]
\[ \text{IF (} \text{INDI}, \text{EQ}, 1 \text{, GO TO 1760} \]

1759 \[ \text{COMPUTING SUM OF THE 24 FOLLOWING INFLOWS} \]
\[ \text{IF (} k = 1, \text{GT}, \text{STOP} \text{, GO TO 3759} \]
\[ m = m + 1 \]
\[ \text{GO TO 1759} \]

3759 \[ \text{IF (} k = 2 \text{, GT}, \text{STOP} \text{, GO TO 3759} \]

4759 \[ \text{STOP} = \text{STOP} + \text{SEFF} - 24 \times \text{STOP} + \text{SEFF} \]

1760 \[ \text{TESTING TO SEE IF FLOOD CONTROL RELEASES ARE NECESSARY} \]
\[ \text{IF (} \text{STOP}, \text{GT}, \text{STOPA} \text{, GO TO 1760} \]
\[ \text{TEMP} = \text{TEMP} \]
\[ \text{NCASE} = 1 \]
\[ \text{GO TO 1774} \]

1760 \[ \text{TEMP} = 5000 + \text{TEMP} \]
\[ \text{NCASE} = 1 \]
\[ \text{IF (} \text{TEMP}, \text{GT}, 115900 \) \text{, TEM} = 115900 \]
\[ \text{IF (} \text{TEMP}, \text{GT}, \text{STOP} \text{, TEM} = \text{STOP} \]
\[ \text{IF (} \text{STOP}, \text{GT}, 730000 \text{, AND, IND}, \text{EQ}, 1 \text{, GO TO 1763} \]
\[ \text{IF (} \text{STOP}, \text{LT}, 730000 \text{, AND, IND}, \text{EQ}, 1 \text{, GO TO 1774} \]

1760 \[ \text{TESTING TO SEE IF RESERVOIR STAGE CAN BE KEPT BELOW GROSS POOL} \]
\[ \text{WITH RELEASES LIMITED TO PROJECT QUANTITIES} \]
\[ \text{NCASE} = 1 \]
\[ \text{NO1} = \text{NO1} - 1 \]
\[ \text{GO TO 1761} \]

1761 \[ \text{J = I, NO1} \]
\[ \text{ITR} = I - 1 \]
\[ \text{IF (} \text{ROF}, \text{GT}, 115900 \) \text{, ROF} = 115900 \]
\[ \text{IF (} \text{OH} \times (J, I), \text{LT, ROF, AND, OH} \times (J+1, I), \text{LT, OH} \times (J, IR)) \text{GO TO 1762} \]
\[ \text{IF (} \text{OH} \times (J, IR), \text{GT, ROF, AND, I, EQ, NO1) GO TO 1763} \]

1761 \[ \text{CONTINUE} \]

1762 \[ \text{STOP} = \text{STOPA} + \text{ROF} \]
\[ \text{IF (} \text{STOP}, \text{GT}, 1010000 \text{, GO TO 1763} \]
\[ \text{GO TO 1774} \]

(next statement on following page)
computing values necessary for tbs subroutine

interpolation for pool elevation

1763 indi = 1
  if (toufel.ge.115000.) go to 1764
  temp = toufel
  ncase = 3
  go to 1765

1764 temp = 115000.
  ncase = 4

1765 if (stra.lt.733000.) go to 1774
  dc 1767 l = 2, nst0r
  if (stra = storn(l)) 1769, 1768, 1767

1767 continue

1768 tmpe1 = fl(l)
  go to 1770

1769 tmpe1 = (fl(l) - fl(l-1))*(stra-sstor(l-1))/(sstor(l) - sstor(l-1)) +
  tfl(l-1)

1770 if (tmpe1.ge.474.5) go to 1771
  if (case..1) phi = 7776.
  if (case.2) phi = phi(1-1, ir)
  call trs(1, inc, npt, tmpe1, ot1, o, 1, phi, 1, -1)
  if (ot1.gt.temp) temp = ot1
  go to 1774

1771 temp = toufel
  ncase = 5
  go to 1774

1772 temp = oh(i, ir)
  ncase = 6
  go to 1774

1773 temp = temp
  ncase = 7

1774 if (oh(i, ir).lt.temp and i.gt.30) ind = ind + 1
  if (ind.ge.3) go to 1778
  str(i) = (str(i)-temp*.5)*temp/12.1
  if (str(i).gt.181718.) go to 3774
  if (temp.gt.oh(i-1, ir)) go to 3774
  go to 3775

3775 temp = oh(i, ir)
  ncase = ncase + 1
  str(i) = (str(i)-temp*.5)*temp/12.1
  3775 print 1775, i, str(i), oh(i, ir), temp, oh(i, ir), str(i), k, outel(k),
  1st0r(k), ncase

1775 format(14, 5f10.0, e10.8, 2e10.8, 15)
  if (temp.gt.twax(i, jx, ir)) twax(i, jx, ir) = temp
  temp = temp
  sum = sum + temp
  continue

1776 continue

1777 print 1777, sum

1778 continue

1779 continue

1780 continue

(continued from preceding page)
Reading in Damage Curve

1781 FORMAT (I1, (PEKFL0(KK), DAM(KK), KK=1, NPE))

Computing Flood Damages for Each (TR) Flood and for Each Combination of Flood Control Reservation (IJ) and Supplementary Storage (IV)

DO 1782 KK=1, NPE
PEKFL0(KK)=PEKFL0(KK)*1000.
DO 1782 KK=1, NPE

1782 CONTINUE

DO 1792 IB=1, 3
DO 1791 JX=1, 11
DO 1790 JJ=1, 6
IF (PEKFL0(1), GE, TMAX(IJ, JX, IB)) GO TO 1787
DO 1793 KK=2, NPE
IF (PEKFL0(KK)-TMAX(IJ, JX, IB)) 1783, 1784, 1785

1783 CONTINUE

1784 FLOW(IJ, JX, IB)=DAM(KK)
GO TO 1786

1785 FLOW(IJ, JX, IB)=((DAM(KK)-DAM(KK-1))/(PEKFL0(KK)-PEKFL0(KK-1)))*
(TMAX(IJ, JX, IB)-PEKFL0(KK-1))+DAM(KK-1)

1786 IF (IB.EQ.2) FLOW(IJ, JX, IB)=2000.*FLOW(IJ, JX, IB)
IF (IB.EQ.3) FLOW(IJ, JX, IB)=6000.*FLOW(IJ, JX, IB)
IF (IB.EQ.4) FLOW(IJ, JX, IB)=20000.*FLOW(IJ, JX, IB)
PEFL0(IJ, JX)=FLOW(IJ, JX, IB)+PFLOM(IJ, JX)
GO TO 1788

1787 FLOW(IJ, JX, IB)=0.

1788 PRINT 1789, IJ, JX, IB, TMAX(IJ, JX, IB), FLOW(IJ, JX, IB)
1789 FORMAT (315, 2F10.0)
1790 CONTINUE
1791 CONTINUE

1792 CONTINUE

PFLOM(IJ, JX)=PFLOM(IJ, JX)+340222.
PFLOM(IJ, JX)=PFLOM(IJ, JX)+235919.
PRINT 1793, ((IJ, JX, PFLOM(IJ, JX), JX=1, 11, IJ=1, 6)
1793 FORMAT (1X, 3Il=1, 15, I13, JX=1, 15, 3X, BADAMAGES=, F13.0)
PUNCH 19, ((PFLOM(IJ, JX), IJ=1, 6, JX=1, 11)
TRANS=3

Intervening Statements - Refer to Source Deck
MODIFICATIONS TO RESERVOIR YIELD PROGRAM

PROGRAM KITTE (INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT, TAPE7, TAPE9, TAPE10, TAPE24, TAPE23, TAPE25, TAPE13)

DIMENSION FEFZ(10), TOTREM(3), VAR(10), SUNDAYS(20), SSTRMX(20)
DIMENSION SSTRXX(17), PFLD(10, 11), NWTEF(12), DPEF(12), FCR(20),
IDFCR(16), SS(17), F1FD(17), TFLDM(12), FLBEN(12), DDAYS(20)
DIMENSION POUT(12), PINT(12), PR(12), W(12, 18), X(12, 18),
LSILB(12, 18), XTEF(12, 18), PW5B(12), DAYS(12), SHTRAV(12), DBFS(12),
2ADBFS(12), AWSB(12), SSS(17)
DIMENSION NDAYS(15), STOR(40), AREA(40), FL(40), PDPW(15), QDCAP(10),
20RTS(15), FFLMT(15), QUALD(15), QUAL(10), OQ(40), QLUQ(10),
30LQUA(10), STRMX(15), STRMN(15), STM2(15), FCAP(15), DT(15), QL(15),
4SHRTD(15), SHRTD(15), POWER(15), ATS(15), LCS(15), OR(16), ALSA(15), OSC(15)
DIMENSION EFCY(10), ELEVY(10), QUTAQ(15), QD(15), M(15), STORB(15),
200STR(10), QMIN(15), QMIN2(15), QMAX(15), QMIN(15), QMAX(15),
30RT(15)
DIMENSION IND(6), UL(6), C(6), INDD(6), ULL(6), CC(6), OSCP(10),
10SS(10), AVAR(13)
COMMON/ALPHA/TAPE7, JTRNS, MX, NCC, LOGST, M1, NCC
REAL MUTE
KST5R=40
KPER=15

THREE OUTPUT TITLE CARDS
BRANCH TO 10 FROM 3390.01 3390.02 3710.03
10 PRINT 20
BRANCH TO 20 FROM 3640.08
20 FORMAT (1H1)
REWIND 7
READ 30, (STOR(I), AREA(I), FL(I), I=1, 140)
PRINT 30, (STOR(I), AREA(I), FL(I), I=1, 140)
30 FORMAT (1X, A1, 39A2)
READ INPUT-OUTPUT CONTROL CARD
ITAPE=TAPE NUMBER CONTAINING HISTORIC DAILY FLOWS, USE 5 FOR CARDS
JTAPE=TAPE NUMBER CONTAINING SYNTHETIC MONTHLY FLOWS, 5 FOR CARDS
CONS = IF SYNTHETIC MONTHLY FLOWS ARE IN CFS-DAYS
CONS = 1000. IF SYNTHETIC MONTHLY FLOWS ARE IN THOUSAND CFS-DAYS
CONS = -1. IF SYNTHETIC MONTHLY FLOWS ARE IN CFS
CONS = .504167 IF SYNTHETIC MONTHLY FLOWS ARE IN ACRE-FEET
CONS = 504.167 IF SYNTHETIC MONTHLY FLOWS ARE IN THOUSAND ACRE-FEET
CONS = 20.9384 IF SYNTHETIC MONTHLY FLOWS ARE IN INCHES
DELT = INCREMENT TO BE ADDED TO FLOWS
ISKIP=NUMBER OF RECORDS TO WASTE BEFORE READING DAILY FLOW TAPE
ISTART=0 FOR READING IN FIRST TWO DAYS OF RECORD, 1 FOR ESTIMATING
IPRNT = -1 FOR GRAND AVG OUTPUT, 0 OR +1 FOR MONTHLY AND DAILY OUT

(next statement on following page)
(continued from preceding page)

READ 40, ITYPE, ITAPE, ISKIP, CCONS, JTAPE, DELT, ISTART, NY, TOD, IVRO,
1PR, DPR, AVR

C BRANCH TO 40 FROM 30.14

40 FORMAT (1X, I7, 218, F8.0, I8, F8.0, 218, 2F8.0 /1X, F7.0, 9E8.0)
LLL=0
C READ KEY DATA AND INITIATE VARIABLES
READ 120, NYRS, IYR, NPER, IPER, NDYS, KSTOR, NCYCL, IACEF, NCMP, IPRT
IYR = IYR-1
IF (NPER - KPER) 50, 50, 60
50 IF (KSTOR - KSTOR) 80, 80, 60
60 PRINT 70
70 FORMAT (19H DIMENSION EXCEEDED)
STOP
C BRANCH TO 80 FROM 50.00
80 IF (NYRS) 90, 90, 100
90 STOP
C BRANCH TO 100 FROM 80.00
100 READ 110, STOR1, CONST, QOMN, QAN2, QOMX, QDMN, QDXM, ORTS, FALT, QULD, QUR(1),
1STMX, STMN, STMN2, PFR, PHRMX, EFFCY, TLWEL, QCAP, EVAP, ALGSS, GLOSS, HYDLS,
2FURS, OVLOD, QSEC, SURCH, DELMX
110 FORMAT (1X, F7.0, 9E8.0)
C BRANCH TO 120 FROM 40.03 430.00
120 FORMAT (1X, I7, 9I8)
AZ=0.
BZ=0.
CZ=0.
NECF=0
NECF1=0
NECF2=0
NECF3=0
NECF4=0
KKK=0
IX=0
QISC=0.0
NO = 0
QAL1 = 0.
IF (QSEC) 130, 140, 140
130 QISC = QSEC

Intervening Statements - Refer to Source Deck
480 FORMAT(/37H ALOSS, CLASS, HYDLS, FULBR, OVL0D)
PRINT 520, ALOSS, CLASS, HYDLS, FULBR, OVL0D
IYR=1YR
NVAP=7
IDG=1
IDERV=1
PRINT 530
PRINT 3700
READ 110, (VAR(JJ), JJ=1, NVAP)
IF (IDERV .EQ. 0) GO TO 510
DO 490 JJ=1, NVAP
IF(2(JJ)=0)
BRANCH TO 490 FROM 480.10
C
500 IF(1ST .EQ. 1)
DO 490 JJ=1, NVAP
BRANCH TO 500 FROM 3670.02 3680.01
C
510 N=0
BRANCH TO 520 FROM 480.01
C
520 FORMAT(/F6.0, F8.4, F8.5, F9.0, F8.3)
530 FORMAT(/F6.0, F8.4, F8.5, F9.0, F8.3)
C
RE-ENTRY FOR NEW CYCLE
C
540 STORE=STORE1
IF (1ST .EQ. 0) GO TO 570
IF (NC-1) EQ 1560, 550, 550
C
550 READ 120, NVAP, IYR
C
560 NC = NC + 1
C
570 SANSR=0.
GTRB=0.0
GFB=0.0
TFLB=0.
TEMP=NYRS
NYRS=1./TEMP
SRMM=0.
SAMN=0.
C
Intervening Statements - Refer to Source Deck
STMAX=0.
ST MIN=F

IF (IERST.NEQ.0) PRINT 20
DO 579 I=1,NPER
DO 578 NSI=1,19
NIS(I,NSI)=0
578 CONTINUE
TRMT(I)=0.
TFLDM(I)=0.
DBFWS(T)=0.
579 CONTINUE
IF (IERST.EQ.0) GO TO 600
PRINT 580,1
580 FORMAT(/6H CYCLE,13)
590 READ 110, (RD(I), I=1,NPER)
READ 110, (PWS8(I), I=1,NPER)
READ 110, (PFO(I), I=1,NPER)
READ 110, (STMXX(I), I=1,NPER)
C BRANCH TO 600 FROM 570.36

600 DD 3010 J=1,NYRS
C AFTER FIRST YEAR OF FIRST CYCLE, N=1. FIRST YEAR N=0
AH = N
IF (IERST.EQ.0) GO TO 650
IF (NDYS+4) 610,650,650
610 READ 120, NDAYS(I), I=1,NPER)
DO 620 I=1,NPER
DAYS(I)=NDAYS(I)
C BRANCH TO 620 FROM 610.01
620 CONTINUE
SNDEAS(I)=0.
DO 630 I=9,12
SNDEAS(I)=SNDAYS(I-1)+DAYS(I)
DAYS(I)=DAYS(I)
C BRANCH TO 630 FROM 620.02
630 CONTINUE
DO 640 I=13,20
SNDAYS(I)=SNDAYS(I-1)+DAYS(I-12)
DDAYS(I)=DAYS(I-12)
C BRANCH TO 640 FROM 630.01
640 CONTINUE
650 SNDYS=0.
JND=0
DO 660 I=1,NPER
ANDYS=NDAYS(I)
MMD=IPFR+(I-1)
IF (MMD.GT.12) MMD=MMD-12
IF (IYR/4) .EQ.1YR. AND. MMD.EQ.2. AND. IYR.NE.1900) ANDYS=29.
C BRANCH TO 660 FROM 650.02
660 SNDYS=SNDYS+ANDYS
IF (IERST.EQ.0) GO TO 1250
IF (QOMN+AN) 680,670,670
670 IF (N) 690,690,720
C BRANCH TO 680 FROM 660.02
680 READ 110, (QOMN(I), I=1,NPER)

Intervening Statements - Refer to Source Deck
1190 IF(EVAP) 1240,1200,1200
1200 DO 1230 I=1,NPER
    IF(STRMN2(I)-STRMN(I))1210,1220,1220
1210 STRMN2(I)=STRMN(I)
    BRANCH TO 1220 FROM 1200.01
1220 TEMP = NDAYS(I)
    TEMP=TEMP/SMDYS
    BRANCH TO 1230 FROM 1200.00
1230 EVAP0(I) = EVAP*TEMP
    BRANCH TO 1240 FROM 1190.00
1240 READ (JTAPF,1280) (Q1(I),I=1,NPER)
    WRITE (13) (Q1(I),I=1,NPER)
    GO TO 1260
1250 READ(13) (Q1(I),I=1,NPER)
    BRANCH TO 1260 FROM 1240.02
1260 N=1
    IF(QDMN) 1270,1290,1270
    READ 1280,(Q1(I),I=1,NPER)
    INITIATE ANNUAL SUMS
    BRANCH TO 1280 FROM 1240.00 1270.00
    BRANCH TO 1290 FROM 1260.01
1290 SM0MN=0.
    YRBT=0.0
    APR=0.0
    SM0MX=0.
    SFTTIMG UPPER AND LOWER BOUNDARIES T STORAGE INTERVALS
    SETTING UPPER AND LOWER BOUNDARIES OF STORAGE INTERVALS
    SILBI(I,1)=STRMX(I)+2000.
    SILBI(I,2)=STRMX(I)-2000.
    DO 2240 MS1=3,10
    SILI(I,NS1)=(STRMX(I)-2000.)-25000.*(NS1-2)
    GO TO 1290

Intervening Statements - Refer to Source Deck

Intervening Statements - Refer to Source Deck
(continued from preceding page)

C 2240 CONTINUE
    BRANCH TO 2240 FROM 2230.02
DO 2250 NST=11,18
    BRANCH TO 2250 FROM 2240.01
SILB(I,NSI)=SILB(I,10)-100000.*(NSI-10)
C 2250 CONTINUE
C CALCULATING NUMBER OF STORAGES GE. THE LOWER BOUNDARY OF EACH
C STORAGE INTERVAL
C 2260 DO 2270 NSI=1,18
    BRANCH TO 2260 FROM 2220.00
IF (STRAV GE SILB(I,NSI)) NISI(I,NSI)=NISI(I,NSI)+1
C 2270 CONTINUE
    DO 2290 I=2,NSTOP
    K=L
    IF(SILB-STOR(K))2320,2320,2280
    K=K-1
    IF(STOR(K)-STOR(K-1))2300,2330,2290
C 2290 CONTINUE
    GO TO 2310
    BRANCH TO 2300 FROM 2280.00
C 2300 K = K - 1
    BRANCH TO 2300 FROM 2290.00
C 2310 PRINT 1450
    BRANCH TO 2320 FROM 2270.03
C AREA = (STRAV-STOR(K-1))*(AREA(K)-AREA(K-1))/STOR(K)-STOR(K-1)
C ECONOMIC ANALYSIS ** RECREATION BENEFITS
    BRANCH TO 2630 FROM 2610.01
C ANNUAL SUMS
C 2630 CONTINUE
    ND=NDAYS(I)
C 2640 CONTINUE
    ECONOMIC ANALYSIS ** POWER BENEFITS
    PC=POWER(I)-POWER(I)
    IF(PC)2660,2660,2650
    PR=POWER(I)*PR+PC*DPR
    GO TO 2670
    BRANCH TO 2660 FROM 2640.03
C 2660 PR=POWER(I)*PR
    BRANCH TO 2670 FROM 2650.01
C 2670 APR=APR+PB
    SMBMN=SMBMN+OMIN(I)*CT
    SMAMN=SMAMN+OMIN2(I)*CT
Intervening Statements - Refer to Source Deck
**COMPUTING PERIOD'S DEFICIT IN WATER SUPPLY BENEFITS (DBFWS)**

\[
QTEMP = ORIVE
\]

**SHTRA(V(I)) = SHRTA*AVR

\[
DBFWS(I) = DBFWS(I) + SHTRA(V(I))
\]

**STORA = STORP(I)

\[
IF(ZPENT) = 0*
\]

**IF(SHPTA.CT.0.) SMTPAV(15) = SHRTA * DAYS(I)*1.9835*AVR

\[
DREWS(I) = DBFWS(I) + SHTRA(I)
\]

**STORA = STORP(I)

\[
IF (I) = 2740, 2710, 2710
\]

**PRINT 2720, (T(I), P(I), RPM(I), RPM2(I), STORR(I), STORMX(I), SHAPA,

\[
QMIN(I), QPR, SHRTA, QMIN(I), QPRI, SHRTA, QMX(I), ICase, IOUR
\]

**Intervening Statements - Refer to Source Deck

2780 IYR = IYR+1

**GTPB=GTPB+APB

**QUP(I)=CUR(NPER+1)

C CYCLE SUMS

\[
SBMN=SBMN+SMN
\]

**Intervening Statements - Refer to Source Deck

PRINT 2980, SMN, SMPWR, SMSHP, SM, SMRTS, SMN, SMQ, SMSHD, SMOMX, SMOF

C TEMP = 0.

PRINT 2950, YRAT

2950 FORMAT (/21H BENEFIT ANALYSIS****/19H ANNUAL REC BEN = $, F7.0)

PRINT 2960, APR

2960 FORMAT (19H ANNUAL PUR BEN = $, F7.0)

C BRANCH TO 2970 FROM 2940.00

2970 FORMAT(13, 3F9.0, 6F8.0, 3F6.0)

C BRANCH TO 2980 FROM 2940.02 3050.02

C 2980 FORMAT(3H YR3F9.0, 6F8.0, 3F6.0)

C 2980 FORMAT(3F9.0, 6F8.0, 3F6.0)

2990 GO TO 3010

C **BRANCH TO 3000 FROM 2890.00

C 3000 TEMP=0.

C BRANCH TO 3010 FROM 600.00 2900.01

C 2990.00

3010 CONTINUE

DO 3020 I = 1, NPER

GTPB=GTPB+RBMT(I)

C BRANCH TO 3020 FROM 3010.01

3020 CONTINUE

SQAL=SQAL/SOD

SQMN=SQMN/SDMN

**Intervening Statements - Refer to Source Deck**
SINDD=SINDD*100.*NYRS
SINDP=SINDP*100.*NYRS
IF(ITRNS.NE.2) GO TO 3090
PRINT 3090

3030 FORMAT //(14H GRAND AVERAGE)
PRINT 1320
PRINT 1330
PRINT 3040,$1 ,STMIN,STMAX,SEVP,SAMN,SQDA,SSHA,SHMN,SOOB,SSHB,SMX

Intervening Statements - Refer to Source Deck

3060 PRINT 3070,SINDA,SINDR,SINDO,SINDP
3070 FORMAT //(25H SHORTAGE INDEX, PIPELINEF7.3,8H OUTLETF7.3,12H DOWN
1STREAMF7.3,7H POWERF7.3//)
C \ BRANCH TO 3030 FROM 3020.27

3080 YRS=NYRS
AGTPR=GTTP/YRS
AGTRB=GTTP/YRS
PRINT 3090,GTPB,AGTPR
3090 FORMAT//(18H TOTAL REC BEN = $,F12.0,5X,19HAVG ANN REC BEN = $,
1FR.0)
PRINT 3100, GTPB, AGTPR
3100 FORMAT//(18H TOTAL PWR BEN = $,F12.0,5X,19HAVG ANN PWR BEN = $,
1FR.0)
C \ ECONOMIC ANALYSIS**WATER SUPPLY BENEFITS
DO 3110 I=1,NPER
ABFWS(I)=ABFWS(I)/YRS
ANSB(I)=PWSB(I)-ABFWS(I)
C \ BRANCH TO 3110 FROM 3100.03
3110 CONTINUE
PRINT 3120,(ABFWS(I),I=1,NPER)
3120 FORMAT//(1X,47H PERIODS TOTAL WATER SUPPLY BENEFIT DEFICITS($),12F6.
10)
DO 3130 I=1,NPER
SANSB=SANSB+ANSB(I)
C \ BRANCH TO 3130 FROM 3120.01
3130 CONTINUE
PRINT 3140,SANSB
3140 FORMAT//(18H ANNUAL WS BEN = $,F12.0)
C \ COMPUTING EXCEEDENCE VALUES(EX) IN PER CENT OF TIME EQUALLED
C OR EXCEEDED
DO 3160 I=1,NPER
DO 3150 NSI=1,19
ANISI=ANISI(I,NSI)
EX(I,NSI)=ANISI/YRS
C \ BRANCH TO 3150 FROM 3140.03
3150 CONTINUE
(continued from preceding page)

C 3160 CONTINUE
BRANCH TO 3160 FROM 3140.02

DO 3180 I=1,NPEP
V(1,1) = F(1,1)
DO 3170 NSI=2,18
V(I,NSI)=F(I,NSI)-F(I,NSI-1)
C 3170 CONTINUE
BRANCH TO 3170 FROM 3160.03
C 3180 CONTINUE
C 3180 CONTINUE
INTERPOLATING AMONG FLOOD CONTROL RESERVATIONS

IF(IERST.EQ.0) GO TO 3200
READ 3190,((PFLOD(I,JX),I,J=1,10),JX=1,11)
3190 FORMAT(IJ,F7.0,9F8.0)
READ110, (MT(1), I=1,12)
READ110, (PPFD(I), I=1,12)

C 3200 DO 3370 I=1,12
IF(IERST.EQ.1) PRINT 3630, I, FCR(I), I, STRMX(I)
3200 CONTINUE
GO TO 3370 FROM 3180.02

C 3210 CONTINUE
BRANCH TO 3210 FROM 3200.04
C 3220 IF(FCR(I),.EQ.0.) GO TO 3240
DO 3230 JX=1,11
FCR(JX)=PFLOD(M,JX)*MT(I)
3230 CONTINUE
GO TO 3280 FROM 3230.01

C 3240 DO 3250 JX=1,11
DFCR(JX)=PFLOD(M+1,JX)*MT(I)
3250 CONTINUE
GO TO 3280 FROM 3250.00

C 3260 DO 3270 JX=1,11
DFCR(JX)=PFLOD(1,JX)*MT(I)
3270 CONTINUE
BRANCH TO 3280 FROM 3230.01 3250.01
C 3280 SS(I)=0.

(next statement on following page)
DO 3310, KKK = 2.9
AA = KKK
SS(KKK) = 14500. + 25000. * (AA - 2.)
SSS(KKK) = SS(KKK) + FCR(1) * 100000.
IF (SSS(KKK) .GE. 1010000.) FIFD(KKK) = 0.
IF (SSS(KKK) .GE. 1010000.) GO TO 3310
DO 3290 JX = 1.3
AAA = JX
IF (SSS(KKK) .LT. 100000. * (AAA - 2.) ) GO TO 3300
BRANCH TO 3290 FROM 3280.04
3290 CONTINUE
C INTERPOLATING AMONG SUPPLEMENTARY STORAGES (SS)
C BRANCH TO 3300 FROM 3290.06
3300 FIFD(KKK) = DFFCR(JX - 1) - ((DFFCR(JX - 1) - DFFCR(JX))/100000.) *
I((SSS(KKK) - 100000. * (AAA - 2.))
C BRANCH TO 3310 FROM 3290.01
3310 CONTINUE
DO 3340, KKK = 10, 17
AA = KKK
SS(KKK) = 252000. + (AA - 10.) * 100000.
DO 3320 JX = 4.11
AAA = JX
IF (SSS(KKK) .LT. 100000. * (AAA - 1.)) GO TO 3330
BRANCH TO 3320 FROM 3310.04
3320 CONTINUE
C BRANCH TO 3330 FROM 3310.06
3330 FIFD(KKK) = DFFCR(JX - 1) - ((DFFCR(JX - 1) - DFFCR(JX))/100000.) *
I((SSS(KKK) - 100000. * (AAA - 2.))
SSS(KKK) = SS(KKK) + FCR(1) * 100000.
IF (SSS(KKK) .GT. 1010000.) FIFD(KKK) = 0.
C BRANCH TO 3340 FROM 3310.01
3340 CONTINUE
FIFD(I) = DFFCR(I)
DO 3350 KKK = 1, 17
TFLDM(I) = TFLDM(I) + FIFD(KKK) * HTE(I, KKK + 1)
C BRANCH TO 3350 FROM 3340.02
3350 CONTINUE
GO TO 3370
C BRANCH TO 3360 FROM 3200.01
3360 TFLDM(I) = 0.
C 3370 CONTINUE
DO 3380 I = 1, NPER
FRBN(I) = PPFD(I) - TFLDM(I)
TFLBN = TFLBN + FRBN(I)
C BRANCH TO 3380 FROM 3370.01
3380 CONTINUE
PRINT 3390, TFLBN
3390 FORMAT(/IX, 1F10.2, ' AVERAGE ANN. FLOOD BENEFIT = ', F12.0)
TREN = TFLBN + SWSB + AGTPR + AGTPR
TOTREN(NCC) = TREN
PRINT 3395, TREN
3395 FORMAT(/IX, 16, ' TOTAL BENEFITS = ', F12.0)
TET(DEFV.1P.0) GO TO 10
(Next statement on following page)
(continued from preceding page)

IF(TRANS.LT.5) GO TO 3397
CALL OPT1(MTREN,NVAR,VAR)
IF(NC2.LT.1) GO TO 3397

TEST FOR REASONABLE MAGNITUDE
GO TO (5396,5390,5391,5392,5393,5394,5395),MX

5390 SL1=VAR(2)/.96
IF(VAR(1).LT.SL1.OR.VAR(1).GT.101000.) L=1
IF(VAR(1).LT.SL1.OR.VAR(1).GT.101000.)
PRINT 3680,L
IF(VAR(1).LT.SL1) VAR(1)=SL1
IF(VAR(1).GT.101000.) VAR(1)=101000.
IF(TRANS.LT.5) GO TO 3397

5391 UL2=.96*VAR(1)
IF(VAR(2).LT.0..OR.VAR(2).GT.UL2) L=2
IF(VAR(2).LT.0..OR.VAR(2).GT.UL2)
PRINT 3680,L
IF(VAR(2).LT.0.) VAR(2)=0.
IF(VAR(2).GT.UL2) VAR(2)=UL2
IF(TRANS.LT.5) GO TO 3397

5392 SL3=VAR(7)/.96
UL3=.96*VAR(4)
IF(VAR(3).LT.SL3.OR.VAR(3).GT.UL3) L=3
IF(VAR(3).LT.SL3.OR.VAR(3).GT.UL3)
PRINT 3680,L
IF(VAR(3).LT.SL3) VAR(3)=SL3
IF(VAR(3).GT.UL3) VAR(3)=UL3
IF(TRANS.LT.5) GO TO 3397

5393 SL4=VAR(3)/.96
UL4=.96*VAR(5)
IF(VAR(4).LT.SL4.OR.VAR(4).GT.UL4) L=4
IF(VAR(4).LT.SL4.OR.VAR(4).GT.UL4)
PRINT 3680,L
IF(VAR(4).LT.SL4) VAR(4)=SL4
IF(VAR(4).GT.UL4) VAR(4)=UL4
IF(TRANS.LT.5) GO TO 3397

5394 SL5=VAR(4)/.96
IF(VAR(5).LT.SL5.OR.VAR(5).GT.334.) L=5
IF(VAR(5).LT.SL5.OR.VAR(5).GT.334.)
PRINT 3680,L
IF(VAR(5).LT.SL5) VAR(5)=SL5
IF(VAR(5).GT.334.) VAR(5)=334.
IF(TRANS.LT.5) GO TO 3397

5395 UL6=.96*VAR(7)-(VAR(1)/138310.)
IF(VAR(6).LT.1..OR.VAR(6).GT.UL6) L=6
IF(VAR(6).LT.1..OR.VAR(6).GT.UL6)
PRINT 3680,L
IF(VAR(6).LT.1.) VAR(6)=1.
IF(VAR(6).GT.UL6) VAR(6)=UL6
IF(TRANS.LT.5) GO TO 3397

(next statement on following page)
(continued from preceding page)

5396 SL7=(VAR(6)/.96)+(VAR(1)/138810.)

UL7=.96*VAR(3)
IF(VAR(7).LT.SL7.OR.VAR(7).GT.UL7) I=7
IF(VAR(7).LT.SL7.OR.VAR(7).GT.UL7)
IPRINT 3680,L
IF(VAR(7).LT.SL7) VAR(7)=SL7
IF(VAR(7).GT.UL7) VAR(7)=UL7

3680 FORMAT (3HVAR,12,22H HAD TO BE CONSTRAINED)
3397 GO TO 3440 I=9,20

N=1
SSTRMX(1)=1010000.- (SNDAYS(1)-VAR(6))*(VAR(1))/(VAR(7)-VAR(6))
IF(SNDAYS(1).GT.VAR(6)) GO TO 3400
SSTRMX(1)=1010000.
GO TO 3440

3400 BRANCH TO 3440 FROM 3390.09

3420 FORMAT(45HVAR(6) AND VAR(7) OCCUR WITHIN THE SAME MONTH)
SSTRMX(I)=1010000.-VAR(1)
FGR(I)= (((VAR(7)-SNDAYS(I))-VAR(6))*(VAR(1)/2.1)*(SNDAYS(I)-VAR(6))
1/DDAYS(I))/100000.

3430 IF(JVNE(1.,1.)) MNCNP=1
IF(JVNE(1., AND. SNDAYS(I).GT.VAR(7))) GO TO 3410
GO TO 3430

3440 CONTINUE

3450 IF(N.EQ.9) SSTRMX(8)=1010000.
FGR(I)= (((VAR(7)-SNDAYS(I-1))*(VAR(1)-1))/SSTRMX(I-1))+VAR(1)
1/2.1)+(SNDAYS(I)-VAR(7))*(VAR(1))/DDAYS(I))/100000.
MNCNP=1
IF(SNDAYS(I).GT.VAR(3)) GO TO 3460
GO TO 3480

3460 PRINT 3470

3470 FORMAT(50HMAX FGR LINE BEGINS AND ENDS WITHIN THE SAME MONTH)
C

3480 GO TO 3490 I=N,20
N=1
IF(SNDAYS(I).LE.VAR(3)) SSTRMX(I)=1010000.-VAR(1)
IF(SNDAYS(I).GT.VAR(3)) GO TO 3500

3490 CONTINUE

(next statement on following page)
IF (SNDAYS(I), I.E. VAR(4)) SSTRMX(I) = 1010000. - (VAR(5) - SNDAYS(I)) * (VAR(2)) / (VAR(5) - VAR(4))

IF (CZ.NE.1. AND. SNDAYS(I), I.E. VAR(5)) FCR(I) = (((VAR(2) + (1010000. - SSTRMX(I - 1)))) / 2.) * (VAR(4) - SNDAYS(I - 1)) / (VAR(5) - SSTRMX(I) + 2/VAR(2)) / 2. / DDAYS(I) / 1/2. / 100000.

IF (CZ.NE.1.) NECR2 = 1

IF (SNDAYS(I). GT. VAR(5) AND. CZ.NE.1.) GO TO 3570

C

GO TO 3530

C

IF (SNDAYS(I). GT. VAR(4)) GO TO 3550

C

CONTINUE

C

GO TO 3540 FROM 3530.00

C

IF (SNDAYS(I - 1). GE. VAR(4)) GO TO 3590

C

CONTINUE

C

GO TO 3570 FROM 3550.08

C

PRINT 3580

C

FORMAT(45HVAR(4) AND VAR(5) OCCUR WITHIN THE SAME MONTH)

C

GO TO 3590 FROM 3550.10

C

IF (CZ.EQ.1.) FCR(I) = (((VAR(5) - SNDAYS(I - 1)) * (1010000. - SSTRMX(I - 1))) / (VAR(2)) / 2. / DDAYS(I) / 1/2. / 100000.

NECR4 = 1

(next statement on following page)
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(continued from preceding page)

3595 DO 3600 I=N,20
   SSTRMX(I)=1010000.
   C BRANCH TO 3600 FROM 3590.03
3600 CONTINUE
   DO 3610 I=9,12
   SSTRMX(I)=SSTRMX(I)
   C BRANCH TO 3610 FROM 3600.01
3610 CONTINUE
   DO 3620 I=13,20
   SSTRMX(I-12)=SSTRMX(I)
   C BRANCH TO 3620 FROM 3610.01
3620 CONTINUE
   IF(NFCRO.NE.9) FCR(I)=(1010000.-(SSTRMX(I)+SSTRMX(I))/2.)/100000.
   DO 3630 I=10,20
   IF(NFCP1.NF.1,AND.NFCP2.NE.1,AND.NFCP3.NE.1,AND.NFCP4.NE.1,AND.
   1IFCRO.NE.1) FCR(I)=(1010000.-(SSTRMX(I-1)+SSTRMX(I))/2.)/100000.
   C BRANCH TO 3630 FROM 3620.02
3630 CONTINUE
   DO 3640 I=13,20
   FCR(I-12)=FCR(I)
   C BRANCH TO 3640 FROM 3630.01
3640 CONTINUE
   AZ=0.
   BZ=0.
   CZ=0.
   NFCRO=0
   NFCR1=0
   NFCR2=0
   NFCR3=0
   NFCR4=0
   PRINT 3645
3645 FORMAT(///1H )
   DO 3660 I=1,12
   PRINT 3650,I,FCR(I),1,STRMX(I)
3650 FORMAT(1X,3HFCR,13,1H=,F10.6,10X,5HSTRMX,13,1H=,F10.0)
   C BRANCH TO 3660 FROM 3640.09
3660 CONTINUE
   IF(ITRNS.EQ.1) GO TO 3690
   DO 3670 J=1,NPER
   SSTRMX(J)=1010000.-FCR(J)*100000.
   C BRANCH TO 3670 FROM 3660.01
3670 CONTINUE
   GO TO 500
3690 PRINT 3700
   WRITE(6,3710) (VAR(JJ),JJ=1,NVAR)
   C BRANCH TO 3700 FROM 480.06 3690.00
3700 FORMAT(10X,7IMAX FCR,8X,14HBREAKPOINT FCR,3X,15HTIME-REDUCE FCR,
   13X,15HTIME-BREAKPOINT,5X,12HTIME-END FCR,5X,14HTIME-START FCR,
   22X,18HTIME-START MAX FCR)
   C BRANCH TO 3710 FROM 480.08 490.08 3690.01
3710 FORMAT(///1X,F17.3,6(F18.3))
   ITRNS=ITZ
   IPRINT=1
   GO TO 500
   IF(NC-NCYCL)540.10,10
END
SUBROUTINE OPTIM(CRITN,NVAR,VAR)
DIMENSION VAR(10),CRITN(3),IFREZ(10),GAIN(10)
COMMON /ALPHA/ IFREZ,ITRNS,M,NC,IDGST,M1,NC2
IF(ITPNS) 5,60,60
C
INITIATE CONSTANTS
5 NCYCL=0
FIN=0.
CMNX=50.
CMMN=-33.3333
TEST=999999.
10 DO 20 M=1,NVAR
20 GAIN(M)=0.
M=0
25 M=M+1
M1=M
IF(IFREZ(M))30,30,25
30 NC1=1
NC2=3
GO TO 50
40 NC1=1
NC2=1
50 ITPNS=0
DO 70 NC=NC1,NC2
RETURN
60 IF(NC.EQ.1) TEMP2=VAR(M)
TMP=NC
VAR(M)=TEMP2*(1.-TMP*.01)
70 CONTINUE
80 IF(NC-2) 90,90,210
90 IF(CRITN(1)-TEST) 140,140,100
100 IF(NADJ-2) 110,120,120
110 VAR(M1)=.3*VAR(M1)+.7*TEMP1
NADJ=NADJ+1
VAR(M)=TEMP2
GO TO 50
120 VAR(M1)=TEMP1
130 FORMAT(4H VAR13,9H ADJ FROM7.2,3H TOF7.2)
VAR(M)=TEMP2
GAIN(M1)=0.
IF(NCYCL-3) 30,30,150
140 NC1=2
NC2=3
IF,IDGST 145,145,144
144 PRINT 130,M1,TEMP1,VAR(M1)
145 GAIN(M1)=1.-CRITN(1)/TEST
TEST=CRITN(1)
IF(NCYCL-3) 50,50,150

(next statement on following page)
AFTER 3 CYCLES, WORK ON VARIABLE HAVING MOST EFFECT

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C

GO TO 170,170,160

160 CANNMX=GAIN(MX)

L=MX

CONTINUE

IF(GANMX-.Ol) 190,190,180

180 VAR(M)=TEMP2

M=1

GO TO 30

190 IF(EIN) 200,200,350

C

CALL FOR ONE MORE SEARCH

200 FIN=1.

VAR(M)=TEMP2

GO TO 10

C

OPTIMIZATION

210 IF(IOGST) 240,240,220

220 PRINT 230,M,(CRITN(NC),NC=1,3)

230 FORMAT(/13H CRITERION FOR VARIABLE 12,3E12,4)

240 DSEF1=CRITN(2)-CRITN(1)

DSEF2=CRITN(3)-CRITN(2)

DIF2=DSEF2-DSEF1

IF(DIF2) 250,260,280

250 IF(DSEF1) 310,310,300

260 IF(DSEF1) 310,270,300

270 CORR=0.

GO TO 320

280 CORR=DSEF1/DIF2-.5

GO TO 320

290 IF(CORR-CORMX) 310,300

300 CORR=CORMX

GO TO 320

310 CORR=CORMX

320 TEMP1=TEMP2

M1=M

VAR(M1)=TEMP2*(1.+CORR*.01)

MADJ=0

330 IF(M-NVAR) 340,335,335

C INCREMENT CYCLE

335 M=0

NCYCL=NCYCL+1

C INCREMENT VARIABLE NUMBER

340 M=M+1

IF(IFRET(M)) 40,40,330

C PRINT RESULTS

350 VAR(M)=TEMP2

PRINT 360,(M,VAR(M),M=1,NVAR)

360 FORMAT(/18H DERIVED VARIABLES 8(I6,F8.3))

RETURN

END