A MULTI-PURPOSE BENEFIT MODEL FOR DYNAMIC RESERVOIR REGULATION

By

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This project was concerned with the development of a computer program to determine the optimum management of a single reservoir with respect to a recreational benefit, a water quality benefit, a navigation benefit, a flood penalty, and a power generation benefit. This was accomplished through a dynamic programming optimization routine, a detailed hydrological model for the reservoir, and a series of benefit curves to simulate the benefits listed above. The performance index can be modified by program options to maximize the number of visitors to the reservoir, the power revenue, a weighted combination of these two, or the maximum energy generated.

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CHAPTER I

INTRODUCTION

Problem Statement

For many years, reservoirs were constructed for three purposes; water supply, flood control, and hydroelectric power generation. Benefits such as recreation, downstream water quality, and navigation were considered to be of only secondary importance. In recent years, however, our society has enjoyed more leisure time and has become more aware of the broad use of water resources. This has caused increased use of reservoirs for recreational purposes and other general benefits. Also, the number of reservoirs which are interconnected electrically and hydrologically has grown and now, vast reservoir systems exist which must be constantly monitored, and more importantly, understood to achieve efficient management of such multi-benefit systems.

As a reservoir system becomes more complex, the approximate regulation techniques which have served so well in the past have necessarily been replaced by more accurate computer-aided systems analysis techniques. Through modeling and computer simulation, all factors relevant to the total reservoir system can be included and their interactions properly considered in any proposed reservoir regulation strategy. Also, contingency plans for abnormal conditions can be developed without actually experiencing such conditions in the real system or deliberately operating the real system abnormally to test proposed strategies.

The fundamental problem in the management of a multi-purpose reservoir - or a system of them - is the task of bringing together in a single computer package adequate models of the several benefits and integrating them with models of the reservoir and power generation processes. The general objective of this research is to synthesize such a grouping of models and develop a flexible computer-aided procedure for finding optimum regulation strategies for a single multi-purpose reservoir. Specific benefits to be considered are:

1. power production,
2. recreation in the pool area and downstream,
3. downstream water quality based upon temperature, dissolved oxygen and total dissolved solids,
4. downstream navigation benefits and
5. flood protection.

Details of the research approach will be discussed after a brief summary of selected references.

Literature Summary

Computer simulation and optimization of reservoir operations are widely reported in the literature, but none were found which deal comprehensively with the total set of benefits listed above. Extensive research has been carried out on the general problem of hydro-thermal power optimization and a comprehensive bibliography appeared in 1963 [1]. Since then, many studies have dealt with the broader aspects of water resource management, integrating power production and water supply benefits. Examples are found in [2], [3] and [4]. Large integrated river systems, such as the Arkansas-White-Red River system have also been successfully treated with individual reservoir projects modeled for power production, water supply and flood control [5].

Mathematical programming techniques have been applied to a wide variety of optimization studies involving reservoir regulation and water resource management [6], [7], [8]. Multi-purpose reservoir projects have been considered in certain studies [9], [10], [11], [12]. However, the primary deficiencies found in these studies relate to over-simplified reservoir and power generation models which do not allow specific elevation-capacity or power-discharge-head relations to be incorporated. Also there is a lack of authenticity in the non-power benefit models such as recreation and water quality. Recent efforts have been directed at estimating recreational benefits related to water resource management [13], [14]. One very recent study analyzes fluctuations in pool elevation and their effects on concession operators and recreationists [15].

In this research, considerable emphasis is placed on the development of an approximate downstream water quality model which approximates values of dissolved oxygen, temperature and total dissolved solids in two separate reaches which are affected by intervening flows. Several sources in the literature proved helpful in this phase of the research. An excellent comprehensive treatment is found in McGauhey [16]. Another useful reference is [17] which gives specific data on the Tenkiller Reservoir, the project which was selected for demonstration of the model. Development of models for fish production and fishing recreation was based, in part, on research reported in [18], [19] and [20]. Other literature consulted during the research will be cited as needed.

Research Approach

An existing model for reservoir analysis and power generation was adapted for use in the optimization package [21]. This model translates daily pool elevation and inflow/evaporation data into a new elevation, given an increment of energy to be generated. Accurate discharge rates are calculated by the model each day and limits on the power pool are incorporated.

The existing reservoir model was modified to improve its computer efficiency and flexibility. The primary development of the benefit model then began. Separate sections to predict the benefits of power generation, recreation, water quality, flood and navigation were constructed and tested. A flexible benefit performance index was developed, allowing the user to emphasize one or more of the benefits in the optimization. Finally, the optimization algorithm, based on the dynamic programming method, was added [22].

To demonstrate the optimization package on a practical regulation problem, Tenkiller Reservoir was selected for study. A twelve-month period of record was selected extending from September, 1970 to August, 1971 and a number of computer runs were executed. These runs demonstrated the optimization of each of the basic benefits plus a study of the trade-off between energy revenue and recreation.

Chapter II presents a general discussion of the entire computer package, except for the benefit model which is discussed in Chapter III. The presentations in these two chapters are intended to give the user general information about the structure and capabilities of the package without giving details of the programming procedures used. The reader interested in such details is referred to the Appendix where a program listing and other related information is presented.

Chapter IV presents the demonstration optimization runs for Tenkiller Reservoir and a discussion is included on preparing the necessary data base for these runs. The results of the runs are compared with actual data on Tenkiller and the corresponding regulation strategies are discussed. Chapter V summarizes the contributions of the research and proposes future research efforts in multi-purpose reservoir optimization.

CHAPTER II

THE RESERVOIR REGULATION OPTIMIZATION PACKAGE

Structure and General Features

This chapter presents a general discussion of the reservoir model, the optimization technique and the interaction of these parts with the benefit model which is discussed in detail in Chapter III. The purpose of this chapter is to give the reader an understanding of the general features and capabilities of the total computer package without presenting programming details of each subroutine. The user having need for such details is referred to the Appendix where the program listing, variable lists and sample input and output are given.

Figure 1 illustrates the general structure of the optimization package and the interaction of the various subroutines. All data is read by the MAIN Program and placed in common storage for use by the other subroutines. The specific data format requirements are discussed in detail in the Appendix and will not be presented here. However, the package has been designed to allow flexibility in data format and all parameters which control the physical processes of the reservoir and generating units as well as the benefit calculations are input controllable. As the several subroutines are discussed later in this chapter, the input data relating to those subroutines will be outlined.

The optimization package will accept daily or monthly hydrologic data for the reservoir, but in the following discussion, it will be

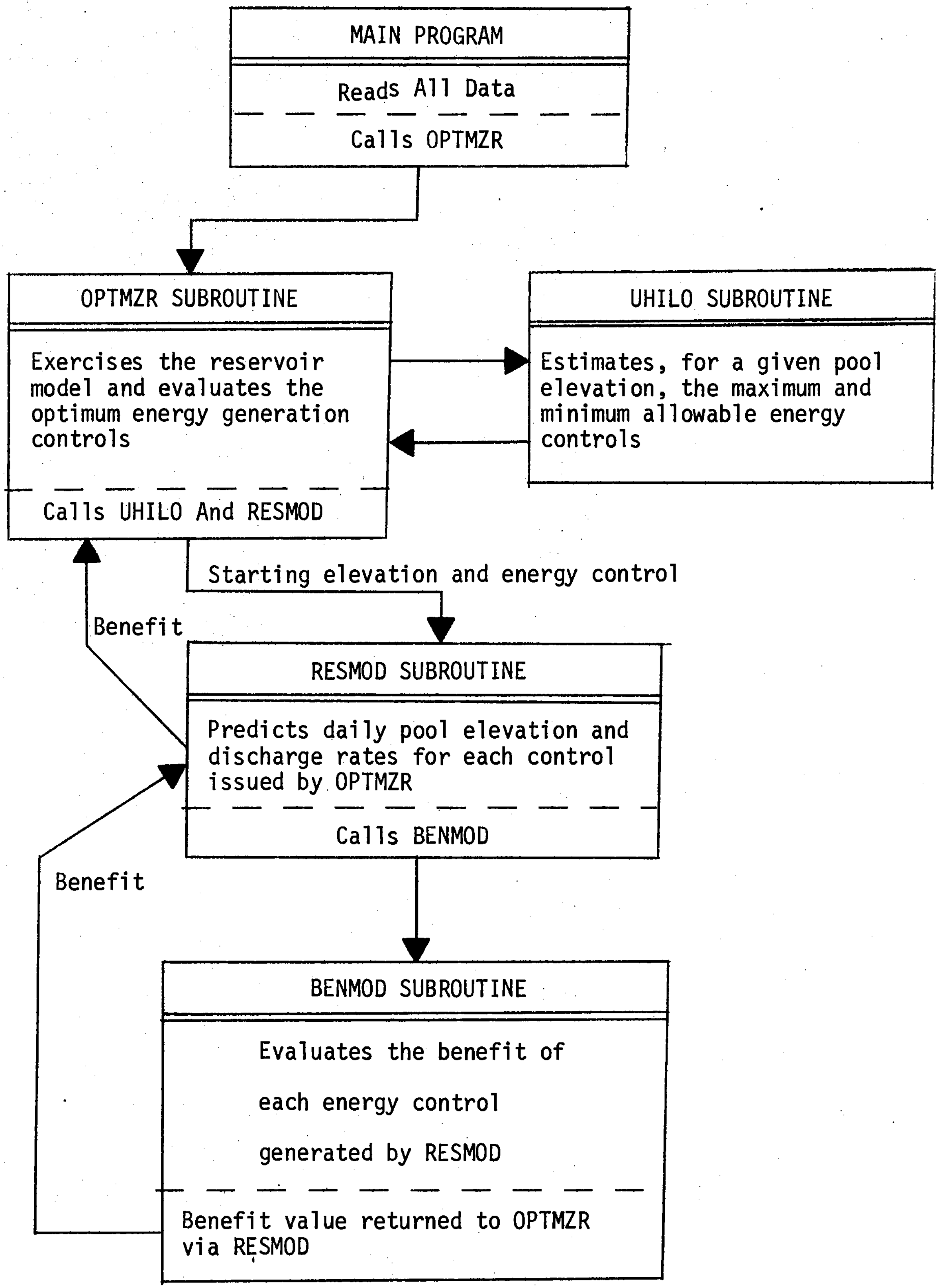


Figure 1. General Structure of the Optimization Package

assumed that monthly average values are used. Furthermore, the MAIN program contains read statements which were intended to allow data for four separate reservoirs to be input. However only one reservoir can be optimized at a time with the present package. In this project only one set of reservoir data (for Tenkiller) was implemented.

As shown in Figure 1, the MAIN program calls the subroutine OPTMZR which controls the entire optimization process. The dynamic programming algorithm is used to determine the optimum sequence of monthly energy generation controls to maximize one of several types of benefit performance indices. The optimization period can be selected from two to twelve months in length with the initial pool elevation specified for the first month of the period. The following types of performance indices can be selected through input control:

1. Maximize revenue, given megawatt-hour dollar rates for generating a specified demand each month, overgenerating the demand (dump energy) and undergenerating the demand (buy energy).
2. Maximize the number of megawatt-hours generated during the total optimization period, irrespective of demand.
3. Maximize the total number of recreational visitors during the optimization period.
4. Maximize a weighted sum of revenue and visitors during the optimization period.
5. Maximize a weighted sum of the following benefits, each normalized each month to a selected value:
    a. Recreation
    b. Water Quality

c. Navigation
d. Flood
e. Energy Generation

The process followed by the OPTIMIZER is based upon the standard dynamic programming method wherein the reservoir is exercised each month from five different pool elevations, called elevation grid points. These grid points are distributed from the bottom of the power pool to a selected elevation at or above the top of the power pool. The reservoir model is designed so that the pool elevation cannot climb above the top grid elevation or fall below the lowest grid elevation.

The purpose of the subroutine UHILO called by OPTMZR is to estimate acceptable energy generation controls which will fully exercise the reservoir model without violating the lower or upper grid elevations. The power-discharge curves of the generating units and the inflow and evaporation data are employed by UHILO to estimate maximum and minimum monthly energy controls which will maintain the pool elevation within the grid range. A third control value equal to the average of the maximum and minimum controls is also used by the OPTMZR to exercise the reservoir model. It should be noted that UHILO only <u>estimates</u> the high, middle and low controls to be issued to the reservoir model at each grid elevation. Protection against actually violating the upper and lower grid elevations is built into the reservoir model as explained below.

The reservoir model, denoted in Figure 1 by the subroutine RESMOD, receives from OPTMZR a starting grid elevation and a value of energy to be generated during the month. RESMOD will exactly generate the energy control issued by OPTMZR unless the bottom or the top of the power pool are penetrated. In these cases, generation is stopped or spill releases are initiated, respectively. More flexible generation rules, including dump energy procedures, are available to the user in the upper region of the power pool. These rules will be discussed in more detail later.

As depicted in Figure 1, RESMOD generates the desired energy control issued by OPTMZR and predicts a new pool elevation and the average discharge rate each day of the month. These hydrologic variables are supplied to the subroutine BENMOD which evaluates the benefits relating to recreation, water quality, flood, navigation and energy generation. One or more of these benefits are summed into a single benefit value at the end of each month and this performance value is returned first to RESMOD (which calls BENMOD) and then to OPTMZR which stores the performance value with the energy control which produced it.

Although a more detailed discussion of the optimization process will be presented in the section describing the subroutine OPTMZR, a brief summary follows:

1. The reservoir model is exercised three times from each of the five grid elevations each month, starting with the <u>last</u> month of interest.
2. From each set of three runs, OPTMZR calculates, from a curve-fit procedure, the energy control which produces the highest benefit performance. This optimum control and the resulting optimum benefit are stored for each of the five grid elevations by OPTMZR for later use.
3. The next-to-last month is then considered and the reservoir model is again exercised at each grid elevation by three different controls. However, the benefit for each candidate control used is set equal to the benefit produced during the

next-to-last month plus the optimum benefit for the last month found in Step 2. When the final pool elevation at the end of the next-to-last month coincides with a grid elevation used as a starting elevation during the last month, the optimum benefit obtained during the last month starting from that grid elevation is used in the sum. Otherwise, a linear interpolation of the two optimum benefit values at the grid elevations adjacent to the final elevation is used.

4. At each starting grid elevation in the next-to-last month, OPTMZR determines the optimal control and the corresponding total optimal benefit produced over the last two month period. These two values are stored for each grid elevation.
5. The process is repeated for the second-from-last month and so on. For each month, OPTMZR determines and stores, for each grid elevation, the optimal control for that month and the total optimal benefit from the first of that month to the end of the optimization period.
6. When the first month of interest is reached in the backward stepping process, the reservoir model is exercised by three energy controls starting from the given initial pool elevation, rather than starting from a grid elevation. OPTMZR then calculates the optimum control for the first month and the total optimal benefit for the entire optimization period. The optimization process is now complete and the optimal controls for each grid elevation at the beginning of each month are stored and ready to be implemented in the next and final step.

7. The reservoir model is directed by OPTMZR to carry out a forward run, starting with the given initial elevation of the first month and using the optimal control calculated for the first month. At the end of the first month, the final pool elevation is compared with the grid elevations for which the optimal controls for the <u>second</u> month are stored. A linear interpolation of the optimal controls for the grid elevations above and below the final pool elevation establish the optimal control for the second month. This month-by-month forward run is continued to the end of the optimization period with the optimal control determined by interpolation of the previously stored optimal controls at the grid elevations.

The user is able to select one of four separate output formats presenting the results of a given optimization run. The following choices are available which list the significant reservoir, hydrologic and benefit variables:

1. Monthly summary of the forward optimum run only.
2. Monthly summary of the forward run plus monthly summaries of every exercise run made from each grid point for every month.
3. Choice 1 plus daily values of all variables printed.
4. Choice 2 plus daily values of all variables printed.

This concludes the discussion of the structure and general features of the total optimization package. The following sections provide more detailed information on the operational characteristics of each of the subroutines which comprise the package.

Reservoir Model (RESMOD)

This section presents a discussion of the subroutine RESMOD which contains models of the reservoir, its generating units and the downstream channel stage-flow characteristics. Also included within RESMOD are the calendar section and the section which assembles the final value of the monthly benefit performance index before returning program control to OPTMZR. RESMOD calls the subroutine BENMOD each day which in turn, calculates daily benefits for recreation, water quality navigation and flood. RESMOD processes these benefits and adds them to the daily power benefit to eventually produce the total monthly benefit performance used by OPTMZR.

The level of detail presented in this section and the following sections on the OPTMZR, CRVFIT and UHILO subroutines is intended to explain the operational features of these subroutines. The discussion will introduce many of the variable names used in the program and the reader is encouraged to refer to the Appendix where the program listing and a complete list of program variable names are included.

The primary function of subroutine RESMOD is to simulate the generation of a given monthly energy demand (U) starting with pool elevation (EL1), if possible, without violating specified elevation bounds. The performance measure is evaluated daily by calling subroutine BENMOD. The value of the performance measure (PI) and the elevation at the end of the month (EL) are returned to the calling program OPTMZR through the call statement when the month run is complete. The calendar section determines which days during the month are weekends and holidays for use in evaluating the performance measure. The reservoir model is capable of working with monthly average energy demands, inflow rates, intervening flows, and evaporation, or with daily average inflows, intervening flows and evaporation.

The various curve fits used in RESMOD are accomplished using a binary search with linear interpolation of data points from the curve which are read in tabular form. The function subprogram FIT performs this search/interpolation on the table of data. The curve fit may be interrogated in either direction by simply interchanging the independent and dependent variables in the calling statement for FIT. Accuracy of the fit can be increased by increasing the number of data points.

Generating units are modeled from data taken from the power-discharge curves. A fundamental assumption made in RESMOD is that the generators operate at maximum efficiency at all times. This assumption establishes unique values of horsepower (HP) and discharge (DIS) for each value of pool elevation (EL) measured in feet MSL. The generation model thus works with two curves; a horsepower versus pool elevation curve and a discharge versus pool elevation curve. These curves have tailwater corrections built in and can be used for one, two or more units of equal size.

The procedure for constructing the two curves which relate the maximum efficiency values of horsepower and discharge for a given pool elevation MSL are as follows: Assume first that one unit is operating.

1. The maximum efficiency operating curve C is constructed on the standard power-discharge curves with net head as a parameter.
2. A single point P is selected on curve C, thus yielding corresponding values of horsepower, discharge and net head.

3. The discharge value at point P is applied to the tailwater curve to obtain the corresponding tailwater elevation in feet MSL.
4. The tailwater elevation is added to the net head value at point P to produce a pool elevation in feet MSL.
5. The value of pool elevation and the value of horsepower at point P produce one point on the desired curve of maximum efficiency horsepower versus pool elevation.
6. The value of pool elevation and the value of discharge produce one point on the desired curve of maximum efficiency discharge versus pool elevation.
7. Steps 2-6 are repeated for another selected point on the curve C.

For two or more units operating, the discharge value for one unit used in Step 3 is doubled or tripled, etc. before the tailwater curve is used. It has been found that the incremental increase in tailwater elevation (ELINC) for additional units is approximately constant over a wide range of net head values and thus the maximum efficiency curves for one unit can be used directly to find the horsepower and discharge values for extra units by merely subtracting the tailwater increment (ELINC) from the actual pool elevation before entering the curves, and then multiplying the one-unit horsepower and discharge values by the appropriate number of units (JX) to be used. This approximation of the power-discharge curves in the model saves a great deal of computer time by eliminating iteration between the pool elevation and tailwater elevation to determine the net head operating point.

In order to calibrate the reservoir model to track actual time histories of energy generation, inflows, evaporation and pool elevations, a generator efficiency variable (EFF) is available to the user. This variable is used to offset the maximum efficiency rule which is applied in the construction of the power-discharge curves.

Referring to Figure 2, the following major steps are accomplished by the reservoir-model. Note that the diamond-shaped elements refer to tests. If the test is positive (yes) and the branch path to the right or left is taken. If the test is negative, the program flow continues downward. In the uppermost block, RESMOD determines the daily increment of energy to be generated (DPDD) and the number of units (JX) to be used. The variable ADTIM controls the maximum number of hours that one or more units will be run before an extra unit will be added. The same amount of energy is generated and the same number of units are used each day of the month unless the pool elevation violates the top of the power pool (TPP) or the bottom of the power pool (BPP). These exceptions are explained below.

The first test establishes EL above or below TPP. If EL > TPP, then the steps along the right side and bottom of Figure 2 are executed. The model will generate energy 24 hours a day with all available units and spill releases are determined by comparing the pool elevation with two discharge control points DISPT1 and DISPT2 set above TPP with DISPT1 < DISPT2. If EL is between TPP and DISPT1, the total of the power discharge rate (DIS) and the spill release rate (DISDMP) is set equal to the fraction FRAC(JJ,1) times the inflow (DADJIN). If EL is between DISPT1 and DISPT2, the total power and spill release rate is set equal

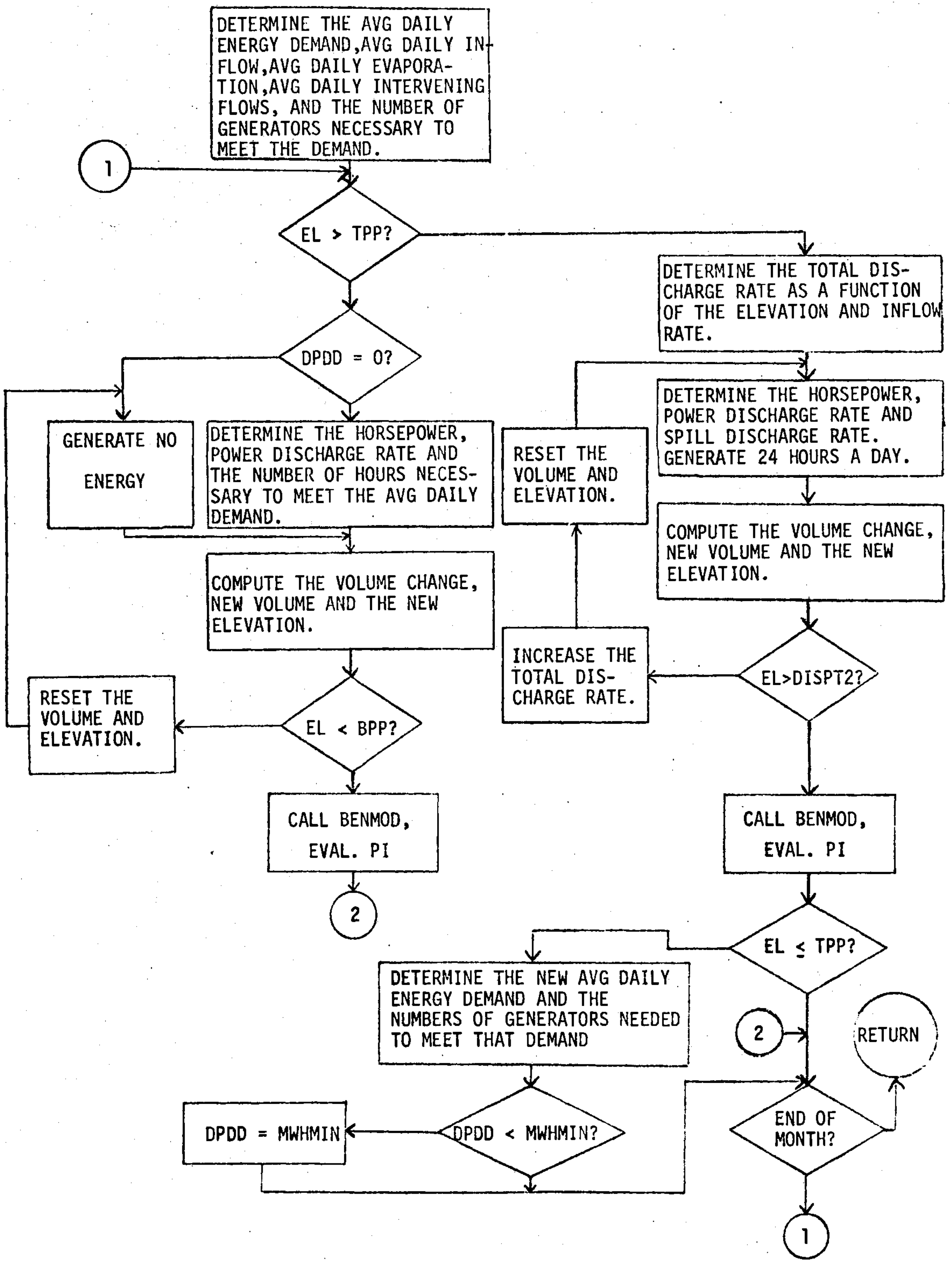


Figure 2. Operational Flow Diagram of the Reservoir Model

to FRAC(JJ,2) times DADJIN. Finally, if EL > DISPT2, the total release rate is set equal to FRAC(JJ,3) times DADJIN.

FRAC(JJ,3) must be greater than unity to insure that the pool elevation never exceeds DISPT2. Furthermore, DISPT2 must always be less than the highest grid elevation used by OPTMZR to insure proper functioning of optimization. This process of determining the spill releases is depicted in Figure 2 just above the (EL > DISPT2?) test. It should be noted that the tailwater curve is implemented in the model for use when spill releases occur. In this case a tailwater correction (TWC) is subtracted from EL before entering the power-discharge curves.

Each day, the initial volume of water in the reservoir (VOL) is calculated from the initial elevation (EL) by the subroutine FIT using the elevation-volume curve data. Then, a second subroutine GEM calculates the change in volume from power discharge rate, hours of generation (HRS), and spill releases. A new volume is evaluated and returned to RESMOD under the same variable name VOL. The FIT subroutine then uses the elevation-volume data again, but in reverse fashion, to calculate the new elevation from the new volume. Daily evaporation is applied directly to this elevation value to establish the initial elevation (EL) for the next day.

When the pool elevation falls below the upper discharge control point (EL < DISPT2), the benefit model is called and the one-day benefits are evaluated and added to the current value of the performance index (PI). Then a test is made to see if the elevation has fallen below the top of the power pool. If not, a test is made to see if the month run is complete. If not, the program proceeds to the next day and 24 hour generation continues as before. When the month run is complete, the value of the benefit performance index (PI), the final elevation (EL) and the total energy generated during the month (ACC) are returned to OPTMZR.

When EL $\leq$ TPP, the model calculates the amount of energy control which remains to be generated (U-ACC) and determines a new daily energy demand using the number of days remaining in the month. The program variable MWHMIN, which is input controllable, defines the minimum daily increment of energy to be generated, regardless of the control issued by OPTMZR. If the new value of the daily energy demand (DPDD) is less than MWHMIN, DPDD is set equal to MWHMIN and the program continues to the next day, unless the month run is complete.

Continuing with the discussion of Figure 2, we examine the case where EL $\leq$ TPP and the program steps depicted along the left side of the figure. If the daily increment of energy (DPDD) is zero, then no water is released and the elevation is corrected by inflow and evaporation to produce a new elevation for the next day. If DPDD $\neq 0$, then the elevation-power and elevation-discharge curves are used to evaluate in order, the value of horsepower (HP), electrical power (PO), the number of hours to run (HRS), the number of units (JX) to use and the power discharge rate (DIS). The subroutine GEM then calculates the new volume from HRS, DIS, the inflow (DADJIN) and the current value of volume. The new elevation is found by calling FIT with the elevation-volume curve and correcting the resulting elevation by evaporation.

If, after executing a day step, the pool elevation drops below the bottom of the power pool, (EL < BPP), the elevation and volume values are reset to the initial values for that day, DPDD is set to zero and no energy is generated that day. Whenever, the inflow (less evaporation) raises the elevation to the point where DPDD can be generated without lowering EL below BPP, then the model will generate that amount each day until EL $\leq$ BPP again.

Each day after a new elevation is calculated, BENMOD is called and the daily benefits are evaluated. At the end of the month, RESMOD determines the total monthly benefit performance index and returns the value to OPTMZR.

Several program sections within RESMOD are unrelated to the reservoir/generator models, but rather serve the needs of BENMOD which is called by RESMOD. First of all, the downstream flow variables (F1) and (F2) at the first and second control points, respectively, are evaluated as follows: the flow F1 is the sum of the average power discharge for the day (DAV) and the given intervening flow (IVFLO1). The flow F2 is the sum of F1 and IVFLO2. Next the stage heights (S1) and (S2) at the two control points are calculated using the FIT subroutine and the stage-flow curves input as data to the program. It should be noted that no provision for time lags have been incorporated in the downstream model. Thus the daily benefits for flood, navigation, downstream recreation and water quality are based on same-day values of power discharge and possibly spill releases.

The CALENDAR section is a second important section within RESMOD. Two parts comprise the section. The first part determines the day of the week from knowledge of the input variable KAL(M,1) which, for each month, takes a value of one through seven, corresponding to the day of the week (i.e. MONDAY = 1, etc.). The day counting variable (MARK) is initialized by KAL(M,1) and counts successively from one to seven as each daily pass is made through RESMOD. When MARK = 6 or 7, NWKHL is set equal to one to flag the weekend days for BENMOD. The second part checks the day variable (JY) against the entered holiday numbers KAL(M,2) and KAL(M,3) to determine if the day is a holiday. KAL(M,2) and KAL(M,3) are non-weekend holidays for month M if any exist during the month. If the day (JY) is a weekday, then NWKHL is set equal to zero.

Just before BENMOD is called, the average daily elevation (ELEVAT) and the daily elevation change (DELEV) are calculated and the current minimum and maximum monthly elevations (ELMIN) and (ELMAX) are updated for later use in the reservoir management factor (RMF) which is evaluated by RESMOD after the month run is complete.

Details of the subroutine BENMOD will be presented in Chapter III. However, for purposes of this discussion, it suffices to say that BENMOD calculates values for the daily benefits of recreation, water quality, navigation and flood each time it is called. Each day, the number of visitors involved in land-based, water-based and downstream recreation are also returned to RESMOD for use in developing the total monthly visitor value (SUM).

The power benefit (GENBN) is evaluated within RESMOD and added (with desired weighting) to the other four benefits at the end of each month. The monthly energy revenue value (REV) is also evaluated within RESMOD. Details of the power benefit, the revenue calculation and the formulation of the selected performance index are given in Chapter III.

RESMOD contains the write statements for the daily and monthly output summaries. When LIST = 2 or 4, daily values of the following variables will be printed:

1. Month and day (MON) and (JY)
2. Initial elevation (ELEV)
3. Average discharge rate (DAV)
4. Daily energy demand (DPDD)
5. Daily energy produced (ENERGY)
6. Number of units used (JX)
7. Number of unit-hours run (UNHRS)
8. Change in elevation for the day (DELEV)
9. Total reservoir visitors (IDAVST)
10. Downstream visitors (IDADVT)
11. Water quality benefit (WAQ)
12. Navigation benefit (NAVBN)
13. Flood benefit (FLDBN)
14. Value of weighted normalized benefit (except for power) accumulated since the first of the month (PI1)

When LIST = 1, 2, 3, or 4, monthly summaries will be printed with the following variables appearing:

1. Month just run (MON)
2. Initial and final elevations (EL1) and (EL)
3. Average monthly inflow (INFLOW)
4. Monthly energy demand (PD)
5. Monthly energy control from OPTMZR (U)
6. Total energy generated during month (ACC)
7. Average monthly discharge rate (DAV1)
8. Average daily unit-hours of generation (UNHRS1)
9. Total number of water-based visitors (IWATER)
10. Total number of land-based visitors (ILAND)

11. Total number of downstream visitors (IDOWN)
12. Recreation benefit (P11)
13. Navigation benefit (P44)
14. Flood benefit (P55)
15. Water quality benefit (P33)
16. Power benefit (GENBN)
17. Power revenue (REV)
18. Total weighted benefit including power, recreation, water quality, navigation and flood benefits (PI)
19. Reservoir management factor (RMF)

Additional output data is controlled by OPTMZR. This data summarizes the results of the backward stepping optimization process and the forward run summary which gives the optimal energy controls for each month and the corresponding optimal trajectory of the pool elevation. A discussion of the OPTMZR follows.

Optimization Subroutine (OPTMZR)

OPTMZR uses an optimization algorithm based on the multi-shape method of dynamic programming [22]. In this particular case, the basic optimization stage corresponds to a month and thus, monthly energy controls are found which maximize the given performance index. A summary of the dynamic programming process was given in the introductory section of this chapter and the reader is encouraged to review that discussion before proceeding.

The general procedure is depicted in Figure 3 where the vertical lines separate the total optimization period into stages (months in the present case). Five grid-points are shown representing five discrete pool elevation levels, from which the reservoir/benefit model is exercised. The lines starting at the grid points represent <u>optimum</u> pool elevation trajectories found by OPTMZR after exercising the model three times from each grid point. These pool elevation trajectories are <u>not</u> stored, but the optimal energy control (USTAR) and the corresponding optimal benefit performance (PSTAR) are stored for each grid point.

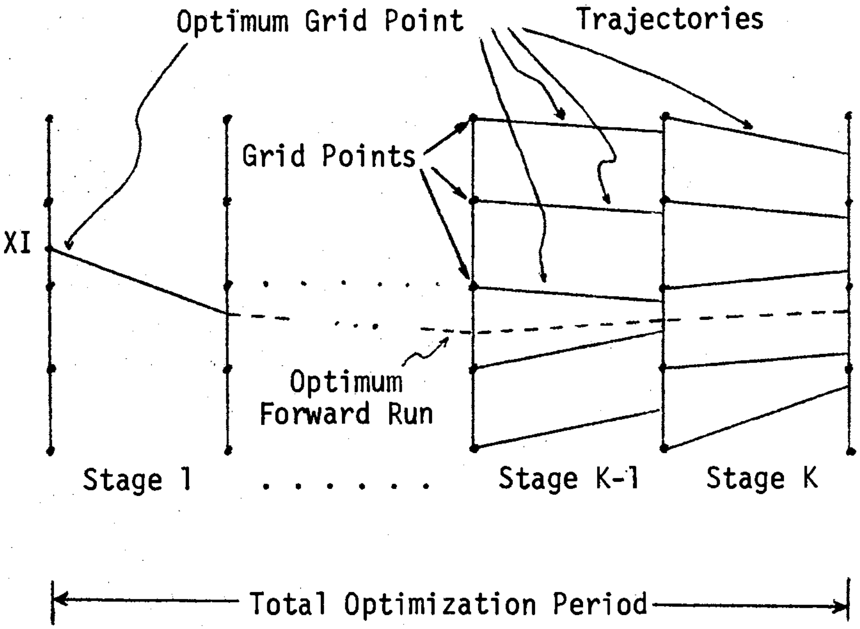


Figure 3. The Dynamic Programming Procedure

The last stage (stage K) is optimized first and USTAR and PSTAR values are stored for each of the five grid points. Then stage K-1 is processed. However the performance for each run during the K-1 stage is added to the optimum performance (PSTAR) previously found for stage K by interpolating the PSTAR values with the elevation reached at the end of the K-1 stage. Thus, when the PSTAR values are stored for each grid point of the K-1 stage, these values represent the total optimal performance from that grid point, over two stages, to the end of the optimization period. Corresponding values of the optimal energy controls are also stored for stage K-1.

The backstepping process is continued until the first stage is reached. Here, only the given initial pool elevation (XI) is used when the model is exercised and the optimum energy control is found and stored. At this time, the program has stored the optimal control for the first stage and optimal controls for each grid point for each of the remaining stages. The PSTAR value found for the first stage represents the forecast (by interpolation) of the total performance to be expected over the entire optimization period.

A "forward optimum run" is then commenced by OPTMZR, starting the pool elevation at XI, and using the optimal energy control for stage 1. When the pool elevation at the end of the first stage is known, the program evaluates the optimal energy control for the second stage by interpolating the values of the USTAR values for the grid points at the beginning of the second stage. This process is repeated for each succeeding stage to find the optimal energy controls.

Referring to the flow diagram of Figure 4, the operation of OPTMZR will be outlined. First, it should be noted in the figure that AREA 100 (top half) and AREA 200 constitute two large separate sections in the actual program itself. AREA 100 is in control of the backward stepping optimization procedure from the last stage to the stage just previous to

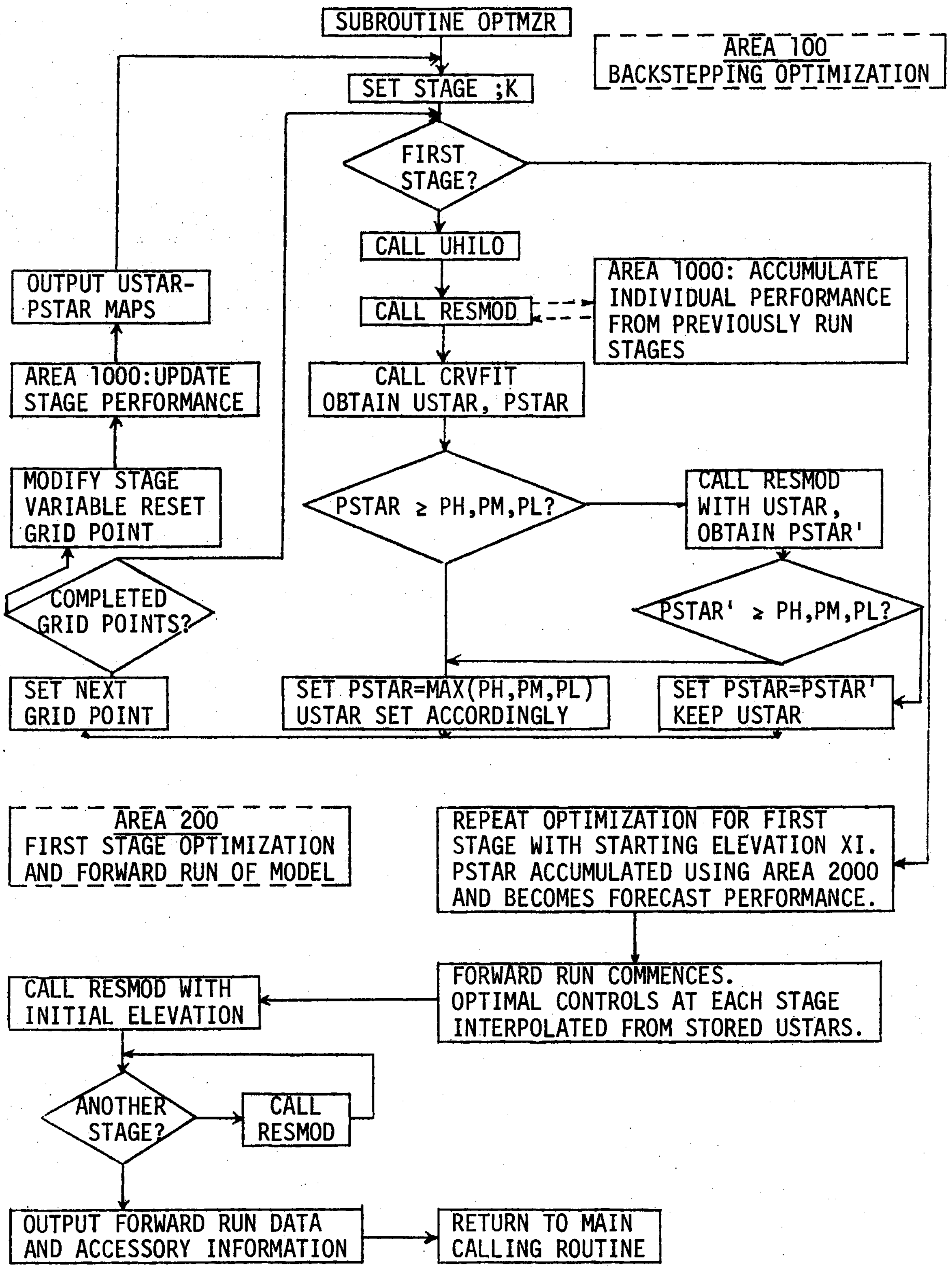


Figure 4. Operational Flow Diagram of OPTMZR

the first stage. AREA 200 controls the optimization of the first stage where the initial elevation is used to start RESMOD rather than a grid elevation point.

Before working through a stage, an initial test is made to determine if the first stage, K = 1, is to be run. If so, the program proceeds to AREA 200. If not, the program remains in AREA 100. First, UHILO is called and given the present grid elevation, X(M), and the current stage value, MONTH. UHILO calculates three controls, UH, UM and UL (high, middle, low) to exercise the model from the given grid point. RESMOD is then called to run each of the three controls. In each case, RESMOD returns to OPTMZR the benefit performance for each control, the final elevation (XNXT) and a corrected control, if RESMOD was forced by power pool constraints to over- or undergenerate the control issued by OPTMZR.

Immediately after each return, the stage performance is relayed to AREA 1000 and accumulated with a PSTAR value interpolated by means of XNXT. This provides a total performance (P=P + Interpolated PSTAR) from the stage being run to the end of the optimization period. For each control UH, UM and UL run, a corresponding total performance PH, PM and PL is evaluated in this fashion. The subroutine CRVFIT is then called to fit a quadratic polynomial to the performance points and determine the best control (USTAR) and associated best performance (PSTAR) from that fit.

Next, a sequence of testing occurs to insure that the USTAR-PSTAR values returned from CRVFIT are truly the best values within the control range used. If PSTAR is at least as great as PH, PM and PL then RESMOD is called using the associated USTAR value. This produces a "true" PSTAR, called PSTAR' in Figure 4. PSTAR' is tested against PH, PM and

PL and if PSTAR' is greater than or equal to each of them, then PSTAR' is stored as PSTAR and the current value of USTAR is kept and stored for the grid point run. If PSTAR' is less than any of PH, PM or PL, then the largest of these three is stored as PSTAR and the corresponding control (UH, UM or UL) is stored as USTAR for the grid point being run.

The grid point is then incremented and a test follows to determine if all five grid points have been used. If not, the optimization proceeds with the next grid point. If so, then the grid point is reset to the bottom of the grid range and the staging variable, N, is incremented. AREA 1000 is entered to store the completed PSTAR map (PSTAR value for each grid point) into the "past" PSTAR map so it can be used for interpolation while the next map is being constructed. At the end of each stage, the USTAR and PSTAR maps for that stage are printed for reference. Then the new stage is set by decrementing K as K = KMAX-N.

When the first stage (first month of interest) is reached, the program branches from the test block to AREA 200 where the optimization of the first stage at the initial elevation, XI, takes place. The optimization procedure is the same as for a single grid point except that performance accumulations take place in AREA 2000. The final PSTAR for XI will then reflect the total forecast optimal performance from that initial elevation to the end of the optimization period, if the optimal controls are applied at each stage.

It should be noted that the interpolation of the PSTAR and USTAR maps produces an inherent error in the evaluation of the optimal energy controls. This error will be reduced as more grid points are used in the procedure. One approach for improving the accuracy of the optimization after one optimization run is complete is to reduce the grid point range so that it closely bounds the pool elevation trajectories found by the first run.

As a final step, OPTMZR causes a complete forward run to be executed starting with stage one and elevation XI. Each new elevation XNXT(K) is used to interpolate the grid points of each USTAR map as each stage is processed. At the end of the forward run, the results of the run are printed together with certain input data for reference. Monthly (or daily) summaries of each month in the forward run are printed as described in the previous section on RESMOD. The following additional items are printed under control of OPTMZR:

1. Forecast performance (PSTAR)
2. Forward run performance (PRUN)
3. Total visitors (ISUM)
4. Total power revenue (REV1)
5. Initial pool elevation (XI)
6. Monthly inflow rates (FLW)
7. Monthly energy demands (DMD)
8. Monthly optimal energy controls (USTAR)
9. Monthly final pool elevations (XNXT)

Subroutine UHILO

UHILO estimates three monthly energy control values (UH, UM and UL) to exercise RESMOD at each grid point. These controls are calculated from energy demands, inflows, and evaporation for the month being run. Referring to Figure 5, a maximum control (UMAX) in MWH is determined for the grid elevation in question. This UMAX is the maximum energy which can be produced at that elevation operating all units twenty-four

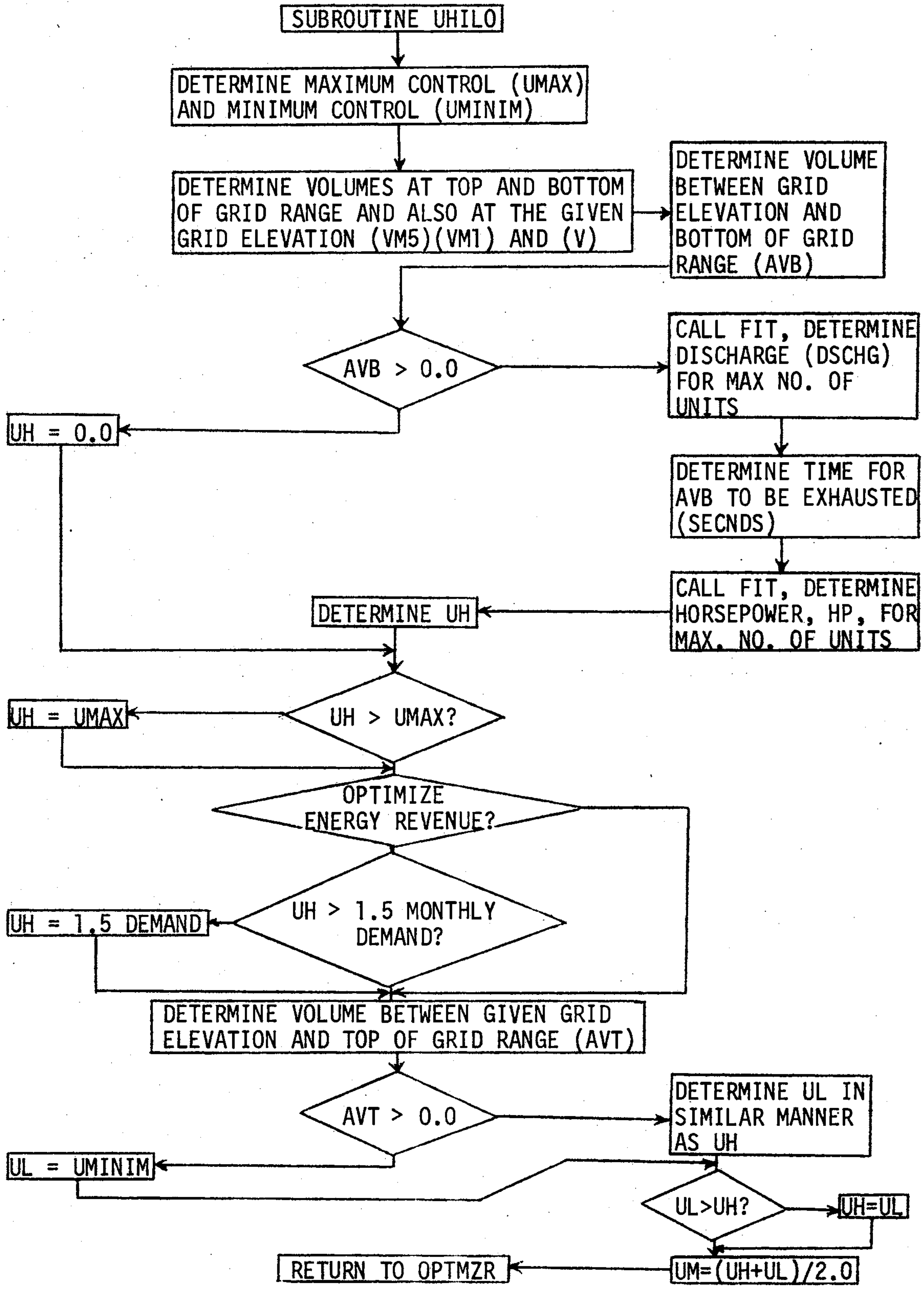


Figure 5. Operational Flow Diagram of Subroutine UHILO

hours a day for the entire month. Also, a minimum value of energy (UMINUM) is evaluated from the number of days in the month (MX) times the input controllable variable (MWHMIN) which specifies the minimum amount of energy to be generated each day by RESMOD (except at the bottom of the power pool).

Next, the reservoir volumes are calculated at the top of the grid range (VM5), the bottom of the grid range (VM1) and the given grid point elevation (V). These are in thousands of cubic feet. Taking into account the monthly inflow and evaporation, the available volume (AVB) for power discharge is calculated from the grid volume (V) and the bottom grid volume (VM1). If AVB > 0, then energy can be generated and UH is estimated from the power-discharge curves and the time (SECNDS) required to discharge AVB, based on all units running. If AVB $\leq$ 0, then UH is set equal to zero.

The value of UH is then tested to be sure that it is no greater than UMAX found previously. As a matter of policy, UHILO will not issue a control greater than 150% of the monthly demand value read in as input data. The purpose of this provision is to constrain the optimization to follow approximately the energy production history of a given period of record. An exception to this rule occurs when energy revenue (or just energy) is being maximized. In this case, UHILO ignores the values of energy demand read in and constrains UH only by UMAX.

The low value of control, UL is found in a similar fashion to UH but, in this case, a check must be made to insure that UL will cause enough power discharge to keep the pool elevation from rising above the top of the grid range. The volume AVT is found which must be discharged through generation (and possibly spill) to insure this condition. If AVT < 0, no volume must be released and UL is set equal to UMINIM calculated earlier. If AVT < 0, then the power-discharge curves are used to determine the energy increment which will cause AVT to be released. A final test is made to see if UL > UH, which may occur during months of high inflow when 24 hour generation of all units will not release the inflow. In this case UH is reset to be equal to UL. The last step shown in Figure 5 indicates the calculation of UM as the average of UH and UL.

Subroutine CRVFIT

Turning to the CRVFIT flow diagram of Figure 6, we note the use of the following notation: X1, X2 and X3 correspond to UL, UM and UH and Y1, Y2 and Y3 correspond to PL, PM and PH. It is clear that a number of tests are made in CRVFIT to guard against violating the mathematical requirements of a second-order curve fit routine. These are as follows:

1. When the curve is flat Y1, Y2 and Y3 (PH, PM, PL) are all equal and the point X2-Y2 is chosen for USTAR-PSTAR.
2. When the control range is narrowed to a single control or when two controls are equal, we may have
    a. X1 = X2 and Y1=Y2>Y3:X2 chosen as USTAR
       If Y1=Y2>Y3:X3 chosen as USTAR
    b. X1 = X3:X1 chosen as USTAR
    c. X2 = X3 and Y2=Y3>Y1:X2 chosen as USTAR
       If Y2=Y3<Y1:X1 chosen as USTAR

Providing no problems of the above kind appear, then coefficients are calculated for second order Lagrange fit and a "maximum" is X-Y pair is

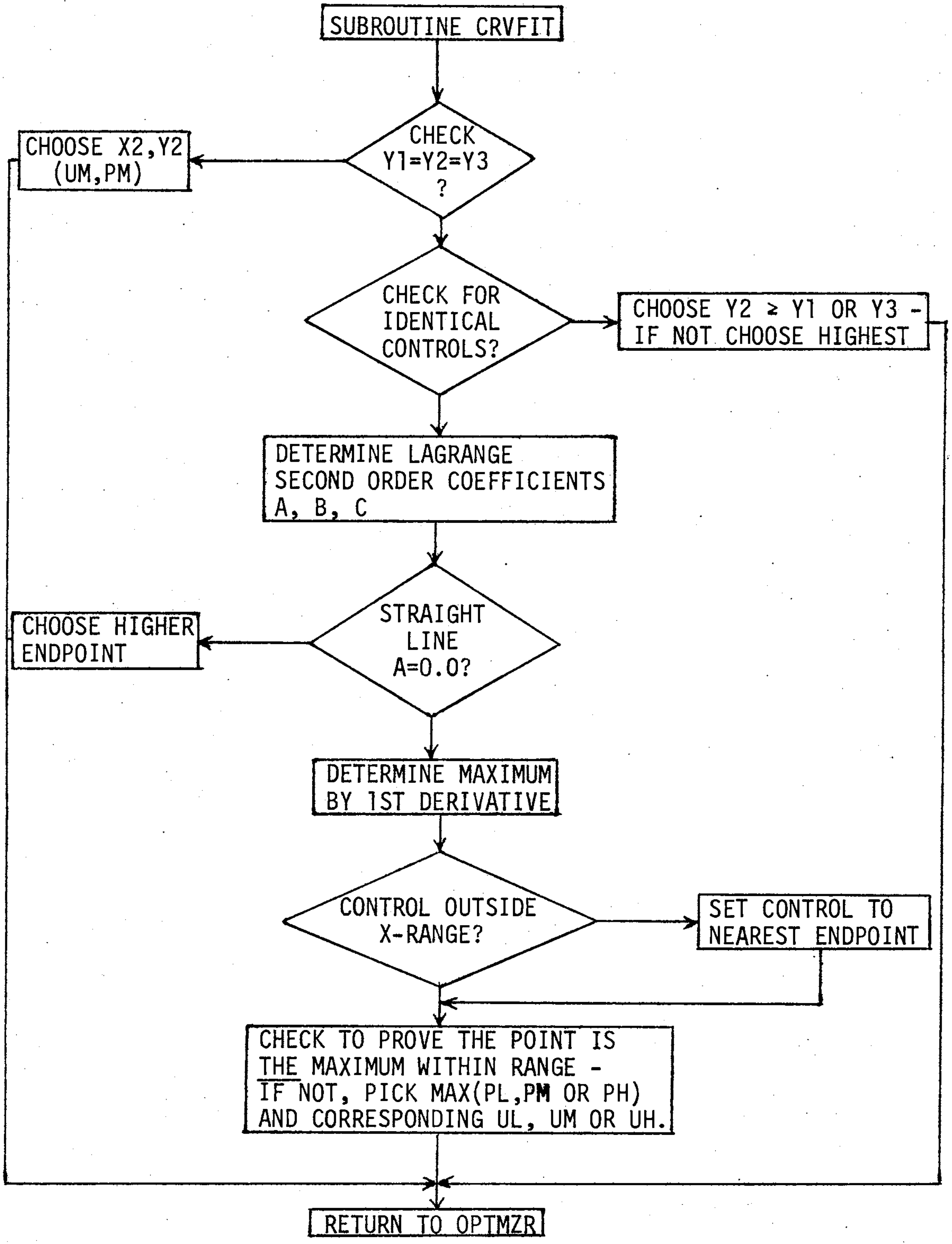


Figure 6. Operational Flow Diagram of Subroutine CRVFIT

found by means of the first derivative. The routine then tests to be sure that X is within the X1-X3 range of controls and that the value of Y found is indeed greater than Y1, Y2 and Y3. Program control is returned to OPTMZR upon completion.

This completes the discussion of the subroutines RESMOD, OPTMZR, UHILO and CRVFIT. Chapter III presents a similar discussion of the subroutine BENMOD.

CHAPTER III

THE BENEFIT MODEL

Introduction

Various recreational, water quality, flood and navigational benefits are modeled in the subroutine BENMOD. BENMOD provides the total model with information on the benefits listed above in the form of a performance index and in the case of visitation the actual number of visitors can be requested. More specifically, BENMOD is composed of a recreational model which predicts land and water-based visitors as well as below the dam visitors, a water quality model which predicts the relative goodness of water at a point down stream from the dam, a navigation model which assesses how well a navigation responsibility is being met, a flood model which uses downstream stage curves to evaluate the penalty associated with flood conditions, and a reservoir management factor which evaluates the stability of a reservoir in the eyes of a visitor to the reservoir. Also, a fish spawning model is proposed and described although it is not incorporated into BENMOD. Each submodel of BENMOD is now described with the logic leading to its formulation.

Recreation Model

The purpose of the recreation model is to translate the hydrologic variables of pool elevation and discharge into expected number of visitors on a daily basis. At the end of each day of reservoir operation, the reservoir model calculates a new pool elevation (in feet, MSL) and a total discharge (in thousands-ft^3) from the day's inflow, expected evaporation, power and spillway releases. These hydrologic variables plus the average daily intervening flows downstream become inputs to the recreation model.

Recreational activities are generally divided between those that occur on and around the reservoir and those occuring downstream from the dam. Furthermore, recreation around and on the reservoir is separated into two basic types: Land-based recreation includes picnicing, camping, sight-seeing and hunting activities and water-based recreation includes boating, swimming, fishing and skiing. It is recognized that most visitors to the reservoir are involved in several activities which fall within both the land and water categories. However, from a modeling standpoint, the effects of pool elevation upon the recreational benefits can be adequately represented by considering only two major types of visitors--those that use the water directly and those that merely observe it.

Seasonal effects are taken into account by weighting the pool elevation and discharge so that they have a different impact upon recreational visitation during each month of the year. The fundamental concept used here is that for normal ranges of pool elevation and discharge values, the visitation and the quality of the recreation during the warmer months is more sensitive to variations in these variables than is visitation during the winter months. Furthermore, it is recognized that there are both short-term and long-term effects on the number of visitors to be expected from pool elevation and discharge fluctuations.

It is also important to consider the fact that a large majority of recreational visitation occurs on weekends and holidays as compared to weekdays. Furthermore, the weekday visitation fraction of the weekend/holiday visitation is much lower during the winter months than in the summer months. To continuously take into account such seasonal variations, the Benefit Model receives from RESMOD a calendar which automatically adjusts the predicted daily number of visitors according to the expected weekend/holiday to weekday ratios.

Finally, it is important to consider briefly the expected use of the recreation model. The model will be used to discover improved regulation strategies for a single reservoir - and ultimately a system of reservoirs. Although it is obvious that recreational visitation at a particular reservoir depends upon <u>many</u> factors - some of which are more dominant than pool elevation and discharge - the proposed model must view these nonhydrologic variables as uncontrollable and therefore, not predictable except in a statistical sense.

The view taken in this modeling approach is that, given an average (over the recent past) set of meterological, economic and social conditions, the number of visitors attending a reservoir will vary when pool elevation and discharge variables vary. The computer simulation will use past hydrologic variables which are known but the results will be interpreted in terms of <u>future</u> regulation strategies. The level of effort undertaken in this project does not allow prediction of those future meterological, economic and social factors which surely affect visitation. Therefore, these factors must be given "average" or "expected" values in the proposed model.

Consider first the short-term effects of pool elevation and discharge on reservoir visitation above the dam. The phrase "short-term effects" implies those effects which are a direct and immediate result when translating pool elevation, pool elevation change and discharge into expected visitation numbers. As might be expected, it is always difficult to precisely separate short-term effects from long-term effects and, depending upon the nature of the simulation, a precise definition may not be necessary in terms of the overall simulation results.

For example, in a simulation it is necessary to reduce the expected number of visitors for water-based recreation when the pool elevation drops to a point where submerged obstacles become a danger to boating and when swimming beaches are separated from the water edge by a mudflat area. The actual reduction in visitor numbers arises in two ways. First of all, the visitor may not engage fully in boating and swimming activities due to the poor conditions and so, it is clear that the quality of his recreational experience is diminished. Furthermore, at some future date, this visitor may elect not to return to the reservoir because of his earlier bad experiences on the day when the pool elevation was low.

The question which arises is the following: Should the model predict a reduced number of visitors on the day at which time the pool elevation was low as well as on some future date when a prospective visitor might have the opportunity to return to the reservoir but declines? In this model the basic approach taken is to penalize immediately, and disregard the lagging or time-shifted penalties. Since the simulations are expected to run for periods of several months up to a year in length, it makes little difference whether the penalty is applied either concurrently with the pool elevation level or several weeks later, as the total visitation for the year will not be affected.

To quantify the lagging penalty effects, a long-term model was developed which attempts to quantify the reputation of the reservoir management in the eyes of the visitor relative to pool elevation. This rating, while not directly affecting the predicted visitation, will assist the planner in ranking alternative regulation strategies.

Figure 7 illustrates the structure of the short-term model for the above dam recreation. At the end of each day the reservoir model will issue a new pool elevation which will be supplied to a simple subroutine to generate the average pool elevation (ELEVAT) and the total change over the previous day (DELEV). The value for the average daily pool elevation is then supplied to subroutines containing the monthly land visitor curve and the monthly water visitor curve. A detailed description of these curves will be presented later. The output variable from these two subroutines is a value of raw monthly number of visitors for land-based (RAVTLA) and water-based (RAVTWA) recreation. The visitor values given in Figure 7 are based on the monthly number of visitors and, following a summation of these two variables they are divided by the equivalent number of days in the month. The equivalent number of days BN(M,11) in the month is calculated from knowledge of the ratio of weekday visitors to holiday or weekend visitors and the number of holidays, weekend days and weekdays in the month. M in BN(M,11) is the number of the month of interest not the monthly calendar number. The formula is as follows:

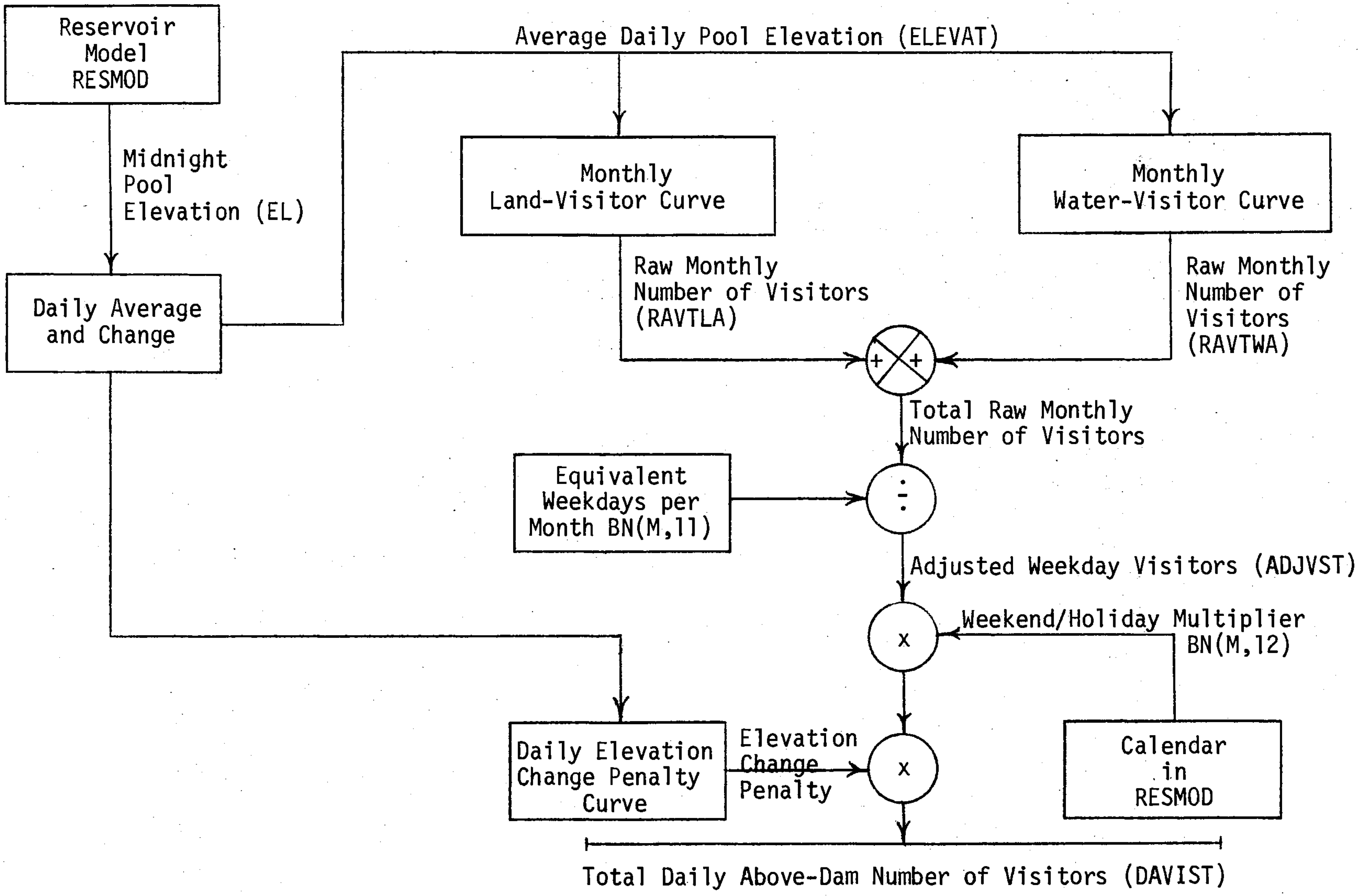


Figure 7. Short-term Model, Above Dam Recreation

$$\begin{array}{c}\text{Equivalent Number of Days}\\ \text{In The Month}\end{array} = \begin{array}{c}\text{Number of}\\ \text{Holidays}\\ \text{and}\\ \text{Weekend Days}\end{array} \times \begin{array}{c}\text{Weekend-}\\ \text{Holiday}\\ \text{Factor}\end{array} + \begin{array}{c}\text{Number}\\ \text{of}\\ \text{Weekdays}\end{array}$$

This factor BN(M,11) is calculated outside the computer program for each month as the number of holiday and weekend days per month and the holiday or weekend factor changes monthly. The result is the number of adjusted weekday visitors (ADJVST) to the reservoir. This value is processed by a weekend/holiday multiplier BN(M,12) which is a seasonally adjusted factor supplied by the calendar in RESMOD to adjust the raw number of weekday visitors upward during Saturdays, Sundays and holidays.

A penalty factor is applied on the basis of the total daily elevation change (DELEV). This penalty factor will further reduce the total number of daily visitors when elevation changes occur during the twenty-four hour period. The final output of the short-term model (DAVIST) is a value for the adjusted total daily above-dam number of visitors. A new value is calculated each day by the model, and supplied to a cummulative register which sums the total visitation since the first day of the month.

We now proceed to give a more detailed discussion of the form of the monthly land and water visitor curves and the daily elevation change penalty curves.

Figure 8 illustrates the form of the visitor curve developed. The horizontal scale is the pool elevation in feet MSL and the vertical scale is the number of thousands of visitors expected monthly. There are two of these curves, one for water-based recreation and one for land-based recreation, for each month of the period under study.

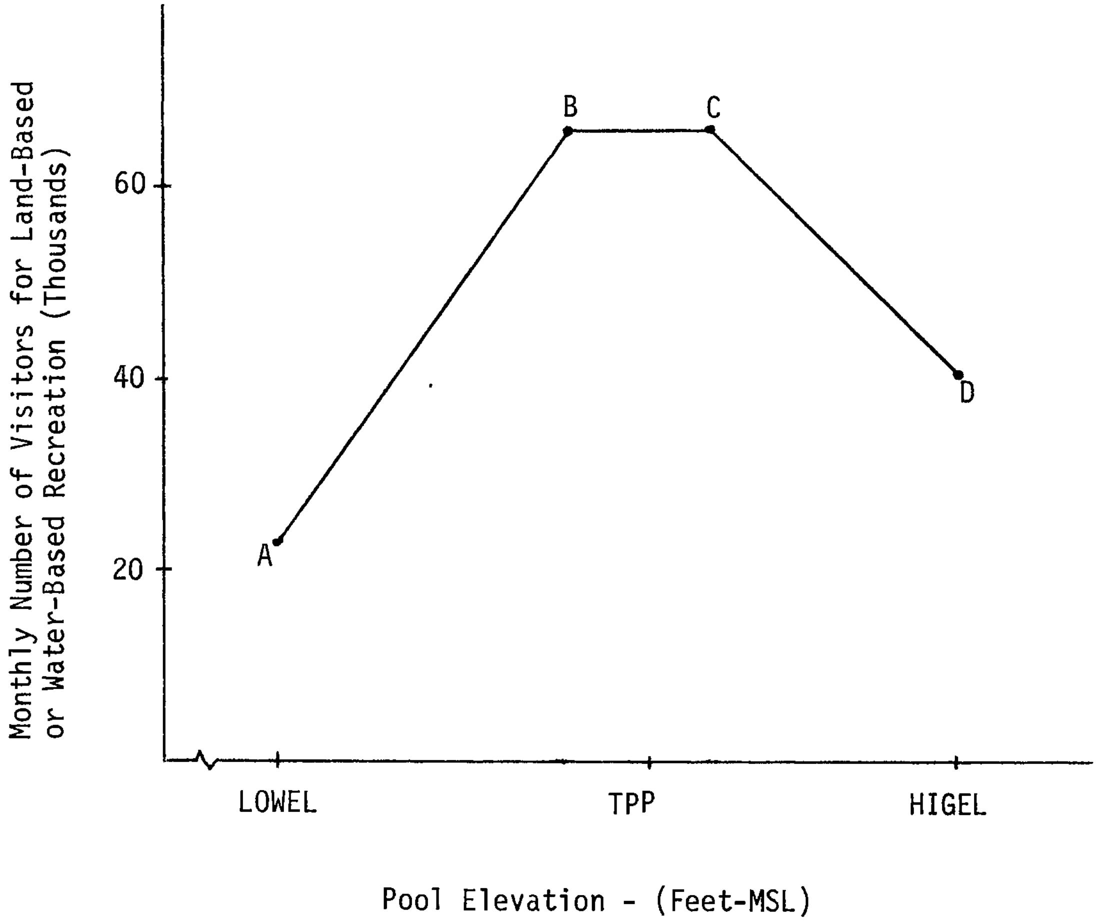


Figure 8. Typical Monthly Visitor Curve

The curve is composed of three straight line segments defined by the four points A, B, C, and D as shown in Figure 8. Implementing the curve in the program involves simply storing the four coordinate points and providing a linear interpolation algorithm to determine intermediate values. The computer variables associated with the points A, B, C, and D for each of the land-based and water-based curves are listed below.

Point	Land-based Curve		Water-based Curve	
	Abscissa	Ordinate	Abscissa	Ordinate
A	LOWEL	BN(M,1)	LOWEL	BN(M,4)
B	BN(M,7)	BN(M,2)	BN(M,9)	BN(M,5)
C	BN(M,8)	Same as B	BN(M,10)	Same as B
D	HIGEL	BN(M,3)	HIGEL	BN(M,6)

Certainly, more complex curves composed of additional straight line segments or polynomial functions can be utilized, assuming that data exists to support such complex curves. However, the four point form was selected as a reasonable compromise between increasing the computing time and possible increase in accuracy.

The seasonal variation in visitation is reflected in the shape of the visitor curve for both land and water based recreation. The basic change in shape from month to month is reflected in the value of the peak expected visitation given by line segment BC as well as the relative slopes of the lines segment AB and CD. In general, during the winter months when the number of visitors is reduced, the effects of pool elevation are reduced and the curves are wider and flatter than those for the summer months. For any month, the basic difference between the land-based and water-based curves is that the elevation range for peak visitation is greater for land-based curve than for the water-based curve. Likewise there is a difference in the penalty associated with the minimum and maximum elevation points. For the land-based curve the penalty associated with the minimum elevation point is less than for the water-based curve but the penalty associated with the maximum elevation point is greater.

To locate the four points, which define each of the monthly land and water-based recreational visitation curves, a general set of rules were developed. These rules reflect the nature of the visitation data for the six year period, the seasonal variation of the number of visitors, the topological nature of the reservoir and the observations of the resident engineer as to the quality of the recreational experience of the visitor. The rules for locating the points A, B, C and D are summarized in Table I and the rationale for their formation will now be discussed.

The data, separately for land-based and water-based recreation, for the past several years (six years in this case) was analyzed by correcting for yearly growth and temperature and plotting the corrected monthly number of visitors against the average monthly pool elevation.

The value of the expected peak number of visitors for each month was selected from these plots. This expected peak number selected is not always the maximum number of visitors recorded. If not, depending upon the scattering of the data points and the range of pool elevations represented by the data during a particular month, a value near the maximum is selected. Separately, for land-based and water-based recreation, each of these selected peak monthly values was plotted versus the month and adjusted to lie on a smooth yearly periodic curve usually with July having the maximum and January the minimum. These adjusted peak values then determine the ordinate value of the line segment BC for each curve.

For the water-base visitor curve, the elevation range of the line segment BC was determined from a consideration of the topology of the reservoir area, the design use-level of the boat ramps and swimming beaches, the under-water hazards existing at various elevations and convenience of fishing facilities. For the land-based curve the items considered were the elevation of access roads, camping, picnicing and toilet facilities and the topology of the reservoir area. These values reflect the feeling that water-based activities are more sensitive than land-based to pool elevation and also that the activities during the summer months are more sensitive to elevation than those activities during the winter months.

These opinions arise from the observation that the water-based activities during the summer consist not only of sking, but swimming, pleasure boating and water skiing while in the winter it is confined mainly to fishing. The assumption is that the fishermen are more hardy and dedicated to that activity.

The procedure for arriving at the expected number of visitors at the expected lowest elevation (LOWEL), usually the bottom of the power pool, and at the expected highest elevation (HIGEL), the top of the flood control pool is complicated by the fact that little, if any, visitation data exists at these elevations extremes. Therefore, use must be made of the data that exists for limited ranges of elevation.

For the location of point A, the elevation is selected as the lowest expected pool elevation (LOWEL) with the bottom of the power pool being a reasonable value. To determine the expected visitation, the plots used to determine the location of segment BC are again used. On the assumption that no visitor data exists at the minimum expected elevation, then the rule is based on the condition that the expected number of visitors should be no greater than the lowest observed number in the data for that month. Indeed, it should generally be less. Therefore, a percentage rule was selected to translate the observed minimum number of visitors for any month into the value for point A. These selected monthly minimum values were then plotted versus the months and adjusted to fall on a smooth yearly periodic curve.

This percentage value selected was based upon the effect on the quality of the recreational experience of such things as mud-flats, exposed swimming beaches, unusable boat ramps, reduced shoreline, increased underwater hazards and other conditions caused by lower pool elevations. Since the availability of land-based recreational facilities are not materially affected by the reduced water level, less penalty is levied against land-based as compared to water-base activity. Also, since the winter activities are confined mainly to fishing the penalty assigned to the winter percentage is less. These percentages for the summer and winter, land and water-based activities are shown in the first column of Table I.

The location of point D involves the highest elevation expected (HIGEL) and the expected visitation for this elevation. The highest expected elevation is usually the top of the flood control pool. Again, since there is little visitation data available for that elevation of operation a percentage rule was developed for selecting the expected visitation. Here the percentage figure is applied to the previously selected peak expected monthly number of visitors. In this case it was reasoned that now the land-based activities would be more sensitive to the high pool-elevation. This exists because at the highest expected pool elevation access roads, picnicing, camping and toilet facilities would be at least partially inundated. Even though the original boat ramps would be covered, boats could be launched from access roads and fishing and some boating would exist. Again, both types of recreational activities in the winter time were considered to be less sensitive to elevation than those in the summer. The percentage values selected are shown in column two of Table I and as shown apply to the previously selected peak monthly expected number of visitors. No seasonal smoothing of these points are required as they were derived from the previously selected peak values. One notes from Table I that the water-based activity is indicated as being more sensitive to seasonal variations. This completes the explanation of the procedure for locating the four points which describe the monthly visitor curve for land and water-based recreation.

TABLE I

GENERAL RULES FOR ESTABLISHING THE VISITOR CURVES

	Percent of Lowest * of Visitors For Lowest ELEV.	Percent of Maximum Expected Visitors For Highest ELEV.
Summer, Land-Based	60%	40%
Winter, Land-Based	70%	50%
Summer, Water-Based	40%	50%
Winter, Water-Based	60%	70%

* Lowest observed visitor values during data period, adjusted for expected seasonal variation.

Because of the detrimental effect of rapid elevation changes (regardless of the absolute pool level), a daily elevation change penalty factor was applied to the daily expected number of visitors. It is assumed that any such daily elevation change (up or down) will be detrimental to land-based as well as water-based activities. Large inflows causing a rapidly rising pool elevation will generate unsightly floating debris which is also hazardous to boaters. Also, rapid elevation drops will likely produce mud flats and reduce fishing success. Thus the elevation change factor will penalize visitation for any change in elevation over the past 24 hours.

From a visitor's standpoint, the elevation change will not be a significant factor in his activities unless the daily change is large. Therefore, the amount of penalty will be relatively small. Due to the fact that a larger number of less hardy visitors are present in the summer months, a greater penalty will be assessed for the months of April through September than for the period October through March.

Figure 9 shows the form of the elevation change penalty curves. The horizontal scale, for Tenkiller as an example, ranges from 1 ft/day down to 3 ft/day up. At these extreme values, supplied to the program by BN(M,19) and BN(M,21), respectively, the curves penalize visitation by 10% for April through September and by 5% for the remaining winter months. For example, if an elevation rise of 3 ft/day occurs, 90% of the value obtained from the visitor curves will be predicted during the summer months and 95% for the winter months. Figure 9 shows that if no elevation change occurs on a given day, 100% of the number of visitors to the reservoir will be predicted. In the program, the location of this no-penalty point is controlled by the input data through the parameter BN(M,20) and may be any value between BN(M,19) and BN(M,21) depending on the characteristics of the reservoir under study. A more complex

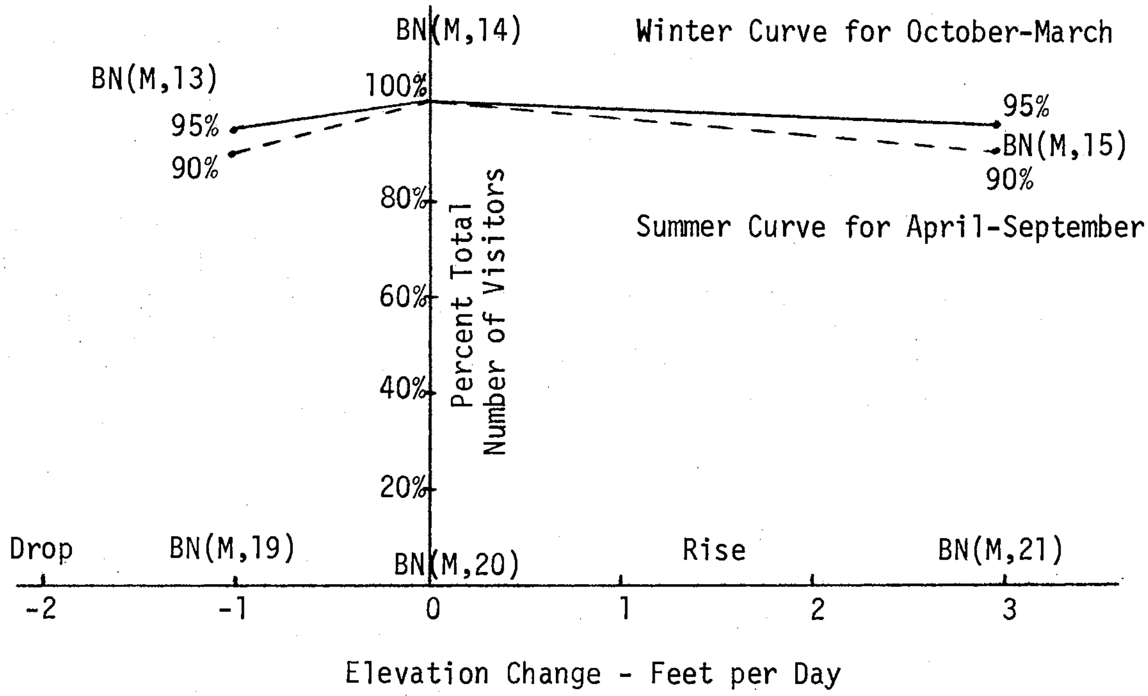


Figure 9. Typical Daily Elevation Change Penalty Curve

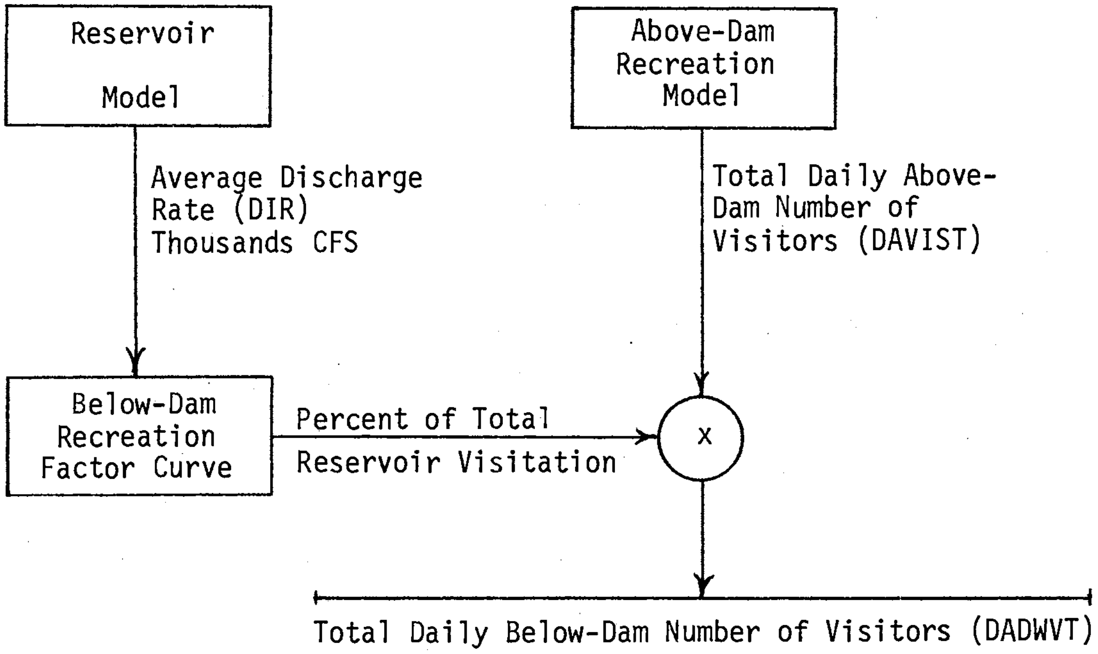
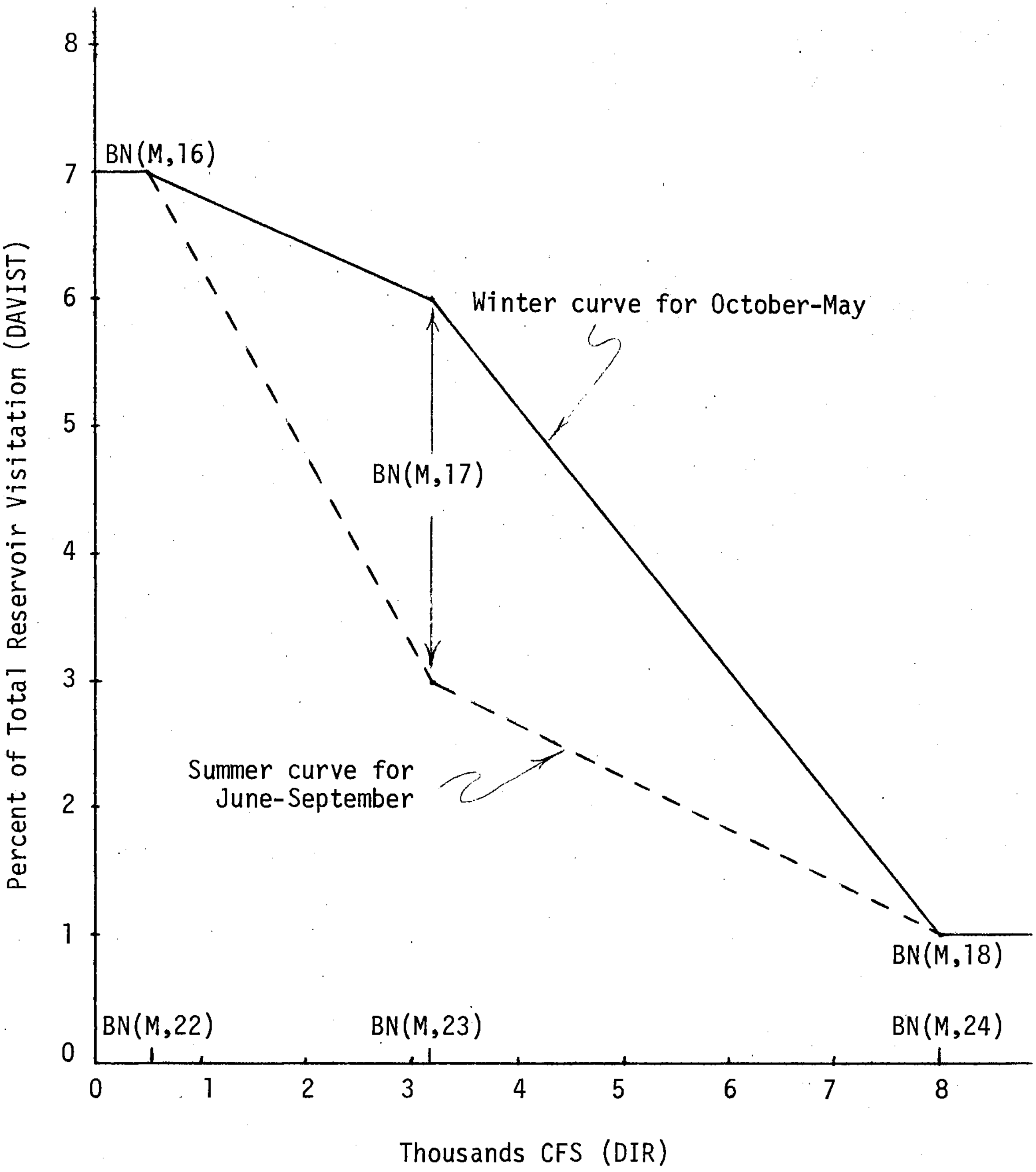


Figure 10. Short-Term Below-Dam Recreation Model

curve, different for each month, could be implemented but such complexity appears unwarranted at this time.

With the formulation of the visitor curves and the daily elevation change penalty curves completed we have described the logic behind the formulation of the BENMOD variable (DAVIST) which is the daily number of visitors to the reservoir corrected for daily elevation change penalties. Since there is some visitation below the dam this too must be included in the Recreation Model. Figure 10 shows the relationship of the downstream visitor model to the reservoir model and above the dam recreation model.

Since the factors affecting the visitors at the reservoir (weather, time of year, holidays, etc.) would also affect visitors below the dam, it was felt necessary to develop a relationship between these two. From discussions with the Resident Engineer of one reservoir he indicated a relationship existed between downstream visitation and discharge. It was felt that this was an intuitive relationship and as a result the below the dam number of visitors is found as a percentage of the above the dam number of visitors for a given discharge rate. Figure 11 shows a representative curve for predicting below the dam number of visitors. Note that seasonal variations are indicated by a summer and winter curve. The break points in these curves are determined by experience with the characteristics of visitation below the reservoir. However, some general items to consider in locating these break points are (1) the optimum flow rate range for fishing BN(M,22), (2) the nominal flow rate with all generating units operating BN(M,23) and (3) the flow rate at which the fishing activity ceases BN(M,24). The curves are simple 3-point curves in this case but can easily be made more complex if data is available to



Notes BN(M,22) - Optimum flow rate range for fishing

BN(M,23) - Nominal flow rate with all generating units operating

BN(M,24) - Flow rate at which fishing activity ceases

Figure 11. Typical Below-Dam Recreation Factor Curve

support such curves. The resulting variable is DADWVT which is the daily down-stream number of visitors and together with DAVIST the daily above dam number of visitors comprise part of the performance index supplied to RESMOD on a daily basis. A complete listing of the computer variables used in the recreation model are defined in the Appendix.

The Water Quality Model

The next part of the benefit model (BENMOD) is the water quality model whose block diagram is shown in Figure 12. This model computes the daily water quality of the stream below the dam at two control points based on three water quality variables. These variables are (1) biological oxygen demand, B.O.D., and dissolved oxygen, D.O., (2) temperature and (3) dissolved solids, D.S. The model although not mathematically complex is complex in the interaction of the three variables mentioned above. A more complex model is discussed in the references [24]. For our purposes the model described below adequately describes the condition of the water below the dam. The water quality model as shown in Figure 12 has its own performance index so that the model issues only one value representing water quality to RESMOD on a daily basis.

Consider first the treatment of the water quality variable, temperature. The data input consists of the temperatures of the reservoir discharge (TMRES) and that of the intervening flows (TMEFF) in degrees centigrade. The daily reservoir discharge (CFSS) is known from RESMOD and the daily average flow rate of the intervening flows (CFSEFF) is entered as input also. Through a simple mixing equation the reservoir

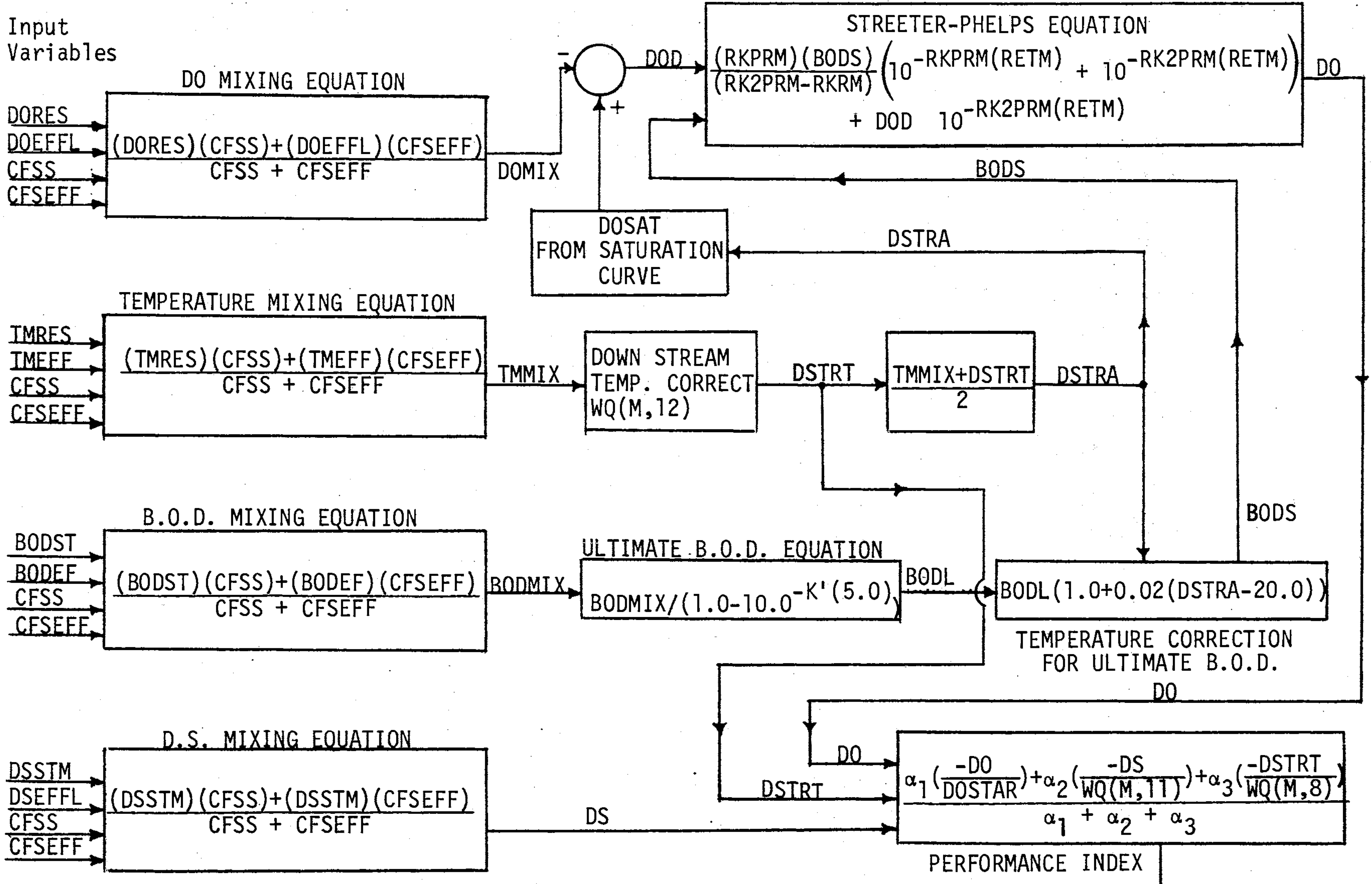


Figure 12. Water Quality Model (Single Stage)

discharge or stream flow is mixed with the intervening flow (effluent) and the resulting mixture equation is found as shown below.

$$\text{Temperature of mixture} = \frac{\text{Temperature of stream)} \times \text{Stream flow rate} + \text{Temperature of intervening flow} \times \text{Intervening flow rate}}{\text{(Intervening flow rate plus stream flow rate)}}$$

In the case of the first reach with reach time (RETM1) the stream flow rate becomes the reservoir discharge in water quality calculations. The temperature of this mixture (TMMIX) is corrected by a downstream temperature correction factor (DMTC) which attempts to simulate the rise in temperature that occurs during the winter as the water flows downstream. The result is the predicted downstream temperature (DSTRT). The mixture temperature (TMMIX) and the predicted downstream temperature (DSTRT) are averaged to determine the average downstream temperature (DSTRA). The average downstream temperature is used in determining the dissolved oxygen deficit. Since only one temperature value is used in the dissolved oxygen model it is natural to use the average downstream temperature (DSTRA) although for the temperature term in the water quality performance index the predicted downstream temperature (DSTRT) is used. See Figure 12.

With the average downstream temperature (DSTRA) known, the dissolved oxygen content of the stream at one or two points, if desired, is then found. The data input consists of the average monthly dissolved oxygen (DO)of the reservoir discharge (DORES) and two intervening flows, WQ(M,2) and WQ(M,18). Again the discharge rate of these flows are used in a mixing equation identical to the temperature mixing formula except that D.O. values are now used. The result is the D.O. of the mixture (DOMIX) at the beginning of the reach in question.

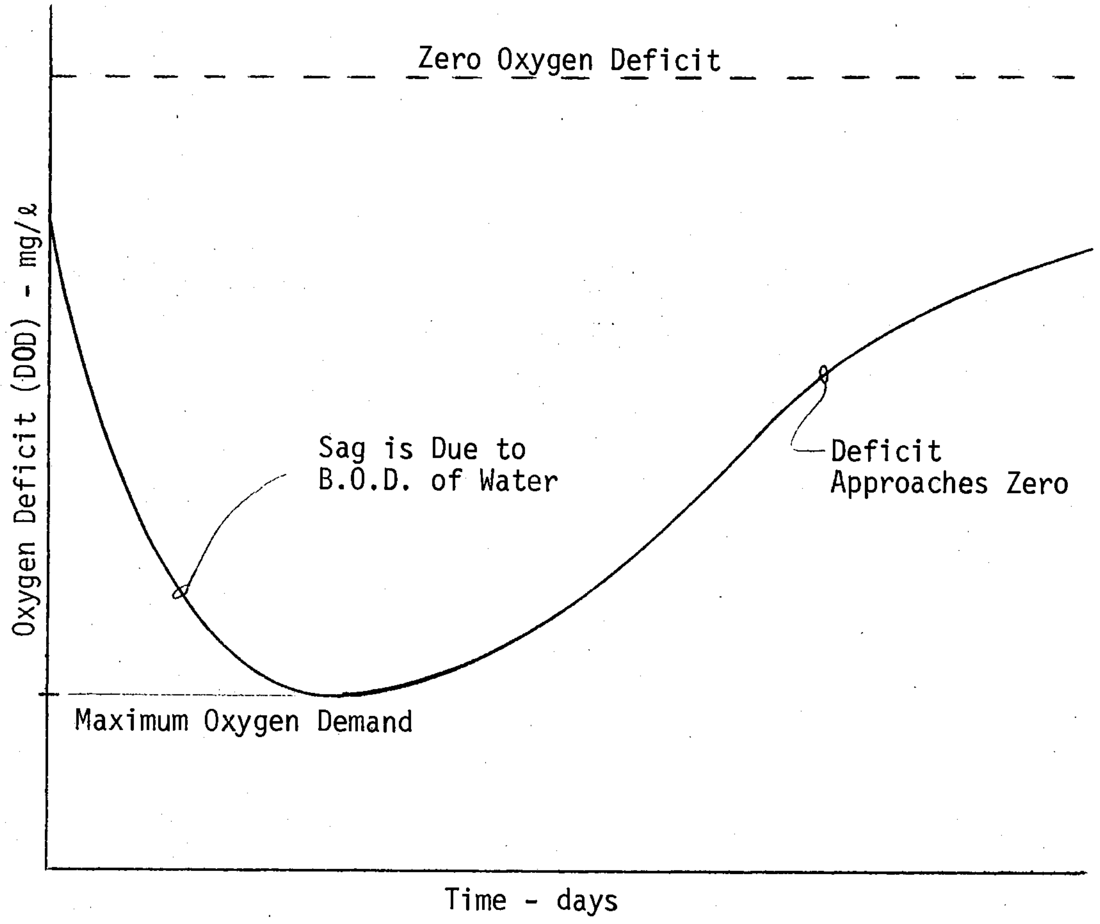


Figure 13. Typical Oxygen Sag Curve

The basic dissolved oxygen model incorporates the oxygen sag curve developed by Streeter-Phelps (S-P). The basic sag equation is shown in Figure 13 and a more detailed explanation is made in the reference [16].

Basically the model computes the downstream D.O. in the following manner. With the average downstream temperature (DSTRA) known, the saturated D.O. associated with this temperature is found. The D.O. of the mixture (DOMIX) is then subtracted from the saturated D.O. value (DOSAT) and the result is the D.O. deficit (DOD). This value (DOD) is the deficit value used in the Streeter-Phelps equation.

The 5-day 20°C biological oxygen demand B.O.D. of the mixture is then computed from input data consisting of the 5-day 20°C B.O.D. of the discharge WQ(M,4) and that of two intervening flows WQ(M,5) and WQ(M,19). The mixture equation described before is used and the result is the 5-day 20°C B.O.D. of the mixture at the beginning of the reach (BODMIX). The Streeter-Phelps model operates on a 10 to 20 day maximum stage for the oxygen sag curve. As a result, the water quality model will not be valid if the sum of the two reach times exceed 10 to 20 days. Since BODMIX is a five day 20°C value the ultimate or maximum B.O.D. must be found to use the Streeter-Phelps equation. This value (BODL) is determined from the equation found in Figure 12. Since we are operating on the average stream temperature (DSTRA), the ultimate B.O.D. must be corrected to (DSTRA). The result (BODS) is the temperature corrected ultimate B.O.D. This value along with the dissolve oxygen deficit (DOD) value are inserted in the S-P equation and the D.O. deficit (DODEF) at the end of the reach time is calculated. This deficit is subtracted from the saturated value (DOSAT) to find the actual D.O. of the stream at the end of the reach (DO). The B.O.D. reaction constant K', WQ(M,13), is temperature corrected to the average stream temperature and inserted in the S-P equation as (RKPRM). Likewise the velocity rate of transfer constant K_2', WQ(M,14) is temperature corrected by (DSTRA) and inserted in the S-P equation as (RK2PRM) as shown in Figure 11.

The final computation in the water quality model is that of the dissolved solids of the mixture at the end of the reach. The mixture equation is used again and the input data is the dissolved solids D.S. of the reservoir discharge or stream flow (DSSTM) and that of the two intervening flows WQ(M,10) and WQ(M,20). The resulting D.S. of the mixture (DS) is used in the water quality performance index.

The three values just described are used in the water quality performance index. Each value of, the downstream temperature (DSTRT), the D.O. at the end of the reach (DO), and the dissolved solids at the end of the reach (DS) is compared to an optimum value designated as WQ(M,8) for the temperature (DOSTAR) for the D.O. and WQ(M,11) for the D.S. in the input data. The desired or optimum D.O. (DOSTAR) becomes DOSAT if no optimum value is specified. To prevent large unmanageable numbers, the deviation from this optimum is limited to 100%. It is assumed that a deviation greater than 100% has already sufficiently degraded the quality of that component so that it is at a minimum. As a result each performance index component (temperature, D.O. and D.S.) is constrained to a maximum good value of one and a minimum poor value of zero. These three are then summed together with a separate input controllable weighting factor ALPHA1 for the D.O., ALPHA2 for the D.S. and ALPHA3 for the temperature so that the effect of each can be studied. The final water quality value (WAQ) is a number between zero and a maximum of three and is supplied to RESMOD on a daily basis.

To determine the water quality for the second reach, with reach time (RETM2), the water quality model is used again with the results computed at the end of the first reach being the stream input data for the second reach. For example, in the mixing equation (DSTRT) becomes the stream temperature (TMRES), (DO) becomes the stream D.O. (DORES) and (DS) becomes the stream D.S. (DSSTM).

For B.O.D., the ultimate values are used in the mixing equation, since the ultimate B.O.D. of the mixture must be used in the Streeter-

Phelps equation and since the B.O.D.'s of each of the flows must be on the same biological time base. For the stream B.O.D., the value is determined as the difference between the ultimate value computed for the first reach BODL and the actual B.O.D. value existing at the end of the first reach. That is, the remaining biological oxygen demand at the end of the first reach (BODST) becomes the ultimate B.O.D. for the stream input to the mixing equation for the second reach. The 5-day 20°C B.O.D. of the intervening flow WQ(M,19) is converted to its ultimate value to use in the mixing equation. The program in BENMOD is so written that the conversion of the first reach B.O.D. values and the 5-day B.O.D. intervening flow values are automatically converted to ultimate values before mixing.

In the program, the model computes the water quality for one reach only if the second reach time data value RETM2 is zero or blank. If a second nonzero (or nonblank) reach time is entered in the data then the water quality is computed for both reaches and supplies the average of the two to RESMOD.

The values for the water quality auxiliary variables are read in monthly from the WQ data array as shown below. M is the monthly order number.

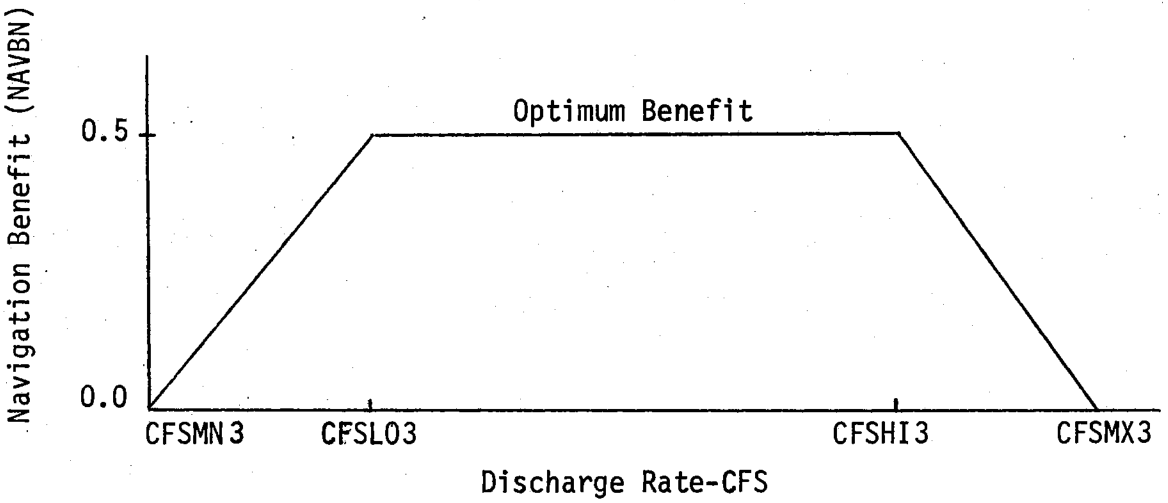
BODEF - WQ(M,5), WQ(M,19)
BODST - WQ(M,4)
CFSEFF - IVFLO1, IVFLO2
DOEFFL - WQ(M,2), WQ(M,18)
DORES - WQ(M,1)
DOSTAR - WQ(M,3)
DSSTM - WQ(M,9)

DSEFFL - WQ(M,10), WQ(M,20)
TMEFF - WQ(M,7), WQ(M,17)
TMRES - WQ(M,6)

A complete listing of the water quality computer variables is given in the Appendix under the Water Quality Model.

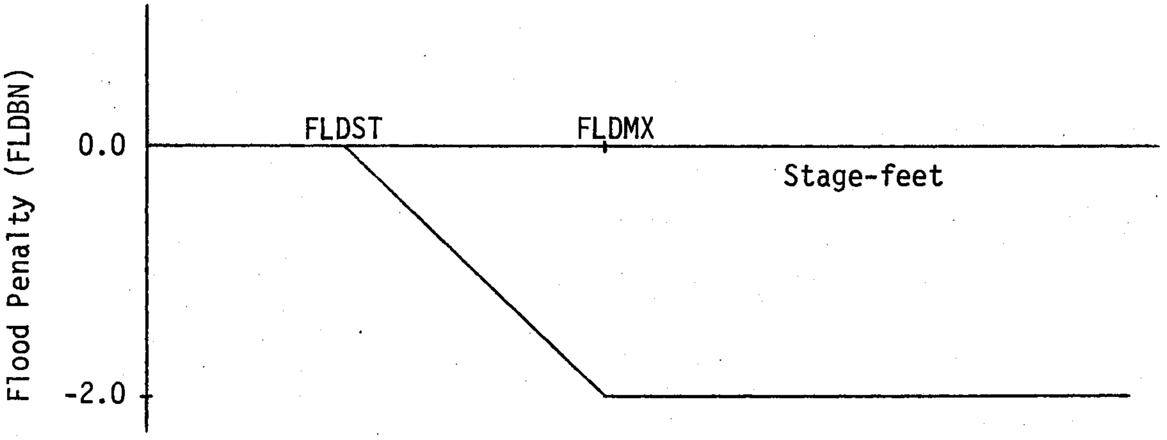
The Navigation Model

Many reservoirs have a responsibility by themselves or through a series of reservoir to maintain a specific channel flow for commercial water traffic. Intuitively this is a discharge phenomena and thus the relative worth of meeting in total or in part this responsibility should be a function of discharge rate. Figure 14 shows a typical navigation benefit curve. There are two of these curves, one for each control point and each having an optimal value of 0.5 so that the optimum sum is 1.0. Note that there is a flat portion which indicates a range of discharge rates which produce a complete fulfillment of the navigation responsibility. At the low discharge end (CFSMN3) the benefit goes to zero indicating that no water traffic is possible at zero or near zero flow rates. Also at high discharge rates (CFSMX3) barge traffic is impeded or halted altogether so the benefit again goes to zero. The optimum range point as well as the low (CFSLO3) and high (CFSHI3) discharge rate cutoff points must be determined from experience with the reservoir system in question. As shown by Figure 13, the navigation benefit for each stage has a value from zero to 0.5, that is, from worse to best and are summed together to obtain the total navigation benefit. This value (NAVBN) is transferred to RESMOD on a daily basis for use in the main performance index.



Note: Two such curves are used for the total navigation benefit for a total optimum value of 1.0 .

Figure 14. Typical Single Reach Navigation Benefit Curve



Note: Two such curves are used for the total flood penalty for a total maximum penalty of -4.0

Figure 15. Typical Single Reach Flood Penalty Curve

The values of the navigation model auxiliary variables are read in monthly from the NAV data array as shown below.

CFSHI3 - NAV(M,3), NAV(M,7)
CFSLO3 - NAV(M,2), NAV(M,6)
CFSMN3 - NAV(M,1), NAV(M,5)
CFSMX3 - NAV(M,4), NAV(M,8)

A complete list of the navigation model computer variables is given in the Appendix.

The Flood Penalty Model

One feature of RESMOD is that it calculates the stage heights at two control points downstream. Thus knowing these stage heights it is relatively easy to construct a flood penalty model. The general form of the flood model is shown in Figure 15. The determining points are the flood stage (FLDST) at control points one and two and the maximum expected stage (FLDMX) at these points. It was decided that the model should not penalize for stages below flood stage but should increase in penalty after flood stage until it reaches the maximum expected stage. At this point it should just cancel the optimum values of the other benefits. Each stage is given a maximum (negative) penalty of -2. Thus for two stages a value of -4 total was chosen for the maximum (negative) penalty for the flood model in the main performance index. Note that the other components of the model have been positive and that the flood penalty is designed to cancel those positive or beneficial values.

The value of the flood stage variable (FLDST) is specified at the control points one and two by input data FLDST1 and FLDST2 respectively.

For the maximum expected stage variable (FLDMX), the value at each control point is specified by the input data FLDMX1 and FLDMX2.

A complete list of the flood model computer variables is given in the Appendix.

The Generation Benefit Model

Because later runs on the computer would involve optimization for power only as well as for some of the other benefits by themselves, a typical generation benefit model as shown in Figure 16 was developed. As shown in Figure 16, a monthly generation from zero to the monthly demand (DEM) produces a benefit from 0.0 to 1.0 with a slope of one. For generation above the demand it was felt that a 25% slope should be used so that some extra benefit would result from over generation. The generation model is actually in the RESMOD subroutine although it is part of the benefit model. This is because the generation benefit is applied at the end of the month and must be outside the daily do loop in RESMOD. A weighting factor (W6) is applied to the generation benefit (GENBN) so that it may be weighted appropriately in the main performance index. The value of (DEM) is read in monthly from the input data array PD(J).

Benefit Model and Performance Index

The main performance index is located in RESMOD subroutine. RESMOD receives from BENMOD a daily value for reservoir visitation (DAVIST), downstream visitation (DADWVT), water quality benefit (WAQ), navigation benefit (NAVBN), and flood penalty (FLDBN). The reservoir visitation (DAVIST) consists of the total number of land and water-based visitors

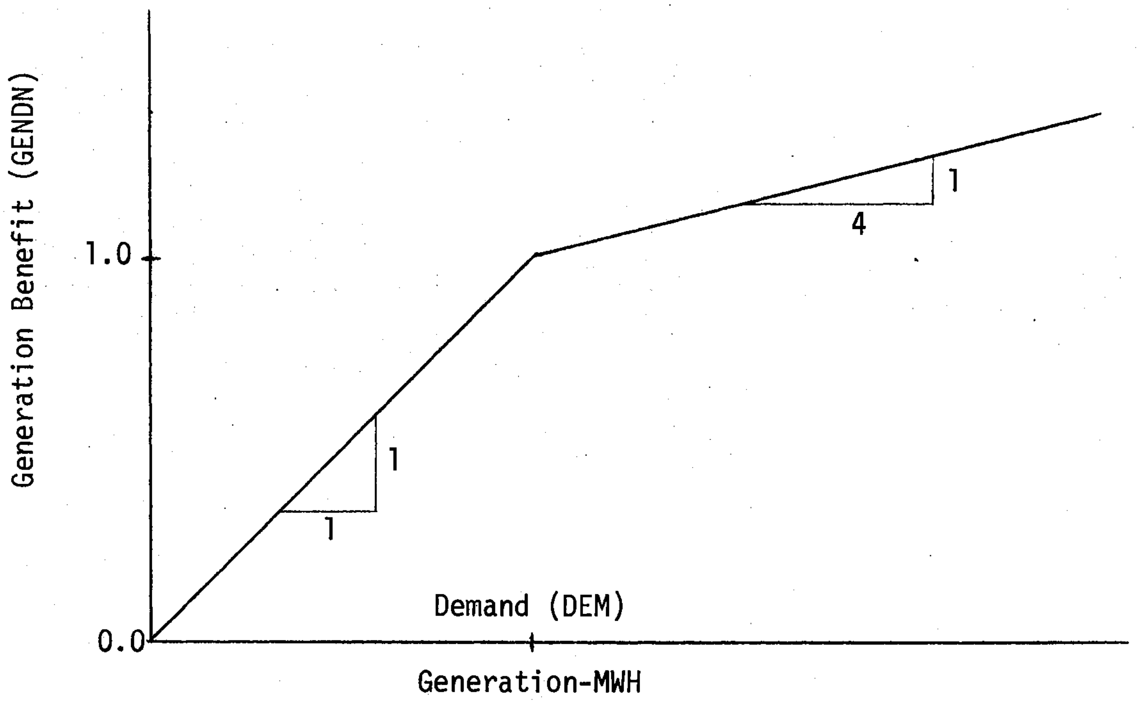


Figure 16. Typical Generation Benefit Curve

to the reservoir for each day. The downstream visitation (DADWVT) is the number of visitors predicted downstream from the reservoir for each day. In the main performance index computation (DAVIST) and (DADWVT) are divided by the optimum number of reservoir visitors and the optimum number of downstream visitors respectively.

The resulting values (P1) and (P2) are multiplied by weighting factors (W1) and (W2). (W1) weights the reservoir visitation and (W2) weights the downstream visitation. The water quality benefit (WAQ) is a number between zero and one so to normalize this daily value it is divided by the number of days in the month. The navigation benefit and flood penalty are both divided by the number of days in the month to normalize them to a daily performance index. The water quality performance, navigation and flood penalty are all multiplied by weighting factors (W3), (W4) and (W5) respectively. These factors are used to observe the effect of these benefits on the overall reservoir management strategy. These benefits are summed on a daily basis inside the RESMOD daily loop and provide a measure of the daily performance (PIDA) of the reservoir. At the end of the month an accumulated performance (PI1) is added to the generation benefit (GENBN) which is weighted by (W6) to form the monthly performance (PI). This is the value that is returned to OPTMZR and used to formulate the management strategy. The components of the performance index are also input controllable. By specifying a number for the input variable (MODIPI), the performance described above, MODIPI = 1, or one involving only revenue, MODIPI = 2, which is described later or one involving only the number of visitors, MODIPI = 3 may be obtained.

Finally, if a weighting of revenue and visitors is desired in the performance index, the weighting factors used are (W7) for revenue, (W8) for visitors and MODIPI is set equal to 4. This allows greater flexibility in the type of performance measure used while reducing program run costs.

Other BENMOD Features

A revenue model considering generation revenue, thermal energy costs, and dump energy revenue is also available. The model is contained in RESMOD due to the monthly nature of its operation. The model determines the amount of revenue produced given the monthly demand (DEM), the monthly generation (GEN), the price per megawatt hour of generated energy sold (REVDEM), the cost per megawatt hour of thermal energy bought (REVBUY), and the price at which dump energy can be sold (REVDMP). The revenue model keeps track of the net revenue earned (REV) by the reservoir generation and sums this for each month.

Reservoir Management Factor

The reservoir management factor (RMF) is intended to be a measure of the opinion a visitor has relative to the stability and control of the pool elevation on the lake. It is assumed that fluctuations either up or down will reduce the long-term "reputation" of the reservoir in the eyes of visitors. The major idea here is that since visitors would prefer to have a fixed recreation environment, visitation is discouraged when reservoir conditions <u>continuously change</u> from week-to-week and month-to-month.

The formula for the monthly reservoir management factor R.M.F. is

R.M.F. = (Average Daily Elevation Change)x(Elevation Range During the Month).

(RMF) = (DACNG/MD(J))(ELMAX-ELMIN)

The average daily elevation change DACNG/MD(J) reflects the fluctuation of elevation in a short-term sense, while the elevation range during the month reflects the overall longer-term effect. The R.M.F. value is calculated on a monthly basis in this study.

The use of the R.M.F. value is indirect. That is, there is no direct use within the model to predict visitation. Its main purpose would be in the comparison of alternative regulation strategies. The R.M.F. value for any previous year could be easily calculated and compared with the optimum strategies determined in the simulation. If desired, the R.M.F. value could be included in the performance index, and used to directly penalize strategies which produce long-term variations in the pool elevation, although the present performance index does not include this feature.

Fish Egg Survival Model

A preliminary investigation of fish nesting and spawning was made to develop a model for fish egg survival. Although this model was not included in the BENMOD subroutine the study is presented here for informational purposes.

The preliminary investigation of fish nesting and spawning characteristics indicated that an increase in lake elevation has little influence on the survival of the fish embryos [20]. However, it is assumed that exposure of the embryos to air will reduce the survival to zero.

Since the spawning time for some species may extend over a long period of time (up to two months), any model which predicts the survival rate must consider the change in egg production during this time period. The hatching time is in the range of one week, so any exposure of the eggs to air during that time will destroy that group of eggs. The model needs to account for the percentage of eggs existing at any time during the spawning season and then determine if any exposure to air occurs during the hatching time.

The proposed model can compute the percentage of eggs in the process of hatching at any time t. Then if the eggs are exposed to air at that time, that percentage is destroyed.

Another factor which complicates the model is that nests are constructed at different depths. One study of large mouth bass in Lake

Powell, Utah, indicated the mean nest depth the first ten days of spawning was 5.36 ft. and ranged from 1.5 to 9.45 ft. During the last 10 days of the next occupation, the mean nest depth was 14.9 ft. and ranged from 9.00 to 23.00 ft. During this same period of time the lake rose 27 feet [20].

The proposed egg production model assumes that the percentage rate of fish egg production is normally distributed about the middle of the total spawning period as shown in Figure 17.

To obtain the percentage of eggs in the process of hatching, one would determine the percentage of eggs existing during the time for hatching. This is shown by the cross hatched area in Figure 17 and also is given by the curve in Figure 18.

To account for the nests being at different depths, the model predicts the percentage of the nests exposed during the hatching time. One way to account for this condition is to assume that the nests are distributed normally about the mean depth of the nests. This is shown in Figure 19. Then a curve showing the percentage of nests exposed versus the change in elevation during the hatching time can be constructed as shown in Figure 20.

The total percentage of the eggs destroyed at any time t is then the product of the percentage of eggs hatching at that time and the percentage of nests exposed during the hatching period divided by 100. This means if the hatching time is 5 days, then the change in elevation during the last 5 days would be used to compute the percentage of nests exposed. This process is illustrated by the block diagram in Figure 21.

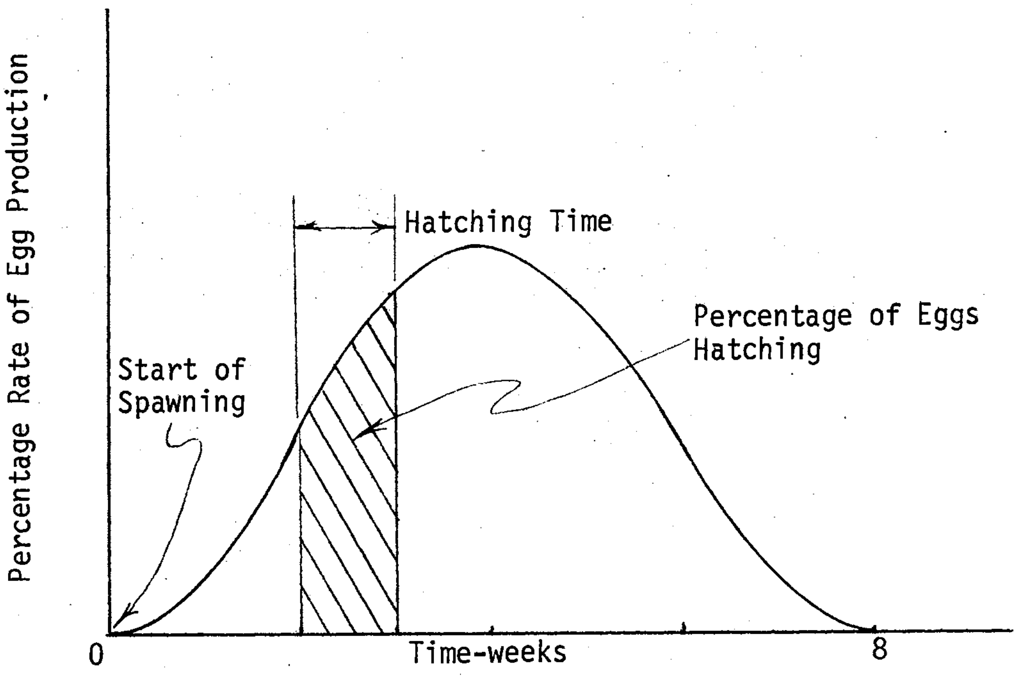


Figure 17. Typical Time Distribution of Fish Egg Rate of Production

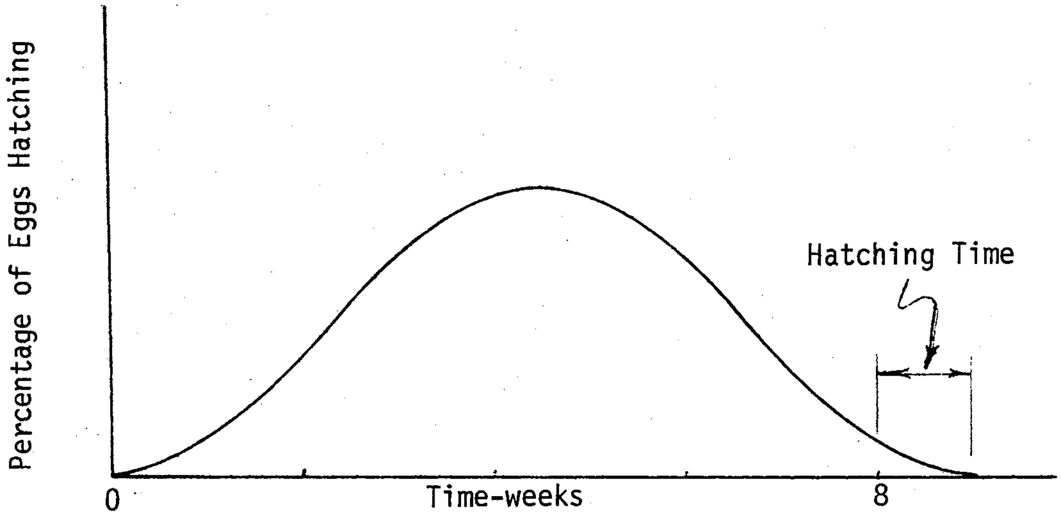


Figure 18. Typical Time Distribution of Percentage of Eggs Hatching

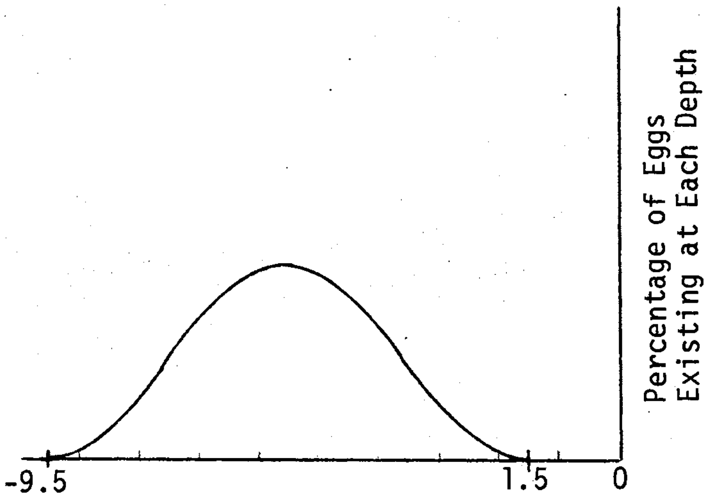


Figure 19. Typical Depth Distribution of Fish Eggs

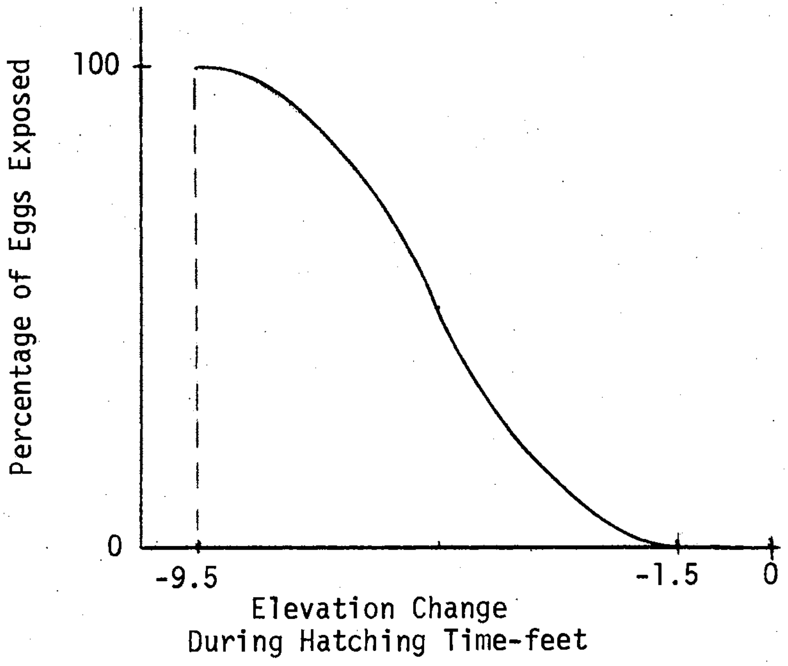


Figure 20. Typical Elevation Change Distribution of Fish Eggs Exposed

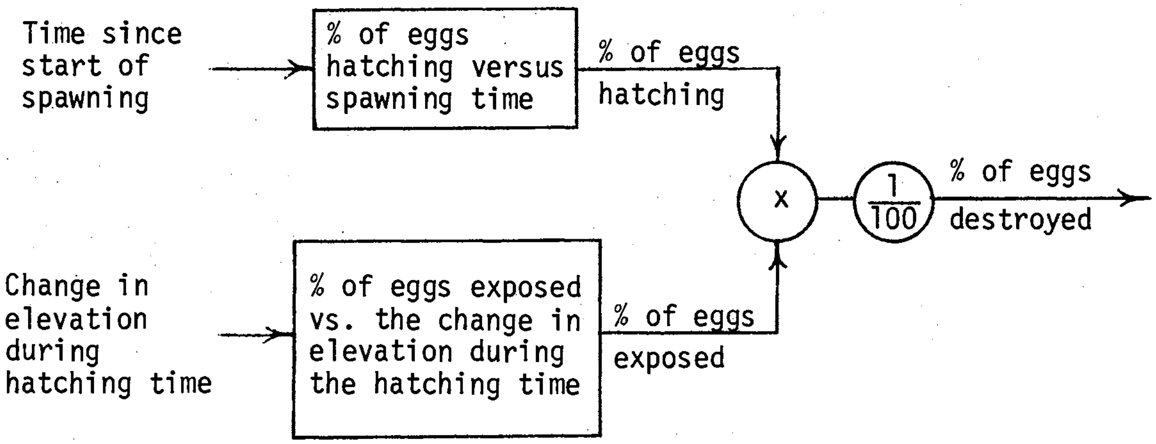


Figure 21. Fish Egg Survival Model

CHAPTER IV

APPLICATION OF THE OPTIMIZATION PACKAGE TO TENKILLER RESERVOIR

Introduction

In order to demonstrate the total optimization package in the development of practical regulation strategies, an operating reservoir project was selected for application. The Tenkiller Ferry Reservoir located on the Illinois River in Northeastern Oklahoma was selected for several reasons. A large amount of data was already available for this project and a concurrent study of the economic impact was underway by the Tulsa District Office. Furthermore, recreational activity is high at Ten-Killer and a number of operational questions relating to the recreation versus power benefit trade-off could be posed.

The period of record selected for the optimization studies was September 1, 1970 to August 31, 1971. This period displayed a varied hydrologic pattern with very large inflows in October and November of 1970, requiring spill releases in these months. The dynamic range of pool elevation during the twelve month period showed a maximum of 641.56 feet MSL on October 30, 1970 and a minimum of 620.65 feet on August 31, 1971. Also, the average monthly inflow rate varied from 248 CFS in August 31, 1971 to 4,787 CFS in October of 1970. With these wide fluctuations, it was felt that the reservoir and benefit models would be fully exercised and that the regulation optimization studies would provide interesting results.

The sources of data for the demonstration are numerous. The Tulsa District Office was the primary source but data was also provided by the Resident Engineer at Tenkiller, the Southwestern Power Administration in Tulsa, and several faculty consultants at Oklahoma State University. As the various data are enumerated, below, specific sources will be credited.

Reservoir, Hydrologic and Energy Demand Data

Table II shows the monthly hydrologic and energy data used in the Tenkiller optimization. The names underlined at the top of each column are the corresponding computer variable names used in the MAIN Program. The inflow values are net inflows which take into account evaporation. Therefore, PANEVP = 0. in the data list. The monthly energy demand values correspond to the actual energy generated by Tenkiller during each month. The two downstream control points were selected at Gore, Oklahoma and Van Buren, Arkansas. The first intervening flow variable (ITVFL1) is assumed to enter the downstream channel immediately below the dam and affect the 6-hour reach to Gore. The second intervening flow (ITVFL2) is the main flow of the Arkansas River where the Illinois River joins the Arkansas just below Gore. As noted in the Table, several values of the intervening flow at the dam were adjusted to artificially produce desired fluctuations in the water quality, flood and navigation benefits. All other values were based upon data or conversations with Corps personnel in Tulsa.

TABLE II

TENKILLER HYDROLOGIC AND ENERGY DATA

Month	INFLOW Average Monthly Inflow * (10^3 CFS)	PD Monthly Energy Demand (MWH)	ITVFL1 Av. Monthly Interv. Flow at Dam (10^3 CFS)	ITVFL2 Av. Monthly Interv. Flow below Gore (10^3 CFS)
SEP '70	2.0863	5,410	0.5[t]	13.694
OCT	4.787	1,687	3.5[t]	41.418
NOV	2.5447	21,100	2.5[t]	23.024
DEC	.7742	13,070	0.015	41.13
JAN '71	1.9297	17,930	1.6[t]	22.687
FEB	1.709	14,670	0.015	19.100
MAR	1.3626	11,730	0.015	20.615
APR	.7217	8,480	0.007	6.36
MAY	1.745	6,940	1.3[t]	11.169
JUN	.7417	7,620	0.005	23.898
JUL	.4513	5,730	0.005	17.841
AUG	.2484	4,110	0.005	11.633

*Net inflow - includes evaporation.

[t] These values for intervening flows just below the dam have been adjusted so that flood, navigation and water quality models are exercised adequately.

The power-discharge, tailwater, volume-elevation and downstream stage-flow curves are stored in tabular form and are based upon standard curves supplied by the Tulsa District Office. For example in Table III, the values of pool elevation from 580 feet to 672 feet MSL and the corresponding volumes in thousands of acre-feet are stored at 4 foot intervals. A binary search and linear interpolation procedure discussed in Chapter II is employed to evaluate specific values from the stored table. Table III also gives the values of flow and stage height for the control points at Gore and Van Buren which are used to calculate the flood benefit each day.

Table IV lists the data used to represent the power-discharge curves and the reservoir tailwater curve. It should be recalled from the discussion in Chapter II that the power-discharge model assumes that the generators are run at maximum efficiency. The values for horsepower and discharge given in Table IV are for one unit assuming maximum efficiency. Furthermore, the corresponding tailwater correction is automatically built into the power-discharge model curve since the discharge at a given pool elevation is known. This calculation causes the unusual values appearing in the "pool elevation" column. As explained in Chapter II, when two generating units are used, a fixed increment in pool elevation (ELINC) is applied before the power-discharge curves are interrogated. For Tenkiller, this value is 1.55 feet. The tailwater curve represented by the data in Table IV is used <u>only</u> when spill releases occur.

To specify the generation spill policy relative to pool elevation, flexible input control variables have been established, as discussed in Chapter II. For Tenkiller, the following rules have been applied. The

TABLE III

DATA FOR ELEVATION-VOLUME AND STAGE-FLOW CURVES

		GORE		VAN BUREN	
ELRES Pool Elev. (Feet MSL)	VRES Capacity (10^3 Ac-Ft)	DISST1 Flow (10^3 CFS)	STAGE1 (Feet)	DISST2 (10^3 CFS)	STAGE2 (Feet)
580	186.8	0.0	1.0	0.0	2.0
584	211.2	0.02	2.52	10.0	6.5
588	237.2	0.03	2.62	20.0	9.0
592	264.9	0.04	2.7	25.0	10.0
596	294.2	0.05	2.775	35.0	12.0
600	325.2	0.07	2.9	42.5	13.0
604	358.2	0.09	3.0	58.5	15.0
608	393.1	0.1	3.08	67.5	16.0
612	430.5	0.3	3.325	78.5	17.0
616	470.2	0.5	4.25	101.25	19.0
620	512.1	1.0	5.2	115.0	20.0
624	556.8	1.5	5.9	128.75	21.0
628	604.1	2.5	6.9	133.0	22.0
632	654.1	4.0	8.1	160.0	23.0
636	706.9	4.5	8.5	176.5	24.0
640	762.5	5.5	9.2	192.0	25.0
644	821.3	6.0	9.55	225.0	27.0
648	883.2	6.5	9.88	243.0	28.0
652	949.0	7.5	10.56	265.0	29.0
656	1010.8	8.0	10.9	313.0	31.0
660	1092.2	9.0	11.6	345.0	32.0
664	1169.2	10.0	12.2	382.0	33.0
668	1251.2	13.0	13.9	425.0	34.0
672	1338.2	15.0	14.9	515.0	36.0

TABLE IV

DATA FOR ELEVATION-POWER/DISCHARGE AND TAIL WATER CURVES

ELRESP Pool Elev. (Feet MSL)	HPRES Power (10^3 HP)
589.11	17.2
600.63	19.5
617.66	23.0
625.67	24.8
635.3	27.0
666.48	27.0

ELRESD Pool Elev. (Feet MSL)	DISPWR Discharge (10^3 CFS)
589.11	1.6
600.63	1.615
617.66	1.64
625.67	1.65
635.3	1.695
640.0	1.659
645.63	1.62
666.48	1.49

SPILL Spill Release (10^3 CFS)	TAIL Tail Water Elevation (Feet)*
0.0	0.0
1.0	0.75
2.0	1.4
3.0	2.0
4.0	2.6
5.0	3.15
6.0	3.63
7.0	4.1
8.0	4.51
9.0	4.93
10.0	5.3
11.0	5.68
12.0	6.0
13.0	6.3
14.0	6.6
15.0	6.85

*This value is subtracted from the MSL value of the pool elevation when spill releases are made.

bottom and top of the power pool (BPP and TPP) are set at 595 feet and 633 feet respectively. Between these values of elevation the reservoir will generate the demand issued by OPTMZR and add the second unit when one unit operates for more than 10 hours; this time being controlled by (ADTIM). Above 633 feet, RESMOD will run both units 24 hours a day regardless of the OPTMZR control. Below 595 feet, no generation will occur above 633 feet, spill is controlled by the variable (FRAC) which established the fraction of the inflow which will be released by spill if not released by generation. Between 633 feet and DISPT(JJ,1) = 638 feet, FRAC(JJ,1) = 0.0 and no spill will occur. Between 638 feet and DISPT(JJ,2) = 640 feet, FRAC(JJ,2) = 0.8 and thus 80% of the inflow will be released through spill and/or generation. Above 640 feet, FRAC(JJ,3) = 1.5 and 150% of the inflow will be released.

When the pool elevation drops below 633 feet, 24 hour generation ceases and the model checks to see if the monthly energy control has been generated. If so, the model will lower its daily generation to one unit operating the number of hours specified by (HRSMIN). For Tenkiller, this is set equal to one hour.

Recreation Model Data

The visitation data acquired from the Tulsa District Office via Dr. Daniel Badger, Professor of Agricultural Economics at Oklahoma State University, consisted of monthly visitation figures for the years 1966 to 1971, inclusive. These monthly values were broken down into categories such as camping, picnicing, boating, fishing, hunting, sightseeing, skiing, swimming, and an "other" category. As described in Chapter III, these were broadly classified into two categories: land-based (camping, picnicing, hunting, sightseeing, and "other") and water-based (boating, fishing, skiing, and swimming). The given data were visitation numbers in which an individual could be included in more than one category. Since the model predicts visitors to the reservoir area (or visitor-days), the visitation data were corrected as follows.

The total visitations for land and water-based activities were summed separately from the given data. Then the ratio of each of these values to the sum of the two was determined. The resulting ratios were then applied to the total number of visitors for all categories (also provided in the data) to determine the water and the land-based visitors to the reservoir for each month of the 1966-71 period.

Next the maximum number of expected visitors for each month for land and water-based activities was determined by plotting maximum observed visitors for a six year period (1966 to 1971) for each month. The individual selected values were then adjusted to produce a smooth seasonal curve. The final values obtained from this process are listed in columns 2 and 5 of Table V for the land and water categories, respectively. These numbers define the ordinate values of points B and C on the four-point curve shown in Figure 8 of Chapter III.

The lowest and highest expected pool elevations (LOWEL and HIGEL) are set at 594.5 feet and 667 feet MSL, respectively. The expected visitor values for these elevations are based on the procedure discussed in Chapter III and the percentages listed in Table I following that discussion. Columns 1 and 4 of Table V list the values for point A of Figure 8 and columns 3 and 6 list the values for point D.

The last item of data for the four-point curve of Figure 8 is the range of elevation between points B and C. This is the elevation range

TABLE V

DATA FOR VISITOR-ELEVATION CURVES AND DAY EQUIVALENTS*

MONTH	EXPECTED LAND-BASED VISITORS			EXPECTED WATER-BASED VISITORS			OPTIMUM RANGE LAND		OPTIMUM RANGE WATER		EQUI-VALENT NUMBER OF DAYS
	VISITORS AT 594.5 FT	VISITORS AT OPT. ELEV.	VISITORS AT 667.0 FT	VISITORS AT 594.5 FT	VISITORS AT OPT. ELEV.	VISITORS AT 667.0 FT	OPTIMUM LOW ELEV.	OPTIMUM HGIH ELEV.	OPTIMUM LOW ELEV.	OPTIMUM HIGH ELEV.	
SEP '70	31000.0	47000.0	38000.0	12000.0	14000.0	70000.0	627.0	633.0	628.0	632.0	49.0
OCT	28000.0	80000.0	40000.0	15000.0	95000.0	67000.0	625.0	635.0	626.0	632.0	71.0
NOV	18000.0	50000.0	36000.0	14000.0	56000.0	41000.0	625.0	635.0	626.0	632.0	67.0
DEC	11000.0	31000.0	25000.0	10000.0	50000.0	36000.0	625.0	635.0	626.0	632.0	74.0
JAN '71	12000.0	31000.0	16000.0	9000.0	40000.0	28000.0	625.0	635.0	626.0	632.0	75.0
FEB	16000.0	40000.0	20000.0	12000.0	51000.0	37000.0	625.0	635.0	626.0	632.0	64.0
MAR	21000.0	57000.0	27000.0	8000.0	67500.0	46000.0	625.0	635.0	626.0	632.0	63.0
APR	33000.0	82000.0	50000.0	17000.0	100000.0	50000.0	627.0	633.0	628.0	632.0	38.0
MAY	47000.0	112000.0	45000.0	19000.0	200000.0	100000.0	627.0	633.0	628.0	632.0	42.0
JUN	57000.0	145000.0	57000.0	32000.0	280000.0	140000.0	627.0	633.0	628.0	632.0	38.0
JUL	62000.0	160000.0	63000.0	38000.0	300000.0	150000.0	627.0	633.0	628.0	632.0	41.0
AUG	57000.0	142000.0	66000.0	32000.0	240000.0	120000.0	627.0	633.0	628.0	632.0	41.0

*All data in this table is read in as the array BN(M,N) where M corresponds to the number of month of interest (SEP 70 ∿ M = 1) and N corresponds to the column number in the table above (LAND-OPTIMUM LOW ELEV ∿ N = 7).

over which the recreational benefits are at the highest level. A seasonal effect on the ranges for both the land and water visitor curves is assumed for Tenkiller as explained below.

First of all, water-based recreation is more sensitive to pool fluctuations than is land-based recreation and summer-time activities are more sensitive than winter-time activities in both water and land-based categories. Discussion with Mr. John Vaughn, the Resident Engineer at Tenkiller indicated that a minimum elevation of 628 feet will not expose boating hazards or degrade swimming beaches while a maximum of 632 feet will not cover swimming beaches or boat ramps. Thus, for water-based visitors during the summer months, the range was chosen to be 628 - 632 feet MSL. For land-based activities during the summer, the selected range was 627 to 633 feet MSL. Pool elevations below 627 feet will produce mud flats and elevations above 633 feet will inundate roads or camping areas.

During the winter, visitors are considered to be more hardy and fewer recreation activities are possible. Thus the elevation ranges are assumed to be wider during the winter. A range of 625 to 635 feet MSL for winter land-based activities will expose some mud flats, but these are not considered to be objectionable during the winter months. Since fishing and boating are the only feasible water-based activities, a range of 626 to 632 feet MSL produces a wider elevation range than taken during the summer. Columns 7, 8, 9 and 10 in Table V list the ranges discussed above.

Finally, the last column of Table V lists the "equivalent week-day" values for each month. These values are based on the number of weekend days and holidays in each month and the holiday/weekday multiplier discussed in Chapter III. All data listed in Table V is read in by the array BN(M,N) as indicated in the note below the table.

The ratio of visitors on weekends and holidays to visitors on weekdays is input controllable using BN(M,12). Based on conversations with Corps personnel, an approximate ratio of five-to-one exists during the winter months (October-March) and a two-to-one ratio is expected during the summer months (April-September). Thus

$$\mathrm{BN}(M,12) = \begin{cases} 5.0\ , & M = 2\text{-}7 \\ 2.0\ , & M = 1,\ 8\text{-}12 \end{cases}$$

The structure of the elevation change penalty curves is depicted in Figure 9 in Chapter III. The Tenkiller Resident Engineer indicated that based on his experience, the maximum elevation changes for Tenkiller will range from 3 ft/day up to 1 ft/day down. For both of these elevation change extremes, it was decided that reasonable values for the penalty against visitors should be 10% during the summer months and 5% during the winter months. No penalty is imposed when the daily elevation change is zero. Therefore the benefit parameters BN(M,N) are evaluated as follows:

$$\mathrm{BN}(M,13) = \begin{cases} 0.90\ , & M = 2\text{-}7 \\ 0.95\ , & M = 1,\ 8\text{-}12 \end{cases}$$

$$\mathrm{BN}(M,14) = 1.0\ ,\ M = 1\text{-}12$$

$$\mathrm{BN}(M,15) = \mathrm{BN}(M,13)\ ,\ M = 1\text{-}12$$

$$\mathrm{BN}(M,19) = -1.0\ ,\ M = 1\text{-}12$$

$$\mathrm{BN}(M,20) = 0.0\ ,\ M = 1\text{-}12$$

$$\mathrm{BN}(M,21) = 3.0\ ,\ M = 1\text{-}12$$

Conversations with Mr. Vaughn at Tenkiller indicate that the percentage of above-dam visitors which occurs below the dam, ranges anywhere from one to seven percent, depending primarily upon the fishing conditions below the dam. At Tenkiller there are no established recreational areas just below the dam so that fishing is the primary activity there.

Figure 11 in Chapter III depicts the form of the below-dam recreation factor curve for Tenkiller Reservoir. As can be seen from the two curves presented, the factor is sensitive to seasonal variations. During the warmer months, power releases produce a temperature shock and oxygen depletion condition immediately downstream from the dam reducing the response of the fish. This occurs in the months from June to September when the difference in released water temperature and the normal downstream water temperature is about 20°F. Due to this detrimental condition for fishing, the stream is stocked with trout only during the months from October to May when the temperature shock and oxygen depletion are minimized. As a result the below dam recreation factor curve predicts a higher percentage of visitors during the winter months of October to May than it does from June to September.

According to Mr. Vaughn, the flow for best fishing conditions is in the range up to 500 CFS whereas an extreme value of 8000 CFS, will essentially eliminate all fishing activity due to flooding. However, even at this extremely high discharge rate, some visitation is to be expected due to sightseeing. Thus, a value of 1% of the above dam visitation is assumed to occur when the discharge rate is 8000 CFS. A value of 7% is associated with discharge rates up to 500 CFS. Values of 3% and 6% were chosen for the summer and winter mid-points respectively, corresponding to a flow rate of 3000 CFS. Assuming the data values given above the BN(M,N) array values of input data are

BN(M,16) = 0.07 , M = 1-12

$$\mathrm{BN}(M,17) = \begin{cases} 0.03 \ , \ M = 1,\ 10\text{-}12 \\ 0.06 \ , \ M = 209 \end{cases}$$

BN(M,18) = 0.01 , M = 1-12

BN(M,22) = 0.5 , M = 1-12

BN(M,23) = 3.0 , M = 1-12

BN(M,24) = 8.0 , M = 1-12

Water Quality Model Data

Complete data for the water quality model was not readily available. Water quality modeling is a relatively new effort and continuous measurements at Tenkiller of dissolved oxygen, biological oxygen demand, temperature and dissolved solids are not made. Thus, much of the data was extrapolated from what was available and the model was programmed to predict water quality only at the first control point, Gore, 2.5 miles downstream.

The discharge water mixes with a standing (or relatively slower moving) body of water just below the dam. Dr. Kent W. Thornton, an aquatic biologist with the Center for Systems Science at Oklahoma State University, was consulted on the modeling of dissolved oxygen depletion below the dam. The dissolved oxygen data obtained from the COE unfortunately did not cover a complete year. The data obtained was for 1972-1973 and showed 10.0 mg/ℓ of dissolved oxygen for January and February, 3.0 mg/ℓ for June and 1.5 mg/ℓ for August as typical values. It was decided to postulate missing monthly data around these values and

Table VI gives the final values used in the simulation. The D.O. for the intervening flow below the dam site was approximated by taking the saturated D.O. level for the temperature of the intervening flow discussed below. These values are reasonable since the slower moving intervening flow has a high D.O. compared to the discharge from the turbines. Also the values fit the seasonal pattern of the discharge D.O. as can be seen from Column 2 of Table VI. The optimum D.O. can be specified as input data but it was decided to set the optimum D.O. equal to the saturated D.O. level associated with the average downstream temperature (DSTRA). The program defaults to this value if the optimum D.O., WQ(M,3) is set to 0.0 in the input data.

The Tulsa District Office provided tailwater temperatures for releases from the dam. This data was recorded in 1972 and 1973 and it was assumed that these values would be representative. The average monthly temperature values are shown in Column 3 of Table VI are used as the temperature of the power discharges. It was felt that the temperature of the stream at Gore, below the dam, could be approximated by the ambient air temperature on an average monthly basis. Thus, the temperature of the intervening flow just below the dam is approximated by dividing the temperature of the stream at Gore by the downstream temperature correction. This has the effect of undoing the temperature correction for the water as it flows downstream to Gore. The desired temperature at Gore was set to the most beneficial to the trout fishery operation or about 60°F (15.54°C). This value is input as WQ(M,8).

No data was available for the B.O.D. of the reservoir. Thus, from discussions with Dr. Thornton, the 5-day 20°C B.O.D. of the reservoir discharge was set to 3.0 mg/ℓ and that of the intervening flow was set

TABLE VI

WATER QUALITY DATA FOR TENKILLER

Month	WQ(M,1) D.O. of Discharge (mg/ℓ)	WQ(M,2) D.O. of Itv. Flow 1 (mg/ℓ)	WQ(M,6) Temp. of Discharge (°C)	WQ(M,7) Temp. of Itv. Flow 1 (°C)	WQ(M,12) Dstm. Temp. Corr. Factor (no dimen.)
SEP 70	2.0	8.745	15.555	22.667	0.92
OCT	3.0	9.528	16.111	18.176	0.92
NOV	5.0	11.051	15.0	11.111	0.92
DEC	9.0	12.504	9.444	5.917	0.92
JAN 71	10.0	13.558	8.889	2.778	0.92
FEB	10.0	12.852	8.889	4.83	0.92
MAR	8.0	11.118	8.333	10.845	0.92
APR	5.0	9.874	8.889	16.389	1.000
MAY	4.0	9.246	10.555	19.722	1.000
JUN	3.0	8.727	11.111	22.782	1.080
JUL	2.0	8.34	12.778	24.897	1.080
AUG	1.5	9.026	14.444	20.988	1.080

to 6.0 mg/ℓ as representative values. These values correspond to WQ(M,4) and WQ(M,5), respectively.

From data supplied by the Tulsa District Office, it was determined that the dissolved solids (D.S.) were almost constant for the entire reach from dam to Gore. To obtain a dynamic response of the effect of D.S. on the water quality performance index, values of 110 mg/ℓ for the reservoir discharge concentration WQ(M,9) and 150 mg/ℓ for the intervening flow concentration WQ(M,10) were chosen. As 110 mg/ℓ is the value of D.S. for Tenkiller measured by the COE, this was the value used as the optimum or desired D.S. concentration WQ(M,11).

The reaction constant K' and the velocity rate of transfer constant K_2' at 20°C for the Streeter-Phelps equation are entered as WQ(M,13) = 0.07 and WQ(M,14) = 0.4 respectively. The reach time for the first reach, RETM1, is taken to be 0.25 hour. The data location for RETM2, the second reach time, is left blank to notify the program that only the first reach values will be calculated.

Since the demonstration did not include the water quality benefit for the second reach, all input data relating to this reach was set equal to zero. These data include monthly average values of temperature, D.O., B.O.D. and D.S. for the intervening flow below Gore (the Arkansas River) which are read in as WQ(M,K) with K = 17, 18, 19 and 20, respectively. Also, RETM2, the second stage reach time is set equal to zero.

Weightings for the three components of the water quality benefit (D.O., D.S. and temperature) were selected so that heavy emphasis was placed on D.O. which is considered to best measure the water quality. Specific weightings for the three components are ALPHA1 = 100, ALPHA2 = 1, ALPHA3 = 1.

Navigation, Flood and Calendar Data

As discussed in Chapter III, the navigation benefit curves for reach 1 and reach 2 are each determined by four flow values. In both reaches, zero navigation benefit is assumed to occur with zero flow so that NAV(M,1) = NAV(M,5) = 0.0. In the Arkansas River at Van Buren, the minimum flow for optimum navigation benefit is taken to be 600 CFS during July when evaporation is assumed to be greatest. During January, this value is assumed to lower 350 CFS and during the remaining months, intermediate values have been postulated as shown in column 4 of Table VII. The maximum flow which will still allow full benefit at Van Buren is 20,000 CFS and it is assumed that no navigation benefit is accrued when the flow reaches 100,000 CFS. These data are listed in columns 5 and 6 of Table VII. Navigation benefits in the Illinois River below Tenkiller were postulated in order to exercise this portion of the model. Since the Illinois flow is approximately 8% of the Arkansas River flow, the minimum optimum flow values in column 1 of Table VII were taken as 8% of the corresponding values in column 4. The values in columns 2 and 3 were postulated but based on the fact that minor flooding below the dam occurs at a flow of 8000 CFS.

The flood benefit model described in Chapter III requires for each control point the flood stage and the stage at which all other reservoir benefits are assumed to be negated or cancelled by flood damage. Values for flood stage, FLDST1 and FLDST2, at Gore and Van Buren were originally provided by the Tulsa District Office but were adjusted downward later to better exercise the flood benefit model. Values for the maximum penalty stage, FLDMX1 and FLDMX2 were postulated. Specific values used in the optimizations are

TABLE VII

NAVIGATION BENEFIT FLOW DATA*

Month	GORE			VAN BUREN		
	NAV(M,2) Min. Opt. Flow	NAV(M,3) Max. Opt. Flow	NAV(M,4) Zero Ben. High Flow	NAV(M,6) Min. Opt. Flow	NAV(M,7) Max. Opt. Flow	NAV(M,8) Zero Ben. High Flow
SEP 70	0.043	5.0	8.0	0.5375	20.0	100.0
OCT	0.038	5.0	8.0	0.475	20.0	100.0
NOV	0.033	5.0	8.0	0.4125	20.0	100.0
DEC	0.2934	5.0	8.0	0.3667	20.0	100.0
JAN 71	0.028	5.0	8.0	0.35	20.0	100.0
FEB	0.02934	5.0	8.0	0.3667	20.0	100.0
MAR	0.033	5.0	8.0	0.4125	20.0	100.0
APR	0.038	5.0	8.0	0.475	20.0	100.0
MAY	0.043	5.0	8.0	0.5357	20.0	100.0
JUN	0.0466	5.0	8.0	0.5833	20.0	100.0
JUL	0.048	5.0	8.0	0.6	20.0	100.0
AUG	0.04666	5.0	8.0	0.5833	20.0	100.0

* All values in thousand CFS

FLDST1 = 9.0 feet

FLDMX1 = 19.0 feet

FLDST2 = 12.0 feet

FLDMX2 = 35.0 feet

The calendar section within RESMOD requires data which (1) gives the number of the day; i.e., Monday = 1, etc., which corresponds to the first day of the month and (2) the dates of any non-weekend holidays during each month, with a maximum of two allowed. Table VIII lists the data for KAL(M,N) used for the optimization period. The input variable KAL(M,3) stores the date of the second non-weekend holiday in a month,

TABLE VIII

DATA FOR CALENDAR SECTION

Month	Number of First Day of the Month	Date of First Non-Weekend Holiday
SEP 70	2	7
OCT	4	12
NOV	7	11
DEC	2	25
JAN 71	5	1
FEB	1	15
MAR	1	0
APR	4	0
MAY	6	31
JUN	2	0
JUL	4	5
AUG	7	3

if such exists. During the period selected, none of the months contained more than one such holiday and KAL(M,3) is not used (data field left blank).

Performance Index and Miscellaneous Data

When MODIPI = 1, the performance index is evaluated as a weighted sum (with weighting coefficients W1-W6) of the normalized benefits for reservoir-area visitation (W1), below dam visitation (W2), water quality (W3), navigation benefit (W4), flood penalty (W5) and power benefit (W6). Six different optimization runs were made using various values of these coefficients. Details will be presented later in this chapter.

When MODIPI = 3, the performance index simply sums the total number of visitors and no weighting coefficients are used. When the MODIPI is 2, the performance index sums the revenue produced by power generation using the following rates for base demand, purchased energy and dump energy:

REVDEM = \$9.00/mwh
REVBUY = \$6.00/mwh
REVDMP = \$2.00/mwh

When MODIPI = 4, the performance index sums revenue and visitors with weighting coefficients W7 and W8, respectively. Other data include:

NMON = 9 (September is first month of data)
NDBUG = 0 (No special debug print statements desired)
LIST = 3 (Monthly output data on forward run desired)
NTOTSG = 12 (Twelve months to be run in the optimization)
DAILY = 0 (No daily hydrologic data will be used)

Calibration of the Tenkiller Model

To determine if the reservoir model will faithfully reproduce the hydrologic and electrical generation mechanisms of the Tenkiller reservoir project, a calibration run is necessary to "tune" the model to actual data. By running RESMOD alone (no optimization) with the given monthly inflow data and energy demand controls (U) equal to the actual monthly energy generated by Tenkiller from September 1, 1970 to August 31, 1971, the pool elevations predicted by the model can be compared to the actual elevations reported by the Corps of Engineers.

RESMOD has no feature by which specific spill amounts can be controlled by the user. Therefore, to simulate the spill conditions during October and November of 1970, reductions were made in the inflow data for those months so that the net water available to the reservoir for generation would be the same. Since the generating units are assumed to operate at the maximum efficiency points on the power-discharge curves, an input controllable variable (EFF) is used to reduce the overall efficiency of the generators to practical values. This variable, as now used in the program, remains fixed during all months of interest.

Several runs were made starting with the initial pool elevation of 622.9 feet MSL with EFF varying from 92% to 97%. A value of 93% produced an average monthly error in the predicted pool elevation of 0.71 feet over the twelve month period with the largest monthly error being 1.45 feet occurring at the end of February. The error at the end of twelve months was 0.62 feet. All optimization runs discussed later in this chapter used the inflow data of Table II and a value of 93% for EFF.

However, after the optimization runs were complete, an error in the inflow data was found. Corrected data was provided by the Tulsa District Office and a second calibration run was made with EFF = 92.2% giving the results shown in Figure 22. The average monthly error, largest error and final error were found to be 0.451 feet, 0.86 feet and 0.68 feet, respectively. These values indicate an improvement over the first calibration run, but since only small differences were observed in the values of final pool elevation and total visitors predicted, the optimization studies were not rerun.

Better than expected accuracy was found in the predicted value of above-dam visitors (total visitors less downstream visitors) attracted to the reservoir project during the twelve-month period. Based on the first calibration run, the following comparisons can be made.

Category	Model Prediction	Actual Corps Data
Land-Based Visitors	955,838	917,224
Water-Based Visitors	1,441,864	1,440,276
Total Visitors	2,397,702	2,357,500

The percent error in total visitors is only 1.7%. It should be noted that large errors were seen during some months due to the fact that the model assumes "average" weather conditions for each month and if unusual weather conditions exist, the model cannot be expected to accurately predict visitor values. Over a period of twelve months, these weather conditions "average out" and the model predicts more satisfactorily.

The calibration run forced the model to generate the same amount of energy actually produced by Tenkiller during the twelve month period; namely, 133,660 megawatt hours. Using the value of $9.00/mwh for generated base demand, a revenue of $1,202,940 can be expected from the actual run. These values will be compared to values obtained later in

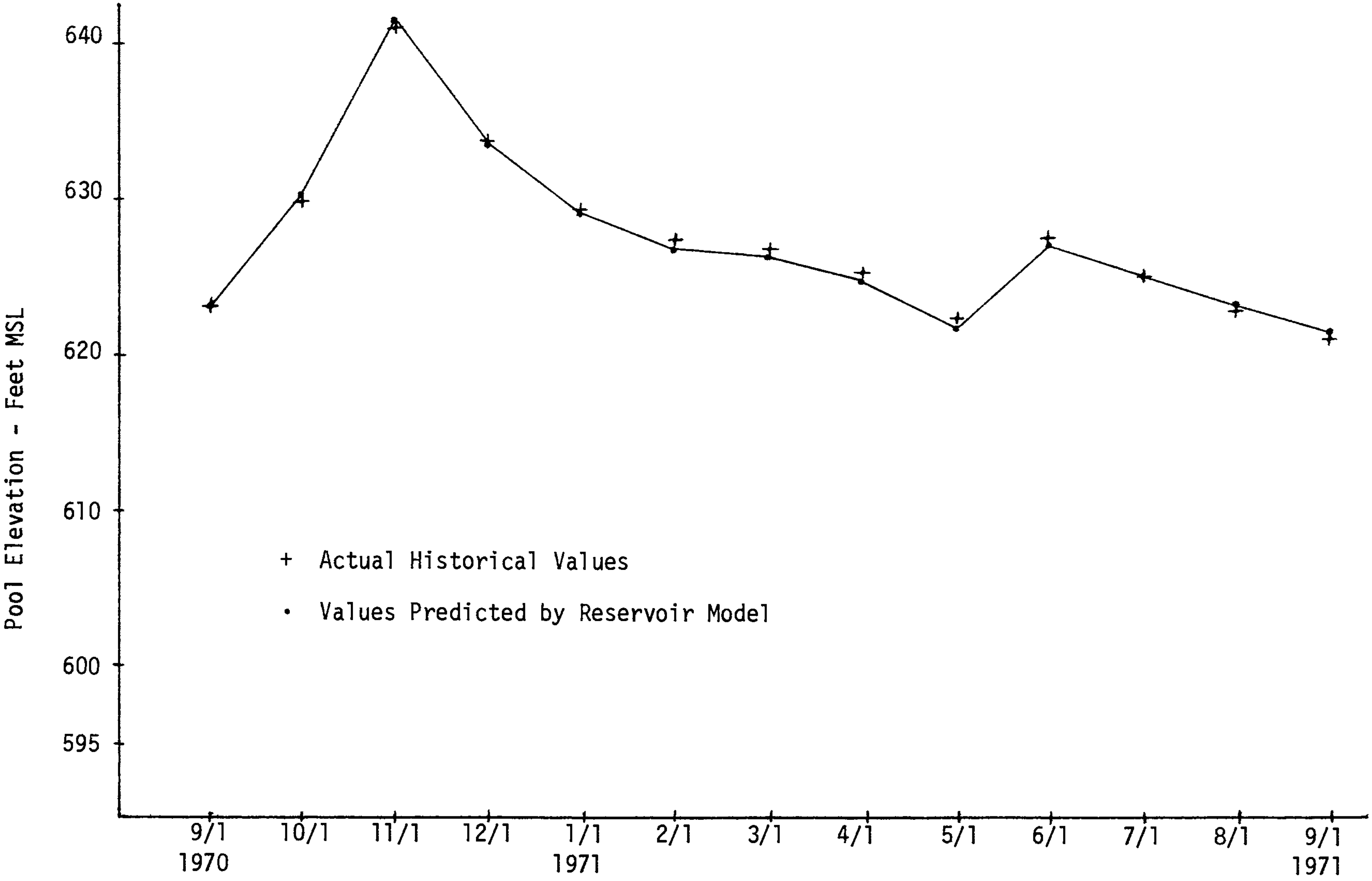


Figure 22. Comparison of Model-Predicted Elevations with Actual Historical Elevation Data

several optimization runs. In all of the runs discussed below, the generator efficiency EFF is set equal to 0.93 so that such comparisons will be valid.

Normalized Benefit Optimization Runs

The monthly performance index is the sum of six benefits. The benefits from reservoir visitation, downstream visitation, water quality, navigation, power, and the flood penalty, are each multiplied by a weighting factor W1 through W6 and summed to produce the monthly normalized performance index. To determine the effect of each of these benefits separately on the management strategy, a group of optimization runs were made as follows:

1. A "standard" run with equal weights on all benefits (reservoir and downstream visitation considered together as the total recreation benefit). Thus, W1 = W2 = 0.5 and W3 = W4 = W5 = W6 = 1.0.
2. A run to maximize the recreation benefit only: W1 = W2 = 0.5 and all other W's = 0.
3. A run to maximize the water quality benefit only: W3 = 1.0 and all other W's = 0.
4. A run to maximize the navigation benefit only: W4 = 1.0 and all other W's = 0.
5. A run to maximize the flood benefit (minimize the flood penalty) only: W5 = 1.0 and all other W's = 0.
6. A run to maximize the power benefit only: W6 = 1.0 and all other W's = 0.

The "standard" or so-called "unity-weighting" run produced the pool elevation trajectory shown in Figure 23. As can be seen, the trajectory remains below the actual pool elevation during the high inflow months, indicating higher generation, then remains higher than the actual elevation until the summer months when again, heavy generation is displayed. It should be noted that each benefit (except power) can contribute a maximum value of one to the performance index each month under the normalized index. The power benefit however can exceed one when overgeneration of the demand occurs. Thus the trajectory for unity weighting displays concern for visitation during the early spring months, but overgenerates the last few months to raise the performance through the power benefit. The model cannot "see" the consequences of leaving the pool elevation at a low level at the end of August. The total benefit produced in the standard run is 43.4266. The maximum possible is 48.0 plus any benefit from overgeneration of the monthly energy demands. This standard run is presented in detail in the Appendix.

Run Number 2 to maximize recreation is also shown in Figure 23. In this case visitors above the dam have the same weight in the performance index as do the visitors below the dam. As expected, the pool elevation tends to remain close to 630 feet MSL. This is due to the monthly visitor curves which produce optimum values around this elevation. Also, the model sees no requirement to meet the energy demand. October, November and May (which are large inflow months) are the only months during which demand is generated. The elevation rises sharply in October and November due to the large inflows. During these months, visitation will be poor any so the model discharges as much as it can to bring the elevation close to 630 feet by the end of December.

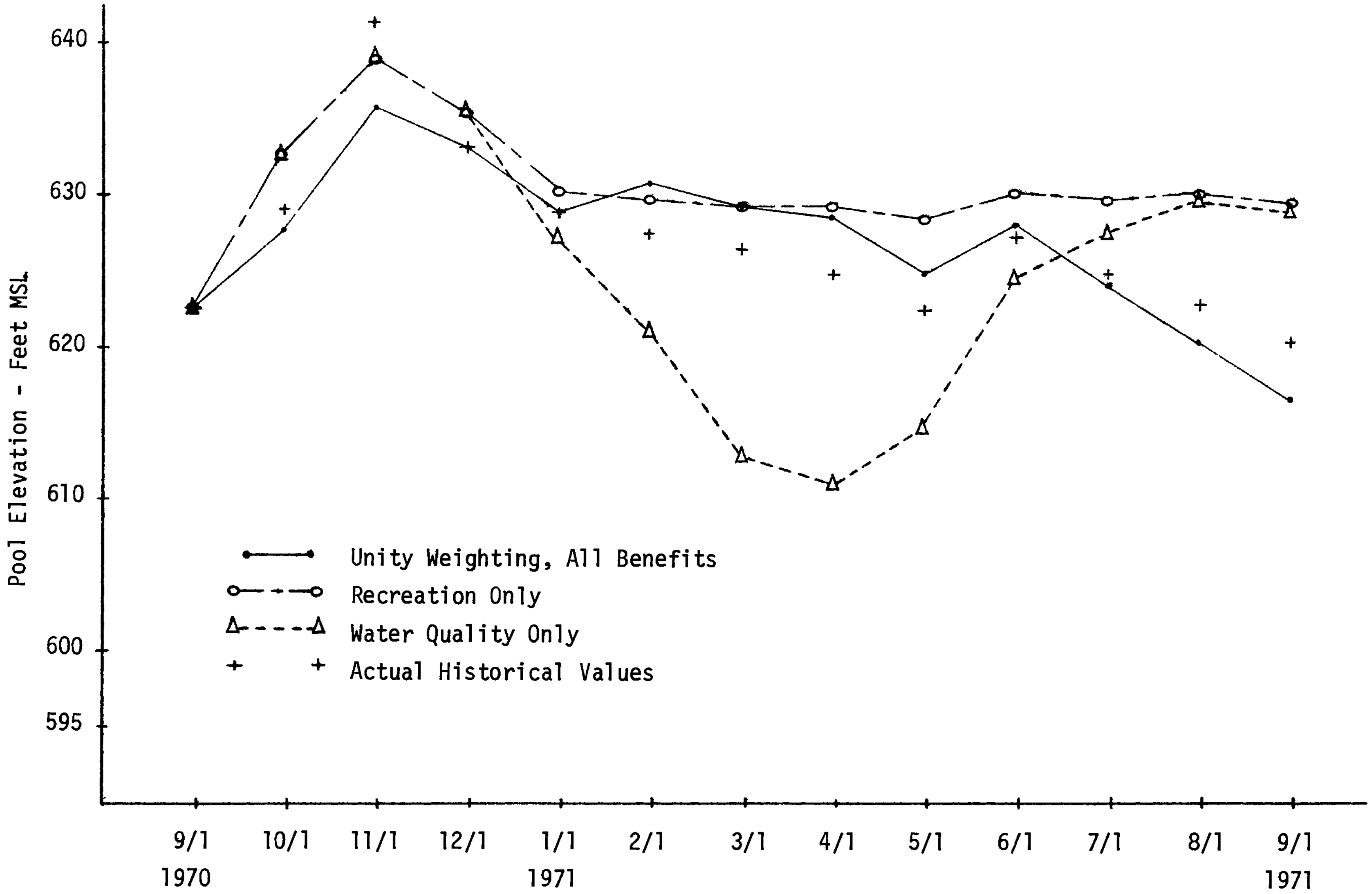


Figure 23. Normalized Optimum Benefit Runs: Unity Weighting, Recreation, and Water Quality

The recreation performance for this run was found to be 10.497, compared to a value of 9.957 produced by the previous "standard" run when all benefits were considered. Thus as expected, the "standard" unity weighted total benefit. Note that the maximum value of recreation benefit is 12.0; one unit per month. Thus recreation during July is given the same value as in January. Later, an optimization run will be considered which maximizes the total number of visitors during the twelve-month period.

Run Number 3, which maximizes the water quality benefit, displays an interesting elevation trajectory as shown in Figure 23. Recall that the weighting of dissolved oxygen within the water quality index is 100 times the weighting of dissolved solids and temperature. Thus the optimal generation and attendant water releases will be determined on the basis of the D.O. produced in the first reach, terminating at Gore. Referring to Table VI, it is clear that the D.O. of the reservoir discharge is less than the D.O. of the intervening flow. Furthermore, the desired D.O. level is taken to be the saturated D.O. level at the average downstream temperature. Therefore, any power discharge, however small, reduces the water quality benefit.

Examining the optimum water quality trajectory in Figure 23, the model generates at a low level in September, but is forced to generate during October and November due to the large inflows and the fact that RESMOD automatically generates 24 hours a day when the pool is above 633 feet. For the remaining months of the year, the D.O. levels of the discharge during December through March are much higher than those during April to August. (See Table VI). Thus the reservoir will discharge water through high levels of generation from December through March to provide storage for inflow during the period April to August when very little discharge is seen in Figure 23. The optimum water quality benefit value found in this run was 8.241 while the standard unity weight run produced a value of 7.62. Again, the maximum possible value is 12.

Figure 24 shows the optimum trajectory for run Number 4, using only the navigation benefit model. The values of the intervening flows below the dam and below Gore at the Arkansas River given in Table II essentially determine whether or not the reservoir discharges water by generation. For example, the intervening flows are both small during April and the navigation trajectory shows a higher generation than any of the other trajectories during that month. Recall that the optimum range (unity value) of the navigation curves extend over wide ranges of flow values and thus high benefits are produced regardless of the specific power releases. Thus little difference is seen in the navigation benefit of this run (11.148) versus the unity weighting run (11.139).

The trajectory for run Number 5, in which the flood benefit is maximized, is also shown in Figure 3. The flood penalty curves allow a wide range of flow values before penalty (negative values of benefit) are imposed. The trajectory in Figure 3 shows that the model generates as little as possible during all months but holds the pool elevation below 633 feet where RESMOD faces 24 hour generation and large power releases. The penalty produced for this run was -0.506 while the penalty produced by the unity weighting run was only slightly higher (more severe) at -0.512. The maximum penalty which could be imposed is -48.0. Thus,

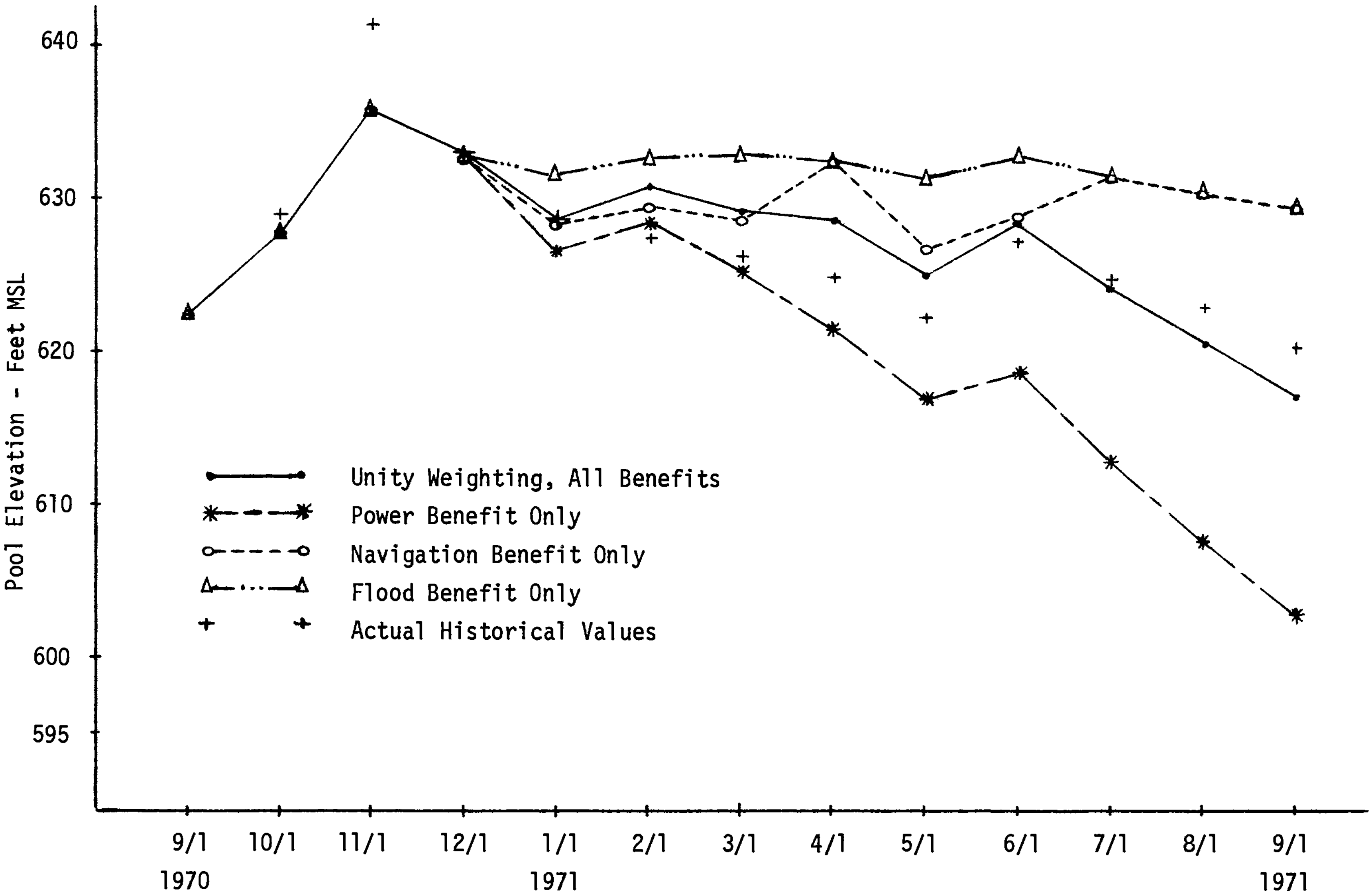


Figure 24. Normalized Optimum Benefit Runs: Unity Weighting, Power, Navigation, and Flood

almost perfect flood control was achieved in both runs, according to the model used.

The trajectory for run Number 6 is also shown in Figure 3. This run maximized the power benefit. Recall that a benefit value of one is given each month the demand (what Tenkiller actually generated) is produced. Thus the benefit curve awards the same value in November when 21,100 mwh are generated as it does in October when only 1,687 mwh are generated. Extra benefit is obtained, however, when overgeneration of the demand occurs in any month.

As can be seen in Figure 3, the power benefit trajectory shows that most overgeneration occurs after April 1, when the energy demand levels are reduced from those seen during the winter. It is expected that the pool elevation should be drawn completely down to the bottom of the power pool at 595 feet, rather than finishing the run at about 603 feet. This can be explained by the fact that the maximum exercising control issued to RESMOD by OPTMZR during the backward stepping optimization from the grid elevations is restricted to 150% of the energy demand (Tenkiller actual generation). Thus the model does not "see" the benefit of extremely large energy generation values during the optimization process. This limit on the exercising control is not imposed in later runs where revenue and total megawatt-hour production are maximized.

The maximum power benefit produced by this run is 15.48 while the unity weighting run produced a power benefit of 15.21. Note that both of these values are greater than the benefit of 12.0 which can be attributed to the calibration run approximating the actual Tenkiller operation during the twelve-month period of interest.

This completes the series of six normalized benefit optimization runs. These runs demonstrated the use of the multi-purpose performance index and the effect of the individual benefits on the regulation strategies. The next series of four runs involve special performance indices designed to look at the trade-off between energy revenue and recreation and to find the maximum energy regulation strategy.

Optimizations of Revenue, Visitors and Energy

One purpose of the optimization package is to facilitate the quantitative examination of the trade-off between power and recreation benefits. An important question is, "How many visitor-days are lost by improper use of the water for energy production?" There is a need for evaluating the ratio of dollars of revenue to visitor-days produced by varying regulation strategies. These questions are partially answered by the simulation results to follow.

The trajectories of the several runs are displayed in Figure 25. In the run to maximize the number of visitors, the performance index simply summed the daily visitors in the land-based, water-based and downstream categories. As can be seen, the pool elevation remained relatively fixed at about 630 feet after the large inflows in October and November were dealt with.

The run to maximize revenue and the run to maximize the total energy are interesting to compare. The revenue trajectory displays the fact that generation of the specified demand (actual Tenkiller generation) produces revenue of $9.00/mwh whereas overgeneration (dump energy) produces only $2.00/mwh. Thus the model distributes the extra energy available over the total optimization period so that the monthly demand can be generated every month. On the other hand, the maximum energy trajectory operates at a high elevation for as long as possible to conserve water. Then, during the last three months, the model uses all of the available power pool to maximize the total energy produced.

For the final run, the revenue and visitors were weighted and summed together as follows:

$$\text{PI} = \$ \text{ of Revenue} + 0.526 \text{ Visitors}$$

The weighting coefficient was found by taking the approximate averages of the dollars of revenue produced by the maximum revenue and maximum visitor runs and dividing this average by the average number of visitors produced in these same two runs. This has the effect of giving approximately equal weighting to revenue and visitors in the performance index PI. The trajectory for this joint performance index is shown in Figure 25 and, as can be seen, the pool elevation remains well above the actual pool elevation reported by the Corps of Engineers.

Table IX summarizes the significant results obtained from the several optimization runs. A rather surprising conclusion which can be drawn is that a maximization of visitors does not reduce energy revenue significantly and energy production (mwh) is actually increased. Pulling the reservoir down to the bottom of the power pool produces only $116,500 in extra revenue over that obtained when maximizing visitors. However, 941,000 visitors are lost. This figures out to be about 12.5 cents of energy revenue gained for each visitor lost; an insignificant gain. Furthermore, the final pool elevation on the maximum revenue trajectory is unacceptable.

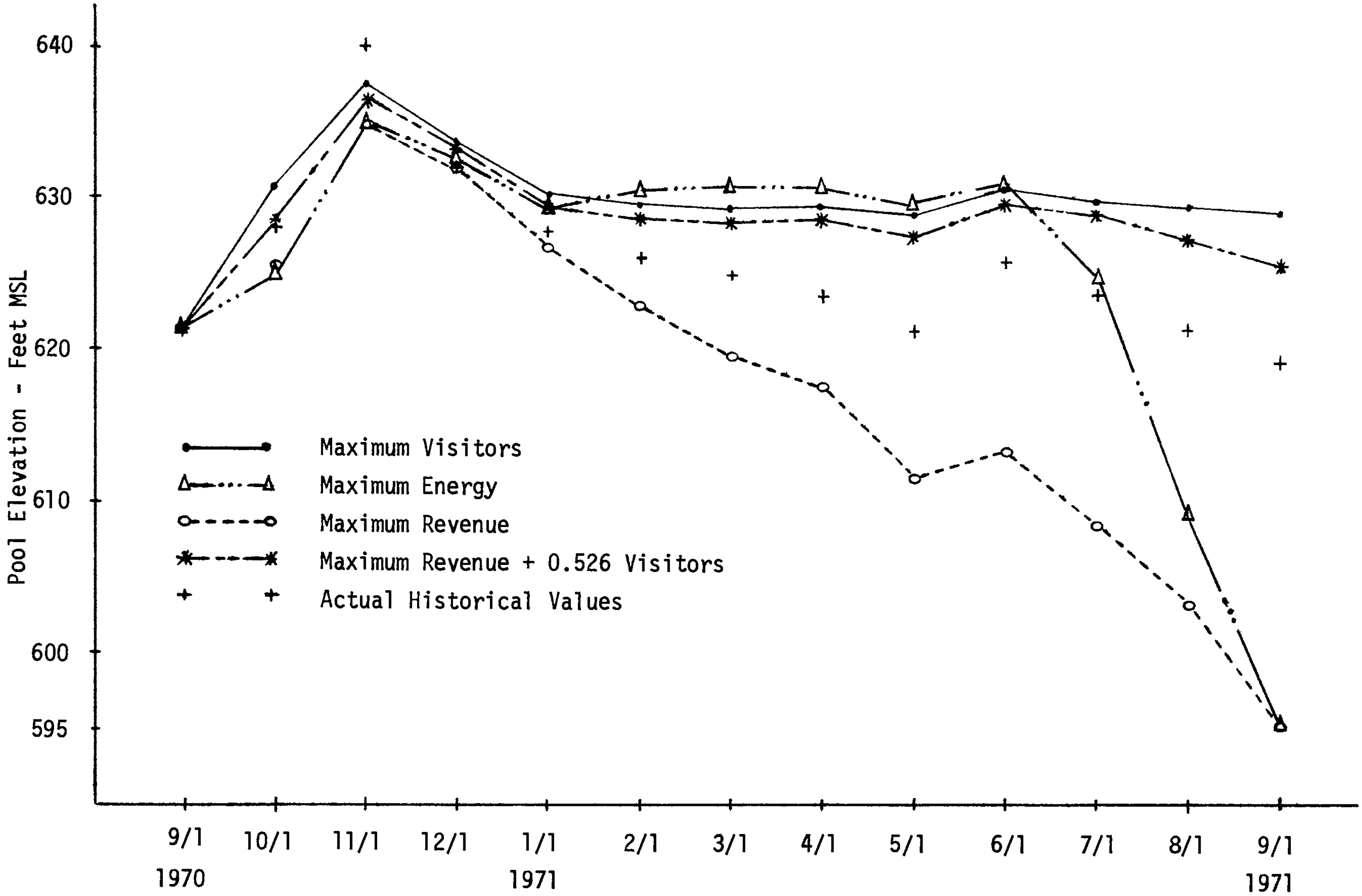


Figure 25. Trajectories for Maximum Revenue, Energy, and Visitors

TABLE IX

SUMMARY OF RESULTS FOR MAXIMUM REVENUE, ENERGY AND VISITOR RUNS

Type Run	Total Visitors	Total Energy Revenue	Total MWH	Final Pool Elevation (Feet MSL)
Calibration Run (Approximates Corps Data)	2,535,300	$1,202,900	133,660	621.27
Max Visitors	2,729,100	$1,156,800	139,708	629.23
Max Revenue	1,788,100	$1,273,300	168,834	595.22
Max Rev. + 0.526 Vis.	2,702,600	$1,195,500	144,740	625.18
Max Energy	2,303,100	$1,126,100	175,970	595.10

CHAPTER V

SUMMARY AND CONCLUSIONS

Introduction

The primary objective of this research was to develop a multipurpose benefit model for dynamic reservoir regulation. The principal tools used in the project fall within the systems science discipline and involve mathematical modeling, computer simulation and optimization theory. A comprehensive, integrated and flexible computer package is now available for use in a wide range of reservoir regulation studies where multi-purpose benefits must be considered.

The project development made use of existing reservoir model (RESMOD) which has proved quite accurate in reproducing elevation/inflow/energy generation data over time periods of up to a year in length. Actual data for the physical characteristics of the reservoir basin and the turbine-generator units can be used in the model. Hydrologic input data for RESMOD can be supplied on a daily or monthly basis and the model predicts daily pool elevation, power discharge given a specified energy amount to be generated. Spill releases are controlled by rules dictated by the user.

The total regulation optimization package consists of the reservoir model subroutine RESMOD, the benefit model subroutine BENMOD and the optimizing subroutine OPTMZR. The subroutine BENMOD uses daily values of pool elevation, power discharge, spill releases and generated energy to evaluate benefits of recreation, downstream water quality and navigation and power generation. Additionally, a flood penalty is calculated from stage values predicted at two downstream control points. A performance index sums one or more of the several benefits, weights each according to the user's instructions, and supplies this sum to the subroutine OPTMZR.

The optimization procedure is based upon the dynamic programming algorithm under which the reservoir and benefit models are exercised from selected pool elevations each month. The subroutine OPTMZR determines the generated energy value each month which maximizes the benefit performance index and provides these values and the resulting pool elevation time trajectories to the user. The user provides a starting elevation for the reservoir and instructs the program to optimize the regulation strategy over any number of months from two to twelve, inclusive.

The total optimization package was demonstrated using past data from Tenkiller Ferry Reservoir. Optimum regulation strategies were found for a twelve-month period from September, 1970 to August, 1971. A variety of optimization runs were made using the basic data for this period. These included runs to individually maximize visitors, energy revenue, energy and measures of navigation, water quality, recreation and power benefits. A run to minimize flood penalty was also made, as well as several runs combining various benefits.

Results and Conclusions

Prior to execution of the optimization runs, a calibration run of the reservoir and benefit models was made. The predictions of pool elevations and visitor-days were well within expected accuracy limits. When the reservoir model was provided the initial pool elevation on September 1, 1970 and the actual inflow data and energy generation data for the twelve-month period under study, the model predicted end-of-month pool elevations with an average error of 0.451 feet, which represents only 2.1% error of the total elevation range of 20.71 feet experienced by Tenkiller during the year. These results are based on the second calibration run using corrected inflow data provided by the Tulsa District Office.

A second test of the model was made during the calibration run by comparing the predicted number of visitors during the year with actual Corps of Engineers data for Tenkiller. The model predicted the reported above-dam visitor value within 2%, which likely is within the accuracy of the data itself. Errors in the prediction of individual months were sometimes large, but these can be attributed, in most months, to unusual weather conditions, not "seen" by the model. The visitation model assumes "average" weather conditions for each month. Modifications to improve the recreation model are discussed at the end of this chapter.

Two groups of optimization runs were made. The first group made use of the so-called "normalized" benefit variables. These variables allow a maximum value of one to be attributed each month to each of the benefits of recreation, water quality and navigation. The power benefit is set equal to one if the given monthly demand is generated plus 25% of this benefit for overgeneration. The flood penalty is zero until flood stage, then a negative value is added to the other benefits as the stage variable increases. At extreme flood conditions, all other benefits are cancelled. Each benefit (or penalty) was optimized separately and the regulation strategies were compared with a standard run in which all benefits were equally weighted.

In the second set of optimization runs, the performance index was specially modified to exercise the trade-offs between the power and recreation benefits. Optimum regulation strategies were evaluated to maximize (1) total yearly energy produced, (2) total revenue, (3) total visitor-days and (4) a weighted sum of revenue and visitor-days. The general conclusion is that revenue is not adversely affected by maximizing the recreation benefit and that the revenue/visitor-day exchange factor between maximizing revenue or maximizing visitor-days is only about 12 cents per visitor for the period of record used in the study.

Recommendations For Further Study

This research project has yielded a collection of models within an integrated framework which allows optimization studies of reservoir regulation strategies. A fundamental premise in system modeling is that no model is ever exact. Therefore, it follows that further research and development effort can usefully be directed at improving each of the models in the optimization package.

Although the reservoir power generation section of the package appears to operate with little error, an improved efficiency parameter should be developed which depends upon the size of the monthly energy control. When the monthly energy control is small, the generators undergo more start-stop cycles per thousand mwh of energy produced and the overall efficiency should be lowered to reflect this. The present model uses a constant generator efficiency value for all months.

Several future studies can be suggested for the recreation model. The basic four-point visitor curve used in the present model appears to have potential for accurate prediction but a calibration method for finding the ordinates of the points on the curve from visitor data should be developed. The method should correct for weather conditions and pool elevation values simultaneously. Other research has attempted to utilize statistical data and multiple regression to develop a correlation between pool elevation and visitation with no success [15]. However, if a model such as the four point curve is proposed for the relationship between pool elevation and visitation, better correlation might result.

Another improvement in the recreation model will be to provide a reduction in the predicted visitors in those months when the inflow is higher than normal; indicating possible rainfall and inclement weather. Conversely, the predicted visitor values should be increased when the inflow is below normal. A close examination of the calibration run results shows that many of the monthly errors in visitation prediction would be reduced with this modification.

The water quality model is probably overdeveloped at the present time in so far as Tenkiller is concerned. The Illinois River below Tenkiller Dam does not exhibit serious water quality problems at the present time. The major problem in fully implementing the water quality model at any given reservoir will probably be a lack of data to calibrate the model for all seasons and flows.

One activity of the early research which did not extend into the program development and the Tenkiller demonstration is the fish spawning model. This is an important part of the long-term recreation benefit at most reservoirs and deserves high priority in future versions of the optimization package.

In its present form, the downstream model is not adequate to optimize flood routing strategies. The model development was oriented toward long-term benefits with the shortest computational interval being one day. Therefore, a substantial increase in computation time will occur if the basic time interval is reduced to one hour, or even two or four hours. The inclusion of time lags or differential equation models of downstream reaches will require special treatment of initial conditions on the reaches when the backward stepping optimization process is underway.

The most important idea that can be contributed at the conclusion of this research is to <u>use</u> the optimization package in a meaningful way to improve the regulation of Tenkiller. It appears that the strategy used by the Corps of Engineers during the twelve month period from September, 1970 to August, 1971 was not optimal in terms of energy production or recreation. From the data presented in Table IX on Page 104, two of the optimization runs (maximum visitors and maximum revenue + visitors) left the pool elevation higher on August 31, 1971, produced higher recreation visitation and generated more energy than was reported by the Corps. A simple project is therefore proposed:

1. Based on historical data, establish monthly average inflows for Tenkiller over a twelve month period. The average inflows for the first two or three months could be adjusted with recent inflow data from the immediate past few months.
2. Using these predicted inflows and the present pool elevation for Tenkiller, use the computer package to establish the

optimum regulation strategy (target pool elevations) for the next twelve months. Operate the reservoir to meet, if possible, the target pool elevation at the end of the first month. Adjustments could be made for unusual inflows during the first month by re-running the optimization with the new inflow data.

3. At the end of the first month, new predictions of inflows for the next twelve months are made and used with the then current pool elevation value in a new optimization study which will yield a new set of pool elevation targets for the following twelve months.
4. The process is repeated monthly. This simple project would demonstrate the computer package developed in this project by making effective use of past historical inflow data to calculate future regulation strategies on a real-time month-to-month basis.

There may be some hesitation to experiment with Tenkiller regulation in this fashion and thus a similar, but synthetic, approach is proposed:

1. Select any twelve month period in the past and use Tenkiller inflow data <u>prior</u> to this period for establishing the predicted inflows to be used in the optimization.
2. Each month, use the actual inflow with the reservoir model and operate the model to follow the pool elevation targets calculated from the optimization using historical data.
3. Re-optimize each month with new predictions of the inflows.
4. Continue this process for a twelve month period and then compare the energy produced, visitation and final pool elevation with actual values from Corps data.

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APPENDIX

OPTIMIZATION PROGRAM USER GUIDE

The reservoir optimization package developed in this study is written in Fortran IV-G. The program was run on an IBM 360/65 computer at the Oklahoma State University Computer Center. Due to differences in computer systems the user should review the control cards and data formats used by this system before attempting to use this program. The entire deck plus data cards totals 1704 cards. The data consists of 156 cards based on 12 months of data.

The user can control various optimization, output, and performance index options within the program through eight control variables. These variables and the options associated with each are now discussed.

The NMON variable identifies which calendar month is associated with the first month in the data set. By choosing a month number between 1 and 12 (September = 9, etc.) the user tells the program how to label output results with the proper month name.

The NDBUG variable controls debug output information from the RESMOD subroutine. The output is used for checking the operation of the RESMOD subroutine. (See program listing).

NDBUG = 0 : No debug output printed.

NDBUG = 1 : Debug output printed.

The LIST variable controls the type of output format provided by the program as follows:

LIST = 1 : Output of monthly summaries for every run in the optimization phase plus monthly summaries for the forward run.

LIST = 2 : Output of LIST = 1 plus daily data on all runs.

LIST = 3 : Output of monthly summaries for forward run only.

LIST = 4 : LIST = 3 output plus daily data on forward run.

No matter what value for LIST is used, all runs will output the PSTAR and USTAR maps at the end of each month during the optimization phase and a summary of the total optimization will appear at the end of the program output. Details of the output appear in Chapter II.

The MODIPI variable controls the performance index to be optimized as follows:

MODIPI = 1 : Performance index sums the reservoir and downstream visitation, the water quality benefit, the navigation benefit, the flood penalty, and the generation benefit all with weighting factors.

MODIPI = 2 : Performance index is equal to the total energy revenue.

MODIPI = 3 : Performance index sums the reservoir and downstream visitors.

MODIPI = 4 : Performance is set equal to the sum of MODIPI = 2 and MODIPI = 3 with weighting factors.

The input variable NTOTSG designates the total number of months of data to be read in.

DAILY determines whether daily data on inflow, evaporation and downstream intervening flows will be read in and used by RESMOD.

DAILY = 0 : Monthly data only.

DAILY = 1 : Monthly and daily data.

Note that monthly data <u>must</u> be supplied to the program even when daily hydrologic data is supplied.

MSTRT is the stage number at which the optimization procedure is to start. MFIN is the stage number at which the optimization procedure is to finish. These stage numbers do not necessarily correspond to the calendar month numbers but rather correspond to the data set number. The example run listed in Tables XIII and XIV optimizes for twelve months from September to and including August. The first month in the data set is September and the twelfth month is August. In this case, NMON = 9, MSTRT = 1 and MFIN = 12.

The package will allow from two to twelve months of data to be read in. Monthly data alone or monthly data with daily hydrologic data for RESMOD can be used. Although some read statements in the MAIN program show a capability to read in data for up to four different reservoirs, the total package is restricted to optimizing only one reservoir and only one set of such data should be supplied. Table X shows the construction of the data deck for one reservoir. In the table, the counting variable JJ refers to the reservoir number (always 1) and the variable J refers to the monthly data set number (1 through NTOTSG).

Table XI provides a list of all variables used in the program. For convenience, the list has been separated into parts corresponding to the various subroutines. Table XII contains a listing of the entire optimization package.

A sample optimization run is included for reference. This run corresponds to the so-called "standard" run discussed in Chapter IV.

The data for this run is listed in Table XIII and the output corresponding to LIST = 3 is given in Table XIV. This run was made from a FORTRAN source deck and the total compile and execution time was 1 minute, 14.6 seconds on the IBM 360/65. An object deck will reduce the run time by about 40 seconds. Input/output time is low; being about one minute for card reading and printer operation. The approximate number of pages of output for LIST = 3 is about 7 pages, when the program is not listed.

TABLE X

INPUT DATA DESCRIPTION

Sequence No.	Number of Cards	Program Variables	Format
1.	1	NMON, NDBUG, LIST and MODIPI	12I3
2.	1	NTOTSG, DAILY	I2,7X,I2
3.	1	MSTRT, MFIN	I2,7X,I2
4.	1	MD(J), number of days in each month	12I3
5.	1 to 3	PD(J), monthly energy demands in MWH, four to a card.	4E20.7
6.	1 or 2	INFLOW(JJ,J), monthly average inflow in thousands of CFS, eight to a card.	8F10.0
7.	1 or 2	PANEVP(JJ,J), monthly pan evaporation in feet	
8.	1 to 3	ITVFL1(JJ,J), monthly average intervening flow just below dam in thousands of CFS, four to a card.	4E20.7
9.	1 to 3	ITVFL1(JJ,J), monthly average intervening flow just below control point 1 in thousands of CFS, four to a card.	4E20.7
10.	1	EFF(JJ), efficiency of generators in decimal function form, one value read.	8F10.0
11.	1	ADTIM(JJ), hours in one day before an additional generating unit is added, one value read.	8F10.0
12.	1 to 3	TPP(JJ,J) and BPP(JJ,J), monthly values of top and bottom of the power pool, in feet MSL, four monthly TPP, BPP pairs per card.	8F10.0

TABLE X (Continued)

Sequence No.	Number of Cards	Program Variables	Format
13.	1	ELST(JJ), starting elevation for the reservoir at the first month of interest, in feet MSL, one value read only.	8F10.0
14.	1	DISPT(JJ,1) and DISPT(JJ,2), upper discharge control points, in feet MSL, two values read; values must lie between TPP and the highest grid elevation GRD(5) DISPT(JJ,1) < DISPT(JJ,2)	8F10.0
15.	1	NUNIT(JJ), number of generating units at the reservoir, one value read.	12I3
16.	1	ELINC(JJ,JX), elevation increment, in feet, to be deducted from pool elevation for each additional unit added, one less value than NUNIT.	8F10.0
17.	1	FRAC(JJ,J) J=1,2,3., fraction of inflow to be discharged (including spill) when pool elevation is between TPP and DISPT(JJ,1), (J=1); DISPT(JJ,1) and DISPT(JJ,2), (J=2); above DISPT(JJ,2), (J=3), three values read.	8F10.0
18.	1	GRD(J), J = 1,5. pool elevation grid points for use by OPTMZR, in feet MSL, five values read, GRD(1) < BPP < TPP < GRD(5).	5E10.5
19.	1	MWHMIN(JJ), minimum number of MWH to be generated each day, one unit must be able to generate this value in fewer hours than ADTIM, one value read.	4E10.3
20.	3	ELRES(JJ,J), elevation values from the reservoir elevation-volume curve, in feet MSL, 24 values, 8 to a card.	8E10.5

TABLE X (Continued)

Sequence No.	Number of Cards	Program Variables	Format
21.	3	VRES(JJ,J), volume values corresponding to ELRES values, in thousands of acre-feet, 24 values, 8 to a card.	8E10.5
22.	3	STAGE1(JJ,J), stage values from stage-flow curve at control point 1, in feet, 24 values, 8 to a card.	8E10.5
23.	3	DISST1(JJ,L), flow values corresponding to STAGE1 values, in thousands of CFS, 24 values, 8 to a card.	8E10.5
24.	3	STAGE2(JJ,J), stage values from stage-flow curve at control point 2, in feet, 24 values, 8 to a card.	8E10.5
25.	3	DISST2(JJ,L), flow values corresponding to STAGE2 values, in thousands of CFS, 24 values, 8 to a card.	8E10.5
26.	1	DISPWR(JJ,J), discharge rate values from the tailwater-corrected maximum efficiency elevation-discharge curve for one unit, in thousands of CFS, 8 values.	8E10.5
27.	1	ELRESD(JJ,L), pool elevation values corresponding to DISPWR values, in feet MSL, 8 values.	8E10.5
28.	1	HPRES(JJ,J), horsepower values from the tailwater-corrected max. efficiency elevation-power curve for one unit, in thousands of horsepower, 6 values.	6E10.5
29.	1	ELRESP(JJ,L), pool elevation values corresponding to HPRES values, in feet MSL, 6 values.	6E10.5

TABLE X (Continued)

Sequence No.	Number of Cards	Program Variables	Format
30.	2	TAIL(JJ,J), values of tailwater rise, in feet, due to spill when all units are operating, 16 values, 8 to a card.	8E10.5
31.	2	SPILL(JJ,L) values of spill discharge rate corresponding to TAIL values, in thousands of CFS, 16 values, 8 to a card.	8E10.5
32.	6 to 36	BN(M,N), the recreation model parameter array, 24 values for each month, 8 values to a card.	8E10.2
33.	1	LOWEL and HIGEL, lowest and highest pool elevations used in visitor-elevation curves, two values.	2E10.3
34.	6 to 36	WQ(M,N), the water quality parameter array, 3 cards per month, 8 values/card for first and second cards and 4 values on the third card, 20 values/month.	8E10.3/ 8E10.3/ 4E10.3
35.	1	ALPHA1, ALPHA2, ALPHA3, water quality weighting factors for D.O., D.S. and temp.; RETM1 and RETM2, reach times for reaches 1 and 2 in D.O. model, in days. RETM2 = 0.0 or left blank inhibits WQ model for second reach.	5F10.3
36.	2 to 12	NAV(M,N), parameter values in thousands of CFS for navigation model, 1 card/month, 8 values/card.	8E10.3
37.	1	FLDST1, FLDMX1, FLDST2, FLDMX2, parameter values for flood penalty model, four values, in feet of stage height.	4E10.3
38.	2 to 12	KAL(M,N), N = 1, 2, 3, data for calendar section, 1 card/month, 2 or 3 values/card.	3I5

TABLE X (Continued)

Sequence No.	Number of Cards	Program Variables	Format
39.	1	REVDEM, REVBUY, REVDMP, rates for demand energy, purchased energy and dump energy, in dollars/MWH.	3F20.3
40.	1	W1 through W8, weighting coefficients for the performance index.	8E10.3
		NOTE: The following cards read only if DAILY = 1.	
41.	8 to 48	DINFLO(JJ,J,JX), daily average inflow, in thousands of CFS, read sequentially by day for each month, start new month on new card.	8F10.3
42.	8 to 48	DPANEV(JJ,J,JX), daily pan evaporation, in feet, read as DINFLO.	8F10.3
43.	16 to 96	DITFL1(JJ,J,JY) and DITFL2(JJ,J,JY), daily average intervening flows below dam and below first control point, respectively, in thousands of CFS, both DITFL1 and DITFL2 read in before month increments.	8F10.3

TABLE XI

PROGRAM VARIABLE LIST

1. MAIN Program

NSTAGE - Variable set by MAIN to control certain DO statements in read in of data.

KK - Variable set to 1 to limit this program to one reservoir usage.

NMON - Variable corresponds to number of month of beginning data to provide for proper month printout in outputs.

NDBUG - Internal decision variable for extra data output from RESMOD.

LIST - Output option control variable.

MODIPI - Optimization option control variable.

NTOTSG - Total number of months of data to be read in.

DAILY - Option variable for read in of daily data.

MSTRT - First month number of interest of data set for optimization.

MFIN - Last month number of interest of data set for optimization.

MD(J) - Number of days per each month.

PD(J) - Monthly energy demand.

INFLOW(JJ,J) - Average daily inflow rate per month.

PANEVP(JJ,J) - Average daily evaporation per month.

EFF(JJ) - Generator efficiency.

ADTIM(JJ) - Number of hours before additional units used.

TPP(JJ,J) - Top of power pool per month.

BPP(JJ,J) - Bottom of power pool per month.

ELST(JJ) - Starting elevation

DISPT(JJ,J) - Upper discharge control points.

TABLE XI (Continued)

NUNIT(JJ) - Total number of units per reservoir.

ITVFL1(JJ,J) - Monthly average intervening flows after DISPT(JJ,1).

ITVFL2(JJ,J) - Monthly average intervening flows after DISPT(JJ,2).

FRAC(JJ,J) - Fractional portions of inflow rates for discharge above TPP(JJ,J).

GRD(J) - Grid point elevations.

MWHMIN(JJ) - Minimum daily energy generation.

ELRES(JJ,J) - Elevations corresponding to points from elevation-volume curve.

VRES(JJ,J) - Volumes corresponding to points from elevation-volume curve.

STAGE1(JJ,J) - Stages corresponding to points from stage-flow rate curve at control point one.

DISST1(JJ,L) - Flow rates corresponding to points from stage-flow rate curve at control point one.

STAGE2(JJ,J) - Stages corresponding to points from stage-flow rate curve at control point one.

DISST2(JJ,L) - Flow rates corresponding to points from stage-flow rate curve at control point one.

DISPWR(JJ,J) - Power discharge rates corresponding to points from the discharge rate - elevation curve.

ELRESD(JJ,L) - Elevations corresponding to points from the discharge rate - elevation curve.

HPRES(JJ,J) - Instantaneous horsepower corresponding to points from horsepower - elevation curve.

TAIL(JJ,J) - Tail water changes corresponding to points from the tail water - discharge rate curve.

SPILL(JJ,J) - Spill discharge rates corresponding to points from the tail water - discharge rate curve.

BN(M,N) - Recreation model data (see BENMOD variables).

TABLE XI (Continued)

LOWEL - Lowest elevation for visitation curves.

HIGEL - Highest elevation for visitation curves.

WQ(M,N) - Water quality model data (see BENMOD variables).

ALPHA1 - Weighting coefficient for D.O. in water quality benefit.

ALPHA2 - Weighting coefficient for D.S. in water quality benefit.

ALPHA3 - Weighting coefficient for temperature in water quality benefit.

RETM1 - First reach reach time variable.

RETM2 - Second reach reach time variable.

NAV(M,N) - Navigation model data (see BENMOD variables).

FLDST1 - Flood stage of first control point.

FLDMX1 - Maximum expected stage at first control point.

FLDST2 - Flood stage at second control point.

FLDMX2 - Maximum expected stage at second control point.

KAL(M,N) - Calendar data (see BENMOD variables).

REVDEM - Dollars/MWH revenue for generating demand energy.

REVBUY - Dollars/MWH bought for difference between demand energy and undergeneration of demand.

REVDMP - Dollars/MWH of revenue for generation above demand.

W1 - Reservoir visitation weighting factor.

W2 - Downstream visitation weighting factor.

W3 - Water quality benefit weighting factor.

W4 - Navigation benefit weighting factor.

W5 - Flood penalty weighting factor.

W6 - Generation benefit weighting factor.

TABLE XI (Continued)

W7 - Revenue weighting factor.

W8 - Visitors weighting factor.

2. Subroutine OPTMZR

DMD(12) - Demands made available for output from OPTMZR.

FLW(4,12) - Inflow rates made available for output from OPTMZR.

ISUM - Integer variable for output of total unfractioned people.

JX - Counting variable for translation of stage to month.

K - Stage variable.

KMAX - Maximum number of stages (equivalent to total months).

KMAX2 - KMAX - 2.

L - Variable used to key program branching.

LHOLD - Storage variable for list (intermediate variable).

LIST - Program output control variable.

M - Counter variable.

MFN - Month counter used only for output of month names.

MST - Month counter used only for output of month names.

MFIN - Last month number of interest.

MFIN1 - Corresponds to MFIN-used for stage to month change.

MSTRT - First month number of interest.

MSTART - Corresponds to MSTRT - used for stage to month change.

TABLE XI (Continued)

MON(12)	-	Alphameric names of months (i.e. SEP, OCT, NOV ...).
N	-	Stage increment variable.
P	-	Unmodified performance.
PL	-	Performance corresponding to UL after being accumulated.
PM	-	Performance corresponding to UM after being accumulated.
PH	-	Performance corresponding to UH after being accumulated.
PRUN	-	Variable for accumulation of total run performance.
PSTAR(5,2)	-	Storage for current and post-stage performances.
REV	-	Power revenue sent through 'COMMON' to OPTMZR.
REV1	-	Accumulation variable for REV.
SI(4)	-	Initial elevations per each reservoir.
SUM	-	Visitors sent through 'COMMON' to OPTMZR.
SUM1	-	Accumulation variable for SUM.
UL	-	Low control value from UHILO.
UM	-	Medium control value from UHILO.
UH	-	High control value from UHILO.
USTAR(12,5)	-	Stored optimum controls for all stages and grid points.
X(5)	-	Grid point elevations.
XI	-	Initial elevation at first stage.

3. <u>Subroutine CRVFIT</u>

A	-	First coefficient of second order curve.
B	-	Second coefficient of second order curve.

TABLE XI (Continued)

C	-	Third coefficient of second order curve.
P	-	Performance value returned to OPTMZR as "best".
U	-	Optimum control value corresponding to P.
X1	-	UL value sent from OPTMZR.
X2	-	UM value sent from OPTMZR.
X3	-	UH value sent from OPTMZR.
Y1	-	PL value sent from OPTMZR.
Y2	-	PM value sent from OPTMZR.
Y3	-	PH value sent from OPTMZR.

4. Subroutine UHILO

AVB	-	Allowable volume change to bottom of grid range.
AVT	-	Allowable volume change to top of grid range if top exceeded.
DMD(12)	-	UHILO variable for demands.
DMWH(12)	-	Total monthly demands sent to UHILO.
DPR(4,24)	-	Discharge data for use with FIT.
DSCHG	-	Discharge rate.
E(12)	-	UHILO evaporation variable.
EL	-	Elevation sent to UHILO from OPTMZR.
EV(4,12)	-	Main program evaporation per month.
ELD(4,24)	-	Elevation data in conjunction to DPR(4,24).
ELP(4,24)	-	Elevation data in conjunction to HPR(4,24).
ELRES(4,24)	-	Elevation data in conjunction to VRES(4,24).
EFF(4)	-	Generator efficiency (per reservoir).
F(12)	-	UHILO inflow variable (initially inflow rate - changed to inflow volume).

TABLE XI (Continued)

FIT - Binary search-linear interpolation subroutine used.

FL(4,12) - Main program inflow rate per month.

GRD(5) - Grid point elevations.

HP - Horsepower variable.

HPR(4,24) - Horsepower data points for interpolation.

IPATH - Internal variable indicating overgeneration.

K - Stage variable from OPTMZR to test for first stage.

M - Variable from OPTMZR to determine grid elevation.

MONTH - Data set month number.

MSECS - Number of seconds in one-half month.

MODIPI - In UHILO only used to by 1.5 demand constraint on UH.

N - Counter variable.

SECNDS - Number of seconds of discharge to release AVB or AVT.

UL - Low control determined from AVT.

UM - Medium control midway between UH and UL.

UH - High control determined from AVB.

UMAX - Maximum possible generation from given elevation.

UMINIM - Minimum generation control.

V - Volume at elevation EL.

VM1 - Volume at elevation GRD(1).

VM5 - Volume at elevation GRD(5).

VRES(4,24) - Volume data points for interpolation.

TABLE XI (Continued)

5. Subroutine RESMOD

ACC - Energy generated to date for the month.

ADTIM(JJ) - Number of hours before addition of another generating unit is added.

BPP(JJ,J) - Bottom of the power pool.

DADJIN - Daily inflow rate.

DAV - Average daily inflow rate.

DAV1 - Variable for accumulating daily discharge rate.

DAILY - Decision variable.

DIS - Power discharge rate.

DISDMP - Spill discharge rate.

DISPT(JJ,1) - First upper discharge control point.

DISPT(JJ,2) - Second upper discharge control point.

DIS1 - Total discharge rate.

DPDD - Daily energy requirement.

EL - Current elevation.

EL1 - Elevation at beginning of month.

EL2 - Elevation at beginning of day.

EL3 - Elevation at beginning of day.

ELC - Modified elevation.

ELINC(JJ,NJX) - Elevation increment for modification of actual elevation.

ENERGY - Daily energy generation.

EVAP - Daily evaporation.

F1 - Flow rate at control point one.

F2 - Flow rate at control point two.

TABLE XI (Continued)

FRAC(JJ,1) - Fraction of the inflow rate used as total discharge rate between TPP and DISPT(JJ,1).

FRAC(JJ,2) - Fraction of the inflow rate used as total discharge rate between DISPT(JJ,1) and DISPT(JJ,2).

FRAC(JJ,3) - Fraction of the inflow rate used as total discharge rate between above DISPT(JJ,2).

FIT - Function subroutine; binary search-linear interpolation for general usage.

HP - Instantaneous horsepower.

HRS - Hours necessary to meet daily energy requirement.

INFLO1 - Daily intervening flow at control point one.

INFLO2 - Daily intervening flow at control point two.

IPOWER - Decision variable.

IU - Number of generating units at the reservoir.

JMON - Number corresponding to the month (1-JAN, 2-FEB, ...).

JX - Number of generation units being used.

JXX - Number of generation units being used.

JY - Day counter.

MD(J) - Number of days in month J.

MDJ - Number of days in the current month.

MON(J) - Array in which the month names are stored.

NDBUG - Decision variable.

MWHMIN(JJ) - Minimum daily energy requirement.

NJX - JX-1

NMON - Number corresponding to first month of data set where 1-JAN, 2-FEB, ...

NDUMP - Decision variable.

TABLE XI (Continued)

NUNIT(JJ) - Number of generating units at reservoir.

PD(J) - Monthly energy demand.

PO - Instantaneous power.

S1 - Stage height at control point one.

S2 - Stage height at control point two.

TPP(JJ,J) - Top of power pool per month.

TWC - Tailwater change determined when spill is necessary.

U - Monthly energy requirement.

VOL - Current volume.

VOL1 - Volume at beginning of a day.

Calendar Variables

JJJ - Counting variable.

KAL(J,1) - Day number of first day in month (Monday = 1, etc.).

KAL(J,2) - Number of day of month on which first holiday falls.

KAL(J,3) - Number of day of month on which second holiday falls.

MARK - Counting variable (day counter).

NWKHL - Control variable (=1, weekend/holiday; = 0, weekday).

Average Daily Elevation - Daily Elevation Change - Performance Index Variables

DACNG - Accumulative elevation change (for RMF).

ELEVAT - Average daily elevation.

EL - Elevation at start of day.

TABLE XI (Continued)

ELEV - Elevation at end of day.

ELMIN - Minimum elevation for total month (for RMF).

ELMAX - Maximum elevation for total month (for RMF).

IDADVT - DADWVT (integer value).

IDAVST - DAVIST (integer value).

ILAND - R11 (integer value).

IWATER - R22 (integer value).

IDOWN - R33 (integer value).

PI - Monthly performance returned to OPTMZR.

PI1 - Monthly performance index, less generation benefit.

P1 - Normalized land and water visitation (daily).

P2 - Normalized downstream visitation (daily).

P3 - Normalized water quality benefit.

P4 - Normalized navigation benefit.

P5 - Normalized flood penalty (daily).

P11 - Monthly summing variable for recreation benefit.

P33 - Monthly summing variable for water quality benefit.

P44 - Monthly summing variable for navigation benefit.

P55 - Monthly summing variable for flood penalty benefit.

PIDA - Daily normalized performance index, less GENBN.

RMF - Reservoir management factor.

R11 - Summing variable for monthly visitors, land.

R22 - Summing variable for monthly visitors, water.

R33 - Summing variable for monthly visitors, downstream visitors.

TABLE XI (Continued)

SUM - Total number of reservoir and downstream visitors for one month.

UNHRS - Total number of hours generated in one day.

UNHRS1 - Average number of hours generated/day during month.

W1 - Reservoir visitation weighting factor.

W2 - Downstream visitation weighting factor.

W3 - Water quality benefit weighting factor.

W4 - Navigation benefit weighting factor.

W5 - Flood penalty weighting factor.

W6 - Generation benefit weighting factor.

W7 - Revenue weighting factor.

W8 - Visitors weighting factor.

Generation and Revenue Benefit Variables

DEM - Monthly Demand (same as PD(J) in RESMOD).

GEN - Energy generated for month (same as ACC in RESMOD)

GENBN - Generation benefit.

REVDEM - Dollar/MWH of revenue for meeting any part of demand.

REVBUY - Dollar/MWH bought for difference between DEM and GEN.

REVDMP - Dollar/MWH of revenue for generation over demand.

REV - Net revenue.

6. Subroutine GEM

DIS - Power discharge rate.

TABLE XI (Continued)

DISTIM - Conversion factor, units are (seconds run - acre feet)/ft^3.

FLOW - Inflow to reservoir.

HRS - Number of hours of generation.

VDOT - Change in volume in acre-feet.

Y - Updated volume in acre-feet.

7. Subroutine FIT

GG(M) - Ordinate values corresponding to YY(M).

IDIF - Arithmetic difference between KUT and KETCH.

JJ - Reference to reservoir number (1 for this program).

JUT - Intermediate variable, midrange calculated from KUT and IDIF.

KETCH - Current low data point of abscissa.

KUT - Current high data point of abscissa.

M - Number of pairs of abscissa-ordinate pairs.

Y - Abscissa value for which an ordinate value will be interpolated.

YY(M) - Abscissa values forming the range of search.

8. Subroutine BENMOD

Input Variables to BENMOD

BN(12,24) - Data for recreation model.

DAV - Daily discharge (turbine and spill).

IVFLO1 - Intervening flow at dam.

IVFLO2 - Intervening flow past Gore.

KAL(12,3) - Calendar data.

M - Number of month.

TABLE XI (Continued)

NAV - Data for recreation model.

PI - Monthly performance index.

STAGE1 - Stage height at Gore.

STAGE2 - Stage height at Van Buren.

WQ(12,20) - Data for water quality model.

Variables for Recreation Model

ADJVST - Total number of weekday land and water-based visitors.

BN(M,1) - Low elevation visitation for land (monthly).

BN(M,2) - Optimum land visitation (monthly).

BN(M,3) - High elevation visitation for land (monthly).

BN(M,4) - Low elevation visitation for water (monthly).

BN(M,5) - Optimum water visitation (monthly).

BN(M,6) - High elevation visitation for water (monthly).

BN(M,7) - Minimum elevation for optimum land visitation (monthly).

BN(M,8) - Maximum elevation for optimum land visitation (monthly).

BN(M,9) - Minimum elevation for optimum water visitation (monthly).

BN(M,10) - Maximum elevation for optimum water visitation (monthly).

BN(M,11) - Equivalent number of day in month.

BN(M,12) - Weekday-weekend/holiday factor.

BN(M,13) - Penalty (%) at low elevation change.

BN(M,14) - Penalty (%) at midpoint elevation change.

BN(M,15) - Penalty (%) at high elevation change.

TABLE XI (Continued)

BN(M,16) - Low discharge daily downstream visitation (%).

BN(M,17) - Midpoint discharge daily downstream visitation (%).

BN(M,18) - High discharge daily downstream visitation (%).

BN(M,19) - Low elevation change for elevation change penalty curve.

BN(M,20) - Midpoint elevation change for elevation change penalty curve.

BN(M,21) - High elevation change for elevation change penalty curve.

BN(M,22) - Lowest discharge rate for downstream visitation curve.

BN(M,23) - Midpoint discharge rate for downstream visitation curve.

BN(M,24) - Highest discharge rate for downstream visitation curve.

DIR - Daily discharge below dam (turbines + spill + intervening flow).

DAVIST - Number of daily visitors above dam.

DELEV - Daily elevation change.

DADWVT - Daily downstream visitors.

ELEVAT - Daily average elevation.

HIGEL - Highest elevation for visitor curves (monthly).

LOWEL - Lowest elevation for visitor curves (monthly).

NWKHL - Weekday-weekend/holiday index (1=holiday/weekend, 0=weekday.)

R1 - Daily visitors for land.

R2 - Daily visitors for water.

RAVTWA - Raw visitation for water (monthly).

RAVTLA - Raw visitation for land (monthly).

TABLE XI (Continued)

Variables for Water Quality Model

ALPHA1	- Weighting coefficient for D.O. in water quality benefit.
ALPHA2	- Weighting coefficient for D.S. in water quality benefit.
ALPHA3	- Weighting coefficient for temperature in water quality benefit.
BODST	- B.O.D. of reservoir or stream flow, auxiliary variable.
BODEF	- B.O.D. of intervening flow, auxiliary variable.
BODMIX	- B.O.D. of reservoir discharge or stream flow and intervening flow.
BODL	- Ultimate B.O.D.
BODS	- Ultimate B.O.D. corrected to DSTRA.
CFSS	- Stream flow or reservoir discharge, auxiliary variable.
CFSS	- Intervening flow rate, auxiliary variable.
DOSTAR	- Auxiliary variable for optimum D.O.
DORES	- D.O. of reservoir or stream flow, auxiliary variable.
DOEFFL	- D.O. of intervening flow, auxiliary variable.
DSTRT	- Predicted downstream temperature.
DSTRA	- Average downstream temperature.
DOMIX	- D.O. of reservoir discharge or stream flow and intervening flow.
DS	- D.S. of reservoir discharge or stream flow and intervening flow.
DODEF	- Streeter-Phelps D.O. deficit.
DO	- D.O. of stream at next control point.

TABLE XI (Continued)

DOSAT - Saturated D.O. value at DSTRA.

DOD - D.O. deficit of mixture.

DMTC - Downstream temperature correction factor.

L - Counting variable in water quality model.

RETM1 - First reach reach time.

RETM2 - Second reach reach time.

RETM - Reach time auxiliary variable.

RKPRU - K' corrected to DSTRA.

RKZPRM - K_2' corrected to DSTRA.

TMRES - Temperature of reservoir or stream flow, auxiliary variable.

TMRES - Temperature of intervening flow, auxiliary variable.

TMMIX - Temperature of mixture.

WAQL - Intermediate summing variable for WAQ.

WQTM - Intermediate temperature water quality variable.

WQDS - Intermediate D.S. water quality variable.

WQDO - Intermediate D.O. water quality variable.

WAQ - Water quality performance.

WQ(M,1) - D.O. of reservoir discharge.

WQ(M,2) - D.O. of intervening flow, first reach

WQ(M,3) - D.O. of optimum.

WQ(M,4) - B.O.D. of reservoir discharge.

WQ(M,5) - B.O.D. of intervening flow, first reach.

WQ(M,6) - Temperature of reservoir discharge.

WQ(M,7) - Temperature of intervening flow, first reach.

WQ(M,8) - Temperature of optimum.

TABLE XI (Continued)

WQ(M,9) - D.S. of reservoir discharge.

WQ(M,10) - D.S. of intervening flow, first reach.

WQ(M,11) - D.S. of optimum.

WQ(M,12) - Downstream temperature correction, first reach.

WQ(M,13) - K at 20°C.

WQ(M,14) - K_2' at 20°C.

WQ(M,15) - Downstream temperature correction, second reach.

WQ(M,16) - Unused.

WQ(M,17) - Temperature of intervening flow, second reach.

WQ(M,18) - D.O. of intervening flow, second reach.

WQ(M,19) - B.O.D. of intervening flow, second reach.

WQ(M,20) - D.S. of intervening flow, second reach.

Navigation Model Variables

CFSMN3 - CFS minimum, auxiliary variable.

CFSLO3 - CFS lo-optimum, auxiliary variable.

CFSHI3 - CFS hi-optimum, auxiliary variable.

CFSMX3 - CFS maximum, auxiliary variable.

KK - Counting variable in navigation model.

NAVBN - Navigation benefit.

NAV(M,1) - CFS minimum for first reach.

NAV(M,2) - CFS lo-optimum for first reach.

NAV(M,3) - CFS hi-optimum for first reach.

NAV(M,4) - CFS maximum for first reach.

NAV(M,5) - CFS minimum for second reach.

TABLE XI (Continued)

NAV(M,6) - CFS lo-optimum for second reach.

NAV(M,7) - CFS hi-optimum for second reach.

NAV(M,8) - CFS maximum for second reach.

NAVBN1 - Summing variable.

RNAV - Check variable to determine if second reach used.

Flood Model Variables

FLDBN1 - Summing variable.

FLDST1 - Flood stage at first control point.

FLDST2 - Flood stage at second control point.

FLDMX1 - Maximum expected stage at first control point.

FLDMX2 - Maximum expected stage at second control point.

FLDST - Flood stage, auxiliary variable.

FLDMX - Maximum expected stage, auxiliary variable.

FLDBN - Flood penalty.

KKK - Counting variable.

TABLE XII

PROGRAM LISTING

```
      EXTERNAL OPTMZR,CRVFIT,UHILO,RESMOD,FIT,GEM,BENMOD
      INTEGER DAILY
      REAL INFLOW,NAV,NAVBN,NAVBN1,ITVFL1,ITVFL2,LOWEL
      REAL MWHMIN
      COMMON/A1/MD(31),PD(12),INFLOW(4,12),PANEVP(4,12)
      COMMON/A2/COT(12),DUMPP(12)
      COMMON/A3/EFF(4),ADTIM(4),ELST(4)
      COMMON/A4/TPP(4,12),BPP(4,12)
      COMMON/A5/STAGE1(4,24),DISST1(4,24),STAGE2(4,24),DISST2(4,24)
      COMMON/A6/DPD(12,31),DINFLO(4,12,31),DPANEV(4,12,31)
      COMMON /A8/DAILY
      COMMON/A9/DIS
      COMMON/A10/JY
      COMMON/A11/FRAC(4,3),ELINC(4,3)
      COMMON/A13/DISPWR(4,24),ELRESD(4,24),HPRES(4,24),ELRESP(4,24)
      COMMON/A21/DISPT(4,2),NUNIT(4)
      COMMON/A30/TAIL(4,24),SPILL(4,24)
      COMMON/A32/ITVFL1(4,12),ITVFL2(4,12),DITFL1(4,12,31),
     1DITFL2(4,12,31)
      COMMON/A33/NMON,NDBUG,LIST,MODIPI
      COMMON /OPT/XNXT(12),USTAR(12,5),PSTAR(5,2)
      COMMON /SAV/DMD(12),F(12),E(12)
      COMMON /GRID/GRD(5)
      COMMON /STFIN/MSTRT,MFIN
      COMMON/FITTER/ELRES(4,24),VRES(4,24)
      COMMON /UMI/MWHMIN(4)
      COMMON/BEN1/BN(12,24),WQ(12,20),NAV(12,8),KAL(12,3)
      COMMON/BEN2/DELEV,NWKHL,ELEVAT
      COMMON/BEN5/ALPHA1,ALPHA2,ALPHA3,RETM1,RETM2
      COMMON/BEN6/FLDST1,FLDMX1,FLDST2,FLDMX2
      COMMON/BEN7/DAVIST,DADWVT,WAQ,NAVBN,FLDBN,GENBN,RMF
      COMMON/BEN8/W1,W2,W3,W4,W5,W6,W7,W8
      COMMON /BEN9/SUM,REV
      COMMON/BEN10/LOWEL,HIGEL
      COMMON/REVGEN/REVDEM,REVBUY,REVDMP
      DIMENSION MON(12)
      DATA MON/4HJAN ,4HFEB ,4HMAR ,4HAPR ,4HMAY ,4HJUN ,4HJUL ,4HAUG ,4
     $HSEP ,4HOCT ,4HNOV ,4HDEC /
C
C     NSTAGE IS COUNTING VARIABLE FOR MONTHLY DATA READ STATEMENTS.
C
      NSTAGE = 1
C
C     KK CORRESPONDS TO THE NUMBER OF RESERVOIRS IN THE SYSTEM.
C
      KK=1
C
C     NMON IS THE NUMBER OF THE MONTH CORRESPONDING TO THE FIRST MONTH
C     OF THE DATA SET, WHERE  1 CORRESPONDS TO JANU, 2 CORRESPONDS TO
C     FEBR, ............. , AND 12 CORRESPONDS TO DECEMBER.
C
C     NDBUG CONTROLS EXTRA WRITE STATEMENTS.
C
C     LIST CONTROLS OUTPUT FORMAT.
C
C     MODIPI CONTROLS TYPE OF PERFORMANCE INDEX.
C
      READ(5,2)NMON,NDBUG,LIST,MODIPI
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                 MAIN               DATE = 73275         18/03/12

              C
              C        READ-IN OF NTOTSG CORRESPONDING TO TOTAL NO. OF MONTHS OF DATA
              C        TO BE USED. ALSO READ-IN OF THE VARIABLE ,DAILY,WHICH DENOTES
              C        THAT DAILY DATA INFORMATION IS TO BE READ IN ALSO.
              C
 0040                READ(5,987)NTOTSG,DAILY
 0041         987    FORMAT(I2,7X,I2)
              C
              C      READ IN 1ST & LAST DATA SET TO BE OPTIMIZED,MSTRT & MFIN.
              C
 0042                READ(5,987)MSTRT,MFIN
              C
              C      READ IN THE NUMBER OF DAYS IN EACH MONTH.
              C
 0043                READ(5,2)(MD(J),J=1,NTOTSG)
 0044              2 FORMAT(12I3)
              C
              C      READ IN THE MONTHLY ENERGY DEMANDS IN MWH.
              C
 0045                READ(5,3)(PD(J),J=1,NTOTSG)
 0046              3 FORMAT(4E20.7)
              C
              C
              C      READ IN THE MONTHLY AVERAGE INFLOW,IN THOUSANDS OF CFS
              C
 0047          1010  DO 200 JJ = 1 , KK
 0048           200  READ(5,4)(INFLOW(JJ,J),J=1,NTOTSG)
 0049              4 FORMAT(8F10.0)
              C
              C      READ IN THE MONTHLY AVERAGE EVAPORATION  IN FEET.
              C
 0050                DO201JJ=1,KK
 0051           201  READ(5,4)(PANEVP(JJ,J),J=1,NTOTSG)
              C
              C
              C      READ IN THE MONTHLY AVERAGE INTERVENING FLOWS IN THOUSANDS OF CFS
              C      JUST BELOW DAM (ITVFL1) AND BELOW CONTROL POINT 1 (ITVFL2)
              C
 0052                DO 3001 JJ=1,KK
 0053                READ(5,3)(ITVFL1(JJ,J),J=1,NTOTSG)
 0054          3001  READ(5,3)(ITVFL2(JJ,J),J=1,NTOTSG)
              C
              C
              C      READ IN THE EFFICIENCY OF THE GENERATORS AT THE VARIOUS RESERVOIRS
              C
 0055                READ(5,4)(EFF(JJ),JJ=1,KK)
              C
              C      READ IN THE NUMBER OF HOURS BEFORE AN ADDITIONAL UNIT IS USED AT
              C      THE VARIOUS RESERVOIRS
              C
 0056                READ(5,4)(ADTIM(JJ),JJ=1,KK)
              C
              C
              C
              C      READ IN THE MONTHLY VALUES OF THE TOP AND BOTTOM OF THE POWER
              C      POOL AT THE VARIOUS RESERVOIRS.
              C
 0057                DO 206 JJ = 1 , KK
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                  MAIN                DATE = 73275          18/03/12
 0058            206 READ(5,4)(TPP(JJ,J), BPP(JJ,J), J = 1 , NTOTSG)
             C
             C       READ IN THE STARTING ELEVATION IN FEET ABOVE SEA LEVEL AT TNE
             C       VARIOUS RESERVOIRS.
             C
 0059                READ(5,4)(ELST(JJ),JJ=1,KK)
             C
             C       READ IN THE UPPER DISCHARGE CONTROL POINTS AT THE VARIOUS RESERVOIRS
             C
 0060                DC 1023 JJ = 1 , KK
 0061           1023 READ(5,4)(DISPT(JJ,J),J=1,2)
             C
             C       REAC IN THE NUMBER OF UNITS AT THE VARIOUS RESERVOIRS.
             C
 0062                READ(5,2)(NUNIT(JJ),JJ=1,KK)
             C
             C       READ IN THE ELEVATION INCREMENTS TO MODIFY THE ELEVATION BEFORE
             C       INTERROGATING THE HORSEPOWER VS ELEVATION OR DISCHARGE RATE VS
             C       ELEVATION CURVE FITS WHEN MORE THAN ONE GENERATING UNIT IS BEING
             C       USED AT THE VARIOUS RESERVCIRS.
             C
 0063                DO 5 JJ = 1 , KK
 0064                NRANGE = NUNIT(JJ) - 1
 0065              5 READ(5,4)(ELINC(JJ,JX),JX=1,NRANGE)
             C
             C       READ IN THE FRACTIONAL AMCUNT OF THE INFLOW TO BE DISCHARGED
             C       AT THE UPPER CISCHARGE CONTROL POINTS.
             C
 0066                DO 55 JJ = 1 , KK
 0067             55 READ(5,4)(FRAC(JJ,J),J = 1 , 3)
             C
             C       READ IN GRID PCINT ELEVATICNS IN FEET
             C
 0068                READ(5,1199)(GRD(J),J=1,5)
 0069           1199 FORMAT(5E10.5)
             C
             C          REAC IN MINIMUM DAILY ENERGY TO BE GENERATED.
             C          (EQUIVALENT NUMBER OF ONE UNIT HRS MUST BE LESS THAN ADTIM)
             C
 0070                READ(5,789)(MWHMIN(JJ),JJ=1,KK)
 0071           789  FORMAT(4E10.3)
             C
             C       REAC-IN OF VOLUME-ELEVATION DATA FOR THE VARIOUS RESERVOIRS.
             C
 0072                DO 56 JJ = 1 , KK
 0073             56 READ(5,5060)(ELRES(JJ,J),J=1,24),(VRES(JJ,L),L=1,24)
 0074           5060 FORMAT(8E10.5)
             C
             C       REAC-IN OF STAGE DISCHARGE DATA AT THE FIRST CONTROL POINT FOR
             C       THE VARIOUS RESERVOIRS.
             C
 0075                DO 50 JJ = 1 , KK
 0076             50 READ(5,5060)(STAGE1(JJ,J),J=1,24),(DISST1(JJ,L),L=1,24)
             C
             C       REAC-IN OF STAGE-DISCHARGE DATA AT THE SECOND CONTROL POINT FOR
             C       THE VARIOUS RESERVOIRS.
             C
 0077                DO 51 JJ = 1 , KK
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                 MAIN                DATE = 73275          18/03/12

 0078            51 READ(5,5060)(STAGE2(JJ,J),J=1,24),(DISST2(JJ,L),L=1,24)
               C
               C     READ-IN OF TAILWATER CORRECTED POWER DISCHARGE-ELEVATION DATA FOR
               C     THE VARIOUS RESERVOIRS.
               C
 0079               DO 52 JJ = 1 , KK
 0080            52 READ(5,5060)(DISPWR(JJ,J),J=1, 8),(ELRESD(JJ,L),L=1, 8)
               C
               C     READ-IN OF TAILWATER CORRECTED HORSEPOWER-ELEVATION DATA FOR
               C     THE VARIOUS RESERVOIRS.
               C
 0081               DO 53 JJ = 1 , KK
 0082            53 READ(5,5061)(HPRES(JJ,J),J=1,6),(ELRESP(JJ,L),L=1,6)
 0083          5061 FORMAT(6E10.5)
               C
               C     READ-IN OF TAILWATER-DISCHARGE DATA, TO BE USED WHEN SPILL IS NECESSARY,
               C     FOR THE VARIOUS RESERVOIRS.
               C
 0084               DO 54 JJ = 1 , KK
 0085            54 READ(5,5060)(TAIL(JJ,J),J=1,16),(SPILL(JJ,L),L=1,16)
               C
               C    READ-IN OF RECREATION MODEL DATA, BN(M,N) ARRAY
               C
 0086               READ(5,122)((BN(M,N),N=1,24),M=1,NTOTSG)
 0087           122 FORMAT(8E10.2/8E10.2/8E10.2)
               C
               C
               C     READ-IN OF LOWEST AND HIGHEST ELEVATIONS CONSIDERED BY THE
               C     RECREATION MODEL, LOWEL AND HIGEL
               C
 0088               READ(5,123)LOWEL,HIGEL
 0089           123 FORMAT(2E10.3)
               C
               C
               C     READ-IN OF WATER QUALITY DATA, WQ(M,N)
               C
 0090               READ(5,180)((WQ(M,N),N=1,20),M=1,NTOTSG)
 0091           180 FORMAT(8E10.3/8E10.3/4E10.3)
               C
               C
               C     READ-IN OF WATER QUALITY PERFORMANCE WEIGHTING COEFFICIENTS
               C     AND REACH TIMES
               C
 0092               READ(5,181)ALPHA1,ALPHA2,ALPHA3,RETM1,RETM2
 0093           181 FORMAT(5F10.3)
               C
               C
               C     READ-IN OF NAVIGATION MODEL DATA, NAV(M,N) ARRAY
               C
 0094               READ(5,190)((NAV(M,N),N=1,8),M=1,NTOTSG)
 0095           190 FORMAT(8E10.3)
               C
               C
               C     READ-IN OF FLOOD PENALTY MODEL DATA
               C
 0096               READ(5,220)FLDST1,FLDMX1,FLDST2,FLDMX2
 0097           220 FORMAT(4E10.3)
               C
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                  MAIN            DATE = 73275          18/03/12

               C
               C    READ-IN OF CALENDAR DATA, KAL(M,N) ARRAY
               C
 0098               READ(5,101)((KAL(M,N),N=1,3),M=1,NTOTSG)
 0099            101 FORMAT(3I5)
               C
               C**
               C**     READ-IN OF REVDEM,REVBUY,REVDMP GENERATION COSTS
               C**
 0100               READ(5,3993)REVDEM,REVBUY,REVDMP
 0101          3993 FORMAT(3F20.3)
               C
               C    READ IN WEIGHTING COEFFICIENTS OF MAIN PERFORMANCE INDEX.
               C
 0102               READ(5,512)W1,W2,W3,W4,W5,W6,W7,W8
 0103          512  FORMAT(8E10.3)
 0104               IF(DAILY)1022,1022,1011
               C
               C
               C    READ IN THE DAILY INFLOW IN THOUSANDS OF CUBIC FEET PER SECOND.
               C
 0105           1011 DO1016JJ=1,KK
 0106               DO1016J=NSTAGE,NTOTSG
 0107               MDJ=MD(J)
 0108           1016 READ(5,1012)(DINFLD(JJ,J,JX),JX=1,MDJ)
               C
               C    READ IN THE DAILY EVAPORATION IN FEET PER DAY.
               C
 0109               DO1018JJ=1,KK
 0110               DO1018J=NSTAGE,NTOTSG
 0111               MDJ=MD(J)
 0112           1018 READ(5,1012)(DPANEV(JJ,J,JX),JX=1,MDJ)
               C    READ IN THE DAILY INTERVENING FLOWS IN THOUSANDS OF CUBIC
               C    FEET PER SECOND AT THE VARIOUS RESERVOIRS.
 0113               DO 3002 JJ=1,KK
 0114               DO 3002 J=1,NTOTSG
 0115               MDJ=MD(J)
 0116               READ(5,1012)(DITFL1(JJ,J,JY),JY=1,MDJ)
 0117           3002 READ(5,1012)(DITFL2(JJ,J,JY),JY=1,MDJ)
 0118           1012 FORMAT(8E10.4)
 0119           1022 CONTINUE
 0120               CALL OPTMZR
 0121               STOP
 0122               END
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                  MAIN                DATE = 73275          18/03/12

C***********************************************************************************
C***********************************************************************************
C***********************************************************************************
C***                                                                            ***
C***                               SUBROUTINE OPTMZR                            ***
C***                                                                            ***
C***********************************************************************************
C***********************************************************************************
      SUBROUTINE OPTMZR
      COMMON /OPT/XNXT(12),USTAR(12,5),PSTAR(5,2)
      COMMON /A1/MX(31),DMD(12),FLW(4,12),PEVP(4,12)
      COMMON/A3/YYY(4),ZZZ(4),SI(4)
      COMMON /GRID/X(5)
      COMMON /STFIN/MSTRT,MFIN
      COMMON /BEN9/SUM,REV
      COMMON/A33/NMON,NDBUG,LIST,MODIPI
      DIMENSION MON(12)
      DATA MON/4HJAN ,4HFEB ,4HMAR ,4HAPR ,4HMAY ,4HJUN ,4HJUL ,4HAUG ,4
     1HSEP ,4HOCT ,4HNOV ,4HDEC /
      SUM1=0.0
      REV1=0.0
      XI=SI(1)
      M=1
      N=0
      MFINI=MFIN
      JX=0
      LHOLD=LIST
      IF((LIST.EQ.1).OR.(LIST.EQ.2))GO TO 3
      LHOLD=LIST
      LIST=5
3     CONTINUE
      IF(MSTRT.LT.MFIN)GO TO 35
      KMAX=13-MSTRT+MFIN
      GO TO 36
35    KMAX=MFIN-MSTRT+1
36    CONTINUE
C***********************************************************************************
C***                                                                            ***
C***                                                                            ***
C***      AREA --- NORMAL OPTIMIZER RUNS PROCEED HERE. STAGES KMAX-1            ***
C***      THROUGH TO STAGE 2. OUTPUT OF USTAR AND PSTAR ARE MADE HERE AF-       ***
C***      TER EACH STAGE IS COMPLETED.                                          ***
C***                                                                            ***
C***                                                                            ***
C***********************************************************************************
100   IF(MSTRT.GT.MFIN)GO TO 37
      MONTH=MFIN-N
      GO TO 38
37    MONTH=MFINI-JX
      JX=JX+1
      IF(MONTH.GE.1)GO TO 38
      MONTH=12
      JX=1
      MFINI=12
38    CONTINUE
111   K=KMAX-N
      KMAX2=KMAX-2
      IF(K.EQ.1)GO TO 200
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                 OPTMZR             DATE = 73275          18/03/12

                  CALL UHILO(X(M),MONTH,UH,UM,UL,K,M,1)
                  IF(LIST.EQ.5)GO TO 631
                  WRITE(6,1123)UL,UM,UH
         1123     FORMAT(1H0,'UL,UM,UH--BEFCR CRVFIT',T26,3F12.4)
         631      CONTINUE
                  IF(UH.LT.-.00004)GO TO 212
                  IF(UH.GE.0.0)GO TO 213
                  UH=0.0
                  GO TO 213
         212      WRITE(6,211)
         211      FORMAT(1H0,'CONTROL WAS NEGATIVE')
                  RETURN
         213      CONTINUE
                  XGRD=X(M)
                  CALL RESMOD(UH,X(M),1,MONTH,XNXT(M),P)
                  X(M)=XGRD
                  L=1
                  GO TO 1001
         101      PH=P
                  IF((ABS(UH-UL)).GT.10.0)GO TO 216
                  UL=UH
                  UM=UH
                  PL=PH
                  PM=PH
                  GO TO 217
         216      CONTINUE
                  XGRD=X(M)
                  CALL RESMOD(UM,X(M),1,MONTH,XNXT(M),P)
                  X(M)=XGRD
                  L=2
                  GO TO 1001
         102      PM=P
                  XGRD=X(M)
                  CALL RESMOD(UL,X(M),1,MONTH,XNXT(M),P)
                  X(M)=XGRD
                  L=3
                  GO TO 1001
         103      PL=P
         217      CONTINUE
                  IF(LIST.EQ.5)GO TO 632
                  WRITE(6,703)PH,PM,PL
         703      FORMAT(1H0,'PH = ',T8,F10.2,T19,'PM = ',T24,F10.2,T35,'PL = ',T40,
                 $F10.2)
         632      CONTINUE
                  CALL CRVFIT(UL,UM,UH,PL,PM,PH,USTAR(K,M),PSTAR(M,2))
                  IF(LIST.EQ.5)GO TO 633
                  WRITE(6,43)USTAR(K,M),PSTAR(M,2)
         43       FORMAT(1H0,'RETURNED FROM CRVFIT',T25,2F12.3)
         633      CONTINUE
                  IF((USTAR(K,M).EQ.UH).OR.(USTAR(K,M).EQ.UL))GO TO 89
                  IF(LIST.EQ.5)GO TO 634
                  WRITE(6,44)
         44       FORMAT(1H0,'CALLING THE MODEL')
         634      CONTINUE
                  XGRD=X(M)
                  CALL RESMOD(USTAR(K,M),X(M),1,MONTH,XNXT(M),P)
                  X(M)=XGRD
                  L=4
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                 OPTMZR             DATE = 73275          18/03/12
            GO TO 1001
      107   CONTINUE
            IF(LIST.EQ.5)GO TO 635
            WRITE(6,45)USTAR(K,M),P
      45    FORMAT(1H0,'RETURNED FROM MODEL',T25,2F12.2)
      635   CONTINUE
            IF((P.GE.PH).AND.(P.GE.PM).AND.(P.GE.PL))GO TO 50
            IF((PH.GT.PM).AND.(PH.GT.PL))GO TO 51
            IF((PM.GT.PH).AND.(PM.GT.PL))GO TO 52
            IF((PL.GT.PH).AND.(PL.GT.PM))GO TO 53
            GO TO 52
      51    USTAR(K,M)=UH
            PSTAR(M,2)=PH
            GO TO 89
      52    USTAR(K,M)=UM
            PSTAR(M,2)=PM
            GO TO 89
      53    USTAR(K,M)=UL
            PSTAR(M,2)=PL
            GO TO 89
      50    PSTAR(M,2)=P
      89    CONTINUE
      90    M=M+1
            IF(M.LE.5)GO TO 111
            N=N+1
            M=1
      C************************************************************************
      C***                                                                  ***
      C***                                                                  ***
      C***     AREA 1000 --- NORMAL PSTAR UPDATE PROCEDURE HERE.            ***
      C***                                                                  ***
      C***                                                                  ***
      C************************************************************************
      1000  GO TO 438
      1001  IF(K.EQ.KMAX)GO TO 437
            DO 222 J=1,4
            IF((XNXT(M).GE.X(J)).AND.(XNXT(M).LE.X(J+1)))GO TO 400
      222   CONTINUE
            WRITE(6,8)
      8     FORMAT(1H0,'AREA 1000 CHECKSTOP - UPDATE')
            RETURN
      400   P=P+PSTAR(J,1)+(PSTAR(J+1,1)-PSTAR(J,1))*((XNXT(M)-X(J))/(X(J+1)-X
           $(J)))
      437   CONTINUE
            GO TO(101,102,103,107),L
      438   DO 333 J=1,5
      333   PSTAR(J,1)=PSTAR(J,2)
            WRITE(6,11)(X(KT),KT=1,5)
            WRITE(6,12)K,(USTAR(K,L),L=1,5)
            WRITE(6,13)K,(PSTAR(L,1),L=1,5)
      11    FORMAT(1H0,'ELEVATION',T25,F6.2,T36,F6.2,T47,F6.2,T58,F6.2,T69,F6.
           $2)
      12    FORMAT(1H0,'USTAR STAGE',T14,I2,T20,5F11.2)
      13    FORMAT(1H0,'PSTAR STAGE',T14,I2,T20,5F11.2)
            GO TO 100
      C************************************************************************
      C***                                                                  ***
      C***                                                                  ***
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                 OPTMZR            DATE = 73275         18/03/12

C***     AREA 2000 --- FINAL PSTAR UPDATE PROCEDURE HERE                        ***
C***                                                                            ***
C***                                                                            ***
C*******************************************************************************
 2000 DO 555 J=1,4
      IF((XNXT(1).GE.X(J)).AND.(XNXT(1).LE.X(J+1)))GO TO 500
  555 CONTINUE
      WRITE(6,9)
    9 FORMAT(1H0,'AREA 2000 CHECKSTOP - UPDATE')
      RETURN
  500 P=P+PSTAR(J,1)+(PSTAR(J+1,1)-PSTAR(J,1))*((XNXT(1)-X(J))/(X(J+1)-X
     $(J)))
      GO TO(104,105,106,108),L
C*******************************************************************************
C***                                                                            ***
C***                                                                            ***
C***     AREA 200 --- OPTIMIZATION OF INITIAL ELEVATION AND BEGINNING OF        ***
C***     FORWARD RUN STARTS HERE. OUTPUT OF FORECAST PERFORMANCE, RUN PER-      ***
C***     FORMANCE, INITIAL ELEVATION ,XI,DEMANDS PER MONTH, CONTROLS AND        ***
C***     ELEVATION ARE MADE HERE.                                               ***
C***                                                                            ***
C***                                                                            ***
C*******************************************************************************
  200 MONTH=MSTRT
      CALL UHILO(XI,MONTH,UH,UM,UL,K,M,1)
      IF(UH.LT.-.00004)GO TO 212
      IF(UH.GE.0.0)GO TO 214
      UH=0.0
  214 CONTINUE
      XGRD=XI
      CALL RESMOD(UH,XI,1,MONTH,XNXT(M),P)
      XI=XGRD
      L=1
      GO TO 2000
  104 PH=P
      IF((ABS(UH-UL)).GT.10.0)GO TO 218
      UL=UH
      UM=UH
      PL=PH
      PM=PH
      GO TO 219
  218 CONTINUE
      XGRD=XI
      CALL RESMOD(UM,XI,1,MONTH,XNXT(M),P)
      XI=XGRD
      L=2
      GO TO 2000
  105 PM=P
      XGRD=XI
      CALL RESMOD(UL,XI,1,MONTH,XNXT(M),P)
      XI=XGRD
      L=3
      GO TO 2000
  106 PL=P
  219 CONTINUE
      IF(LIST.EQ.5)GO TO 636
      WRITE(6,703)PH,PM,PL
  636 CONTINUE
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                OPTMZR            DATE = 73275          18/03/12

                 CALL CRVFIT(UL,UM,UH,PL,PM,PH,USTAR(K,1),PSTAR(1,2))
                 IF(LIST.EQ.5)GO TO 637
                 WRITE(6,43)USTAR(K,1),PSTAR(1,2)
       637       CONTINUE
                 IF((USTAR(K,1).EQ.UH).OR.(USTAR(K,1).EQ.UL))GO TO 75
                 IF(LIST.EQ.5)GO TO 638
                 WRITE(6,44)
       638       CONTINUE
                 XGRD=XI
                 CALL RESMOD(USTAR(K,1),XI,1,MONTH,XNXT(M),P)
                 XI=XGRD
                 IF(LIST.EQ.5)GO TO 639
                 WRITE(6,45)USTAR(K,1),PSTAR(1,2)
       639       CONTINUE
                 L=4
                 GO TO 2000
       108       CONTINUE
                 IF((P.GE.PH).AND.(P.GE.PM).AND.(P.GE.PL))GO TO 71
                 IF((PH.GT.PM).AND.(PH.GT.PL))GO TO 72
                 IF((PM.GT.PH).AND.(PM.GT.PL))GO TO 73
                 IF((PL.GT.PH).AND.(PL.GT.PM))GO TO 74
                 GO TO 73
       72        USTAR(K,1)=UH
                 PSTAR(1,2)=PH
                 GO TO 70
       73        USTAR(K,1)=UM
                 PSTAR(1,2)=PM
                 GO TO 70
       74        USTAR(K,1)=UL
                 PSTAR(1,2)=PL
                 GO TO 70
       71        PSTAR(1,2)=P
       70        CONTINUE
       75        WRITE(6,9083)
       9083      FORMAT(1H1,'************************************************
                $*********************************************',/,1H ,'***',T10,'
                $                FORWARD RUNS ARE COMMENCING FROM THIS POINT ONWARD
                $',T97,'****',/,1H ,'**********************************************
                $*************************************************')
                 LIST=LHOLD
                 XGRD=XI
                 CALL RESMOD(USTAR(K,1),XI,1,MONTH,XNXT(M),P)
                 XI=XGRD
                 PRUN=P
                 SUM1=SUM1+SUM
                 REV1=REV1+REV
                 DO 666 J=1,4
                 IF((XNXT(K).GE.X(J)).AND.(XNXT(K).LE.X(J+1)))GO TO 777
       666       CONTINUE
                 WRITE(6,25)
       25        FORMAT(1H0,'CHECKSTOP FINAL RUN 1 ST. ENTRY')
                 RETURN
       777       K=K+1
                 IF(MSTRT.GT.MFIN)GO TO 61
       63        MONTH=MSTRT+1
                 GO TO 62
       61        IF(MSTRT.LT.12)GO TO 63
                 MONTH=1
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                 OPTMZR              DATE = 73275          18/03/12

  62     CONTINUE
         USTAR(K,1)=USTAR(K,J)+(USTAR(K,J+1)-USTAR(K,J))*((XNXT(K-1)-X(J))/
        $(X(J+1)-X(J)))
         M=M+1
         XGRD=XNXT(K-1)
         CALL RESMOD(USTAR(K,1),XNXT(K-1),1,MONTH,XNXT(M),P)
         XNXT(K-1)=XGRD
         PRUN=PRUN+P
         SUM1=SUM1+SUM
         REV1=REV1+REV
         IF(KMAX2.EQ.0)GO TO 1991
         JX=1
         MSTART=MSTRT
         DO 999 JJ=1,KMAX2
         DO 888 J=1,4
         IF((XNXT(K).GE.X(J)).AND.(XNXT(K).LE.X(J+1)))GO TO 990
  888    CONTINUE
         WRITE(6,26)M
  26     FORMAT(1H0,I2,T5,'STAGE CHECKSTP - FINAL RUN')
         RETURN
  990    K=K+1
         IF(MSTRT.GT.MFIN)GO TO 64
         MONTH=MSTART+K-1
         GO TO 65
  64     JX=JX+1
         MONTH=MSTART+JX
         IF(MONTH.LE.12)GO TO 65
         JX=0
         MONTH=1
         MSTART=1
  65     CONTINUE
         USTAR(K,1)=USTAR(K,J)+(USTAR(K,J+1)-USTAR(K,J))*((XNXT(K-1)-X(J))/
        $(X(J+1)-X(J)))
         M=M+1
         XGRD=XNXT(K-1)
         CALL RESMOD(USTAR(K,1),XNXT(K-1),1,MONTH,XNXT(M),P)
         XNXT(K-1)=XGRD
         PRUN=PRUN+P
         SUM1=SUM1+SUM
         REV1=REV1+REV
  999    CONTINUE
  1991   CONTINUE
         ISUM=SUM1
         WRITE(6,27)PSTAR(1,2)
         WRITE(6,33)PRUN
         WRITE(6,4900)ISUM
         WRITE(6,4901)REV1
  4900   FORMAT(1H0,14HTOTAL VISITORS,11X,I11)
  4901   FORMAT(1H0,19HTOTAL POWER REVENUE,6X,F11.2)
         WRITE(6,47)XI
         MST=MSTRT-1+NMON
         IF(MST-12)755,755,756
  756    MST=MST-12
  755    MFN=MFIN-1+NMON
         IF(MFN-12)757,757,758
  758    MFN=MFN-12
  757    CONTINUE
         IF(MST.LT.MFN)GO TO 1892
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                OPTMZR            DATE = 73275          18/03/12

              WRITE(6,81)(MON(L),L=MST,12),(MON(M),M=1,MFN)
              GO TO 1893
       1892   WRITE(6,81)(MON(L),L=MST,MFN)
       1893   CONTINUE
              IF(MSTRT.LT.MFIN)GO TO 1992
              WRITE(6,49)(FLW(1,L),L=MSTRT,12),(FLW(1,M),M=1,MFIN)
              WRITE(6,48)(DMD(L),L=MSTRT,12),(DMD(M),M=1,MFIN)
              GO TO 1993
       1992   WRITE(6,49)(FLW(1,M),M=MSTRT,MFIN)
              WRITE(6,48)(DMD(L),L=MSTRT,MFIN)
       1993   CONTINUE
              WRITE(6,31)(USTAR(I,1),I=1,KMAX)
              WRITE(6,32)(XNXT(J),J=1,KMAX)
         27   FORMAT(1H0,T25,'STAGES IN INCREASING ORDER BEGINNING FROM BETWEEN
             $STAGE ONE AND TWO',/,1H0,'FORECAST PERFORMANCE',T25,F12.4)
         33   FORMAT(1H0,'RUN-PERFORMANCE',T25,F12.4)
         31   FORMAT(1H0,'CONTROLS VALUES',T21,12F9.2)
         32   FORMAT(1H0,'RESERVOIR ELEVATION',T21,12F9.2)
         47   FORMAT(18H0INITIAL ELEVATICN,T21,F8.2)
         48   FORMAT(16H0MONTHLY DEMANDS,T21,12F9.2)
         49   FORMAT(13H0INFLOW RATES,T21,12F9.2)
         81   FORMAT(1H0,/,T26,A4,T35,A4,T44,A4,T53,A4,T62,A4,T71,A4,T80,A4,T89,
             $A4,T98,A4,T107,A4,T116,A4,T125,A4)
              RETURN
              END
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                MAIN              DATE = 73275          18/03/12

      C***********************************************************************
      C***********************************************************************
      C***********************************************************************
      C***                                                                 ***
      C***                         SUBROUTINE CRVFIT                       ***
      C***                                                                 ***
      C***********************************************************************
      C***********************************************************************
            SUBROUTINE CRVFIT(X1,X2,X3,Y1,Y2,Y3,U,P)
            IF((Y1.EQ.Y2).AND.(Y1.EQ.Y3))GO TO 62
            IF(X1.EQ.X3)GO TO 49
            IF(X1.EQ.X2)GO TO 60
            IF(X2.EQ.X3)GO TO 61
            A=(Y1/((X1-X2)*(X1-X3)))+(Y2/((X2-X1)*(X2-X3)))+(Y3/((X3-X1)*(X3-X
           $2)))
            B=(Y1/((X1-X2)*(X1-X3)))*(X2+X3)+(Y2/((X2-X1)*(X2-X3)))*(X1+X3)+(Y
           $3/((X3-X1)*(X3-X2)))*(X1+X2)
            C=(Y1/((X1-X2)*(X1-X3)))*X2*X3+(Y2/((X2-X1)*(X2-X3)))*X1*X3+(Y3/((
           $X3-X1)*(X3-X2)))*X1*X2
            IF(A.EQ.0.0)GO TO 29
            U=B/(2.0*A)
            P=A*(U*U)-(B*U)+C
            IF(U.LT.X3)GO TO 10
            U=X3
            P=Y3
            GO TO 30
      10    IF(U.GT.X1)GO TO 30
            U=X1
            P=Y1
            GO TO 30
      29    P=Y1
            U=X1
      30    IF((P.GE.Y1).AND.(P.GE.Y2).AND.(P.GE.Y3))GO TO 50
            IF(Y1.GT.P)P=Y1
            IF(Y2.GT.P)P=Y2
            IF(Y3.GT.P)P=Y3
            IF(P.EQ.Y1)U=X1
            IF(P.EQ.Y3)U=X3
            IF(P.EQ.Y2)U=X2
            GO TO 50
      60    IF(Y2.GT.Y3)GO TO 62
      63    U=X3
            P=Y3
            GO TO 50
      62    U=X2
            P=Y2
            GO TO 50
      61    IF(Y2.GT.Y1)GO TO 62
            U=X1
            P=Y1
            GO TO 50
      49    U=X1
            P=Y1
      50    CONTINUE
            RETURN
            END
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                MAIN              DATE = 73275          18/03/12

      C**********************************************************************
      C**********************************************************************
      C***                                                                ***
      C***                       SUBROUTINE UHILO                         ***
      C***                                                                ***
      C**********************************************************************
      C**********************************************************************
            SUBROUTINE UHILO(EL,MONTH,UH,UM,UL,K,M,NR)
            REAL MWHMIN
            COMMON /SAV/DMD(12),F(12),E(12)
            COMMON /A13/DPR(4,24),ELD(4,24),HPR(4,24),ELP(4,24)
            COMMON /A1/MX(31),DMWH(12),FL(4,12),EV(4,12)
            COMMON/A3/EFF(4),A(4),EXZ(4)
            COMMON/A33/NMON,NDBUG,LIST,MODIPI
            COMMON /GRID/GRD(5)
            COMMON /FITTER/ELRES(4,24),VRES(4,24)
            COMMON /A21/DDD(4,2),NUNIT(4)
            COMMON /UMI/MWHMIN(4)
            DO 1000 N=1,12
            DMD(N)=DMWH(N)
            F(N)=FL(1,N)
            E(N)=EV(1,N)
       1000 CONTINUE
            UMAXGD=NUNIT(NR)*0.746*EFF(NR)*FIT(EL,ELP,HPR,6,NR)
            MSECS=MX(MONTH)*4.32E04
            F(MONTH)=2.0*MSECS*F(MONTH)
            UMAX=24.0*MX(MONTH)*UMAXGD
            UMINIM=MWHMIN(NR)*MX(MONTH)
       19   CONTINUE
            IF(K.EQ.1)UMAX=((2.0*MSECS)*NUNIT(NR)*0.746*EFF(NR)*FIT(EL,ELP,HPR
           $,6,NR))/3600.0
            ELADJ=EL-E(MONTH)
            V=4.356E04*FIT(ELADJ,ELRES,VRES,24,NR)
            VM1=4.356E04*FIT(GRD(1),ELRES,VRES,24,NR)
            VM5=4.356E04*FIT(GRD(5),ELRES,VRES,24,NR)
            AVB=(V+F(MONTH))-VM1
            IF(AVB.LE.0.0)GO TO 10
            DSCHG=FIT(EL,ELD,DPR,8,NR)
            SECNDS=AVB/(DSCHG*NUNIT(NR))
            HP=NUNIT(NR)*FIT(EL,ELP,HPR,6,NR)
            UH=(EFF(NR)*0.746*HP*SECNDS)/3600.0
            GO TO 105
       10   UH=0.0
       105  CONTINUE
            IF(UH.GT.UMAX)UH=UMAX
            IF(MODIPI.EQ.2)GO TO 101
       100  IF(UH.GT.(1.5*DMD(MONTH)))UH=1.5*DMD(MONTH)
       101  SECNDS=0.0
            AVT=(V+F(MONTH))-VM5
            IF(AVT.LE.0.0)GO TO 110
            DSCHG=FIT(EL,ELD,DPR,8,NR)
            SECNDS=AVT/(DSCHG*NUNIT(NR))
            HP=NUNIT(NR)*FIT(EL,ELP,HPR,6,NR)
            UL=(EFF(NR)*0.746*HP*SECNDS)/3600.0
       200  CONTINUE
            IF(UL.LE.UH)GO TO 360
            UH=UL
            IPATH=3

            GO TO 350
       110  UL=UMINIM
       360  IPATH=1
       350  CONTINUE
            IF(UL.LT.UMINIM)UL=UMINIM
            UM=(UH+UL)/2.0
            RETURN
            END
```

TABLE XII (Continued)

```
C***************************************************************************
C
      SUBROUTINE RESMOD(U,EL1,JJ,J,EL,PI)
C
C     RESMOD IS THE RESERVOIR MODEL CONTROL PROGRAM.
C
      INTEGER DAILY
      REAL INFLOW,NAV,NAVBN,NAVBN1,ITVFL1,ITVFL2,IVFLO1,IVFLO2
      COMMON/A1/MD(31),PD(12),INFLOW(4,12),PANEVP(4,12)
      COMMON/A2/COT(12),DUMPP(12)
      COMMON/A3/EFF(4),ADTIM(4),ELST(4)
      COMMON/A4/TPP(4,12),BPP(4,12)
      COMMON/A5/STAGE1(4,24),DISST1(4,24),STAGE2(4,24),DISST2(4,24)
      COMMON/A6/DPD(12,31),DINFLO(4,12,31),DPANEV(4,12,31)
      COMMON /A8/DAILY
      COMMON/A9/DIS
      COMMON/A10/JY
      COMMON/A11/FRAC(4,3),ELINC(4,3)
      COMMON/A13/DISPWR(4,24),ELRESD(4,24),HPRES(4,24),ELRESP(4,24)
      COMMON/A21/DISPT(4,2),NUNIT(4)
      COMMON/A30/TAIL(4,24),SPILL(4,24)
      COMMON/A32/ITVFL1(4,12),ITVFL2(4,12),DITFL1(4,12,31),
     1DITFL2(4,12,31)
      COMMON/A33/NMON,NDBUG,LIST,MODIPI
      COMMON/FITTER/ELRES(4,24),VRES(4,24)
      COMMON/BEN1/BN(12,24),WQ(12,20),NAV(12,8),KAL(12,3)
      COMMON/BEN2/DELEV,NWKHL,ELEVAT
      COMMON/BEN3/R1,R2
      COMMON/BEN7/DAVIST,DADWVT,WAQ,NAVBN,FLDBN,GENBN,RMF
      COMMON /UMI/MWHMIN(4)
      COMMON/BEN8/W1,W2,W3,W4,W5,W6,W7,W8
      COMMON /BEN9/SUM,REV
      COMMON/REVGEN/REVDEM,REVBUY,REVDMP
      DIMENSION MON(12)
C
      DATA MON/4HJAN ,4HFEB ,4HMAR ,4HAPR ,4HMAY ,4HJUN ,4HJUL ,4HAUG ,4
     1HSEP ,4HOCT ,4HNOV ,4HDEC /
      JJJ=0
      MARK=KAL(J,1)-1
      DACNG=0.0
      ELMIN=680.0
      ELMAX=0.0
      PI1=0.0
      R11=0.0
      R22=0.0
      R33=0.0
      P11=0.0
      P33=0.0
      P44=0.0
      P55=0.0
      UNHRS1=0.0
      DAV1=0.0
      SUM=0.0
      EL = EL1
      ELEV=EL1
      DISDMP=0.0
      ACC=0.0
      IPOWER=0
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21              RESMOD              DATE = 73275          18/03/12

            KW=6
            X=0.
            JMON = J + NMON - 1
            IF(JMON-12)32,32,33
         33 JMON = JMON - 12
         32 NDUMP = 0
            IF(LIST.EQ.5)GC TO 640
            WRITE(6,526)
        526 FORMAT(1H0,'****************************************************')
      640   CONTINLE
            IF((LIST.EQ.1).OR.(LIST.EQ.3).OR.(LIST.EQ.5))GO TC 505
            WRITE(6,522)
            WRITE(6,523)
            WRITE(6,524)
        522 FORMAT(1H0,T11,'INIT.')
        523 FORMAT(1X,T10,'DAILY',T21,'DAILY',T33,'DAILY',T45,'DAILY',T56,'NO.
           $',T63,'HRS.',T70,'DELTA',T82,'DAILY',T93,'DAILY',T103,'DAILY',T113
           $,'NAV.',T120,'FLOOD',T128,'DAILY')
        524 FORMAT(1X,T3,'DATE',T10,'ELEV.',T22,'DIS.',T33,'DEMAND',T46,'GEN.
           $',T55,'UNITS',T63,'GEN.',T70,'ELEV.',T81,'R-VIST.',T92,'DN-VIST.',
           $T102,'W-QUAL.',T113,'BEN.',T121,'BEN.',T129,'P.I.')
        505 IU = NUNIT(JJ)
            VOL = FIT(EL,ELRES,VRES,24,JJ)
            MDJ = MD(J)
            DPDD = U/MDJ
            IF(DAILY)30,30,5
         30 EVAP=PANEVP(JJ,J)*0.7
            DADJIN = INFLOW(JJ,J)
            IVFLO1 = ITVFL1(JJ,J)
            IVFLO2 = ITVFL2(JJ,J)
          5 DO 4 JX = 1 , IU
            NJX = JX - 1
            ELC = EL
            IF(JX.GT.1)ELC = EL - ELINC(JJ,NJX)
            HP = JX * FIT(ELC,ELRESP,HPRES,6,JJ)
            PO = HP*0.746*EFF(JJ)
            HRS = DPDD/PO
            IF(HRS-ADTIM(JJ))10,10,4
          4 CONTINUE
            JX = IU
         10 JXX=JX
            DO 3 JY = 1 , MDJ
            NUMBER=1
            EL3 = EL
            VOL1 = VOL
            IF(DAILY)47,47,48
         48 DADJIN = DINFLO(JJ,J,JY)
            EVAP = DPANEV(JJ,J,JY)*0.7
            IVFLO2 = DITFL2(JJ,J,JY)
            IVFLO1 = DITFL1(JJ,J,JY)
         47 IF(NDBUG)49,49,1062
       1062 WRITE(6,1085) MON(JMON) , JY , DPDD
       1085 FORMAT(///5X,6HDATE  ,A4,3X,I2,10X,15HENERGY DEMAND  ,E12.4/)
       1098 WRITE(6,1086) EL , VOL
       1086 FORMAT(5X,'THE INITIAL ELEVATION IS  ',E12.4,5X,'THE INITIAL VOLUM
           1E IS  ',E12.4/)
         49 IF(EL-TPP(JJ,J))1049,1049,16
       1049 IF(DPDD)1048,1048,11
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                RESMOD            DATE = 73275          18/03/12

 1048 DIS=0.0
      PO=0.0
      HP=0.0
      HRS=0.0
      JX = 0
      EL = EL3
      VOL = VOL1
      NUMBER=NUMBER+1
      IF(NUMBER.GE.3)GO TO 1036
      GO TO 1054
 1036 WRITE(6,1037)
 1037 FORMAT(5X,'CHECKSTOP IN RESMOD - ELEVATION CHANGE DUE TO EVAPORATI
     1ON GREATER THAN CHANGE DUE TO INFLOW')
      STOP
   11 JX=JXX
      NJX = JX - 1
      ELC = EL
      IF(JX.GT.1)ELC = EL - ELINC(JJ,NJX)
      HP = JX * FIT(ELC,ELRESP,HPRES,6,JJ)
      PO = HP * 0.746 * EFF(JJ)
      HRS = DPDD/PO
      IF(HRS-24.0)23,23,24
   24 HRS = 24.0
   23 DIS = JX * FIT(ELC,ELRESD,DISPWR,8,JJ)
 1054 CALL GEM(VOL,DADJIN,DIS,HRS)
      EL = FIT(VOL,VRES,ELRES,24,JJ)
      EL = EL - EVAP
      IF(BPP(JJ,J)-EL)1095,1095,1048
   16 IF(EL-DISPT(JJ,1))17,18,18
   17 DIS1 = FRAC(JJ,1)*DADJIN
      GO TO 12
   18 DIS1 = FRAC(JJ,2) * DADJIN
      GO TO 12
   12 JX=IU
      NJX = JX - 1
      ELC = EL
      IF(JX.GT.1)ELC = EL - ELINC(JJ,NJX)
      DIS=JX*FIT(ELC,ELRESD,DISPWR,8,JJ)
      IF(DIS1-DIS)13,13,14
   13 NDUMP = 1
      GO TO 1042
   14 EL2 = EL
      DISDMP = DIS1 - DIS
      TWC=FIT(DISDMP,SPILL,TAIL,16,JJ)
      EL = EL - TWC
      ELC = EL
      IF(JX.GT.1)ELC = EL - ELINC(JJ,NJX)
      DIS=JX*FIT(ELC,ELRESD,DISPWR,8,JJ)
      IF(DIS1-DIS)1042,1042,1
    1 DISDMP = DIS1 - DIS
      TWC=FIT(DISDMP,SPILL,TAIL,16,JJ)
      EL = EL2 - TWC
      DIS=DIS1
      ELC = EL
      IF(JX.GT.1)ELC = EL - ELINC(JJ,NJX)
 1042 HP = JX * FIT(ELC,ELRESP,HPRES,6,JJ)
      PO = HP*0.746*EFF(JJ)
      HRS = 24.0
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                  RESMOD              DATE = 73275          18/03/12

            CALL GEM(VOL,DADJIN,DIS,HRS)
            EL = FIT(VOL,VRES,ELRES,24,JJ)
            EL = EL - EVAP
            IF(EL-DISPT(JJ,2))42,42,41
         41 EL = EL3
            VOL = VOL1
            DIS1 = FRAC(JJ,3) * DADJIN
            GO TO 12
         42 IF(TPP(JJ,J)-EL)22,21,21
         21 IPOWER = 1
         22 IF(NDUMP)43,43,1094
         43 IF(NDBUG)1095,1095,1044
       1044 WRITE(6,1045)
       1045 FORMAT(/5X,59H********************** DUMP STRATEGY ***************
           1*******/)
            WRITE(6,1046) HP , DIS
       1046 FORMAT(10X,4HHP  ,E12.4,10X,5HDIS  ,E12.4//)
       1094 NDUMP = 0
       1095 ENERGY = PO * HRS
            ACC = ACC + ENERGY
            IF(NDBUG)31,31,1097
       1097 WRITE(6,1039) JX , HRS
       1039 FORMAT(5X,10HUNITS ON  ,I2,23X,5HHRS  ,E12.4/)
            WRITE(6,1087) PO , ENERGY
       1087 FORMAT(5X,18HPOWER GENERATED   ,E12.4,5X,18HENERGY GENERATED  ,E12
           1.4/)
         31 DAV = (DIS * HRS ) / 24.0
            DAV1=DAV1+DAV
            F1 = DAV + IVFLO1
            F2 = F1 + IVFLC2
            S1 = FIT(F1,DISST1,STAGE1,24,JJ)
            S2 = FIT(F2,DISST2,STAGE2,24,JJ)
      C*************************************************************************
      C*************************************************************************
      C***                                                                  ***
      C***                     CALENDAR SECTION                             ***
      C***                                                                  ***
      C*************************************************************************
      C*************************************************************************
            N=JY
        120 IF(JJJ.EQ.1)GO TO 110
            MARK=MARK+1
            GO TO (109,109,109,109,109,108,108),MARK
        110 MARK=MARK+1
            IF(MARK.EQ.6)GO TO 108
            IF(MARK.EQ.7)GO TO 108
            GO TO 109
        108 NWKHL=1
            IF(MARK.NE.7)GO TO 112
            MARK=0
            JJJ=1
            GO TO 112
        109 NWKHL=0
        112 IF(KAL(J,2).EQ.JY)GO TO 113
            IF(KAL(J,3).EQ.JY)GO TO 113
            GO TO 114
        113 NWKHL=1
      114   CONTINUE
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                    RESMOD              DATE = 73275          18/03/12

             C***********************************************************************
             C***********************************************************************
             C***                                                                 ***
             C***  THIS SECTION DETERMINES THE AVERAGE DAILY ELEVATION AND THE DAILY ***
             C***  ELEVATION CHANGE. TERMS OF THE RESERVIOR MANAGEMENT FACTOR ARE    ***
             C***  ALSO DETERMINED                                                   ***
             C***                                                                 ***
             C***********************************************************************
             C***********************************************************************
                   ELEVAT=(EL+ELEV)/2.0
                   DELEV=EL-ELEV
                   DACNG=DACNG+ABS(DELEV)
                   IF(EL.GT.ELMIN)GO TO 500
                   ELMIN=EL
               500 IF(EL.LT.ELMAX)GO TO 501
                   ELMAX=EL
               501 CONTINUE
                   CALL BENMOD(J,PI,S1,S2,DAV,IVFLO1,IVFLO2)
             C***********************************************************************
             C***********************************************************************
             C***                                                                 ***
             C***  THIS SECTION COMPUTES THE PERFORMANCE INDEX ON A DAILY BASIS AND SUMS ***
             C***  THESE OVER THE ENTIRE MONTH .                                     ***
             C***                                                                 ***
             C***********************************************************************
             C***********************************************************************
                   R11=R11+R1
                   R22=R22+R2
                   R33=R33+CADWVT
                   P1=(DAVIST/(BN(J,2)+BN(J,5)))
                   P2=(DADWVT/(BN(J,16)*(BN(J,2)+BN(J,5))))
                   P3=WAQ/MD(J)
                   P4=(NAVBN/MD(J))
                   P5=(FLDBN/MD(J))
                   P11=P11+W1*P1+W2*P2
                   P33=P33+P3
                   P44=P44+P4
                   P55=P55+P5
                   PIDA=W1*P1+W2*P2+W3*P3+W4*P4+W5*P5
                   SUM=SUM+DAVIST+DADWVT
                   PI1=PIDA+PI1
                   IDADVT=DADWVT
                   IDAVST=DAVIST
                   UNHRS=JX*HRS
                   UNHRS1=UNHRS1+UNHRS
                   IF((LIST.EQ.1).OR.(LIST.EQ.3).OR.(LIST.EQ.5))GO TO 504
                   WRITE(6,525)MON(JMON),JY,ELEV,DAV,DPDD,ENERGY,JX,UNHRS,DELEV,IDAVS
                  $T,IDADVT,WAQ,NAVBN,FLDBN,PI1
               525 FORMAT(1H0,A4,T6,I2,T10,F6.2,T17,F9.2,T31,F9.2,T43,F9.2,T56,I2,T62
                  $,F5.2,T70,F5.2,T78,I9,T90,I9,T103,F6.3,T112,F5.2,T120,F5.2,T128,
                  $F5.2)
               504 ELEV=EL
                   IF(IPOWER)1195,1195,1190
              1190 IF(JY-MDJ)1191,1195,1195
             1191  IF(ACC-U)1193,1194,1194
             1193  DPDD=(U-ACC)/(MD(J)-JY)
                   IF(DPDD.LT.MWHMIN(JJ))GO TO 1194
                   DO 1196 JX = 1 , IU
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                    RESMOD               DATE = 73275           18/03/12

      NJX = JX - 1
      ELC = EL
      IF(JX.GT.1)ELC=EL-ELINC(JJ,NJX)
      HP = JX * FIT(ELC,ELRESP,HPRES,6,JJ)
      PO = HP * 0.746 * EFF(JJ)
      HRS = DPDD/PO
      IF(HRS-24.0)1222,1222,1333
 1333 HRS = 24.0
 1222 IF(HRS-ADTIM(JJ))1197,1197,1196
 1196 CONTINUE
      JX = IU
 1197 JXX = JX
      GO TO 1195
 1194 DPDD = MWHMIN(JJ)
      JX = 1
      JXX = 1
1195  IPOWER=0
    3 CONTINUE
      RMF=ABS((DACNG/MD(J))*(ELMAX-ELMIN))
      ILAND=R11
      IWATER=R22
      IDOWN=R33
      UNHRS1=UNHRS1/MD(J)
      DAV1=DAV1/MD(J)
      DEM=PD(J)
      GEN=ACC
C*******************************************************************************
C*******************************************************************************
C***  THIS SECTION DETERMINES THE BENEFIT OF GENERATION IN RELATION TO       ***
C***  DEMAND IN MEGAWATTS                                                    ***
C***                                                                         ***
C*******************************************************************************
C*******************************************************************************
      IF(GEN-0.0)301,301,302
  301 GENBN=0.0
      GO TO 310
  302 IF(GEN-DEM)303,304,305
  303 GENBN=(1.0/DEM)*GEN
      GO TO 310
  304 GENBN=1.0
      GO TO 310
  305 GENBN=(0.25/DEM)*GEN+1.0
  310 IF(DEM-GEN)311,311,312
311   REV=DEM*REVDEM+(GEN-DEM)*REVDMP
      GO TO 313
312   REV=DEM*REVDEM-(DEM-GEN)*REVBUY
313   CONTINUE
      PI=W6*GENBN+PI1
      IF(LIST.EQ.5)GO TO 1701
      WRITE(6,8907)MON(JMON)
      WRITE(6,8908)EL1,EL
      WRITE(6,8901)
      WRITE(6,8902)
      WRITE(6,8903)
      WRITE(6,8904)INFLOW(JJ,J),PD(J),U,ACC,DAV1,UNHRS1,IWATER,ILAND,
     $IDOWN,P11,P44,P55
      WRITE(6,8906)P33
      WRITE(6,8905)GENBN,REV,PI,RMF
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                 RESMOD            DATE = 73275          18/03/12

           8907 FORMAT(1HO,23HTHE MONTH BEING RUN IS ,A4)
           8908 FORMAT(1HO,27HTHE INITIAL ELEVATION IS = ,F10.3,T40,
               $25HTHE FINAL ELEVATION IS = ,F10.3)
          8901  FORMAT(1HO,T5,3HAVG,T15,7HMONTHLY,T25,9HOPTIMIZER,T37,6HENERGY,T47
               $,9HAVG-DAILY,T60,9HAVG-DAILY,T73,5HTOTAL,T84,5HTOTAL,T95,5HTOTAL,
               $T106,5HTOTAL,T116,5HTCTAL,T126,5HTCTAL)
          8902  FORMAT(1H ,T3,6HINFLOW,T15,6HDEMAND,T26,7HCONTROL,T38,4HGEN.,T47,
               $9HDISCHARGE,T60,8HGEN-TIME,T73,5HWATER,T84,4HLAND,T95,7HDOWNSTRM,
               $T106,5HRECR.,T116,4HNAV.,T126,5HFLOCO)
          8903  FORMAT(1H ,11H(THOUS-CFS),T16,5H(MWH),T27,5H(MWH),T37,5H(MWH),T46,
               $11H(THOUS-CFS),T60,9H(UNIT-HR),T72,8HVISITORS,T83,8HVISITORS,T94,
               $8HVISITJRS,T105,7HBENEFIT,T115,7HBENEFIT,T124,7HBENEFIT)
          8904  FORMAT(1HO,T3,F6.3,T14,F8.2,T26,F8.2,T35,F8.2,T49,F6.3,T61,F4.1,
               $T73,I6,T84,I6,T95,I6,T106,F5.3,T116,F5.3,T126,F5.3)
          8905  FORMAT(1HO,1X,16HPOWER BENEFIT = ,F10.3,T30,16HPOWER REVENUE =$,
               $F10.2,T60,16HTOTAL BENEFIT = ,F10.2,T90,6HRMF = ,F10.3)
          8906  FORMAT(1HO,2X,5HWATER,/,1X,7HQUALITY,/,3X,F4.2)
          1701  GO TO(551,552,553,554),MODIPI
          551   PI=PI
                GO TO 521
          552   PI=REV
                GO TO 521
          553   PI=SUM
                GO TO 521
          554   PI=W7*PEV+W8*SUM
            521 CONTINUE
                U=ACC
                RETURN
                END
```

TABLE XII (Continued)

```
FORTRAN IV G LEVEL  21                MAIN                DATE = 73275          18/03/12

C***********************************************************************
C
C
      SUBROUTINE GEM(Y,FLOW,DIS,HRS)
      COMMON/A33/NMON,NDBUG,LIST,MODIPI
C
C     GEM PERFORMS AN EULER INTEGRATION.
C
C
C
      KW=6
C
C     FLOW IS THE EXPECTED INFLOW RATE.
C
      DISTIM = ( HRS * 3600. ) / 43560.
      VDOT = FLOW * 1.983471 - DIS * DISTIM
      IF(NDBUG)19,19,20
   20 WRITE(KW,21) FLOW , DIS , VDOT
   21 FORMAT(5X,13HINFLOW RATE   ,E12.4,3X,16HDISCHARGE RATE   ,E12.4,3X,1
     15HVOLUME CHANGE   ,E12.4/)
C
   19 Y = Y + VDOT
      RETURN
      END
```

```
FORTRAN IV G LEVEL  21                FIT                 DATE = 73275          18/03/12

      FUNCTION FIT(Y,YY,GG,M,JJ)
      DIMENSION YY(4,M),GG(4,M)
      IF((Y.GE.YY(JJ,1)).AND.(Y.LE.YY(JJ,M)))GO TO 20
      WRITE(6,10)Y
 10   FORMAT(51H0**** VALUE GIVEN TO FIT OUTSIDE RANGE OF PTS.      =,
     $F12.4,5H ****)
      STOP
 20   KETCH=1
      KUT=(M+1)/2
      IF(Y-YY(JJ,KUT)) 40,60,30
 30   KETCH=KUT
      KUT=M
 40   IDIF=KUT-KETCH
      IF(IDIF.EQ.1)GO TO 50
      JUT=KUT-(IDIF/2)
      IF(Y-YY(JJ,JUT)) 70,80,90
 70   KUT=JUT
      GO TO 40
 90   KETCH=JUT
      GO TO 40
   60 FIT = GG(JJ,KUT)
      GO TO 100
   80 FIT = GG(JJ,JUT)
      GO TO 100
   50 FIT=GG(JJ,KETCH)+((Y-YY(JJ,KETCH))/(YY(JJ,KETCH+1)-YY(JJ,KETCH)))*
     $(GG(JJ,KUT)-GG(JJ,KETCH))
 100  RETURN
      END
```

TABLE XII (Continued)

```
C*******************************************************************************
      SUBROUTINE BENMOD(M,PI,STAGE1,STAGE2,DAV,IVFLO1,IVFLO2)
      REAL NAV,NAVBN,NAVBN1,IVFLO1,IVFLO2,LOWEL
      COMMON/BEN1/BN(12,24),WQ(12,20),NAV(12,8),KAL(12,3)
      COMMON/BEN2/DELEV,NWKHL,ELEVAT
      COMMON/BEN3/R1,R2
      COMMON/BEN5/ALPHA1,ALPHA2,ALPHA3,RETM1,RETM2
      COMMON/BEN6/FLDST1,FLDMX1,FLDST2,FLDMX2
      COMMON/BEN7/DAVIST,DADWVT,WAQ,NAVBN,FLDBN,GENBN,RMF
      COMMON/BEN10/LOWEL,HIGEL
C*******************************************************************************
C*******************************************************************************
C***                                                                         ***
C***  BENEFIT MODEL                                                          ***
C***                                                                         ***
C*******************************************************************************
C*******************************************************************************
C*******************************************************************************
C*******************************************************************************
C***                                                                         ***
C***  CALCULATE VALUE OF RAW MONTHLY LAND VISITATION                         ***
C***                                                                         ***
C*******************************************************************************
C*******************************************************************************
      DIR=DAV+IVFLO1
      IF(ELEVAT-LOWEL)130,130,131
  130 RAVTLA = BN(M,1)
      GO TO 139
  131 IF(ELEVAT-BN(M,7))132,133,134
  132 RAVTLA=((BN(M,2)-BN(M,1))*ELEVAT+BN(M,1)*BN(M,7)
     1-LOWEL*BN(M,2))/(BN(M,7)-LOWEL)
      GO TO 139
  133 RAVTLA=BN(M,2)
      GO TO 139
  134 IF(ELEVAT-BN(M,8))135,135,136
  135 RAVTLA=BN(M,2)
      GO TO 139
  136 IF(ELEVAT-HIGEL)137,138,138
  137 RAVTLA=((BN(M,3)-BN(M,2))*ELEVAT+BN(M,2)*HIGEL
     1-BN(M,3)*BN(M,8))/(HIGEL-BN(M,8))
      GO TO 139
  138 RAVTLA=BN(M,3)
  139 CONTINUE
C*******************************************************************************
C*******************************************************************************
C***                                                                         ***
C***  RAW LAND BASED VISITATION HAS BEEN CALCULATED AS RAVTLA               ***
C***  CALCULATE RAW WATER BASED VISITATION                                   ***
C***                                                                         ***
C*******************************************************************************
C*******************************************************************************
      IF(ELEVAT-LOWEL)140,140,141
  140 RAVTWA=BN(M,4)
      GO TO 149
  141 IF(ELEVAT-BN(M,9))142,143,144
  142 RAVTWA=((BN(M,5)- BN(M,4))*ELEVAT+BN(M,4)*BN(M,9)
     1-LOWEL*BN(M,5))/(BN(M,9)-LOWEL)
      GO TO 149
```

TABLE XII (Continued)

```
  143 RAVTWA=BN(M,5)
      GO TO 149
  144 IF(ELEVAT-BN(M,10))145,145,146
  145 RAVTWA=BN(M,5)
      GO TO 149
  146 IF(ELEVAT-HIGEL)147,148,148
  147 RAVTWA=((BN(M,6)-BN(M,5))*ELEVAT+BN(M,5)*HIGEL
     1-BN(M,6)*BN(M,10))/(HIGEL-BN(M,10))
      GO TO 149
  148 RAVTWA=BN(M,6)
  149 CONTINUE
C***********************************************************************
C***********************************************************************
C***                                                                 ***
C***  BOTH LAND AND WATER BASED VISITATION ARE CALCULATED            ***
C***  CALCULATE TOTAL DAILY VISITORS                                 ***
C***                                                                 ***
C***********************************************************************
C***********************************************************************
      R1=RAVTLA/BN(M,11)
      R2=RAVTWA/BN(M,11)
      ADJVST=(RAVTLA+RAVTWA)/BN(M,11)
      IF(NWKHL.EQ.0)GO TO 150
      DAVIST=BN(M,12)*ADJVST
      GO TO 158
  150 DAVIST=ADJVST
C***********************************************************************
C***********************************************************************
C***                                                                 ***
C***  THIS GIVES DAVIST AS # OF DAILY VISITORS                       ***
C***                                                                 ***
C***********************************************************************
C***********************************************************************
C***  THIS SECTION APPLIES THE DAILY ELEVATION CHANGE PENALTY        ***
C***                                                                 ***
C***********************************************************************
C***********************************************************************
  158 IF(DELEV-BN(M,19))151,151,152
  151 DAVIST=DAVIST*BN(M,13)
      GO TO 160
  152 IF(DELEV-BN(M,20))153,154,155
  153 DAVIST=DAVIST*((BN(M,14)-BN(M,13))*DELEV+BN(M,13)*BN(M,20)
     1-BN(M,19)*BN(M,14))/(BN(M,20)-BN(M,19))
      GO TO 160
  154 DAVIST=DAVIST*BN(M,14)
      GO TO 160
  155 IF(DELEV-BN(M,21))156,157,157
  156 DAVIST=DAVIST*((BN(M,15)-BN(M,14))*DELEV+BN(M,14)*BN(M,21)
     1-BN(M,15)*BN(M,20))/(BN(M,21)-BN(M,20))
      GO TO 160
  157 DAVIST=DAVIST*BN(M,15)
  160 CONTINUE
      R1=(R1/(R1+R2))*DAVIST
      R2=DAVIST-R1
C***********************************************************************
C***********************************************************************
C***                                                                 ***
C***  THE DAILY AVERAGE VISITATION, DAVIST, HAS BEEN FOUND FOR ABOVE DAM    ***
```

TABLE XII (Continued)

```
C*******************************************************************************
C*******************************************************************************
C***                                                                         ***
C***  THE FOLLOWING COMPUTES THE DOWNSTREAM VISITATION
C***                                                                         ***
C*******************************************************************************
C*******************************************************************************
      IF(DIR-BN(M,22))161,161,162
  161 DADWVT=DAVIST*BN(M,16)
      GO TO 170
  162 IF(DIR-BN(M,23))163,164,165
  163 DADWVT=DAVIST*((BN(M,17)-BN(M,16))*DIR+BN(M,16)*BN(M,23)
     1-BN(M,17)*BN(M,22))/(BN(M,23)-BN(M,22))
      GO TO 170
  164 DADWVT=DAVIST*BN(M,17)
      GO TO 170
  165 IF(DIR-BN(M,24))166,167,167
  166 DADWVT=(DAVIST*((BN(M,18)-BN(M,17))*DIR+BN(M,17)*BN(M,24)
     1-BN(M,18)*BN(M,23)))/(BN(M,24)-BN(M,23))
      GO TO 170
  167 DADWVT=DAVIST*BN(M,18)
  170 CONTINUE
C*******************************************************************************
C*******************************************************************************
C***                                                                         ***
C***                           WATER QUALITY MODEL                           ***
C***                                                                         ***
C***  THIS MODEL COMPUTES THE WATER QUALITY AT A POINT DOWNSTREAM            ***
C***  FROM THE RESERVOIR AS DETERMINED BY A REACH TIME IN DAYS               ***
C***                                                                         ***
C*******************************************************************************
C*******************************************************************************
      WAQ=0.0
      DOSTAR=WQ(M,3)
      TMRES=WQ(M,6)
      TMEFF=WQ(M,7)
      DORES=WQ(M,1)
      DOEFFL=WQ(M,2)
      BODST=WQ(M,4)
      BODEF=WQ(M,5)
      DSSTM=WQ(M,9)
      DSEFFL=WQ(M,10)
      CFSS=DAV
      CFSEFF=IVFLO1
      DMTC=WQ(M,12)
      L=1
      RETM=RETM1
C*******************************************************************************
C*******************************************************************************
C***                                                                         ***
C***  THIS SECTION COMPUTES THE TEMPERATURE OF THE STREAM AT THE RESERVOIR   ***
C***  AND DOWNSTREAM AT THE NEXT CONTROL POINT                               ***
C***                                                                         ***
C*******************************************************************************
C*******************************************************************************
  182 TMMIX=(TMRES*CFSS+TMEFF*CFSEFF)/(CFSS+CFSEFF)
      DSTRT=TMMIX*DMTC
      DSTRA=(DSTRT+TMMIX)/2.0
```

TABLE XII (Continued)

```
      RKPRM=WQ(M,13)*(1.047**(DSTRA-20.0))
      RK2PRM=WQ(M,14)*(1.0159**(DSTRA-20.0))
C*******************************************************************************
C*******************************************************************************
C***                                                                         ***
C***  THIS SECTION COMPUTES THE DO OF THE MIXTURE                            ***
C***                                                                         ***
C*******************************************************************************
C*******************************************************************************
      DOMIX=(DORES*CFSS+DOEFFL*CFSEFF)/(CFSS+CFSEFF)
      DOSAT=(-9.832E-5)*(DSTRA)**3
     1+(8.6854E-3)*(DSTRA)**2
     2+(-.4055)*(DSTRA)
     3+14.61951
      IF(DOSTAR.EQ.0.0)DOSTAR=DOSAT
      DOD=DOSAT-DOMIX
      IF(DOD)186,186,187
  186 DOD=0.0
C*******************************************************************************
C*******************************************************************************
C***                                                                         ***
C***  THIS SECTION COMPUTES THE BOD AT THE RESERVOIR AND CORRECTS IT TO      ***
C***  THE STREAM TEMPERATURE AT THE NEXT CONTROL POINT                       ***
C***                                                                         ***
C*******************************************************************************
  187 BODMIX=(BODST*CFSS+BODEF*CFSEFF)/(CFSS+CFSEFF)
      IF(L.EQ.2)BODL=BODMIX
      IF(L.EQ.2)GO TO 184
      BODL=(BODMIX)/(1.0-10.0**(-WQ(M,13)*5.0))
  184 BODS=BODL*(1.0+0.02*(DSTRA-20.0))
C*******************************************************************************
C*******************************************************************************
C***                                                                         ***
C***  THIS SECTION COMPUTES THE DO OF THE STREAM CORRECTED FOR TEMPERATURE   ***
C***  AT THE NEXT CONTROL POINT.  (THE STREETER-PHELPS EQUATION)             ***
C***                                                                         ***
C*******************************************************************************
C*******************************************************************************
      DODEF=((RKPRM*BODS)/(RK2PRM-RKPRM))*(10.0**(-RKPRM*RETM)-10.0**
     1(-RK2PRM*RETM))+DOD*(10.0**(-RK2PRM*RETM))
      DO=DOSAT-DODEF
C*******************************************************************************
C*******************************************************************************
C***                                                                         ***
C***  THIS SECTION COMPUTES THE DS AT THE NEXT CONTROL POINT                 ***
C***                                                                         ***
C*******************************************************************************
C*******************************************************************************
  255 DS=(DSSTM*CFSS+DSEFFL*CFSEFF)/(CFSS+CFSEFF)
C*******************************************************************************
C*******************************************************************************
C***                                                                         ***
C***  WATER QUALITY PERFORMANCE INDEX                                        ***
C***                                                                         ***
C*******************************************************************************
C*******************************************************************************
      WQDO=ABS((DO-DOSTAR)/DOSTAR)
      WQDS=ABS((DS-WQ(M,11))/WQ(M,11))
```

TABLE XII (Continued)

```
      WQTM=ABS((DSTRT-WQ(M,8))/WQ(M,8))
      IF(WQDO.LT.1.0)GO TO 260
      WQDO=1.0
  260 IF(WQDS.LT.1.0)GO TO 261
      WQDS=1.0
  261 IF(WQTM.LT.1.0)GO TO 262
      WQTM=1.0
  262 WAQ=(ALPHA1*(1.0-WQDO)+ALPHA2*(1.0-WQDS)+ALPHA3*(1.0-WQTM))
     $/(ALPHA1+ALPHA2+ALPHA3)
      IF(RETM2.EQ.0.0)GO TO 201
      IF(L.EQ.2)GO TO 183
      TMRES=DSTRT
      TMEFF=WQ(M,17)
      DORES=DO
      DOEFFL=WQ(M,18)
      BODST=BODL-BODL*(1.0-10.0**(-RKPRM*RETM1))
      BODEF=(WQ(M,19))/(1.0-10.0**(-RKPRM*5.0))
      DSSTM=DS
      DSEFF=WQ(M,20)
      CFSS=CFSS+CFSEFF
      CFSEFF=IVFLO2
      WAQL=WAQ
      RETM=RETM2
      L=2
      GO TO 182
  183 CONTINUE
      WAQ=(WAQ+WAQL)/2.0
C*******************************************************************************
C*******************************************************************************
C***                                                                         ***
C***                   NAVIGATION BENEFIT MODEL                              ***
C***                                                                         ***
C*******************************************************************************
C*******************************************************************************
  201 NAVBN1=0.0
      RNAV=(NAV(M,5)+NAV(M,6)+NAV(M,7)+NAV(M,8))
      KK=1
      CFSMN3=NAV(M,1)
      CFSLO3=NAV(M,2)
      CFSHI3=NAV(M,3)
      CFSMX3=NAV(M,4)
      DSC=DIR
C*******************************************************************************
C*******************************************************************************
C***                                                                         ***
C***  DETERMINATION OF NAVIGATION BENEFIT                                    ***
C***                                                                         ***
C*******************************************************************************
C*******************************************************************************
  205 IF(DSC-CFSMN3)192,192,193
  192 NAVBN=0.0
      GO TO 202
  193 IF(DSC-CFSLO3)194,195,196
  194 NAVBN=(0.5*(DSC-CFSMN3))/(CFSLO3-CFSMN3)
      GO TO 202
  195 NAVBN=0.5
      GO TO 202
  196 IF(DSC-CFSHI3)197,197,198
```

TABLE XII (Continued)

```
  197 NAVBN=0.5
      GO TO 202
  198 IF(DSC-CFSMX3)199,200,200
  199 NAVBN=(0.5*(CFSMX3-DSC))/(CFSMX3-CFSHI3)
      GO TO 202
  200 NAVBN=0.0
  202 IF(RNAV.EQ.0.0)GO TO 206
      IF(KK.EQ.2)GO TO 204
      NAVBN1=NAVBN
      KK=2
      CFSMN3=NAV(M,5)
      CFSLO3=NAV(M,6)
      CFSHI3=NAV(M,7)
      CFSMX3=NAV(M,8)
      DSC=DIR+IVFLO2
      GO TO 205
  206 NAVBN=2.0*NAVBN
  204 NAVBN=NAVBN1+NAVBN
C***********************************************************************
C***********************************************************************
C***                                                                 ***
C***                     FLOOD BENEFIT MODEL                         ***
C***                                                                 ***
C***********************************************************************
C***********************************************************************
      FLDBN1=0.0
      KKK=1
      FLDST=FLDST1
      FLDMX=FLDMX1
      STAGE=STAGE1
C***********************************************************************
C***********************************************************************
C***                                                                 ***
C***  DETERMINE FLOOD BENEFIT                                        ***
C***                                                                 ***
C***********************************************************************
C***********************************************************************
  228 IF(STAGE-FLDST)222,222,223
  222 FLDBN=0.0
      GO TO 226
  223 IF(STAGE-FLDMX)224,224,225
  224 FLDBN=(-2.0*STAGE+2.0*FLDST)/(FLDMX-FLDST)
      GO TO 226
  225 FLDBN=-2.0
  226 IF(KKK.EQ.2)GO TO 227
      IF(STAGE2.EQ.0.0)GO TO 229
      FLDBN1=FLDBN
      KKK=2
      FLDST=FLDST2
      FLDMX=FLDMX2
      STAGE=STAGE2
      GO TO 228
  229 FLDBN=2.0*FLDBN
  227 FLDBN=FLDBN1+FLDBN
      RETURN
      END
```

TABLE XIII

DATA FOR SAMPLE RUN

```
12345678911111111112222222222333333333344444444445555555555666666666677777777778
         01234567890123456789012345678901234567890123456789012345678901234567890
  9  0  3  1
12        0
 1       12
 30 31 30 31 31 28 31 30 31 30 31 31
 5410.0              16870.0             21100.0             13070.0
 17930.0             14670.0             11730.0             8480.0
 6940.0              7620.0              5730.0              4110.0
    2.0863    4.787     2.5447    0.7742    1.9297    1.709     1.3626    0.7217
    1.745     0.7417    0.4513    0.2484
    0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
    0.0       0.0       0.0       0.0
 0.5                 3.5                 2.5                 0.015
 1.6                 0.015               0.015               0.007
 1.3                 0.005               0.005               0.005
  13.694             41.418              23.024              41.13
 22.687              19.100              20.615              6.36
  11.169             23.898              17.841              11.633
       .93
      10.0
 633.0     595.0     633.0     595.0     633.0     595.0     633.0     595.0
 633.0     595.0     633.0     595.0     633.0     595.0     633.0     595.0
 633.0     595.0     633.0     595.0     633.0     595.0     633.0     595.0
 622.9
     638.0     640.0
  2
      1.55
    0.0       0.8       1.5
595.0     606.0     617.0     628.0     640.0
 17.0
 580.0    584.0     588.0     592.0     596.0     600.0     604.0     608.0
 612.0    616.0     620.0     624.0     628.0     632.0     636.0     640.0
 644.0    648.0     652.0     656.0     660.0     664.0     668.0     672.0
 186.8    211.2     237.2     264.9     294.2     325.2     358.2     393.1
430.5     470.2     512.1     556.8     604.1     654.1     706.9     762.5
821.3     883.2     949.0     1010.8    1092.2    1169.2    1251.2    1338.2
1.0       2.52      2.62      2.7       2.775     2.9       3.0       3.08
3.325     4.25      5.2       5.9       6.9       8.1       8.5       9.2
9.55      9.88      10.56     10.9      11.6      12.2      13.9      14.9
0.0       .02       .03       .04       .05       .07       .09       .1
.3        .5        1.0       1.5       2.5       4.0       4.5       5.5
6.0       6.5       7.5       8.0       9.0       10.0      13.0      15.0
2.0       6.5       9.0       10.0      12.0      13.0      15.0      16.0
17.0      19.0      20.0      21.0      22.0      23.0      24.0      25.0
27.       28.       29.       31.       32.       33.       34.       36.
0.0       10.0      20.       25.       35.       42.5      58.5      67.5
78.5      101.25    115.      128.75    133.      160.      176.5     192.
225.      243.      265.      313.      345.      382.      425.      515.
1.6       1.615     1.64      1.65      1.695     1.659     1.62      1.49
589.11    600.63    617.66    625.67    635.3     640.0     645.63    666.48
17.2      19.5      23.       24.8      27.0      27.0
589.11    600.63    617.66    625.67    635.3     666.48
0.0       .75       1.4       2.0       2.6       3.15      3.63      4.1
4.51      4.93      5.3       5.68      6.0       6.3       6.6       6.85
0.0       1.0       2.0       3.0       4.0       5.0       6.0       7.0
8.0       9.0       10.0      11.0      12.0      13.0      14.       15.
31000.0   97000.0   38000.0   12000.0   140000.0  70000.0   627.0     633.0
628.0     632.0     49.0      2.0       0.90      1.0       0.90      0.07
0.03      0.01      -1.0      0.0       3.0       0.5       3.0       8.0
28000.0   80000.0   40000.0   15000.0   95000.0   67000.0   625.0     635.0
626.0     632.0     71.0      5.0       0.95      1.0       0.95      0.07
0.06      0.01      -1.0      0.0       3.0       0.5       3.0       8.0
```

TABLE XIII (Continued)

```
18000.0    50000.0    36000.0    14000.0    56000.0    41000.0    625.0      635.0
626.0      632.0      67.0       5.0        0.95       1.0        0.95       0.07
0.06       0.01       -1.0       0.0        3.0        0.5        3.0        8.0
11000.0    31000.0    25000.0    10000.0    50000.0    36000.0    625.0      635.0
626.0      632.0      74.0       5.0        0.95       1.0        0.95       0.07
0.06       0.01       -1.0       0.0        3.0        0.5        3.0        8.0
12000.0    31000.0    16000.0    9000.0     40000.0    28000.0    625.0      635.0
626.0      632.0      75.0       5.0        .95        1.0        .95        .07
.06        .01        -1.0       0.0        3.0        0.5        3.0        8.0
16000.0    40000.0    20000.0    12000.0    51000.0    37000.0    625.0      635.0
626.0      632.0      64.0       5.0        .95        1.0        .95        .07
.06        .01        -1.0       0.0        3.0        0.5        3.0        8.0
 21000.0    57000.0    27000.0    8000.0     67500.0    46000.0    625.0      635.0
 626.0      632.0      63.0       5.0        .95        1.0        .95        .07
.06        .01        -1.0       0.0        3.0        0.5        3.0        8.0
33000.0    82000.0    50000.0    17000.0    100000.0   50000.0    627.0      633.0
628.0      632.0      38.0       2.0        0.90       1.0        0.90       0.07
0.06       0.01       -1.0       0.0        3.0        0.5        3.0        8.0
47000.0    112000.0   45000.0    19000.0    200000.0   100000.0   627.0      633.0
628.0      632.0      42.0       2.0        0.90       1.0        0.90       0.07
0.06       0.01       -1.0       0.0        3.0        0.5        3.0        8.0
57000.0    145000.0   57000.0    32000.0    280000.0   140000.0   627.0      633.0
628.0      632.0      38.0       2.0        0.90       1.0        0.90       0.07
0.03       0.01       -1.0       0.0        3.0        0.5        3.0        8.0
62000.0    160000.0   63000.0    38000.0    300000.0   150000.0   627.0      633.0
628.0      632.0      41.0       2.0        0.90       1.0        0.90       0.07
0.03       0.01       -1.0       0.0        3.0        0.5        3.0        8.0
57000.0    142000.0   66000.0    32000.0    240000.0   120000.0   627.0      633.0
628.0      632.0      41.0       2.0        0.90       1.0        0.90       0.07
0.03       0.01       -1.0       0.0        3.0        0.5        3.0        8.0
 594.5      667.0
2.0        8.745      0.0        3.0        6.0        15.555     22.667     15.54
110.0      150.0      110.0      0.920      0.07       0.4        0.0        0.0
0.0        0.0        0.0        0.0
3.0        9.528      0.0        3.0        6.0        16.111     18.176     15.54
110.0      150.0      110.0      0.920      0.07       0.4        0.0        0.0
0.0        0.0        0.0        0.0
5.0        11.051     0.0        3.0        6.0        15.0       11.111     15.54
110.0      150.0      110.0      0.920      0.07       0.4        0.0        0.0
0.0        0.0        0.0        0.0
9.0        12.504     0.0        3.0        6.0        9.444      5.917      15.54
110.0      150.0      110.0      0.920      0.07       0.4        0.0        0.0
0.0        0.0        0.0        0.0
10.0       13.558     0.0        3.0        6.0        8.889      2.778      15.54
110.0      150.0      110.0      0.92       0.07       0.4        0.0        0.0
0.0        0.0        0.0        0.0
10.0       12.852     0.0        3.0        6.0        8.889      4.83       15.54
110.0      150.0      110.0      0.92       0.07       0.4        0.0        0.0
0.0        0.0        0.0        0.0
8.0        11.118     0.0        3.0        6.0        8.333      10.845     15.54
110.0      150.0      110.0      0.92       0.07       0.4        0.0        0.0
0.0        0.0        0.0        0.0
5.0        9.874      0.0        3.0        6.0        8.889      16.389     15.54
110.0      150.0      110.0      1.000      0.07       0.4        0.0        0.0
0.0        0.0        0.0        0.0
4.0        9.246      0.0        3.0        6.0        10.555     19.722     15.54
110.0      150.0      110.0      1.000      0.07       0.4        0.0        0.0
0.0        0.0        0.0        0.0
3.0        8.727      0.0        3.0        6.0        11.111     22.782     15.54
110.0      150.0      110.0      1.080      0.07       0.4        0.0        0.0
0.0        0.0        0.0        0.0
2.0        8.39       0.0        3.0        6.0        12.778     24.897     15.54
110.0      150.0      110.0      1.080      0.07       0.4        0.0        0.0
```

TABLE XIII (Continued)

```
0.0       0.0       0.0       0.0
1.5       9.026     0.0       3.0       6.0       14.444    20.988    15.54
110.0     150.0     110.0     1.080     0.07      0.4       0.0       0.0
0.0       0.0       0.0       0.0
 100.0     1.0       1.0       0.25
0.0       0.043     5.0       8.0       0.0       0.5375    20.0      100.0
0.0       0.038     5.0       8.0       0.0       0.475     20.0      100.0
0.0       .033      5.0       8.0       0.0       .4125     20.0      100.0
0.0       0.02934   5.0       8.0       0.0       0.3667    20.0      100.0
0.0       0.028     5.0       8.0       0.0       0.35      20.0      100.0
0.0       0.02934   5.0       8.0       0.0       0.3667    20.0      100.0
0.0       0.033     5.0       8.0       0.0       0.4125    20.0      100.0
0.0       0.038     5.0       8.0       0.0       0.475     20.0      100.0
0.0       0.043     5.0       8.0       0.0       .5357     20.0      100.0
0.0       0.04666   5.0       8.0       0.0       0.5833    20.0      100.0
0.0       0.048     5.0       8.0       0.0       0.6       20.0      100.0
0.0       .04666    5.0       8.0       0.0       .5833     20.0      100.0
  9.0      19.0      12.0      35.0
    2    7
    4   12
    7   11
    2   25
    5    1
    1   15
    1    0
    4    0
    6   31
    2    0
    4    5
    7    3
               9.0                 6.0                 2.0
 0.5      0.5       1.0       1.0       1.0       1.0       1.0       0.526
```

TABLE XIV

OUTPUT FOR SAMPLE RUN

```
ELEVATION           595.00     606.00     617.00     628.00     640.00
USTAR STAGE 12     1418.27    6164.96    6164.96    6164.96   20769.51
PSTAR STAGE 12        1.92       3.10       3.36       3.62       4.31
ELEVATION           595.00     606.00     617.00     628.00     640.00
USTAR STAGE 11     2576.75    6144.21    8594.99    8594.99   21248.01
PSTAR STAGE 11        3.97       5.73       6.59       7.15       7.73
ELEVATION           595.00     606.00     617.00     628.00     640.00
USTAR STAGE 10      510.00    3312.58    9928.14   11429.92   21740.56
PSTAR STAGE 10        6.54       8.16       9.56      10.52      11.09
ELEVATION           595.00     606.00     617.00     628.00     640.00
USTAR STAGE  9      527.00     527.00   10409.96    9160.74   27184.22
PSTAR STAGE  9       10.72      12.13      13.49      14.65      15.08
ELEVATION           595.00     606.00     617.00     628.00     640.00
USTAR STAGE  8      510.00     510.00    5014.85   10686.71   21734.39
PSTAR STAGE  8       13.31      14.84      16.37      18.05      18.79
ELEVATION           595.00     606.00     617.00     628.00     640.00
USTAR STAGE  7      527.00     527.00     527.00   10103.11   24485.31
PSTAR STAGE  7       16.85      18.44      20.16      21.62      22.44
ELEVATION           595.00     606.00     617.00     628.00     640.00
USTAR STAGE  6      476.00     476.00     476.00   11240.48   24988.51
PSTAR STAGE  6       20.84      22.54      24.08      25.25      26.12
ELEVATION           595.00     606.00     617.00     628.00     640.00
USTAR STAGE  5      527.00     527.00     527.00   10265.86   27688.29
PSTAR STAGE  5       25.35      26.81      28.03      28.88      29.65
```

TABLE XIV (Continued)

```
ELEVATION                595.00     606.00     617.00     628.00     640.00
USTAR STACE  4           527.00     527.00     527.00   12285.45   22184.77
PSTAR STAGE  4            28.05      29.54      30.78      31.92      32.88
ELEVATION                595.00     606.00     617.00     628.00     640.00
USTAR STAGE  3           510.00     510.00     510.00   12908.94   26971.13
PSTAR STAGE  3            32.69      33.85      34.94      35.51      36.10
ELEVATION                595.00     606.00     617.00     628.00     640.00
USTAR STAGE  2           527.00     527.00   12534.69   23240.43   27873.25
PSTAR STAGE  2            37.66      38.18      38.71      38.98      38.53
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**********************************************************************************************
***                   FORWARD RUNS ARE COMMENCING FROM THIS POINT ONWARD                   ****
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THE MONTH BEING RUN IS SEP

THE INITIAL ELEVATION IS =     622.900 THE FINAL ELEVATION IS =     627.932

   AVG        MONTHLY    OPTIMIZER   ENERGY      AVG-DAILY      AVG-DAILY    TOTAL      TOTAL      TOTAL      TOTAL      TOTAL      TOTAL
  INFLOW      DEMAND      CONTROL     GEN.       DISCHARGE      GEN-TIME     WATER      LAND      DWNSTRM     RECR.       NAV.      FLOOD
(THOUS-CFS)   (MWH)        (MWH)     (MWH)     (THOUS-CFS)    (UNIT-HR)   VISITORS   VISITORS   VISITORS   BENEFIT    BENEFIT   BENEFIT

  2.086      5410.00      8114.94   8114.91        1.098          16.0       102946      74076       9281      0.653      1.000       0.0

  WATER
QUALITY
  0.52

 POWER BENEFIT =       1.375 POWER REVENUE =$  54099.82    TOTAL BENEFIT =       3.55     RMF =       0.815
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TABLE XIV (Continued)

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THE MONTH BEING RUN IS OCT

THE INITIAL ELEVATION IS =    627.932 THE FINAL ELEVATION IS =     635.950

   AVG        MONTHLY    OPTIMIZER    ENERGY    AVG-DAILY     AVG-DAILY     TOTAL       TOTAL       TOTAL       TOTAL      TOTAL      TOTAL
 INFLOW       DEMAND     CONTROL      GEN.      DISCHARGE     GEN-TIME      WATER       LAND        DWNSTRM     RECR.      NAV.       FLOOD
(THOUS-CFS)   (MWH)      (MWH)        (MWH)    (THOUS-CFS)   (UNIT-HR)     VISITORS    VISITORS    VISITORS    BENEFIT    BENEFIT    BENEFIT

  4.787     16870.00    23173.89 24908.36       3.113        44.6          93705       79551        4193       0.666      0.556      -0.339

  WATER
QUALITY
  0.70

 POWER BENEFIT =       1.369 POWER REVENUE =$ 167906.69    TOTAL BENEFIT =        2.96     RMF =       1.999

*******************************************************

THE MONTH BEING RUN IS NOV

THE INITIAL ELEVATION IS =    635.950 THE FINAL ELEVATION IS =     633.003

   AVG        MONTHLY    OPTIMIZER    ENERGY    AVG-DAILY     AVG-DAILY     TOTAL       TOTAL       TOTAL       TOTAL      TOTAL      TOTAL
 INFLOW       DEMAND     CONTROL      GEN.      DISCHARGE     GEN-TIME      WATER       LAND        DWNSTRM     RECR.      NAV.       FLOOD
(THOUS-CFS)   (MWH)      (MWH)        (MWH)    (THOUS-CFS)   (UNIT-HR)     VISITORS    VISITORS    VISITORS    BENEFIT    BENEFIT    BENEFIT

  2.545     21100.00    22225.66 25088.19       3.198        45.6          57197       51886        3602       0.757      0.815      -0.082

  WATER
QUALITY
  0.76

 POWER BENEFIT =       1.297 POWER REVENUE =$ 197876.38    TOTAL BENEFIT =        3.55     RMF =       0.353

*******************************************************

THE MONTH BEING RUN IS DEC

THE INITIAL ELEVATION IS =    633.003 THE FINAL ELEVATION IS =     628.371

   AVG        MONTHLY    OPTIMIZER    ENERGY    AVG-DAILY     AVG-DAILY     TOTAL       TOTAL       TOTAL       TOTAL      TOTAL      TOTAL
 INFLOW       DEMAND     CONTROL      GEN.      DISCHARGE     GEN-TIME      WATER       LAND        DWNSTRM     RECR.      NAV.       FLOOD
(THOUS-CFS)   (MWH)      (MWH)        (MWH)    (THOUS-CFS)   (UNIT-HR)     VISITORS    VISITORS    VISITORS    BENEFIT    BENEFIT    BENEFIT

  0.774     13070.00    16412.38 13817.18       1.727        24.8          44927       27863        4739       0.867      0.857      -0.091

  WATER
QUALITY
  0.81

 POWER BENEFIT =       1.264 POWER REVENUE =$ 119124.31    TOTAL BENEFIT =        3.71     RMF =       0.634
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TABLE XIV (Continued)

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THE MONTH BEING RUN IS JAN

THE INITIAL ELEVATION IS =    628.371 THE FINAL ELEVATION IS =    631.118

    AVG        MONTHLY   OPTIMIZER   ENERGY    AVG-DAILY    AVG-DAILY    TOTAL      TOTAL      TOTAL     TOTAL     TOTAL     TOTAL
  INFLOW       DEMAND     CONTROL     GEN.     DISCHARGE    GEN-TIME     WATER      LAND      DWNSTRM    RECR.     NAV.      FLOOD
 (THOUS-CFS)   (MWH)      (MWH)      (MWH)    (THOUS-CFS)  (UNIT-HR)   VISITORS   VISITORS   VISITORS  BENEFIT   BENEFIT   BENEFIT

   1.930     17930.00   10804.64 10804.60      1.371        19.8        39940      30954       4261     0.928     0.965      0.0

  WATER
 QUALITY
  0.93

 POWER BENEFIT =       0.603 POWER REVENUE =$ 118617.56    TOTAL BENEFIT =        3.43    RMF =       0.236
****************************************************

THE MONTH BEING RUN IS FEB

THE INITIAL ELEVATION IS =    631.118 THE FINAL ELEVATION IS =    629.501

    AVG        MONTHLY   OPTIMIZER   ENERGY    AVG-DAILY    AVG-DAILY    TOTAL      TOTAL      TOTAL     TOTAL     TOTAL     TOTAL
  INFLOW       DEMAND     CONTROL     GEN.     DISCHARGE    GEN-TIME     WATER      LAND      DWNSTRM    RECR.     NAV.      FLOOD
 (THOUS-CFS)   (MWH)      (MWH)      (MWH)    (THOUS-CFS)  (UNIT-HR)   VISITORS   VISITORS   VISITORS  BENEFIT   BENEFIT   BENEFIT

   1.709     14670.00   14812.30 14812.24      2.073        29.9        50852      39884       5774     0.952     0.993      0.0

  WATER
 QUALITY
  0.87

 POWER BENEFIT =       1.252 POWER REVENUE =$ 132314.44    TOTAL BENEFIT =        4.07    RMF =       0.090
****************************************************

THE MONTH BEING RUN IS MAR

THE INITIAL ELEVATION IS =    629.501 THE FINAL ELEVATION IS =    628.748

    AVG        MONTHLY   OPTIMIZER   ENERGY    AVG-DAILY    AVG-DAILY    TOTAL      TOTAL      TOTAL     TOTAL     TOTAL     TOTAL
  INFLOW       DEMAND     CONTROL     GEN.     DISCHARGE    GEN-TIME     WATER      LAND      DWNSTRM    RECR.     NAV.      FLOOD
 (THOUS-CFS)   (MWH)      (MWH)      (MWH)    (THOUS-CFS)  (UNIT-HR)   VISITORS   VISITORS   VISITORS  BENEFIT   BENEFIT   BENEFIT

   1.363     11730.00   11901.77 11901.71      1.516        21.9        67417      56930       8191     0.969     0.987      0.0

  WATER
 QUALITY
  0.73

 POWER BENEFIT =       1.254 POWER REVENUE =$ 105913.38    TOTAL BENEFIT =        3.94    RMF =       0.018
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TABLE XIV (Continued)

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THE MONTH BEING RUN IS APR

THE INITIAL ELEVATION IS =     628.748 THE FINAL ELEVATION IS =     624.769

    AVG        MONTHLY    OPTIMIZER    ENERGY     AVG-DAILY      AVG-DAILY     TOTAL       TOTAL       TOTAL      TOTAL      TOTAL      TOTAL
   INFLOW      DEMAND      CONTROL      GEN.      DISCHARGE      GEN-TIME      WATER       LAND       DWNSTRM     RECR.      NAV.       FLOOD
 (THOUS-CFS)   (MWH)       (MWH)       (MWH)     (THOUS-CFS)    (UNIT-HR)    VISITORS    VISITORS    VISITORS    BENEFIT    BENEFIT    BENEFIT

   0.722      8480.00    11374.94  11374.92       1.521         22.1         95639       80054       11576      0.937      1.000       0.0

   WATER
 QUALITY
   0.53

  POWER BENEFIT =       1.335 POWER REVENUE =$  82109.81    TOTAL BENEFIT =        3.80     RMF =       0.511
*****************************************************

THE MONTH BEING RUN IS MAY

THE INITIAL ELEVATION IS =     624.769 THE FINAL ELEVATION IS =     627.392

    AVG        MONTHLY    OPTIMIZER    ENERGY     AVG-DAILY      AVG-DAILY     TOTAL       TOTAL       TOTAL      TOTAL      TOTAL      TOTAL
   INFLOW      DEMAND      CONTROL      GEN.      DISCHARGE      GEN-TIME      WATER       LAND       DWNSTRM     RECR.      NAV.       FLOOD
 (THOUS-CFS)   (MWH)       (MWH)       (MWH)     (THOUS-CFS)    (UNIT-HR)    VISITORS    VISITORS    VISITORS    BENEFIT    BENEFIT    BENEFIT

   1.745      6940.00     9527.66   9527.66       1.240         18.1        189140      109788       18485      0.902      1.000       0.0

   WATER
 QUALITY
   0.71

  POWER BENEFIT =       1.343 POWER REVENUE =$  67635.31    TOTAL BENEFIT =        3.95     RMF =       0.215
*****************************************************

THE MONTH BEING RUN IS JUN

THE INITIAL ELEVATION IS =     627.392 THE FINAL ELEVATION IS =     623.372

    AVG        MONTHLY    OPTIMIZER    ENERGY     AVG-DAILY      AVG-DAILY     TOTAL       TOTAL       TOTAL      TOTAL      TOTAL      TOTAL
   INFLOW      DEMAND      CONTROL      GEN.      DISCHARGE      GEN-TIME      WATER       LAND       DWNSTRM     RECR.      NAV.       FLOOD
 (THOUS-CFS)   (MWH)       (MWH)       (MWH)     (THOUS-CFS)    (UNIT-HR)    VISITORS    VISITORS    VISITORS    BENEFIT    BENEFIT    BENEFIT

   0.742      7620.00    11346.96  11346.92       1.534         22.3        257297      138754       21143      0.821      0.966       0.0

   WATER
 QUALITY
   0.41

  POWER BENEFIT =       1.372 POWER REVENUE =$  76033.81    TOTAL BENEFIT =        3.57     RMF =       0.521
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TABLE XIV (Continued)

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THE MCNTH BEING RUN IS JUL

THE INITIAL ELEVATION IS =    623.372 THE FINAL ELEVATION IS =    619.416

   AVG         MONTHLY    OPTIMIZER    ENERGY     AVG-DAILY     AVG-DAILY     TOTAL       TOTAL       TOTAL       TOTAL       TOTAL       TOTAL
  INFLOW       DEMAND      CONTROL      GEN.      DISCHARGE     GEN-TIME      WATER       LAND       DWNSTRM      RECR.       NAV.        FLOOD
(THOUS-CFS)     (MWH)       (MWH)       (MWH)    (THOUS-CFS)   (UNIT-HR)    VISITORS    VISITORS    VISITORS    BENEFIT     BENEFIT     BENEFIT

  0.451        5730.00     8594.99    8594.93      1.164         17.0        245720      141483       22966       0.778       1.000        0.0

  WATER
QUALITY
  0.34

 POWER BENEFIT =      1.375 POWER REVENUE =$  57299.85    TOTAL BENEFIT =        3.50    RMF =       0.489
****************************************************

THE MONTH BEING RUN IS AUG

THE INITIAL ELEVATION IS =    619.416 THE FINAL ELEVATION IS =    615.802

   AVG         MONTHLY    OPTIMIZER    ENERGY     AVG-DAILY     AVG-DAILY     TOTAL       TOTAL       TOTAL       TOTAL       TOTAL       TOTAL
  INFLOW       DEMAND      CONTROL      GEN.      DISCHARGE     GEN-TIME      WATER       LAND       DWNSTRM      RECR.       NAV.        FLOOD
(THOUS-CFS)     (MWH)       (MWH)       (MWH)    (THOUS-CFS)   (UNIT-HR)    VISITORS    VISITORS    VISITORS    BENEFIT     BENEFIT     BENEFIT

  0.248        4110.00     6164.96    6164.93      0.862         12.6        173753      116203       18595       0.727       1.000        0.0

  WATER
QUALITY
  0.31

 POWER BENEFIT =      1.375 POWER REVENUE =$  41099.85    TOTAL BENEFIT =        3.42    RMF =       0.408
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TABLE XIV (Continued)

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                    STAGES IN INCREASING ORDER BEGINNING FROM BETWEEN STAGE ONE AND TWO

FORECAST PERFORMANCE       42.5335

RUN-PERFORMANCE            43.4266

TOTAL VISITCRS              2498777

TOTAL POWER REVENUE      1220029.00

INITIAL ELEVATION    622.90

                       SEP       OCT       NOV       DEC       JAN       FEB       MAR       APR       MAY       JUN       JUL       AUG

INFLOW RATES          2.09      4.79      2.54      0.77      1.93      1.71      1.36      0.72      1.74      0.74      0.45      0.25

MONTHLY DEMANDS    5410.00  16870.00  21100.00  13070.00  17930.00  14670.00  11730.00   8480.00   6940.00   7620.00   5730.00   4110.00

CONTROLS VALUES    8114.91  24908.36  25088.19  13817.18  10804.60  14812.24  11901.71  11374.92   9527.66  11346.92   8594.93   6164.93

RESERVOIR ELEVATICN 627.93    635.95    633.00    628.37    631.12    629.50    628.75    624.77    627.39    623.37    619.42    615.80
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VITA

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Master of Science

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