METHODOLOGY FOR THE ANALYSIS OF AN EXISTING SINGLE MULTIPURPOSE RESERVOIR

by:

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A Thesis

Submitted to the Faculty of Graduate Studies in Partial

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To my husband,

Addin and Jik

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ABSTRACT

The analysis of reservoir operation and management is a complex dynamic problem that involves physical, environmental, and socioeconomic issues. The variables which determine reservoir yield optimization are highly stochastic. Mathematical programming, such as simulation and optimization, is widely used to assist in making decisions.

The objective of this study is to address the management problem of an existing single multipurpose reservoir, to select appropriate tools, and to implement the selected approaches to a case study. The procedure of managing an existing reservoir consist of two steps of analysis. First, the use of reservoir storage for additional purposes is investigated by simulation using RESER and ResQ simulation models. Second, the potential yield of the reservoir is optimized using the ISRYO optimization algorithm. By using the optimization algorithm, the best possible compromise among the multiple users being considered is achieved.

The Wonogiri Reservoir which is located in Central Java - Indonesia is chosen as a case study. The simulation analysis of the storage capacity for the Wonogiri Reservoir pointed out that the present storage capacity is larger than that required for the irrigation of an area of 25,319 ha. Thus, *the present size of the reservoir allows for additional multipurpose use.* Optimization of the reservoir yield demonstrated that the best possible compromise among three water users was derived using a demand ratio of 0.4

for water supply, 0.2 for irrigation, and 0.4 for hydropower. This combination of demand ratios satisfies the three demands with an irigation area larger than that being presently used.

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The RESER model

i - month index

j - year index

n - number of years

S - storage (m^3/s)

$QU_{i,j}$ - monthly inflow (m^3/s)

$LEV_{i,j}$ - monthly evaporation losses ($m^3\ s^{-1}\ ha^{-1}$)

$LIF_{i,j}$ - monthly infiltration losses (m^3/s)

BIO_i - monthly minimum required reservoir release (m^3/s)

$DCITY_i$ - monthly water supply requirement (m^3/s)

NOF_T - the number of months over T=12.n period with $S_{i,j} <= SREQ_{i,j}$

NOF_Y - the number of months over the yearwith $S_{i,j} <= SREQ_{i,j}$

α_R - required reservoir water supply reliability

β_R - required yearly water supply reliability

γ_R - required yearly water supply vulnerability

δ_R - required monthly water supply vulnerability

The ResQ model

S_{t+1} - end-of-month storage

S_t - beginning-of-month storage

I_t - total inflow volume during a month

O_t - total outflow volume during a month

W_t - withdrawal volume during a month

R_t - release volume during a month

E_t - evaporation volume during a month

S_{av} - average storage

The ISRYO model

d_i - water demand for user i

r_i - water allocation for user i

ru_i - water allocation inducing unit loss

L - loss

N - total number of reservoir users

t - time interval

t_t - number of time interval when failure occur

T - total number of time intervals

α - reservoir yield

q_t - reservoir inflow in time interval t

$d_{i,t}$ - total water demand of user i in time interval t

dm_t - monthly water supply demand

WM_m - relative water supply demand coeficients

DM - total water supply demand

m - month (m=1,2,...,12)

da_t - monthly irrigation water demand

WA_m - relative irrigation demand coeficients

H - crop water requirement

Q_m - the mean inflow for season m

F - irrigated area

de_t - water demand for hydropower generation

E_t - enegy demand

ρ - water density

g - gravity constant

η - coefficient of efficiency

QE_t - flow

H_t - hydraulic head

WE_m - relative hydropower demand coefficients

S_t - reservoir storage for period t

R_t - reservoir release for period t

k - total losses during period t

SMIN - minimum reservoir storage

SMAX - maximum reservoir storage

θ - reservoir release

a_m & b_m - coefficient of the release policy

d_t - total water demand

D_m - mean total demand for season m

CHAPTER 1

INTRODUCTION

In recent years, mathematical models have been developed in the field of water resources engineering in order to solve complicated problems of reservoir design, planning, and operation. These mathematical models have been used to estimate reservoir storage capacities, to determine planning reservoir operations, to justify release decisions during real-time reservoir operation, and to modify operating policies of existing reservoirs. The complex problem of reservoir design, planning, and operation involves uncertain factors and stochastic processes such as reservoir inflow, reservoir sedimentation, water demand, evaporation and infiltration losses. The accuracy of measurement of historical reservoir inflow is also limited. Environmental and physical systems tend to change over time. The future is uncertain. Therefore mathematical models can not address accurately all the uncertainties. Hence, applying mathematical procedures to reservoir design necessarily involves many assumptions, approximations and simplifications.

However, *Yeh* (1985) stated that many successful applications of mathematical programming methods have been established in reservoir studies. Furthermore, *Wurbs* (1991) declared that mathematical approaches provide useful capabilities for analyzing complex problems that involve a large number of values for decision variables.

The objective of the work presented in this thesis is to examine the potential yield of an existing reservoir for multiple uses. The existing reservoir chosen as a case study is the Wonogiri Reservoir in Central Java-Indonesia. Mathematical models consisting of two simulation approaches and an optimization algorithm are used to accomplish this task.

1.1 PROBLEM STATEMENT

Reservoir storage capacity is usually divided into three different water storages: (1) flood control storage; (2) conservation storage; and (3) dead storage. Flood control storage is provided to reduce the flood peak and to minimize potential damage downstream from the reservoir. The conservation storage, or active pool, is operated to regulate streamflow and to provide water supply for various purposes such as irrigation, municipal and industrial requirements, hydroelectric power generation, low flow augmentation etc. The dead storage, or inactive pool, is used to deposit sediment and to provide recreational opportunities (*Loucks et al.*, 1981).

Once the reservoir storage capacity has been determined, a release rule or operating procedure is established to control water releases. *McMahon & Mein* (1978) define releases as "the volume of controlled water released from a reservoir during a given time interval". *Wurbs* (1991) extends this definition to explain operating policy as "a set of rules for determining the quantities of water to be stored and to be released or withdrawn from a reservoir or system of several reservoirs under various conditions".

Storage allocation and operating policies are usually designed for the existing conditions present during the period of reservoir construction.

After a reservoir has been in operation for some time, storage allocations and/or operating procedures may need to be modified. The modification of the use of an existing multipurpose reservoir may serve two objectives. They are reallocation of reservoir storage and optimization of reservoir use. Reallocation of reservoir storage refers to changing the allocation of reservoir storage space to meet present and future needs. Optimization of reservoir use refers to developing a release policy to best satisfy all purposes. Modifications may be necessary in order to respond to an increased need for water which is a limited resource. As a consequence, reallocation of reservoir storage and simultaneously, optimization of release policies will be two of the most important tools in the future. Therefore, the main objective of this thesis is to investigate their potential in the analysis of an existing reservoir.

Compared to reservoir sizing and reservoir planning which are completed during the project planning phase of new reservoirs already having a *specific demand*, the management of existing reservoirs refers to the ability to meet "new conditions" which may arise after the reservoirs have been in operation for some times. The new condition may be such things as new users who must be accomodated, changes in the priorities of existing users, modifications of original purposes, completing a downstream water resources project, etc. Due to the actual condition of existing reservoirs which are *constrained by the existing maximum storage capacity*, the difference between reservoir sizing or planning and the management of existing reservoirs can be stated as follows:

* How should the reservoir be built and operated *to meet specific demand* ? (reservoir sizing and planning), and
* *What demands can be met*, if we want to optimize an existing reservoir, given by the maximum reservoir storage ? (the management of existing reservoir).

In the case of the Wonogiri Reservoir, after nine years of operation, reallocation of the reservoir storage capacity must be investigated in order to (i) examine possible ways of supplying water to other potential water users without ignoring the present function, and to (ii) modify originally authorized project purposes which may no longer be required under present conditions.

Once reallocation of an existing reservoir storage occurs, modification of the operating policies should be investigated.

1.2 SCOPE OF WORK

The contribution of methodology for the management of an existing reservoir proposed in this study is the optimization of the use of an existing reservoir by determining the best combination of priorities of using the reservoir between the multiple users being considered. The work is performed in two phases. The first phase consists of analyzing the existing reservoir storage allocation. Two simulation approaches, ***RESER*** (*Simonovic*, 1985) and ***RESQ*** (*Ford*, 1990), are used in this study. The results of the first phase provide information concerning the possibility, given the existing storage capacity, of supplying water to meet other water needs. This analysis is given in Chapter 4.2.

The second phase examines the potential yield of the existing reservoir storage for multiple purposes. Since the specific demand is not known, the reservoir yield is optimized using physical information on the general character of demands represented by relative demand coefficients. An algorithm, called ***ISRYO***, Implicit Stochastic Reservoir Yield Optimization developed by *Simonovic* (1987), solves this specific problem and produces an *optimal reservoir yield.* The application of the ISRYO algorithm will result in the optimal use of an existing reservoir constrained by actual reservoir size and the particular inflow condition. Monthly releases for the three water users are obtained to determine the reservoir operating policy. In addition, for each demand, the model calculates the number of failures and the failure magnitudes. This examination is located in Chapter 4.3.

The objective of the case study is to reexamine the potential yield of the Wonogiri Reservoir for water supply, irrigation, and hydropower generation. The analysis of the first phase is carried out for the following reasons: (i) the design of the reservoir has been based on the synthetic flow sequence that was generated from the gaging station located about 110 km downstream of the reservoir site and new information of reservoir inflow is available; (ii) new potential users such as electric hydropower generation and industrial water supply may demand water from the reservoir. The existing storage capacity has been analyzed under different inflow scenarios. *In this study, the term* *water supply refers to municipal and industrial water supply.* The examination of the second phase is carried out by assigning different priorities to different reservoir users. Setting the irrigation demand as a high priority may lead to a low reservoir yield value. In addition, the impact of different supply levels for irrigation purpose has been investigated. For example, assigning lower value of supply level for irrigation tends to generate a higher yield. The analysis of reservoir yields obtained under different scenarios is used to identify "the best" possible combination of reservoir users measured by the optimal reservoir yield.

CHAPTER 2

A REVIEW OF THE LITERATURE

2.1 RESERVOIR SIZING

Reservoir sizing can be defined as the determination of required reservoir storage to meet a certain demand with an acceptable level of reliability. The required reservoir storage depends on the variability of reservoir inflow, demand magnitude including losses, and the level of reliability to satisfy demand. The techniques for reservoir sizing can be classified into 3 main groups: critical period methods; stochastic theory; and system analysis approach.

The mass diagram tecnhique (critical period method) presented by *Ripple* (1883) is considered the first rigorous theory for estimating reservoir storage capacity (*McMahon & Mein*, 1978; *Loucks et al.*, 1981; *Klemes*, 1987). The active storage capacity is derived by finding the maximum cumulative difference between releases and inflows. The method uses historical inflow with an assumption that future inflows will not change considerably. The unknown factor of future inflows is an inherent weakness in this technique (*Klemes*, 1987). In addition, it does not take into account losses and probability of failure in the analysis. However, because of its simplicity, the method is still in use today by many water resources planners. Sequent peak analysis introduced by *Thomas and Burden* (1963) is a kind of algorithmic transcription of the modified

Ripple's mass diagram procedure. This analysis still uses an historical sequence to obtain a single estimate of reservoir design capacity, and lately, promotes the use of computers in the calculation (*Klemes*, 1987).

Stochastic storage theory is an approach addressed and recommended by many researchers for use in obtaining the probability distribution of a required reservoir storage capacity (e.g., *Fiering*, 1967; *Wallis and Matalas*, 1972; *Bayazit*, 1982; *Vogel and Stedinger*, 1987). This theory is based on work by Moran, therefore it is sometimes called Moran's Theory. *Hazen* (1914) is considered to be the first researcher to introduce the concept of failure probability to the theory of stochastic storage reservoir design. Hazen's tables provide a relationship between the over-year design storage capacity, yield, and characteristics of reservoir inflow. Unfortunately, *McMahon & Mein* (1978) found that Hazen's tables led to an error in calculation of the probability of failure of a finite reservoir. However, *Klemes'* work (1987) proved that the error is not too large for small values of risk. A complete explanation of Ripple's and Hazen's methods and their variations can be found in *McMahon & Mein* (1978).

Systems analysis techniques - simulation and optimization - have been applied to the problems of reservoir management since 1960. *Fiering* (1961) applied a simulation technique to the problem of selecting the optimal design of a single multi-purpose reservoir. The simulation is combined with the queing theory in order to determine a reservoir size for which the average gross benefit exceeds the cost of the system. However, the use of the queuing theory in this simulation study incorporates too many parameters that may cause inefficiencies in reservoir design practice.

Loucks et al (1981) presented an optimization analysis to calculate the required reservoir capacity. The optimization is capable of incorporating evaporation losses and infiltration losses which are considered important factors in the determination of reservoir storage. Evaporation and infiltration losses are assumed to be a function of the storage volumes in the period being considered. The optimization is based on the continuity equation and formulated to a linear programming procedure.

The Hydrologic Engineering Center (HEC) has applied system analysis tools, which consist of simulation and optimization, to solve water resources problems including the problem of reservoir sizing. The principal technique of the system analysis applied by HEC has been mathematical simulation. The HEC-3 model (reservoir system analysis for conservation) and HEC-5 (simulation of flood and conservation systems) model are used to simulate the response of water resources systems designed to meet a variety of water needs (*Fieldman*, 1981).

Simonovic (1985) developed RESER, the reservoir simulation-optimization algorithm for reservoir design. The simulation is combined with the direct search tehnique to determine the optimal required reservoir capacity. It incorporates reliability constraints which provide additional information concerning different risk levels associated with a certain reservoir demand. The model is used in this thesis and is therefore presented in detail in Chapter 3.

2.2 PLANNING RESERVOIR OPERATION

Reservoir planning can be defined as the determination of reservoir releases for a given capacity within a certain time interval (one week or longer). Usually, the process of reservoir planning performed by using a time period of one week or longer is called long-term operations planning. The main contribution of system analysis related to reservoir planning problems is the application of mathematical simulation and optimization models to provide an improved basis for decision making (*Simonovic*, 1992).

Young (1967) first proposed an algorithm to derive general operating reservoir policies from the result of a deterministic optimization model for annual usage of single reservoirs. The algorithm consists of 3 levels. At the first level, the inflow sequence is generated using a stochastic model. At the second level, a dynamic programming technique is used to get a near-optimal policy based on the generated inflow sequence derived at the first level. At the third level, a least squares regression analysis is used to derive an optimal reservoir policy.

ReVelle et al. (1969) initially introduced the Linear Decision Rule (LDR) to find optimal operating policies. The LDR is used to linearize the relationship between reservoir storage and release. This can be expressed as R = S - b, where R is the release during a period of reservoir operation, S denotes the storage at the end of the previous period, and b is the decision parameter to be determined. The main defficiency of the LDR is its inability to deal with the random character of reservoir inflow.

Therefore there is no quarantee for the existence of an optimal solution (*Loucks and Dorfman*, 1975). Many modifications of the original LDR have been reported in the literature (e.g., Loucks, 1970; Revelle and Kirby, 1970; Loucks and Dorfman, 1975; Houck, 1979; Stedinger, 1984).

Loucks (1970) modified the original LDR by incorporating inflow during time period t in the form of the LDR as follows: $R_t = S_{t-1} + I_t - b_t$. He stated that this modified rule produced a more accurate result than the original LDR. *Revelle and Kirby* (1970) also modified the original LDR to include evaporation losses using linearized storage- area curves and projected storage. Many modifications of the original LDR as a single type linear decision rule have been reviewed by *Yeh* (1985).

Houck (1979) developed a multiple LDR which was then compared to the single LDR by *Houck and Datta* (1981). The comparison pointed out the superiority of multiple LDR over single LDR models. Under identical conditions of an operating reservoir, the multiple LDR model provides a smaller reservoir capacity than the single LDR model. As the number of LDR's per season increases, the optimal reservoir capacity decreases. However, this study also documented intensive data needs for the application of the multiple LDR. Therefore, it was suggested that a single LDR be used for limited data sets.

Stedinger (1984) evaluated the performance of LDR models and concluded that the LDR rule performs poorly as an operating policy for simple and complex multipurpose water management problems. Although for some cases, the LDR may produce ecceptable results, it is not recommended for multipurpose reservoir management except for preliminary analysis.

Simonovic (1987) developed the Implicit Stochastic Reservoir Yield Optimization (ISRYO) model to derive the optimal reservoir yield for a given storage capacity. The model incorporates simulation and optimization procedures and consists of three levels of computation. The model is used in this study and therefore explained in detail in Chapter 3.

2.3 REAL-TIME RESERVOIR OPERATION

Real-time reservoir operation is concerned with determining the optimal release of a reservoir within a short time interval. The time interval is usually defined to be one day or shorter. Most of the models for real-time reservoir operation propose the use of streamflow forecasting to derive optimal solutions and have an objective of minimizing the total penalties, or maximizing benefits over the time horizon.

A combination of Linear Programming (LP) and Dynamic Programmimg (DP) to determine the optimum real time reservoir operation of the California Central Valley Project was suggested by *Becker and Yeh* (1974). They used LP to minimize the loss of potential energy generated in each period. Other objectives are embedded in the constraints of the LP. The solution of LP is then used in a deterministic forward DP for multiple-period optimization.

Yazicigil et al.(1983) formulated a linear programming model to simulate the decision-making process for the operation of four multipurpose reservoirs in the Green River Basin. The model, called the GRBOOM (Green River Basin Operation Optimization Model), is used in real-time operations as well as in long-term operation studies. Following by this work, *Can & Houck* (1984) used Goal Programming (GP) for solving daily reservoir system operation problems. They applied the GP model to the Green River Basin and compared the result of the GP program to the GRBOOM mentioned above. They concluded that goal programming may be easier to implement and, in some cases, may be better than linear programming. However, they realized that the application of both models to other case studies might not generate the same conclusion.

Simonovic & Burn (1989) have introduced an improved methodology for the short-term operation of a single multipurpose reservoir. The improvement is based on the existence of a trade-off between the length of the operating horizon and the reliability of forecasted inflows (*Can & Houck*, 1985). Can & Houck concluded that using perfect forecast inflows, models of real-time operation perform better operation as the time horizon increases. Unfortunately, as the forecasted horizon increases, the reliability of the forecast decreases. The work of Simonovic & Burn is based on the assumption that the forecasts are reliable. Moreover, since the performance of the models depend on the operating time horizon, the model was formulated by assigning the operating time horizon as a decision variable. The objective of the improved methodology is to determine the optimal operating horizon for short-term reservoir operation. The methodology comprises three interconnected algoritms within a single computer package. The algorithms are: (1) an adaptive forecasting algorithm based on the Kalman filter procedure, (2) a real-time reservoir operation model based on a linear programming procedure, and (3) a multiobjective compromise programming procedure for achieving the best compromise between forecast reliability and the reservoir operation penalties. The application of the methodology to the operation of the Green Reservoir in Kentucky illustrated the advantages of this methodology.

Using the above methodology, *Reznicek et al.*(1991) simply replaced the original linear programming (LP) model of *Simonovic & Burn* (1989) with a goal programming (GP). The intent of modifying the approach is based on the consideration that the application of goal programming is easier than linear programming. The result of GP application compared to the original LP showed that the alteration is viable.

2.4 REALLOCATION OF RESERVOIR STORAGE AND OPTIMAL OPERATIONS OF EXISTING RESERVOIRS

Reallocation of reservoir storage and optimal operations of existing reservoirs are two new techniques for addressing reservoir management problems. These techniques will gain importance in response to the requirements of sustainable water development. Furthermore, the analysis will become more and more important in dealing with the increased demand for a limited resource.

Reallocation of reservoir storage *generally* occurs when a reservoir meeting "new conditions" after being in operation. These "new conditions" may be such things as new users who must be accomodated, changes in the priorities of existing users, modifications of original purposes, completing a downstream water resources project, etc. In addition, reallocation can be carried out since the existing storage capacity of the reservoir being considered proves the existence of storage-space in the reservoir that can be allocated for other requirements. However, the most important reason for reallocating reservoir storage is to improve the utilization of existing reservoirs in meeting expected water needs. Improving the utilization of existing reservoirs is the main task optimization.

The need for reallocation can occur anywhere for a variety of reasons and in many ways depending upon the character, objectives, and climatic condition of each reservoir. *Wurbs et al.*(1988) documented an investigation of proposed and actual storage reallocations focusing particularly on the state of Texas. *Johnson et al.* (1990) summarized the documentation and provied supporting information derived from the experience of the Hydrologic Engineering Center of the U.S Army Corps of Engineers referring to eight general cases of reallocation (shown in Figure 1-8) as follows:

1. ***Use of water-supply storage not under contract***

In this case, a portion of storage space is allocated for future water supply before construction begins. Unfortunately, the expected users do not exist. Reallocation is established to make water available for other water supply users.

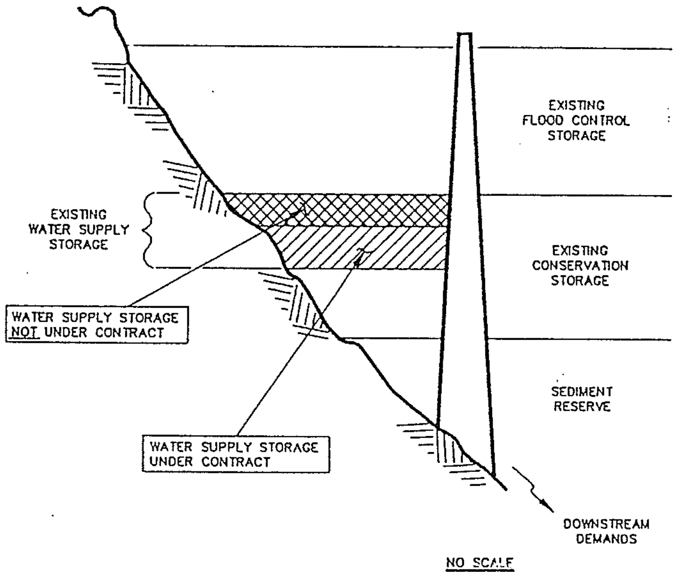

Figure 1 : Use of water supply storage not under contract (Johnson et al., 1990)

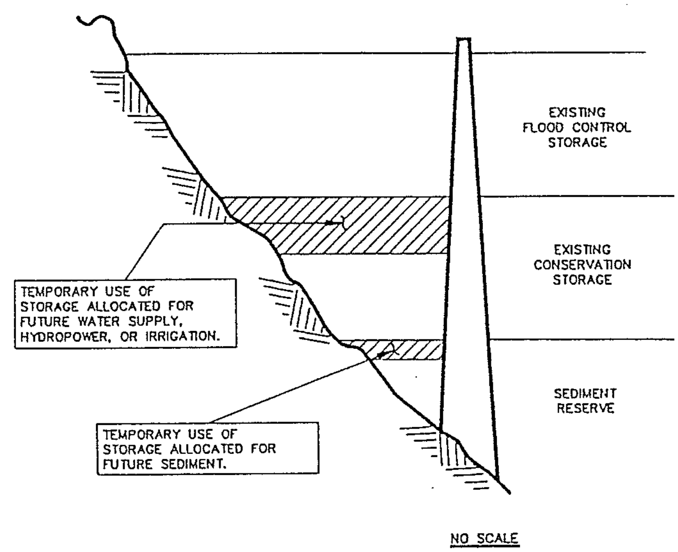

Figure 2 : Temporary use of storage allocated for future conservation purpose and sediment (Johnson et al., 1990)

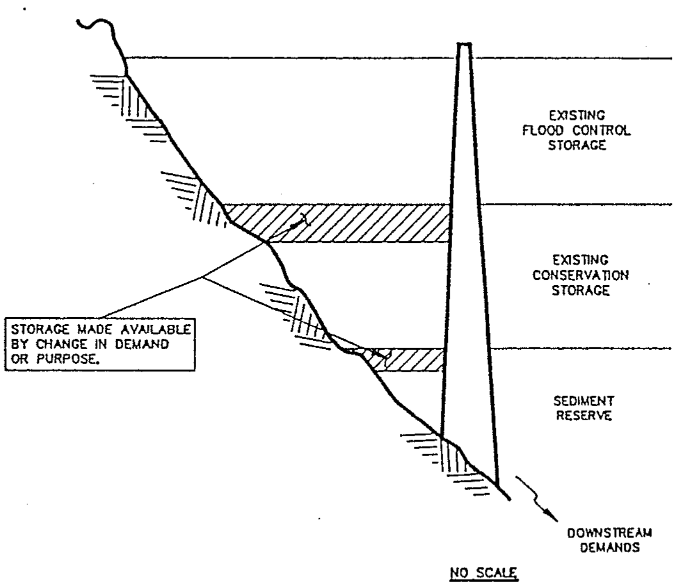

Figure 3 : Storage made available by change in conservation demand or purposes (Johnson et al., 1990)

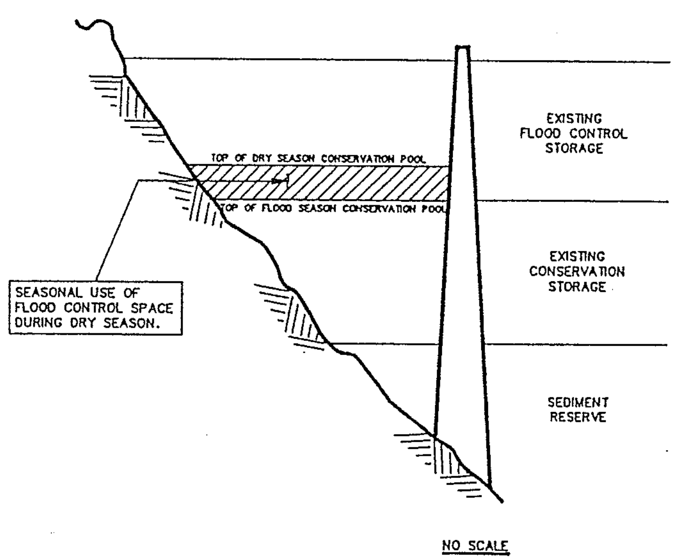

Figure 4 : Seasonal use of flood control space during dry season (Johnson et al., 1990)

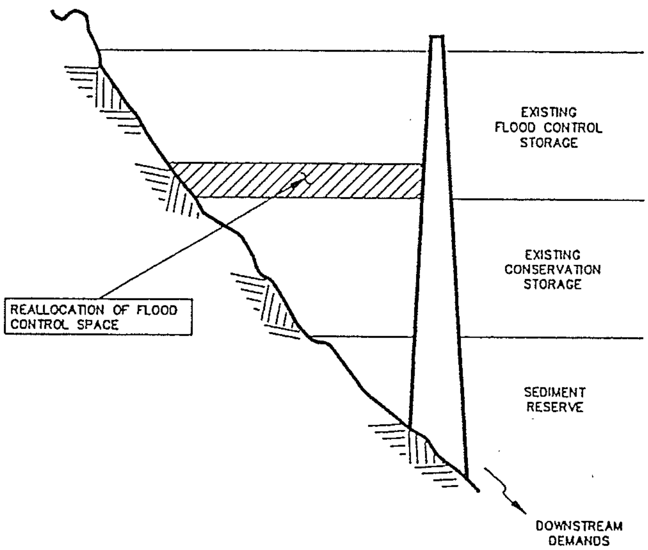

Figure 5 : Reallocation of flood control space (Johnson et al., 1990)

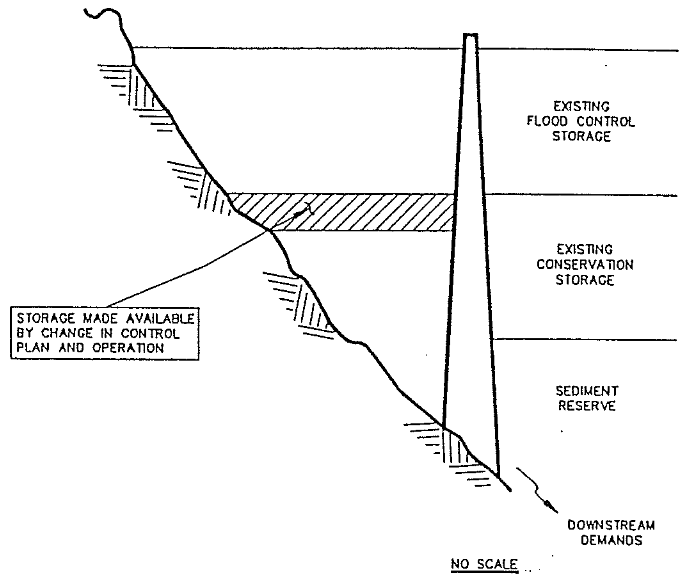

Figure 6 : Modification of reservoir water control plan and method of regulation (Johnson et al., 1990)

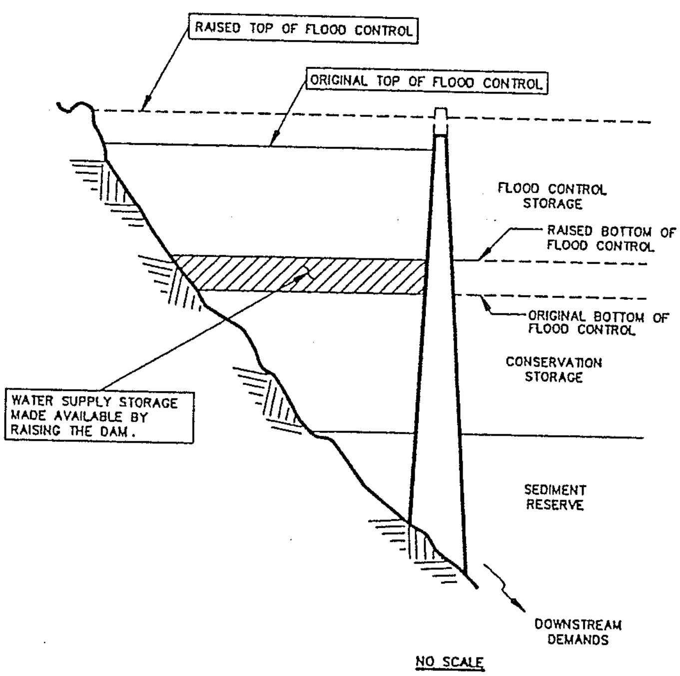

Figure 7 : Raising existing dam (Johnson et al., 1990)

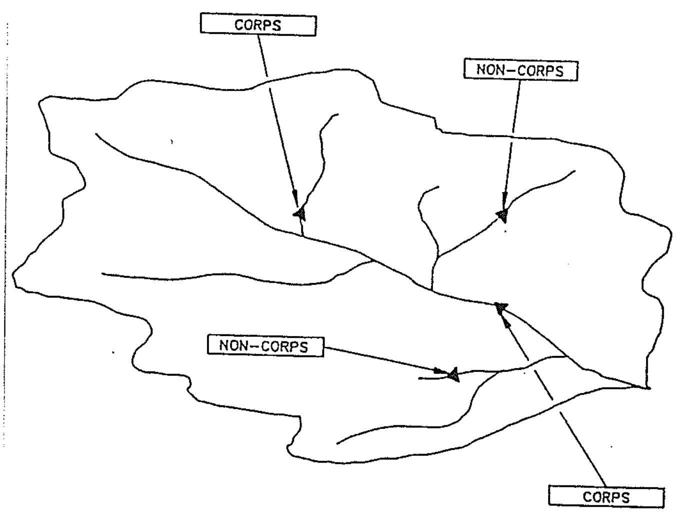

Figure 8 : Operate reservoirs as a system (Johnson et al., 1990)

2. ***Temporary use of storage allocated for future conservation use or sediment retention***

This case allows for temporary reallocation of storage meant for future conservation uses and sediment retention. The temporary reallocation allows water to be used to fulfill other requirements until it is needed for the original users.

3. ***Storage made available by change in conservation demand or purpose.***

This case provides an opportunity to reallocate the authorized project purposes. The reason is that the originally authorized project purpose no longer exists. For example, the hydropower storage of the Denison Dam in Texas were reallocated to water supply storage when the benefits obtained by the reallocation were improved.

4. ***Use of flood-control space during the dry season.***

Reallocation in this case allows conservation water to be stored temporarily in flood control storage. This type of reallocation is recommended for regions which have very low probability of flooding during dry periods. This type of reallocation has been implemented in the Cooper Reservoir in Texas.

5. ***Permanently reallocate flood-control space***

This case allows for the possibility of reallocating a portion of flood control space to other water needs. Reallocation can be considered: (i) where the volume of reallocated water is small and has no effect on flood protection, (ii) where supplemental flood control structures downstream of the reservoir have been completed, (iii) where hydrological analysis indicates that the existing storage maximum is larger than the required capacity (The Chatfield Reservoir in Colorado has the potential to reallocate up to 28 million m3 of flood control space to water supply), and (iv) where new reservoirs are built upstream of an existing reservoir. The construction of the Proctor Reservoir at the upstream basin facilitates reallocation of a part of the flood control storage of the Belton Reservoir in Texas.

6. ***Modification of the reservoir water-control plan and the method of regulation.***

In this case, changing the method of reservoir regulation may provide additional water supply without affecting the supply to other users.

7. ***Raising existing dam.***

The case provides additional capacity without reducing existing allocations. It may be costly, however, The Lavon dam has been raised to get an additional 345.3 million m3 capacity for municipal and industrial purposes.

8. ***Operate reservoirs as a system***

Operating reservoirs in one basin as a system may save much more water than operating reservoirs individually.

Most of the reallocation cited above emphasizes increasing municiple and industrial water-supply-storage capacity for existing water supply users. Therefore, in general, reallocation in developed countries is carried out in order to maximize the existing storage for the *existing users*. By contrast, reallocation in developing countries is generally carried out due to meeting *new demand* which may be not have been considered when the reservoir was built or which may have arisen with the passage of time. It is consistent with the characteristics of developing countries that new conditions can arise very quickly. In addition, the construction of reservoirs in developing countries are emphasizing the fulfilment of existing requirements when the reservoirs are built. As a consequence, no allocated storage capacity is provided for future demands.

A tool developed to simulate reservoir storage reallocation has been introduced by *Ford* (1990). The tool, called the ResQ program, is designed as a PC based reservoir-operation simulator. The ResQ program is used in this thesis and therefore explained in detail in Chapter 3.

Simonovic (1991) employed the ResQ program combined with multiobjective analysis to examine the existing operation rules of the Shellmouth reservoir. The investigation was done under existing conditions using different downstream demand criteria. ResQ simulates the operation of the reservoir for each downstream demand. The simulation results are then evaluated using a multiobjective analysis procedure.

Risk based criteria, i.e., reliability, resiliency, storage vulnerability, and release vulnerability are incorporated in the analysis as well. The investigation arrived at the conclusion that the present size of the Shellmouth reservoir is large enough to satisfy the additional requirements of the downstream demand.

Modification of the operation policies of Lake Shelbyville, Illinois has been done several times due to unusual weather conditions and changes in basin-wide water resources development. *Lee et al.* (1992) have demonstrated the performance evaluation of operation policies for Lake Shelbyville by developing the Stochastic Dynamic Programming (SDP) model. The development of the model is based on the assumption that the optimal operating policy is determined by minimizing long-term damage to the reservoir system. The model analyzes the effective storage capacity of the system by combining the joint-use storage and the flood control storage. The formulation of the model incorporates economic losses which consist of agricultural losses, property damages, and recreation losses. Each of the losses is assumed as a function of the lake storage or the downstream release. The model yields an expected performance of Lake Shelbyville into 12 monthly operation periods. The expected performance incorporates the variation of lake level, probability of lake level in the effective storage, and probability of release greater than the maximum allowable flood control release.

CHAPTER 3

DESCRIPTION OF MATHEMATICAL ALGORITHMS USED FOR THE ANALYSIS OF EXISTING RESERVOIRS

The contribution of the overall procedure or methodology for the management of an existing reservoir is the optimization of the use of an existing reservoir by determining the best combination of priorities of using the reservoir between the multiple users being considered. Therefore, each user has the opportunity to be satisfied dependent upon its priority. The priority is represented by a relative demand ratio. The best combination of demand ratios is measured by the optimal value of reservoir yield.

The study proposes the procedure of managing an existing reservoir through 2 step solution. First, the analysis of the existing reservoir storage allocation, and second, the examination of the potential yield of the reservoir for multiple users. The result of the first step provides information concerning the possibility, given the existing storage capacity, of supplying water to meet the multiple users. This step is accomplished using simulation models. The result of the second step presents the optimal yield of the existing reservoir for the multiple users being considered constrained by actual reservoir size and particular inflow condition. This step is established using an optimization model.

Many mathematical algorithms are available in the literature, however the selection of mathematical algorithms used for the analysis of reservoir problems should be based on the problem of the reservoir being considered. Simulation models should cover all components of reservoir sizing such as reservoir inflow, demand, releases, evaporation and infiltration losses. In addition, the model should include additional performance measurement, i.e., reliability criteria to produce the computed reservoir storage capacity, given a specific demand, associated with the reliability criteria assigned by the planner. Optimization models should address the problem of optimizing the use of an existing reservoir for multiple users by determining the best combination of priorities among the multiple users.

3.1 SIMULATION

Simulation is a computer-based modelling technique used to illustrate all the characteristics of a system by means of mathematical or algebriac description (*Acko*, 1961; *Maass et al.*, 1962). In addition, under a given set of input data, the simulation is used to generate the response of the system (*Yeh*, 1985). Recently, *Wurbs* (1991) categorized simulation as a descriptive approach which demonstrates what will happen to the system if specified decisions are made. *Loucks et al.* (1981) stated that *simulation is not an optimizing procedure*, but it is the most widely used procedure in the field of water resources engineering. According to *Simonovic* (1992), simulation is easier to understand than other modelling techniques and when the simulation model is run a number of times with different decision policies, an optimal or close to optimal solution can be observed.

The ***RESER*** model developed by *Simonovic* (1985) and the ***ResQ*** model introduced by *Ford* (1990) are simulation algorithms for the analysis of a single multipurpose reservoir system. The RESER model covers all components of reservoir design procedures including additional performance measure, i.e., reliability criteria. In addition, the model is effective, widely used, and easy to understand. The ResQ model incorporates state-of-the-practice simulation with a state-of-the-art user interface. Hence, the model accelerates the process of the edit-simulate-evaluate cycle. For those reasons, both simulation models are used in this study.

3.1.1 Description of the RESER model

RESER, a mathematical model, is used for reservoir storage capacity simulation. It has been developed for practical use in everyday reservoir design practice (*Simonovic*, 1992). This simulation is coupled with a direct search optimization technique for finding the optimal value of required reservoir capacity under given sets of input data. The model is based on the continuity equation and includes four reliability criteria regarding the supply of water required by the reservoir users. The reliability criteria are required reservoir water supply reliability (alpha), required yearly water supply reliability (beta), required yearly water supply vulnerability (gamma), and required monthly water supply vulnerability (delta).

The mathematical formulation of the simulation-optimization algorithm is as follows: (Symbols are located in the list of notation).

$$minimize \quad S \tag{1}$$

subject to

. continuity constraints:

$$S_{i,j} = S_{i-1,j} + QU_{i,j} - LEV_{i,j} - LIF_{i,j} - BIO_i - DCITY_i \tag{2}$$

. four reliability constraints:

$$\alpha \geq \alpha_r \tag{3}$$

$$\beta \geq \beta_r \tag{4}$$

$$\gamma_j \geq \gamma_r \qquad \forall_j \tag{5}$$

$$\delta_{i,j} \geq \delta_r \qquad \forall_j \tag{6}$$

The reliability constraints are defined as follows :

(a) reliability of water supply

$$\alpha = 1 - \frac{NOF_T}{12n} \tag{7}$$

(b) yearly reliability of water supply

$$\beta = 1 - \frac{NOF_y}{12} \qquad \forall_j \tag{8}$$

(c) yearly vulnerability of water supply

$$\gamma_j = \frac{\sum_{i=1}^{12} (S_{ij} - SREQ_{ij})}{\sum_{i=1}^{12} SREQ_{ij}} \qquad \forall_{i,j} \tag{9}$$

(d) monthly vulnerability of water supply

$$\delta_{i,j} = \frac{S_{ij} - SREQ_{ij}}{SREQ_{ij}} \qquad \forall_{i,j} \tag{10}$$

where:

$$SREQ_{ij} = DCITY_i + BIO_i + LEV_{i,j} + LIF_{i,j} \qquad \forall_{i,j} \tag{11}$$

The flow chart of the RESER model is presented in Figure 9.

The procedure of computing the storage capacity by using the RESER simulation model can be described as follows: First, the initial storage value provided by the user is utilized in the simulation of the reservoir monthly operation reservoir under given sets of inflow, evaporation and infiltration losses, demands and desired reliability criteria. This simulation allows the calculation of the reliability of delta, gamma, beta and alpha. Then, each of the computed reliability values is compared with the desired value. If the criteria are not satisfied, the simulation procedure is repeated with a higher initial storage value. The new initial storage value is increased by a step size provied by the user. The process of simulation is repeated until all desired values of reliability criteria are satisfied. Finally, coinciding with the fulfillment of all reliability criteria, the value of optimal required reservoir capacity is generated.

Combining the elements of simulation as well as optimization in the RESER model causes the model to be effective for analyzing optimal required reservoir storage. During simulation, the computed storage can be monitored, storage-dependent losses can be directly calculated and storage failures can be observed. The model also provides additional information regarding different risk levels associated with a certain reservoir demand. The advantage of the model over other methods is that the model presents a "double-reliability" scheme.

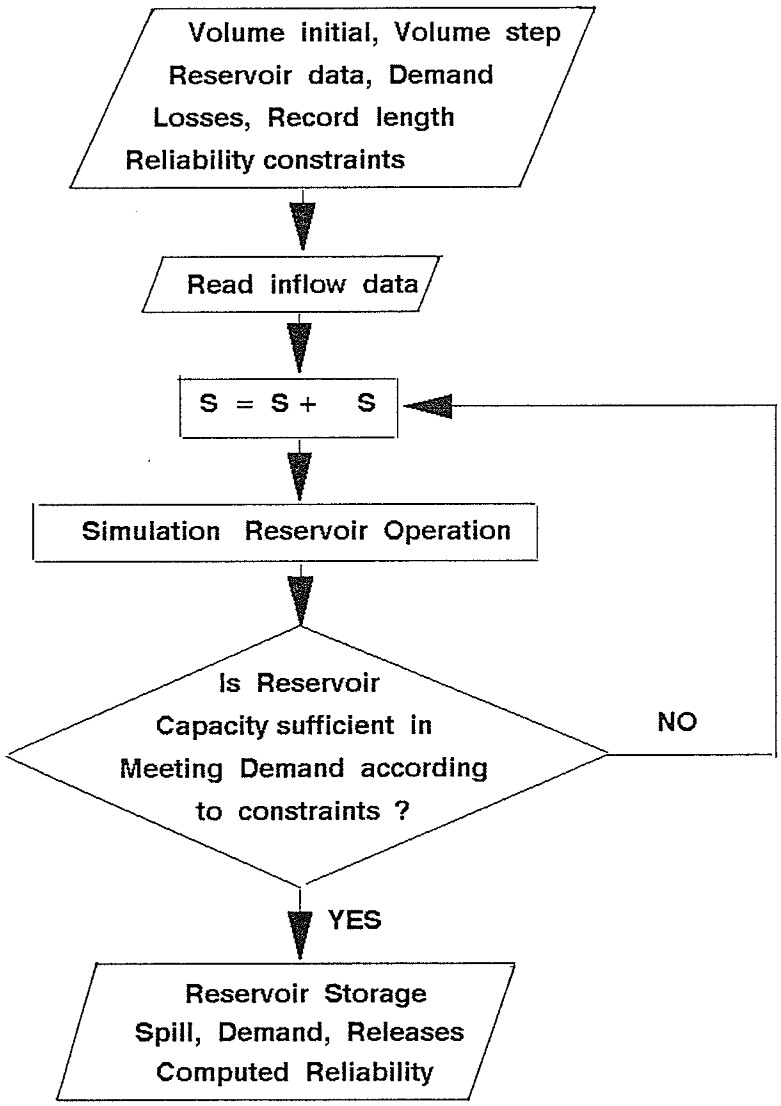

Figure 9. Flowchart of the RESER model

3.1.2 Description of the ResQ model

ResQ, a single reservoir simulator, has been developed to simulate the monthly operation of a water-resources system that includes a reservoir and a downstream demand point. ResQ provides a ballance between gain and loss of water and calculates this at three locations: (1) gain and loss of water in the reservoir, including evaporation, released water from the reservoir or diversion requirement, and spilled water to the downstream channel; (2) gain and loss of water between the reservoir and a downstream demand point, including local runoff and channel losses; and (3) loss of water at the downstream demand point, including withdrawal of water there to satisfy demands.

This model simulator is based on the continuity equation below:

$$S_{t+1} = S_t + I_t - O_t \tag{12}$$

The outflow is derived from:

$$O_t = R_t + S_t + E_t \tag{13}$$

The released water and evaporation losses depend on the existing volume of water in storage during the month. The storage during a month is assumed as an average storage calculated as follows:

$$S_{av} = 1/2\ (S_t + S_{t+1}) \qquad (14)$$

Using the reservoir continuity equation, the end-of- month storage can be estimated. However, the end of month storage will not be obtained until the total outflow, which depends on storage, is determined. Therefore an iterative solution is needed as follows:

1. The average storage is assumed to be equal to the beginning-of-month storage;
2. The surface area, elevation, and outlet capacity responding to the average storage are estimated;
3. The release, spill, and evaporation are estimated and then the total outflow is calculated;
4. The end-of-month storage is computed by applying the continuity equation;
5. The average storage is computed;
6. Steps 2, 3, 4, and 5 are repeated until the release selected in step 2 varies by no more than 1 cfs from the previous iteration.

3.2 OPTIMIZATION

Optimization is an operation research technique for the analysis of a system described by means of a mathematical model which consists of an objective function, decision variables and constraints. A more complex system may involve more than one objective. An objective function can be stated as a means for expressing the concepts of *optimality* or *best*. Decision variables are the controllable and partially controllable inputs. Constraints are restrictions applied to models (*Goodman*, 1984).

The development of an optimization techniques to solve reservoir operation problems has been the focus of research for many years. The textbook of *Loucks et al.* (1981) contains some of the optimization techniques. A literature review of the state-of-the-art modelling and analysis approaches for evaluating reservoir system operations has been documented by *Yeh* (1985) and *Wurbs* (1991).

The ***ISRYO*** model developed by *Simonovic* (1987) is the only approach which is close to the solution of reallocating reservoir storage for an existing reservoir. In addition, the approach is flexible in determining the optimal reservoir yield, defined as the "best" possible compromise among multiple users of a reservoir when the *demands are not known.* The basis of the optimization embedded in the ISRYO model is the estimation of monthly demand coefficients. These coefficients represent the characters of different users that are derived from physical information of each user. The value of the coefficients assigned for each month determines the monthly demand and release for each user. In other words, the magnitude of monthly demands and releases for each user are greatly influenced by the magnitude of these coefficients constrained by assigning the value of demand ratio.

3.2.1 Description of the ISRYO model

Simonovic (1987) formulated the ISRYO algorithm which has an objective of finding the optimal yield of a single multipurpose reservoir when the *demand is not known*. The optimal value of the reservoir yield is derived by knowing the character of different water demands represented by *relative demand coefficients*. Assuming that the maximum storage capacity is known, the Simonovic algorithm employs three basic principles. The three principles are as follows: (1) multipurpose use of the reservoir; (2) equal treatment of the reservoir users; and (3) relative water allocation level.

Some assumptions are used in developing the principle of equal treatment of reservoir users. The assumptions are that the reservoir is satisfying N different users; and the penalties for not satisfying demands are linear functions of released amount of water (*Jettmar and Young*, 1975). In this case, the penalties are stated as the sum of negative effects caused by water shortages. Mathematical formulation of the principle can be expressed as follows:

$$\frac{1-\frac{r_1}{d_1}}{1-\frac{ru_1}{d_1}} = \ldots = \frac{1-\frac{r_i}{d_i}}{1-\frac{ru_i}{d_i}} = \ldots = \frac{1-\frac{r_N}{d_N}}{1-\frac{ru_N}{d_N}} = L(1) \qquad (15)$$

$$\frac{r_i}{d_i} = 1 - (1 - \frac{ru_i}{d_i}) * L \qquad \forall i \tag{16}$$

The equal treatment principle follows a procedure which result in the user with the largest penalty is being satisfied first.

The model covers the lack of strong and reliable economic criteria by optimizing the reliability of satisfying water demands from reservoirs. *Hashimoto et al.* (1982) analyzed the reliability of the water supply system as follows

$$\nu = 1 - \frac{t_t}{T} \tag{17}$$

However, the above approch considers only the number of failures, not their magnitude. *Simonovic* (1987) incorporated both failure magnitude and number of failures into the model through the relative water allocation level principle. The reliability of satisfying user demand can be expressed as a function of losses due to unsatisfied demand:

$$\nu = 1 - \frac{\sum_{t=1}^{T} L_t (1 - \frac{RU_t}{D_t})}{T} \tag{18}$$

If a reservoir is dealing with more than one user, equation (16) can be written as follows:

$$\frac{r_i}{d_i} = 1-(1-v_i)\frac{1-\frac{R}{D}}{\sum_{i=1}^{N}(1-v_i)\frac{d_i}{D}} \qquad \forall_i \tag{19}$$

The multipurpose reservoir yield is defined as follows:

$$\alpha = \frac{D}{Q} \tag{20}$$

where:

$$D = \frac{1}{T}\sum_{t=1}^{T}\sum_{i=1}^{N} d_{i,t} \tag{21}$$

$$Q = \frac{1}{T}\sum_{t=1}^{T} q_t \tag{22}$$

Based on the three basic principles described above, an optimal reservoir yield is determined by a mathematical model that consists of three levels. Each of the basic principles is embedded in one of the algorithm levels.

At the first level, a simulation procedure is used to calculate the objective function and to test the performance of the reservoir operating rules. At the second level, an optimization approach is used to derive reservoir operating rules by finding the optimal value of the two parameters used in the first level and simultaneously minimizing the objective function. The third level calculates optimal reservoir yield based on the predefined demand ratios and supply levels.

At the first level, a simulation model is used. The algorithm is formulated based on the continuity equation as follows:

$$S_t = S_t - 1 + q_t - R_t - k_t \qquad \forall_t \tag{23}$$

and set of constraints

$$S_{MIN} \leq S_t \leq S_{MAX} \qquad \forall_t \tag{24}$$

$$R_t \geq 0 \qquad \forall_t \tag{25}$$

The initial reservoir storage is estimated as follows:

$$S_o = 0.5(S_{MAX} - S_{MIN}) + S_{MIN} \tag{26}$$

The illustration of maximum and minimum storage can be seen in Figure 10.

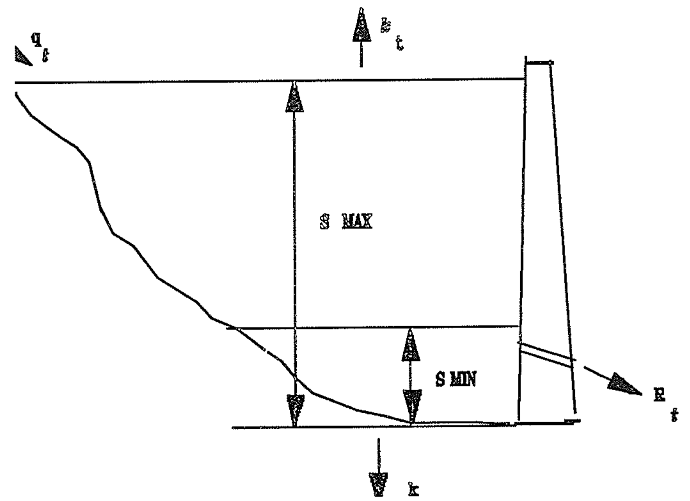

Figure 10. Schematic representation of a reservoir

At this level, a reservoir operation rule is needed to determine the end-of-month storage and reservoir releases. The reservoir releases are assumed as a function of reservoir inflow and forecast of the future reservoir inflow, reservoir storage at the previous time interval, and reservoir water demand. Following the recommendation by Bhasckar and Whitlatch (1980), the reservoir release is expressed as the quadratic rule:

$$\theta_t = a_m d_t + b_m \frac{(S_{t-1} - S_{MIN} + q_t)^2}{(S_{MAX} - S_{MIN} + Q_m)^2} D_m \qquad \forall_t \forall_m \qquad (27)$$

Using the above quadratic rule, the reservoir operation can be defined as follows:

1. IF

$$S_{MIN} \le S_{t-1} + q_t - k_t - \max(0,\theta) \le S_{MAX} \tag{28}$$

THEN

$$R_t = \max(0,\theta_t) \tag{29}$$

$$S_t = S_{t-1} + q_t - k_t - \max(0,\theta_t) \tag{30}$$

2. IF

$$S_{t-1} + q_t - k_t - \max(0,\theta_t) > S_{MAX} \tag{31}$$

THEN

$$R_t = S_{t-1} + q_t - k_t - S_{MAX} \tag{32}$$

$$S_t = S_{MAX} \tag{33}$$

3. IF

$$S_{t-1} + q_t - k_t - \max(0,\theta_t) < S_{MIN} \tag{34}$$

THEN

$$R_t = S_{t-1} + q_t - k_t - S_{MIN} \tag{35}$$

$$S_t = S_{MIN} \tag{36}$$

Figure 11 shows the flow chart of the first level.

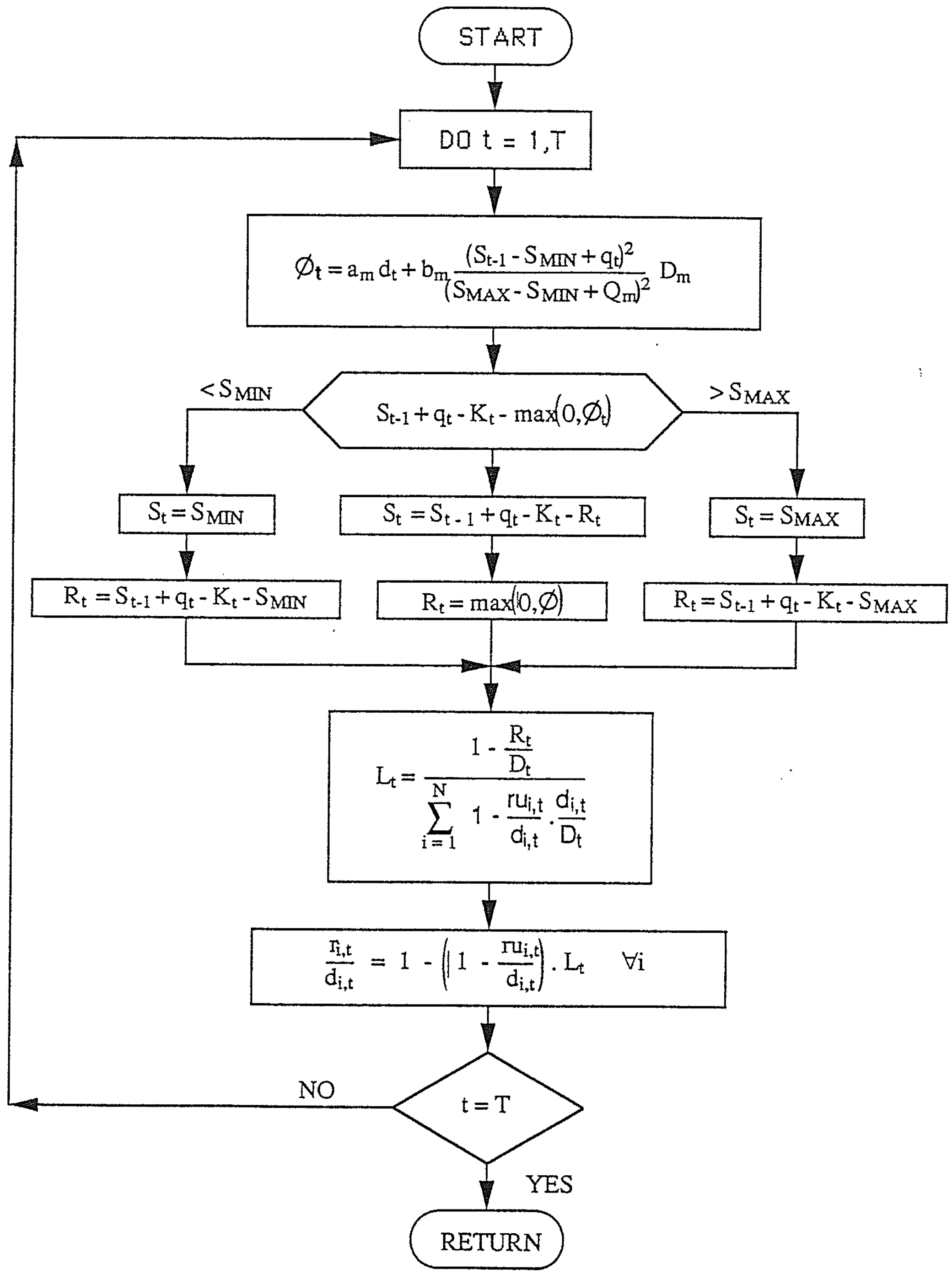

Figure 11. Flowchart of the first level

At the second level, an optimization procedure is applied to derive the reservoir operating rules. The model incorporates deterministic optimization and regression analysis which are coupled in the nonlinear optimization algorithm. The objective function at this level is the minimization of the sum of all losses in the system. Figure 12 illustrates the flowchart of computation procedure at the second level.

Hence, the optimization problem at this level is minimizing the total losses, *LOSS*, by finding the optimal values for a_m and b_m:

$$minimize \quad LOSS = \frac{1}{T} \sum_{t=1}^{T} \sum_{i=1}^{N} L_{i,t} \qquad \forall_m \tag{37}$$

The relationship between LOSS and a_m & b_m is an unconstrained, multivariable, and nonlinear function. Therefore Powell's feasible direction search procedure is used at this level to obtain the minimum value of the loss. The procedure is based on the method of M.J.D. Powell and presented in Appendix C.

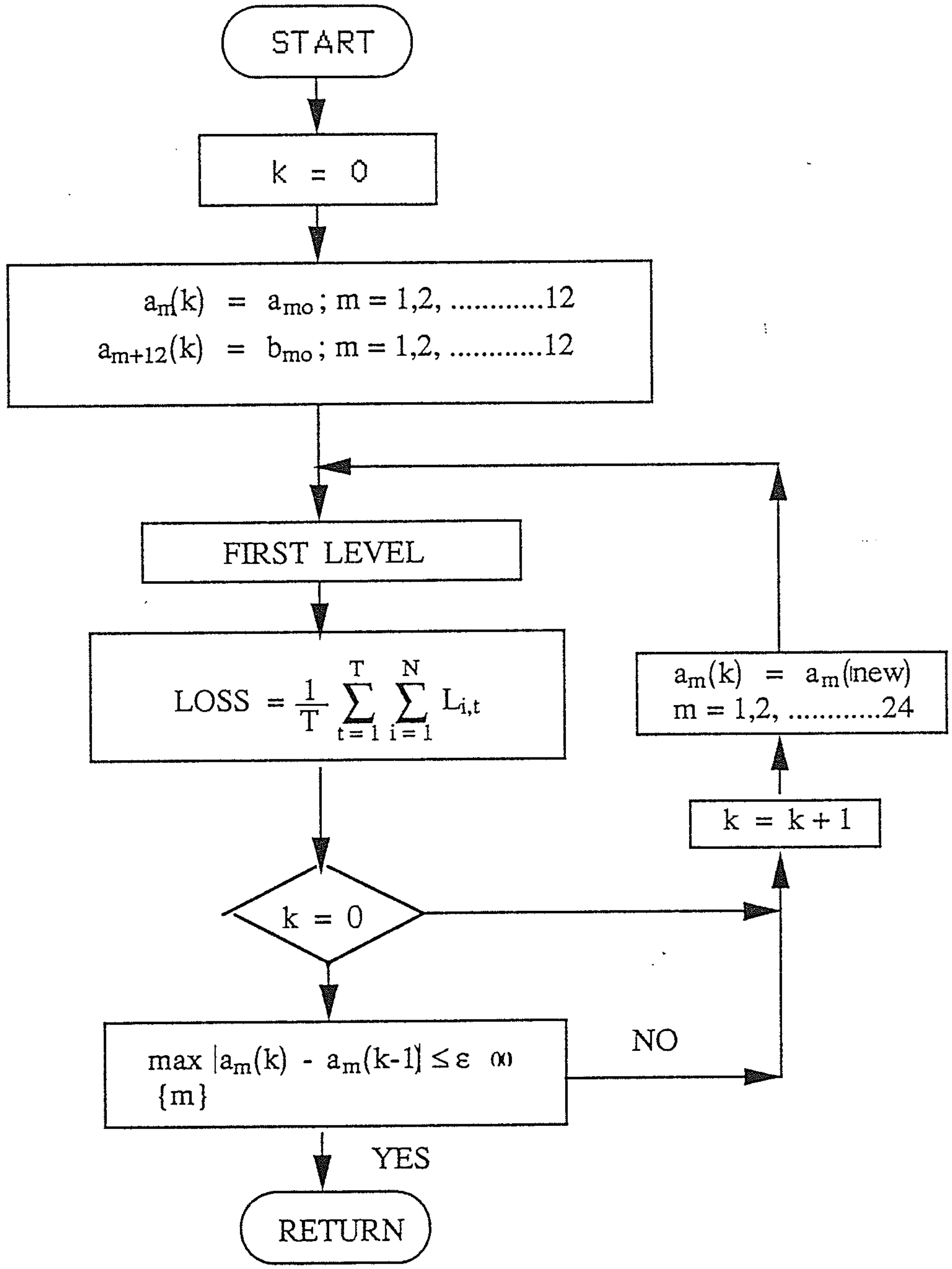

Figure 12. Flowchart of the second level.

At the third level, an optimization procedure is used to compute the single multipurpose reservoir yield that is expressed as follows:

$$\alpha = \frac{\left(\frac{1}{T}\sum_{t=1}^{T}\sum_{i=1}^{N} d_{i,t}\right)}{\frac{1}{T}\sum_{t=1}^{T} q_t)} \tag{38}$$

The optimization problem at this level is formulated as follows:

$$minimize\ Y = \left(\sum_{t=1}^{T}\sum_{i=1}^{N}\frac{r_{i,t}}{d_{i,t}v_{i,t}} - N\right)^2 \tag{39}$$

subject to

$$0 \le \alpha \le 1 \tag{40}$$

The procedure used at this level is a single variable constrained optimization. Therefore, the Fibonaccian search technique is appropriate to be used here. The Fibonaccian procedure is described in Appendix C.

Figure 13 illustrates the flow chart of the third level.

The main characteristic of reservoirs is multi-purpose use, usually including water supply, irrigation, and hydro power generation. The monthly water supply demand is assumed to be fairly stable during a year and is expressed as follows:

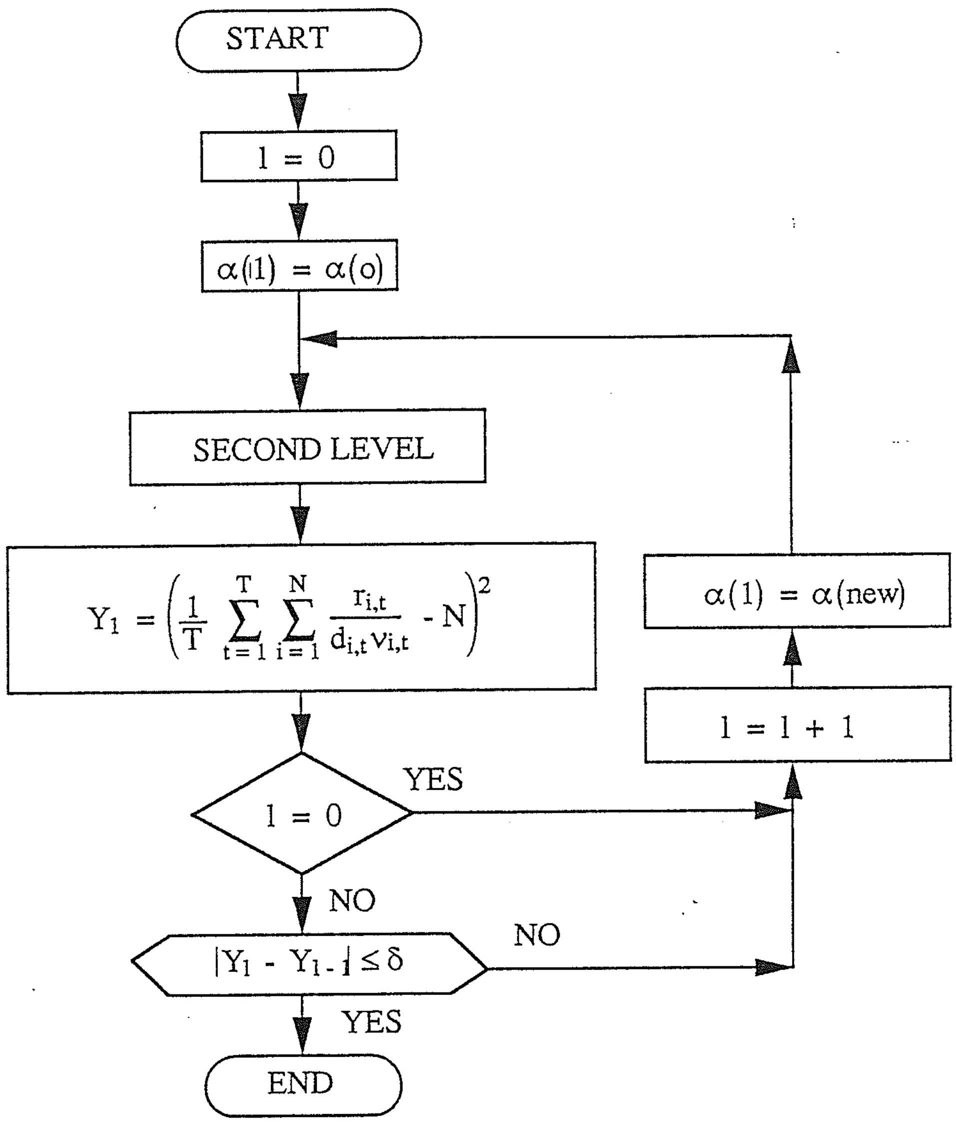

Figure 13. Flowchart of the third level.

$$dm_t = WM_m \, DM \qquad \forall_t \forall_m \tag{41}$$

The irrigation demand is defined as a function of soil moisture, precipitaion, streamflow, and irrigated area. Therefore, the irrigation demand is highly irregular due to the season and analyzed region being considered. The monthly irrigation demand can be defined as follows:

$$da_t = WA_m \, H \left(\frac{q_t}{Q_m} \right) F \qquad \forall_t \tag{42}$$

The required release to satisfy the hydropower demand is a function of the hydraulic head. Furthermore, the hydraulic head is a function of reservoir storage. The monthly hydropower demand can be expressed as folows:

$$de_t = WE_m \frac{E_t}{\rho g \eta \left[(H_t + H_{t-1})/2 \right]} \qquad \forall_t \forall_m \tag{43}$$

Use of the ISRYO model facilitates the determination of optimal reservoir yield without knowing the explicit demand. This determination requires the expression of priorities associated with different demands and water allocations. By changing these priorities, alternative reservoir yields may be determined. This type of analysis is very useful in the early steps of reallocating storage capacity for other purposes and in assisting decision makers in the selection of the best compromise among the users of a reservoir.

Important input required for the model is the assignment of the monthly demand coefficient for each user. These coefficients are the basis of the optimization. Therefore the selected coefficients should accurately represent the general character of the demand of the particular user. However, because of the *flexibility* of the model, changing the demand coefficient can be easily accomplished.

The model produces monthly releases for each water demand. Therefore it can be used for the reexamination of operating policies. As well, the model is capable of determining a global risk associated with meeting the projected demand.

CHAPTER 4

WONOGIRI RESERVOIR CASE STUDY

4.1 BACKGROUND OF THE WONOGIRI RESERVOIR

The Wonogiri Reservoir is a part of the Bengawan Solo River Basin Development Project in Java - Indonesia. The reservoir is located about 35 km upstream of the city of Solo. The Bengawan Solo river basin has approximately 600 km of river length and a 16,100 km^2 drainage area which extends over the Central and Eastern Java provinces. Figure 14 shows the location of the Wonogiri Reservoir.

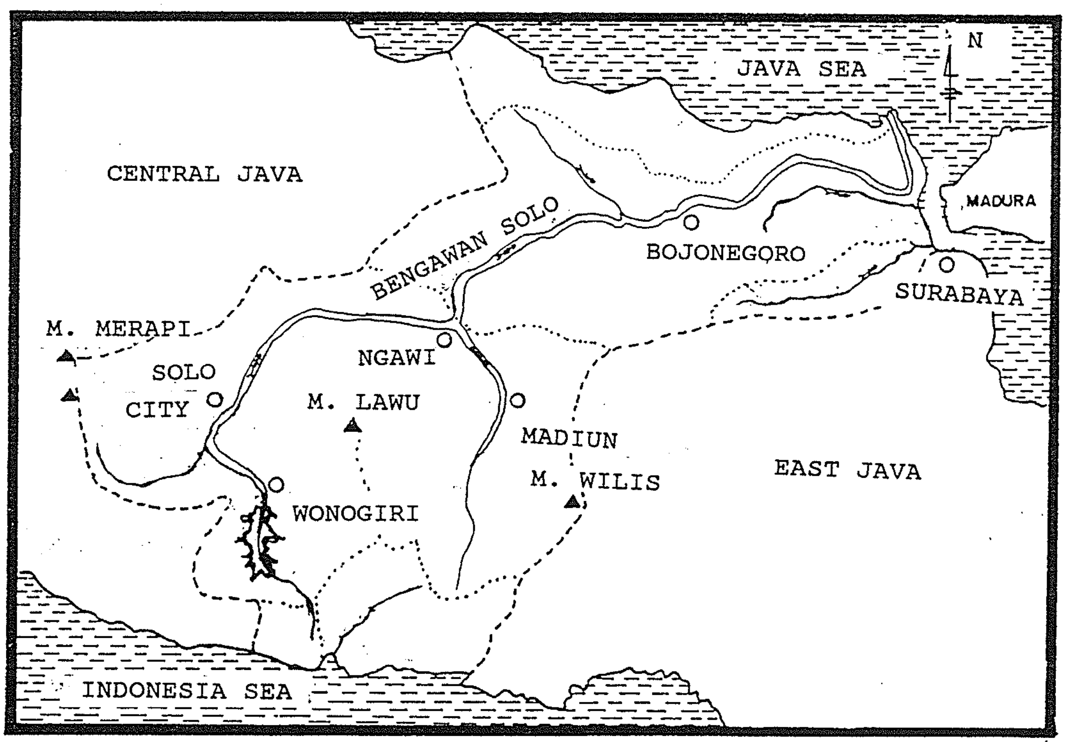

Figure 14. The location of the Wonogiri Reservoir

According to the master plan of the Bengawan Solo River Basin Development (1974), the Wonogiri Reservoir was considered as the most viable project with high economic return in agriculture. It was therefore decided to construct the Wonogiri Dam with the main objective being *irrigation and flood control* as the first priority of the river basin development. Additional secondary functions of the reservoir consist of hydropower generation, low flow augmentation, recreation, and fisheries.

Due to insufficient data for estimating long-term water discharge at the Wonogiri site, the monthly discharge at the Wonogiri Dam was simply estimated from the correlation with the Karangnongko gauging station located about 110 km downstream of the dam site. The gauging station was the representative one which had recorded daily river stages throughout a 20 year period from 1952-1971. The monthly discharge used in designing the Wonogiri Dam was estimated by the simple correlation as follows (JICA, 1975):

$$Q_{Wonogiri} = 0.102\ Q_{Karangnongko}$$

(This data set is also used in this study as one inflow scenario for the analysis of the existing storage capacity of the Wonogiri Reservoir in the next section).

In 1976, construction of the Wonogiri Multipurpose Dam Project began. The project included construction of the Wonogiri Dam it self as well as a plan to meet the needs of irrigation and flood control. The construction of the dam was completed in 1982. The irrigation system covered an area of 23,200 ha and was finished in 1987. Recently, the flood control section including river improvement and dikes construction of the Upper Solo reach was also completed.

December 1983 was the first month of full operation of the Wonogiri Reservoir. Reservoir operation rules established to regulate reservoir inflows are still in use today. The operation rules should be applied *until* the flood control work of the Upper Solo reach and the second phase of the Wonogiri Project are completed (Manual for Operation and Maintenance, 1984, p.1).

The monthly released water from the Wonogiri Reservoir is based on the diversion requirements which consists of monthly irrigation requirement and the need for low flow augmentation. The low flow augmentation is determined to be equal to 2 m3/s during the dry period (April to November) and zero during the wet period (December to March). During the dry period the released water is equal to the diversion requirement; in the wet period, the released water can be gradually increased, to generate more electricity, *as long as* hydrological forecasting does not indicate a long drought period. If an abnormally dry year is predicted in the coming period, the released water can be decreased, but not less than the diversion requirement in all cases. In conclusion, all water allocated in the reservoir is mainly provided to fulfill the irrigation requirement (and low flow augmentation). None of the reservoir storage is specifically allocated for hydropower generation, recreation, and fisheries. Recreation and fisheries only temporarily use the conservation storage in the wet season or the dead storage in the dry period.

The storage capacity of the Wonogiri Reservoir is divided into three zones: dead storage, active storage, and flood control storage. The dead storage is 83 million m^3 provided to deposit sediment, the active storage is 435 million m^3, and is used for conservation needs. The flood control storage is 210 million m^3 with an overlapping space of 50 million m^3 provided to reduce the flood peak. Figure 15 shows the storage allocation of the Wonogiri Reservoir. The low water level or the top of the inactive pool is at +127.0 m, the normal water level or the top of the active pool is at +136.0 m, and the high water level or the top of the flood control pool is at +138.2 m. The elevation-storage curve described above is based on new information measured in 1987.

Other facilities of the Wonogiri reservoir are: an overflow spillway with 4 gates and a spillway crest at an elevation of +130.7 m; an intake structure located at elevation +122.0 m with a maximum capacity of 76 m^3/s; an existing power plant consisting of 2 units, with a capacity of 12.4 MW.

Due to changes in the cropping pattern, from 5 rice crops within 2 years to 2 rice crops and one of polowijo per year, not all water allocated for irrigation is used. As a consequence, some extentions of the irrigated area have been proposed. One of the proposals, i.e., an increase of the irrigated area to 25,319 ha has been proposed and the irrigation requirement for the area has been calculated as well (Nippon Koei, 1987). This irrigation requirement is used in this study.

Based on the master plan of the Bengawan Solo River Basin Development mentioned above, the original authorized project purpose of the Wonogiri Reservoir was to help increase rice production. In addition, there was the possibility of enlarging the

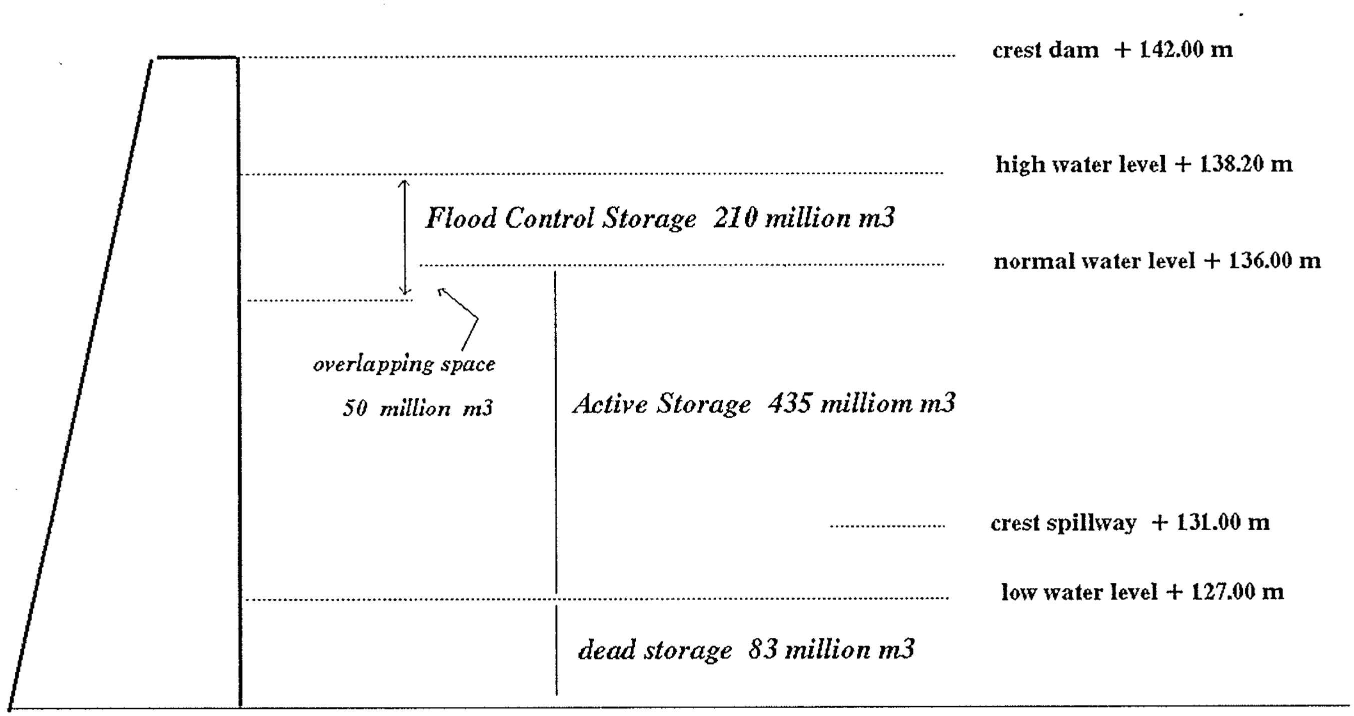

Figure 15 : Storage allocation of the Wonogiri Reservoir

irrigation area up to 30,000 ha. However, times have changed in that (i) Self-supporting rice production in Indonesia was attained in 1985, (ii) there is now industrial growth downstream of the reservoir area, and (iii) the need for electricity tends to increase steadily due to the advancement of many industries on Java Island. Therefore, reallocation of reservoir storage to meet other water needs should be given serious consideration.

The plan to analyze the Wonogiri Reservoir consists of two steps. The first step is analyzing the existing reservoir storage allocation using simulation models. Data provided for the analysis include reservoir inflow sequences, irrigation demand, required minimum reservoir release, evaporation and infiltration losses, volume-reservoir surface area, and required reliability criteria. The reservoir inflow sequences are derived from the historical data recorded after completing the reservoir. The irrigation requirement is based on the extended area of 25,319 ha. The required minimum reservoir releases are for low flow augmentation during April to November.

The second step is optimization of the reservoir yield considering the three main reservoir purposes: water supply, irrigation, and hydropower. Required data for this step have been prepared including such information as a 50 year generated inflow sequence, an elevation-volume curve, storage maximum, storage minimum, required demand ratio and supply level, and the assumption of relative demand coefficients.

This study is carried out in order to examine the possibility of optimizing the Wonogiri Reservoir for more than one user keeping in mind the future needs as well as the present function of the reservoir. By providing different values of optimal reservoir yield associated with the importance of each user, this study may assist decision makers in managing the Wonogiri Reservoir in such a way that it benefits all reservoir users.

4.2 SIMULATION OF RESERVOIR STORAGE CAPACITY

4.2.1 Simulation by the RESER model

The ***RESER*** model analyzes the Wonogiri reservoir storage capacity using four inflow scenarios: (i) 8 years of historical data recorded since the completion of the reservoir; (ii) 20 years of synthetic sequence derived from generating the historical data using the ARMA model; (iii) 50 years of synthetic sequence generated using the ARMA model; and (iv) 20 years of synthetic sequence to the design of Wonogiri Dam. The use of different sets of inflow data is aimed at obtaining a variety of results, thus offering a better illustration of the analysis of the existing storage capacity.

The storage capacity is simulated under several sets of required reliability and vulnerability criteria. These reliability constraints provide information about different risk levels associated with the irrigation demand applied to the simulation. Since irrigation demand is assumed to have a high probability level of failure associated with the drought period, the monthly vulnerability (delta) is assigned values between 0.60, 0.65, and 0.70. Yearly vulnerability (gamma) and yearly reliability (beta) values are set equal to 0.60, 0.70, 0.80 and 0.70, 0.75 0,80 respectively. Overall reliability (alpha) value is set equal to 0.80 and 0.90 respectively. The intent of assigning different sets of the reliability constraints is to derive storage capacity which fulfils the 4 required reliability measures. The computed reservoir storage capacity is presented in Table 1 and Figure 16.

Table 1. THE COMPUTED RESERVOIR STORAGE (10^6 m^3/s)

Required Reliability				Reservoir inflow sequences			
alpha	beta	gamma	delta	a	b	c	d
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0.80	0.70	0.60	0.60	416.52	400.50	397.83	403.17
0.80	0.70	0.60	0.65	419.19	403.17	400.50	403.17
0.80	0.70	0.60	0 70	421.86	405.84	403.17	405.84

Columns 1 to 4 in Table 1 present the reliability constraints: alpha, beta, gamma, and delta respectively. Columns 5 to 8 present the computed reservoir storage derived using 8 years of hystorical records, 20 years of synthetical sequence generated by the ARMA model, 50 years of synthetical sequence generated by the ARMA model, and 20 years of synthetical sequence used in the design of the Wonogiri Reservoir.

The complete results of the simulation, a sample output of the RESER simulation, a listing of the required data for the RESER model, and a copy of the RESER program are located in Appendix A.

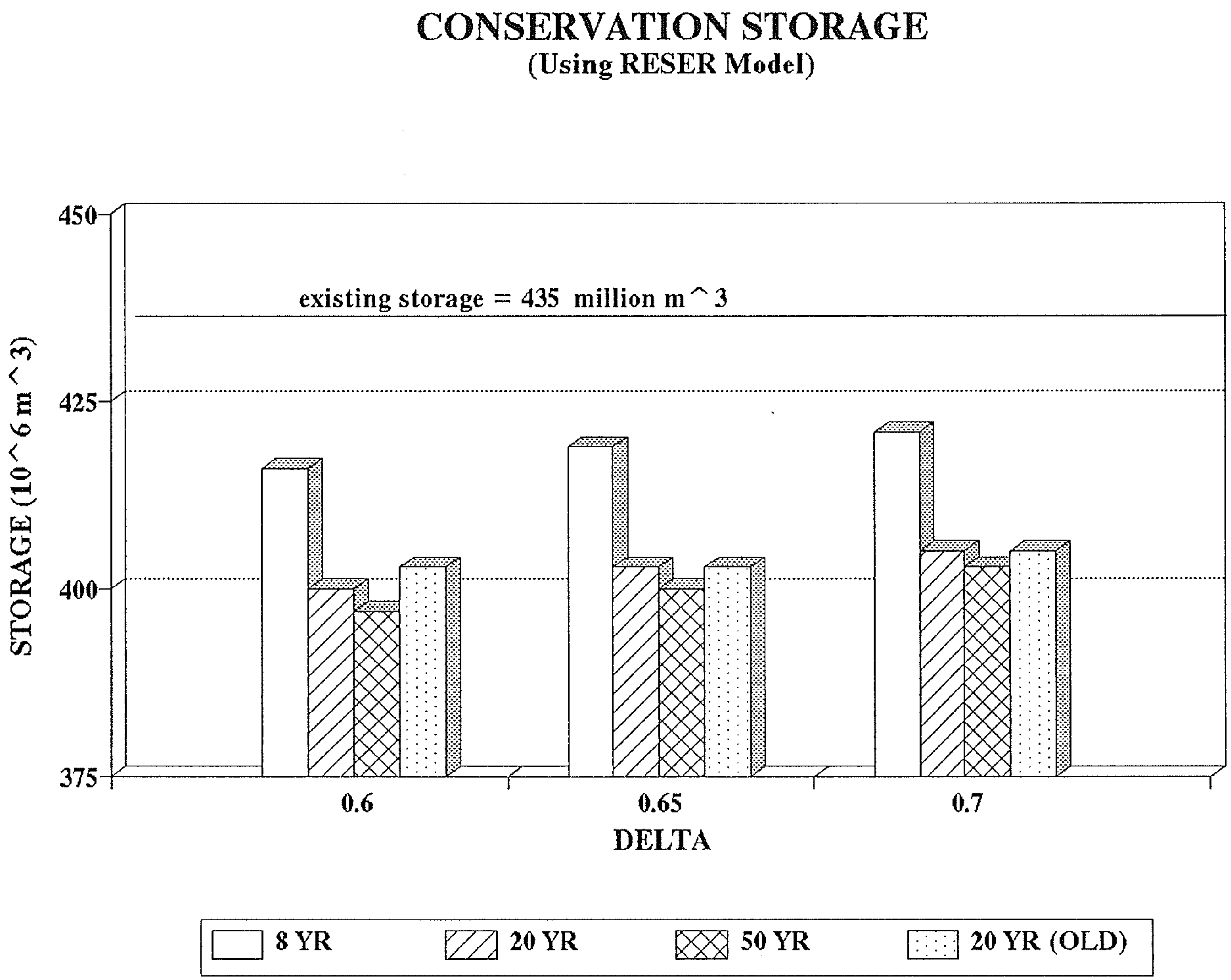

Figure 16 : The computed conservation storage using RESER model

4.2.2 Simulation by the ResQ model

The use of *ResQ* is intended to check the *RESER* output in the analysis of the storage capacity since the result of this analysis determines whether further investigation should be done to optimize the existing storage capacity. ResQ simulates the Wonogiri Reservoir operation by assigning the value of the active storage capacity derived from the RESER simulation. The volume of the active storage capacity added to the volume of existing dead storage gives the value of the top of the active storage or the active pool. By assigning the top of the active pool, the ResQ simulation is performed. Data used in running the RESER model are applied in the ResQ simulation as well. Required data and a sample output of the ResQ simulation are presented in Appendix B.

In order to identify how the results of the ResQ program support the RESER program simulation, the end-of-month storage of both models are compared by plotting them on one graph. Figures 17 and 18 show the end-of-month storage which resulted from both simulation programs using the historical record and the 20 year synthetic sequence.

4.2.3 Conclusion of the first step

Table 1 and Figure 16 show that the computed storage capacity varied under different value of monthly vulnerability criteria (delta). The smaller the delta, the smaller the required reservoir storage capacity. As well, different inflow sequences produced different values for the required storage capacity. Among the inflow

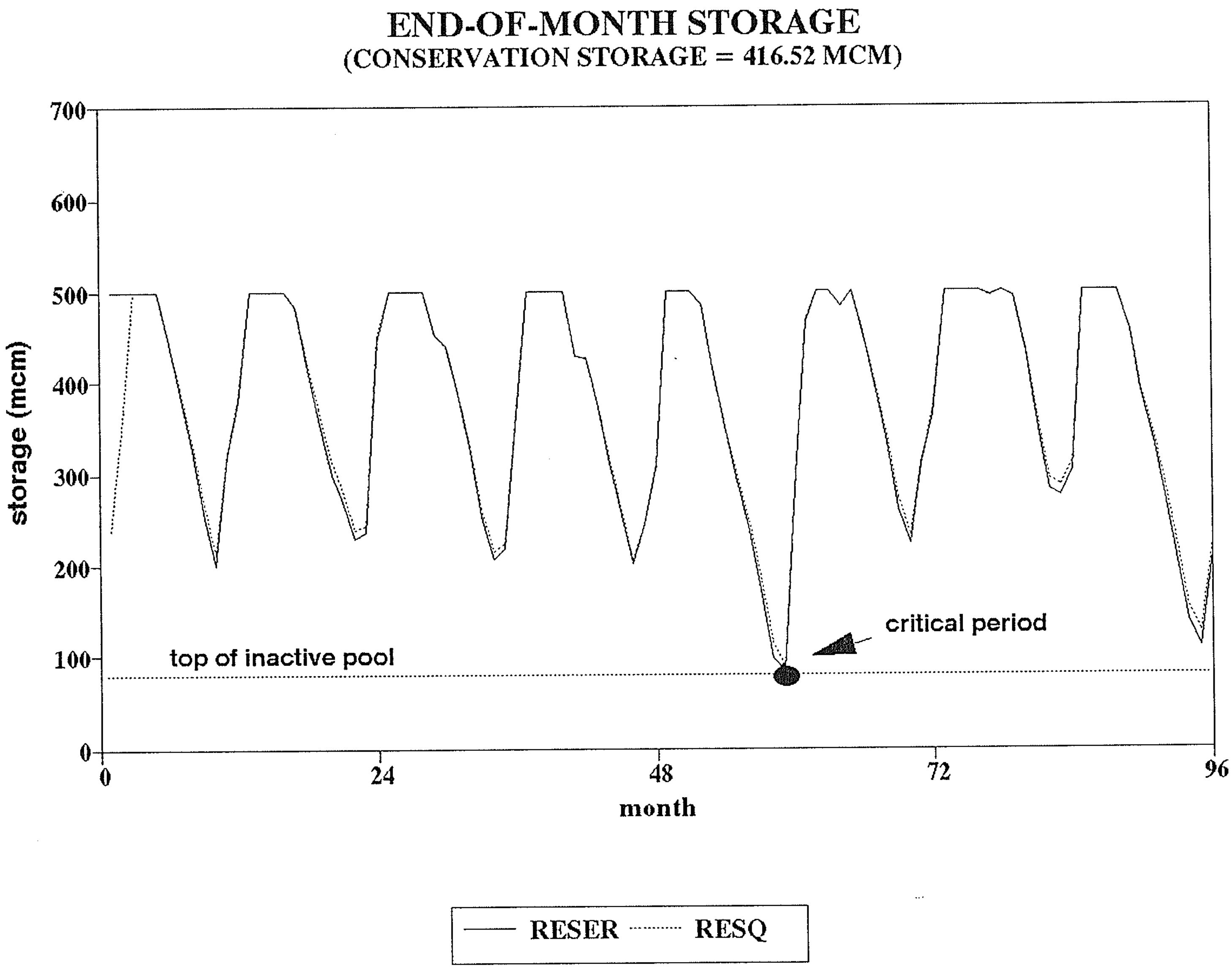

Figure 17 : The end-of-month storage for capacity = 416.52 million m^3

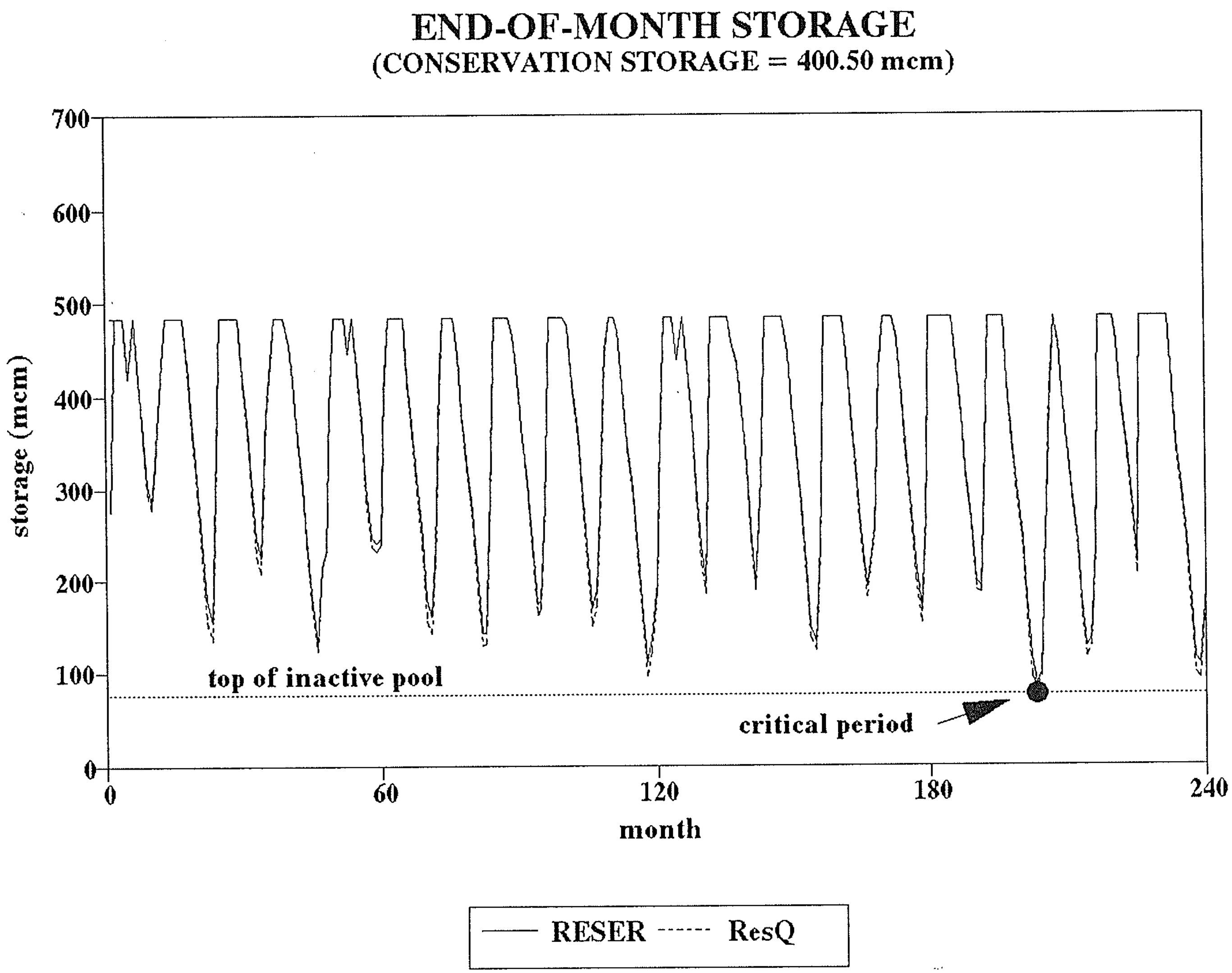

Figure 18 : The end-of-month storage for capacity = 400.50 million m^3

sequences, the historical record yielded larger storage capacities than did the others each delta. This result was reasonable since the 8 year historical record contains many drought periods. When a short historical record contains many drought periods, there is a tendency to overestimate the required storage capacity. The first 20 year generated sequence and the second 20 year synthetical inflow produced similar storage capacities which ranged from 400.50 million m^3 to 405.84 million m^3. The 50 year generated sequence gave the smallest storage capacity for each delta. Even so, these storage capacities, which varied from 397.83 million m^3 to 403.17 million m^3, were similar in result to both 20 year synthetical sequences. The largest storage capacity was 421.86 m^3/s and was derived from the historical record for delta equal to 0.70. However, it was still smaller than the existing reservoir storage capacity, i.e., 435 million m^3/s.

Figures 17 and 18 show the comparison of the end-of-month storage between the RESER and the ResQ simulation programs for active storage of 416.52 million m^3 and 400.50 million m^3, respectively. The end-of-month storage was similar for every month along the planning horizon. The ResQ program confirmed the results obtained by using the RESER program. The critical condition in Figure 18 resulted from the synthetical sequence came later than in Figure 17 which based upon the historical inflow. The illustration shows that the use of stochastic streamflow models can lead to improvements in the precision of reservoir storage estimates (*Vogel and Stedinger*, 1988).

In conclusion, the analysis of the storage capacity for the Wonogiri Reservoir pointed out that the present storage capacity was larger than that required for the increased irrigated area of 25.319 ha. *The present size of the reservoir allows for possible supply of water to fulfil other requirements.* Therefore, an examination of the potential yield of the reservoir to satisfy multiple users should be investigated. An optimal reservoir yield for multiple users can be found by reallocating the existing reservoir capacity. When reallocation occurs, modification of the existing operation rules must be implemented.

4.3 RESERVOIR YIELD OPTIMIZATION

4.3.1 Optimization by the ISRYO model

The Implicit Stochastic Model optimizes the potential yield of the Wonogiri Reservoir for the requirements of water supply, irrigation, and hydropower generation. In this study, the term water supply represents municipal and industrial water supply. An important assumption must be made to derive the "best" possible compromise to fulfill the three different water requirements. The best posible compromise in this case is represented by the value of reservoir yield (*alpha*) as the final result of the optimization. Important input for the ***ISRYO*** model is the monthly relative demand coefficients for water supply, irrigation, and hydropower. These coefficients are the basis of the optimization and are estimated by using available physical information. In this study, the relative demand coefficients for water supply are assigned as being fairly stable during the planning period. They are based on the consideration that during the dry and wet seasons, the municipal and industrial water supply requirements do not vary greatly. The relative demand coefficiets for irrigation are assigned high values during the dry season and low values in the wet season. This is reasonable since no rainfall occurs in the dry season. Water needed for irrigation is drawn from the reservoir. Inversely, to optimize the use of water accumulated in the reservoir during the wet season, the relative demand coefficients for hydropower generation are set high in the wet season and low in the dry season. These relative demand coeficients are provided for each month of the planning period (12 months). Figure 19 shows the monthly demand coefficients for water supply, irrigation, and hydropower.

The values of maximum and minimum storage needed for the analysis are assigned to be equal to the existing reservoir maximum of 518 million m^3 and minimum of 83 million m^3. In addition, this analysis uses an external autoregressive moving average (ARMA) model to generate inflow sequence as input data.

As mentioned in the description of the ISRYO model, Powell's feasible direction search method is used in the second level of this model to minimize the objective function. The procedure requires an initial point at which to start the examination. The model is run numerous times in order to choose the best value for the starting point. Finally, the starting point, which gives a high value of alpha, is selected equal to 0.80 and used for further analysis.

The ISRYO model optimizes the system under a given set of relative demand ratio associated with required supply level. Demand ratio can be defined as the ratio of total demand to total inflow. Supply level can be defined as the probability risk level associated with each user. Each combination of demand ratio associated with required supply level generates a value of reservoir yield. By running the model under various combination of demand ratios, various values of alpha are produced as well. The combinations which produce a high value of alpha are selected as the result of this investigation. The results of the reservoir yield optimization are presented in Table 2 for combination 2e (having a demand ratio of 0.4 for water supply, 0.2 for irrigation,

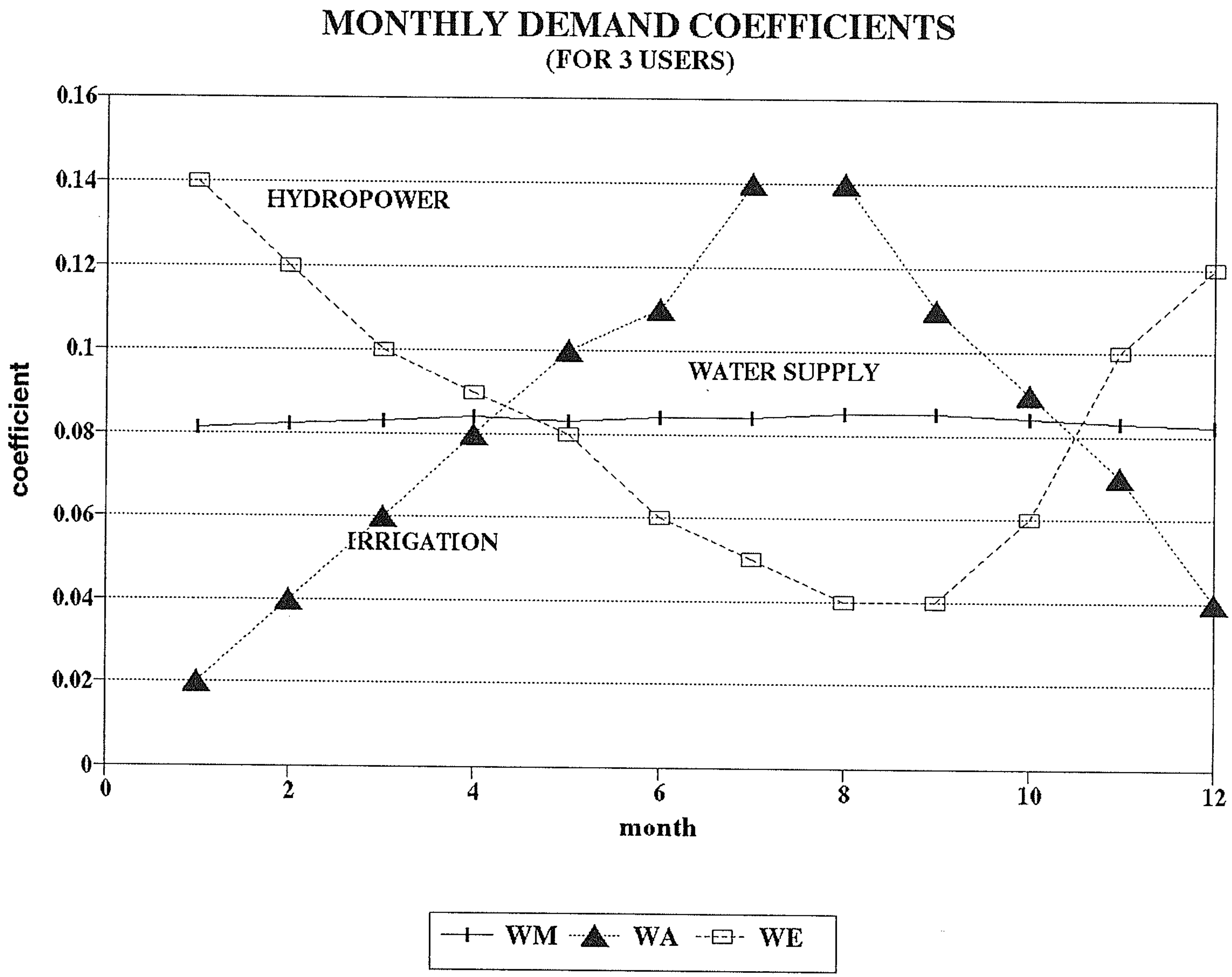

Figure 19 : The monthly demand coefficient for water supply, irrigation, and hydropower

0.4 for hydropower and 0.70 for supply level). Tables C-1 to C-13 present the rest of the combinations and are found in Appendix C. Graphical presentation of these results for analysis are recorded in Figure 20 for combination 2e and in Figures C-1 to C-13, Appendix C to present the rest of the combinations.

Table 2. THE RESULT OF RESERVOIR YIELD OPTIMIZATION

ALPHA = 0.91; BETA = 0.31

PERIOD	MEAN INFLOW	WATER SUPPLY DEM.	WATER SUPPLY REL.	RRIGATION DEM.	RRIGATION REL.	HYDRO POWER DEM.	HYDRO POWER REL.
1	302.766	41.665	41.665	5.144	5.144	72.013	72.013
2	278.643	42.179	42.179	10.288	10.288	61.726	61.726
3	227.477	42.694	42.694	15.431	15.431	51.438	51.438
4	130.533	43.208	43.208	20.575	20.575	46.294	46.294
5	103.815	42.694	42.129	25.719	23.679	41.150	39.518
6	114.307	43.208	42.637	28.291	26.047	30.863	29.639
7	3.884	43.208	42.469	36.007	32.313	25.719	24.400
8	0.268	43.722	42.975	36.007	32.313	20.575	19.520
9	6.195	43.722	42.940	28.291	25.253	20.575	19.470
10	24.025	43.208	42.435	23.147	20.661	30.863	29.206
11	68.714	42.694	42.092	18.003	16.481	51.438	49.263
12	152.937	42.179	41.585	10.288	9.417	61.726	59.115
SUM	1413.564	514.380	509.006	257.190	237.601	514.380	501.601
DEMAND RATIO		0.400	0.360	0.200	0.168	0.400	0.355
SUPPLY LEVEL		0.950	0.990	0.700	0.924	0.850	0.975

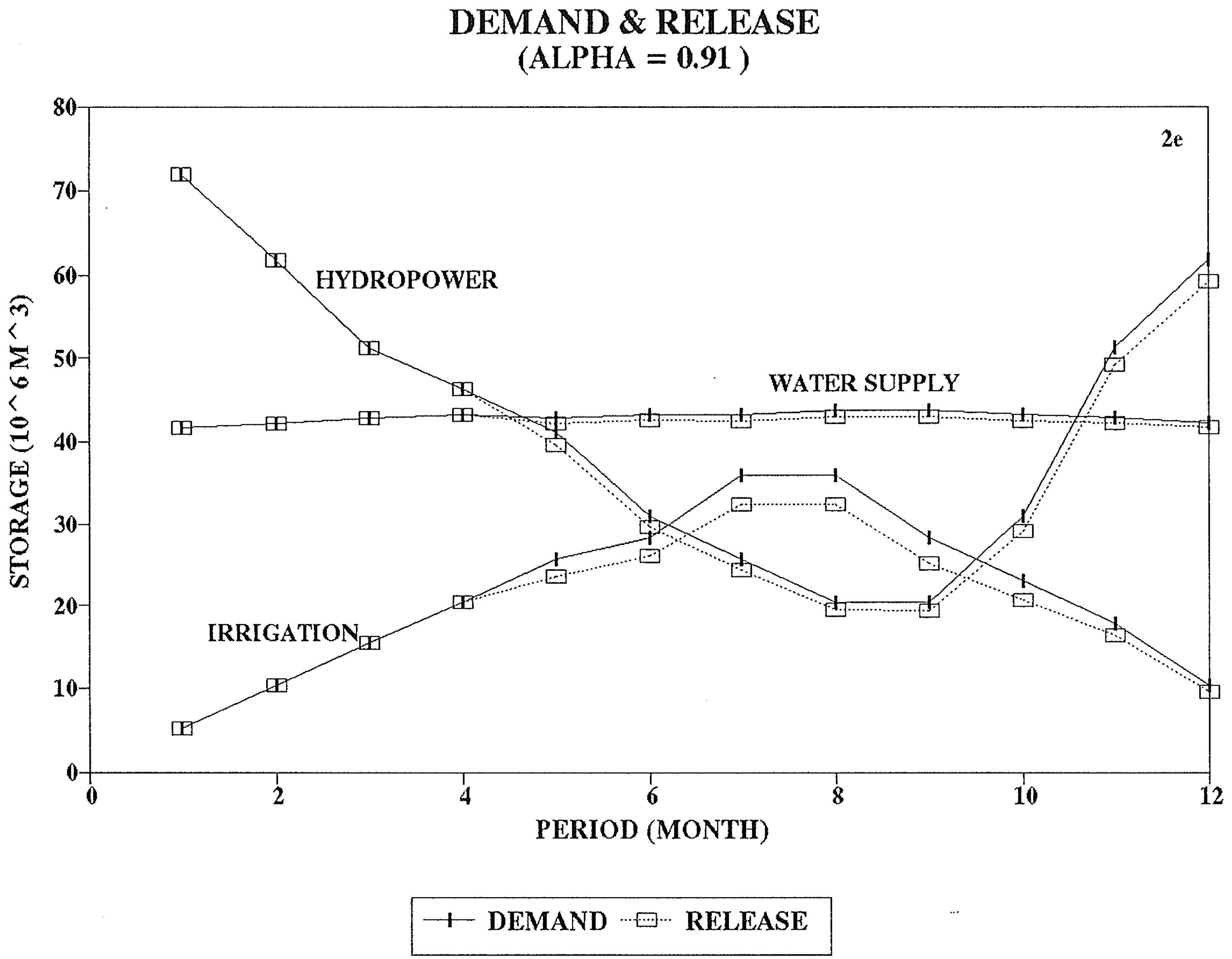

Figure 20 : Demand and release for combination 2e

Table 2 is the result of the optimization for the second combination of demand ratios and fifth combination of the required supply level (combination 2e - see Table 3). Alpha represents the final output of the reservoir yield optimization that is the "best" possible compromise for the different water needs. Beta is the ratio of total inflow and reservoir capacity. The second column contains the average reservoir inflow. Colomns 3 to 8 present the monthly demand and monthly optimal release for water supply, irrigation and hydropower. The monthly demand is derived from the *optimal* demand multiplied by the monthly relative demand coefficient for each requirement. The releases are the optimal monthly releases for each purpose. The demand ratio row gives the values of the ratio of total demand and total releases to total inflow. The supply level row presents the required supply reliability level and computed reliability level for each purpose.

Figure 20 illustrates the demand and release for each water user presented in Table 2. This figure shows that the curve of releases closely resembles to the curve of demands. It indicates that the three demands: water supply, irrigation, and hydropower can be fulfilled satisfactorily. For the irrigation curve, the releases during the dry period are slightly lower than the demand compared to water supply and hydropower. The result is consistent with the low reliability level assigned to irrigation in this particular run (0.70).

Table 3 shows the set of computational experiments performed to find the optimal reservoir yield (alpha). However, only 14 sets of results (anotated by *) are used for

TABLE 3. COMPUTED RESERVOIR YIELD (ALPHA)

Combination of Supply Level	Combination of Demand Ratio 1	2	3	4
a	0.83*	0.91*	0.58	0.58
b	0.87*	0.91*	0.74	0.62
c	0.85*	0.91*	0.88*	0.62
d	0.94*	0.91*	0.76	0.80*
e	0.85*	0.91*	0.85*	0.91*

Note:

SUPPLY LEVEL :

. Combination	PM	PA	PE
a	.95	.90	.85
b	.95	.85	.85
c	.95	.80	.85
d	.95	.75	.85
e	.95	.70	.85

. PM --> WATER SUPPLY
. PA --> IRRIGATION
. PE --> HYDROPOWER

DEMAND RATIO :

. Combination	WM	WA	WE
1	.40	.40	.20
2	.40	.20	.40
3	.30	.60	.10
4	.20	.60	.20

. WM --> WATER SUPPLY
. WA --> IRRIGATION
. WE --> HYDROPOWER

further analysis. In the first column: a, b, c, d, and e represent the combinations of the required supply level. The supply level for water supply (PM) is set equal to 0.95. It is based on the consideration that water supply losses are high compared to other users. The supply level for irrigation (PA) varies from 0.90 to 0.70. This setting is based on the consideration that the irrigation demand is highly irregular and has a greater probability of failures compared to other users. Setting various PA may provide a better way to determine the selected combination of demand ratios. For hydropower, the supply level is assigned equal to 0.85 due to the assumption that hydropower is only one possible source of electric energy. The second row of Table 3 gives 4 combinations of demand ratios for the three water needs. *The 4 sets are selected as sets generating high alpha value. This has been confirmed after running the program many times under many sets of demand ratios.*

Moreover, the model calculates the number of failures and the reliability of release for each time interval and for different failure magnitudes. Six two-month time intervals are used in this study to present efficiently the number of failures as well as the reliability of the release. The different failure magnitudes are obtained for each user and for each time interval during planning horizon. In this study, 8 different failure magnitudes are assigned to the model: 1%, 10%, 20%, 30%, 40%, 50%, 60%, and 70%. The results of this calculation for alpha equal to 0.94 and 0.91 are shown in Tables 4 and 5 and Figures 21 to 26. A sample output of the computer calculation and the ISRYO program listing are given in Appendix C.

Table 4. NUMBER OF FAILURES and RELIABILITY LEVEL
(COMBINATION 1d - ALPHA = 0.94)

Period	FAILURE MAGNITUDE (%) 1	10	20	30	40	50	60	70
- WATER SUPPLY								
1	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1
2	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1
3	31	26	1	0	0	0	0	0
	0.38	0.48	0.98	1	1	1	1	1
4	37	37	0	0	0	0	0	0
	0.26	0.26	1	1	1	1	1	1
5	26	0	0	0	0	0	0	0
	0.48	1	1	1	1	1	1	1
6	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1
- IRRIGATION								
1	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1
2	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1
3	31	31	31	30	28	26	0	0
	0.38	0.38	0.38	0.40	0.44	0.48	1	1
4	37	37	37	37	37	37	0	0
	0.26	0.26	0.26	0.26	0.26	0.26	1	1
5	28	20	0	0	0	0	0	0
	0.44	0.60	1	1	1	1	1	1
6	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1
- HYDROPOWER								
1	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1
2	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1
3	31	31	28	26	22	16	0	0
	0.38	0.38	0.44	0.48	0.56	0.68	1	1
4	37	37	37	37	0	0	0	0
	0.26	0.26	0.26	0.26	1	1	1	1
5	28	10	0	0	0	0	0	0
	0.44	0.80	1	1	1	1	1	1
6	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1

Table 5. NUMBER OF FAILURES and RELIABILITY LEVEL
(COMBINATION 2e - alpha = 0.91)

Period	FAILURE MAGNITUDE (%)							
	1	10	20	30	40	50	60	70
- WATER SUPPLY								
1	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1
2	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1
3	26	0	0	0	0	0	0	0
	0.48	1	1	1	1	1	1	1
4	36	0	0	0	0	0	0	0
	0.28	1	1	1	1	1	1	1
5	30	0	0	0	0	0	0	0
	0.4	1	1	1	1	1	1	1
6	18	1	1	0	0	0	0	0
	0.64	0.98	0.98	1	1	1	1	1
- IRRIGATION								
1	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1
2	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1
3	26	25	0	0	0	0	0	0
	0.48	0.50	1	1	1	1	1	1
4	37	34	0	0	0	0	0	0
	0.26	0.32	1	1	1	1	1	1
5	33	30	5	0	0	0	0	0
	0.34	0.40	0.90	1	1	1	1	1
6	18	16	6	1	1	1	1	1
	0.64	0.68	0.88	0.98	0.98	0.98	0.98	0.98
- HYDROPOWER								
1	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1
2	0	0	0	0	0	0	0	0
	1	1	1	1	1	1	1	1
3	26	0	0	0	0	0	0	0
	0.48	1	1	1	1	1	1	1
4	37	0	0	0	0	0	0	0
	0.26	1	1	1	1	1	1	1
5	33	5	0	0	0	0	0	0
	0.34	0.9	1	1	1	1	1	1
6	18	6	1	1	1	1	1	1
	0.64	0.88	0.98	0.98	0.98	0.98	0.98	0.98

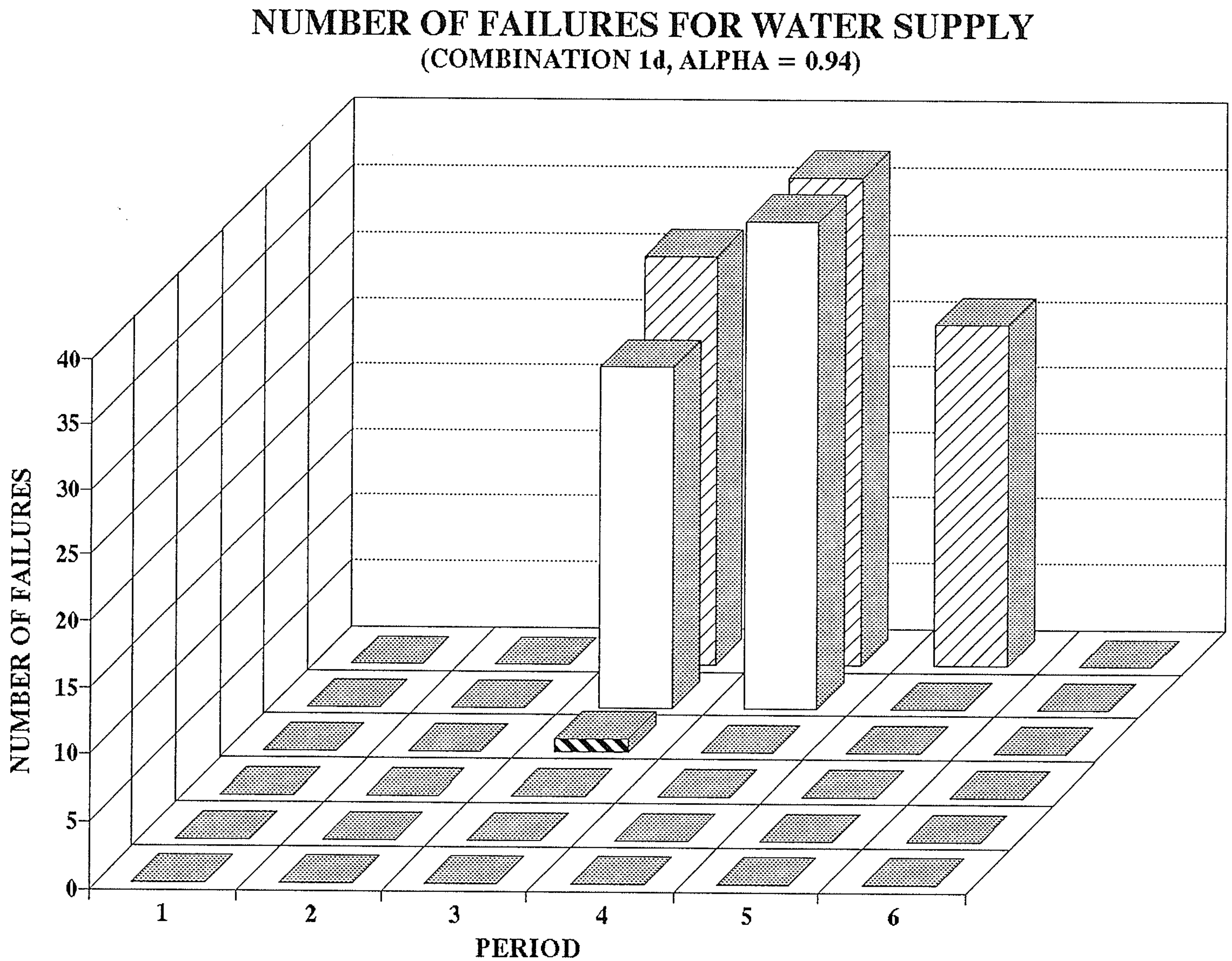

Figure 21 : The number of failures for water supply (alpha = 0.94)

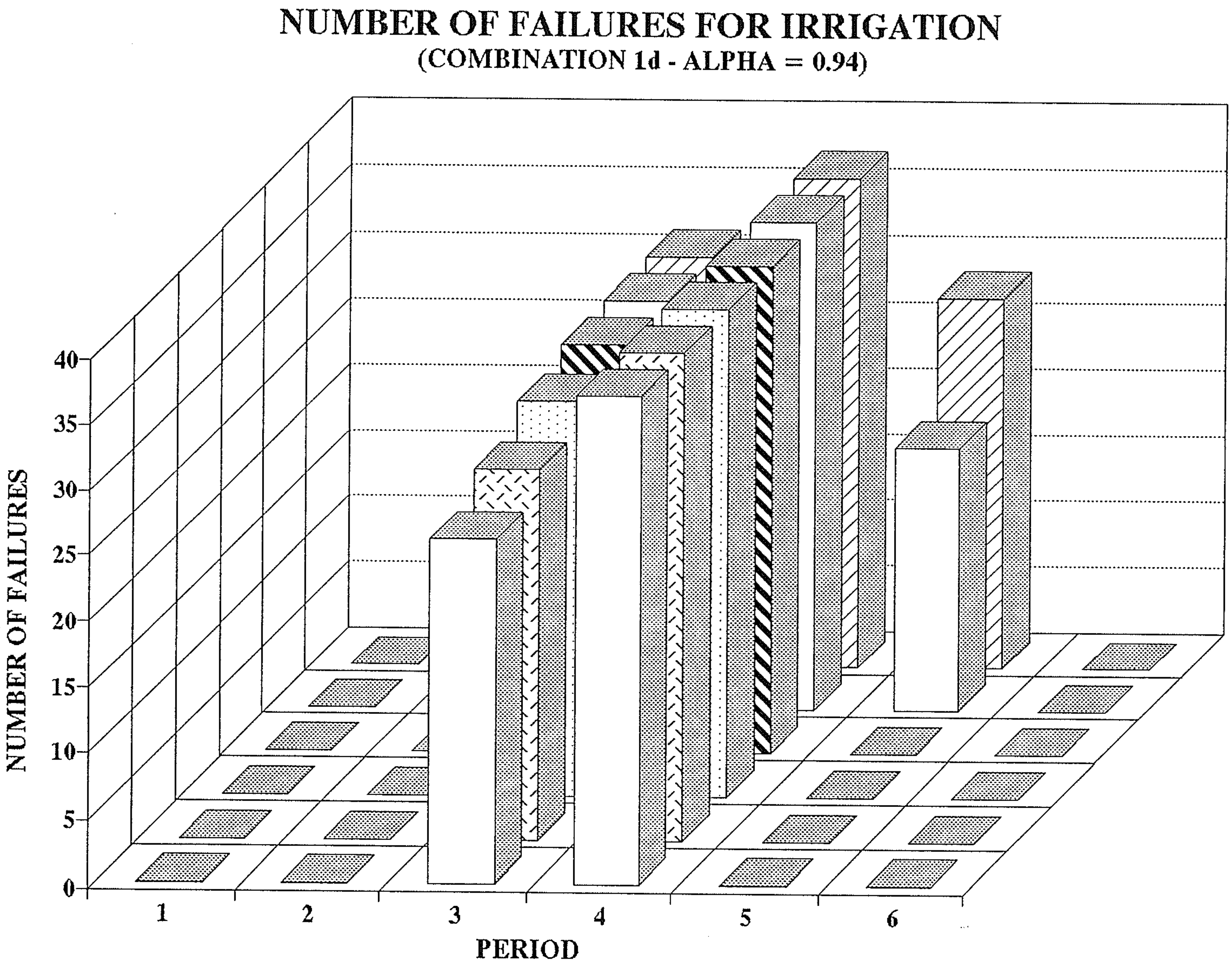

Figure 22 : The number of failures for irrigation (alpha = 0.94)

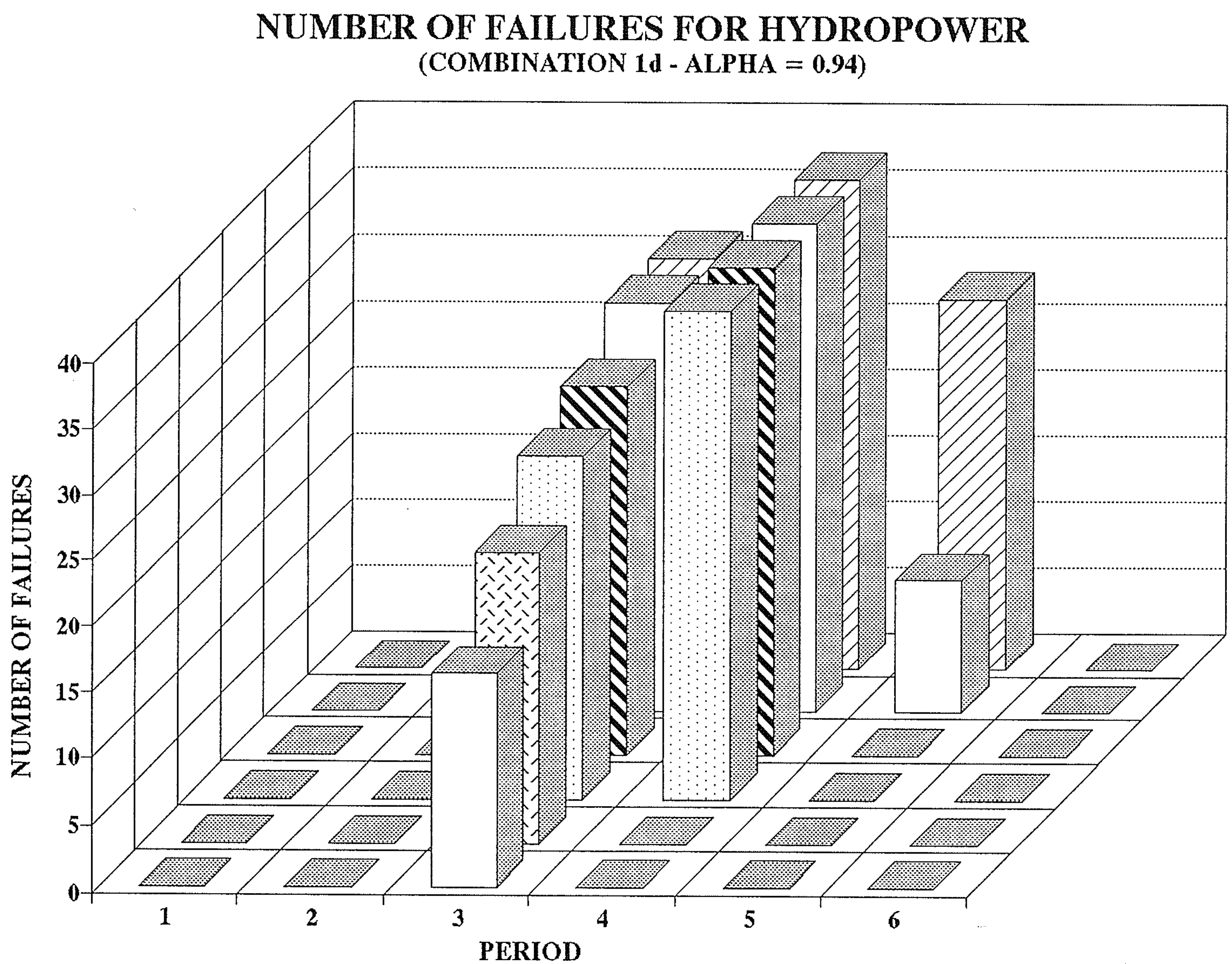

Figure 23 : The number of failures for hydropower (alpha = 0.94)

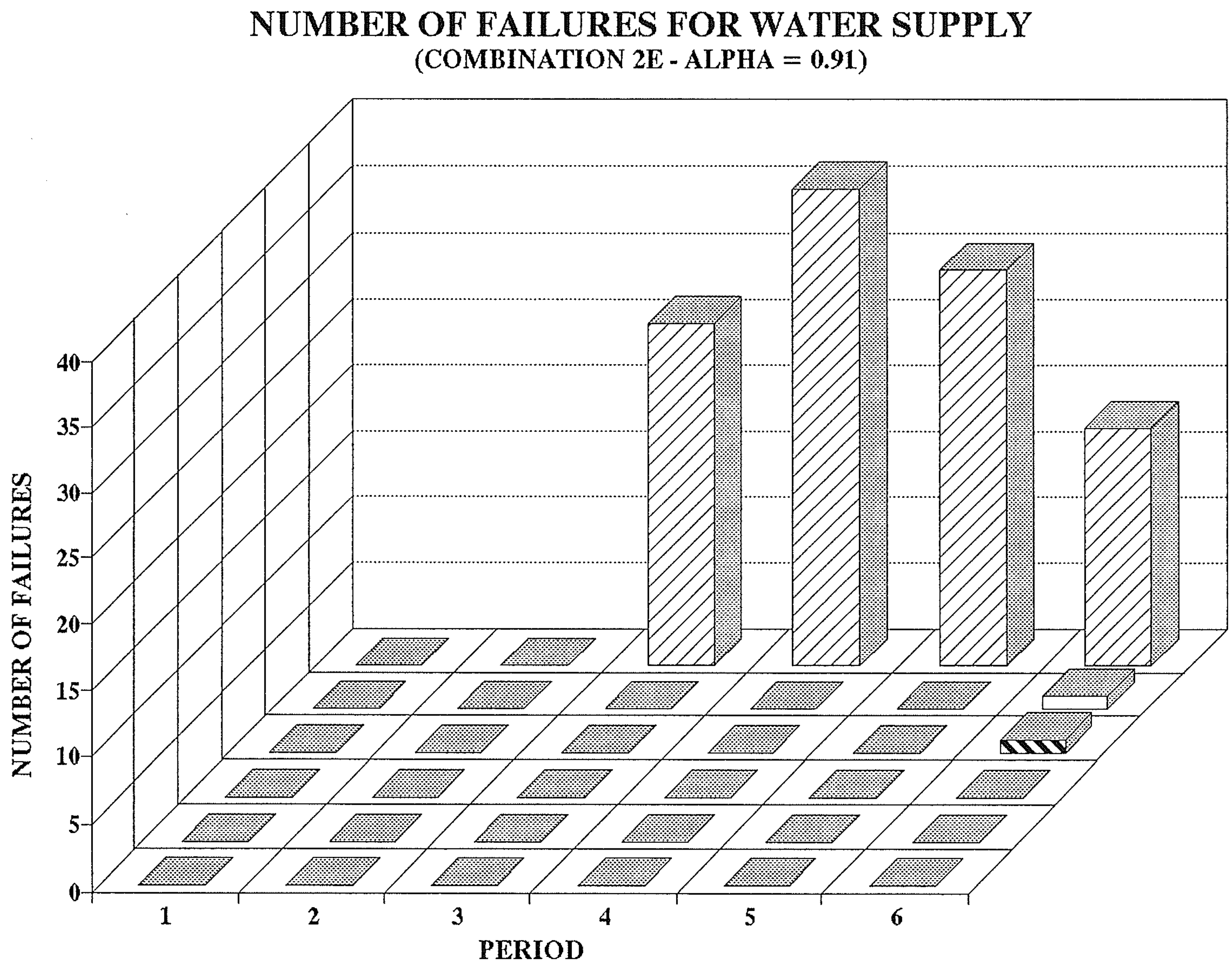

Figure 24 : The number of failures for water supply (alpha = 0.91)

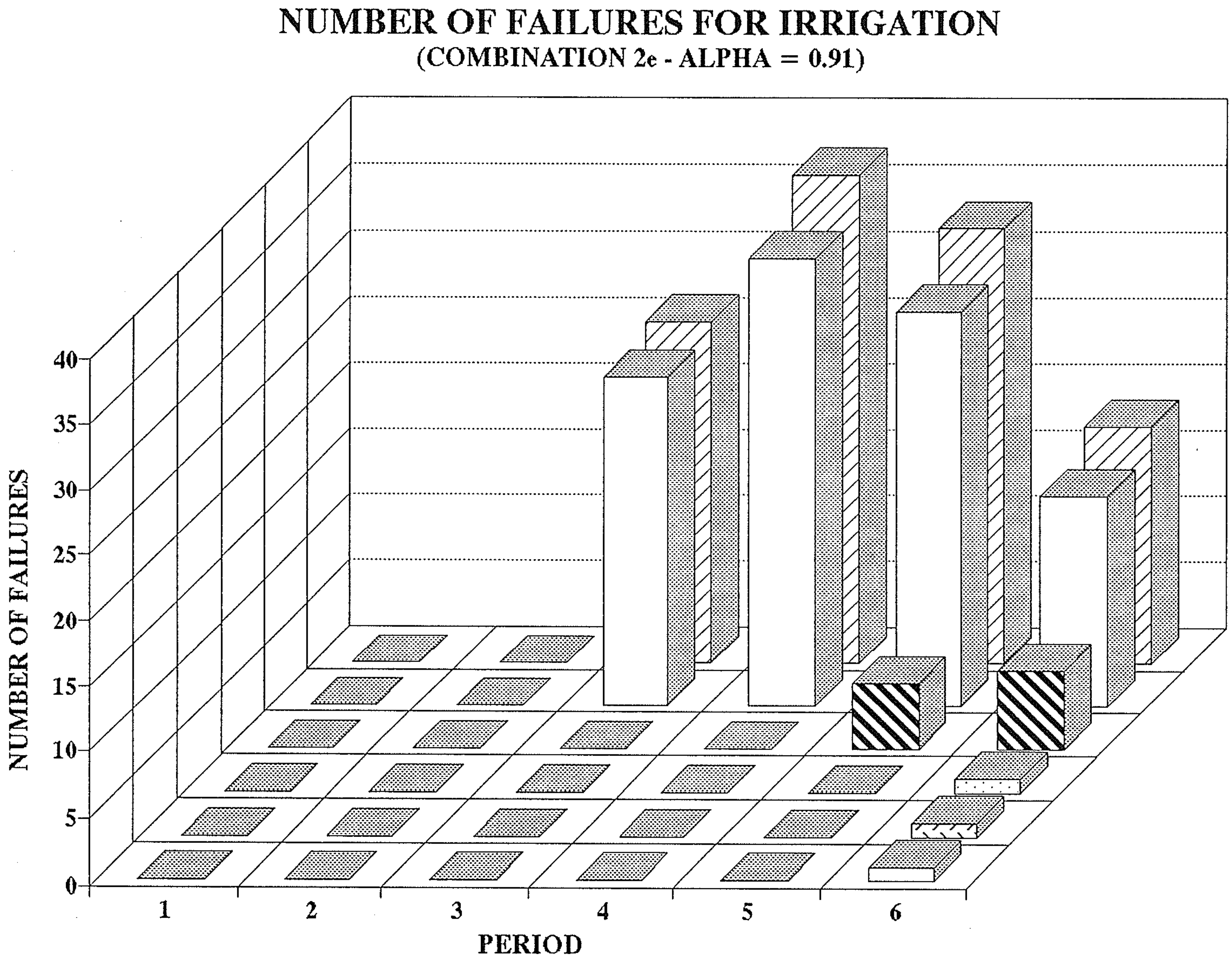

Figure 25 : The number of failures for irrigation (alpha = 0.91)

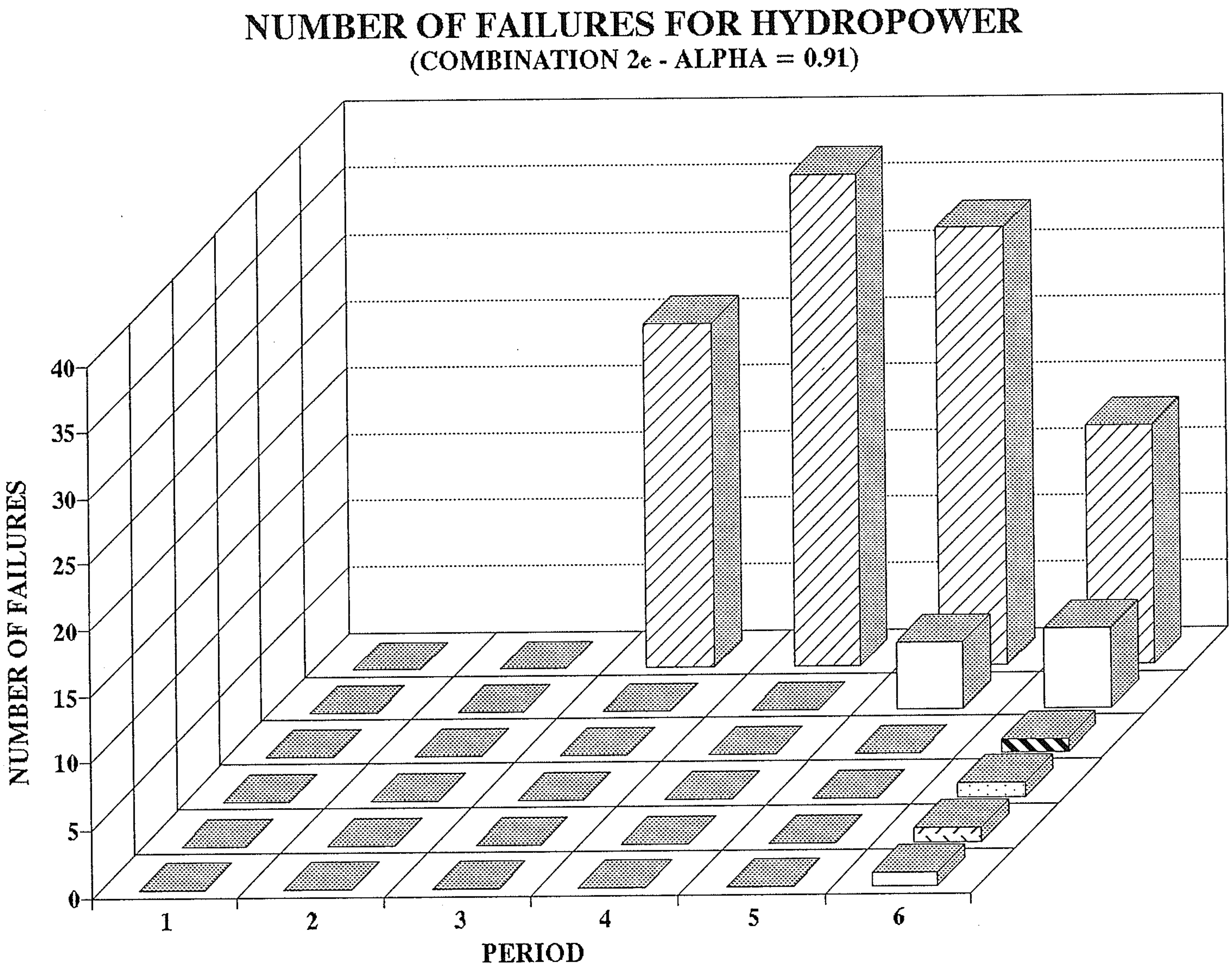

Figure 26 : The number of failures for hydropower (alpha = 0.91)

4.3.2 DISCUSSION OF THE RESULTS

Table 3 points out that the second combination of demand ratios, which is equal to 0.4 for water supply, 0.2 for irrigation and 0.4 for hydropower, gives the same value of alpha, i.e., 0.91 for all required supply levels. The last row of Table 2 as well as Table C-6 to C-9 show that the computed supply levels are larger than that required for all water users. Thus, this combination facilitates satisfactorily all demands associated with the required supply level (see also Figures C-6 to C-9 and Figure 21). This might be caused by the low value of irrigation demand ratio assigned in this group. Assigning a low value to the irrigation demand ratio tends to minimize the probability of failure for all demands. In addition, Table 2 and Tables C-6 to C-9 point out that irrigation releases are greater than that required for the extention of the irrigated area of 25,319 ha used in the analysis of the existing storage of the Wonogiri Reservoir in Chapter 4.2.

Combination 1 presents four different values of alpha ranging from 0.83 to 0.94. Figures C-1 to C-5 show that irrigation releases could not satisfactorily fulfill the irrigation demand during the dry period. However, assigning a low priority to the irrigation supply can produce better results. This can be seen in combinations 1d and 1e presented in Figures C-4 and Figure C-5. Needs for water supply and hydropower are not as well satisfied in combinations 1a, 1b, and 1c drawn in Figures C-1 to C-3. Therefore, combinations 1d and 1e can be selected as better choices. These combinations are relatively sensitive to a change in the required supply level. However, the alphas produced are still comparatively high. Although irrigation demand assigned in this combination can not be fulfilled satisfactorily during the dry period, the irrigation releases (see Table C-1 to C-6) are approximately one and one half times that required for 25,319 ha. Therefore, it can be assumed that the irrigation releases are sufficient for irrigation of the expected area of 30,000 ha (see background of the Wonogiri Reservoir in Chapter 4.1). Combination 1d, which has alpha greater than combination 1e, is used for this group to compare it to other alternatives.

Combinations 3 and 4 in Table 3, which are assigned as having a high value of irrigation demand ratio, produce a variety of alpha which ranges from 0.58 to 0.88 for combination 3, and 0.58 to 0.91 for combination 4. Figures C-10 to C-13 illustrate unsatisfactory result in meeting the irrigation demand. There was a considerable shortage of water for irrigation during the dry period.

Most of the combinations of demand ratios and supply level satisfy the water supply and hydropower requirements. The problem of finding an optimal reservoir yield may be greatly influenced by assigning the irrigation demand ratio. This seems reasonable, since irrigation is a dependent on a number of different physical parameters such as precipitation and soil moisture over the analyzed region.

Tables 4 and 5 present the number of failures for each time interval and the different failure magnitudes for combination 1d and 2e, respectively. For each time interval, the first row contains the number of failures and the second row gives the reliability levels. When no failure, represented by zero value, occurs, the reliability level is equal to one. This means that the demand can be satisfactorily fulfilled. When failures occur, the reliability levels are equal to a certain value associated with the number of failures. It has been observed that the number of failures smaller in magnitude is larger than the number of failures larger in magnitudes. Tables 4 and 5 show that for each requirement - water supply, irrigation or hydropower -, the total number of failures obtained with alpha of 0.94 is larger than the number obtained with alpha of 0.91. These tables are very useful in analyzing the number of failures and their relationship to reservoir yield.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Based on the computation and discussion in the previous chapter, a number of conclusions and recommendations can be drawn as follows:

- New reservoir management problem, i.e., reallocation of reservoir storage and modification of operating policy for an existing single multipurpose reservoir, has been addressed in the field of reservoir operation and management.

- The overall procedure or methodology for the management of an existing reservoir contributes in optimizing the use of the existing reservoir by determining the priority of using the reservoir among the reservoir users being considered. The best combination of the priority is measured by the optimal value of reservoir yield.

- This study proposes two step solution for the management of an existing single multipurpose reservoir as follows: (i) Analysis of the existing reservoir storage using simulation models, and (ii) Examination of the reservoir yield using an optimization approach.

- The RESER and the ResQ models simulate the existing reservoir storage in the first step. The ISRYO algorithm accomplishes properly the reservoir yield in the second step.

- The use of synthetic inflows can lead to improve in the precision of reservoir storage estimates and gives the planner a clearer picture of the variety of the reservoir storage estimates.

- The estimation of monthly demand coefficients plays an important role in the optimization of reservoir yield.

CASE STUDY :

- Due to the attainment of self-sufficiency in rice production and industrial growth in Java Island-Indonesia, reallocation of the existing storage of the Wonogiri Reservoir to incorporate the need for hydropower generation and industrial and municipal water supply is recommended.

- The analysis of the existing storage of the Wonogiri Reservoir demonstrates that the present storage capacity of the reservoir is greater than that required for the increased irrigated area of 25,319 ha. Therefore reallocation of the existing storage capacity for electric generation and water supply without ignoring the present function, i.e., irrigation, is workable.

- The water supply-irrigation-hydropower demand ratio of 0.4/0.2/0.4 generates the "best" possible compromise among the three water users. Obtained reservoir yield equals 0.91 for all supply levels. Therefore, this demand ration is recommended. During the planning period, the monthly releases for the three water needs have satisfactorily fulfilled the demands. In addition, the irrigation releases are still larger than that required for the irrigation area of 25,319 ha even for the case of the lowest reliability level (0.70). Thus, this combination is sufficient for all three requirements even with an with an irigation area larger than presently being considered.

- If decision makers still emphasize a need to increase rice production, combination 1 can be selected. Although, this combination is not as satisfactory as combination 2 in fulfilling all demands, it maybe successful in providing water for a further extention of the irrigation area. Increasing the irrigation demand ratio to more than 0.4, is *not* recommended. This was substantiated by the results of combinations 3 and 4 which show 0.6 as the irrigation demand ratio. However, since the self-sufficiency confidence of rice production has been attained, this combination maybe less important than combination 2.

- Further research should concentrate on determining more accurate monthly relative demand coefficients. The best estimate can be derived by reviewing general information on water demands in Indonesia.

- The results of this study are confirm that:

  . Due to the achievement of self-sufficiency in rice production, decision makers may change their policies associated with the original authorized purposes for Wonogiri Reservoir.

  . The emphasis on irrigation represented by assigning a demand ratio of 0.2 (combination 2) or 0.4 (combination 1) covers an extention area that is in the process of being implemented.

  . There is a consideration to supply water from the Wonogiri Reservoir to fulfill an existing need in East Java province (direct communication with the chief of Operation and Maintenance for the Wonogiri Reservoir).

  . The need for electricity tends to increase steadily. Currently, the Island of Java is facing an energy crisis. As a consequence, some industrial demands for electricity can not be met.

FUTURE WORK

- Analysis of the storage capacity of an existing reservoir should incorporate a large number of synthetic inflow sequences to produce a variety of reservoir storage estimates. The reservoir storage estimates are then fitted to a frequency distribution. The computed reservoir storage is determined based on a desired probability level.

- The improvement of the ISRYO model should cover the procedure of using stochastic input data as follows:

  . The montly demand coefficients should be stochastic demand coefficients which range based on a desired confident interval.

  . The reservoir inflows should be stochastic inflow sequences which produce a value of reservoir yield (alpha) for each sequence.

  . The various values of alpha are then fitted to a frequency distribution.

  . A value of alpha, as a final result of reservoir yield optimization, is selected based on a desired probability level.

REFERENCES

Can, E.K. and M.H. Houck. 1984. **Real-Time Reservoir Operation by Goal Programming.** *Journal of Water Resources Planning and Management.* 110(3):297-308.

Can, E.K. and M.H. Houck. 1985. **Problems with Modelling Real-Time Reservoir Operations.** *Journal of Water Resources Planning and Management.* 111(4):367-381.

Fiering, M.B. 1961. **Queing Theory and Simulation in Reservoir Design.** *Journal of the Hydraulic Division.* 87(HY6):39-69).

Ford, D.T. 1990. **Reservoir Storage Reallocation Analysis with PC.** *Journal of Water Resources Planning and Management.* 116(3):402-416.

Feldman, A.D. 1992. **Systems Analysis Applications at The Hydrologic Engineering Centre.** *Journal of Water Resources Planning and Management.* 118(3):249-261).

Goodman, A.S. 1984. *Principles of Water Resources Planning.* Prentice Hall. Englewood Cliffs. New Jersey.

Houck, M.H. and B. Datta. 1981. **Performance Evaluation of a Stochastic Optimization Model for Reservoir Design and Management With Explicit Reliability Criteria.** *Water Resources Research.* 17(4):827-832.

Johnson, W.K., R.A. Wurbs, and J.E. Beegle. 1990. **Opportunities for Reservoir-Storage Reallocation.** *Journal of Water Resources Planning and Management.*

116(4):550-566.

Klemes, V. 1987. **One Hundred Years of Applied Storage Reservoir Theory**. *Water Resouces Management I*. 159-175.

Kuester, J.L., and J.H. Mize. 1973. *Optimization Techniques with Fortran*. McGraw-Hill. New York.

Loucks, D.P., J.R. Stedinger and D.A. Haith. 1981. *WaterResources Systems Planning and Analysis*. Prentice Hall, Englewood. Cliffs,NY,USA.

Lee, H., J.C. Liebman., and E. Downey. 1992. **Performance Evaluation of Lake Shelbyville by Stochastic Dynamic Programming.** *Journal of Water Resources Planning and Management*. 118(2):185-204.

McMahon, T.A. and R.G. Mein. 1978. *Reservoir Capacity and Yield*. Elsevier Scientific Publishing Co. NY.

Nippon Koei CO, LTD. 1984. *Wonogiri Multipurpose Dam Project Manual Operation and Maintenance*. Indonesia.

Reznicek, K.R. and S.P. Simonovic. 1991. **Optimization of short-term operation of a single multipurpose reservoir - a goal programming approach.** *Canadian Journal Civil Engineering*. 18:397-406.

Stedinger, J.R. 1984. **The Performance of LDR Models for Preliminary Design and Reservoir Operation**. *Water Resources Research*. 20(2):215-224.

Simonovic, S.P. 1987. **The Implicit Stochastic Model for Reservoir Yield Optimization.** *Water Resources Research*. 23(12): 2159-2165.

Simonovic, S.P. and D.H. Burn. 1989. **An Improved Methodology for Short-Term Operation of a Single Multipurpose Reservoir.** *Water Resources Research.* 25(1):1-8.

Simonovic, S.P. 1991. **Coping with changing objective in managing an existing multipurpose reservoir.** *Hydrology of Natural and Manmade Lakes.* IAHS Publ. no. 206.

Simonovic, S.P. 1992. **Reservoir Systems Analysis: Closing The Gap between Theory and Practice.** *Journal of Water Resources Planning and Management.* 118(3):262-280.

Vogel, R.M. and J.R. Stedinger. 1988. **The Value of Stochastic Streamflow Models in Overyear Reservoir Design Applications**. *Water Resources Research.* 24(9):1483-1490.

Wurbs, R.A. 1991. **Review of Modelling and Analysis Approaches for Optimization of Reservoir System Operation.** *Hydraulic Enginering: Proceedings of the 1991 National Conference*. Nashville, Tannessee.

Yeh, W. W-G. 1985. **Reservoir Management and Operations Models: A state of-the-Art-Review.** *Water Resources Research.* 21(12):1797-1818.

Young, K. 1967. **Finding Reservoir Operating Rules.** *Journal of Hydraulic Division.* 93(HY6):297-320.

Yazicigil, H., M.H. Houck, and G.H. Toebes. 1983. **Daily Operation of a Multipurpose Reservoir System.** *Water Resources Research*. 19(1):1-13

APPENDIX A

RESER SIMULATION PROGRAM

TABLE A-1: THE RESULTED CONSERVATION STORAGE (MIL M3/S) WITH DIFFERENT SET OF RELIABILITY AND VULNERABILITY

	REQUIRED				RESERVOIR INFLOW SEQUENCES			
	ALPHA	BETA	GAMMA	DELTA	(8 YR) a	(20 YR) b	(50 YR) c	(20 YR) d
1	0.80	0.70	0.60	0.60	416.52	400.50	397.83	403.17
2				0.65	419.19	403.17	400.50	403.17
3				0.70	421.86	405.84	403.17	405.84
4	0.80	0.70	0.70	0.60	416.52	400.50	397.83	403.17
5				0.65	419.19	403.17	400.50	403.17
6				0.70	421.86	405.84	403.17	405.84
7	0.80	0.70	0.80	0.60	416.52	400.50	397.83	403.17
8				0.65	419.19	403.17	400.50	403.17
9				0.70	421.86	405.84	403.17	405.84
10	0.80	0.75	0.60	0.60	416.52	400.50	397.83	403.17
11				0.65	419.19	403.17	400.50	403.17
12				0.70	421.86	405.84	403.17	405.84
13	0.80	0.75	0.70	0.60	416.52	400.50	397.83	403.17
14				0.65	419.19	403.17	400.50	403.17
15				0.70	421.86	405.84	403.17	405.84
16	0.80	0.75	0.80	0.60	416.52	400.50	397.83	403.17
17				0.65	419.19	403.17	400.50	403.17
18				0.70	421.86	405.84	403.17	405.84
19	0.80	0.80	0.60	0.60	416.52	400.50	397.83	403.17
20				0.65	419.19	403.17	400.50	403.17
21				0.70	421.86	405.84	403.17	405.84
22	0.80	0.80	0.70	0.60	416.52	400.50	397.83	403.17
23				0.65	419.19	403.17	400.50	403.17
24				0.70	421.86	405.84	403.17	405.84
25	0.80	0.80	0.80	0.60	416.52	400.50	397.83	403.17
26				0.65	419.19	403.17	400.50	403.17
27				0.70	421.86	405.84	403.17	405.84

a: Historical record
b: Synthetical inflow (ARMA)
c: Synthetical inflow (ARMA)
d: Synthetical inflow used in designing the Wonogiri Dam

	REQUIRED ALPHA	BETA	GAMMA	DELTA	RESERVOIR INFLOW SEQUENCES (8 YR) a	(20 YR) b	(50 YR) c	(20 YR) d
28	0.90	0.70	0.60	0.60	416.52	400.50	397.83	403.17
29				0.65	419.19	403.17	400.50	403.17
30				0.70	421.86	405.84	403.17	405.84
31	0.90	0.70	0.70	0.60	416.52	400.50	397.83	403.17
32				0.65	419.19	403.17	400.50	403.17
33				0.70	421.86	405.84	403.17	405.84
34	0.90	0.70	0.80	0.60	416.52	400.50	397.83	403.17
35				0.65	419.19	403.17	400.50	403.17
36				0.70	421.86	405.84	403.17	405.84
37	0.90	0.75	0.60	0.60	416.52	400.50	397.83	403.17
38				0.65	419.19	403.17	400.50	403.17
39				0.70	421.86	405.84	403.17	405.84
40	0.90	0.75	0.70	0.60	416.52	400.50	397.83	403.17
41				0.65	419.19	403.17	400.50	403.17
42				0.70	421.86	405.84	403.17	405.84
43	0.90	0.75	0.80	0.60	416.52	400.50	397.83	403.17
44				0.65	419.19	403.17	400.50	403.17
45				0.70	421.86	405.84	403.17	405.84
46	0.90	0.80	0.60	0.60	416.52	400.50	397.83	403.17
47				0.65	419.19	403.17	400.50	403.17
48				0.70	421.86	405.84	403.17	405.84
49	0.80	0.80	0.70	0.60	416.52	400.50	397.83	403.17
50				0.65	419.19	403.17	400.50	403.17
51				0.70	421.86	405.84	403.17	405.84
52	0.80	0.80	0.80	0.60	416.52	400.50	397.83	403.17
53				0.65	419.19	403.17	400.50	403.17
54				0.70	421.86	405.84	403.17	405.84

a: Historical record
b: Synthetical inflow (ARMA)
c: Synthetical inflow (ARMA)
d: Synthetical inflow used in designing the Wonogiri Dam

TABLE A-2 : INPUT DATA USED IN RESER SIMULATION MODEL

35	1	0.9	20								
0.00032	0.00035	0.00048	0.00053	0.00054	0.00049						
0.00064	0.00075	0.00091	0.00089	0.00068	0.00052						
0.008	0.008	0.007	0.005	0.004	0.003	0.003	0.002	0.002	0.002	0.003	0.003
1.71	2.13	2.43	14.82	23.63	20.57	15.04	17.03	21.33	21.13	14.49	5.54
0	0	0	2	2	2	2	2	2	2	2	0
14											
32.02	2650										
38.58	3050										
50.93	3500										
65.59	4000										
81.79	4500										
98.76	5000										
115.74	5500										
138.89	6100										
165.12	6750										
195.99	7450										
223.76	8060										
253.09	8750										
277.78	9350										
308.64	10100										
0.8	0.7	0.6	0.6								

TABLE A-3 : 8 YEARS HISTORICAL SEQUENCE

JAN	FEB	MAR	APR	MAY	JUN	JUL	AGT	SEP	OCT	NOV	DEC
58.50	58.70	62.30	80.60	95.20	4.60	0.10	0.10	0.10	7.00	63.50	30.50
138.30	145.20	105.70	115.50	23.50	0.10	0.10	0.10	17.00	10.20	22.00	85.80
70.20	113.00	173.90	62.90	11.70	21.00	0.60	0.10	0.10	9.20	23.50	62.30
154.10	107.50	81.50	73.70	2.70	24.80	0.30	0.10	5.70	7.20	34.60	32.50
143.50	105.70	65.20	14.90	2.70	0.90	0.10	0.10	0.10	0.10	7.60	81.10
72.50	144.60	64.60	14.50	41.60	7.20	0.10	0.10	0.10	12.70	50.70	29.50
73.70	120.60	63.70	47.60	27.70	40.50	19.40	0.10	0.10	0.10	17.00	17.90
85.80	80.60	58.80	24.90	12.90	0.10	0.10	0.10	0.10	2.00	8.10	43.90

TABLE A-4 : 20 YEARS SYNTHETICAL INFLOW DERIVED FROM ARMA MODEL

JAN	FEB	MAR	APR	MAY	JUN	JUL	AGT	SEP	OCT	NOV	DEC
71.86	106.37	100.87	77.27	5.67	178.55	2.10	0.10	0.14	20.78	36.44	43.23
113.68	170.58	120.15	109.16	48.01	0.26	0.02	0.10	0.05	0.17	10.02	61.40
145.76	93.52	67.50	62.43	33.38	0.06	0.07	0.10	0.05	19.77	80.23	25.07
103.91	141.97	84.65	9.11	15.36	0.82	0.83	0.10	2.31	6.27	52.25	14.16
61.43	99.29	119.54	51.67	15.80	51.10	0.24	0.10	0.13	6.29	17.71	10.23
63.54	130.87	82.65	33.17	33.19	0.24	0.03	0.10	0.31	0.23	12.72	36.39
69.03	96.38	90.02	66.59	14.50	0.70	0.01	0.10	0.05	2.19	19.54	64.44
131.65	118.57	62.25	62.49	22.47	7.30	1.50	0.10	0.10	0.64	21.00	47.08
227.18	195.58	54.37	42.85	26.26	0.19	0.08	0.10	0.55	0.16	26.92	39.14
69.38	97.26	37.12	15.20	6.86	0.12	0.08	0.10	0.49	1.10	28.11	31.09
61.55	135.64	149.28	73.57	12.74	376.06	0.67	0.10	0.03	0.03	5.87	186.50
174.96	108.82	47.68	31.10	19.59	16.98	1.13	0.10	0.10	4.72	64.61	103.42
114.19	70.59	103.17	120.44	14.93	4.65	0.07	0.10	0.06	2.45	12.16	46.16
105.42	88.95	88.94	39.52	40.08	6.73	0.10	0.10	0.34	3.05	29.79	22.73
66.94	73.56	57.73	23.90	20.26	0.04	0.04	0.10	0.03	7.07	57.77	103.48
199.66	163.31	58.89	159.34	64.77	5.50	1.04	0.10	6.50	0.46	17.65	48.60
76.73	120.80	77.65	63.75	2.69	0.13	0.10	0.10	0.06	0.36	8.46	11.74
45.94	75.98	100.98	9.90	9.26	4.13	0.05	0.10	0.02	8.28	22.28	45.92
106.78	84.49	61.17	39.92	19.28	0.35	0.14	0.10	1.46	367.51	42.67	31.03
78.19	76.20	107.72	58.90	1.72	0.02	0.01	0.10	0.12	2.91	16.04	37.98

TABLE A-5 : 50 YEARS SYNTHETICAL INFLOW DERIVED FROM ARMA MODEL

JAN	FEB	MAR	APR	MAY	JUN	JUL	AGT	SEP	OCT	NOV	DEC
71.86	115.23	93.65	31.57	20.80	1.97	0.64	0.10	0.78	10.79	71.21	67.00
132.99	120.19	111.37	51.08	8.62	0.23	0.03	0.10	0.04	0.82	37.58	39.97
124.99	141.89	52.52	106.15	19.05	875.68	18.10	0.10	1.24	0.03	13.02	102.99
172.34	149.49	90.86	46.38	31.90	4.32	0.14	0.10	0.19	12.42	15.27	19.52
68.92	86.63	77.91	76.02	44.87	0.00	0.02	0.10	0.05	4.06	12.79	38.72
102.36	119.23	43.21	40.17	40.40	4.60	0.12	0.10	0.27	7.83	26.67	48.26
76.37	65.84	48.67	9.25	39.65	1.76	0.11	0.10	1.24	0.18	7.32	155.41
180.44	213.16	110.15	86.61	11.55	1.13	1.40	0.10	0.41	2.26	12.19	138.75
334.55	121.99	110.79	9.80	21.35	158.33	0.52	0.10	2.64	65.95	44.57	13.94
47.94	83.17	98.44	79.01	326.75	8.76	0.07	0.10	0.28	10.05	18.12	32.47
62.51	66.15	65.10	21.18	6.64	25.43	0.43	0.10	1.76	0.74	19.11	52.26
110.94	147.35	105.30	18.83	17.04	16.72	0.74	0.10	0.09	16.24	74.50	41.51
82.35	67.27	59.44	13.57	56.72	0.19	0.10	0.10	0.31	4.61	18.89	19.92
78.02	114.13	118.04	36.77	27.90	57.58	3.33	0.10	8.76	2.04	11.57	52.76
90.49	118.39	85.42	42.26	2.13	1.80	0.03	0.10	0.01	36.27	18.09	102.17
198.75	203.99	87.96	35.65	0.84	6.78	1.39	0.10	0.10	0.96	11.43	53.05
79.17	115.09	89.52	19.62	6.61	0.01	0.00	0.10	0.21	1.39	7.44	71.63
87.79	126.77	134.44	73.81	3.82	6.13	0.11	0.10	1.40	8.25	53.39	80.35
130.47	145.04	117.75	24.86	11.28	0.25	0.27	0.10	3.24	1.61	17.94	29.93
77.19	51.74	70.84	38.53	11.41	279.06	9.96	0.10	0.24	6.32	19.40	30.34
81.78	91.89	159.62	132.42	107.95	0.58	0.03	0.10	27.12	6.87	49.37	31.43
82.64	90.02	51.61	76.06	67.58	17.15	0.03	0.10	15.14	5.10	21.86	32.43
70.09	109.66	96.03	93.32	7.14	221.45	0.67	0.10	0.60	0.05	3.61	117.59
222.07	175.78	184.68	141.57	24.69	119.37	0.34	0.10	1.77	0.52	6.78	61.73
64.26	110.60	54.97	25.81	10.32	5.66	0.21	0.10	0.11	1.13	18.44	94.47
160.53	112.02	97.93	43.55	27.97	3.67	0.23	0.10	0.00	0.07	12.50	49.74
62.62	89.19	104.64	32.73	92.54	1.53	3.37	0.10	0.71	0.13	7.11	75.73
118.50	123.11	105.41	72.42	45.79	0.74	0.04	0.10	2.21	1.80	48.75	58.49
185.18	175.54	89.05	111.86	13.64	0.02	0.02	0.10	0.78	0.16	9.54	88.48
121.13	104.93	58.70	18.96	78.98	2.94	1.46	0.10	0.62	0.64	20.67	52.92

TABLE A-5 : (CONTINUE)

JAN	FEB	MAR	APR	MAY	JUN	JUL	AGT	SEP	OCT	NOV	DEC
60.85	83.76	72.25	19.30	3.20	100.14	6.32	0.10	7.31	2.37	30.23	76.19
134.88	226.79	75.70	27.49	21.66	4.91	0.39	0.10	0.15	67.74	18.41	99.87
65.22	112.26	81.87	87.68	82.11	1.77	0.19	0.10	0.24	3.33	28.06	60.49
260.10	71.22	48.62	20.36	18.03	0.00	0.00	0.10	4.40	53.54	80.89	21.80
76.62	107.74	90.29	11.43	3.53	11.27	0.83	0.10	0.08	2.51	30.35	57.42
116.48	112.44	123.09	64.61	8.90	18.51	0.40	0.10	0.27	0.88	19.20	29.39
58.02	65.47	44.14	24.51	3.27	3.08	6.65	0.10	0.42	0.85	30.49	19.82
73.38	126.00	66.02	17.23	5.08	0.40	0.04	0.10	1.07	0.90	8.00	49.12
91.09	80.47	36.10	23.21	2.79	17.60	0.42	0.10	6.51	39.09	91.90	20.23
46.25	86.09	98.07	119.45	17.05	5.85	0.39	0.10	0.01	5.44	44.68	44.27
84.75	112.98	82.17	24.08	81.08	0.05	1.69	0.10	0.32	8.70	27.22	42.87
101.77	75.03	72.15	85.68	5.55	0.68	0.09	0.10	0.31	0.40	24.56	39.79
124.62	128.65	60.05	26.14	16.29	2.80	0.61	0.10	24.29	12.96	57.76	27.22
84.33	57.05	69.54	20.63	156.53	0.27	0.05	0.10	0.16	12.12	25.03	27.45
157.07	193.69	68.19	35.58	38.31	23.51	0.97	0.10	0.15	11.00	21.13	69.46
181.24	115.98	57.89	22.94	13.21	28.86	0.30	0.10	0.39	0.12	10.40	89.84
153.74	153.64	95.18	102.41	16.96	7.01	1.76	0.10	0.51	9.94	18.15	48.43
120.16	81.15	90.29	42.15	3.86	150.90	6.13	0.10	0.20	6.44	26.43	21.55
66.75	107.64	90.09	120.40	253.34	0.18	0.01	0.10	0.29	0.53	9.01	87.76
115.41	105.21	50.65	12.92	1.49	3.15	1.39	0.10	0.04	0.40	14.39	68.18

TABLE A-6 : 20 YEARS SYNTHETICAL INFLOW USED IN THE FEASIBILITY STUDY OF THE WONOGIRI DAM

JAN	FEB	MAR	APR	MAY	JUN	JUL	AGT	SEP	OCT	NOV	DEC
69.80	69.90	67.60	18.60	5.00	2.50	0.70	1.30	1.00	4.20	34.10	32.40
25.10	65.20	58.70	54.70	72.80	2.10	2.50	0.60	0.60	0.50	7.20	28.90
62.80	77.40	45.70	44.40	45.80	12.80	7.00	4.30	1.20	3.20	53.80	41.30
56.70	41.00	43.50	56.90	21.80	15.60	23.90	8.40	3.80	5.60	37.80	26.60
62.50	60.10	31.00	11.90	13.60	29.20	17.80	7.40	3.10	4.80	7.70	35.50
29.60	38.20	91.80	35.60	8.90	1.30	13.30	5.30	0.80	0.70	3.50	49.90
17.00	78.90	62.30	61.10	32.20	2.70	14.00	3.90	1.80	11.80	11.90	57.90
81.20	86.30	69.70	35.70	27.10	15.20	5.90	1.00	1.40	0.80	8.00	53.90
46.10	90.60	60.00	55.10	54.00	4.20	3.30	0.90	0.80	0.80	28.30	20.60
37.50	52.10	53.40	31.30	23.00	2.70	1.20	1.00	0.80	0.80	5.30	14.60
73.10	51.30	45.40	80.70	19.30	5.30	3.80	1.80	0.70	1.40	10.10	39.30
69.40	71.90	80.20	37.40	4.30	3.10	1.00	0.90	0.80	0.80	1.40	8.60
16.30	21.30	50.00	43.80	22.00	13.80	1.90	1.30	1.00	23.80	18.70	17.70
47.80	69.70	54.70	35.40	4.70	1.90	1.50	0.90	0.70	0.60	2.80	30.20
41.20	67.10	95.50	43.60	31.80	26.50	5.30	3.00	0.80	4.10	18.90	51.60
105.30	71.10	45.80	47.70	13.10	3.90	2.10	1.10	0.70	0.60	1.30	26.20
45.50	53.80	91.50	65.90	62.00	40.70	39.10	24.80	12.70	10.30	31.50	58.30
61.30	78.80	70.60	80.10	20.20	11.40	3.20	1.10	0.70	0.80	3.90	28.70
31.90	62.80	73.90	46.70	45.90	19.50	6.60	1.40	1.20	0.90	20.60	47.50
59.10	87.80	72.90	43.20	36.40	30.40	5.10	1.60	1.20	17.30	58.60	60.80

TABLE A-7 : A SAMPLE OUTPUT OF RESER PROGRAM

OPTIMAL RESERVOIR VOLUME RESULT

RESERVOIR : WONOGIRI
RIVER : SOLO

RESERVOIR CONSERVATION STORAGE : 416.52 MIL M3

RELIABILITY OF WATER SUPPLY : - COMPUTED 0.990
- REQUIRED 0.800

SIMULATION RESULTS - YEAR 1

VOLUME (MIL M3) :	416.52	416.52	416.52	416.52	416.52	360
	304.52	243.05	169.43	117.02	236.65	296.75
SPILL (MIL M3) :	104.71	144.92	151.47	161.05	176.33	0
	0	0	0	0	0	0
EVAPORATION :	5.24	6.1	8.36	9.23	9.41	8.54
(MIL M3)	10.24	10.91	11.6	9.33	5.88	6.53
WATER DEMAND :	4.57	5.69	6.49	39.57	63.09	54.92
(MIL M3)	40.16	45.47	56.95	56.42	38.69	14.79
WATER RELEASE :	4.57	5.69	6.49	39.57	63.09	54.92
(MIL M3)	40.16	45.47	56.95	56.42	38.69	14.79
REQUIRED DELTA :	0.6					
COMPUTED DELTA :	1	1	1	1	1	1
	1	1	1	1	1	1

REQUIRED GAMMA : 0.6 COMPUTED: 1
REQUIRED BETA : 0.7 COMPUTED: 1

SIMULATION RESULTS - YEAR 2

VOLUME (MIL M3) :	416.52	416.52	416.52	416.52	401.42	333.06
	278.03	217.15	189.34	144.92	153.06	362.18
SPILL (MIL M3) :	240.33	375.88	267.35	254.23	0	0
	0	0	0	0	0	0
EVAPORATION :	4.58	6.1	8.36	9.23	9.41	8.35
(MIL M3)	9.8	10.33	10.9	9.9	6.56	5.16
WATER DEMAND :	4.57	5.69	6.49	39.57	63.09	54.92
(MIL M3)	40.16	45.47	56.95	56.42	38.69	14.79
WATER RELEASE :	4.57	5.69	6.49	39.57	63.09	54.92
(MIL M3)	40.16	45.47	56.95	56.42	38.69	14.79
REQUIRED DELTA :	0.6					
COMPUTED DELTA :	1	1	1	1	1	1
	1	1	1	1	1	1
REQUIRED GAMMA :	0.6	COMPUTED:	1			
REQUIRED BETA :	0.7	COMPUTED:	1			

SIMULATION RESULTS - YEAR 3

VOLUME (MIL M3) :	416.52	416.52	416.52	416.52	369.91	357.74
	303.63	242.19	168.59	122.08	134.78	281.49
SPILL (MIL M3) :	123.37	289.9	449.45	113.79	0	0
	0	0	0	0	0	0
EVAPORATION :	5.14	6.1	8.36	9.23	9.41	7.97
(MIL M3)	10.21	10.89	11.57	9.31	6.01	4.84
WATER DEMAND :	4.57	5.69	6.49	39.57	63.09	54.92
(MIL M3)	40.16	45.47	56.95	56.42	38.69	14.79
WATER RELEASE :	4.57	5.69	6.49	39.57	63.09	54.92
(MIL M3)	40.16	45.47	56.95	56.42	38.69	14.79
REQUIRED DELTA :	0.6					
COMPUTED DELTA :	1	1	1	1	1	1
	1	1	1	1	1	1
REQUIRED GAMMA :	0.6	COMPUTED:	1			
REQUIRED BETA :	0.7	COMPUTED:	1			

SIMULATION RESULTS - YEAR 4

VOLUME (MIL M3) :	416.52	416.52	416.52	416.52	345.88	344.16
	289.48	228.35	170.07	118.18	160.61	227.29
SPILL (MIL M3) :	267.39	275.22	202.74	142.62	0	0
	0	0	0	0	0	0
EVAPORATION :	4.44	6.1	8.36	9.23	9.41	7.66
(MIL M3)	9.98	10.58	11.2	9.35	5.91	5.3
WATER DEMAND :	4.57	5.69	6.49	39.57	63.09	54.92
(MIL M3)	40.16	45.47	56.95	56.42	38.69	14.79
WATER RELEASE :	4.57	5.69	6.49	39.57	63.09	54.92
(MIL M3)	40.16	45.47	56.95	56.42	38.69	14.79
REQUIRED DELTA :	0.6					
COMPUTED DELTA :	1	1	1	1	1	1
	1	1	1	1	1	1
REQUIRED GAMMA :	0.6	COMPUTED:	1			
REQUIRED BETA :	0.7	COMPUTED:	1			

SIMULATION RESULTS - YEAR 5

VOLUME (MIL M3) :	416.52	416.52	416.52	402.15	331.7	266.35
	212.52	153.09	82.03	14.24	0	198.06
SPILL (MIL M3) :	185.4	270.41	159.22	0	0	0
	0	0	0	0	0	0
EVAPORATION :	3.93	6.1	8.36	9.23	9.21	7.48
(MIL M3)	8.59	8.88	9.04	6.3	4.81	3.68
WATER DEMAND :	4.57	5.69	6.49	39.57	63.09	54.92
(MIL M3)	40.16	45.47	56.95	56.42	38.69	14.79
WATER RELEASE :	4.57	5.69	6.49	39.57	63.09	54.92
(MIL M3)	40.16	45.47	56.95	56.42	24.37	14.79
REQUIRED DELTA :	0.6					
COMPUTED DELTA :	1	1	1	1	1	1
	1	1	1	1	0.63	1
REQUIRED GAMMA :	0.6	COMPUTED:	0.966			
REQUIRED BETA :	0.7	COMPUTED:	0.917			

SIMULATION RESULTS - YEAR 6

VOLUME (MIL M3) :	383.4	416.52	416.52	401.08	416.52	366.94
	311.34	249.73	175.93	138.55	223.47	281.11
SPILL (MIL M3) :	0	341.45	157.61	0	17.99	0
	0	0	0	0	0	0
EVAPORATION :	3.64	5.81	8.36	9.23	9.2	8.54
(MIL M3)	10.36	11.06	11.77	9.53	6.41	6.33
WATER DEMAND :	4.57	5.69	6.49	39.57	63.09	54.92
(MIL M3)	40.16	45.47	56.95	56.42	38.69	14.79
WATER RELEASE :	4.57	5.69	6.49	39.57	63.09	54.92
(MIL M3)	40.16	45.47	56.95	56.42	38.69	14.79
REQUIRED DELTA :	0.6					
COMPUTED DELTA :	1	1	1	1	1	1
	1	1	1	1	1	1
REQUIRED GAMMA :	0.6	COMPUTED:	1			
REQUIRED BETA :	0.7	COMPUTED:	1			

SIMULATION RESULTS - YEAR 7

VOLUME (MIL M3) :	416.52	416.52	416.52	416.52	412.63	416.52
	411.67	348.14	271.83	198.24	191.84	219.01
SPILL (MIL M3) :	52.34	310.2	155.21	72.94	0	35.49
	0	0	0	0	0	0
EVAPORATION :	4.44	6.1	8.36	9.23	9.41	8.49
(MIL M3)	11.15	12.97	14.29	12.09	7.75	5.82
WATER DEMAND :	4.57	5.69	6.49	39.57	63.09	54.92
(MIL M3)	40.16	45.47	56.95	56.42	38.69	14.79
WATER RELEASE :	4.57	5.69	6.49	39.57	63.09	54.92
(MIL M3)	40.16	45.47	56.95	56.42	38.69	14.79
REQUIRED DELTA :	0.6					
COMPUTED DELTA :	1	1	1	1	1	1
	1	1	1	1	1	1
REQUIRED GAMMA :	0.6	COMPUTED:	1			
REQUIRED BETA :	0.7	COMPUTED:	1			

SIMULATION RESULTS - YEAR 8

VOLUME (MIL M3) :	416.52	416.52	416.52	416.52	373.11	305.1
	250.54	190.27	118.1	53.94	26.72	125.45
SPILL (MIL M3) :	23.14	203.4	142.13	12.33	0	0
	0	0	0	0	0	0
EVAPORATION :	3.85	6.1	8.36	9.23	9.41	8.01
(MIL M3)	9.32	9.72	10.14	7.74	4.81	3.68
WATER DEMAND :	4.57	5.69	6.49	39.57	63.09	54.92
(MIL M3)	40.16	45.47	56.95	56.42	38.69	14.79
WATER RELEASE :	4.57	5.69	6.49	39.57	63.09	54.92
(MIL M3)	40.16	45.47	56.95	56.42	38.69	14.79
REQUIRED DELTA :	0.6					
COMPUTED DELTA :	1	1	1	1	1	1
	1	1	1	1	1	1

REQUIRED GAMMA :	0.6	COMPUTED:	1
REQUIRED BETA :	0.7	COMPUTED:	1

```
CSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS
CSSSSSSSS     ****   ****  ****  ****  ****     SSSSSSSSS
CSSSSSSSS     *  *   *     *     *     *  *     SSSSSSSSS
CSSSSSSSS     * *    ****  ****  ****  * *      SSSSSSSSS
CSSSSSSSS     *  *   *        *  *     *  *     SSSSSSSSS
CSSSSSSSS     *   *  ****  ****  ****  *   *    SSSSSSSSS
CSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS
C
C       RESERVOIR STORAGE CAPACITY SIMULATION PROGRAM
C                         USING
C           DIRECT SEARCH AND SIMULATION APPROACH
C
C          - Author: Slobodan P. Simonovic, 1985 -
C
      CHARACTER FNAME1*10,FNAME2*10,AKUMULA*40,REKA*40,FNAME8*10
      CHARACTER*1 VT
      REAL LEV,LIF,LLEV
      COMMON/EVA/ V(12,100),VOL(50),AREA(50),LEV(12),LLEV(12,100)
     +,POVR(12,100)
      DIMENSION S(12,100),LIF(12),DCITY(12),BIO(12),PREL(12,100),
     +RCITY(12,100),BEZV(4),RBV2(100),RBV3(100),
     +RBV4(12,100),QU(12,100)
C
C     ****************************
C     *                          *
C     *    READING INPUT DATA    *
C     *                          *
C     ****************************
C
C     SKORP    - INITIAL RESERVOIR VOLUME    (m^3/s)
C     DSKOR    - SEARCH STEP, INCREASE IN STORAGE     (m^3/s)
C     POC      - HOW FULL RESERVOIR IS AT START   (%)
C                  (REAL)
C     N        - NUMBER OF YEARS OF DATA
C     IFO      - INDICATOR OF TYPE OF INFLOW DATA, IFO=1 THEN
C                HISTORICAL SEQUENCE, IFO=2 THEN GENERATED SERIES
C     IFI      - INDICATOR FOR DESIRED OUTPUT,
C                IFI=1 COMPLETE OUTPUT, IFI=2 OPTIMAL VALUE ONLY
C     IFA      - OUTPUT INDICATOR, IFA=1 PRINTER ,IFA=2 HARD DISK
C                  (INTEGER)
C     LEV(I)   - MEAN MONTHLY EVAPORATION LOSS   (m^3/s/ha)
C     LIF(I)   - MEAN MONTHLY INFILTRATION LOSSES   (m^3/s)
C     DCITY(I) - MEAN MONTHLY WATER DEMAND   (m^3/s)
C     BIO(I)   - MEAN MONTHLY REQUIRED MINIMUM RESERVOIR
C                RELEASES   (m^3/s)
C     M        - NUMBER OF POINTS ON VOLUME - AREA CURVE
C     VOL(K)   - VOLUME   (m^3/s)
C     AREA(K)  - RESERVOIR SURFACE AREA   (ha)
C
C     QU(I,J)  - MEAN MONTHLY INFLOWS   (m^3/s)
C
C                RELIABILITY & VULNERABILITY CRITERIA
```

```
C
C     BEZV(1)  - REQUIRED RELIABILITY OF ALPHA  1 - # OF FAILURES
C                LENGTH OF PERIOD (N * 12)
C     BEZV(2)  - REQUIRED YEARLY RELIABILITY BETA  1 - # OF
C                FAILURES/12
C     BEZV(3)  - REQUIRED VALUE FOR YEARLY VULNERABILITY, GAMMA
C                EXPRESSED AS SUM OF RELIABILITIES OVER SUM OF
C                DEMANDS
C     BEZV(4)  - REQUIRED VALUE OF MONTHLY VULNERABILITY, DELTA
C                EXPRESSED AS RELIABILITY OVER DEMAND
C
C
      VT=CHAR(12)
      WRITE(*,*)'PROGRAM  R E S E R'
      WRITE(*,*)'ENTER RESERVOIR NAME IN QUOTES  -=>  '
      READ(*,*)AKUMULA
      WRITE(*,*)'ENTER RIVER NAME IN QUOTES      -=>  '
      READ(*,*)REKA
      REKA='RESER'
      FNAME2='FLOW20.DAT'
      IFO=1
      WRITE(*,*)'ENTER NAME OF THE FILE WITH'
      WRITE(*,*)'INPUT DATA IN QUOTES            -=>  '
      READ(*,*)FNAME1
      AKUMULA=FNAME1
      FNAME1='WO.DAT'
      WRITE(*,*)'ENTER NAME OF THE FILE WITH'
      WRITE(*,*)'RESERVOIR INFLOW DATA IN QUOTES -=>  '
      READ(*,*)FNAME2
      WRITE(*,*)'IF THEY ARE HISTORICAL INFLOWS ENTER 1'
      WRITE(*,*)'OR ENTER 2 IF SYNTHETIC FLOWS   -=>  '
      READ(*,*)IFO
      OPEN(UNIT=1,FILE=FNAME1)
      READ(1,*)SKORP,DSKOR,POC,N
      READ(1,*)(LEV(I),I=1,12)
      READ(1,*)(LIF(I),I=1,12)
      READ(1,*)(DCITY(I),I=1,12)
      READ(1,*)(BIO(I),I=1,12)
      READ(1,*)M
      READ(1,*)(VOL(K),AREA(K),K=1,M)
      READ(1,*)(BEZV(I),I=1,4)
      OPEN(UNIT=2,FILE=FNAME2)
      IF (IFO.EQ.1) GOTO 10
      N = 50
      DO 15 J=1,N
5     READ(2,1)(QU(I,J),I=1,12)
      FORMAT(4X,12(F6.2))
      GOTO 30
10    DO 35 J=1,N
35    READ(2,*)(QU(I,J),I=1,12)
30    CONTINUE
C
```

```
C       *************************
C       *                       *
C       *   PROGRAM EXECUTION   *
C       *                       *
C       *************************
C
C       J             - COUNTER FOR MONTHS
C       I             - COUNTER FOR YEARS
C       IBR3          - COUNTER OF NUMBER OF FAILURE MONTHS OVER
C                       TOTAL PERIOD USED TO CHECK IF RBV4(I,J) < 1.0
C       IBRG3         - COUNTER OF NUMBER OF FAILURE MONTHS FOR JUST
C                       ONE YEAR USED TO CHECK IF RBV4(I,J) < 1.0
C       POMC          - YEARLY WATER DEMAND TOTAL
C       POMRC         - YEARLY WATER DEMAND TOTAL
C                       (FOR N YEARS)
C       S(I,J)        - STORAGE
C
C
        SKOR=SKORP
        GOTO 100
1000    SKOR=SKOR+DSKOR
c       WRITE (*,*) SKOR
100     IBR3=0
        DO 200 J=1,N
        IBRG3=0
        POMC=0.
        POMRC=0.
        DO 300 I=1,12
        IF ((I.EQ.1).AND.(J.EQ.1)) GOTO 310
        GOTO 320
310     V(I,J)=POC*SKOR
        GOTO 330
320     IF (I.EQ.1) GOTO 325
        V(I,J)=S(I-1,J)
        GOTO 330
325     V(1,J)=S(12,J-1)
330     CALL EVAP(I,J,M)
        PREL(I,J)=0.
        RCITY(I,J)=DCITY(I)
        S(I,J)=V(I,J)+QU(I,J)-LLEV(I,J)-LIF(I)-BIO(I)-DCITY(I)
        IF (S(I,J).GT.SKOR) GOTO 340
        POM=V(I,J)+QU(I,J)-BIO(I)-LIF(I)-LLEV(I,J)
        A=DCITY(I)
        GOTO 350
340     PREL(I,J)=S(I,J)-SKOR
        S(I,J)=SKOR
        GOTO 292
350     IF (POM.GE.A) GOTO 292
        IF (POM.LE.0.) GOTO 1000
        RCITY(I,J)=POM
        S(I,J)=0.
C
```

```
C       *************************
C       *                       *
C       *   CHECKING CRITERIA   *
C       *                       *
C       *************************
C
C       RCITY(I,J)     - CALCULATED AMOUNT OF RELEASE
C       RBV1           - CALCULATED VALUE OF RELIABILITY
C                        (ALPHA)
C       RBV2(J)        - CALCULATED VALUE OF YEARLY RELIABILITY
C                        (BETA)
C       RBV3(J)        - CALCULATED VALUE OF YEARLY VULNERABILITY
C                        (GAMMA)
C       RBV4(I,J)      - CALCULATED VALUE OF MONTHLY VULNERABILITY
C                        (DELTA)
C
        IF (RCITY(I,J).EQ.DCITY(I)) GOTO 292
        D=BEZV(4)*DCITY(I)
        IF (RCITY(I,J).LT.D) GOTO 1000
        IBR3=IBR3+1
        IBRG3=IBRG3+1
 292    POMC=POMC+DCITY(I)
        POMRC=POMRC+RCITY(I,J)
        IF (DCITY(I).NE.0.) GOTO 299
        RBV4(I,J)=1.
        GOTO 300
 299    RBV4(I,J)=RCITY(I,J)/DCITY(I)
 300    CONTINUE
        DD=BEZV(3)*POMC
        IF (POMRC.LT.DD) GOTO 1000
        IF (POMC.NE.0.) GOTO 244
        RBV3(J)=1.
        GOTO 245
 244    RBV3(J)=POMRC/POMC
 245    IF (IBRG3.EQ.0) GOTO 234
        RBV2(J)=IBRG3/12.
        GOTO 235
 234    RBV2(J)=0.
 235    RBV2(J)=1.-RBV2(J)
        IF (RBV2(J).LT.BEZV(2)) GOTO 1000
 200    CONTINUE
        IF(IBR3.EQ.0)GOTO 205
        RBV1=IBR3/(12.*N)
        GOTO 206
 205    RBV1=0.
 206    RBV1=1.-RBV1
        IF (RBV1.LT.BEZV(1)) GOTO 1000
        SKOR=SKOR*2.67
        DO 303 I=1,12
   303  DCITY(I)=DCITY(I)*2.67
        DO 301 J=1,N
        DO 302 I=1,12
```

```
      S(I,J)=S(I,J)*2.67
      PREL(I,J)=PREL(I,J)*2.67
      LLEV(I,J)=LLEV(I,J)*2.67
      RCITY(I,J)=RCITY(I,J)*2.67
  302 CONTINUE
  301 CONTINUE
C
C     ****************************
C     *                          *
C     *   PRINTING OUTPUT DATA   *
C     *                          *
C     ****************************
C
      CLOSE(UNIT=1)
      CLOSE(UNIT=2)
      WRITE(*,*)'COMPUTATION IS FINISHED  !!! '
      WRITE(*,*)'IF YOU WOULD LIKE OUTPUT DATA TO BE '
      WRITE(*,*)'SAVED ON DISK TYPE 2, OTHERWISE TYPE 1 -=>  '
      READ(*,*)IFA
      WRITE(*,*)'TYPE THE NAME OF THE OUTPUT FILE -=>  '
      READ(*,*)FNAME8
      WRITE(*,*)'IF YOU WOULD LIKE FINAL DATA ONLY TYPE 2'
      WRITE(*,*)'IF YOU WOULD LIKE ALL THE RESULTS TYPE 1  -=>  '
      READ(*,*)IFI
      IF(IFA.NE.2) GOTO 1030
      OPEN(UNIT=8,FILE=FNAME8,STATUS='NEW')
      OPEN(UNIT=8,FILE=FNAME8)
      WRITE(8,101)
101   FORMAT(//,10X,'OPTIMAL RESERVOIR VOLUME RESULTS',//,' ',
     +10X,'RESERVOIR: WONOGIRI',/' ',14X,'RIVER: SOLO',///)
      WRITE(8,102)SKOR
102   FORMAT(//,10X,'RESERVOIR CONSERVATION STORAGE ',
     +F10.2,3X,'MIL M3',//)
      WRITE(8,105)RBV1,BEZV(1)
102   FORMAT(F10.2)
105   FORMAT(/,10X,'RELIABILITY OF WATER SUPPLY:  COMPUTED',
     +3X,F5.3,/ ,40X,'REQUIRED',3X,F5.3)
      IF(IFI.EQ.2) GOTO 1020
      DO 107 J=1,N
      WRITE(8,106)J
106   FORMAT(///,10X,'SIMULATION RESULTS - YEAR ',I2,/)
      WRITE(8,108)(S(I,J),I=1,12)
      WRITE(8,109)(PREL(I,J),I=1,12)
      WRITE(8,130)(LLEV(I,J),I=1,12)
      WRITE(8,120)(DCITY(I),I=1,12)
      WRITE(8,121)(RCITY(I,J),I=1,12)
      WRITE(8,112)BEZV(4)
      WRITE(8,113)(RBV4(I,J),I=1,12)
      WRITE(8,114)BEZV(3),RBV3(J)
      WRITE(8,115)BEZV(2),RBV2(J)
108   FORMAT('VOLUME (MIL M3) :',6(F7.2),/,17X,6(F7.2),/)
109   FORMAT('SPILL  (MIL M3) :',6(F7.2),/,17X,6(F7.2),/)
```

```
112    FORMAT('REQUIRED DELTA   :',F10.3)
113    FORMAT('COMPUTED DELTA   :',6(F7.2),/,17X,6(F7.2),/)
114    FORMAT('REQUIRED GAMMA   :',F7.3,5X,'COMPUTED: ',F7.3)
115    FORMAT('REQUIRED BETA    :',F7.3,5X,'COMPUTED: ',F7.3)
120    FORMAT('WATER DEMAND     :',6(F7.2),/,17X,6(F7.2),/)
121    FORMAT('WATER RELEASE    :',6(F7.2),/,17X,6(F7.2),/)
130    FORMAT('EVAPOR.(MIL M3)  :',6(F7.2),/,17X,6(F7.2),/)
107    CONTINUE
020    IF(MFL.EQ.1) GOTO 1030
       MFL=1
1030   END
C
C      ****************************
C      *                          *
C      *  EVAPORATION SUBROUTINE  *
C      *                          *
C      ****************************
C
       SUBROUTINE EVAP(I,J,M)
C
C
       REAL LEV,LLEV
       COMMON/EVA/V(12,100),VOL(50),AREA(50),LEV(12),LLEV(12,100),
      +POVR(12,100)
       IF(V(I,J).GT.VOL(1)) GOTO 60
       POVR(I,J)=AREA(1)
       LLEV(I,J)=POVR(I,J)*LEV(I)
       RETURN
60     IF(V(I,J).LT.VOL(M)) GOTO 61
       POVR(I,J)=AREA(M)
       LLEV(I,J)=POVR(I,J)*LEV(I)
       RETURN
61     DO 70 K=2,M
       IF(V(I,J).GT.VOL(K)) GOTO 70
       POVR(I,J)=AREA(K-1)+(AREA(K)-AREA(K-1))*
      +(V(I,J)-VOL(K-1))/(VOL(K)-VOL(K-1))
       LLEV(I,J)=POVR(I,J)*LEV(I)
       RETURN
70     CONTINUE
       END
```

APPENDIX B

ResQ SIMULATION PROGRAM

TABLE B-1 : INPUT DATA USED IN ResQ PROGRAM

File View Run Option Help

Reservoir Description

Capacity 10^6 m3	Area ha	Elevation m	Outlet m3/s	Power eff.frc.
83.0	2650.0	127.0	400.0	-
100.0	3000.0	128.0	400.0	-
132.0	3600.0	129.0	400.0	-
170.0	4000.0	130.0	400.0	-
212.0	4720.0	131.0	400.0	-
256.0	5100.0	132.0	400.0	-
300.0	5550.0	133.0	400.0	-
360.0	6200.0	134.0	400.0	-
428.0	6750.0	135.0	400.0	-
518.0	7360.0	136.0	400.0	-
580.0	7900.0	137.0	400.0	-
656.0	8550.0	138.0	400.0	-
720.0	9150.0	139.0	400.0	-
800.0	9600.0	140.0	400.0	-

Maximum 678.0

File View Run Option Help

Demands at Reservoir

	Maximum Permissible Release m3/s	Minimum m3/s	Reservoir Diversion Req'mnt. m3/s	Energy req'd 1000 kwh
Jan	400	0	1.710	0
Feb	400	0	2.126	0
Mar	400	0	2.433	0
Apr	400	0	14.820	0
May	400	0	23.632	0
Jun	400	0	20.566	0
Jul	400	0	15.043	0
Ags	400	0	17.030	0
Sep	400	0	21.327	0
Oct	400	0	21.126	0
Nov	400	0	14.489	0
Dec	400	0	5.535	0

File View Run Option Help

Storage Allocation

	Top of Conserv. pool 10^6 m3	Top of inactive pool 10^6 m3	Top of buffer pool 10^6 m3
Jan	483.50	83	83
Feb	483.50	83	83
Mar	483.50	83	83
Apr	483.50	83	83
May	483.50	83	83
Jun	483.50	83	83
Jul	483.50	83	83
Ags	483.50	83	83
Sep	483.50	83	83
Oct	483.50	83	83
Nov	483.50	83	83
Dec	483.50	83	83

File View Run Option Help

Demands Downstream

	Maximum Permissible Downstream flow m3/s	Minimum m3/s	Downstr. Water Right m3/s
Jan	400	0	0
Feb	400	0	0
Mar	400	0	0
Apr	400	0	2
May	400	0	2
Jun	400	0	2
Jul	400	0	2
Ags	400	0	2
Sep	400	0	2
Oct	400	0	2
Nov	400	0	2
Dec	400	0	0

TABLE B-2 : A SAMPLE OUTPUT OF RESQ PROGRAM

Conservation storage = 416.52 million m3
Local flow = 0 m3/s
Top of buffer = inactive pool
Min. permissible downstream flow = 0 m3/s
Max. permissible downstream flow = 400 m3/s

Perode	Reservoir Inflow	Top of Inactive Pool	Top of Conserv. Pool	Act.End-of-Month Storage	Permissible Release min	max	Actual Reservoir Release	Minimum Req'd Withdraw.
1								
1	69.8	83	499.5	272.3	0	400	0.0	0
2	69.9	83	499.5	441.9	0	400	0.0	0
3	67.6	83	499.5	499.5	0	400	43.5	0
4	18.6	83	499.5	499.5	0	400	3.6	2
5	5.0	83	499.5	443.9	0	400	2.0	2
6	2.5	83	499.5	391.6	0	400	2.0	2
7	0.7	83	499.5	351.0	0	400	0.7	2
8	1.3	83	499.5	305.0	0	400	1.3	2
9	1.0	83	499.5	249.3	0	400	1.0	2
10	4.2	83	499.5	198.3	0	400	2.0	2
11	34.1	83	499.5	243.6	0	400	2.0	2
12	32.4	83	499.5	315.4	0	400	0.0	0
2								
1	25.1	83	499.5	377.8	0	400	0.0	0
2	65.2	83	499.5	499.5	0	400	12.7	0
3	58.7	83	499.5	499.5	0	400	56.2	0
4	54.7	83	499.5	499.5	0	400	39.7	2
5	72.8	83	499.5	499.5	0	400	49.0	2
6	2.1	83	499.5	446.2	0	400	2.0	2
7	2.5	83	499.5	406.8	0	400	2.0	2
8	0.6	83	499.5	360.8	0	400	0.6	2
9	0.6	83	499.5	305.1	0	400	0.6	2
10	0.5	83	499.5	248.1	0	400	0.5	2
11	7.2	83	499.5	223.7	0	400	2.0	2
12	28.9	83	499.5	286.1	0	400	0.0	0
3								
1	62.8	83	499.5	449.5	0	400	0.0	0
2	77.4	83	499.5	499.5	0	400	54.5	0
3	45.7	83	499.5	499.5	0	400	43.2	0
4	44.4	83	499.5	499.5	0	400	29.4	2
5	45.8	83	499.5	499.5	0	400	22.0	2
6	12.8	83	499.5	473.9	0	400	2.0	2
7	7.0	83	499.5	446.6	0	400	2.0	2
8	4.3	83	499.5	406.7	0	400	2.0	2
9	1.2	83	499.5	350.9	0	400	1.2	2
10	3.2	83	499.5	297.1	0	400	2.0	2
11	53.8	83	499.5	393.5	0	400	2.0	2
12	41.3	83	499.5	489.0	0	400	0.0	0

Conservation storage = 416.52 million m3
Local flow = 0 m3/s
Top of buffer = inactive pool
Min. permissible downstream flow = 0 m3/s
Max. permissible downstream flow = 400 m3/s

		Reservoir Inflow	Top of Inactive Pool	Top of Conserv. Pool	Act.End-of-Month Storage	Permissible Release min	max	Actual Reservoir Release	Minimum Req'd Withdraw.
4									
	1	56.7	83	499.5	499.5	0	400	51.0	0
	2	41.0	83	499.5	499.5	0	400	38.8	0
	3	43.5	83	499.5	499.5	0	400	41.0	0
	4	56.9	83	499.5	499.5	0	400	41.9	2
	5	21.8	83	499.5	488.9	0	400	2.0	2
	6	15.6	83	499.5	470.5	0	400	2.0	2
	7	23.9	83	499.5	488.5	0	400	2.0	2
	8	8.4	83	499.5	459.6	0	400	2.0	2
	9	3.8	83	499.5	408.4	0	400	2.0	2
	10	5.6	83	499.5	361.0	0	400	2.0	2
	11	37.8	83	499.5	415.9	0	400	2.0	2
	12	26.6	83	499.5	472.0	0	400	0.0	0
5									
	1	62.5	83	499.5	499.5	0	400	50.4	0
	2	60.1	83	499.5	499.5	0	400	57.9	0
	3	31.0	83	499.5	499.5	0	400	28.5	0
	4	11.9	83	499.5	486.4	0	400	2.0	2
	5	13.6	83	499.5	453.9	0	400	2.0	2
	6	29.2	83	499.5	470.8	0	400	2.0	2
	7	17.8	83	499.5	472.4	0	400	2.0	2
	8	7.4	83	499.5	440.8	0	400	2.0	2
	9	3.1	83	499.5	387.8	0	400	2.0	2
	10	4.8	83	499.5	338.3	0	400	2.0	2
	11	7.7	83	499.5	315.2	0	400	2.0	2
	12	35.5	83	499.5	395.2	0	400	0.0	0
6									
	1	29.6	83	499.5	469.7	0	400	0.0	0
	2	38.2	83	499.5	499.5	0	400	23.6	0
	3	91.8	83	499.5	499.5	0	400	89.3	0
	4	35.6	83	499.5	499.5	0	400	20.6	2
	5	8.9	83	499.5	454.4	0	400	2.0	2
	6	1.3	83	499.5	400.8	0	400	1.3	2
	7	13.3	83	499.5	390.4	0	400	2.0	2
	8	5.3	83	499.5	353.2	0	400	2.0	2
	9	0.8	83	499.5	297.5	0	400	0.8	2
	10	0.7	83	499.5	240.5	0	400	0.7	2
	11	3.5	83	499.5	206.6	0	400	2.0	2
	12	49.9	83	499.5	325.2	0	400	0.0	0

Conservation storage = 416.52 million m3
Local flow = 0 m3/s
Top of buffer = inactive pool
Min. permissible downstream flow = 0 m3/s
Max. permissible downstream flow = 400 m3/s

	Reservoir Inflow	Top of Inactive Pool	Top of Conserv. Pool	Act.End-of-Month Storage	Permissible Release min	max	Actual Reservoir Release	Minimum Req'd Withdraw.
7								
1	17.0	83	499.5	365.9	0	400	0.0	0
2	78.9	83	499.5	499.5	0	400	21.5	0
3	62.3	83	499.5	499.5	0	400	59.8	0
4	61.1	83	499.5	499.5	0	400	46.1	2
5	32.2	83	499.5	499.5	0	400	8.4	2
6	2.7	83	499.5	447.7	0	400	2.0	2
7	14.0	83	499.5	439.2	0	400	2.0	2
8	3.9	83	499.5	398.2	0	400	2.0	2
9	1.8	83	499.5	342.5	0	400	1.8	2
10	11.8	83	499.5	311.7	0	400	2.0	2
11	11.9	83	499.5	299.5	0	400	2.0	2
12	57.9	83	499.5	439.4	0	400	0.0	0
8								
1	81.2	83	499.5	499.5	0	400	57.0	0
2	86.3	83	499.5	499.5	0	400	84.1	0
3	69.7	83	499.5	499.5	0	400	67.2	0
4	35.7	83	499.5	499.5	0	400	20.7	2
5	27.1	83	499.5	499.5	0	400	3.3	2
6	15.2	83	499.5	480.1	0	400	2.0	2
7	5.9	83	499.5	449.9	0	400	2.0	2
8	1.0	83	499.5	403.8	0	400	1.0	2
9	1.4	83	499.5	348.1	0	400	1.4	2
10	0.8	83	499.5	291.0	0	400	0.8	2
11	8.0	83	499.5	268.7	0	400	2.0	2
12	53.9	83	499.5	398.0	0	400	0.0	0
9								
1	46.1	83	499.5	499.5	0	400	6.4	0
2	90.6	83	499.5	499.5	0	400	88.4	0
3	60.0	83	499.5	499.5	0	400	57.5	0
4	55.1	83	499.5	499.5	0	400	40.1	2
5	54.0	83	499.5	499.5	0	400	30.2	2
6	4.2	83	499.5	451.6	0	400	2.0	2
7	3.3	83	499.5	414.4	0	400	2.0	2
8	0.9	83	499.5	368.4	0	400	0.9	2
9	0.8	83	499.5	312.6	0	400	0.8	2
10	0.8	83	499.5	255.7	0	400	0.8	2
11	28.3	83	499.5	286.0	0	400	2.0	2
12	20.6	83	499.5	326.1	0	400	0.0	0

Conservation storage = 416.52 million m3
Local flow = 0 m3/s
Top of buffer = inactive pool
Min. permissible downstream flow = 0 m3/s
Max. permissible downstream flow = 400 m3/s

	Reservoir Inflow	Top of Inactive Pool	Top of Conserv. Pool	Act.End-of-Month Storage	Permissible Release min	max	Actual Reservoir Release	Minimum Req'd Withdraw.
13								
1	16.3	83	499.5	201.3	0	400	0.0	0
2	21.3	83	499.5	249.2	0	400	0.0	0
3	50.0	83	499.5	376.3	0	400	0.0	0
4	43.8	83	499.5	446.0	0	400	2.0	2
5	22.0	83	499.5	435.9	0	400	2.0	2
6	13.8	83	499.5	412.9	0	400	2.0	2
7	1.9	83	499.5	372.3	0	400	1.9	2
8	1.3	83	499.5	326.3	0	400	1.3	2
9	1.0	83	499.5	270.5	0	400	1.0	2
10	23.8	83	499.5	272.0	0	400	2.0	2
11	18.7	83	499.5	277.4	0	400	2.0	2
12	17.7	83	499.5	309.7	0	400	0.0	0
14								
1	47.8	83	499.5	433.0	0	400	0.0	0
2	69.7	83	499.5	499.5	0	400	40.0	0
3	54.7	83	499.5	499.5	0	400	52.2	0
4	35.4	83	499.5	499.5	0	400	20.4	2
5	4.7	83	499.5	443.1	0	400	2.0	2
6	1.9	83	499.5	389.5	0	400	1.9	2
7	1.5	83	499.5	348.9	0	400	1.5	2
8	0.9	83	499.5	302.9	0	400	0.9	2
9	0.7	83	499.5	247.2	0	400	0.7	2
10	0.6	83	499.5	190.3	0	400	0.6	2
11	2.8	83	499.5	154.6	0	400	2.0	2
12	30.2	83	499.5	220.4	0	400	0.0	0
15								
1	41.2	83	499.5	326.1	0	400	0.0	0
2	67.1	83	499.5	483.1	0	400	0.0	0
3	95.5	83	499.5	499.5	0	400	86.8	0
4	43.6	83	499.5	499.5	0	400	28.6	2
5	31.8	83	499.5	499.5	0	400	8.0	2
6	26.5	83	499.5	499.5	0	400	5.8	2
7	5.3	83	499.5	467.7	0	400	2.0	2
8	3.0	83	499.5	424.3	0	400	2.0	2
9	0.8	83	499.5	368.5	0	400	0.8	2
10	4.1	83	499.5	317.1	0	400	2.0	2
11	18.9	83	499.5	323.0	0	400	2.0	2
12	51.6	83	499.5	446.1	0	400	0.0	0

Conservation storage = 416.52 million m3
Local flow = 0 m3/s
Top of buffer = inactive pool
Min. permissible downstream flow = 0 m3/s
Max. permissible downstream flow = 400 m3/s

		Reservoir Inflow	Top of Inactive Pool	Top of Conserv. Pool	Act.End-of-Month Storage	Permissible Release min	max	Actual Reservoir Release	Minimum Req'd Withdraw.
16									
	1	105.3	83	499.5	499.5	0	400	83.6	0
	2	71.1	83	499.5	499.5	0	400	68.9	0
	3	45.8	83	499.5	499.5	0	400	43.3	0
	4	47.7	83	499.5	499.5	0	400	32.7	2
	5	13.1	83	499.5	465.6	0	400	2.0	2
	6	3.9	83	499.5	416.9	0	400	2.0	2
	7	2.1	83	499.5	376.6	0	400	2.0	2
	8	1.1	83	499.5	330.6	0	400	1.1	2
	9	0.7	83	499.5	274.8	0	400	0.7	2
	10	0.6	83	499.5	217.9	0	400	0.6	2
	11	1.3	83	499.5	180.1	0	400	1.3	2
	12	26.2	83	499.5	235.2	0	400	0.0	0
17									
	1	45.5	83	499.5	352.4	0	400	0.0	0
	2	53.8	83	499.5	481.6	0	400	0.0	0
	3	91.5	83	499.5	499.5	0	400	82.3	0
	4	65.9	83	499.5	499.5	0	400	50.9	2
	5	62.0	83	499.5	499.5	0	400	38.2	2
	6	40.7	83	499.5	499.5	0	400	20.0	2
	7	39.1	83	499.5	499.5	0	400	23.9	2
	8	24.8	83	499.5	499.5	0	400	7.6	2
	9	12.7	83	499.5	471.4	0	400	2.0	2
	10	10.3	83	499.5	436.5	0	400	2.0	2
	11	31.5	83	499.5	475.0	0	400	2.0	2
	12	58.3	83	499.5	499.5	0	400	43.5	0
18									
	1	61.3	83	499.5	499.5	0	400	59.5	0
	2	78.8	83	499.5	499.5	0	400	76.6	0
	3	70.6	83	499.5	499.5	0	400	68.1	0
	4	80.1	83	499.5	499.5	0	400	65.1	2
	5	20.2	83	499.5	484.6	0	400	2.0	2
	6	11.4	83	499.5	455.4	0	400	2.0	2
	7	3.2	83	499.5	417.9	0	400	2.0	2
	8	1.1	83	499.5	371.9	0	400	1.1	2
	9	0.7	83	499.5	316.1	0	400	0.7	2
	10	0.8	83	499.5	259.2	0	400	0.8	2
	11	3.9	83	499.5	226.2	0	400	2.0	2
	12	28.7	83	499.5	288.1	0	400	0.0	0

Conservation storage = 416.52 million m3
Local flow = 0 m3/s
Top of buffer = inactive pool
Min. permissible downstream flow = 0 m3/s
Max. permissible downstream flow = 400 m3/s

		Reservoir Inflow	Top of Inactive Pool	Top of Conserv. Pool	Act.End-of-Month Storage	Permissible Release min	max	Actual Reservoir Release	Minimum Req'd Withdraw.
19									
	1	31.9	83	499.5	368.8	0	400	0.0	0
	2	62.8	83	499.5	499.5	0	400	6.5	0
	3	73.9	83	499.5	499.5	0	400	71.4	0
	4	46.7	83	499.5	499.5	0	400	31.7	2
	5	45.9	83	499.5	499.5	0	400	22.1	2
	6	19.5	83	499.5	491.3	0	400	2.0	2
	7	6.6	83	499.5	462.9	0	400	2.0	2
	8	1.4	83	499.5	416.8	0	400	1.4	2
	9	1.2	83	499.5	361.1	0	400	1.2	2
	10	0.9	83	499.5	304.0	0	400	0.9	2
	11	20.6	83	499.5	314.3	0	400	2.0	2
	12	47.5	83	499.5	426.5	0	400	0.0	0
20									
	1	59.1	83	499.5	499.5	0	400	30.0	0
	2	87.8	83	499.5	499.5	0	400	85.6	0
	3	72.9	83	499.5	499.5	0	400	70.4	0
	4	43.2	83	499.5	499.5	0	400	28.2	2
	5	36.4	83	499.5	499.5	0	400	12.6	2
	6	30.4	83	499.5	499.5	0	400	9.7	2
	7	5.1	83	499.5	467.1	0	400	2.0	2
	8	1.6	83	499.5	421.1	0	400	1.6	2
	9	1.2	83	499.5	365.3	0	400	1.2	2
	10	17.3	83	499.5	349.2	0	400	2.0	2
	11	58.6	83	499.5	458.0	0	400	2.0	2
	12	60.8	83	499.5	499.5	0	400	39.6	0

APPENDIX C

ISRYO OPTIMIZATION PROGRAM

TABLE C-1 : THE RESULT OF RESERVOIR YIELD OPTIMIZATION
(Combination 1a)

ALFA = 0.83
BETA = 0.31

PERIOD	MEAN INFLOW	WATER SUPPLY DEMAND	RELEASE	IRRIGATION DEMAND	RELEASE	HYDRO POWER DEMAND	RELEASE
1	302.766	38.166	38.115	9.424	9.399	32.983	32.851
2	278.643	38.637	38.586	18.848	18.797	28.271	28.158
3	227.477	39.109	39.104	28.271	28.265	23.559	23.551
4	130.533	39.580	39.575	37.695	37.687	21.203	21.196
5	103.815	39.109	39.051	47.119	46.981	18.848	18.765
6	114.307	39.580	39.522	51.831	51.679	14.136	14.074
7	3.884	39.580	36.509	65.966	55.732	11.780	9.038
8	0.268	40.051	36.944	65.966	55.732	9.424	7.231
9	6.195	40.051	31.807	51.831	31.543	9.424	4.804
10	24.025	39.580	31.432	42.407	25.808	14.136	7.206
11	68.714	39.109	37.790	32.983	30.758	23.559	21.200
12	152.937	38.637	37.334	18.848	17.576	28.271	25.440
SUM	1413.564	471.188	445.770	471.188	409.956	235.594	213.514
REL. DEMAND RATIO		0.400	0.315	0.400	0.290	0.200	0.151
REL. SUPPLY LEVEL		0.950	0.946	0.900	0.870	0.850	0.906

TABLE C-2 : THE RESULT OF RESERVOIR YIELD OPTIMIZATION
(Combination 1b)

ALFA = 0.87
BETA = 0.31

PERIOD	MEAN INFLOW	WATER SUPPLY DEMAND	RELEASE	IRRIGATION DEMAND	RELEASE	HYDRO POWER DEMAND	RELEASE
1	302.766	39.756	39.710	9.816	9.782	34.357	34.236
2	278.643	40.247	40.200	19.633	19.563	29.449	29.345
3	227.477	40.738	40.533	29.449	29.005	24.541	24.171
4	130.533	41.229	41.021	39.266	38.673	22.087	21.754
5	103.815	40.738	40.590	49.082	48.548	19.633	19.419
6	114.307	41.229	41.079	53.990	53.403	14.725	14.564
7	3.884	41.229	35.635	68.715	40.746	12.271	7.276
8	0.268	41.720	36.059	68.715	40.746	9.816	5.821
9	6.195	41.720	37.866	53.990	39.192	9.816	7.126
10	24.025	41.229	37.420	44.174	32.066	14.725	10.689
11	68.714	40.738	36.984	34.357	24.859	24.541	17.756
12	152.937	40.247	36.538	19.633	14.205	29.449	21.307
SUM	1413.564	490.821	463.636	490.821	390.787	245.410	213.463
DEMAND RATIO		0.400	0.328	0.400	0.276	0.200	0.151
SUPPLY LEVEL		0.950	0.945	0.850	0.796	0.850	0.870

TABLE C-3 : THE RESULT OF RESERVOIR YIELD OPTIMIZATION
(Combination 1c)

ALFA = 0.85
BETA = 0.31

PERIOD	MEAN INFLOW	WATER SUPPLY DEMAND	WATER SUPPLY RELEASE	IRRIGATION DEMAND	IRRIGATION RELEASE	HYDRO POWER DEMAND	HYDRO POWER RELEASE
1	302.766	39.120	39.120	9.659	9.659	33.808	33.808
2	278.643	39.603	39.603	19.319	19.319	28.978	28.978
3	227.477	40.086	40.086	28.978	28.978	24.148	24.148
4	130.533	40.569	40.569	38.637	38.637	21.734	21.734
5	103.815	40.086	35.516	48.297	26.272	19.319	12.711
6	114.307	40.569	35.944	53.126	28.900	14.489	9.534
7	3.884	40.569	36.946	67.615	43.459	12.074	8.839
8	0.268	41.052	37.386	67.615	43.459	9.659	7.071
9	6.195	41.052	40.294	53.126	49.200	9.659	9.124
10	24.025	40.569	39.820	43.467	40.255	14.489	13.686
11	68.714	40.086	40.086	33.808	33.808	24.148	24.148
12	152.937	39.603	39.603	19.319	19.319	28.978	28.978
SUM	1413.564	482.968	464.974	482.968	381.264	241.484	222.759
DEMAND RATIO		0.40	0.33	0.40	0.27	0.20	0.16
SUPPLY LEVEL		0.95	0.96	0.80	0.79	0.85	0.92

TABLE C-4 : THE RESULT OF RESERVOIR YIELD OPTIMIZATION
(Combination 1d)

ALFA = 0.94
BETA = 0.31

PERIOD	MEAN INFLOW	WATER SUPPLY DEMAND	WATER SUPPLY RELEASE	IRRIGATION DEMAND	IRRIGATION RELEASE	HYDRO POWER DEMAND	HYDRO POWER RELEASE
1	302.766	43.255	43.255	10.680	10.680	37.381	37.381
2	278.643	43.789	43.789	21.361	21.361	32.041	32.041
3	227.477	44.323	44.323	32.041	32.041	26.701	26.701
4	130.533	44.857	44.857	42.721	42.721	24.031	24.031
5	103.815	44.323	40.118	53.401	28.070	21.361	15.281
6	114.307	44.857	40.601	58.741	30.877	16.020	11.461
7	3.884	44.857	40.824	74.762	41.155	13.350	9.750
8	0.268	45.391	41.310	74.762	41.155	10.680	7.800
9	6.195	45.391	44.733	58.741	54.484	10.680	10.216
10	24.025	44.857	44.207	48.061	44.578	16.020	15.324
11	68.714	44.323	44.323	37.381	37.381	26.701	26.701
12	152.937	43.789	43.789	21.361	21.361	32.041	32.041
SUM	1413.564	534.013	516.130	534.013	405.863	267.006	248.725
DEMAND RATIO		0.400	0.365	0.400	0.287	0.200	0.176
SUPPLY LEVEL		0.950	0.967	0.750	0.760	0.850	0.932

TABLE C-5 : THE RESULT OF RESERVOIR YIELD OPTIMIZATION
(Combination 1e)

ALFA = 0.85
BETA = 0.31

PERIOD	MEAN INFLOW	WATER SUPPLY DEMAND	WATER SUPPLY RELEASE	IRRIGATION DEMAND	IRRIGATION RELEASE	HYDRO POWER DEMAND	HYDRO POWER RELEASE
1	302.766	39.120	39.120	9.659	9.659	33.808	33.808
2	278.643	39.603	39.603	19.319	19.319	28.978	28.978
3	227.477	40.086	40.086	28.978	28.978	24.148	24.148
4	130.533	40.569	40.569	38.637	38.637	21.734	21.734
5	103.815	40.086	37.027	48.297	26.179	19.319	14.895
6	114.307	40.569	37.473	53.126	28.797	14.489	11.171
7	3.884	40.569	37.968	67.615	41.607	12.074	9.752
8	0.268	41.052	38.420	67.615	41.607	9.659	7.802
9	6.195	41.052	40.679	53.126	50.231	9.659	9.396
10	24.025	40.569	40.201	43.467	41.098	14.489	14.094
11	68.714	40.086	40.086	33.808	33.808	24.148	24.148
12	152.937	39.603	39.603	19.319	19.319	28.978	28.978
SUM	1413.564	482.968	470.838	482.968	379.240	241.484	228.905
DEMAND RATIO		0.400	0.333	0.400	0.268	0.200	0.162
SUPPLY LEVEL		0.950	0.975	0.700	0.785	0.850	0.948

TABLE C-6 : THE RESULT OF RESERVOIR YIELD OPTIMIZATION
(Combination 2a)

ALFA = 0.91
BETA = 0.31

PERIOD	MEAN INFLOW	WATER SUPPLY DEMAND	WATER SUPPLY RELEASE	IRRIGATION DEMAND	IRRIGATION RELEASE	HYDRO POWER DEMAND	HYDRO POWER RELEASE
1	302.766	41.665	41.665	5.144	5.144	72.013	72.013
2	278.643	42.179	42.179	10.288	10.288	61.726	61.726
3	227.477	42.694	42.694	15.431	15.431	51.438	51.438
4	130.533	43.208	43.208	20.575	20.575	46.294	46.294
5	103.815	42.694	41.078	25.719	23.773	41.150	36.480
6	114.307	43.208	41.573	28.291	26.150	30.863	27.360
7	3.884	43.208	41.061	36.007	32.429	25.719	21.886
8	0.268	43.722	41.550	36.007	32.429	20.575	17.509
9	6.195	43.722	41.529	28.291	25.452	20.575	17.478
10	24.025	43.208	41.040	23.147	20.825	30.863	26.218
11	68.714	42.694	41.667	18.003	17.138	51.438	47.729
12	152.937	42.179	41.165	10.288	9.793	61.726	57.275
SUM	1413.564	514.380	500.410	257.190	239.427	514.380	483.406
DEMAND RATIO		0.400	0.354	0.200	0.169	0.400	0.342
SUPPLY LEVEL		0.950	0.973	0.900	0.931	0.850	0.940

TABLE C-7 : THE RESULT OF RESERVOIR YIELD OPTIMIZATION
(Combination 2b)

ALFA = 0.91
BETA = 0.31

PERIOD	MEAN INFLOW	WATER SUPPLY DEMAND	WATER SUPPLY RELEASE	IRRIGATION DEMAND	IRRIGATION RELEASE	HYDRO POWER DEMAND	HYDRO POWER RELEASE
1	302.766	41.665	41.665	5.144	5.144	72.013	72.013
2	278.643	42.179	42.179	10.288	10.288	61.726	61.726
3	227.477	42.694	42.694	15.431	15.431	51.438	51.438
4	130.533	43.208	43.208	20.575	20.575	46.294	46.294
5	103.815	42.694	41.591	25.719	23.727	41.150	37.963
6	114.307	43.208	42.092	28.291	26.100	30.863	28.472
7	3.884	43.208	41.754	36.007	32.372	25.719	23.123
8	0.268	43.722	42.251	36.007	32.372	20.575	18.498
9	6.195	43.722	42.211	28.291	25.357	20.575	18.441
10	24.025	43.208	41.714	23.147	20.747	30.863	27.662
11	68.714	42.694	41.844	18.003	16.929	51.438	48.369
12	152.937	42.179	41.340	10.288	9.674	61.726	58.043
SUM	1413.564	514.380	504.544	257.190	238.715	514.380	492.042
DEMAND RATIO		0.400	0.357	0.200	0.169	0.400	0.348
SUPPLY LEVEL		0.950	0.981	0.850	0.928	0.850	0.957

TABLE C-8 : THE RESULT OF RESERVOIR YIELD OPTIMIZATION
(Combination 2c)

ALFA = 0.91
BETA = 0.31

PERIOD	MEAN INFLOW	WATER SUPPLY DEMAND	WATER SUPPLY RELEASE	IRRIGATION DEMAND	IRRIGATION RELEASE	HYDRO POWER DEMAND	HYDRO POWER RELEASE
1	302.766	41.665	41.665	5.144	5.144	72.013	72.013
2	278.643	42.179	42.179	10.288	10.288	61.726	61.726
3	227.477	42.694	42.694	15.431	15.431	51.438	51.438
4	130.533	43.208	43.208	20.575	20.575	46.294	46.294
5	103.815	42.694	41.857	25.719	23.703	41.150	38.731
6	114.307	43.208	42.361	28.291	26.073	30.863	29.049
7	3.884	43.208	42.109	36.007	32.343	25.719	23.756
8	0.268	43.722	42.610	36.007	32.343	20.575	19.005
9	6.195	43.722	42.569	28.291	25.306	20.575	18.947
10	24.025	43.208	42.068	23.147	20.705	30.863	28.421
11	68.714	42.694	41.956	18.003	16.759	51.438	48.772
12	152.937	42.179	41.450	10.288	9.577	61.726	58.527
SUM	1413.564	514.380	506.726	257.190	238.246	514.380	496.678
DEMAND RATIO		0.400	0.358	0.200	0.169	0.400	0.351
SUPPLY LEVEL		0.950	0.985	0.800	0.926	0.850	0.966

TABLE C-9 : THE RESULT OF RESERVOIR YIELD OPTIMIZATION
(Combination 2d)

ALFA = 0.91
BETA = 0.31

PERIOD	MEAN INFLOW	WATER SUPPLY DEMAND	WATER SUPPLY RELEASE	IRRIGATION DEMAND	IRRIGATION RELEASE	HYDRO POWER DEMAND	HYDRO POWER RELEASE
1	302.766	41.665	41.665	5.144	5.144	72.013	72.013
2	278.643	42.179	42.179	10.288	10.288	61.726	61.726
3	227.477	42.694	42.694	15.431	15.431	51.438	51.438
4	130.533	43.208	43.208	20.575	20.575	46.294	46.294
5	103.815	42.694	42.019	25.719	23.689	41.150	39.201
6	114.307	43.208	42.526	28.291	26.057	30.863	29.401
7	3.884	43.208	42.324	36.007	32.325	25.719	24.141
8	0.268	43.722	42.828	36.007	32.325	20.575	19.313
9	6.195	43.722	42.790	28.291	25.274	20.575	19.259
10	24.025	43.208	42.287	23.147	20.679	30.863	28.888
11	68.714	42.694	42.034	18.003	16.612	51.438	49.053
12	152.937	42.179	41.527	10.288	9.493	61.726	58.864
SUM	1413.564	514.380	508.081	257.190	237.892	514.380	499.592
DEMAND RATIO		0.400	0.359	0.200	0.168	0.400	0.353
SUPPLY LEVEL		0.950	0.988	0.750	0.925	0.850	0.971

TABLE C-10 : THE RESULT OF RESERVOIR YIELD OPTIMIZATION
(Combination 3c)

ALFA = 0.88
BETA = 0.31

PERIOD	MEAN INFLOW	WATER SUPPLY DEMAND	WATER SUPPLY RELEASE	IRRIGATION DEMAND	IRRIGATION RELEASE	HYDRO POWER DEMAND	HYDRO POWER RELEASE
1	302.766	30.056	30.050	14.842	14.831	17.316	17.306
2	278.643	30.427	30.421	29.685	29.662	14.842	14.834
3	227.477	30.798	30.773	44.527	44.380	12.369	12.338
4	130.533	31.169	31.143	59.370	59.173	11.132	11.104
5	103.815	30.798	28.695	74.212	53.941	9.895	7.868
6	114.307	31.169	29.041	81.633	59.335	7.421	5.901
7	3.884	31.169	27.461	103.897	54.452	6.184	3.977
8	0.268	31.540	27.788	103.897	54.452	4.947	3.182
9	6.195	31.540	28.586	81.633	51.047	4.947	3.557
10	24.025	31.169	28.250	66.791	41.766	7.421	5.336
11	68.714	30.798	30.770	51.948	51.759	12.369	12.335
12	152.937	30.427	30.399	29.685	29.577	14.842	14.802
SUM	1413.564	371.060	353.376	742.121	544.376	123.687	112.539
DEMAND RATIO		0.300	0.250	0.600	0.385	0.100	0.080
SUPPLY LEVEL		0.950	0.952	0.800	0.734	0.850	0.910

TABLE C-11 : THE RESULT OF RESERVOIR YIELD OPTIMIZATION
(Combination 3e)

ALFA = 0.85
BETA = 0.31

PERIOD	MEAN INFLOW	WATER SUPPLY DEMAND	WATER SUPPLY RELEASE	IRRIGATION DEMAND	IRRIGATION RELEASE	HYDRO POWER DEMAND	HYDRO POWER RELEASE
1	302.766	29.340	29.336	14.489	14.477	16.904	16.897
2	278.643	29.703	29.698	28.978	28.955	14.489	14.483
3	227.477	30.065	30.003	43.467	42.934	12.074	12.000
4	130.533	30.427	30.365	57.956	57.246	10.867	10.800
5	103.815	30.065	29.092	72.445	58.378	9.659	8.722
6	114.307	30.427	29.442	79.690	64.215	7.245	6.541
7	3.884	30.427	27.183	101.423	36.537	6.037	4.106
8	0.268	30.789	27.506	101.423	36.537	4.830	3.285
9	6.195	30.789	29.536	79.690	60.231	4.830	4.240
10	24.025	30.427	29.189	65.201	49.280	7.245	6.360
11	68.714	30.065	29.084	50.712	40.788	12.074	10.893
12	152.937	29.703	28.734	28.978	23.307	14.489	13.071
SUM	1413.564	362.226	349.169	724.451	512.885	120.742	111.398
DEMAND RATIO		0.300	0.247	0.600	0.363	0.100	0.079
SUPPLY LEVEL		0.950	0.964	0.700	0.708	0.850	0.923

TABLE C-12: THE RESULT OF RESERVOIR YIELD OPTIMIZATION
(Combination 4d)

ALFA = 0.80
BETA = 0.31

PERIOD	MEAN INFLOW	WATER SUPPLY DEMAND	WATER SUPPLY RELEASE	IRRIGATION DEMAND	IRRIGATION RELEASE	HYDRO POWER DEMAND	HYDRO POWER RELEASE
1	302.766	18.288	18.288	13.547	13.547	31.609	31.609
2	278.643	18.514	18.514	27.093	27.093	27.093	27.093
3	227.477	18.740	18.728	40.640	40.514	22.578	22.536
4	130.533	18.965	18.954	54.187	54.019	20.320	20.282
5	103.815	18.740	16.898	67.733	34.446	18.062	12.736
6	114.307	18.965	17.101	74.507	37.891	13.547	9.552
7	3.884	18.965	16.373	94.827	30.013	11.289	6.659
8	0.268	19.191	16.568	94.827	30.013	9.031	5.327
9	6.195	19.191	19.084	74.507	72.427	9.031	8.880
10	24.025	18.965	18.859	60.960	59.259	13.547	13.320
11	68.714	18.740	18.726	47.413	47.238	22.578	22.528
12	152.937	18.514	18.500	27.093	26.993	27.093	27.033
SUM	1413.564	225.778	216.592	677.333	473.454	225.778	207.556
DEMAND RATIO		0.200	0.153	0.600	0.335	0.200	0.147
SUPPLY LEVEL		0.950	0.959	0.750	0.699	0.850	0.919

TABLE C-13: THE RESULT OF RESERVOIR YIELD OPTIMIZATION
(Combination 4e)

ALFA = 0.91
BETA = 0.31

PERIOD	MEAN INFLOW	WATER SUPPLY DEMAND	WATER SUPPLY RELEASE	IRRIGATION DEMAND	IRRIGATION RELEASE	HYDRO POWER DEMAND	HYDRO POWER RELEASE
1	302.766	20.832	20.810	15.431	15.332	36.007	35.890
2	278.643	21.090	21.067	30.863	30.664	30.863	30.763
3	227.477	21.347	21.244	46.294	44.956	25.719	25.347
4	130.533	21.604	21.500	61.726	59.941	23.147	22.813
5	103.815	21.347	19.598	77.157	39.233	20.575	15.519
6	114.307	21.604	19.834	84.873	43.156	15.431	11.639
7	3.884	21.604	19.340	108.020	40.115	12.860	8.818
8	0.268	21.861	19.571	108.020	40.115	10.288	7.054
9	6.195	21.861	21.362	84.873	73.256	10.288	9.584
10	24.025	21.604	21.111	69.441	59.937	15.431	14.375
11	68.714	21.347	21.138	54.010	50.838	25.719	24.964
12	152.937	21.090	20.883	30.863	29.050	30.863	29.957
SUM	1413.564	257.190	247.459	771.570	526.592	257.190	236.722
DEMAND RATIO		0.200	0.175	0.600	0.373	0.200	0.167
SUPPLY LEVEL		0.950	0.962	0.700	0.682	0.850	0.920

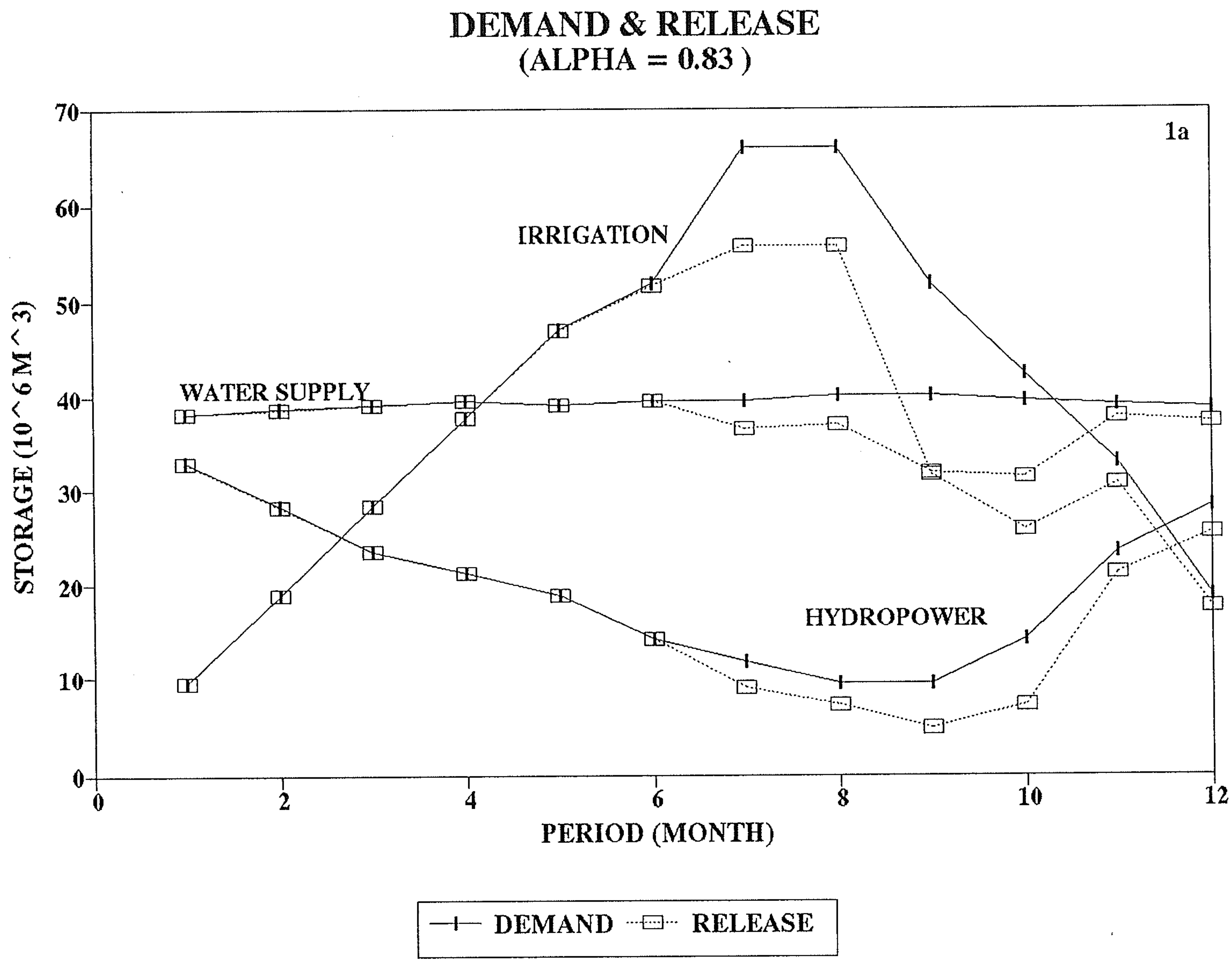

Figure C-1 : Demand and release for combination 1a

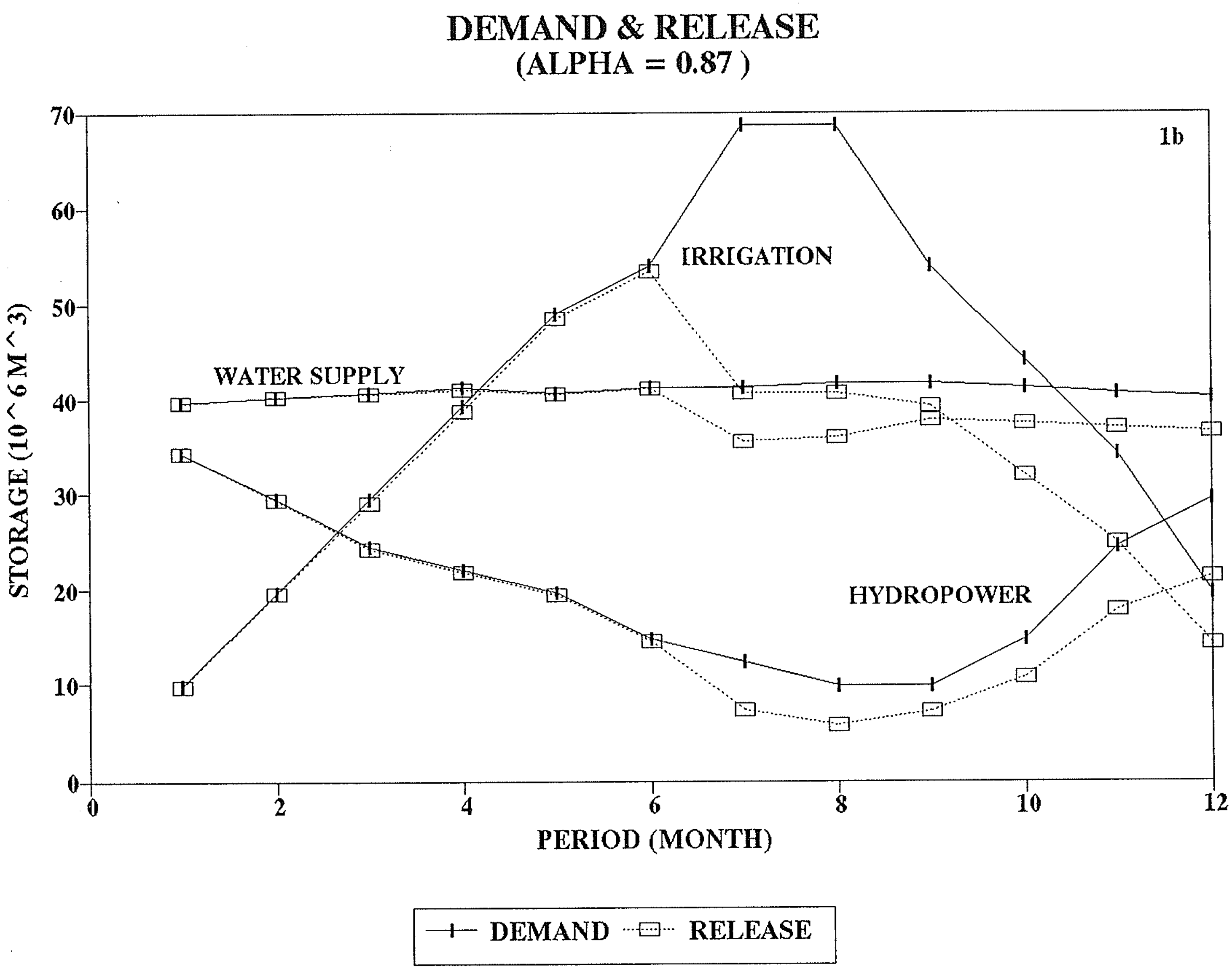

Figure C-2 : Demand and release for combination 1b

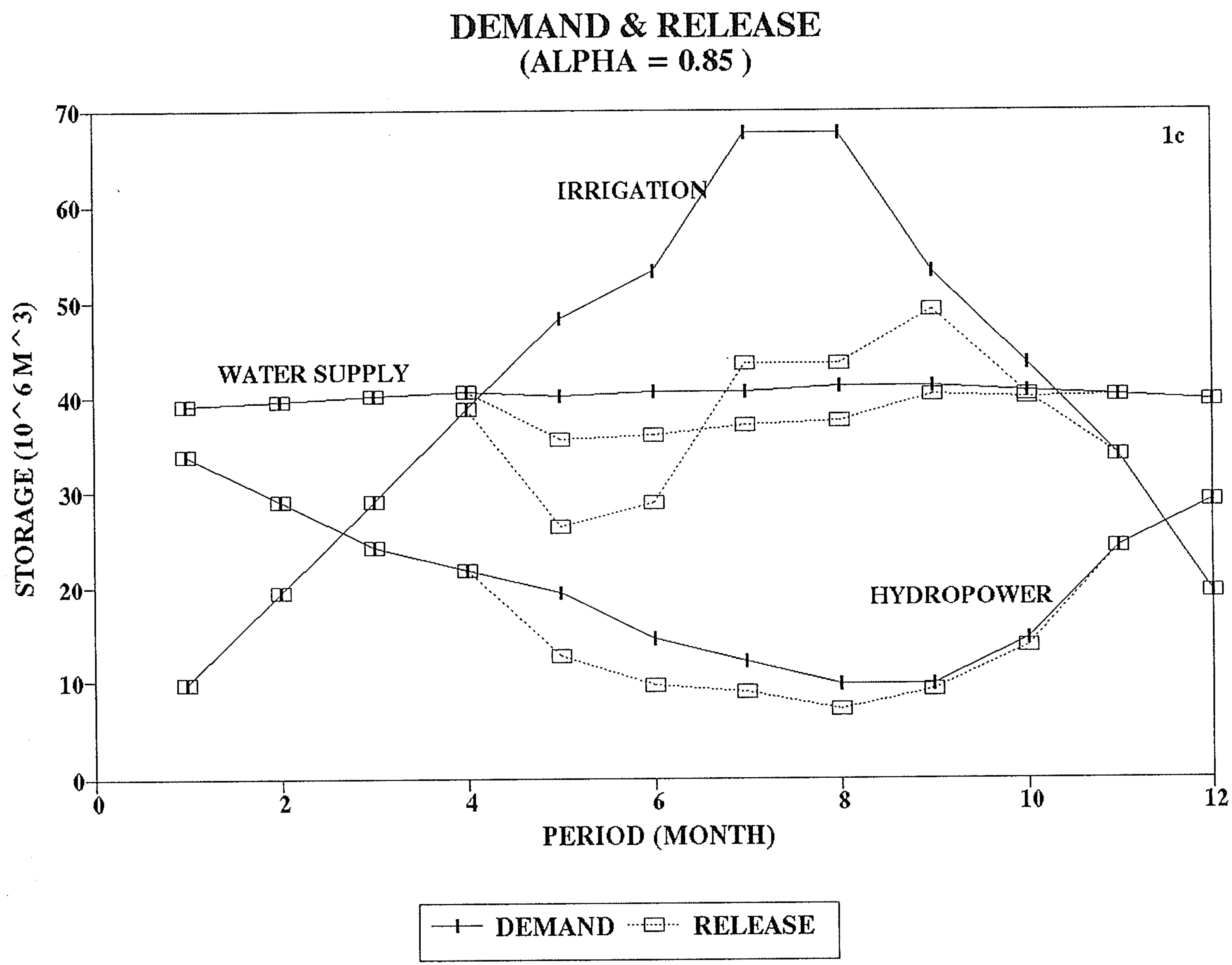

Figure C-3 : Demand and release for combination 1c

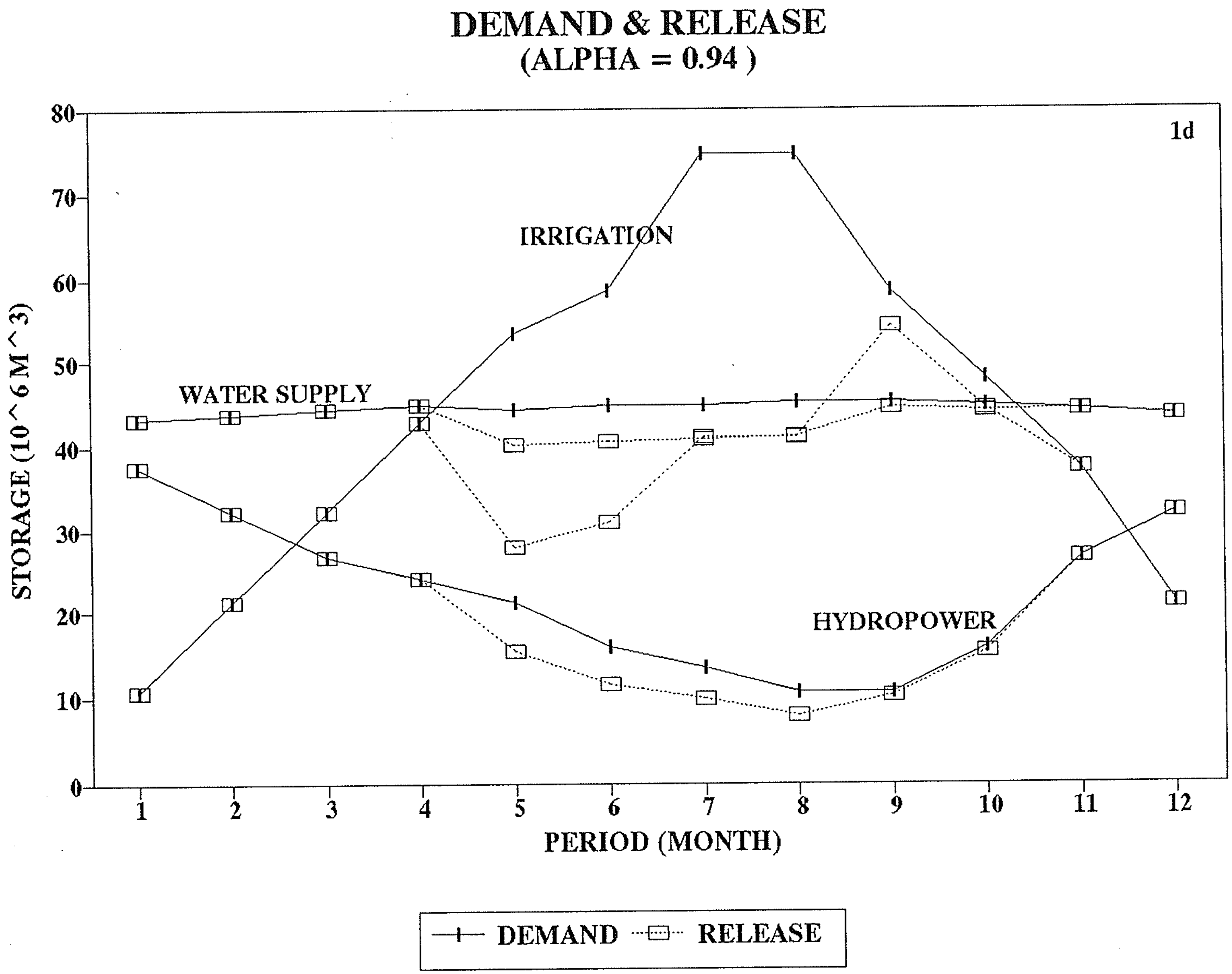

Figure C-4 : Demand and release for combination 1d

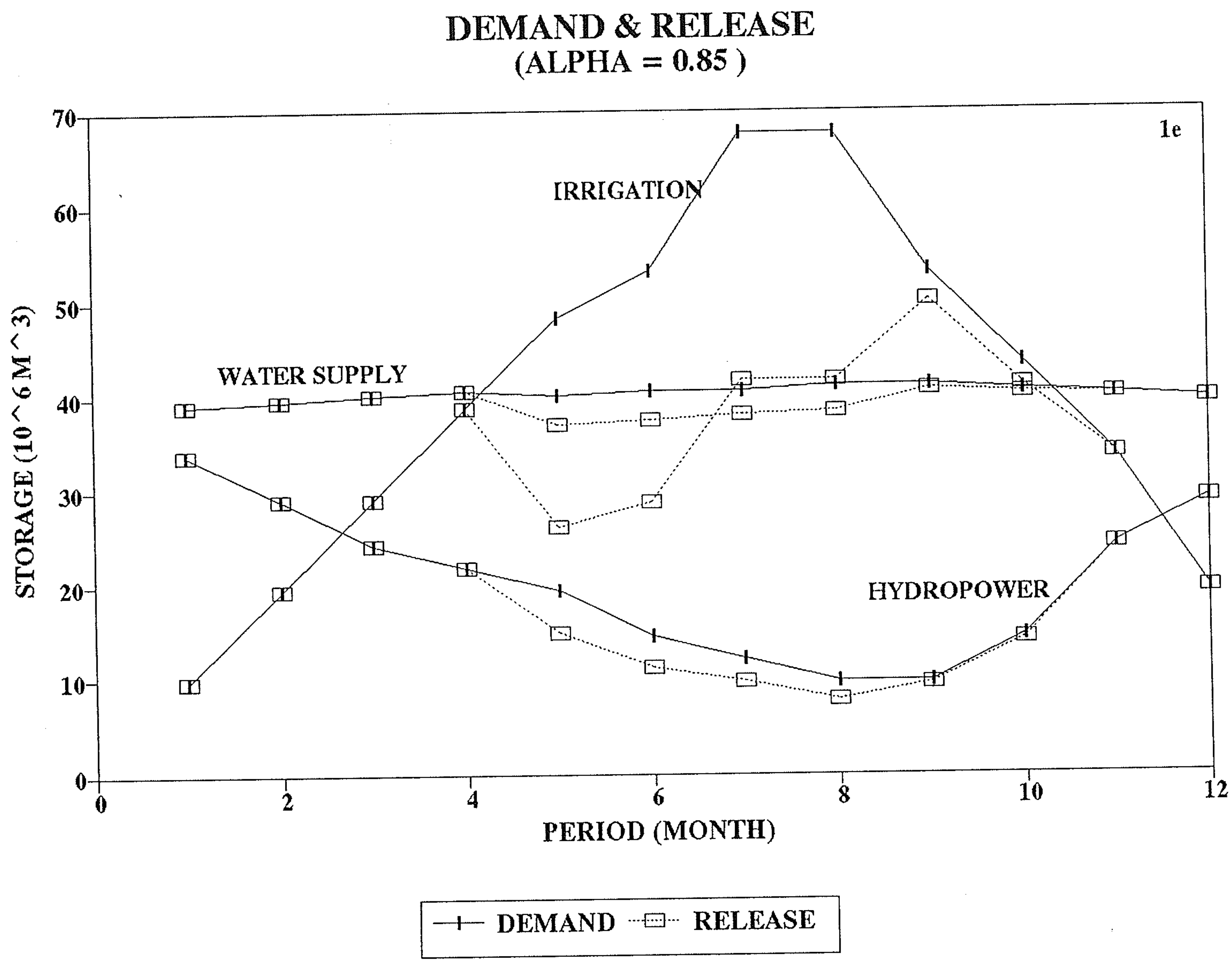

Figure C-5 : Demand and release for combination 1e

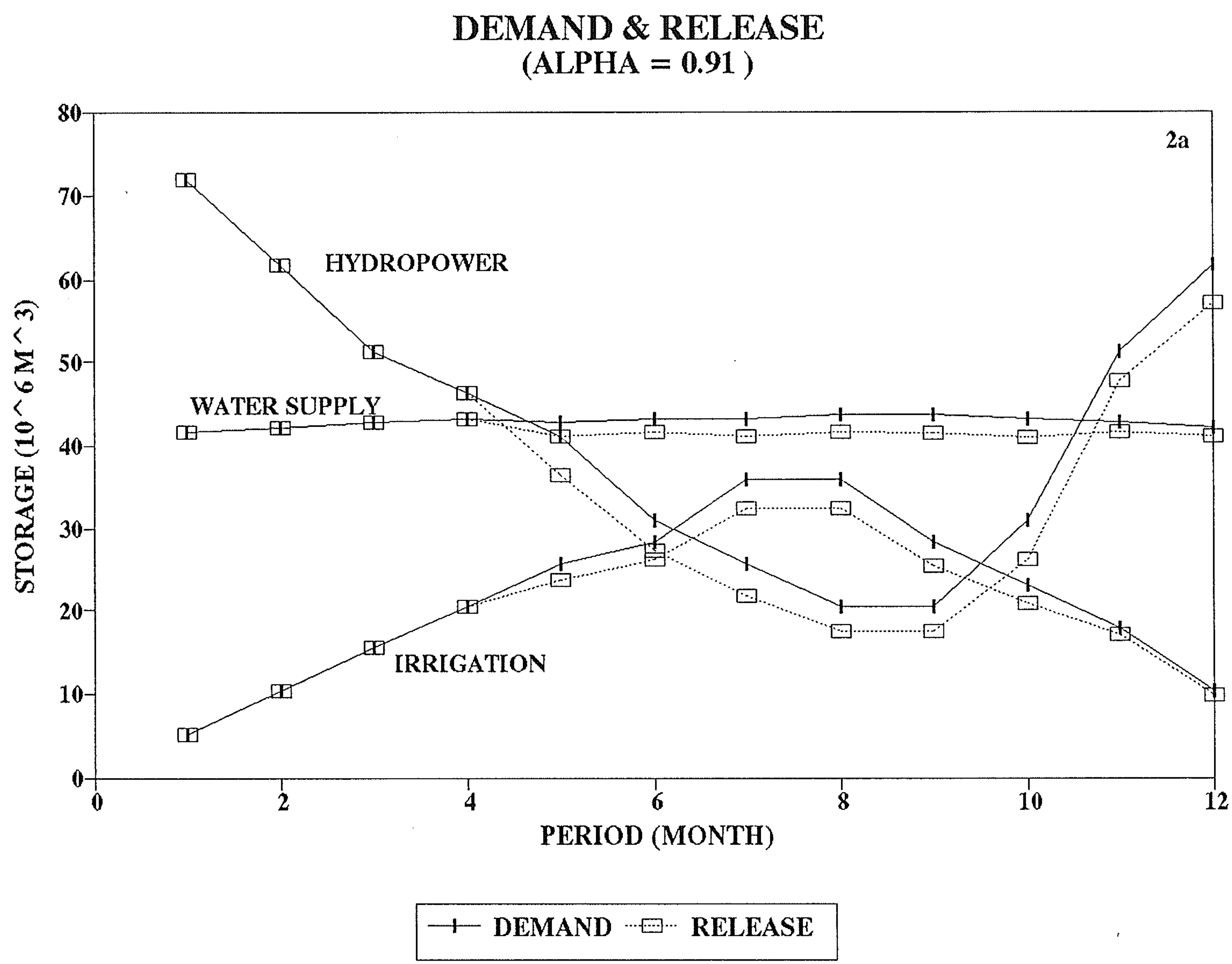

Figure C-6 : Demand and release for combination 2a

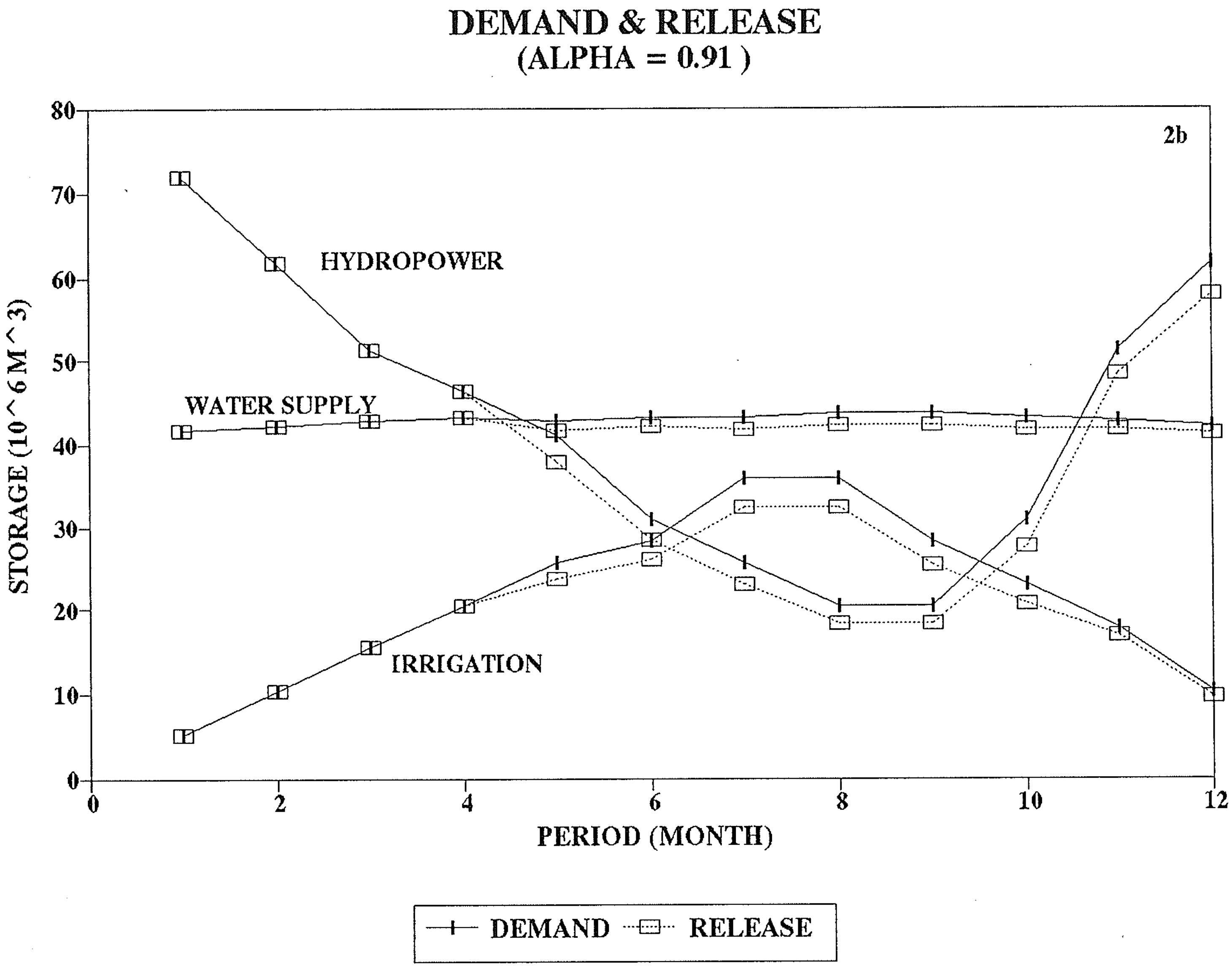

Figure C-7 : Demand and release for combination 2b

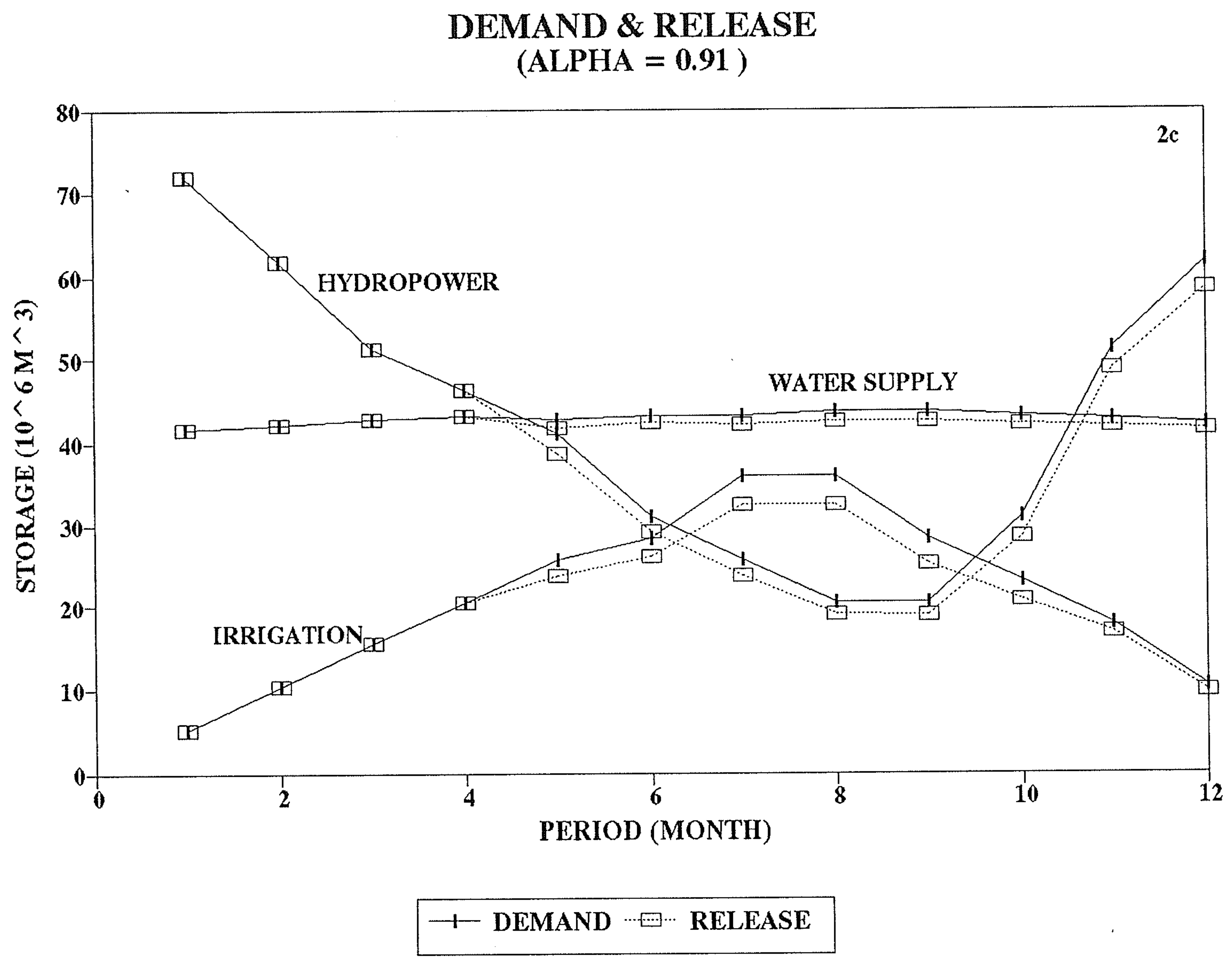

Figure C-8 : Demand and release for combination 2c

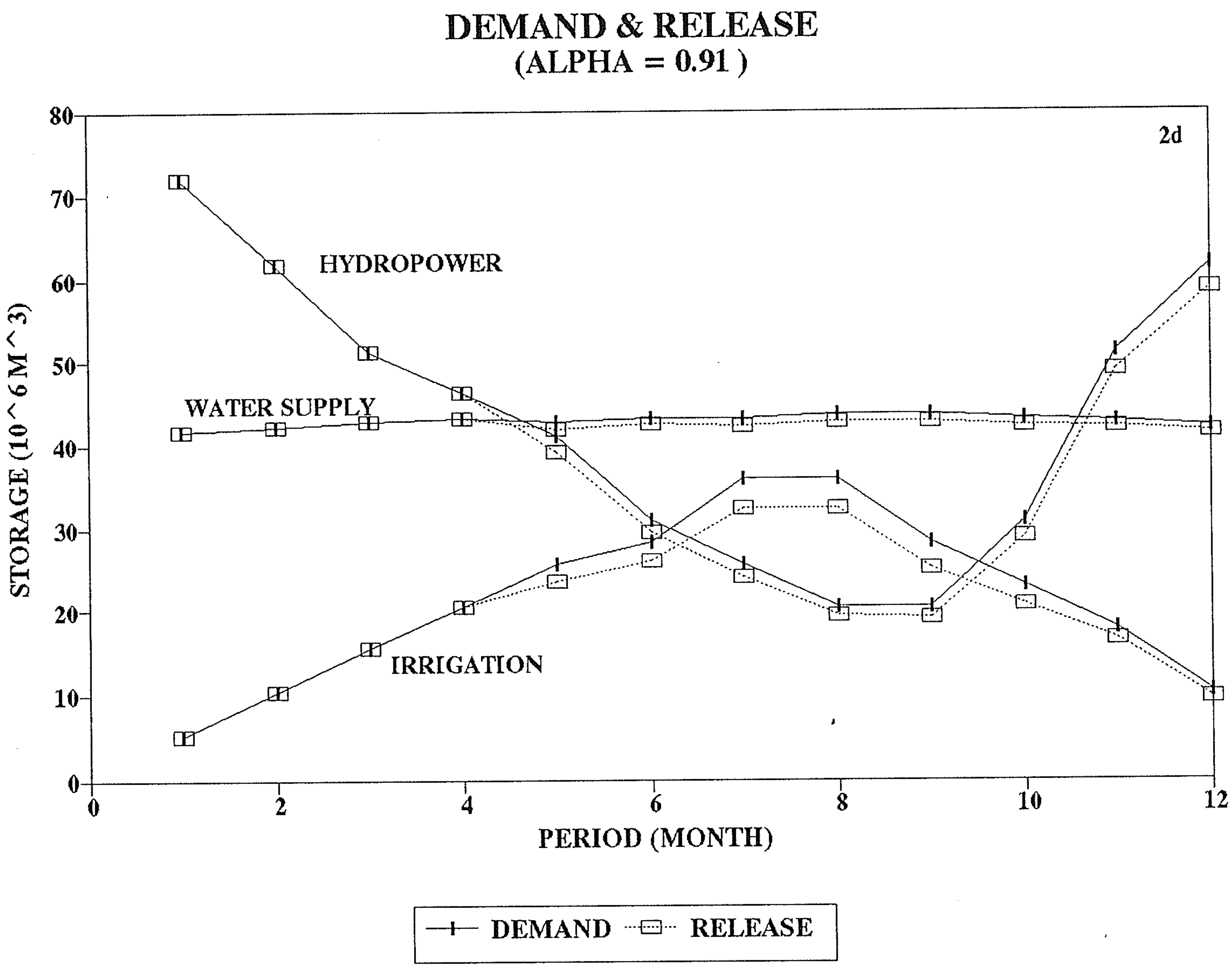

Figure C-9 : Demand and release for combination 2d

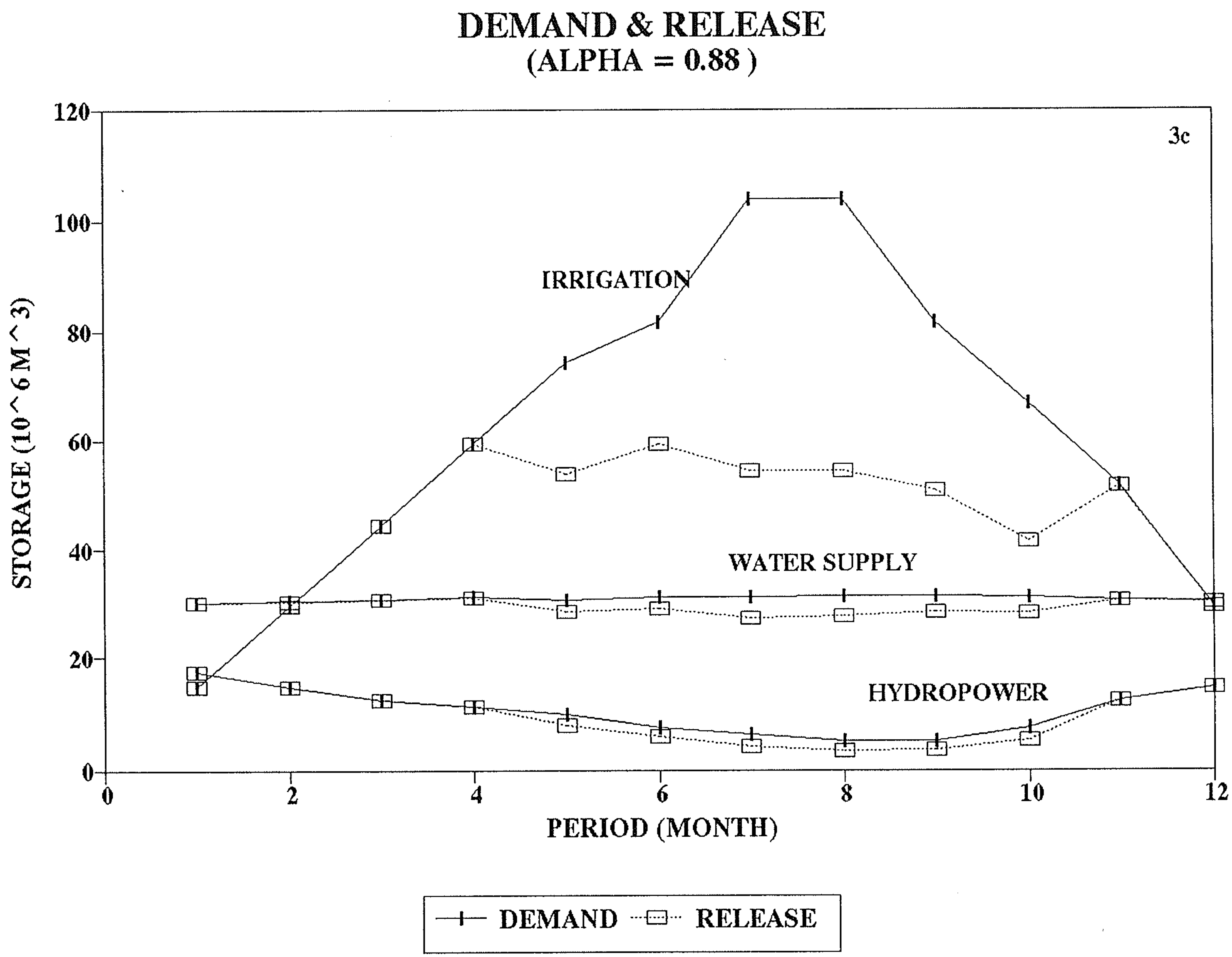

Figure C-10 : Demand and release for combination 3c

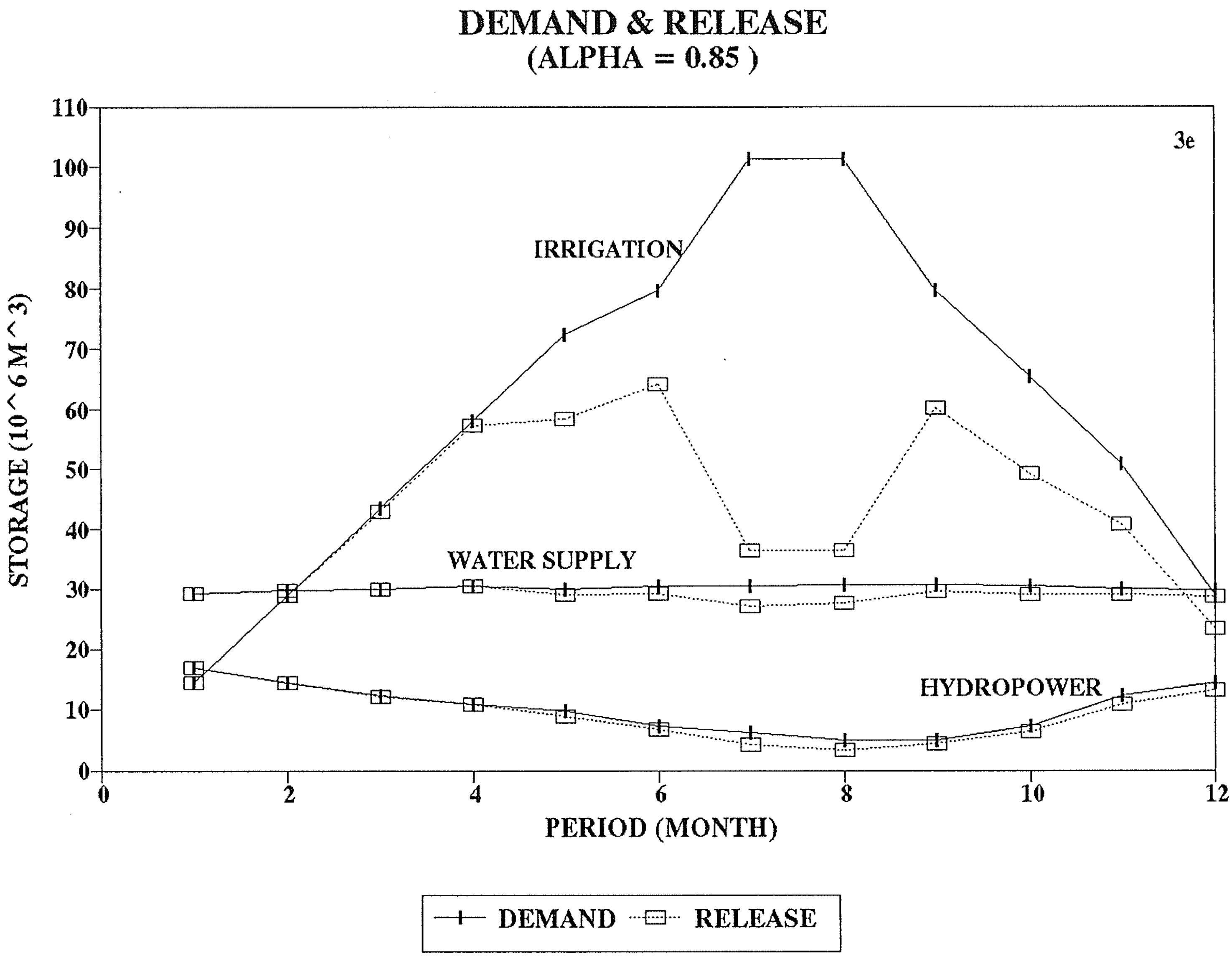

Figure C-11 : Demand and release for combination 3e

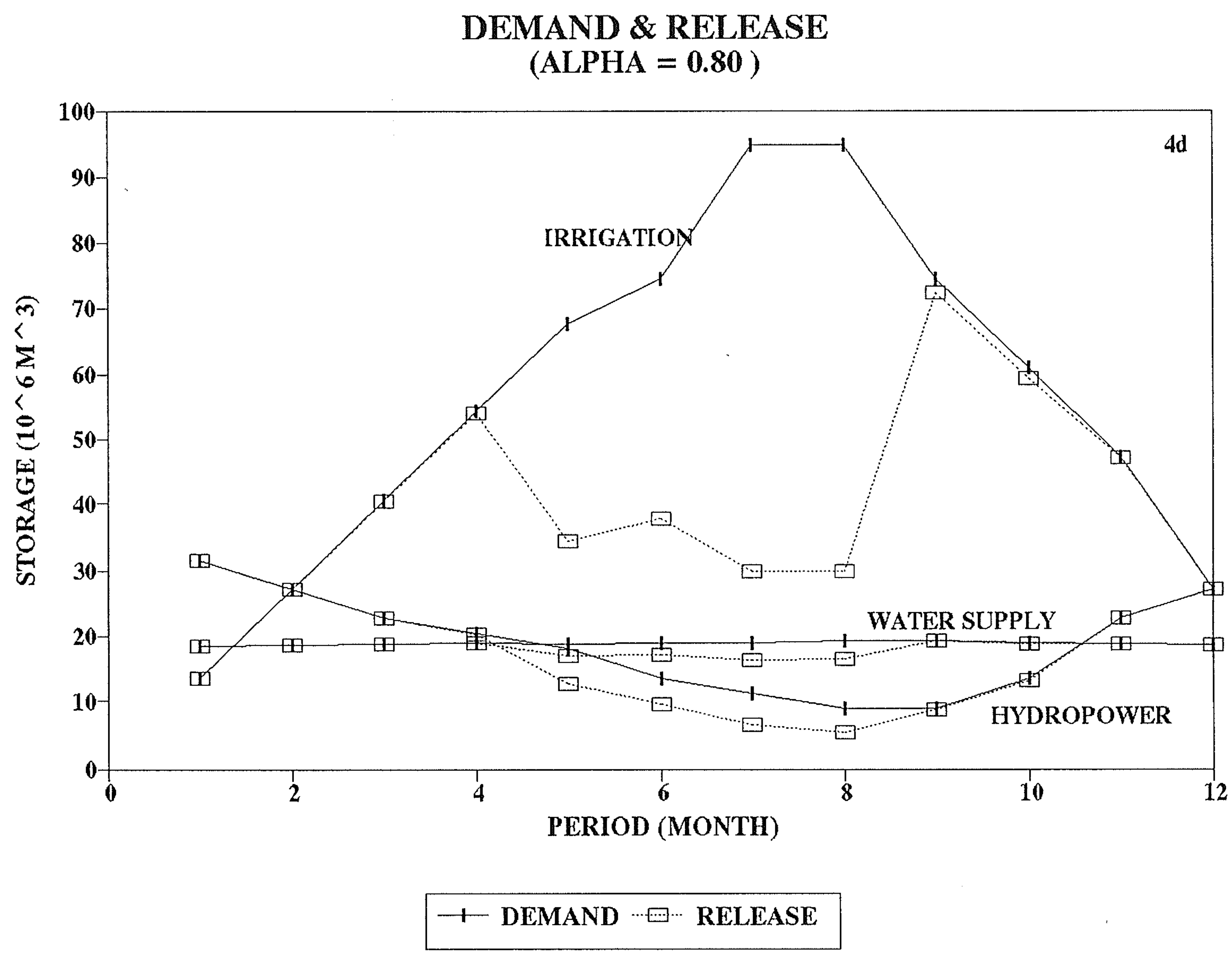

Figure C-12 : Demand and release for combination 4d

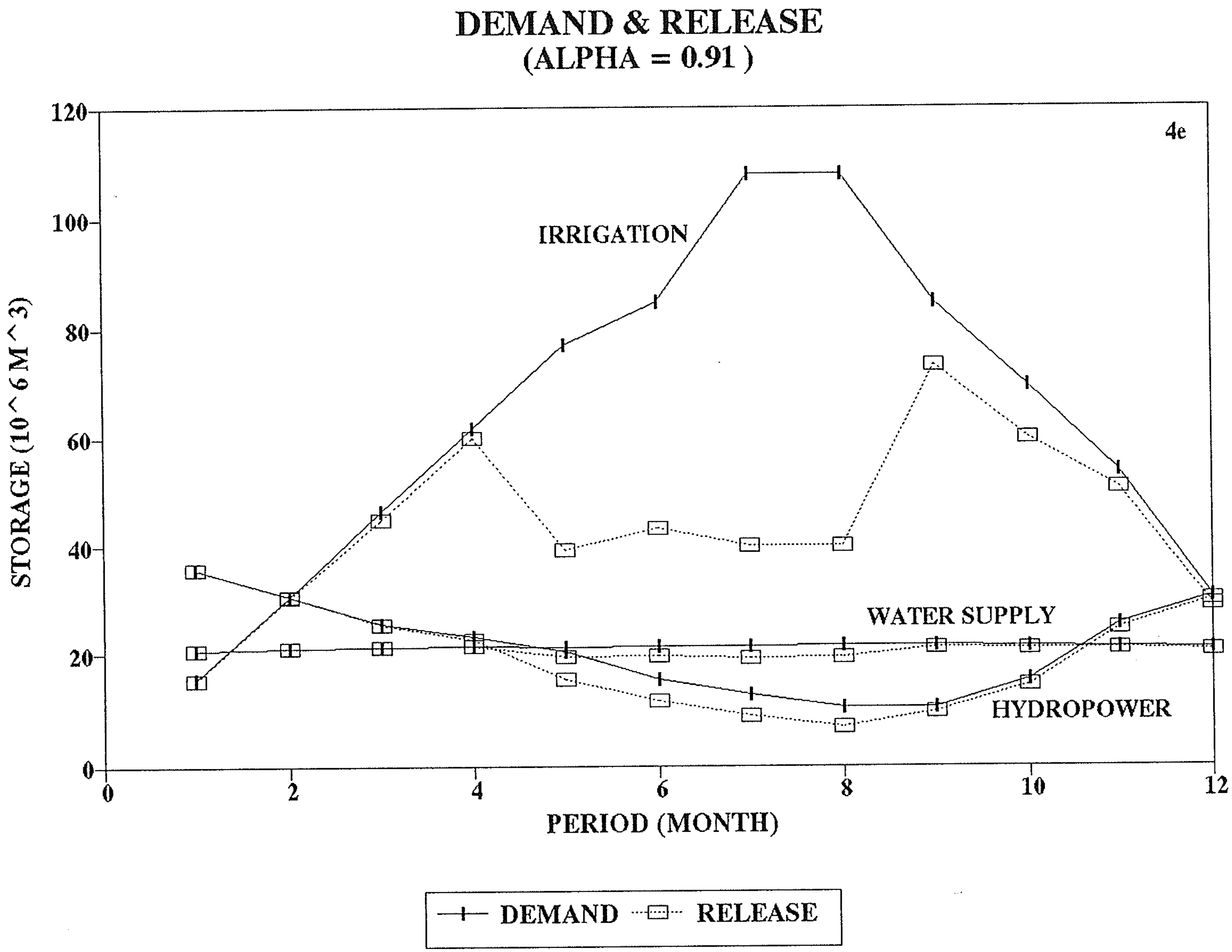

Figure C-13 : Demand and release for combination 4e

1 FIBONACCI SINGLE-VARIABLE PROCEDURE

2 FUNCTION EVALUATIONS

VALUE OF VARIABLES

1.800	0.800
0.800	0.800
0.800	0.800
0.800	0.800
0.800	0.800
0.800	0.800

RELATIVE WATER DEMAND : 0.382

OPTIMAL VALUE F

F(1) : 0.431

NUMBER OF FAILURES AND RELIABILITY OF RELEASES

REL. RELEASE PERIOD	0.99	0.90	0.80	0.70	0.60	0.50	0.40	0.30
1	0	0	0	0	0	0	0	0
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1	0	0	0	0	0	0	0	0
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1	0	0	0	0	0	0	0	0
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0	0	0	0	0	0	0	0
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0	0	0	0	0	0	0	0
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0	0	0	0	0	0	0	0
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3	17	0	0	0	0	0	0	0
	0.660	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3	17	16	0	0	0	0	0	0
	0.660	0.680	1.000	1.000	1.000	1.000	1.000	1.000
3	17	0	0	0	0	0	0	0
	0.660	1.000	1.000	1.000	1.000	1.000	1.000	1.000
4	36	0	0	0	0	0	0	0
	0.280	1.000	1.000	1.000	1.000	1.000	1.000	1.000
4	37	32	0	0	0	0	0	0
	0.260	0.360	1.000	1.000	1.000	1.000	1.000	1.000
4	37	0	0	0	0	0	0	0
	0.260	1.000	1.000	1.000	1.000	1.000	1.000	1.000
5	28	0	0	0	0	0	0	0
	0.440	1.000	1.000	1.000	1.000	1.000	1.000	1.000
5	31	28	0	0	0	0	0	0
	0.380	0.440	1.000	1.000	1.000	1.000	1.000	1.000
5	31	0	0	0	0	0	0	0
	0.380	1.000	1.000	1.000	1.000	1.000	1.000	1.000
6	4	0	0	0	0	0	0	0
	0.920	1.000	1.000	1.000	1.000	1.000	1.000	1.000
6	5	1	0	0	0	0	0	0
	0.900	0.980	1.000	1.000	1.000	1.000	1.000	1.000
6	5	0	0	0	0	0	0	0
	0.900	1.000	1.000	1.000	1.000	1.000	1.000	1.000

2 FUNCTION EVALUATIONS

VALUE OF VARIABLES

2.800	0.800
0.800	0.800
0.800	0.800
0.800	0.800
0.800	0.800
0.800	0.800

RELATIVE WATER DEMAND : 0.618

OPTIMAL VALUE F

F(1) : 0.514

NUMBER OF FAILURES AND RELIABILITY OF RELEASES

REL. RELEASE PERIOD	0.95	0.90	0.80	0.70	0.60	0.50	0.40	0.30
1	0	0	0	0	0	0	0	0
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1	0	0	0	0	0	0	0	0
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1	0	0	0	0	0	0	0	0
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0	0	0	0	0	0	0	0
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0	0	0	0	0	0	0	0
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	0	0	0	0	0	0	0	0
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3	22	0	0	0	0	0	0	0
	0.560	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3	22	22	0	0	0	0	0	0
	0.560	0.560	1.000	1.000	1.000	1.000	1.000	1.000
3	22	0	0	0	0	0	0	0
	0.560	1.000	1.000	1.000	1.000	1.000	1.000	1.000
4	36	0	0	0	0	0	0	0
	0.280	1.000	1.000	1.000	1.000	1.000	1.000	1.000
4	37	34	0	0	0	0	0	0
	0.280	0.320	1.000	1.000	1.000	1.000	1.000	1.000
4	37	0	0	0	0	0	0	0
	0.260	1.000	1.000	1.000	1.000	1.000	1.000	1.000
5	30	0	0	0	0	0	0	0
	0.400	1.000	1.000	1.000	1.000	1.000	1.000	1.000
5	32	28	0	0	0	0	0	0
	0.360	0.440	1.000	1.000	1.000	1.000	1.000	1.000
5	32	0	0	0	0	0	0	0
	0.360	1.000	1.000	1.000	1.000	1.000	1.000	1.000
6	10	0	0	0	0	0	0	0
	0.800	1.000	1.000	1.000	1.000	1.000	1.000	1.000
6	12	8	0	0	0	0	0	0
	0.760	0.840	1.000	1.000	1.000	1.000	1.000	1.000
6	12	0	0	0	0	0	0	0
	0.760	1.000	1.000	1.000	1.000	1.000	1.000	1.000

LK	AK	BK	LLK	X	Y
FIBONACCI ITERATION : 1					
0.1000E+01	0.0000E+00	0.1000E+01	0.3819E+00	0.6181E+00	0.2569E+01

2 FUNCTION EVALUATIONS

```
VALUE OF VARIABLES
     3.800        0.800
     0.800        0.800
     0.800        0.800
     0.800        0.800
     0.800        0.800
     0.800        0.800

RELATIVE WATER DEMAND : 0.764

OPTIMAL VALUE F

F(1) :        0.567
```

NUMBER OF FAILURES AND RELIABILITY OF RELEASES

REL. RELEASE / PERIOD	0.99	0.90	0.80	0.70	0.60	0.50	0.40	0.30
1	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
1	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
1	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	24 0.520	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	25 0.500	24 0.520	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	25 0.500	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	36 0.280	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	37 0.260	34 0.320	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	37 0.260	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	30 0.400	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	32 0.360	30 0.400	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	32 0.360	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	15 0.700	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	17 0.660	12 0.760	2 0.980	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	16 0.680	2 0.960	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000

```
FIBONACCI ITERATION :  2
0.6181E+00  0.3819E+00  0.1000E+01  0.2361E+00  0.7639E+00  0.2486E+01
                                                0.7639E+00  0.2433E+01

     2  FUNCTION EVALUATIONS

VALUE OF VARIABLES
     4.800        0.800


     0.800        0.800
     0.800        0.800
     0.800        0.800
     0.800        0.800
     0.800        0.800

RELATIVE WATER DEMAND : 0.854

OPTIMAL VALUE F

F(1) :        0.595
```

NUMBER OF FAILURES AND RELIABILITY OF RELEASES

REL. RELEASE / PERIOD	0.99	0.90	0.80	0.70	0.60	0.50	0.40	0.30
1	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
1	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
1	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	25 0.500	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	25 0.500	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	36 0.280	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	37 0.260	34 0.320	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	37 0.260	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	30 0.400	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	32 0.360	30 0.400	4 0.920	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	32 0.360	4 0.920	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	17 0.660	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	18 0.640	14 0.720	5 0.900	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	18 0.640	5 0.900	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000

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FIBONACCI ITERATION :  3
0.3819E+00  0.6181E+00  0.1000E+01  0.1458E+00  0.8542E+00  0.2433E+01
                                                0.8542E+00  0.2405E+01

     8  FUNCTION EVALUATIONS

VALUE OF VARIABLES
     4.800        1.800
     0.800        0.800
     0.800        0.800
```

0.800 0.800
0.800 0.800
0.800 0.800

RELATIVE WATER DEMAND = 0.910

OPTIMAL VALUE F

F(1) = 2.482

NUMBER OF FAILURES AND RELIABILITY OF RELEASES

REL. RELEASE / PERIOD	0.99	0.90	0.80	0.70	0.60	0.50	0.40	0.30
1	7 0.860	7 0.860	3 0.940	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
1	7 0.860	7 0.860	7 0.860	7 0.860	7 0.860	7 0.860	7 0.860	6 0.880
1	7 0.860	7 0.860	7 0.860	7 0.860	6 0.880	4 0.920	3 0.940	1 0.980
2	7 0.860	7 0.860	5 0.900	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	7 0.860	7 0.860	7 0.860	7 0.860	7 0.860	7 0.860	7 0.860	7 0.860
2	7 0.860	7 0.860	7 0.860	7 0.860	7 0.860	5 0.900	5 0.900	4 0.920
3	30 0.400	6 0.880	4 0.920	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	30 0.400	29 0.420	6 0.880	6 0.880	6 0.880	6 0.880	6 0.880	6 0.880
3	30 0.400	6 0.880	6 0.880	6 0.880	6 0.880	4 0.920	4 0.920	4 0.920
4	39 0.220	6 0.880	6 0.880	2 0.960	0 1.000	0 1.000	0 1.000	0 1.000
4	39 0.220	37 0.260	6 0.880	6 0.880	6 0.880	6 0.880	6 0.880	6 0.880
4	39 0.220	6 0.880	6 0.880	6 0.880	6 0.880	6 0.880	6 0.880	6 0.880
5	35 0.300	6 0.880	6 0.880	3 0.940	0 1.000	0 1.000	0 1.000	0 1.000
5	37 0.260	35 0.300	11 0.780	6 0.880	6 0.880	6 0.880	6 0.880	6 0.880
5	37 0.260	11 0.780	6 0.880	6 0.880	6 0.880	6 0.880	6 0.880	6 0.880
6	23 0.540	7 0.860	7 0.860	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	23 0.540	21 0.580	12 0.760	7 0.860	7 0.860	7 0.860	7 0.860	7 0.860
6	23 0.540	12 0.760	7 0.860	7 0.860	7 0.860	7 0.860	7 0.860	6 0.880

FIBONACCI ITERATION = 4
0.2361E+00 0.7639E+00 0.1000E+01 0.9028E-01 0.9097E+00 0.2405E+01
0.9097E+00 0.5175E+00

6 FUNCTION EVALUATIONS

VALUE OF VARIABLES
-6.200 2.800
0.800 0.800
0.800 0.800
0.800 0.800
0.800 0.800

0.800 0.800

RELATIVE WATER DEMAND = 0.944

OPTIMAL VALUE F

F(1) = 0.875

NUMBER OF FAILURES AND RELIABILITY OF RELEASES

REL. RELEASE / PERIOD	0.99	0.90	0.80	0.70	0.60	0.50	0.40	0.30
1	1 0.980	1 0.980	1 0.980	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
1	1 0.980	1 0.980	1 0.980	1 0.980	1 0.980	1 0.980	1 0.980	1 0.980
1	1 0.980	1 0.980	1 0.980	1 0.980	1 0.980	1 0.980	1 0.980	1 0.980
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	26 0.480	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	36 0.280	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	37 0.260	34 0.320'	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	37 0.260	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	30 0.400	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	33 0.340	30 0.400	6 0.880	1 0.980	0 1.000	0 1.000	0 1.000	0 1.000
5	33 0.340	6 0.880	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	18 0.640	4 0.920	4 0.920	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	18 0.640	17 0.660	7 0.860	4 0.920	4 0.920	4 0.920	4 0.920	4 0.920
6	18 0.640	7 0.860	4 0.920	4 0.920	4 0.920	4 0.920	4 0.920	4 0.920

FIBONACCI ITERATION = 5
0.1458E+00 0.8542E+00 0.1000E+01 0.5556E-01 0.9444E+00 0.5175E+00
0.9444E+00 0.2125E+01

2 FUNCTION EVALUATIONS

VALUE OF VARIABLES
-5.200 2.800
0.800 0.800
0.800 0.800
0.800 0.800
0.800 0.800
0.800 0.800

RELATIVE WATER DEMAND = 0.889

OPTIMAL VALUE F

F(1) = 0.611

NUMBER OF FAILURES AND RELIABILITY OF RELEASES

REL. RELEASE PERIOD	0.99	0.90	0.80	0.70	0.60	0.50	0.40	0.30
1	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
1	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
1	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	25 0.500	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	36 0.280	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	37 0.260	34 0.320	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	37 0.260	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	30 0.400	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	33 0.340	30 0.400	5 0.900	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	33 0.340	5 0.900	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	18 0.640	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	18 0.640	15 0.700	5 0.900	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	18 0.640	5 0.900	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000

FIBONACCI ITERATION = 6
0.9028E-01 0.8542E+00 0.9444E+00 0.3472E-01 0.9444E+00 0.5175E+00
0.8889E+00 0.2389E+01

2 FUNCTION EVALUATIONS

VALUE OF VARIABLES

-4.200	2.800
0.800	0.800
0.800	0.800
0.800	0.800
0.800	0.800
0.800	0.800

RELATIVE WATER DEMAND = 0.824

OPTIMAL VALUE F

F(1) = 0.842

NUMBER OF FAILURES AND RELIABILITY OF RELEASES

REL. RELEASE PERIOD	0.99	0.90	0.80	0.70	0.60	0.50	0.40	0.30
1	1 0.980	1 0.980	1 0.980	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
1	1 0.980	1 0.980	1 0.980	1 0.980	1 0.980	1 0.980	1 0.980	1 0.980
1	1 0.980	1 0.980	1 0.980	1 0.980	1 0.980	1 0.980	1 0.980	1 0.980
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	26 0.480	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	36 0.280	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	37 0.260	34 0.320	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	37 0.260	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	30 0.400	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	33 0.340	30 0.400	5 0.900	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	33 0.340	5 0.900	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	18 0.640	4 0.920	4 0.920	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	18 0.640	17 0.660	6 0.880	4 0.920	4 0.920	4 0.920	4 0.920	4 0.920
6	18 0.640	6 0.880	4 0.920	4 0.920	4 0.920	4 0.920	4 0.920	3 0.940

FIBONACCI ITERATION = 7
0.5556E-01 0.8889E+00 0.9444E+00 0.2083E-01 0.9236E+00 0.5175E+00
0.9236E+00 0.2158E+01

2 FUNCTION EVALUATIONS

VALUE OF VARIABLES

-3.200	2.800
0.800	0.800
0.800	0.800
0.800	0.800
0.800	0.800
0.800	0.800

RELATIVE WATER DEMAND = 0.903

OPTIMAL VALUE F

F(1) = 0.615

NUMBER OF FAILURES AND RELIABILITY OF RELEASES

REL. RELEASE / PERIOD	0.99	0.90	0.80	0.70	0.60	0.50	0.40	0.30
1	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
1	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
1	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	25 0.500	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	36 0.280	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	37 0.260	34 0.320	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	37 0.260	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	30 0.400	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	33 0.340	30 0.400	5 0.900	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	33 0.340	5 0.900	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	18 0.640	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	18 0.640	16 0.680	6 0.880	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	18 0.640	6 0.880	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000

FIBONACCI ITERATION = 8
0.3472E-01 0.8889E+00 0.9236E+00 0.1389E-01 0.9236E+00 0.5175E+00
0.9028E+00 0.2385E+01

2 FUNCTION EVALUATIONS

VALUE OF VARIABLES

-2.200	2.800
0.800	0.800
0.800	0.800
0.800	0.800
0.800	0.800
0.800	0.800

RELATIVE WATER DEMAND = 0.917

OPTIMAL VALUE F

F(1) = 0.696

NUMBER OF FAILURES AND RELIABILITY OF RELEASES

REL. RELEASE / PERIOD	0.99	0.90	0.80	0.70	0.60	0.50	0.40	0.30
1	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
1	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
1	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	26 0.480	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	36 0.280	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	37 0.260	34 0.320	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	37 0.260	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	30 0.400	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	33 0.340	30 0.400	5 0.900	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	33 0.340	5 0.900	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	18 0.640	2 0.960	1 0.980	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	18 0.640	16 0.680	6 0.880	2 0.960	2 0.960	2 0.960	2 0.960	2 0.960
6	18 0.640	6 0.880	2 0.960	2 0.960	2 0.960	2 0.960	1 0.980	1 0.980

FIBONACCI ITERATION = 9
0.2083E-01 0.9028E+00 0.9236E+00 0.6944E-02 0.9167E+00 0.5175E+00
0.9167E+00 0.2304E+01

2 FUNCTION EVALUATIONS

VALUE OF VARIABLES

-1.200	2.800
0.800	0.800
0.800	0.800
0.800	0.800
0.800	0.800
0.800	0.800

RELATIVE WATER DEMAND = 0.910

OPTIMAL VALUE F

F(1) = 0.853

NUMBER OF FAILURES AND RELIABILITY OF RELEASES

REL. RELEASE / PERIOD	0.99	0.90	0.80	0.70	0.60	0.50	0.40	0.30
1	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
1	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
1	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
2	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	25 0.480	25 0.500	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
3	26 0.480	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	36 0.280	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	37 0.260	34 0.320	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
4	37 0.260	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	30 0.400	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	33 0.340	30 0.400	5 0.900	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
5	33 0.340	5 0.900	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	18 0.640	1 0.980	1 0.980	0 1.000	0 1.000	0 1.000	0 1.000	0 1.000
6	18 0.640	16 0.680	6 0.880	1 0.980	1 0.980	1 0.980	1 0.980	1 0.980
6	18 0.640	6 0.880	1 0.980	1 0.980	1 0.980	1 0.980	1 0.980	0 1.000

FIBONACCI ITERATION = 10

0.1389E-01 0.9028E+00 0.9167E+00 0.6944E-02 0.9167E+00 0.5175E+00
0.9097E+00 0.2347E+01

0

FINAL RESULT

ALPHA=0.91
BETA =0.31

USER:		WATER SUPPLY		IRRIGATION		HYDRO POWER	
PERIOD	MEAN VALUE	DEMAND	RELEASE	DEMAND	RELEASE	DEMAND	RELEASE
1	302.766	41.665	41.665	5.144	5.144	72.013	72.013
2	278.643	42.179	42.179	10.288	10.288	61.726	61.726
3	227.477	42.694	42.694	15.431	15.431	51.438	51.438
4	130.533	43.208	43.208	20.575	20.575	46.294	46.294
5	103.815	42.694	42.129	25.719	23.679	41.150	39.518
6	114.307	43.208	42.637	28.291	26.047	30.863	29.639
7	3.884	43.208	42.469	36.007	32.313	25.719	24.400
8	0.268	43.722	42.975	36.007	32.313	20.575	19.520
9	6.195	43.722	42.940	28.291	25.253	20.575	19.470
10	24.025	43.208	42.435	23.147	20.661	30.863	29.206
11	68.714	42.694	42.092	18.003	16.481	51.438	49.263
12	152.937	42.179	41.585	10.288	9.417	61.726	59.115
SUM	1413.564	514.380	509.006	257.190	237.601	514.380	501.601
DEMAND RATIO :		0.400	0.360	0.200	0.168	0.400	0.355
SUPPLY LEVEL :		0.950	0.990	0.700	0.924	0.850	0.975

```
CSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS
CSSSSSSSSSSSSSS     *  ****  **** *    *  ****     SSSSSSSSSSSSSS
CSSSSSSSSSSSSSS     *  *     *  *  * *    *  *     SSSSSSSSSSSSSS
CSSSSSSSSSSSSSS     *  ****  ***     *    *  *     SSSSSSSSSSSSSS
CSSSSSSSSSSSSSS     *     *  *  *    *    *  *     SSSSSSSSSSSSSS
CSSSSSSSSSSSSSS     *  ****  *    *  *    ****     SSSSSSSSSSSSSS
CSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS
C
C       IMPLICIT STOCHASTIC RESERVOIR YIELD OPTIMIZATION
C
C             - Author: Slobodan P.Simonovic, 1987 -
C
C
      DIMENSION WMM(12),WMA(12),WME(12),QMN(12),PYM(12),
     + PYA(12),PYE(12),DRMD(12),DRAD(12),DRED(12)
       COMMON/DPOWELL SAF(9),DM(12),DA(12),DE(12),WM,WA,WE,DDDD,
     + YM(12),YA(12),YE(12)
       COMMON/DH/ VC(10),HC(10),MLIN
       COMMON/DFUNC/ Q(3600),QSR(12),RIMAX(12),CONST(12)
     + SMAX,SMIN,NGOD,NMES,NS,DRM(12),DRA(12),DRE(12),HA,
       HM,PM,PA,PE
       COMMON/DBOTM/X(24)
       NI = 20
       NI = 12
      OPEN(20,FILE='ISR650.DAT')
      OPEN(12,FILE='GEN501.IMP')
      READ(20,2) (CONST(I),I=1,12)
      READ(20,3) (SAF(I),I=1,8)
      READ(20,1)NGOD,NS,MLIN,SMAX,SMIN,RMAX,ZDV,
     + WM,WA,WE,PM,PA,PE
      NMES=NGOD*12
1     FORMAT(3I4,/,4F8.0,/,6F6.3)
      READ (20,4) (VC(L),L=1,MLIN)
      READ (20,4) (HC(L),L=1,MLIN)
      READ (20,4) HM,HA
      READ (20,5)(WMM(I),I=1,12)
      READ (20,5)(WMA(I),I=1,12)
      READ (20,5)(WME(I),I=1,12)
      N=NS*2.
      READ (20,5)(X(II),II=1,N)
2     FORMAT(12F7.4)
3     FORMAT(8F6.2)
4     FORMAT(10F6.0)
5     FORMAT(12F6.3)
      DO 6 J=1,12
6     READ (12,8)QSR(J)
      DO 7 J=1,NMES
7     READ (12,8) Q(J)
8     FORMAT(F7.3)
      DO 9 L=1,MLIN
      HC(L)=HC(L)-ZDV
9     CONTINUE
```

```
      D=0.
      DO 10 I=1,12
      D=D+QSR(I)*CONST(I)
10    CONTINUE
      SM=(SMAX-SMIN)*.50+SMIN
      HS=H(SM)
      E=D*HS*.75*9.81/3600.
      A=D/HM
      DO 11 I=1,12
      DM(I)=0.
      DA(I)=0.
      DE(I)=0.
      RIMAX(I)=0.
      J=(I-1)/(12/NS)+1
      DM(J)=DM(J)+D*WM*WMM(I)*CONST(I)/3.6/2.4/3.65
      DA(J)=DA(J)+A*WA*WMA(I)*CONST(I)/3.6/2.4/3.65
      DE(J)=DE(J)+E*WE*WME(I)*CONST(I)/3.6/2.4/3.65
      QSP=QSR(I)
      QMN(I)=QSP*CONST(I)
      QSR(I)=0.
      QSR(J)=QSR(J)+QSP*CONST(I)
11    RIMAX(J)=RIMAX(J)+RMAX*CONST(I)
      DO 12 NG=1,NGOD
      DO 13 I=1,12
      INS=(I-1)/(12/NS)+1
      K=NG*NS-NS+INS
      J=NG*12-12+I
      QP=Q(J)
      IF (QP.LT.0.) QP=0.
      Q(J)=0.
13    Q(K)=Q(K)+QP*CONST(I)
12    CONTINUE
C
      CALL FIBON (DDDD)
C
C     **********************************
C     *          PRINT THE RESULT      *
C     **********************************
C
      BETA=(SMAX-SMIN)/D
      WRITE (60,14) DDDD,BETA
14    FORMAT(1H0,///,3X,'FINAL RESULT'//3X,'ALFA=',F4.2/
     1 3X,'BETA=',F4.2//1X,'USER:',19X,'WATER SUPPLY',13X,
     2 'IRRIGATION',13X,'HYDRO POWER'//,1X,'PERIOD',2X,
     3 'MEANVALUE',3X,3('DEMAND',6X,'RELEASE',6X)/)
      DRELD=0.
      ARELD=0.
      ERELD=0.
      DO 15 I=1,12
      IN=(I+1)/2
      PYM(I)=YM(IN)/NGOD
      PYA(I)=YA(IN)/NGOD
```

```
      PYE(I)=YE(IN)/NGOD
      DRM(I)=D*WM*WMM(I)*DDDD
      DRA(I)=D*WA*WMA(I)*DDDD
      DRE(I)=D*WE*WME(I)*DDDD
      DRMD(I)=DRM(I)*PYM(I)
      DRELD=DRELD+DRMD(I)
      DRAD(I)=DRA(I)*PYA(I)
      ARELD=ARELD+DRAD(I)
      DRED(I)=DRE(I)*PYE(I)
      ERELD=ERELD+DRED(I)C
      SDRM=SDRM+DRM(I)
      SDRA=SDRA+DRA(I)
      SDRE=SDRE+DRE(I)
15    WRITE (60,16)I,QMN(I),DRM(I),DRMD(I),
     1 DRA(I),DRAD(I),DRE(I),DRED(I)
16    FORMAT(I4,7F12.3)
      DREL=D*DDDD*WM
      WMD=DRELD/D
      AREL=D*DDDD*WA
      WAD=ARELD/D
      EREL=D*DDDD*WE
      WED=ERELD/D
      WRITE (60,17) D,SDRM,DRELD,SDRA,ARELD,SDRE,ERELD
17    FORMAT(1X,'SUM',7F12.3)
      PMD=PM
      IF (DREL.GT.0.) PMD=DRELD/SDRM
      PAD=PA
      IF (AREL.GT.0.) PAD=ARELD/SDRA
      PED=PE
      IF (EREL.GT.0.) PED=ERELD/SDRE
      WRITE (60,18) WM,WMD,WA,WAD,WE,WED
18    FORMAT(/1X,'REL.PODELA VODE  :',F9.3,5F12.3)
      WRITE (60,19) PM,PMD,PA,PAD,PE,PED
19    FORMAT(1X,'REL.NIVO ISPORUKE:',F9.3,5F12.3)
      STOP
      END
C
C     ****************************
C     *   SUBROUTINE FIBONACCI   *
C     ****************************
C
      SUBROUTINE FIBON (W)
      DIMENSION FIB(50)
      NI = 50
      NO = 60
      OPEN(NI,FILE='FIBON.DAT')
      OPEN(NO,FILE='FIBON.RES')
      READ (NI,016) ALPHA, A, B
  016 FORMAT (3F5.2)
      DEL = B - A
      WRITE (NO,001)
  001 FORMAT (1H1,10X,35HFIBONACCI SINGLE-VARIABLE PROCEDURE )
```

```
C
C     DEFINE THE FIRST THREE FIBONACCI NUMBERS
C
      FIBO = 1.0
      FIB(1) = 1.0
      FIB(2) = 2.0
C
C      CALCULATE THE REMAINING FIBONACCI NUMBERS
C
    5 BB = DEL/ALPHA
      IF (BB - 2.0)  10, 10, 11
   10 GO TO 14
   11 CONTINUE
      JJ=2
   12 JJ=JJ+1
      FIB(JJ)=FIB(JJ-1)+FIB(JJ-2)
      CC=FIB(JJ)
      IF(CC-BB) 13,15,15
   13 GO TO 12
   14 WRITE (NO,002)
  002 FORMAT (///,10X,42HACCURACY SPECIFIED IN FUNC NOT
    1 SUFFICIENT.,//,10X,33HPROGRAM RESET ALPHA, ALPHA = 0.01 )
      ALPHA = 0.01
      GO TO 5
C
C      FIRST STEP IN THE TABLEAU
C
   15 I=0
      KK=JJ-2
      IK=JJ-2
      BL=B-A
      ALL=FIB(IK)*BL/FIB(JJ)
      W=A+ALL
      V=B-ALL
      CALL POWELL(W,T,JJ)
      CALL POWELL(V,U,JJ)
      JK=1
      WRITE (NO,003)
  003 FORMAT (//,7X,2HLK,10X,2HAK,11X,2HBK,09X,3HLLK,11X,1HX,
     1 12X,1HY )
      WRITE (NO,004)  JK, BL, A, B, ALL, W, T
  004 FORMAT (/,1X,'FIBONACCI ITERATION =',I2/1X,E10.4,
    1 2X,E10.4,2X,E10.4,2X,E10.4,2X,E10.4,2X,E10.4)
  006 FORMAT(49X,E10.4,2X,E10.4)
C
C     SUCCEEDING STEPS IN THE TABLEAU
C
      IK=IK-1
      JJ=JJ-1
      DO 70 I=1,KK
      IF(U-T) 20,20,22
   20 A=A+ALL
```

```
      BL=B-A
      W=V
      T=U
      ALL=FIB(IK)*BL/FIB(JJ)
      V=B-ALL
      CALL POWELL (V,U,JJ)
      II=I+1
      IK=IK-1
      JJ=JJ-1
      IF(IK-1) 28,29,29
   28 IK=1
   29 CONTINUE
      WRITE (NO,004) II, BL, A, B, ALL, W, T
      WRITE (NO,006) V, U
      GO TO 90
   22 B=B-ALL
      BL=B-A
      V=W
      U=T
      ALL=FIB(IK)*BL/FIB(JJ)
      W=A+ALL
      CALL POWELL(W,T,JJ)
      II=I+1
      IK=IK-1
      JJ=JJ-1
      IF(IK-1) 30,31,31
   30 IK=1
   31 CONTINUE
      WRITE (NO,004) II, BL, A, B, ALL, V, U
      WRITE (NO,006) W, T
90    CONTINUE
   70 CONTINUE
      RETURN
      END
C
C     *********************************
C     *      SUBROUTINE POWELL        *
C     *********************************
C
      SUBROUTINE POWELL(DR,Y,JZ)
      DIMENSION V(700),E(25)
      DIMENSIONALM(9,12),NALM(9,12),ALA(9,12),
     1 NALA(9,12),ALE(9,12),NALE(9,12)
      COMMON/DPOWELL/ SAF(9),DM(12),DA(12),DE(12),WM,WA,WE,DDDD,
     1 YM(12),YA(12),YE(12)
      COMMON/DFUNC/ Q(3600),QSR(12),RIMAX(12),CONST(12)
     1 SMAX,SMIN,NGOD,NMES,NS,DRM(12),DRA(12),
     2 DRE(12),HA,HM,PM,PA,PE
      COMMON/REL/R(600),S(0:600),NQ,YRM(600),YRA(600),YRE(600)
      COMMON/DBOTM/X(24)
        NI = 40
        NO = 30
```

```
      NO = 70
      OPEN (UNIT=40,FILE='POWELL.DAT')
      READ (40,25) IPRINT, MAXIT, ESCALE
      GO TO (701,702,703,703),IPRINT
701   OPEN (UNIT=30,FILE='POWELL.REZ')
702   OPEN (UNIT=70,FILE='POWELL.IZL')
703   CONTINUE
C
      NQ=0
      DDDD=DR
      S(0)=SMIN+(SMAX-SMIN)*.5
      DO 222 I=1,NS
      DRM(I)=DM(I)*DR
      DRA(I)=DA(I)*DR
222   DRE(I)=DE(I)*DR
C
      N=NS*2.
      NI = 40
      NO = 70
C
25    FORMAT (2I10,2F10.5)
      READ (NI,3) (E(JJ), JJ=1,N)
3     FORMAT(12F6.0)
      NW = N * (N+3)
      CALL BOTM (E,N,EF,ESCALE,IPRINT,MAXIT,V,NI,NO,NW,NFCC)
      IF ((IPRINT.LT.4).OR.(JZ.EQ.2)) THEN
      IF (IPRINT.LT.4) THEN
      WRITE (60,353) NFCC
353   FORMAT(//5X,I5,2X,'FUNCTION EVALUATIONS')
      ENDIF
      WRITE (60,021)
  021 FORMAT (//5X,'VALUE OF VARIABLES' )
      WRITE (60,022) (X(J),J=1,N)
  022 FORMAT (5X,2F10.3)
      WRITE (60,555) DR
555   FORMAT(/5X,'RELATIVE WATER DEMAND = ',F5.3)
      WRITE (60,023) EF
  023 FORMAT (//,5X,15HOPTIMAL VALUE F//5X,'F(1) = ',F12.3)
      ENDIF
      DO 40 I=1,8
      DO 41 M=1,NS
      YM(I)=0.
      YA(I)=0.
      YE(I)=0.
      NALM(I,M)=0
      NALA(I,M)=0
41    NALE(I,M)=0
40    CONTINUE
400   CONTINUE
      DO 20 NG=1,50
      DO 30 I=1,NS
      J=NS*NG-NS+I
```

```
      YM(I)=YM(I)+YRM(J)
      YA(I)=YA(I)+YRA(J)
      YE(I)=YE(I)+YRE(J)
      DO 401 IS=1,8
      IF (YRM(J).LT.SAF(IS)) NALM(IS,I)=NALM(IS,I)+1
      IF (YRA(J).LT.SAF(IS)) NALA(IS,I)=NALA(IS,I)+1
      IF (YRE(J).LT.SAF(IS)) NALE(IS,I)=NALE(IS,I)+1
401   CONTINUE
30    CONTINUE
      IF ((IPRINT.LT.4).AND.(JZ.EQ.2)) THEN
      NGI=NG+NQ*50
      WRITE (30,90) NGI
90    FORMAT(/,5X,'YEAR = ',I5/)
      NPOC=NG*NS-NS+1
      NPQ=NPOC+NQ*NS*50
      NKR=NG*NS
      NKQ=NKR+NQ*NS*50
      WRITE (30,5) (Q(I),I=NPQ,NKQ)
5     FORMAT(/12F10.3)
      WRITE (30,5) (R(J),J=NPOC,NKR)
      WRITE (30,5) (S(J),J=NPOC,NKR)
      WRITE (30,5) (YRM(J),J=NPOC,NKR)
      WRITE (30,5) (YRA(J),J=NPOC,NKR)
      WRITE (30,5) (YRE(J),J=NPOC,NKR)
      ENDIF
20    CONTINUE
      NY=NGOD/50-1
      IF (NQ.EQ.NY) GO TO 404
      NQ=NQ+1
      S(0)=S(NS*50)
      CALL FUNC (N,F)
      NQI=NQ+1
      IF ((IPRINT.LT.4).OR.(JZ.EQ.2)) THEN
      WRITE (60,505) NQI,F
      ENDIF
      EF=EF+F
      GO TO 400
404   CONTINUE
      DO 50 I=1,8
      DO 51 M=1,NS
      ALM(I,M)=1.-(1.*NALM(I,M)/NGOD)
      ALA(I,M)=1.-(1.*NALA(I,M)/NGOD)
51    ALE(I,M)=1.-(1.*NALE(I,M)/NGOD)
50    CONTINUE
      IF ((IPRINT.LT.4).OR.(JZ.EQ.2)) THEN
      WRITE (60,60) (SAF(IS),IS=1,8)
60    FORMAT(/5X,'NUMBER OF FAILURES AND RELIABILITY OF
     1 RELEASES'/5X,'REL. RELEASE',1X,8(F6.2,6X)/5X,'PERIOD'/)
      DO 62 M=1,NS
      WRITE (60,61) M,(NALM(I,M),I=1,8)
61    FORMAT(I10,8I13)
      WRITE (60,945) (ALM(I,M),I=1,8)
```

```
      WRITE (60,61) M,(NALA(I,M),I=1,8)
      WRITE (60,945) (ALA(I,M),I=1,8)
      WRITE (60,61) M,(NALE(I,M),I=1,8)
62    WRITE (60,945) (ALE(I,M),I=1,8)
945   FORMAT(10X,8F13.3)
505   FORMAT(5X,'F(',I1,') = ',F12.3)
      ENDIF
      Y=EF/(NGOD/50)
      WW=3.
      IF (WM.LE.0) WW=WW-1.
      IF (WA.LE.0) WW=WW-1.
      IF (WE.LE.0) WW=WW-1.
      Y=ABS(Y-WW)
      CLOSE (UNIT=40)
      GO TO (801,802,803,803),IPRINT
801   CLOSE (UNIT=30)
802   CLOSE (UNIT=70)
803   CONTINUE
      RETURN
      END
C
C     ****************************
C     *   SUBROUTINE FUNC(N,F)   *
C     ****************************
C
      SUBROUTINE FUNC (N,F)
      COMMON/DBOTM/X(24)
      COMMON/DFUNC/ Q(3600),QSR(12),RIMAX(12),CONST(12),SMAX,
     1 SMIN,NGOD,NMES,NS,DRM(12),DRA(12),DRE(12),HA,HM,PM,PA,PE
      COMMON/REL/R(600),S(0:600),NQ,YRM(600),YRA(600),YRE(600)
      FSUM=0.
      SRM=0.
      SRA=0.
      SRE=0.
      JQ=NQ*NS*50
      DO 11 M=1,NS
      SRM=SRM+DRM(M)/NS
      SRA=SRA+DRA(M)/NS
11    SRE=SRE+DRE(M)/NS
      SJ=(SMAX+SMIN)/2.
      HN=H(SJ)*9.81*.75/3.6/1000.
      SRU=SRM+SRA*HM+SRE/HN
      SJ=S(0)
      HS=H(SJ)*9.81*.75/3.6/1000.
      DO 1 NG=1,50
      DO 2 M=1,NS
      J=NG*NS-NS+M
      JQ=JQ+1
      X1MES=X(2*M-1)
      X2MES=X(2*M)
      DMMAX=DRM(M)
      DAMAX=(1+HA*(1.-Q(JQ)/QSR(M)))
```

```
      IF (DAMAX.LT.0.) DAMAX=0.2
      DAMAX=DAMAX*HM*DRA(M)
      DUMAX=DMMAX+DAMAX+DRE(M)/HS
      DEMAX=DRE(M)/HS
      IH=0.
C     WRITE (30,666)M,DRM(M),DRA(M),DRE(M)
8     R(J)=X1MES*DUMAX+X2MES*((S(J-1)+Q(JQ)-SMIN)/(SMAX-SMIN+
     1 QSR(M)))**2*SRU
      IH=IH+1
      IF (R(J).LT.0.) R(J)=0.
      S(J)=S(J-1)+Q(JQ)-R(J)
      IF(S(J).GT.SMAX) S(J)=SMAX
      IF(S(J).LT.SMIN) S(J)=SMIN
      R(J)=S(J-1)+Q(JQ)-S(J)
      SJ=S(J)
      HN=H(SJ)*9.81*.75/3.6/1000.
      IF (HN.LE.0.) HN=.0001
      IF (HS.LE.0.) HS=.0001
      DEMAS=DEMAX
      DEMAX=DRE(M)/(HN+HS)*2.
      DUMAX=DAMAX+DMMAX+DEMAX
C      WRITE (30,666) IH,DUMAX,DAMAX,DMMAX,DEMAX,HS,HN
666   FORMAT(I8,6F9.4)
      IF (DEMAX.LE.0.) GO TO 7
      IF ((ABS((DEMAX-DEMAS)/DEMAX).GT.0.05).AND.(IH.LT.10))
      GOTO 8
      HS=HN
7     CM=DMMAX/DUMAX
      CA=DAMAX/DUMAX
      CE=DEMAX/DUMAX
      U=R(J)/DUMAX
C     WRITE (30,666) J,CM,CA,CE,U,R(J)
      IF (U.GT.1.) THEN
      UA=1.
      UE=1.
      UM=1.
      ELSE
      Z=(1-U)/((1-PA)*CA+(1-PE)*CE+(1-PM)*CM)
      UE=1-(1-PE)*Z
      IF (UE.LT.0.) THEN
      UE=0.
      Z=(DMMAX+DAMAX-R(J))/((1-PA)*DAMAX+(1-PM)*DMMAX)
      UA=1-(1-PA)*Z
      IF (UA.LT.0.) THEN
      UA=0.
      Z=(1-R(J)/DMMAX)/(1-PM)
      ENDIF
      ELSE
      UA=1-(1-PA)*Z
      ENDIF
      UM=1-(1-PM)*Z
      IF (CA.LE.0.) UA=1.
```

```
      IF (CE.LE.0.) UE=1.
      IF (CM.LE.0.) UM=1.
      ENDIF
      YRM(J)=UM
      YRA(J)=UA
      YRE(J)=UE
      FG=0.
      FD=(1-UM)/(1-PM)+(1-UA)/(1-PA)+(1-UE)/(1-PE)
C     WRITE (30,666) M,YRM(J),YRA(J),YRE(J)
      IF(R(J).GT.RIMAX(M)) FG=.1*(R(J)/RIMAX(M))
2     FSUM=FSUM+FG+FD
1     CONTINUE
      F=FSUM/NS/50
      RETURN
      END
C
      FUNCTION H(V)
      COMMON/DH/ VC(10),HC(10),MLIN
C
      DO 10J=2,MLIN
      IF (V.LE.VC(J)) GO TO 2
10    CONTINUE
2     H=HC(J-1)+(HC(J)-HC(J-1))/(VC(J)-VC(J-1))*(V-VC(J-1))
C
      RETURN
      END
C
C     ***************************
C     *    SUBROUTINE  BOTM     *
C     ***************************
C
      SUBRUTINE BOTM(E,N,EF,ESCALE,IPRINT,MAXIT,W,NI,NO,NW,NFCC)
C
      DIMENSION  W(NW), E(N)
      COMMON/DBOTM/X(24)
      IF (IPRINT.EQ.3) GO TO 005
      WRITE (NO,001)
  001 FORMAT (1H1,10X,32HPOWELL-BOTM OPTIMIZATION ROUTINE )
      WRITE (NO,002) N, MAXIT, ESCALE, (I, X(I), I=1,N)
      WRITE (NO,003) (J,E(J),J=1,N)
  002 FORMAT (//,2X,10HPARAMETERS,//,2X,4HN = ,I2,4X,8HMAXIT
    1 =,I4,4X,9HESCALE = ,F5.2,//,2X,15HINITIAL GUESSES,
    2 //,(2(2X,2HX(,I2,4H) =,1PE16.8)))
  003 FORMAT(//,2X,31HACCURACY REQUIRED FOR VARIABLES,
    3 //,2(2X,2HE,I2,4H) = ,E16.8) )
      CALL FUNC(N,F)
      WRITE (NO,004) F
004   FORMAT(//,2X,'INITIAL VALUE OF F = ',E16.8)
005   CONTINUE
C
      DDMAG=0.1*ESCALE
      SCER=0.05/ESCALE
```

```
      JJ=N*(N+1)
      JJJ=JJ+N
      K=N+1
      NFCC=1
      IND=1
      INN=1
      DO 4 I=1,N
      W(I)=ESCALE
      DO 4 J=1,N
      W(K)=0.
      IF(I-J)4,3,4
    3 W(K)=ABS (E(I))
    4 K=K+1
      ITERC=1
      ISGRAD=2
      CALL FUNC(N,F)
      FKEEP=2.*ABS (F)
    5 ITONE=1
      FP=F
      SUM=0.
      IXP=JJ
      DO 6 I=1,N
      IXP=IXP+1
 6    W(IXP)=X(I)
      IDIRN=N+1
      ILINE=1
    7 DMAX=W(ILINE)
      DACC=DMAX*SCER
      DMAG=AMIN1 (DDMAG,0.1*DMAX)
      DMAG=AMAX1(DMAG,20.*DACC)
      DDMAX=10.*DMAG
      GO TO (70,70,71),ITONE
C
   70 DL=0.
      D=DMAG
      FPREV=F
      IS=5
      FA=FPREV
      DA=DL
    8 DD=D-DL
      DL=D
   58 K=IDIRN
      DO 9 I=1,N
      X(I)=X(I)+DD*W(K)
 9    K=K+1
      CALL FUNC(N,F)
      NFCC=NFCC+1
      GO TO (10,11,12,13,14,96),IS
   14 IF(F-FA)15,16,24
C
   16 IF (ABS (D)-DMAX) 17,17,18
   17 D=D+D
```

```
      GO TO 8
   18 WRITE (NO,019)
   19 FORMAT(5X,38HMAXIMUM CHANGE DOES NOT ALTER FUNCTION)
      GO TO 20
C
   15 FB=F
      DB=D
      GO TO 21
   24 FB=FA
      DB=DA
      FA=F
      DA=D
   21 GO TO (83,23),ISGRAD
   23 D=DB+DB-DA
      IS=1
      GO TO 8
   83 D=0.5*(DA+DB-(FA-FB)/(DA-DB))
      IS=4
      IF((DA-D)*(D-DB))25,8,8
   25 IS=1
      IF(ABS (D-DB)-DDMAX)8,8,26
   26 D=DB+SIGN (DDMAX,DB-DA)
      IS=1
      DDMAX=DDMAX+DDMAX
      DDMAG=DDMAG+DDMAG
      IF (DDMAG.GE.1.0E+25)  DDMAG = 1.0E+25
      IF(DDMAX-DMAX)8,8,27
   27 DDMAX=DMAX
      GO TO 8
   13 IF(F-FA)28,23,23
   28 FC=FB
      DC=DB
   29 FB=F
      DB=D
      GO TO 30
   12 IF(F-FB)28,28,31
   31 FA=F
      DA=D
      GO TO 30
   11 IF(F-FB)32,10,10
   32 FA=FB
      DA=DB
      GO TO 29
   71 DL=1.
      DDMAX=5.
      FA=FP
      DA=-1.
      FB=FHOLD
      DB=0.
      D=1.
   10 FC=F
      DC=D
```

```
   30 A=(DB-DC)*(FA-FC)
      B=(DC-DA)*(FB-FC)
      IF((A+B)*(DA-DC))33,33,34
   33 FA=FB
      DA=DB
      FB=FC
      DB=DC
      GO TO 26
   34 D=0.5*(A*(DB+DC)+B*(DA+DC))/(A+B)
      DI=DB
      FI=FB
      IF(FB-FC)44,44,43
   43 DI=DC
      FI=FC
   44 GO TO (86,86,85),ITONE
   85 ITONE=2
      GO TO 45
   86 IF (ABS (D-DI)-DACC) 41,41,93
   93 IF (ABS (D-DI)-0.03*ABS (D)) 41,41,45
   45 IF ((DA-DC)*(DC-D)) 47,46,46
   46 FA=FB
      DA=DB
      FB=FC
      DB=DC
      GO TO 25
   47 IS=2
      IF ((DB-D)*(D-DC)) 48,8,8
   48 IS=3
      GO TO 8
   41 F=FI
      D=DI-DL
      DD=SQRT ((DC-DB)*(DC-DA)*(DA-DB)/(A+B))
      DO 49 I=1,N
      X(I)=X(I)+D*W(IDIRN)
      W(IDIRN)=DD*W(IDIRN)
 49   IDIRN=IDIRN+1
      W(ILINE)=W(ILINE)/DD
      ILINE=ILINE+1
      IF(IPRINT-2)50,51,51
C
   50 WRITE(NO,52)ITERC,NFCC,F,(X(I),I=1,N)
   52 FORMAT(/10H ITERATION,I5,I15,16H FUNCTION  VALUES,10X,3HF
=,E15.8/
     +2(E16.8,2X))
      GO TO(51,53,53),IPRINT
   51 GO TO (55,38),ITONE
   55 IF (FPREV-F-SUM) 94,95,95
   95 SUM=FPREV-F
      JIL=ILINE
   94 IF (IDIRN-JJ) 7,7,84
   84 GO TO (92,72),IND
   92 FHOLD=F
```

```
      IS=6
      IXP=JJ
      DO 59 I=1,N
      IXP=IXP+1
59    W(IXP)=X(I)-W(IXP)
      DD=1.
      GO TO 58
   96 GO TO (112,87),IND
  112 IF(FP-F) 37,37,91
   91 D=2.*(FP+F-2.*FHOLD)/(FP-F)**2
      IF (D*(FP-FHOLD-SUM)**2-SUM) 87,37,37
   87 J=JIL*N+1
      IF (J-JJ) 60,60,61
   60 DO 62 I=J,JJ
      K=I-N
62    W(K)=W(I)
      DO 97 I=JIL,N
97    W(I-1)=W(I)
   61 IDIRN=IDIRN-N
      ITONE=3
      K=IDIRN
      IXP=JJ
      AAA=0.
      DO 67 I=1,N
      IXP=IXP+1
      W(K)=W(IXP)
      IF (AAA-ABS (W(K)/E(I))) 66,67,67
   66 AAA=ABS (W(K)/E(I))
   67 K=K+1
      DDMAG=1.
      W(N)=ESCALE/AAA
      ILINE=N
      GO TO 7
   37 IXP=JJ
      AAA=0.
      F=FHOLD
      DO 99 I=1,N
      IXP=IXP+1
      X(I)=X(I)-W(IXP)
      IF(AAA*ABS (E(I))-ABS (W(IXP))) 98,99,99
98    AAA=ABS (W(IXP)/E(I))
   99 CONTINUE
       GO TO 72
   38 AAA=AAA*(1.+DI)
      GO TO (72,106),IND
   72 IF(IPRINT-2)53,50,53
   53 GO TO (109,88),IND
  109 IF (AAA - 0.1) 20,20,76
C
76    IF(F-FP)35,78,78
   78 WRITE (NO,80)
   80 FORMAT(5X,31HACCURACY LIMITED BY ERRORS IN F)
```

```
      GO TO 20
C
   88 IND=1
   35 DDMAG=0.4*SQRT(ABS(FP-F))
      IF (DDMAG.GE.1.0E+25)  DDMAG = 1.0E+25
      ISGRAD=1
C
  108 ITERC=ITERC+1
      IF(ITERC-MAXIT)5,5,81
   81 WRITE (NO,82) MAXIT
 82   FORMAT(I5,29H ITERATIONS COMPLETED BY BOTM)
      IF(F-FKEEP)20,20,110
  110 F=FKEEP
      DO 111 I=1,N
      JJJ=JJJ+1
 111  X(I)=W(JJJ)
      GO TO 20
C
  101 JIL=1
      FP=FKEEP
      IF(F-FKEEP)105,78,104
  104 JIL=2
      FP=F
      F=FKEEP
  105 IXP=JJ
      DO 113 I=1,N
      IXP=IXP+1
      K=IXP+N
      GO TO (114,115),JIL
 114  W(IXP)=W(K)
      GO TO 113
 115  W(IXP)=X(I)
      X(I)=W(K)
 113  CONTINUE
      JIL=2
      GO TO 92
 106  IF(AAA-0.1) 20,20,107
C
 20   EF=F
      RETURN
C
 107  INN=1
      GO TO 35
C
      STOP
      END
```

FIBONACCI (FIBON ALGORITHM)*

The Fibon algorithm is used to find the minimum of a single variable, non linear function subject to constraints: Minimize F(X)

Subject to $a_1 \le X \le b_1$

where the lower and upper, a_1 and b_1, are constants.

The procedure of the Fibon algorithm is as follows:

1. Designate the original search interval as L_1 with boundaries a_1 and b_1.

2. Predetermine the desired accuracy α and the number of required Fibonacci numbers (N)

   $\alpha = 1/F_N$

   $F_o = F_1 = 1$

   $F_n = F_{n-1} + F_{n-2},\ n \ge 2$

   where F_n is called a Fibonacci number.

3. Place the first two points, X_1 and X_2 ($X_1 < X_2$) within L_1 at a distance l_1 from each boundary.

   $l_1 = (F_{N-2}/F_N)L_1$

   $X_1 = a_1 + l_1$

   $X_2 = b_1 - l_1$

---

* Kuester, J.L., and J.H. Mize. 1973. Optimization Techniques With Fortran. McGraw-

Hill. New York.

4. Evaluate the objective function at X_1 and X_2. Designate the functions as $F(X_1)$ and $F(X_2)$. Narrow the search interval as follows:

$a_1 \leq X^* \leq X_2$ for $F(X_1) < F(X_2)$

$X_1 \leq X^* \leq b_1$ for $F(X_1) > F(X_2)$

where X^* is the location of the optimum. The new search interval is given by

$L_2 = (F_{N-1} / F_N).L_1 = L_1 - l_1$ with boumdaries a_2 and b_2.

5. Place the third point in the new L_2 subinterval, symmetric about the remaining point.

$l_2 = (F_{N-3} / F_{N-1}).L_2$

$X_3 = a_2 + l_2$ or $b_2 - l_2$

6. Evaluate the objective function $F(X_3)$, compare with the function for the point remaining in the interval and reduce the interval to

$L_3 = (F_{N-2} / F_N).L_1 = L_2 - l_2$

7. The process is continued per the preceeding rules for N evaluations. The general equation are:

$$l_k = \frac{F_{N-(k+1)}}{F_{N-(k-1)}}.L_k$$

$X_{k+1} = a_k + l_k$ or $b_k - l_k$

$$L_k = \frac{F_{N-(k-1)}}{F_N} \cdot L_1 = L_{k-1} - l_{k-1}$$

After N-1 evaluations and discarding the appropriate interval at each step, the remaining point will be precisely in the center of the remaining interval. Point N is also at the midpoint and replaced by a point perturbed some small distance $\in$ to one side or the other of the mid point. The objective function is then evaluated and the final interval where the optimum is located is determined.

POWELL (BOTM ALGORITHM)*

This program finds the minimum of an unconstrained, multivariable, and nonlinear function:

Minimize $F(X_1, X_2, ... X_N)$

The procedure is based on the method of M.J.D.Powell that does not need derivatives. The algorithm peoceeds as follows:

1. A starting point, $X_o^{(o)}$, is selected. The initial search directions, $M_i^{(o)}$, i=1, 2,...,N, are parallel to the original coordinate axes.
2. A sequence of single variable searches are made in the N initial directions, using quadratic approximation.
3. The following points are then located:

   $X_N^{(k)}$ = the last point from the sequence of single variable searches.

   $X_M(k)$ = the point of greatest function improvement between successive single variable searches.

   $Xt^{(k)} = 2X_N^{(k)} - X_o^{(k)}$ = expanded point

   $X_o^{(k)}$ = starting point for the iteration

   where k is the stage index which is incremented for each new set of search directions.

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* Kuester, J.L., and J.H.Mize. *Optimization Technique with Fortran.* McGraw-Hill.

New York. 1973

4. A check is made to see if the value of the objective function at the expanded point, $X_t^{(k)}$, is better than that at the starting point, $X_o^{(k)}$. If there is no improvement, the last point, $X_N^{(k)}$, become the new starting point and a new sequence of single variable searches are made in the same directions as before,

$X_o^{(k+1)} = X_N^{(k)}$

$M_i^{(k+1)} = M_i^{(k)}, \quad i = 1, 2, ..., N.$

If the objective function, $F_t^{(k)}$, at the expanded point is an improvement over the starting point function, $F_o^{(k)}$, then the following test is performed,

$$[F_o^{(k)} - 2F_N^{(k)} + F_t^{(k)}][F_o^{(k)} - F_N^{(k)} - \quad]^2 \geq \frac{(F_o^{(k)} - F_t^{(k)})^2}{2}$$

where :

$$= F_M^{(k)} - F_{M-1}^{(k)}$$

The test determines whether the function in this region is a valley, i.e., $F_t^{(k)}$ is an improvement but the surface is rising. If the test is satisfied, the old search directions are retained and a new sequence of single variable searches started as above. If the test is not satisfied, a single variable search is performed in the $\mu^{(k)}$ direction,

$\mu^{(k)} = X_N^{(k)} - X_o^{(k)}$

untill the best value, $X_o^{(k+1)}$ is found. New search directions are then chosen as follows:

$M_i^{(k+1)} = M_i^{(k)}$ for i = 1, 2, ..., M-1

$M_i^{(k+1)} = M^{i+1(k)}$ for i = M, ..., N-1

$M_n^{(k+1)} = \mu^{(k)}$

A new sequence of single variable searches is then started.

5. Convergence is assumed when the values for the independent variables between successive iterations are less than preset limits,

   $X_i^{(k)} - X_i^{(k-1)} < \in \qquad i = 1, 2, ..., N$