DIGITAL SIMULATION OF WATER RESOURCES SYSTEMS

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CHAPTER I

INTRODUCTION

The progress of civilization has increased the importance of water resources engineering. This importance is reflected in the need for planning, design, construction, and operation of facilities for regulation and efficient utilization of water. The prime objective of a public water project is the maximization of the national welfare, that is the national income. This goal cannot be reached unless the various alternatives of the system are investigated. The first step in design is to determine which of these alternatives reflect the needs of the society interested in the development of efficient water utilization. Once the objective has been defined, the employed methods must lead to a combination of these alternatives which will best achieve the objective. In order to estimate the available water, accurate hydrologic methods have to be applied. An efficient use of this available water must be attained in order to reduce the associated cost, and hence the water system becomes economically feasible.

1.1 DEFINITION OF THE PROBLEM:

A water resource system may include reservoir(s), dam(s), and power plant(s) which are discribed in terms of their physical characteristics such as capacity of reservoir storage, effective water head, and power plant capacity. The primary function of reservoirs is to provide a water storage for the various purposes such as, irrigation, power generation, water supply, flood control and recreation. A compromise takes place between the cost of project construction, which is a function of its capacity, and its expected benefits resulting from the output resources produced. Power plants are utilized for the generation of hydro-electric power. The amount of energy generated depends on both the effective water head, which is a function of the reservoir content, and the actual water flow through the turbines. The function of a dam is to keep certain required water level in the reservoir so that a water supply and/or a water head are provided.

In general, the resources employed by water projects are, available water (inflows), site, construction materials, manpower, and equipments for which costs are incurred. The resources produced (outputs) are water at time, place, and quantity required for, irrigation, hydro-electric energy, urban supply, and a variety of recreational facilities. Both of these resources have to be interrelated by a model which controls the system operating policy. Accordingly, the main function of the study conducted in this paper is to develop such a model so that an optimal design is reached.

Since the inflow to any real world water system behaves stochastically, some stochastic parameters which describe this behavior have to be included in the developed model. Because of the existence of these stochastic factors, benefits are evaluated in terms of expectation. These expected benefits can be considered as a criterion on which the selection among various combinations of the system variables is based.

Due to the large number of variables involved in water systems and the wide combinations of these variables, operations research techniques, as a tool to provide optimal decisions, have been employed in the design of water resources systems. These techniques can be promising when a high speed digital computer is available.

1.2 PROPOSED RESEARCH:

This work is concerned with the determination of the optimal capacities of reservoirs for a water resource system where the variables describing the physical dimensions are assumed to be known. The simulation of a queuing model for a system of reservoirs has been performed. The following is a brief discussion of the methods proposed for the study of water resources system.

A system of three multi-purpose reservoirs is simulated as a multi-channel and series queuing model. Inflows to the first reservoir are randomly generated from a recursive relation following a certain known probability distribution. Serial correlation among monthly inflows on their stochastic behavior is included. Irrigation and flood control target outputs are fulfilled using the system as a whole while other target outputs are met using a certain reservoir(s). A seasonal pattern is considered for some of the system target outputs. Moreover, they are considered to behave stochastically within certain limits. An operating policy is constructed and the questions regarding, quantity, time, and place at which water is released are answered. Furthermore, the operating policy regulates the water flow from one reservoir to the other. The system has only one inlet. Part of the outputs of the first reservoir forms the inputs to the other two reservoirs which are constructed in parallel.

The capacity of the system is determined, according to the constructed operating policy, from the known parameters explaining the system inflows and its target outputs. The study of the effect of evaporation on the water storage, which might be significant especially in hot and dry places is performed. The reservoirs storages are obtained. The net head is calculated and the energy generated is determined. Concisely, all the target outputs are met. The cost of construction, operating and maintenance is evaluated. The expected benefits resulting from the target outputs fulfillment are also evaluated. A compromise between these two economic criteria is performed. The preceding procedure is employed for the study of several combinations of reservoirs' capacities. These combinations are also examined for the various inflows. For all the combinations at various inflows the expected net profit is obtained. At each inflow mean, a combination of maximum benefits is selected. In other words, an optimal decision is reached for the best combination of storage capacities which provides the maximum expected net benefits.

Recently, simulation in water resources systems has been performed in some published work [28] and [18], to be discussed in chapter II. In general, these articles have not included the effect of inflow changes on the system performance. Moreover, the target outputs of the system have been considered to be constant from one year to another. As a result, the benefits obtained from their systems are deterministic which might not be true for any real world situation at all times. Furthermore, they have examined the capacity of each reservoir while the work, conducted in this paper, considers the combination of reservoirs capacities as a whole. The latter approach might explain the interrelationship among all reservoirs and the effect of each reservoir on the other. Besides, they have not included the influence of evaporation loss on the reservoirs' storages.

The study conducted here, has used simulation for system operation in addition to system design. It should be pointed out that this study has not considered any special system in a particular area.

CHAPTER II

LITERATURE REVIEW

Many articles treating the stochastic behavior of the system and its application in the study of water reservoirs and dams have been introduced in the last decade.

In reviewing the literature it has been found that most research in this area can be classified into two main categories: (1) analytical approach; and (2) simulation approach.

2.1 ANALYTICAL APPROACH:

Among the first researchers to use this approach is Moran [30] who employed probability theory to find the quantity of water stored in a reservoir assuming the inputs and the outputs are given. Later, he followed his study by modifications regarding release rules [31, 32].

Gani and Prabhu [6] have shown that negative exponential distribution inflows resulted in dam contents similar to that distribution. Furthermore several input distributions of approximately the Gamma type shown to give rise to similar negative exponential distribution. The probabilities of dam contents in case of finite and infinite dams are numerically compared.

In his paper, Langbein [22] has described a method for determining the amount of holdover storage for regulating water systems in terms of probability based on analogy with queuing theory. His paper discusses the effect of serial correlation with different lag intervals of time on the stochastic behavior of the inflows.

Gani [3] has presented a wide and varied study in the probability theory of storage systems, and has introduced an outline of various storage problems. A similar study in the theory of dams is introduced by Kendall [19]. Gani and Prabhu [7] have studied a continuous - time model for a finite dam with simple poisson inputs. The authors, in another article [8], have investigated the time dependent distribution function of the content of an infinite dam fed by a poisson input with steady release ceasing only when the dam is empty. Moreover, they have derived the distribution of the dam content taking the limit of the time dependent distribution as time goes to infinity.

Gani [4] has presented an article that considers the probabilities of first emptiness of two dams in parallel both subject to steady release of unit rate and fed by discrete additive inflows. In another paper Gani and Pyke [10] have studied the relation between the content of a dam and the supremum of a certain infinitely divisible process. Furthermore, they have developed the distribution functions of the total time during which these dams are empty or non-empty. These authors [11] have also studied the probabilities of first emptiness times for a dam fed by sequenced discrete and additive stream of inflows and subject to a steady release rule. The same problem, before overflow occurs and where there is overflowing, is discussed by Weesakul [38]. Following the same procedure used by Gani and Prabhu [8], Yeo [40] has derived the distribution of storage for a dam with geometric inputs. In his paper Ghosal [12] has stated a general method to develop the storage distribution. In the case of negative binomial inputs a special approach is provided. Gani [5] has considered the distribution function for the dam content fed by non-homogeneous stochastically independent poisson inflows independent of arrival time. In a paper by Kingman [20], it is shown that the difficulties of assuming the inputs to be a continuous time stochastic process can be avoided by the adoption of slightly different and more realistic formulation of the problem. This new approach has provided a solution for the difficulties encountered by Gani and Prabhu [9] when they formulated the problem of reservoir storage in an infinite dam with a continuous release in probabilistic terms considering a continuous time stochastic process input.

Most of the studies have adopted the assumptions of independent inflows until Lloyd [24] outlined a method to take account of the serial correlation in the sequence of inflows through the approximation of this sequence by a Markov chain. Various policies are treated including those involving stochastic release elements. Lloyd and Odoom [27] provided an algorithm for solving the equations governing the equilibrium of reservoir levels for both independent and serially correlated (Markovian) inflows. Hasofer [15] introduced a storage model with an inverse Gaussian input in which he followed the procedure of Gani and Prabhu [9] to study the transient behavior of water systems in general and dams in particular. This author [16] studied the content of a dam with infinite depth, unit release per unit time and poisson process inputs by means of an integral equation technique. Takacs [36] presented a method to determine the stochastic model of the fluctuations of the dam content assuming an input process with stationary independent increments. Lloyd [25] studied on a discrete time scale, the waiting time to first emptiness and to <u>nth</u> emptiness of a semi-infinite Moran reservoir fed by stochastically independent discrete inputs and unit outputs. Mott [32] studied the same problem by deriving the distribution of the time to emptiness of a dam, with the same characteristics assumed by Lloyd [25], from a combinatorial lemma. As a general discussion, Lloyd [26] presented an article treating the stochastic behavior in reservoirs with both nonseasonal independent inflows and seasonal serially correlated inputs.

Since the analytical approach to the design of water resource systems is based generally on some unrealistic assumptions, simulation, has been used as a practical and applicable approach with more realistic assumptions.

2.2 SIMULATION APPROACH:

The simulation approach to water resource systems has been initiated by Fiering [2]. In his paper, the theory of queues, the monte carlo technique, and simulation to the problem of selecting the optimal design of a single multipurpose reservoir used for irrigation, power generation, and flood control have been applied. Fiering assumed serially correlated annual inflows of one year lag with a known distribution. The correlation coefficient is assumed to be the same, from one year to another, within the length of the simulation. A cost analysis has been provided in this study. Since the major problem encountered in simulating a reservoir system is the prediction of what the actual inflows will be when the project is put into operation, much attention has been paid to the study of this problem. Fiering [2] used the recursive equation

$$\hat{Q}_i = \bar{Q} + R(Q_{i-1} - \bar{Q}) + ts(1 - R^2)^{1/2} \qquad i = 1, 2, \ldots, N, \qquad (2.1)$$

where

$\hat{Q}_i$ is the estimated annual inflows in acre ft.,

$\bar{Q}$ is the mean inflow (obtained from the historic data) in acre ft.,

R is the correlation coefficient (obtained from the historic data),

t is a random variable normally distributed with zero mean and unit variance,

s is the standard deviation of the estimate $\hat{Q}_i$ (obtained from the historic data),

N is the length of simulation in years,

to generate the inflows for larger period of time taking into consideration the assumptions stated above.

A completely detailed methodology of designing water resource systems has been developed and is introduced in a book by Maas and others [28]. A systematic research procedure is presented in this work taking into consideration the specific characteristics and variables involved in a reservoir design. Concisely, the main objectives of water resources development, the economic factors, the system analysis and simulation, the operating procedures and stochastically sequential inflows are considered in this book. In this book, Thomas and Fiering [37] model for the generation of serially correlated monthly inflows has been used. A consideration was given to the monthly inputs and the effect of these inflows on each other in the model which was stated as follows:

$$\hat{Q}_{i+1} = \bar{Q}_{j+1} + \beta_j (Q_i - \bar{Q}_j) + t_i s_{j+1} (1 - R_j^2)^{1/2}, \qquad (2.2)$$

$$i = 1, 2, \ldots, N,$$

where

$\hat{Q}_{i+1}$ = the estimated inflow during the (i+1)st month in acre ft.,

$\bar{Q}_{j+1}$ = the mean monthly inflows during the (j+1)st month in acre ft.,

β_j = the regression coefficient for estimating flow in the (j+1)st month from the jth month,

t_i = a random variable normally distributed with mean zero and unit variance,

s_{j+1} = the standard deviation of inflow in the (j+1)st month,

R_j = the correlation coefficient between the inflows of the jth and (j+1)st month,

N = the number of years overwhich the simulation is conducted.

The development in the above recursion equation, as might be noted, is reflected in the assumptions of varied correlation and regression coefficients from month to month.

Yagil [38] added one equation to the model presented by Thomas and Fiering [37] in order to generate the inflow for the first month in every year under consideration. This equation is

$$\hat{Q}_1 = \bar{Q}_1 + t_1 s_1 \ . \tag{2.3}$$

The previous definitions hold for the variables in equation (2.3). A validation of Yagil's procedure was introduced by the generation of lake Tiberias inflows.

A case study was carried out by Hufschmidt and Fiering [18]. They presented a coded simulation model of the Lehigh basin in which a complete procedure to study a water resource system was introduced. An elaborate explanation of organizing for simulation, inflow generation, operating policy, loss and benefit analysis, and the computer logic used in this study was given. Moreover it was shown that the inflow distribution can be altered by changing the random additive component to generate any non-normal inflows as presented by Thomas and Fiering [37].

In their article, Harms and Campbell [14] have extended the famous model of Thomas and Fiering [37] to an algorithm for the sequential generation of a log-normal correlated monthly inflows embbeded into non-historic annual normal correlated inflows.

The authors [14] have introduced a method to adjust the error in the generated inflows due to the independence of nonhistoric annual and monthly sequences and to equalize the weighted average of monthly inflows to the annual inflow. Furthermore, they have compared the nonhistoric inflows generated by their algorithm with the historic inflows. It was found that, in general, the match between both inflows was good. The equation which was used was

$$Q_{ij} = \frac{365\, Q^0_{ij} Q_j}{\sum_{i=1}^{12} C_i\, Q^0_{ij}} \qquad \begin{array}{l} i = 1, 2, \ldots, 12, \\ j = 1, 2, \ldots, N, \end{array} \tag{2.4}$$

where

Q^0_{ij} = the nonhistoric monthly flow for ith month of the jth year,

Q^0_{ij} = the initial estimate of the inflow (Q_{ij}). This value is obtained from the recursion equation (2.2),

Q_j = the annual inflow of the jth year,

C_i = the number of days in the ith month,

N = the number of years.

Benson and Matalas [1] indicated that practical application of the synthetic hydrology model (equations 2.2, 2.3) developed by Thomas and Fiering, and others, has showed two major deficiencies: 1) the large errors due to the sampling errors of the original sample, and 2) the generation of inflows for ungaged sites. The authors [1] have suggested deriving the statistical parameters, such as mean monthly inflows, and monthly standard deviations of the inflows, used to generate the inputs from generalized multiple regression relations with physical and climatic characteristics of the involved basin in order to reduce the error resulting from the previously mentioned deficiencies. These characteristics might be, the drainage basin surface area, the slope of the water channel, the amount of rainfall in this area, etc.

In order to have an accurate estimate of the water storage, the amount of water evaporated must be precisely determined. In this field, Harbeck [13] used mass transfer theory to measure a reservoir evaporation by introducing the empirical equation

$$E = M\, U_8\, (e_s - e_a), \tag{2.5}$$

where

E = the evaporation in inches per day,

M = the mass-transfer coefficient, a coefficient of proportionality,

U_8 = the wind speed, in miles per hour, at 8 meters height above the water surface,

e_s = the saturation vapor pressure in millibars, corresponding to the temperature of the water surface,

e_a = vapor pressure of the air, in millibars.

Moreover, it has been indicated that the mass-transfer coefficient "M" represents a combination of many variables, such as the size of the storage, the trend of wind speed on different heights, the roughness of the water surface, and the atmospheric stability. The mass-transfer coefficient has been given as a linear function of the reservoir surface area, as follows:

$$M = 0.00\ 338A^{-0.05}, \tag{2.6}$$

Where A is the reservoir surface area. This function is shown in Figure 2.1.

In the same field, Yu and Brutsaert [41] presented an algorithm to generate the monthly mean values of evaporation from lake Ontaria using mass transfer theory. Also they estimated the mass-transfer coefficient using equation (2.6) introduced by Harbeck [35]. A comparison between the evaporation data generated by the mass-transfer method and those estimated by the water budget method has indicated that, on the average, the two methods yield reasonable results. Furthermore, the authors have concluded that these good results are obtained because of the accurate value of the mass-transfer coefficient evaluated from Harbeck's equation (2.6). In another article, Yu and Brustsaert [41], conducted a time series analysis on a long range monthly evaporated mean quantity from Lake Ontario. It has been shown that, spectral analysis and correlation reveal the dominance of the annual cycle in the time series. The authors have pointed out that evaporation quantity and relative humidity residuals can be adequately predicted by a Markov model of the first order while a second order Markov model can be used to describe adequately the residuals of wind speed and surface temperature. Also, they have introduced some explanation about the seasonal variation of the variables involved in the evaporation process.

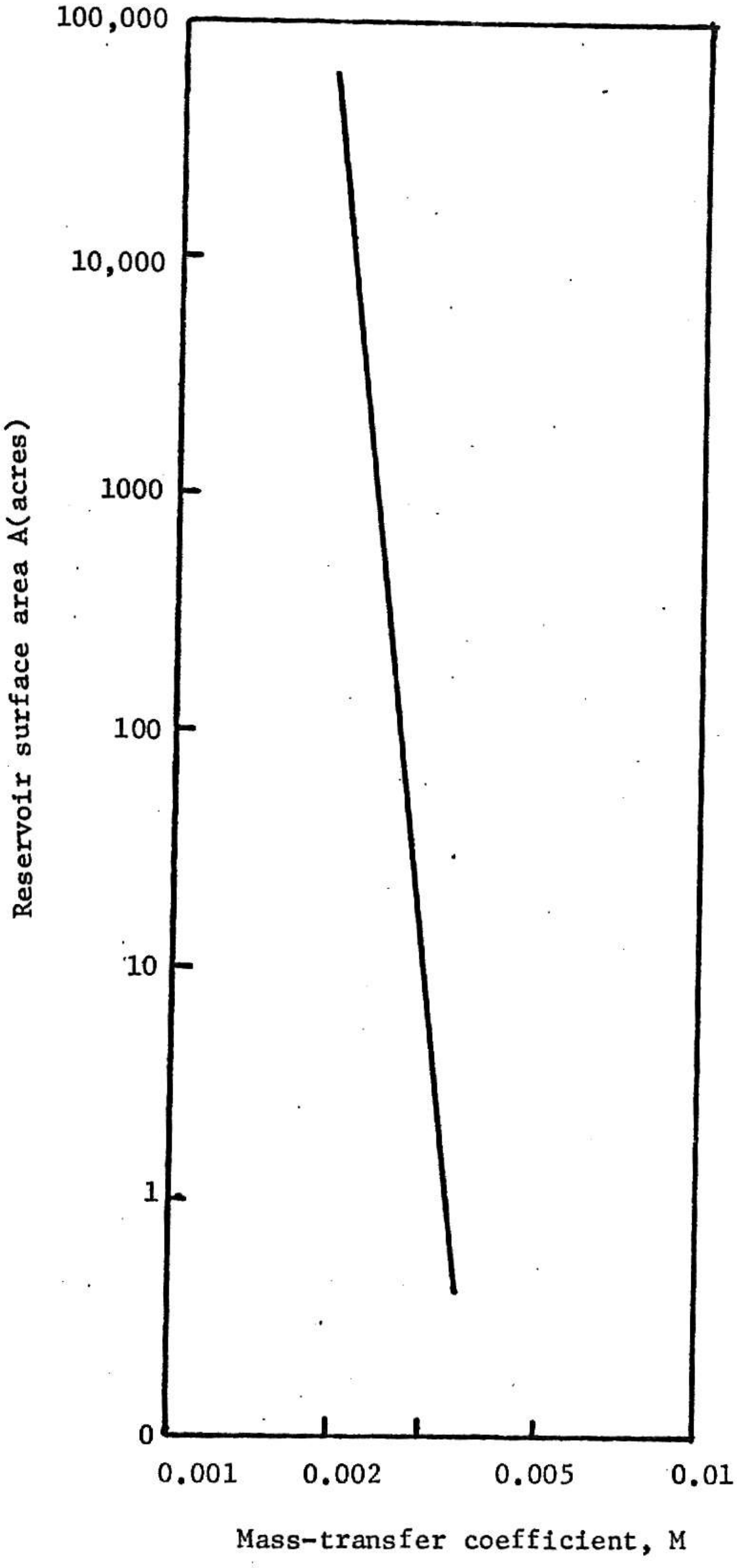


Fig. 2.1 Relation between mass transfer coefficient, M, and reservoir surface area A.

Again, a comparison of the mass-transfer data with that of the water budget has indicated that both of the two approaches yield similar results. It was concluded that the mass-transfer time series usually lags the water budget series.

Kupier [21] presented an economical analysis of water resources systems that is based on direct and tangible benefits. Several methods to calculate annual costs and depreciation charges were presented. Measurement of benefits was shown to be a reliable basis for the selection of certain project among several combinations of projects.

Hillier [17] has introduced some economic models for waiting lines which may be of use in the evaluation of water resource systems in the general classification of expected costs in terms of service cost and waiting cost.

2.3 SUMMARY AND COMMENTS:

In this chapter an attempt has been made to summarize the history and the development of research in water resource systems. In the analytical approach, Moran [30] is the pioneer in the application of probability theory to the study of reservoirs in order to determine the water storage when both of the inflows and outputs are given. Several similar studies were conducted assuming certain inflow distributions and that the storage distribution is derived. Some of the authors considered discrete inflows, such as poisson, binomial, and geometric distributions while others assume continuous inflows, such as Erlang, normal, and inverse Gaussian distributions, which is a more realistic assumption for water inflows. The unrealistic assumption of stochastically independent inflows was adopted by most of the authors. Lloyd [24] provided a method to study reservoir systems with serially correlated inflows by involving Markov chains. Two articles by Lloyd [25] and Mott [33] considered the waiting time to the nth emptiness of a reservoir. Langbein [22] studied reservoir system based on analogy with queuing theory. Moreover, he considered serial correlation among inflows. The latter article has been a guide for the start of studies, based on more realistic assumptions such as, simulation in the design of water resources systems.

The main drawback of the analytical studies is that they have been of very slight practical value. Their major advantages are the initiation in handling this problem which has drawn the attention for applicable studies in the later periods and the development of academic and theoretical background that made practical studies feasible.

As concerning the simulation approach particular emphasis was given to the simulation approach since the work conducted in this thesis is a continuation of this approach. The two integrated simulation models have been introduced in the articles [28] and [18]. Those two models have not considered the evaporation effect on the water storages which might be significant in hot and dry places. Moreover, the target outputs of the system were treated in a deterministic form which might not hold for any real world situation. Some other articles have been published in which the problems of inflow generation and evaporation were studied.

CHAPTER III

SINGLE RESERVOIR MODEL WITH MULTI-PURPOSES

As a preperation for the three-reservoir model, a study on a multi-purpose reservoir has been conducted. A simulation model for the reservoir is developed and the optimal reservoir capacity is obtained. The system is studied over a period of several years and various reservoir capacities are examined. The target outputs considered in the current model are irrigation, power generation and flood control. The stochastic behavior of the serially correlated inflows has been also considered. Moreover, seasonal variations are included in the model.

In this chapter, model is described, mathematical functions are established, operating policy is explained, experiments are performed, and results are obtained and presented. The study of this model has been performed as a basis for the study of the more complicated model with three multi-purpose reservoirs to be discussed in chapter IV.

3.1 SYSTEM LAYOUT:

The system is shown in fig 3.1. It comprises a single reservoir A, a power plant A located at the outlet of the reservoir, and one diversion dam for irrigation at point B. A flood damage zone is set aside downstream from point C. The power plant is a variable head station. The inflows to the system are assumed to come through point D.

In the following the assumptions governing the system are stated. The statistical parameters influencing the system inflows are assumed to be stochastically independent random variables generated from known probability distributions. Conservation storage, surcharge storage, and

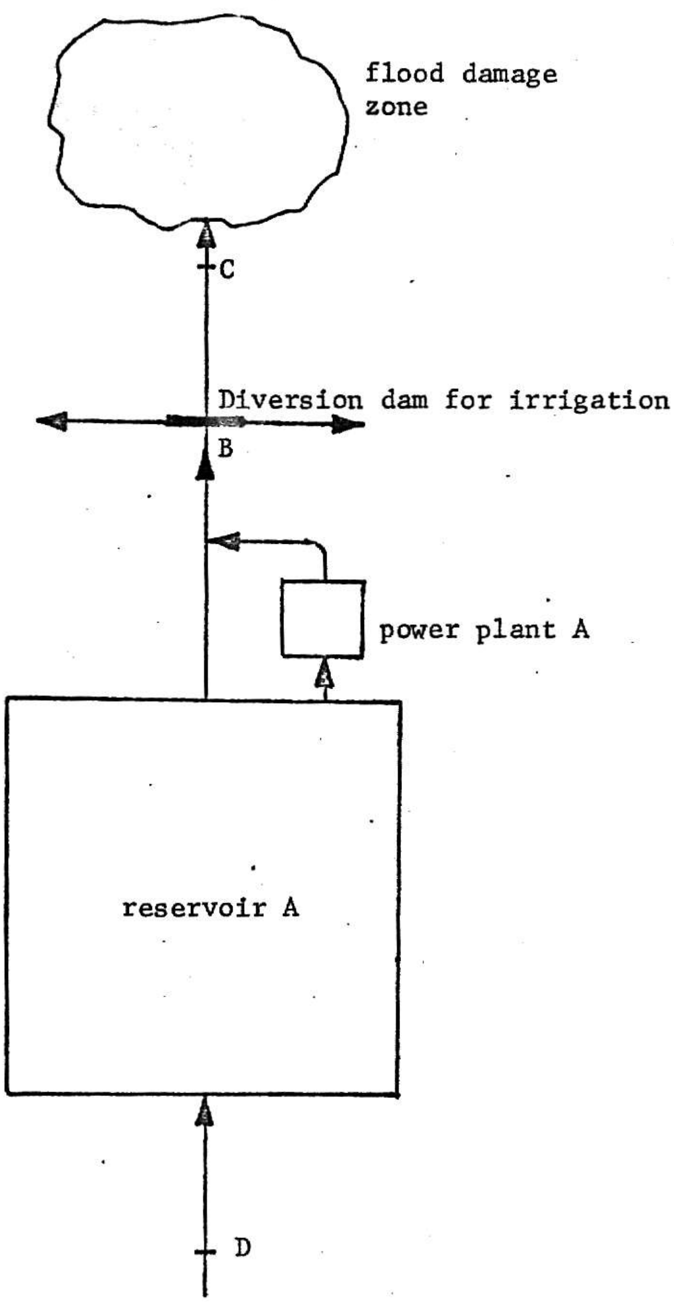


Fig. 3.1 Physical layout of multi-purpose single reservoir system.

bank storage have not been considered. Moreover the net effective head is the only head accounted for. The initial reservoir content is assumed to be one half of its capacity. The release for irrigation and power generation is regulated according to an operating policy to be discussed later. The effect of the number and type of turbines on the capacity of power plant A is excluded. Also the influence of turbine capacity on power plant capacity is not considered.

3.2 MATHEMATICAL FUNCTIONS:

In the current system, it has been assumed that there is a serial correlation between the successive inflows at point D. The following equations, introduced by Thomas and Fiering [37] and Yagil [39] are used to represent the model.

$$\hat{Q}_1 = \bar{Q}_1 + t_1 s_1 \tag{3.1}$$

and

$$\hat{Q}_{i+1} = \bar{Q}_{j+1} + \beta_j(Q_i - \bar{Q}_j) + t_i \, s_{j+1}(1 - R_j^2)^{1/2}$$

$$\left.\begin{array}{l} i = 1, 2, \ldots, N \\ j = 1, 2, \ldots, 12 \end{array}\right\} \tag{3.2}$$

where

$\hat{Q}_{i+1}$ = the estimated inflow during the (i+1)st month

$\bar{Q}_{j+1}$ = the mean monthly inflows during the (j+1)st month

Q_i = the inflow of the ith month

β_j = the regression coefficient for estimating flow in the (j+1)st month from the jth month,

t_i = random deviate normally distributed with mean zero and unit variance,

s_{j+1} = the standard deviation of inflows in the (j+1)st month,

R_j = the correlation coefficient between the inflows of the jth and (j+1)st month,

N = number of monthly inflows considered in the simulation.

The model represented by equation (3.1) specifies that the system inflow in the (i+1)st month consists of two additive components: 1) a component linearly related to that in the ith month $[\bar{Q}_{j+1} + \beta_j(Q_j - \bar{Q}_j)]$ and 2) a random additive component $[t_i\ s_{j+1}(1 - R_j^2)^{1/2}]$. The trend line defined by the first component is serrounded by a band of width $s_{j+1}(1 - R_j^2)^{1/2}$ on its both sides, where all observations fall with a definite frequency. The magnitude of serial correlation coefficient of lag one is a measure of closeness of fit between the variables Q_i and Q_{i+1}. This correlation coefficient, R, lies in the range ± 1. The ratio of the explained variation by Q_i to the total variation is called the coefficient of determination, R^2. If there is no explained variation by Q_i, this ratio is zero. If there is no unexplained variation by Q_i, this ratio is one. In any other case the coefficient of determination lies between zero and one. Thus for r = 0, the random additive component equals $t_i \cdot s_{j+1}$, and there is no explained variation in $\hat{Q}_{i+1}$ by Q_i; and for $r = \pm 1$, this component goes to zero, and there is explained variation. Given N normal random deviates, the statistical parameters $\bar{Q}_j$ and s_j for 12 months and β_j and

R_j^2 for each pair of successive months over 12 months, the inflows are obtained. The statistical parameters $\bar{Q}_{j+1}$, β_j, s_{j+1}, R_j are supposed to be obtained from a sample of historical data. Due to the lack of such data, these parameters have been generated as random numbers within certain ranges for each parameter. These ranges have been specified according to either past work and experience, as for $\bar{Q}_{j+1}$ and s_{j+1} or the standard and theoretical basis, as for R_j. The trouble arises when the regression coefficient β_j is generated since no basis to limit the generated numbers can be followed. As a result, a standardization process for the regression coefficients has been performed to be discussed in appendix A. Since the major concern is to determine the optimal capacity of the reservoir, the following equation has been utilized.

$$\bar{Q}_t - \Delta S = \bar{O}t, \tag{3.3}$$

where $\bar{Q}$ and $\bar{O}$ are the average rates of inflow and outflow during time t, respectively and ΔS is the change in the amount of water in storage between the inflow and the outflow sections during time t. Obviously, the equation (3.3) can be solved for ΔS if both of $\bar{Q}$ and $\bar{O}$ are known. In order to determine the storage contents precisely, evaporation is also considered. The following equation, introduced by Harbeck [13] is used:

$$E = M\, u_8(e_s - e_a), \tag{3.4}$$

where

E = the evaporation in inches per day,

M = the mass-transfer coefficient, a coefficient of proportionality,

U_8 = the wind velocity, in miles per hour, measured at 8 meters hight,

e_s = the saturation vapor pressure in millibars,

e_a = the vapor pressure of the air in millibars.

The wind velocity can be measured in different sites surrounding the area of interest. The measurements have to be performed at certain hight above the water surface. If the water surface temperature T is measured the saturation vapor pressure e_s can be obtained from steam tables which is correlated as equation (3.7) and listed in table 3.1. The relative humidity (RH) has to be measured before the vapor pressure e_a can be obtained. The following equation is used:

$$e_a = (RH) \cdot e_s \ . \tag{3.8}$$

The mass-transfer coefficient M can be obtained from [13]

$$M = 0.00338\ A^{-0.05}, \tag{3.5}$$

where A is the reservoir surface area. A trial and error procedure has to be followed in order to determine the exact storage content, its net head, and its surface area. The head of the reservoir can be calculated from an initial estimate of the reservoir storage using equation (3.9), see Table 3.1. Accordingly, the reservoir surface area can be determined from equation (3.6), listed in table 3.1. Substituting the obtained surface area into equation (3.5) the mass-transfer coefficient can be calculated. Consequently the evaporated quantities are obtained using equation (3.4). Now a new estimate of the reservoir storage is obtained by subtracting the evaporated quantities from the initial estimate of the reservoir storage. This new estimate is used to get the reservoir head and consequently its surface area. The preceding procedure is repeated until two successive values of the reservoir storage are almost the same.

Because of lack of data, such as water surface temperature and wind velocity, it is impossible to follow the preceding procedure for the determination of the evaporated quantities. A random number has been generated to represent these quantities in this work.

After the reservoir storage has been determined precisely using the above procedure, the reservoir head is obtained using equation (3.9). Consequently the hydro-electric energy generated from power plant A is calculated using [28]

$$E_m = (0.0871) \cdot (\text{HEAD}) \cdot (\text{EPF}), \qquad (3.10)$$

where

E_m = the energy generated per month (MWhr/month),

HEAD = Net effective head (ft),

EPF = effective water flow through turbines (acre ft).

The constant 0.0871 is a (conversion factor) multiplier of .001024 for converting acre ft to MW hr and 0.85 is the assumed efficiency of the turbines. As might be clear from equation (3.10), the energy generated is maximum when: 1) the net effective head of the reservoir is maximum (maximum reservoir capacity); and 2) the effective water flow is large. As a result, the power plant capacity has been designed and installed considering the reservoir capacity and the maximum water quantities assumed to be released through the turbines.

In order to evaluate the costs incurred for the construction of the project, a set of equations (3.11) through (3.16) have been employed. These functions are summarized in table 3.1 while their graphs are traced in figures 3.5 through 3.10 [28]. The capital costs of, reservoir A, power plant A, and irrigation are evaluated using the first three functions, respectively, while the next three functions are applied to evaluate their operation maintenance and replacement (OMR) costs. No capital costs and operation costs for flood control have been considered.

In order to measure the system performance, its expected benefits and losses have to be estimated. Equations (3.17) and (3.18) which are graphically illustrated in figures 3.11 and 3.12 [28], are employed for the evaluation of expected benefits and losses for irrigation, respectively. Equation (3.17) is listed in table 3.1 while (3.18) is

$$\left.\begin{aligned}
&IL = (0.7) \cdot (IS), && IS \leq 0.1,\\
&IL = [(2.(BI-0.07)/0.6](IS-(0.1).(TO)) + 6.07).(TO) && 0.1 < IS \leq 0.7,\\
&IL = 0.2\ (IS - (0.07) \,.\, (TO)) + (0.07) \,.\, (TO) \,.\, (2.(BI) - 0.07) \,.\, TO && \\
& && IS > 0.7,
\end{aligned}\right\} \quad (3.18)$$

where IL is the loss of benefits in percent if irrigation benefits (BI), expressed in 10^6 dollars, and IS is the irrigation shortage in percent of irrigation target output, (TO), expressed in million acre ft. The following set of equations [28] has been applied for the evaluation of expected energy benefits and losses:

$$\left.\begin{aligned}
BRE &= 0.0070\ E_f,\\
BDE &= 0.0015\ E_d,\\
LLE &= 0.0020\ E_L,
\end{aligned}\right\} \quad (3.19)$$

where BRE is the firm energy benefits, BDE is the dump-energy benefits, LLE is the loss for energy deficits all in dollars, E_f is the firm energy, E_d is the dump energy; and E_L is the lost energy all in KW hr. Furthermore, expected flood damage losses have been accounted for using the relation (3.20) introduced by Maass and others [28], given in table 3.1 and illustrated in fig 3.13.

The capital cost of the project is expressed in terms of annual payments and depreciation of the project has been accounted for assuming an interest rate.

3.3. OPERATING POLICY:

Concerning the inflows at point D, reservoir A is filled first, the rest, if any, is released through point C to the flood damage zone.

In order to fullfil the target outputs, water is released until the irrigation target output is met or the reservoir is emptied. If the water released is too large portion, this draft is by-passed through power plant A. Accordingly, water for power generation can not be released, unless there is a release for irrigation.

3.4 EXPERIMENTS AND RESULTS:

Experiments. In order to find the reservoir capacity associated with the maximum net profits, eight experiments have been conducted. Table 3.2 shows the parameters used to generate the variables of the system and the statistical parameters utilized to generate the monthly inflows. The normal random deviate t_i has been limited within $\pm$ 3 standard deviation which includes 99.7% of the area under the normal curve. For the purpose of study this limit was used in order to avoid some of the inflows which would be too large to represent the typical situation. In each experiment a predetermined reservoir capacity has been tested. The parameters used to generate the inflows and the irrigation target outputs have not been altered from one experiment to the other. As a result the irrigation costs remain constant while the power plant costs changes with the change of the reservoir capacity.

The predetermined capacities have been tested ranging from 2 to 9 maf incremented each experiment by one. The experiments have been run over a period of 30 years.

The irrigation net benefits, the energy net benefits and the losses due to flood flows have been evaluated. Flood losses take place when the streamflow at point C is greater than 120 x 10^3 cu ft/sec. The expected profits and the benefit cost ratio have been evaluated for each experiment.

Results. It has been found that the maximum benefit cost ratio results in case of 3 maf reservoir capacity. Figure 3.13 shows the relation between this ratio and the various reservoir capacities tested. If it is desired to obtain a maximum rate of return on the investment, the point at which the ratio of benefits to costs is maximum, should be the limit to the project size. Furthermore, fig. 3.14 shows the relation between cost and benefit for the eight experiments. As might be noted, the maximum net profit has been obtained at the highest cost and the largest reservoir-capacity. This capacity is still economically feasible. Moreover, three relations, explaining the irrigation benefits, the power benefits and the flood losses for all the experiments in terms of expectation, have been presented in fig. 3.15. Investigating this graph shows that the expected benefits of irrigation represents the largest portion of the total annual expected benefits.

Table 3.1 Summary of Correlated Functions

Equation	Figure	Element of the System	Variables		Intercept	Coefficients				Range
			Dependent	Independent		Linear	Square	Cubic	Fourth Degree	
3.6	3.2 [23]*	Reservoir A	Area (acre)	Head (ft)	-0.8524	0.01592	456×10^{-8}	---	---	0 - 420
3.7	3.3	Reservoir A	satura-time vapor pressure (HG)	surface temper-ature (°F)	0.08937	-0.001534	1578×10^{-7}	-1135×10^{-9}	15.52×10^{-9}	32 - 110
3.9	3.4 [28]	Reservoir A	Head (ft)	capacity (maf)	15.1299	135.7530	-20.6567	1.4876	-3912×10^{-5}	0 - 15
3.11	3.5 [28]	Reservoir A	Capital cost (10^6 dol-lars)	Capacity (maf)**	-2.6664	38.8582	-4.7017	0.2729	4483×10^{-6}	0 - 15
3.12	3.6 [28]	Power plant A	Capital cost (10^6 dol-lars)	Capacity (MW)***	2.9973	0.1628	-6975×10^{-8}	---	---	0 - 600
					4.18	0.1380	---	---	---	600 - 900
3.13	3.7 [28]	irrigation	Capital cost	Capacity (maf)						
			Main channel		-9.01099	34.0004	-.6645	---	---	0 - 6
			Distri-bution and drainage		---	4.1667	---	---	---	0 - 6
			pumping work		-80.00	20.00	---	---	---	4.2 - 6

continue

Table 3.1 Summary of Correlated Functions

Equation	Figure	Element of the System	Variables		Intercept	Coefficients				Range
			Dependent	Independent		Linear	Square	Cubic	Fourth Degree	
3.14	3.8 [28]	Reservoir A	OMR cost 10^3 dollars	capacity (maf)	1.5479	11.8057	-0.7442	0.02412	---	
3.15	3.9 [28]	power plant A	OMR cost 10^3 dollars	capacity (maf)	1931×10^{-6}	1876×10^{-6}	-124×10^{-9}	---	---	
3.16	3.10 [28]	irrigation	OMR Cost (10^6 dollars)	capacity						0 - 6
				diversion and drainage work (maf)	0.000	0.0714				0 - 6
				Energy for pumping (maf)	-3.5048	8323×10^{-4}				5.2 - 6
3.20	3.13 [28]	Flood Damage function	losses (10^6 dollars)	stream flow behind point C. (10^3 cuft/sec)	-80.0	0.6667				
					-15093.71	302.208	-2.3585	80524×10^{-7}		150 - 260
						0.500				260 and up

*Number of reference from which the relation is obtained.

**maf = million acre ft.

***MW = Mega Watt.

Table 3.2. Parameters Used To Generate The System Variables

Parameter	Distribution	Mean	Lower Limit	Upper Limit	Standard Deviation
Irrigation (maf*)	Erlang				K
A **		1.0	0.20	1.5	2.0
B **		2.0	1.51	2.5	4.0
C **		2.8	2.51	3.5	5.0
Inflow					
Mean $\bar{Q}_{j+1}$ (maf)	Normal	5.5	1.0	10.00	1.5
Standard Deviation s_{j+1} (maf)	Normal	2.0	0.5	3.5	0.5
Random Deviation t_i	Normal	0.0	-3.0	+3.0	1.0
Evaporated quantities (maf)	Normal	0.70	0.00	1.00	0.10
Regression coefficients β_j	Erlang	0.20	0.00	1.00	K 1.0
Correlation coefficients R_j	Erlang	0.14	0.00	1.00	K 6.00

*maf = million acre feet

**A to generate values for months January, February, November and December.
B to generate values for the mid four months.
C to generate values for months March, April, September and October.

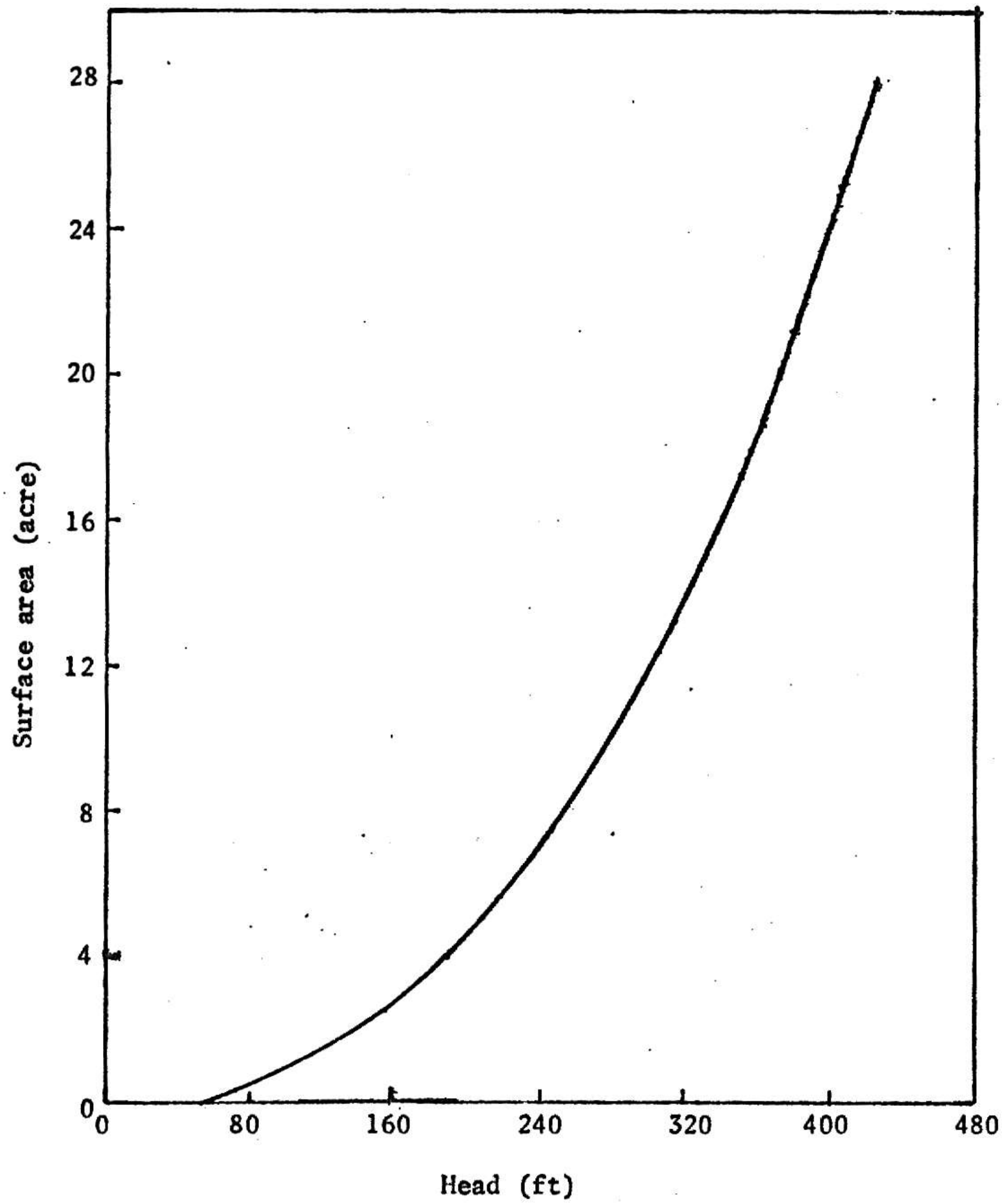


Fig. 3.2 Surface area of reservoir A against its head

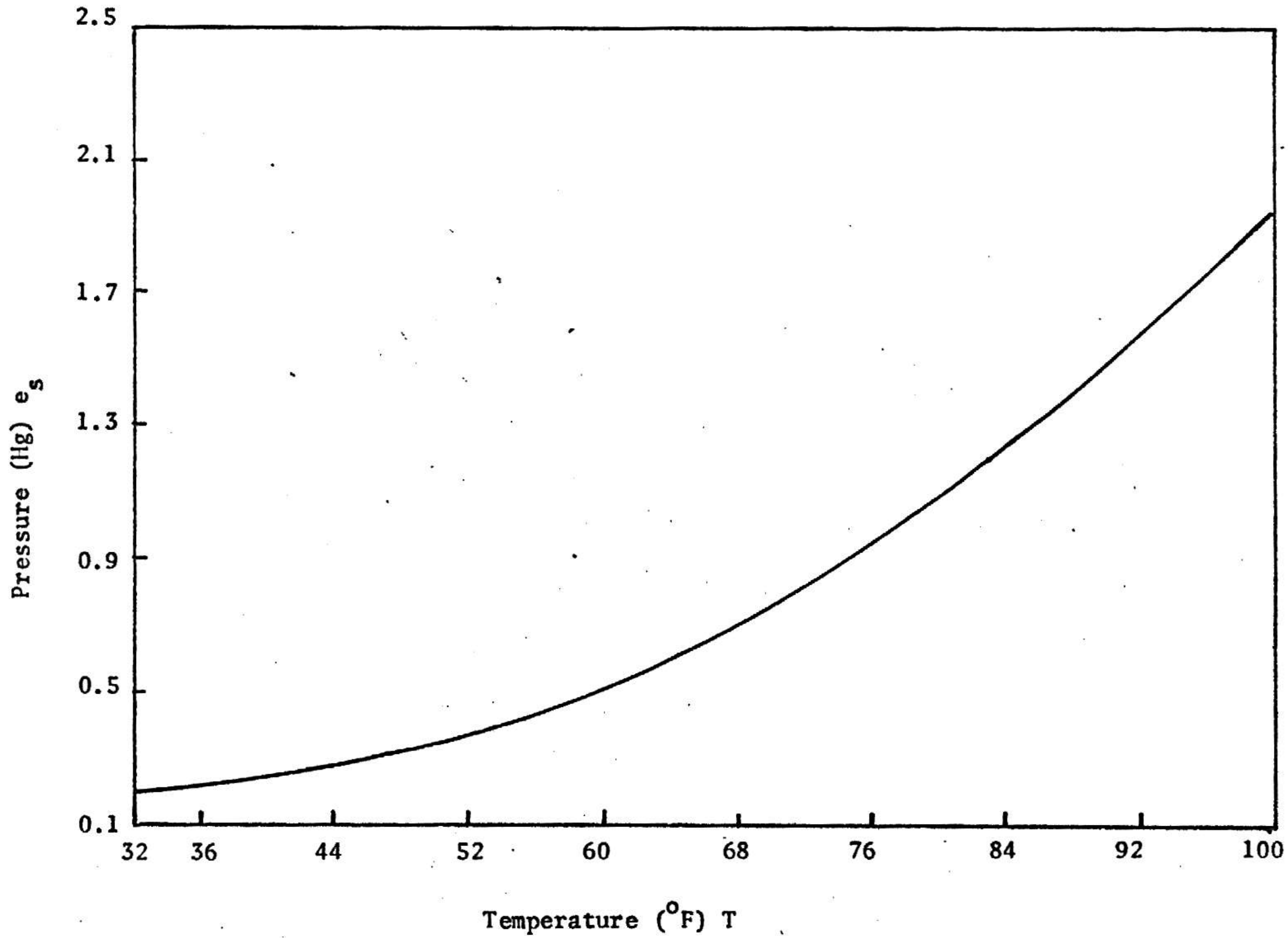


Fig. 3.3 Saturation vapor pressure and surface temperature

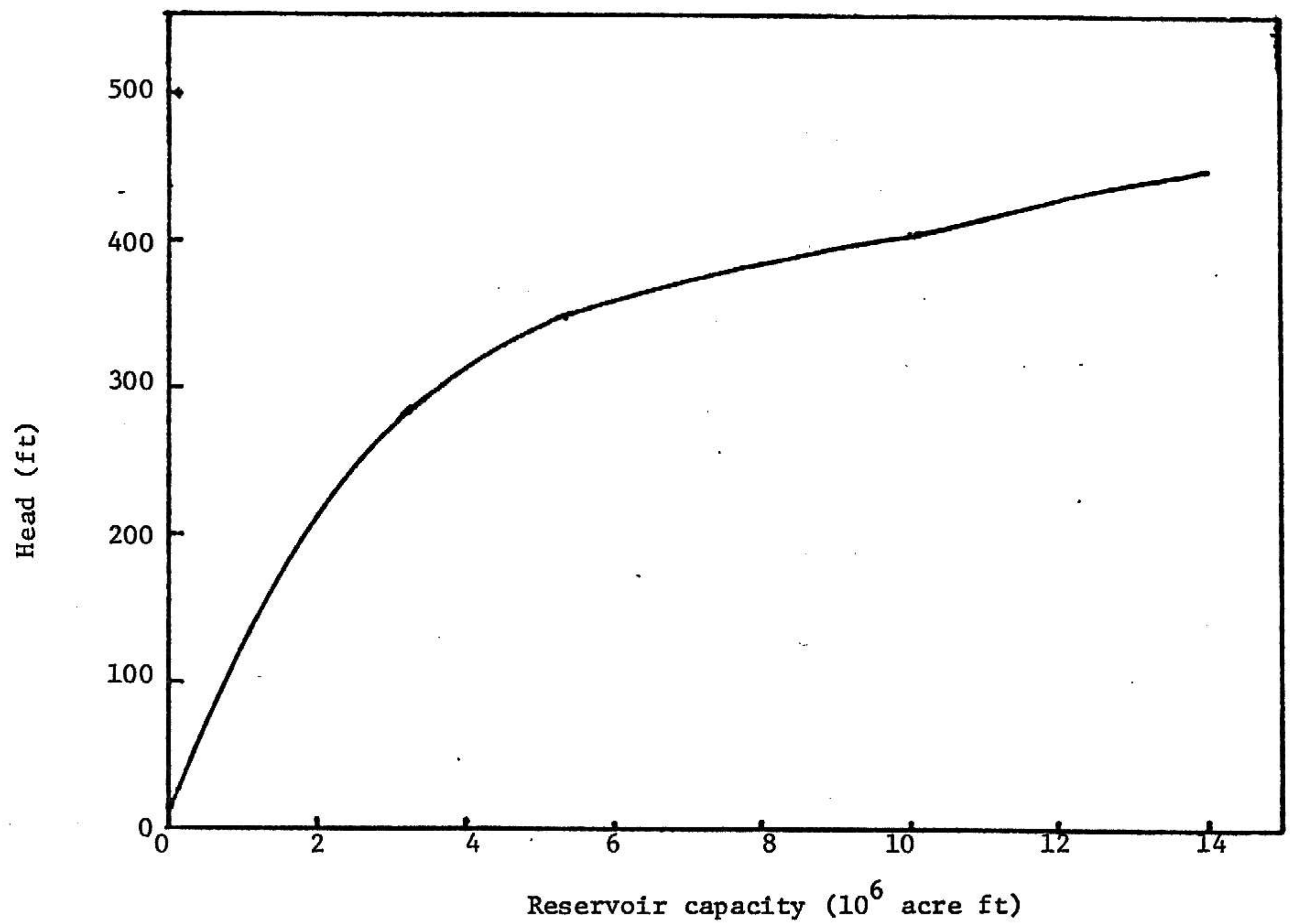


Fig. 3.4 Head and capacity of reservoir A

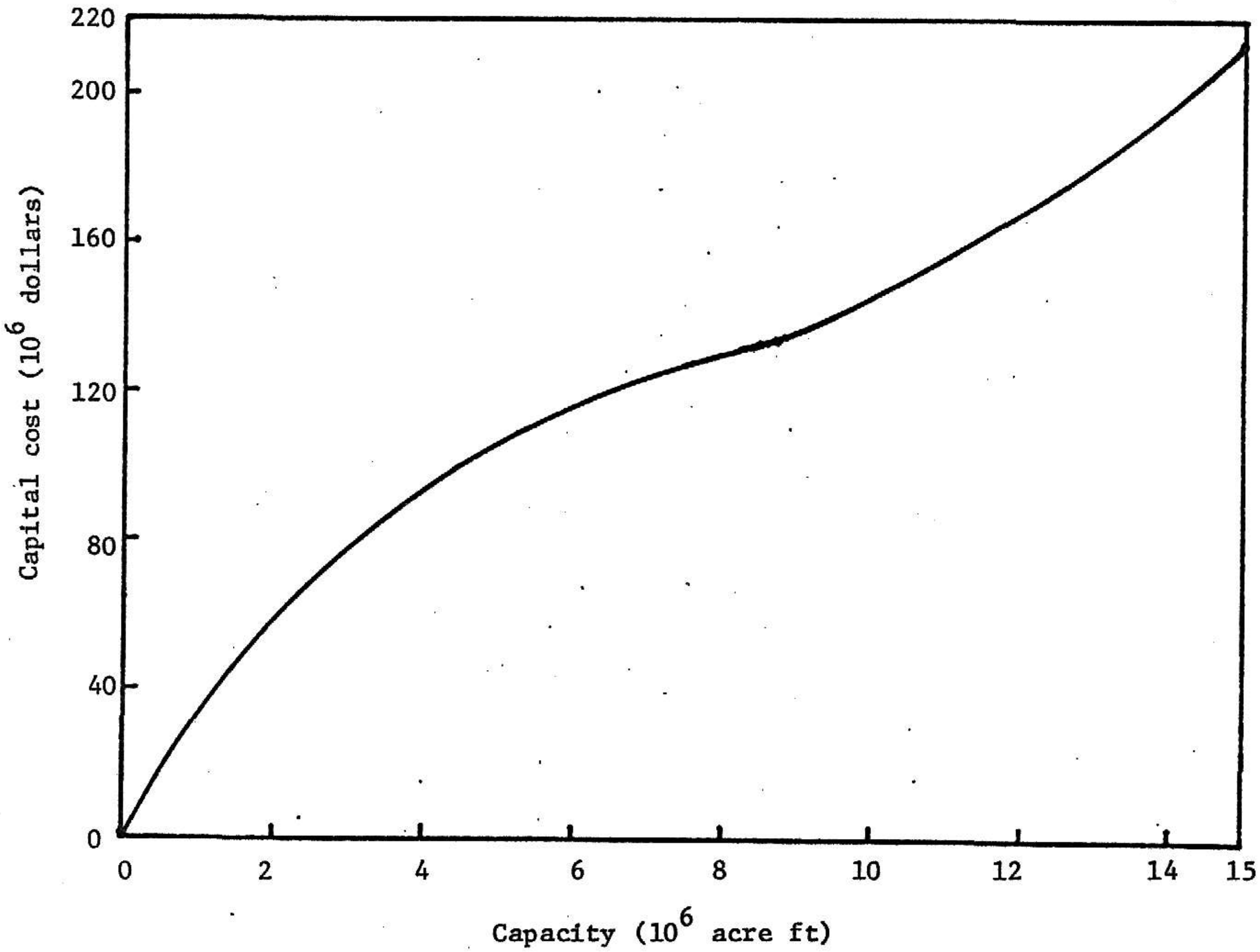


Fig. 3.5 Capital cost of reservoir A

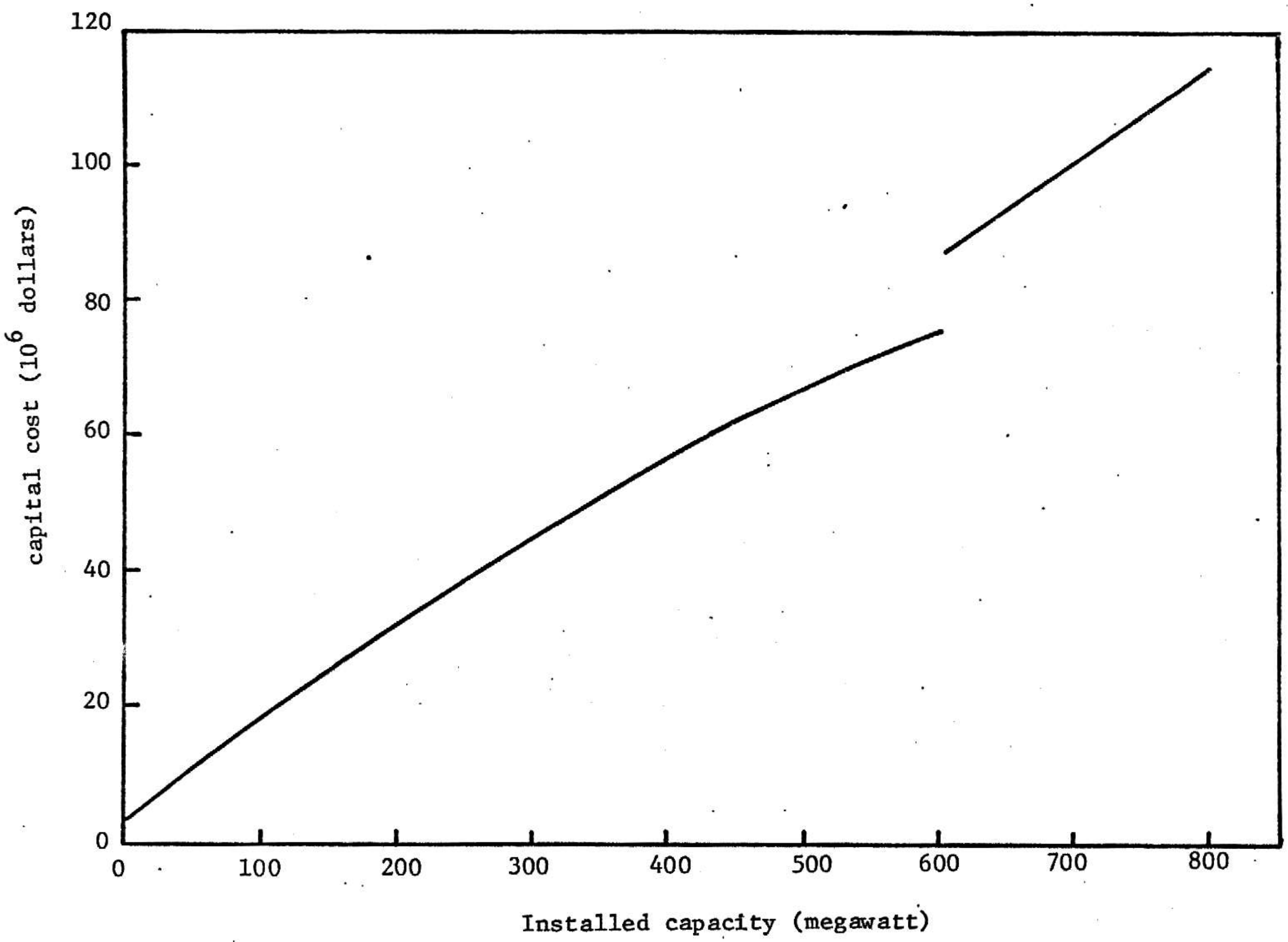


Fig. 3.6 Capital cost of power plant A

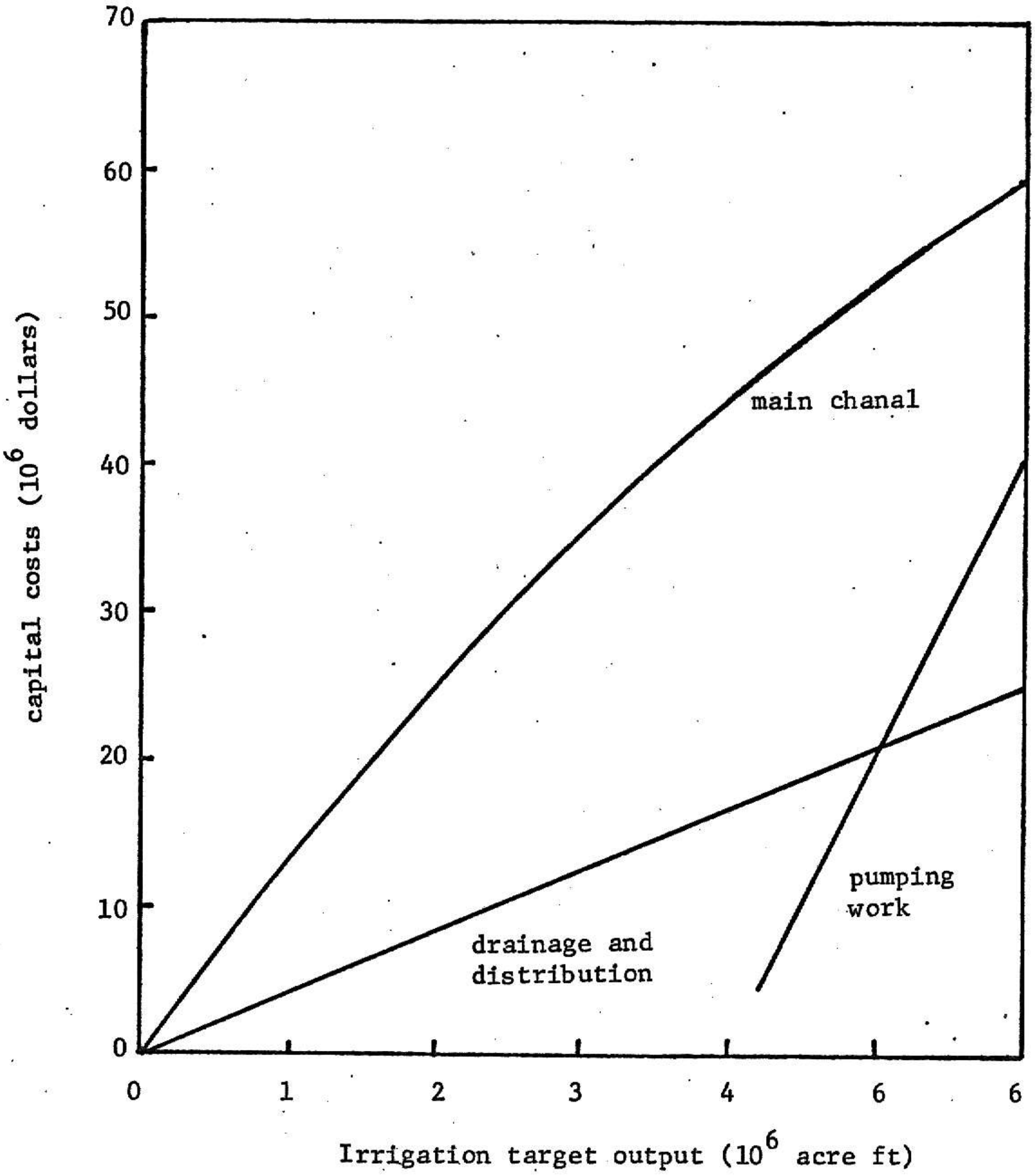


Fig. 3.7 Capital costs of irrigation

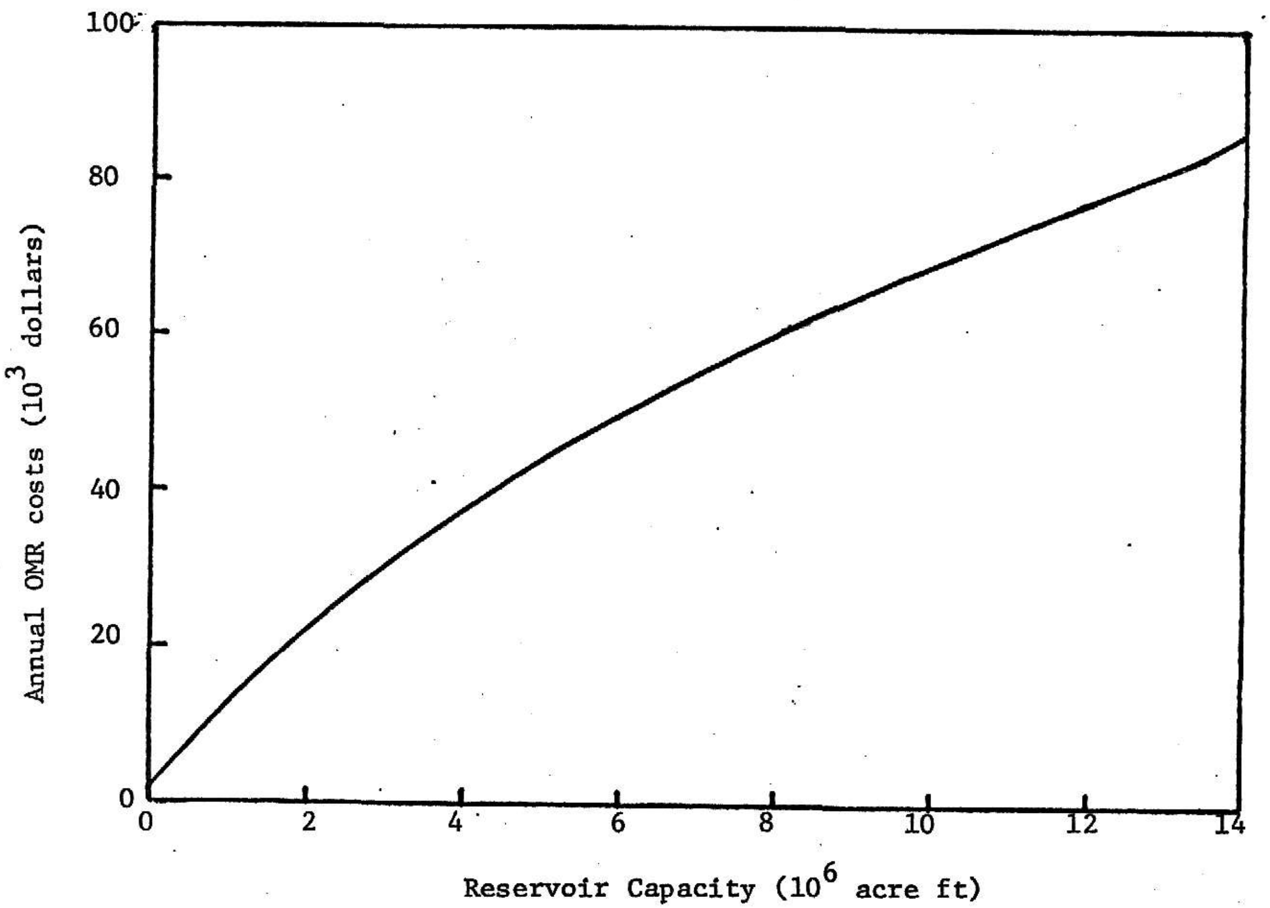


Fig. 3.8 Annual OMR costs of reservoir A

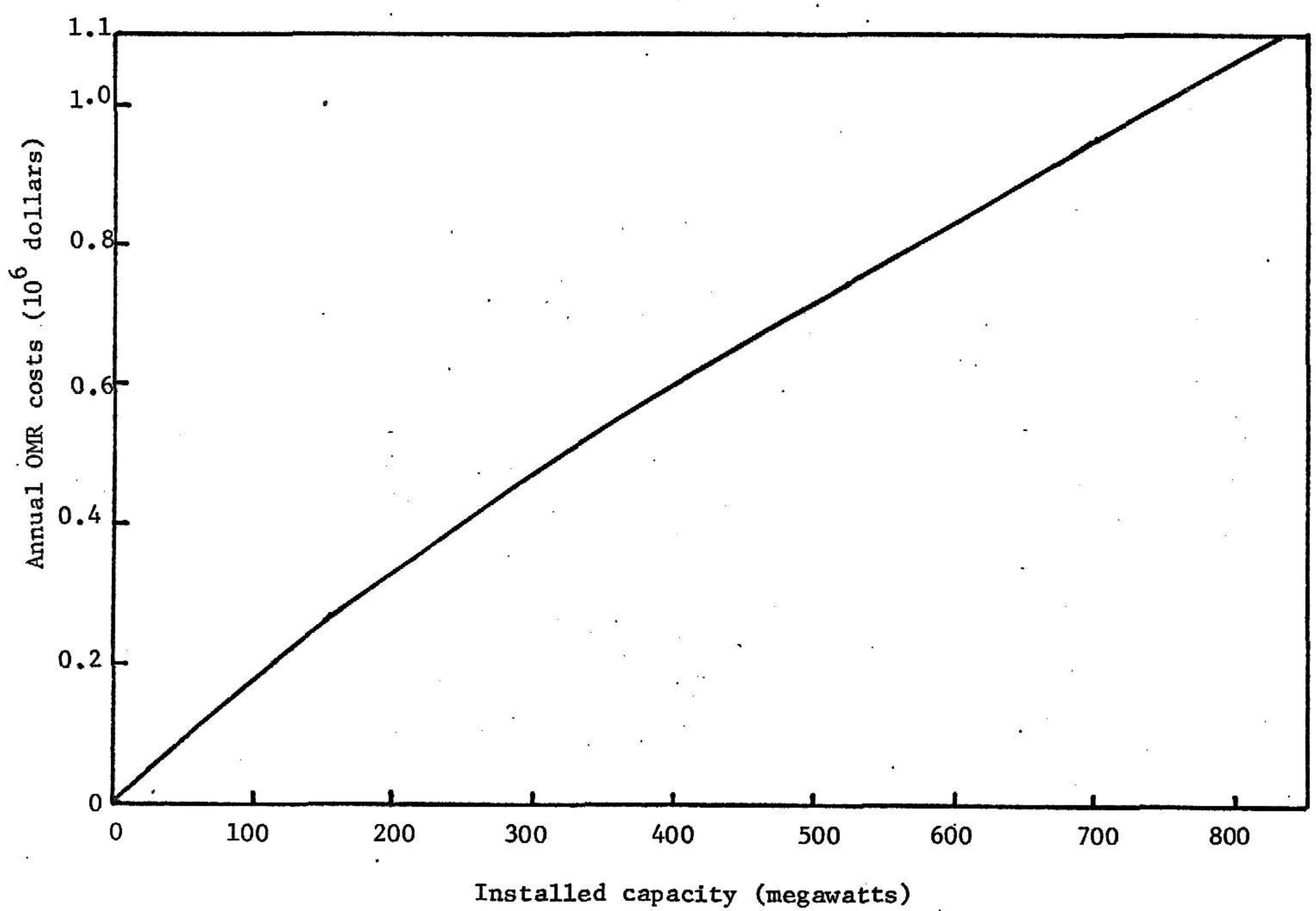


Fig. 3.9 Annual OMR costs of power plant A

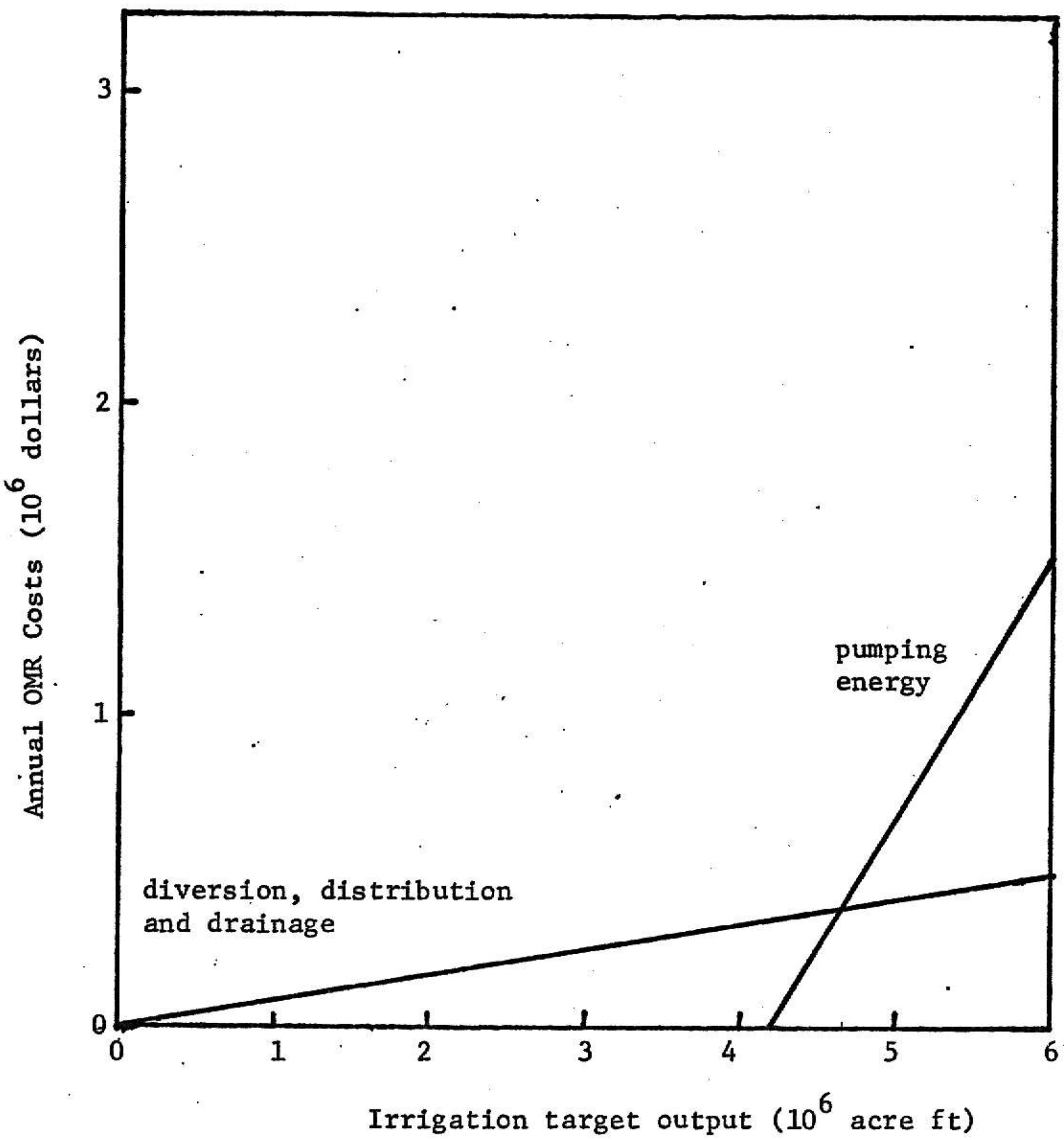


Fig. 3.10 Annual OMR cost of irrigation

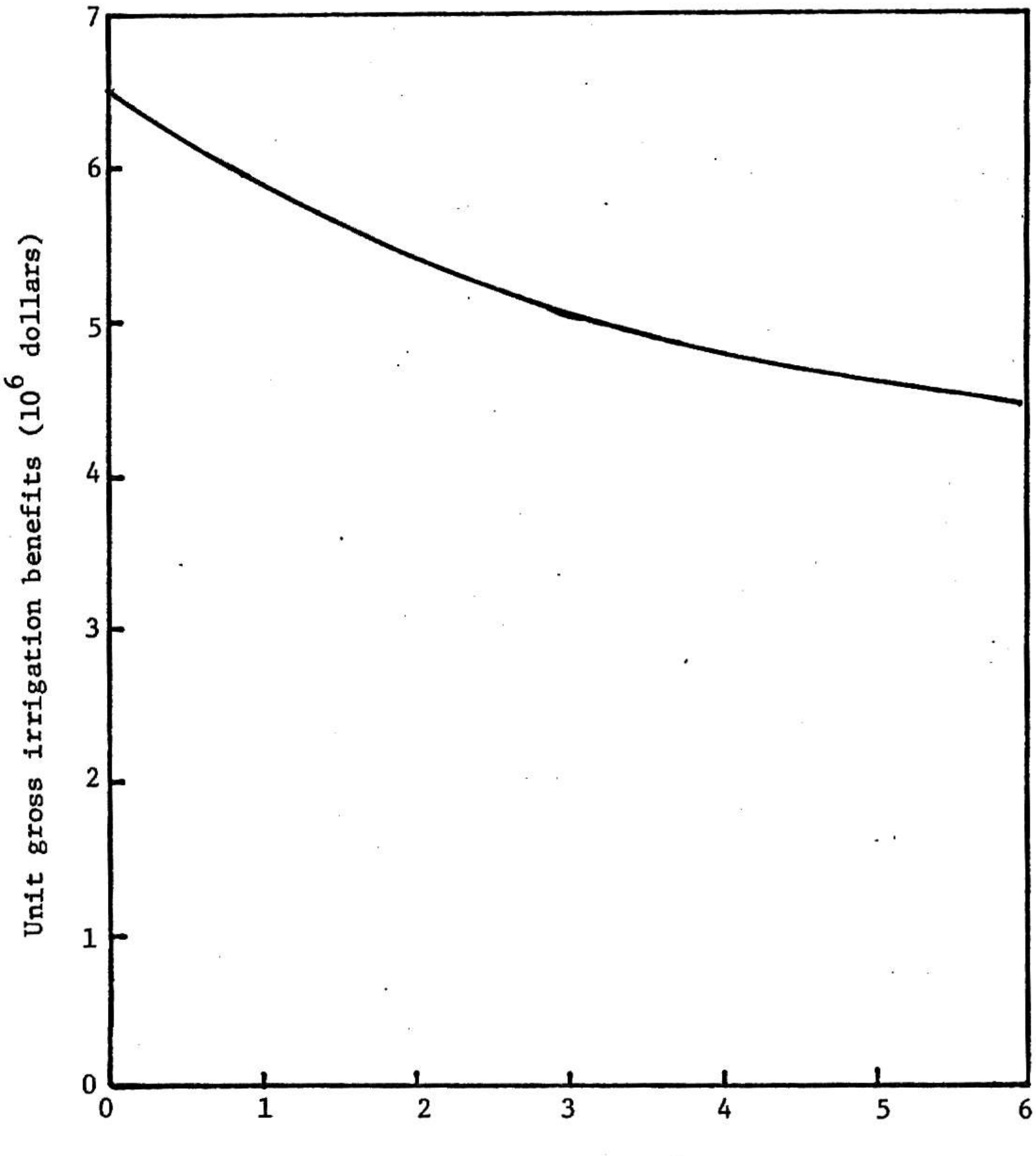


Fig. 3.11 Unit gross irrigation benefits

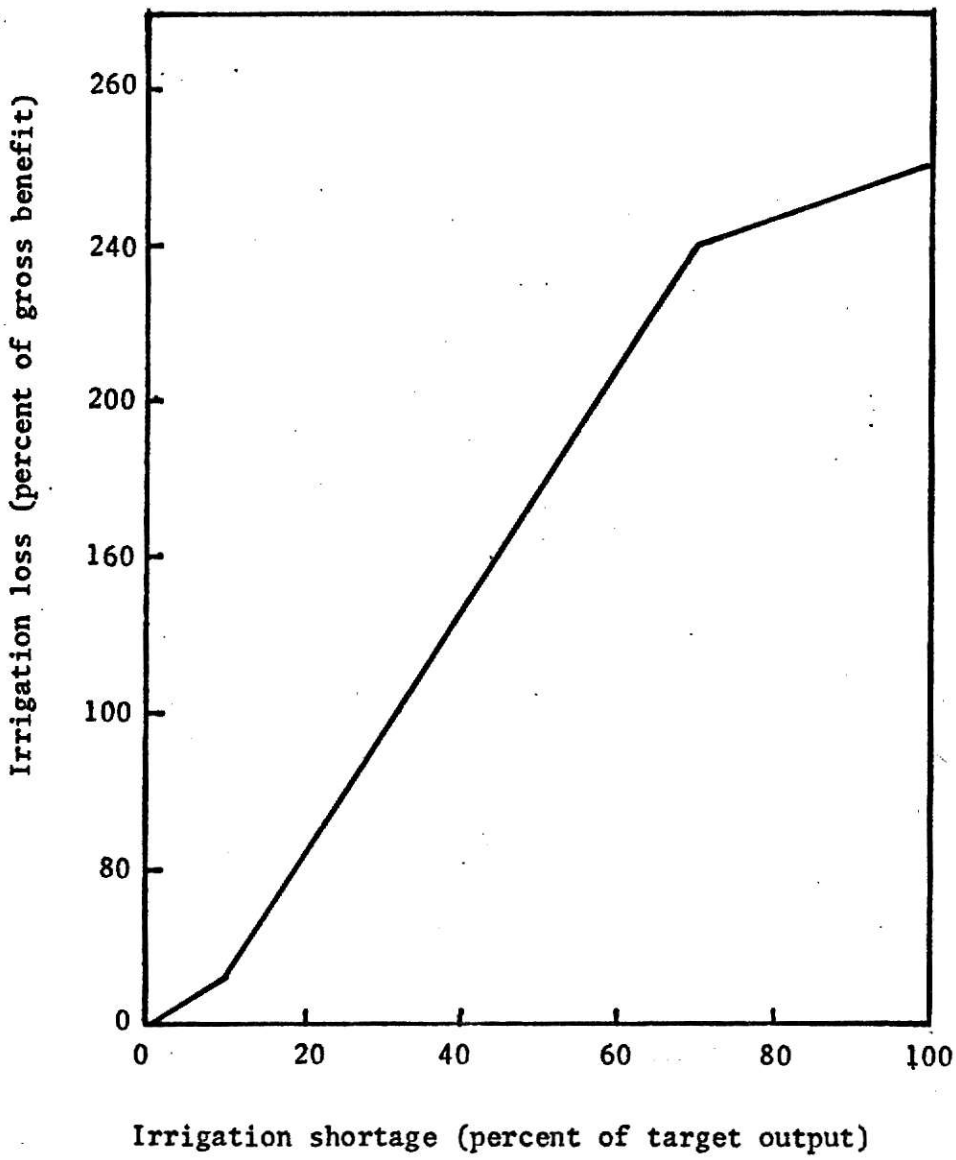


Fig. 3.12 Irrigation loss function

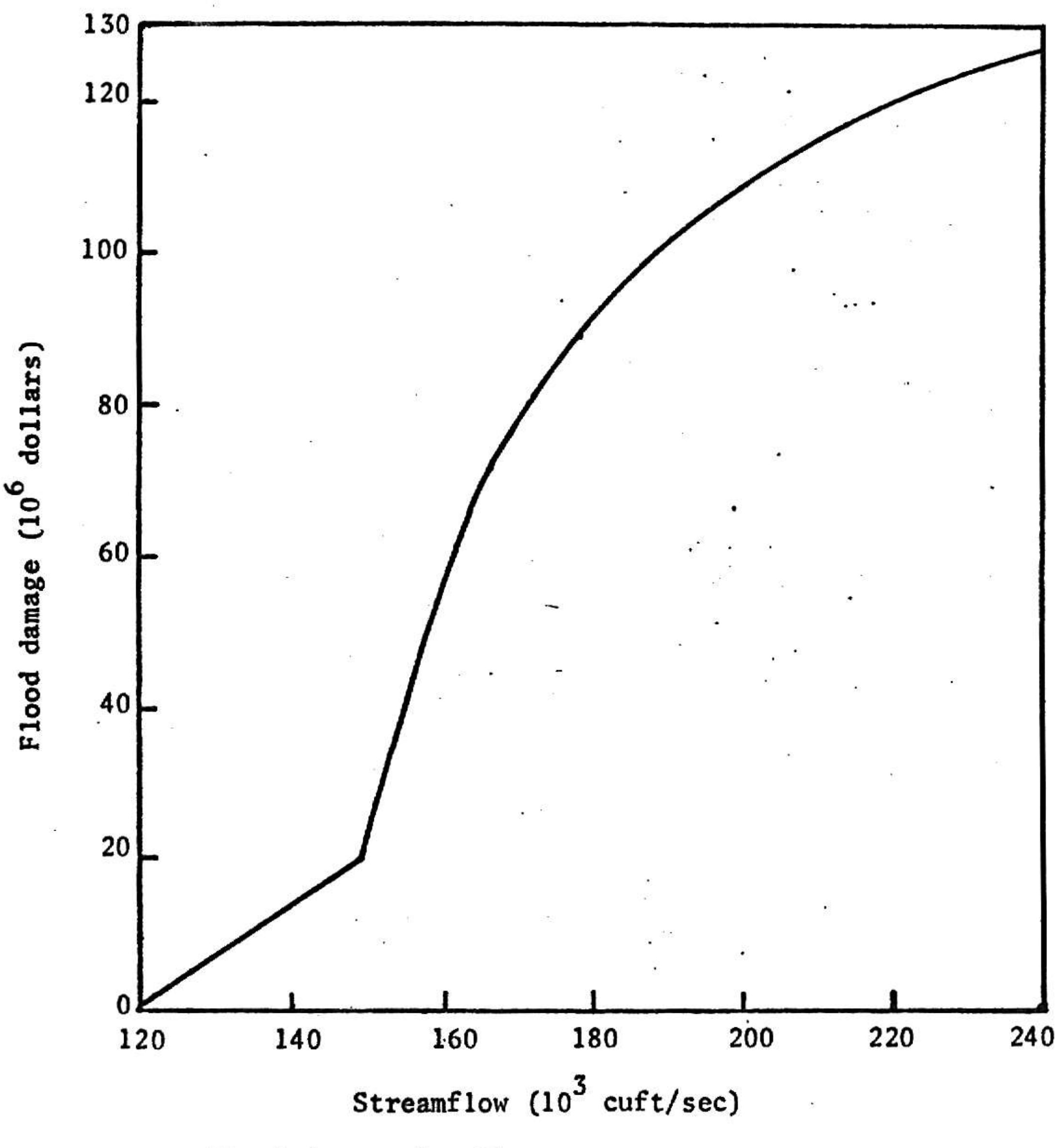


Fig. 3.13 Flood damage function

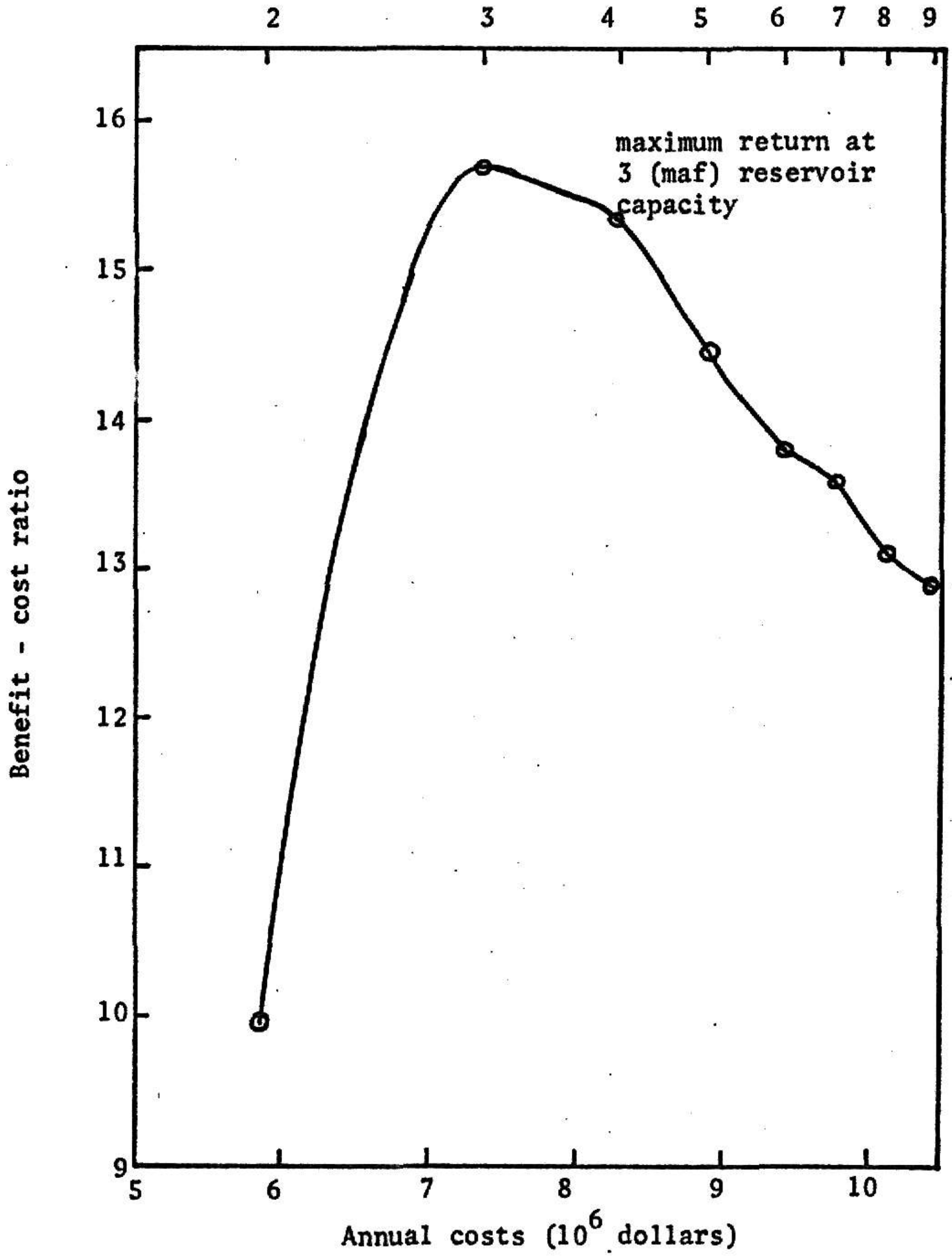


Fig. 3.14 Benefit - cost ratio

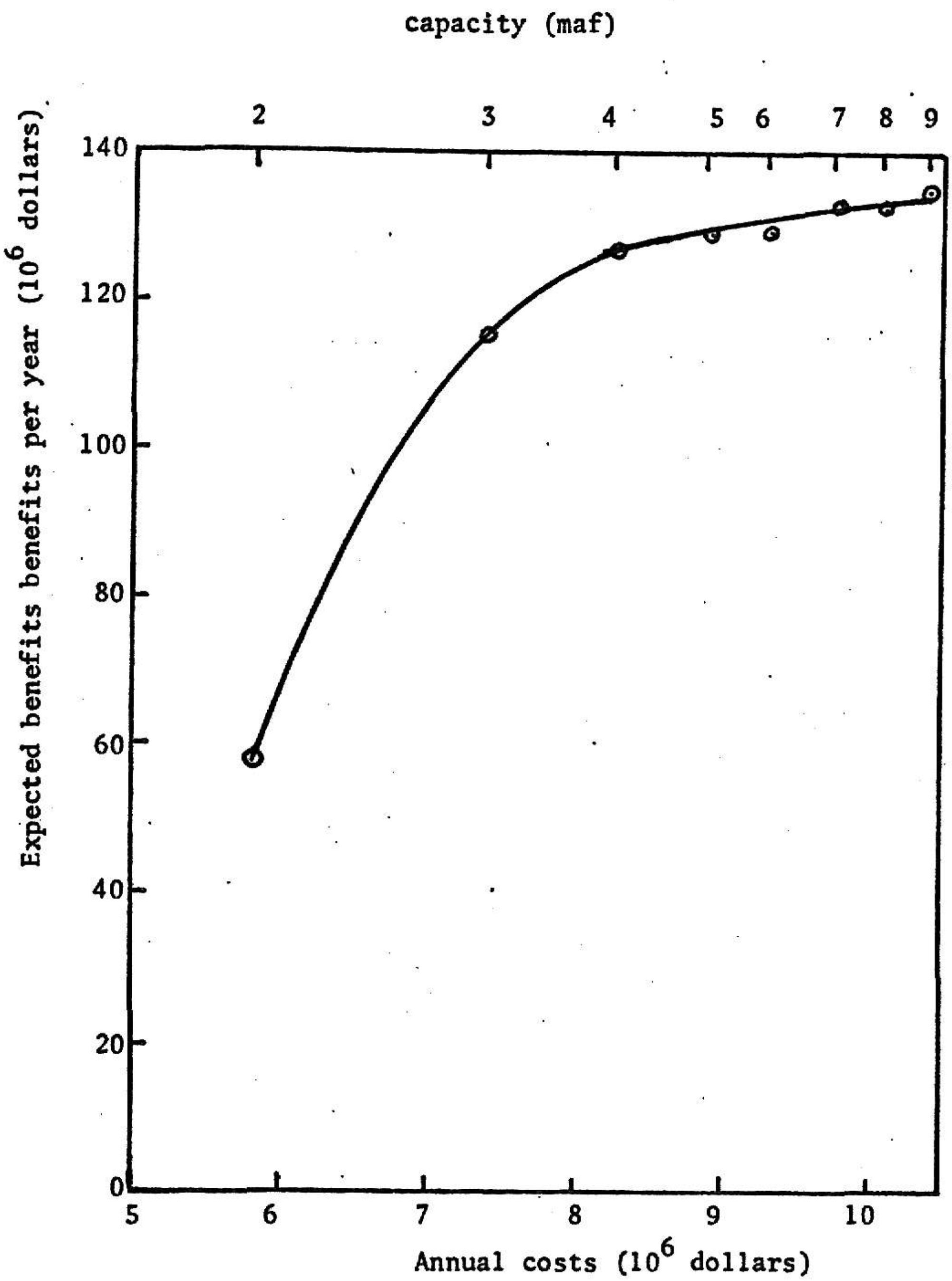


Fig. 3.15 Relation between annual expected benefits and annual costs

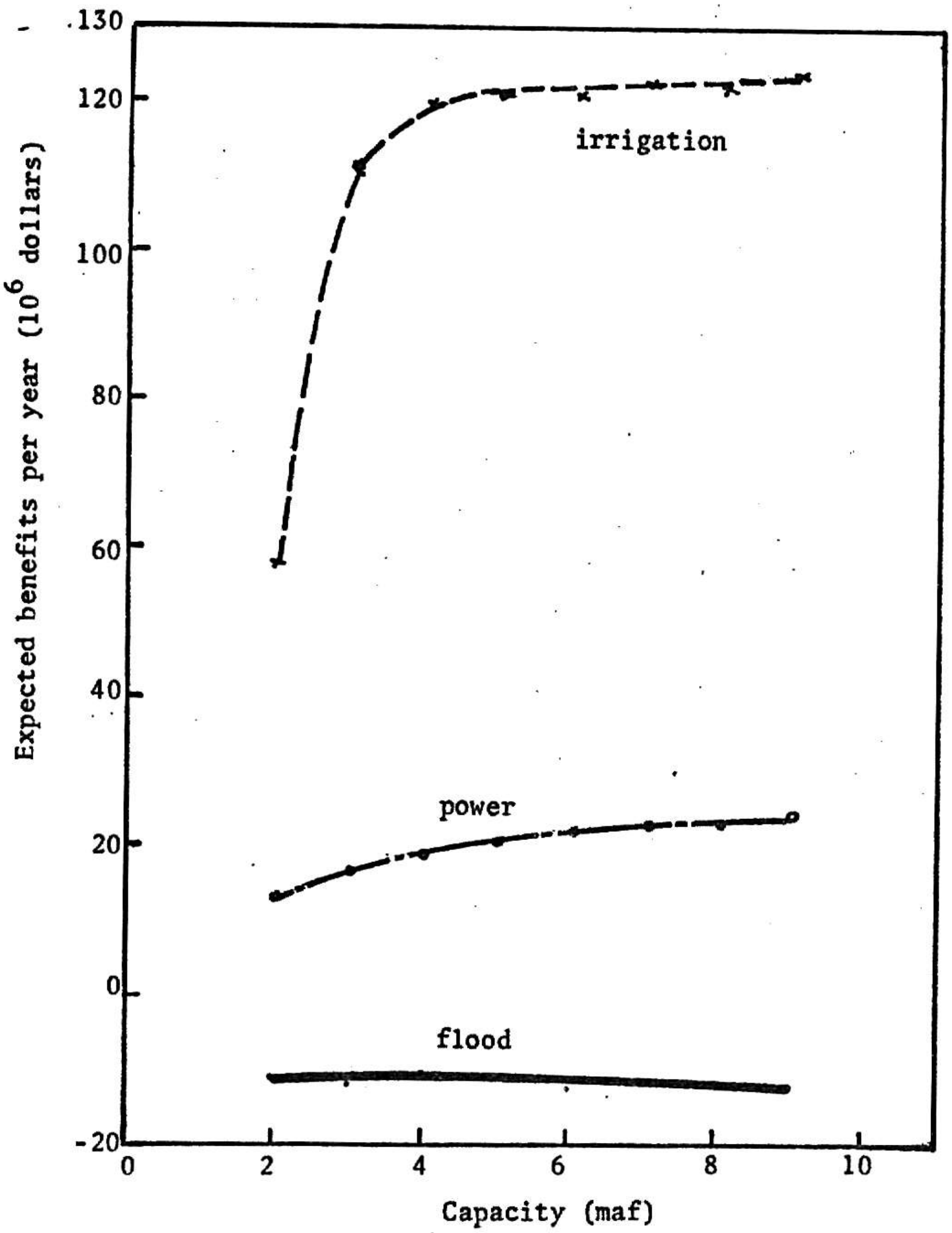


Fig. 3.16 Expected benefits of irrigation, power generation, and flood control

CHAPTER IV

MULTI-PURPOSE THREE-RESERVOIR MODEL

A three-reservoir model with stochastic inflows is considered. The system is simulated on an electronic digital computer in order to evaluate its performance over a period of several years. Various combinations of reservoir capacities are examined. A stochastic storage-release relationship for the system in probabilistic form is obtained by considering the stochastic behavior of the inflows. This model should lead to a maximum expected net profit. The purpose of this chapter is to, describe the model, define the required target outputs, state all the assumptions governing the system, establish the employed mathematical models, and explain the selected operating policy. Some of the above items have been discussed previously in chapter III. As a result, the discussion in the current chapter handles only the specific characteristics of the three-reservoir model.

4.1 THE SIMPLIFIED SYSTEM:

This section includes the discription of the physical layout of the model established and the discussion of the required target outputs.

4.1.1 Physical Layout of the System:

The system (fig. 4.1) comprises three reservoirs A, B, and C; one power plant at reservoir A, one diversion dam for irrigation at point D, one main channel along with the diversion dam, and two channels at points E and F. All three reservoirs can provide releases for irrigation while only reservoir A can provide releases for power generation. Power plant A

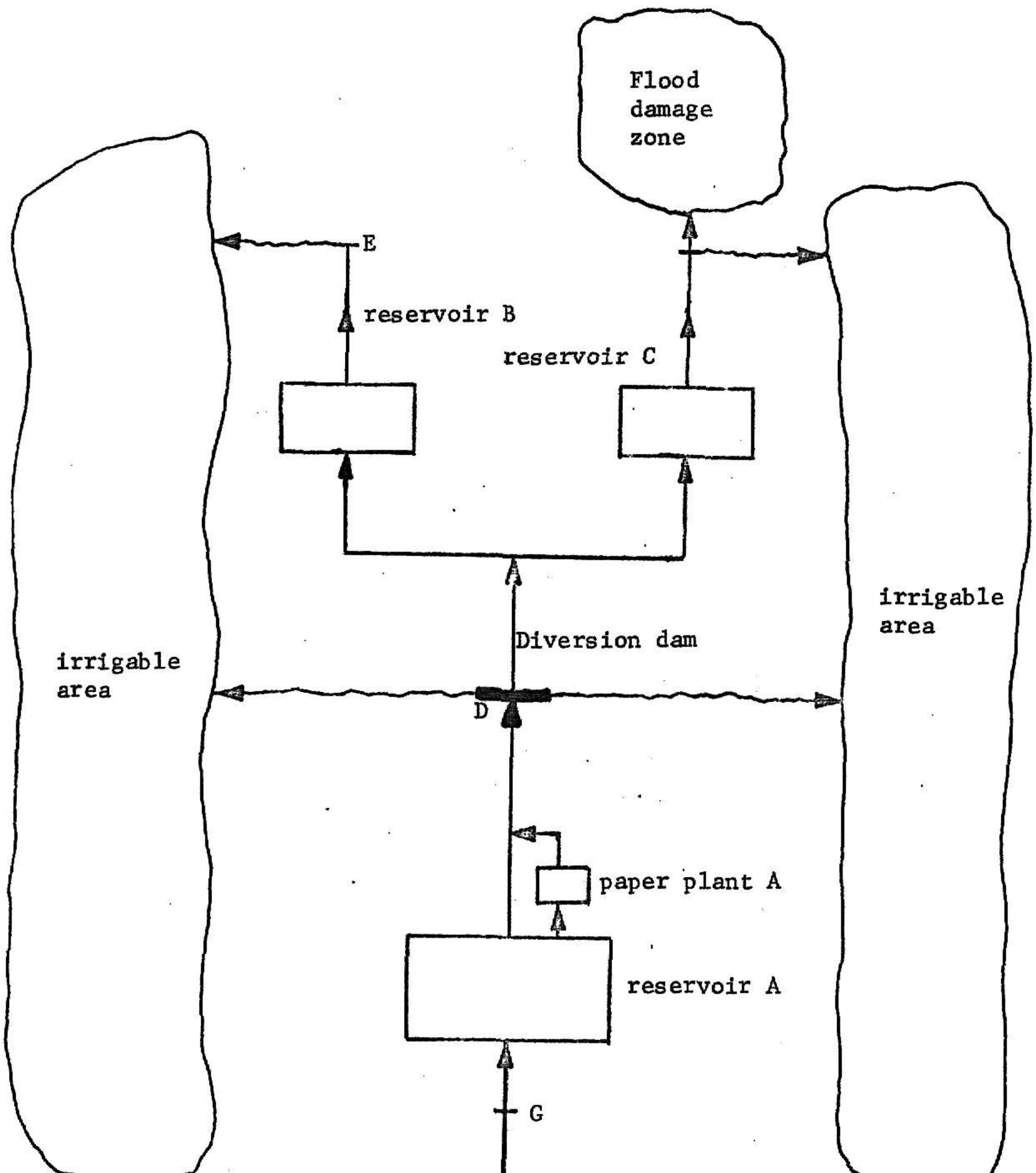


Fig. 4.1 Physical layout of multi-purpose three-reservoir system.

is a variable - head station operating in connection with the main reservoir storage. Irrigable areas lie on both sides of the system to which it is connected by the three channels at point D, E, and F. A flood damage zone is situated behind point F. In general, the three reservoirs offer flood control storage.

The selected sites for the construction of these structures are supposed to be the only feasible ones. Accordingly, reservoirs B, and C are assumed to be constructed in an urban area. Due to this assumption reservoirs B, and C are supposed to offer water supply for both, municipal and industrial needs, and recreational use of water.

Point G is assumed to be the only streamflow inlet to the system. Gaging stations and records are located at the system's inlet and outlets, points G, D, E, and F. The inflows to reservoirs B and C are released from A according to a certain operating procedure to be discussed later. The conditions at the sites are supposed to allow for different alternatives of reservoirs' capacities. Since the water quantities released by the system are mainly dependent on the nature of the system target outputs, a detailed discussion concerning these outputs is presented below.

4.1.2 System Outputs:

As has been mentioned earlier, the five required outputs of the system are, irrigation, hydro-electric power, flood damage reduction, recreational use, and municipal and industrial needs. Each target output is discussed in detail in the following.

Irrigation. Irrigation is the quantity of water that must be released by a water system to the land in order to ensure crop production. This yield depends upon several factors, such as, the system capacity, the method of irrigation, the type of crop to be grown, and the climate. From the viewpoint of this study, the only factor of concern is the system capacity and consequently its yield. Since no real figures about the irrigation demand are available, a random variable representing this demand per month is generated. A seasonal pattern has been considered where the mean of the random variables changes according to this pattern. Irrigation outputs are supposed to be fulfilled from the three reservoirs A, B, and C. Expected irrigation benefits and losses are evaluated and used as a measure of performance.

Water Power. The energy generated by power plant A is used by industry, commerce, and domestic needs. The monthly target outputs of energy are assumed to be a random variable for the reason of lack of data. The expected demand of energy is expressed in terms of water quantities released for power generation. However; the amount of energy generated depends on the net effective head, which is a function of the reservoir content. The power plant capacity is determined based on the maximum energy that can be obtained from the system. This maximum energy can be generated when the reservoir storage is completely full (maximum head) and the streamflow through the turbines is maximum. The monthly load distribution is not considered.

Flood Control. The system is assumed to act for flood damage reduction. Only one flood damage zone is specified and situated just behind the diversion channel at point F. Certain capacity for this flood damage is specified. No particular space is set aside for floods in the three reservoir. Floods should be distributed between the reservoirs according to 1) their capacities; and 2) the space available in each reservoir, at the time of floods. Surcharge storage is not specified in each reservoir. Flood damages are assumed to be a function of floods only. The velocity of streamflows, the quantity of flood waters, and the time of the year are neglected. In any real world situation, these factors must be of considerable effect.

Recreation. It is assumed that reservoirs B and C are also used for recreation. The ideal recreational reservoir should remain nearly full during the recreation season to permit picnicking, boating, swimming, fishing and other various water sports. The other possible and more economical extreme is to fulfill the other target outputs (irrigation - energy, and urban supply) of the system regardless of the pool level required for recreation. The main criterion is to select the project that give rise to the maximum possible return and reasonable fulfillment for recreational target outputs. The number of visitors to the reservoir pool is considered as the measure of recreational benefits. This number is a function of the reservoir surface area and consequently of the reservoir contents. On the other hand, the recreational losses are measured as the difference between the target output and the actual one in number of persons. Compared with the other components of the project, the cost of the recreational facilities is negligable. As a result, no costs are evaluated for this purpose. A discrete random variable is generated to represent the recreational monthly target outputs in number of persons. Moreover, the parameters used to generate this variate have been altered according to certain seasonal pattern.

Water Supply. The municipal and industrial requirements are assumed to be fulfilled through releases from both reservoir B and C. This purpose has essentially the same characteristics as irrigation in the sence that both of these outputs need water release only for their direct use. However;water supply is much more simpler than irrigation since the latter require more regulations and constructions. As a result, no additional constructions are considered for this purpose. Furthermore, water quality is neglected and its effect on the output benefits is excluded. Since the demand for municipal and industrial supply is nearly constant throughout, the year, apart from some slight seasonal fluctuations, a random variable is assumed to represent the monthly urban target outputs. However; the demand of water supply usually increases slowly from one year to another, no provision is made for this increase. In order to measure the degree of the target output fulfillment, the expected benefits and losses of these outputs are evaluated.

4.2 ASSUMPTIONS GOVERNING THE SYSTEM:

Physical Characteristics. The features of the model are discussed and the assumptions concerning the physical characteristics of the system are stated. Since an infinite number of various combinations of the storage capacity for each of the three reservoirs are possible, the following assumption is stated.

$$CA > CB > CC \tag{4.1}$$

where, CA, CB, and CC are the capacities of reservoirs A, B, and C respectively. Certain ranges for the feasible reservoirs' capacities have been placed, as a physical constraint, due to the limited area specified for construction in the selected sites. These sites are supposed to be the only feasible one for the structure of the system elements. The only storage considered in this study is the active storage. Furthermore, the power plant A is designed to be a storage type hydro-electric plant with variable head. In the current model, the net effective head is the only head of concern for the production of energy. The losses in various connections and due to friction have not been accounted for. Furthermore, the various elements of the power plant have not been considered. The capacity of the system canals has not been concerned with except from the viewpoint of irrigation system capacity.

System Software. In the following, the assumptions controlling, the system regulation are stated. The inflows at point G are assumed to be serially correlated. The problem of finding the statistical parameters necessary to generate the monthly inflows has been fully discussed in section 3.2. This discussion also holds for the current model. The evaporated quantities can be always calculated using Harbeck's procedure [13]. However, this procedure is not used because of lack of information. A random variable has been generated to represent these quantities. All other losses are assumed to be negligable. The irrigation return flow has not been accounted for as well as losses from drainage and wasteway channels. A priority rule has been placed for fulfilling the target outputs of the system. First, there must be enough empty storage space for the reduction of flood damage. Second, water supply for industrial and municipal use is ensured. Third, irrigation and power generation needs are fulfilled. Consequently, recreational use has the lowest priority. The water quantities required for power generation is usually less than or equal to that required for irrigation. Accordingly, surplus energy is expected to be existing and utilized as dump energy. The initial content of each of the three reservoirs is taken to be one half of its capacity.

The flood control function, graphed and presented in chapter III, is assumed to take account of losses only. As a result, the maximum benefits can be only obtained in case of no losses. If these benefits are to be received, some empty storage has to be specified. The whole project is assumed to have economic life of fifty year. Furthermore, the capital costs and operation and maintenance costs (OMR) of all the elements of the system are evaluated as a function of the capacities of these elements. Depreciation of the project has been accounted for using the sinking fund method based on a long range interest rate.

4.3 MATHEMATICAL MODELS:

In order to avoid repitition of the mathematical functions established in section 3.2, and employed in the three-reservoir model only the new functions needed are introduced. Since the current model has only one inlet at point G the same equations (3.1) and (3.2) have been used to generate the monthly inflows under the same assumptions stated in section 3.2. Moreover, equation (3.3) has been applied on each of the three reservoirs in order to determine its capacity. Evaporation equation (3.4) is also applicable in the current model. However this equation has not been used for the same reason mentioned in section 3.2. Under the same assumptions, equation (3.10) has been employed for the determination of energy generated from power plant A.

The cost equations (3.11) through (3.16) are applied for the evaluation of capital costs and OMR costs of reservoir A, power plant A, and irrigation facilities respectively. The capital costs and OMR costs of reservoirs B, and C have been incurred by introducing equations (4.2) and (4.3), summarized in table 4.1 and graphed in figures 4.1 and 4.2 [28], respectively.

Figure 3.10 shows the gross irrigation benefit [28]. The irrigation loss function, sketched in fig. 3.10, explains the relation between water shortages and the associated net economic losses. The set of equations (3.19) is employed to evaluate the benefits or land losses of energy generated. Losses caused by flood damages within the simulation are illustrated in fig. 3.13. The benefits of municipal and industrial supply have been evaluated using the function (4.4), summarized in table 4.1 and graphically illustrated in fig. 4.3, while its losses function (4.5) is presented in the same table and graphed in fig. 4.4. These two equations have been adopted from Hutschmidt and Fiering [18].

Recreation has to be measured in number of visitors per month. This number is determined in persons per unit surface area of the reservoir. As has been discussed in chapter III, in order to calculate the surface area of the reservoir its head is needed. In fig. 4.5 [23] the reservoir head is expressed as a function of its capacity. This curve is represented by equation (4.6) and summarized in table 4.1. Consequently, equation (3.6) is employed to calculate the surface area of the reservoir from its head. Figure 4.6 traces the function (4.7), summarized in table 4.1, from which the number of visitors per acre is determined if the reservoir storage is known. By multiplying the number of visitors per acre into the surface area, that is expressed in acres, the absolute number of visitors per month is obtained. The preceding discussion holds for reservoir B as well as for reservoir C. Of course if the number of visitors is less than the target output, generated as poisson random variate, the losses will be the difference between that target output and the actual number of recreated persons in this month.

Finally, the total capital costs of the project ought to be expressed in terms of annual costs so that a comparison between the annual costs and the expected annual benefits can be performed.

This expression can be obtained using the equation

$$AC = TC.\ I\ (1+I.)^{n}\ /\ (1+I)^{n-1} \tag{4.7}$$

where

AC = Annual costs in dollars.

TC = Total capital costs in dollars.

I = Interest rate.

n = economic life of the project.

Over the forthcoming n years, it would be allowed for an annual payment to build up a fund in order to replace the old project. This depreciation can be accounted for using the following equation

$$AD = TC.\ I\ /\ (1+I)^{n-1} \tag{4.8}$$

where AD is the annual depreciation payment. The other variables have the same definitions as presented earlier.

4.4 OPERATING POLICY:

Based on the characteristics of the physical layout of the system, the nature of the stochastic inflows, the nature of the expected outputs, and the assumptions stated in section 2; operating instructions have been constructed. Regarding the inflows at point G, the storage of reservoir A is filled first, reservoir B is filled next, and reservoir C is filled last. If the amount of inflow G is more than the available space in the three reservoir's storages, the excess amount is released to flood damage zone.

In order to fulfill the target outputs, water is released from reservoirs B and C for the urban supply purposes. If both or any of them are empty a supply from A is discharged to B or/and C until the domestic supply target output is met or A is emptied. Use the draft from reservoir A, if any, to provide the target output for irrigation. If the target output for irrigation is not realized, draw water from storage in reservoir B. If both storages in reservoirs A and B are emptied and the target output for irrigation still remained unsatisfied, release from reservoir C until the target output is reached or C is emptied.

For the power generation schedule, energy is generated from power plant A through the use of as much as the power plant capacity can take of the irrigation release from reservoir A. The generated energy is computed and the energy target output is checked whether it is met or not. Detailed steps of this operating policy is included in the computer flow chart introduced in Appendix B.

Table 4.1. Summary of the Correlated Functions

Equation	Figure	Element of the System	Dependent	Independent	Intercept	Coefficients: Linear	Square	Cubic	Fourth Degree	Range
4.2	4.2 [28]	Reservoir B,C	Capital cost (10^6 dollars)	Capacity maf	0.5349	31.8345	-3.1238	0.1145		0 - 10
4.3	4.3 [28]	Reservoir B,C	OMR Cost (10^3 dollars	Capacity (maf)	0.1748	13.5559	-1.6208	0.1559	6265 $\times 10^{-6}$	0 - 10
4.4	4.4 [18]	Domestic supply	Benefits (10^6 dollars)	Percent of monthly	300.6462	-981.552	1286.3910	-595.4962		0 - 10
4.5	4.5 [18]	Domestic supply	Losses (10^6 dollars)	target output	-0.1190	98.2937	-269.0476	361.1110		0 - 0.6
4.6	4.6 [23]	reservoir B,C	Head (ft)	capacity (maf)	0.5349	31.8345	-3.1238	0.1145		0 - 8
4.7	4.7 [23]	recreation	Benefits number of visitors	reservoir contents (maf)	182.87	252.7096	-105.4714	10.7334		0 - 5

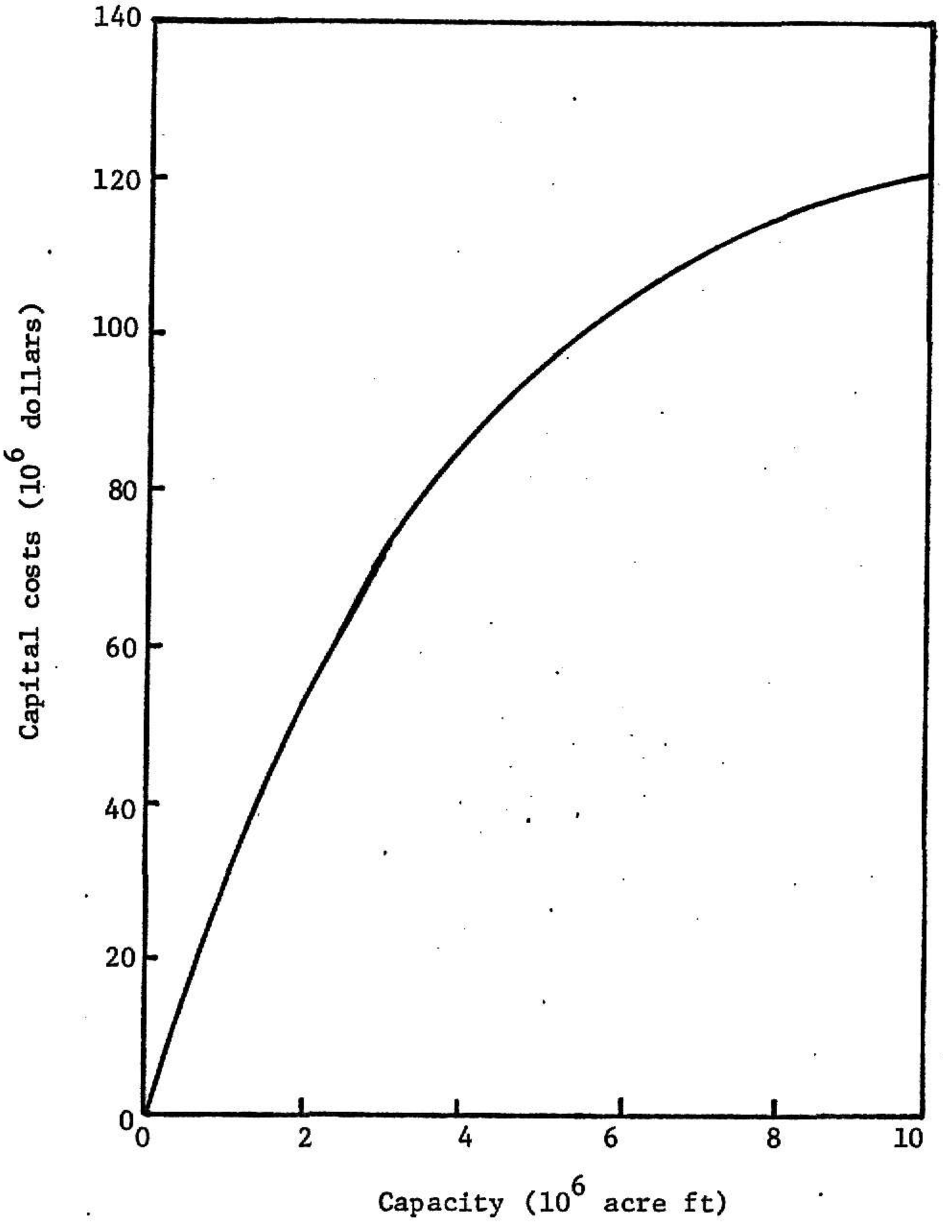


Fig. 4.2 Capital costs of reservoir B and C

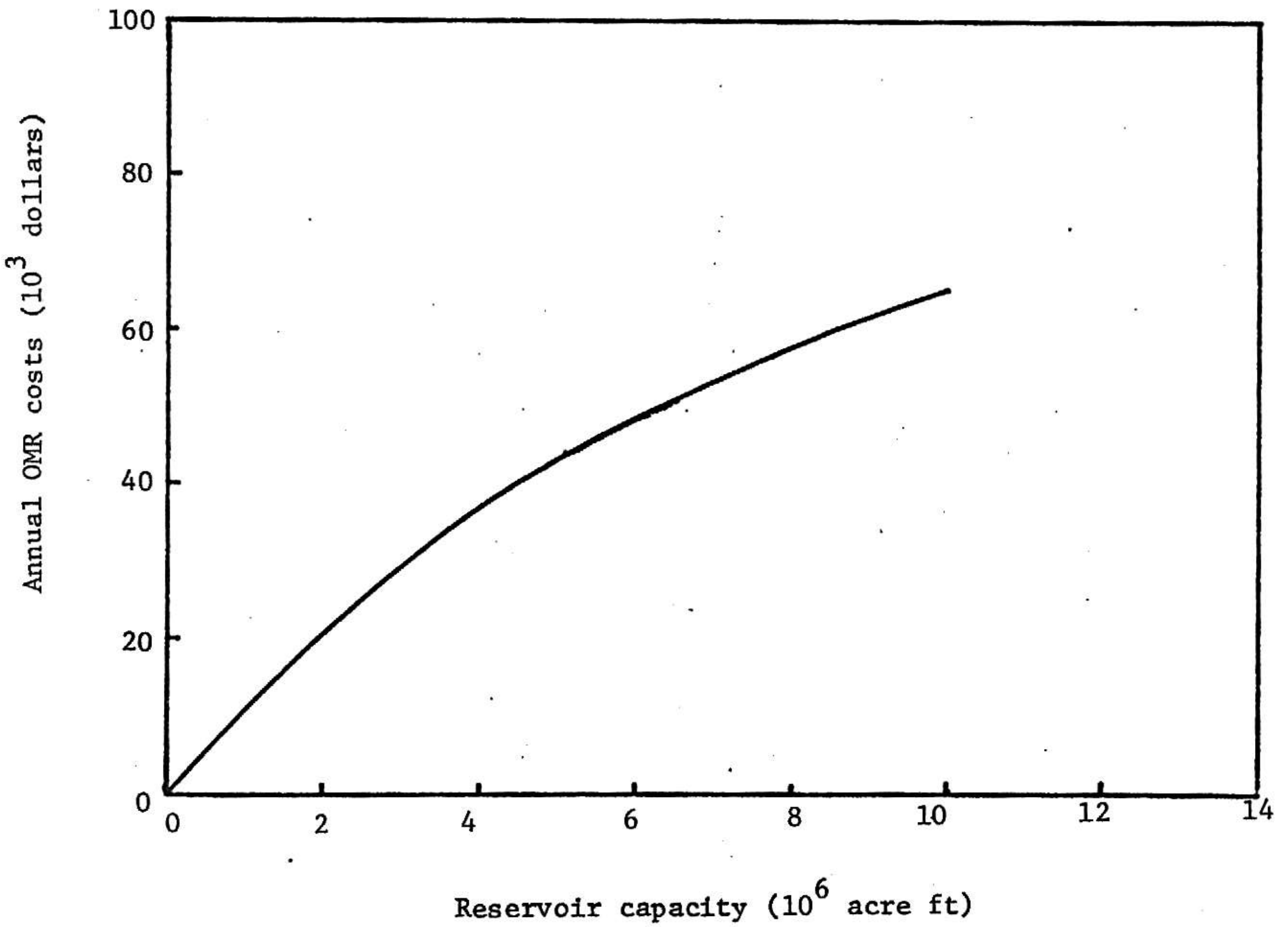


Fig. 4.3 Annual OMR costs of reservoirs B and C

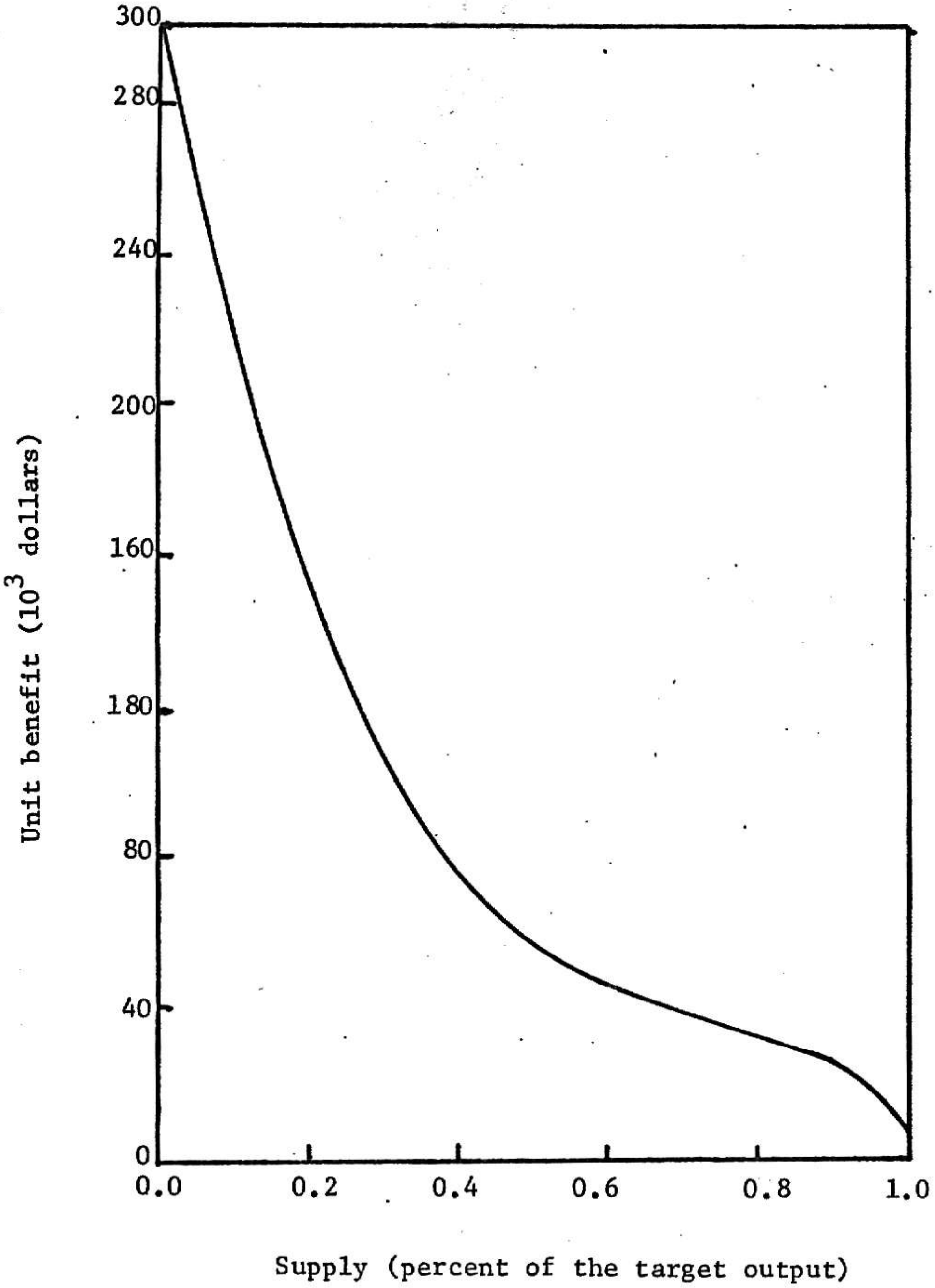


Fig. 4.4 Domestic supply benefit function

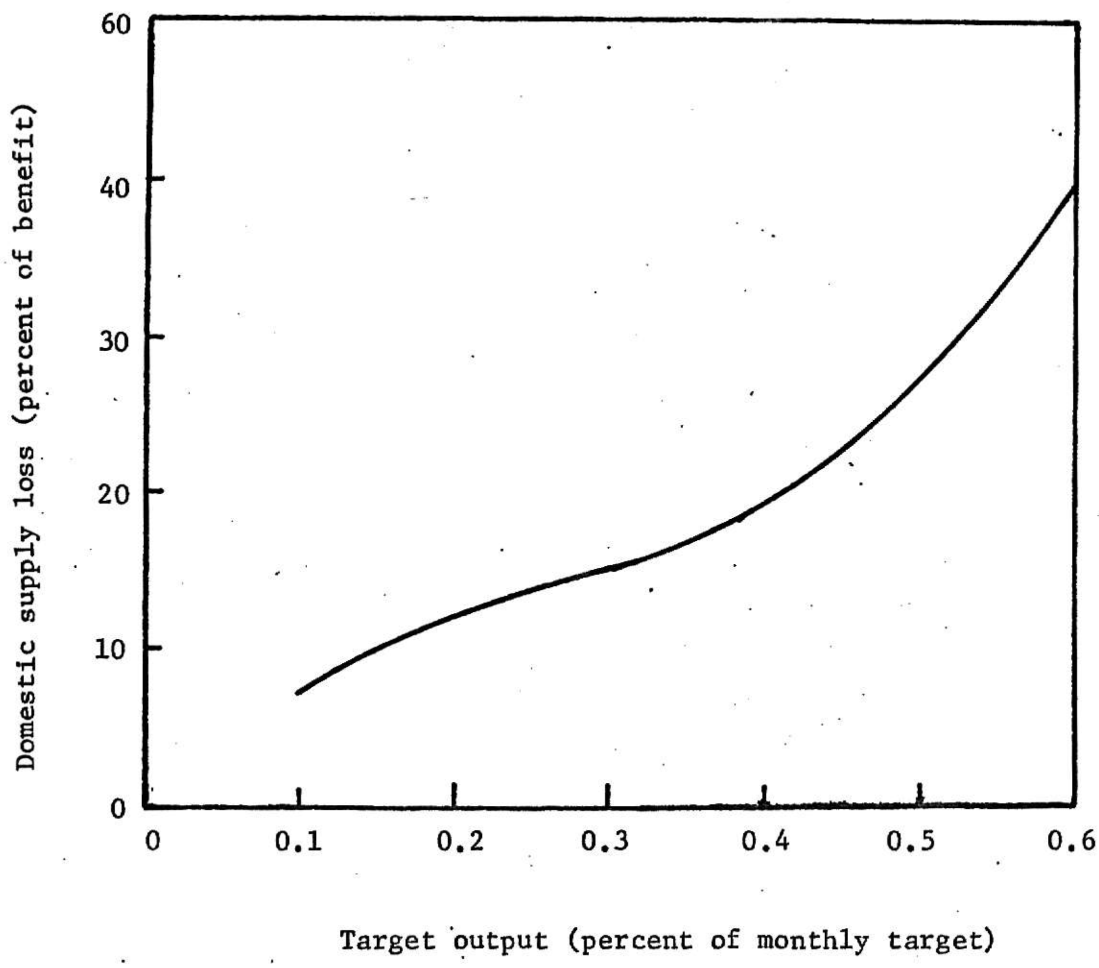


Fig. 4.5 Domestic supply loss function

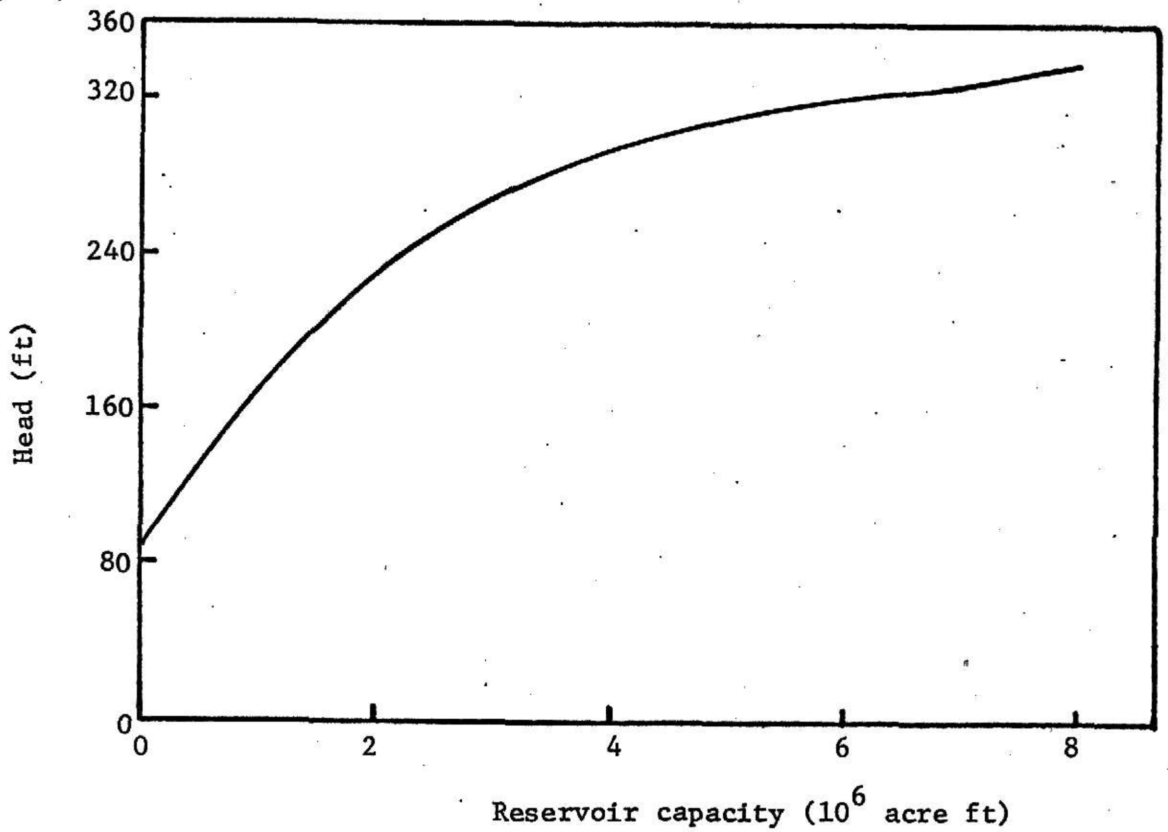


Fig. 4.6 Head and capacity of reservoirs B and C

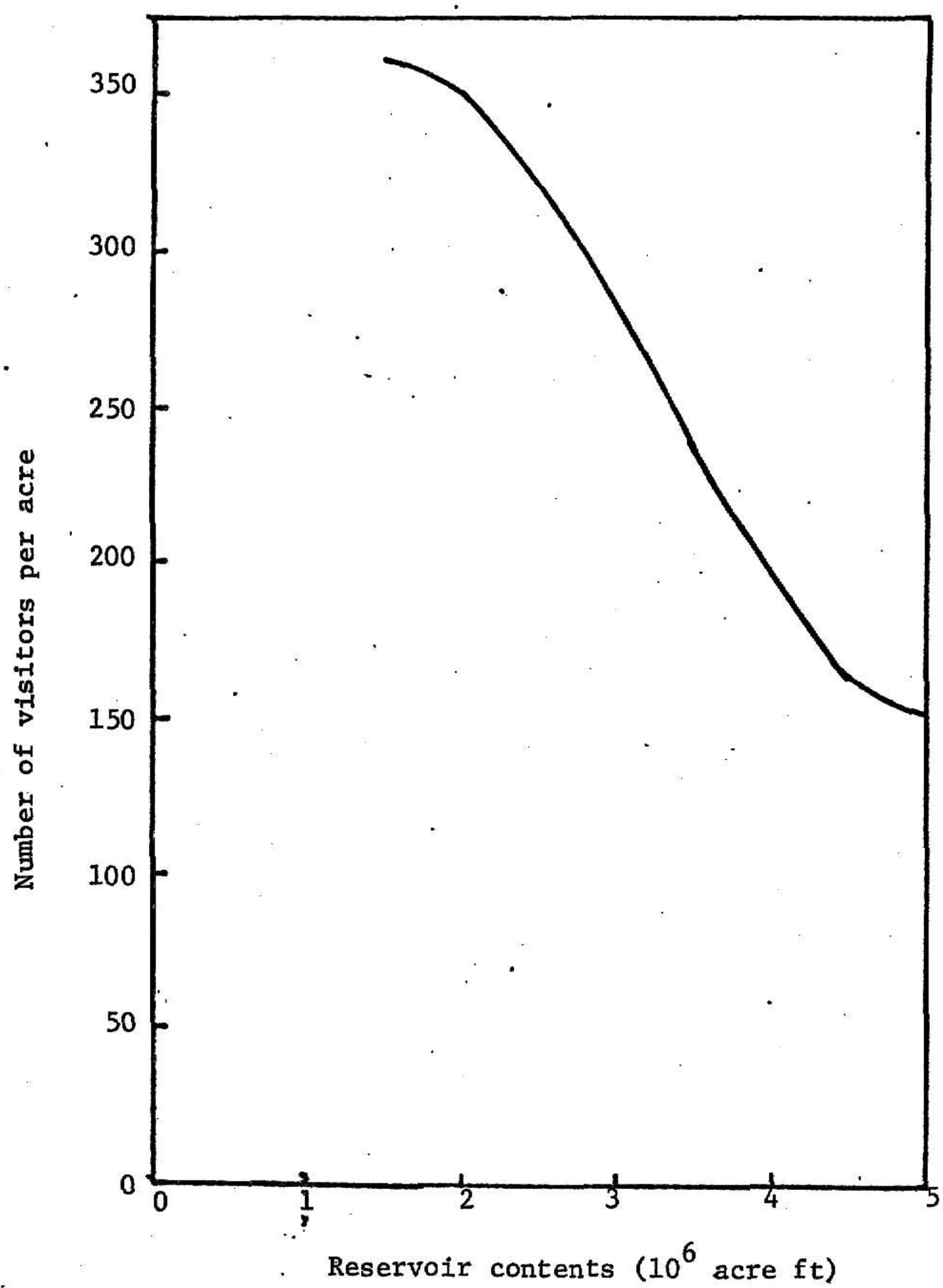


Fig. 4.7 Recreation benefit function

CHAPTER V

EXPERIMENTAL RESULTS

The model of the proposed system is prescribed by three major design variables, the capacities of reservoirs A, B, and C. These variables have been allocated under different inflow means. The target outputs for irrigation, energy, urban supply, and recreational use are assumed to be varying stochastically within specified limits of the parameters. All experiments have been performed using digital simulation and the design variables have been investigated under the same operating procedure which has been presented in section 4.4. Each simulation run covers a period of fifty years. The procedure for regulating the system has been on monthly basis. A synthesized stream-flows have been generated and employed in the current simulation studies. The system outputs and its performance during each experiment have been evaluated and their economic results are obtained. A month by month trace of the system status in general has been performed. Annual expected net benefits resulting from each experiment have been evaluated and considered, with the benefit - cost ratio as a criterion to measure the system performance. The operation, maintenance and replacements (OMR) costs are on annual basis. No constraints have been assumed for the total cost of the project. Since all economic outcomes should be based on similar units so that they will be comparable, total capital costs have been expressed in terms of annual basis at an annual interest rate of 2.5 percent. The period of economic analysis (economic life of the project) is assumed to be equal to the simulation period.

5.1 EXPERIMENTS:

The major concern of the current study has been with methods of investigation and the applicability of the results obtained by using these methods. The specific characteristics of the system and the assumed functions relating the system variables have been employed as a tool only, as long as they are consistent with logic and reality. However, any particular project must has its own characteristics that might be different from those specified here. The preceding discussion has been included in order to emphasize the fact that the numerical results obtained hold only when those functions, presented in chapters III and IV, are employed. It is believed that the application of different functions should give results of the same trend, and leads to the same conclusions but different numerical values.

As has been outlined in section 4.2, certain range of reservoirs' capacities have been assumed. These capacities are the maximum allowable storage volume for each reservoir. Table 5.1 shows the specified range of each reservoir capacity. As a result, various combinations of reservoirs' capacities have been established according to the specified range and the assumption expressed by equation (4.1). These combinations are listed in table 5.2.

Each of the ten combinations has been studied under four different monthly inflow means. The statistical parameters necessary to generate the monthly inflows are summarized in table 5.3. As may be noted the effect of altering the standard deviation of the monthly inflows has been excluded. As has been mentioned in section 3.4, 12 of each of the correlation and regression coefficients have been used for the generation of

Table 5.1 Ranges of Reservoirs' Capacities

Reservoir	Range in 10^6 acre ft (maf)
A	4 - 6
B	3 - 5
C	2 - 4

Table 5.2 Combinations of Reservoirs Capacities

Combination Number	Capacities (maf) Reservoir A	Reservoir B	Reservoir C
1	4	3	2
2	5	3	2
3	5	4	2
4	6	3	2
5	6	4	2
6	5	4	3
7	6	5	2
8	6	4	3
9	6	5	3
10	6	5	4

Table 5.3 Inflow Parameters

Parameter	Distribution	Mean	Standard Deviation	Ranges	
				Lower	Upper
Mean Monthly Inflow (maf)	Normal	4 6 8 10	2	1	12
Monthly Standard Deviation of the Inflows (maf)	Normal	4.5	1	8	1.2

the monthly correlated inflows using equations (3.1) and (3.2). Also, a normal random additive component is needed. This random deviate has the same parameters as in the one-reservoir model, table 3.2. The discussion regarding the limit of this deviate in section 3.4 also holds in the current model for the same reasons stated in that section. The variation in sign and magnitude of this component gives a serially correlated sequence of inflows. According to the preceding discussion, forty experiments have been run. These experiments have been conducted without varying the target outputs from one experiment to another. Target outputs for irrigation and recreational use are assumed to follow certain seasonal pattern. The parameters used to generate irrigation and recreation target outputs have been specified according to that seasonal pattern. These parameters, in addition to the parameters employed for the generation of energy release and urban supply release, are summarized in table 5.4.

In the following the procedure to conduct all the experiments:

1. Assign the capacity of each reservoir for the first combination.
2. Measure the performance of the system with the assigned capacities of the three reservoirs as follows.

a. Evaluate the capital and OMR costs of the system.

b. Generate the system target outputs.

c. Generate the montly correlated inflows using equations (3.1) and (3.2).

d. Generate the evaporated quantities.

e. As initial conditions, set the storage of each reservoir equal to half of its capacity.

f. Fill the three reservoirs according to the constructed operating policy, section 4.4.

g. Update the storage of each reservoir by adding the inlets and reducing the evaporated quantities.

h. Fulfill the system target outputs according to the priority rule specified in section 4.4.

i. If the target outputs are completely met benefits are evaluated, otherwise losses are considered.

j. Total expected net benefits per year are evaluated. Further, benefit-cost ratio is obtained. These two criteria are used to measure the system performance.

k. The preceding procedure is repeated for ten combinations of reservoirs capacities at four various mean inflows.

l. The combination associated with the highest considered criteria is selected to be the optimal solution.

5.2 COMPUTATIONAL RESULTS:

This section includes results and economic outputs of the forty experiments, explained in the preceding section. The effect of inflow

Table 5.4 Parameters of the System Target Outputs

Output	Distribution	Mean	Standard Deviation	Ranges	
				Lower	Upper
Irrigation (maf)*	Erlang				
A**		1.5	7.4	0.500	2
B		2.5	4.6	2.0001	3
C		4.0	2	3.0001	5
Energy release (maf)	Uniform	1.5		1	2
Urban supply reservoir B	Uniform	0.7		0.008	1.392
reservoir C	Poisson	0.6		0.004	1.196
use from reservoir B (in persons)					
A		25		10	50
B		201		51	225
C		476		226	550
recreational use from reservoir C (in persons)	Poisson				
A		15		5	25
B		126		26	150
C		351		151	450

*maf = million acre ft

**A parameters are used during January - February - November - December.
B parameters are used during March - April - September - October.
C parameters are used during May - June - July - August.

means on the system performance and its output is studied. A monthly detailed trace of the system status, when an optimal solution is obtained, is also included. In order to give a clear concept about the system outputs all the results have been graphically illustrated.

In the following the economic measures of the system are defined. Costs incurred for the project construction is known as capital cost. The (OMR) cost is the cost incurred for the system operation and maintenance. The annual cost is the summation of, (OMR), depreciation, and capital costs expressed in annual basis. The benefit resulting from certain target output is defined to be the gross benefit. If a target output is not met, losses are included. Accordingly, net benefit is defined as follows.

Annual Net Benefit = Total annual gross benefit - Annual Losses - Annual Cost

The preceding expressions are used with the same meaning all over the current section.

Figure 5.1 shows the total capital cost of the system when various combinations are considered. It is clear that capital cost is directly proportional to the system capacity. For the ten combinations, total capital cost of each of the system elements is shown in fig. 5.2. From this graph, it can be easily noted that the change in capital cost of both of power plant A and reservoir A is exactly the same. This is due to the fact that capacity of power plant A is a function of capacity of reservoir A. The total capital cost of irrigation facilities remains always constant since the capacity of irrigation system has been assumed to be fixed in all combinations. Because of technical complexities, usually encountered in the installation of large power plants, capital cost of power plant A is the largest one compared with that of other elements of the system. It is also clear that capital costs of the three reservoirs are influenced by equation (4.1) in all combinations, that is, for one combination capital cost of reservoir A is larger than that of reservoir B which by consequence is larger than that of reservoir C. It should be pointed out that operating, maintenance, and replacement cost per year has not been included in these graphs since it is negligable compared with the capital cost of the project.

5.2.2 Expected Benefits:

As has been mentioned earlier, in section 5.2, the criteria used to measure the system performance are benefit - cost ratio and annual expected net benefits. In the following the annual expected gross and net benefits of the system target outputs are calculated and discussed.

Irrigation. For all combinations, irrigation expected gross benefits per year are larger than that of any other target output of the system. As a result, large portion of the total expected net benefits per year is contributed by the irrigation output. Figure 5.3 shows the obtained expected gross benefits of irrigation resulting from the ten combinations of the four inflow means 4, 6, 8, and 10 (maf). It is obvious that annual irrigation expected gross benefits increases as the inflow mean rises. For all the combinations, the irrigation benefits obtained at inflow mean 4 (maf) are very low compared with those obtained at the other inflow means 6.8, and 10 (maf). In general, the change in irrigation benefits from one combination to another are almost the same for the four inflow means.

Energy. The preceding discussion regarding the irrigation expected gross benefits holds for the energy expected gross benefit. The trend of the energy expected gross benefits is about the same as that of irrigation expected gross benefits, fig. 5.4. This can be explained by the fact that no power is generated unless there is an irrigation release. Sudden rise in the energy expected gross benefits is obtained in case of combinations 4 and 6. In these two combinations capacity of reservoir A is 6 (maf), which is larger than its correspondent in the first three combinations. As a result, reservoir A has a greater influence on the system performance than any of the other two reservoirs. This is further proved in case of combination 6 where capacity of reservoir A is reduced to 5 (maf).

Urban Supply. Figure 5.5 shows the annual expected gross benefits of urban supply. The water shortage for urban supply at 4 (maf) inflow mean give rise to losses. The trend of urban supply benefits follows that of irrigation benefits; however; this output is fulfilled through the water released from reservoirs B, and C. The annual expected gross benefits of urban supply contribute a very slight portion of the total expected benefits.

Floods. It is the purpose of the proposed project to reduce losses caused by flood damage. Figure 5.6 illustrates the annual expected losses of floods for each of the four inflow means in all combinations. From this graph, it can be seen that it may be neither practical nor economical to avoid flood losses completely; however; its effect can be reduced as in case of low inflow mean 4 (maf) and combinations of large capacities of reservoirs. In spite of the large reservoirs capacities specified in combination 10 flood losses are not significantly reduced. Combination 9 seems to be the most efficient one in the reduction of flood losses while combination 3 seems to be the least efficient one. Stochastic variations sound to be the only explanation for the preceding remarks.

Recreation. The recreation target outputs is expressed in number of persons. The trend of the number of visitors is the same from one inflow mean to another, for all combinations. Although combination 9 give rise to the maximum expected net benefits, combination 8 allows recreation for the largest possible number of visitors, fig. 5.7. The sudden drop in the annual expected number of visitors, in case of combination 7, is caused by the small capacity specified for reservoir C. For all the inflow means, the general trend of the expected number of visitors per year goes upward as the capacities of reservoirs B, and C increases.

Net Annual Totals. The total expected net benefits per year obtained when using all combinations at the four inflow mean is graphically illustrated in fig. 5.8. As might be observed the total expected net benefits at 8 and 10 (maf) inflow means are greatly influenced by the expected flood losses per year while they are much more affected by irrigation and energy expected gross benefits at 4 and 6 inflow means.

This is further assured by examining figures 5.9 through 5.18 where; the expected gross benefits of; irrigation, energy, and urban supply; expected flood losses; and total expected net benefits are graphed against the four inflows for each combination. For all combinations the total expected net benefits and the expected gross benefits of the target outputs behave exactly the same. Combinations 1 and 3 are the only ones that sum to total expected losses at 10 (maf) inflow mean. This can be explained by the large losses caused by flood damages. Combination 9, fig 5.17, gives a high total expected net benefits per year for all the inflow means in general and for 6 (maf) inflow mean in particular. Moreover, all the combinations at 6 (maf) inflow mean give rise to maximum expected net benefits per year among the other inflow mean. Figure 5.19 traces the relation between total expected net benefits per year and the capacity of reservoir A while holding capacities of reservoirs B and C constant at 3 and 2 (maf) respectively. The maximum expected net benefits per year is obtained when the capacity of reservoir A is 5 (maf). Similarly, holding capacity of reservoir A fixed at 5 (maf) while capacities of reservoirs B and C change, fig 5.20, combination 2 gives reasonable expected net benefits for all inflow means. But for inflow means 6, 8, and 10 (maf) maximum expected net benefits are obtained when combination 6 is used. Among all combinations, fig. 5.21, combination 9 is the most efficient one for the highest three inflow means. For 4 (maf) inflow mean combination 8 is the most efficient one among others.

Benefit-Cost Ratio: The relation between annual costs and the benefit-cost ratio are traced in figures 5.22 through 5.25 for the four inflow means. These curves are supposed to be smooth and unimodel for any deterministic case. The obtained curves have the same trend of the deterministic case; however; they fluctuate in the current model because of the stochastic variations of the system.

The maximum benefit - cost ratio is obtained at 6 (maf) inflow mean when combination 9 is used, fig. 5.23. Combinations 1 and 3 give rise to very low benefit - cost ratio at the same inflow mean. At 4 (maf) inflow mean combination 8 is the most efficient one, fig. 5.22. Combination 4 is the most efficient one at 8 and 10 (maf) inflow means, figures 5.24 and 5.25.

In the following, a detailed trace of the system status is presented for the optimal combinations. This is performed by graphical illustration of the system variables over one typical year, for the four inflow means.

Inflow Mean 4 (maf). As might be clear from the preceding discussion combination 8 gives the best criteria at this inflow mean. A month by month trace of the system variables over one year is presented. The monthly gross benefits of irrigation and energy behave almost the same, fig. 5.26. According to the assumed seasonal pattern, these gross benefits are supposed to be maximum during the mid four months. Because of water shortage in months 6 and 7, fig. 5.27, irrigation target output is not met. Flood losses do not exist in this case, fig. 5.26. On the other hand severe losses of urban supply do exist, fig. 5.28. Figure 5.29 shows the very small number of visitors recreated at pools of reservoirs B and C. Of course the recreation target output is not fulfilled in this case. This can be explained by the empty storages of reservoirs B and C almost most of the time, fig. 5.30. The heads of the reservoirs are affected by these storage, fig. 5.31. In this case, reservoir A can be considered the most effective one.

In order to avoid the repitition of the preceding discussion the graphs of the system status for the other three inflow mean are only presented, figures 5.32 through 5.43.

In case of 10 (maf) inflow mean, the changed variables from the case of 8 (maf) inflow mean are only graphed, since the optimal combination is the same for both inflows. Figure 5.44 shows the flood losses to be more frequent and severe. This is further proved by looking at fig. 5.45. Compared with the system at 4 (maf) inflow mean, the recreation target output is almost fulfilled, fig. 5.46.

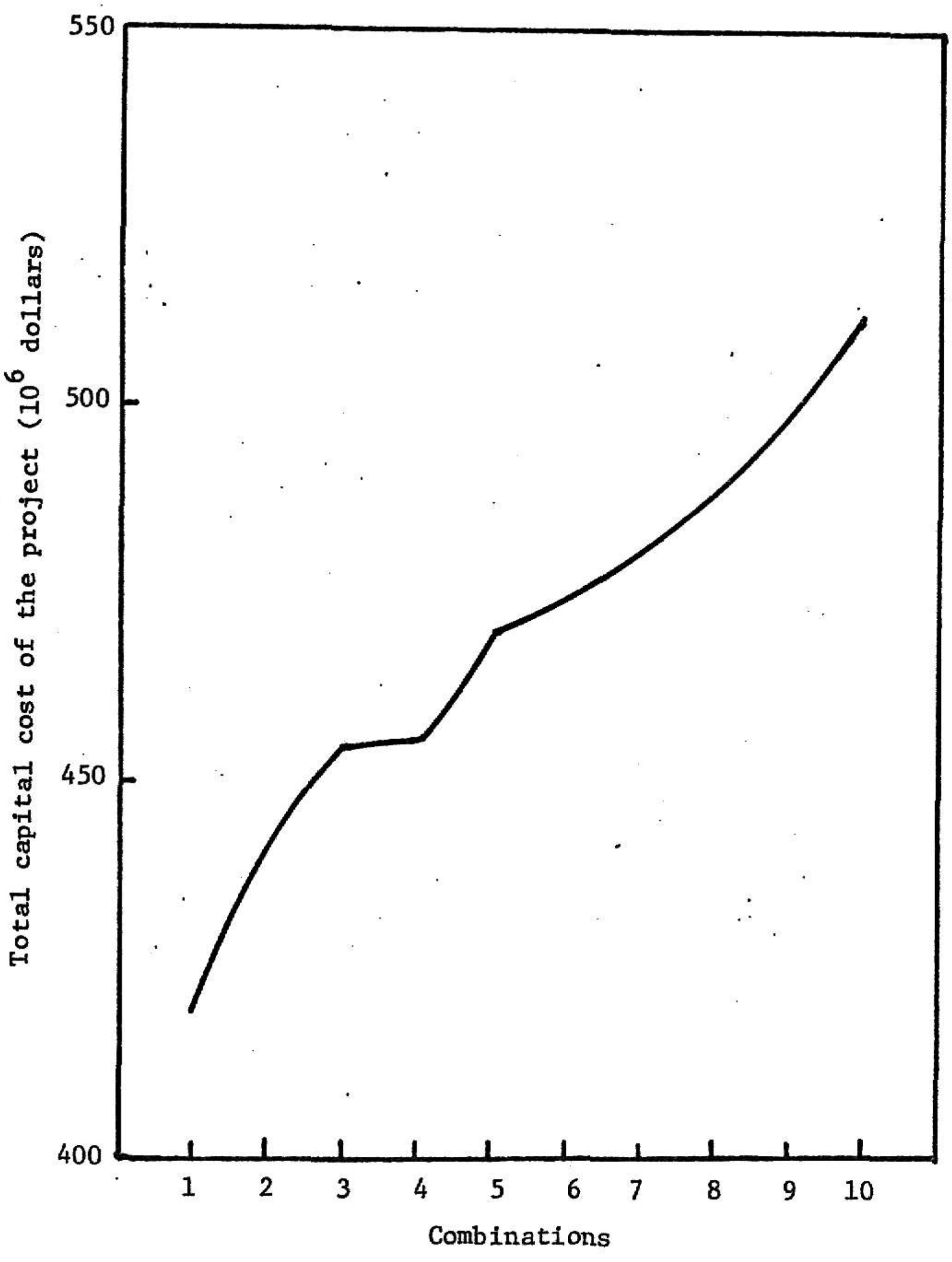


Fig. 5.1 Total capital cost of each combination

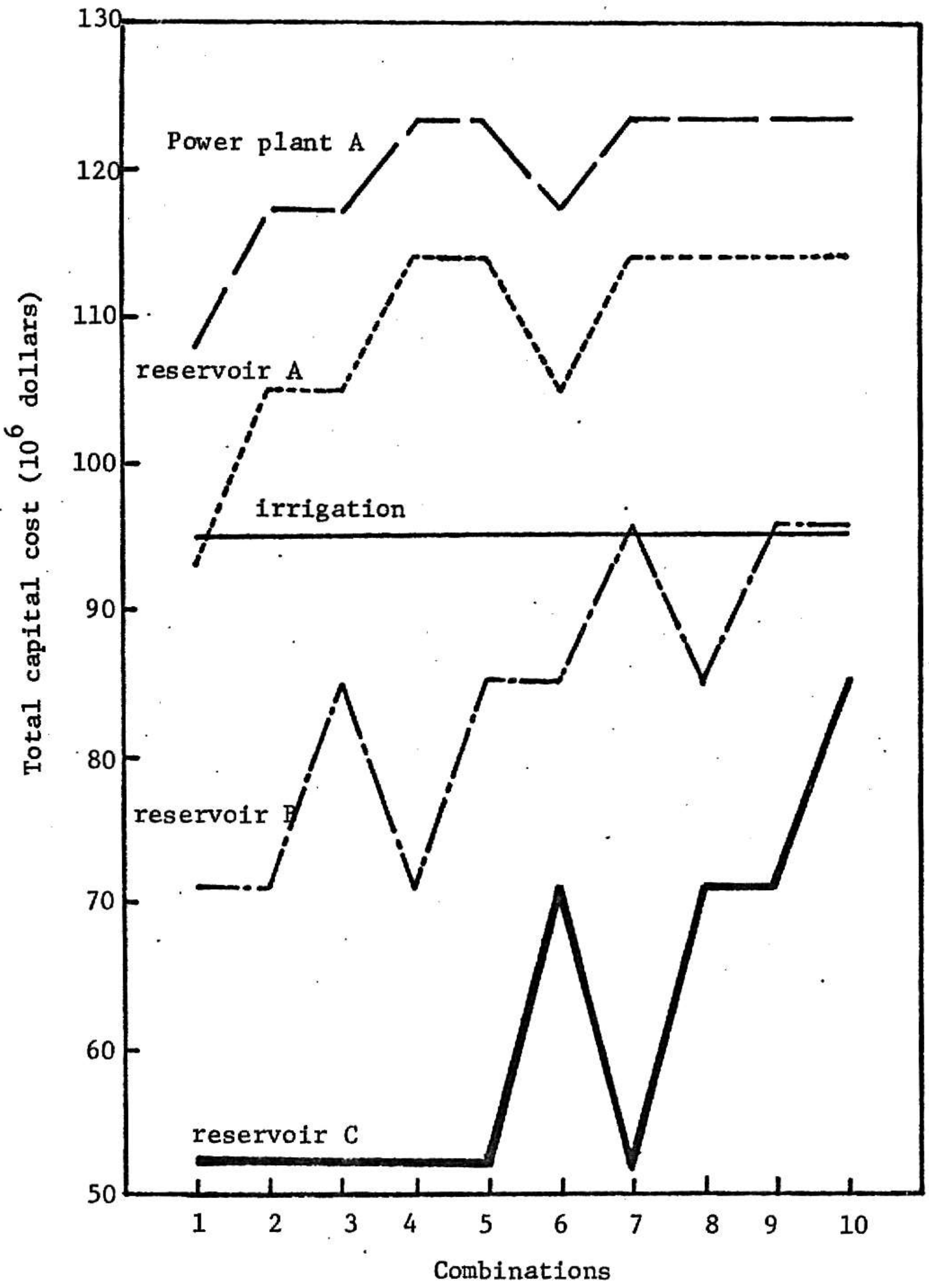


Fig. 5.2 Total capital cost of each element of the system in all combinations.

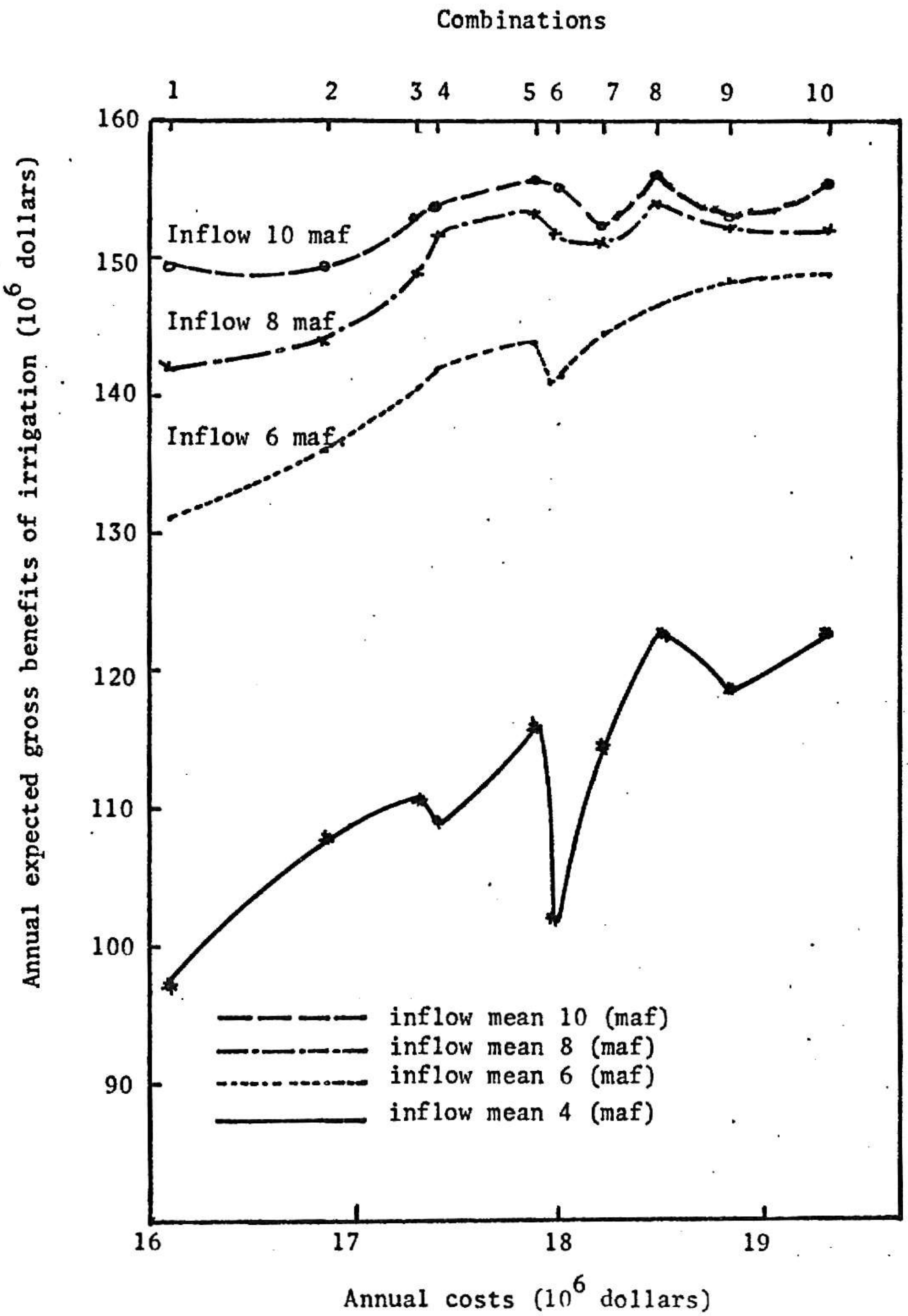


Fig. 5.3 Annual expected gross benefits of irrigation for all combinations at the four inflow means

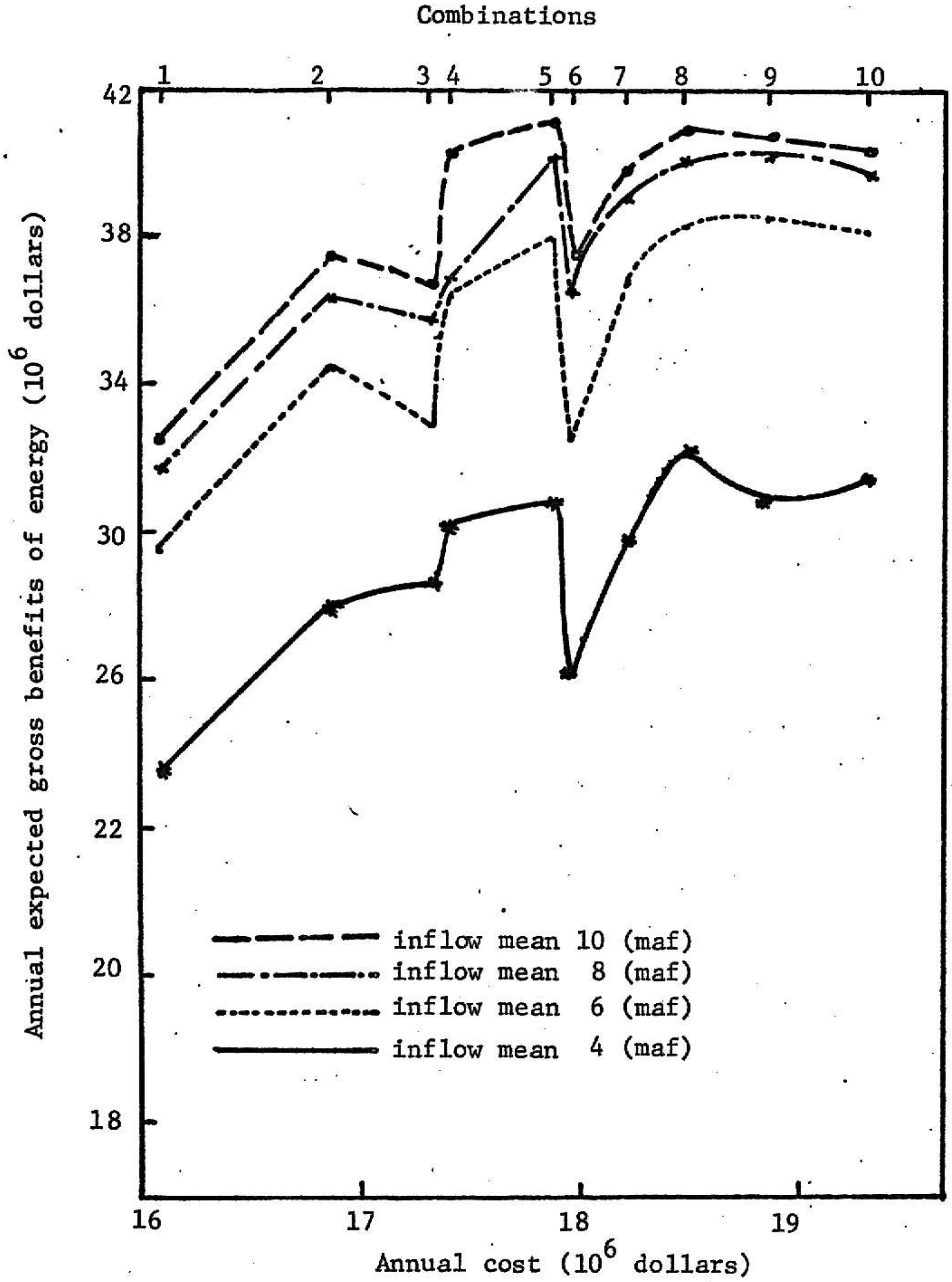


Fig. 5.4 Annual expected gross benefits of energy for all combinations at the four inflow means.

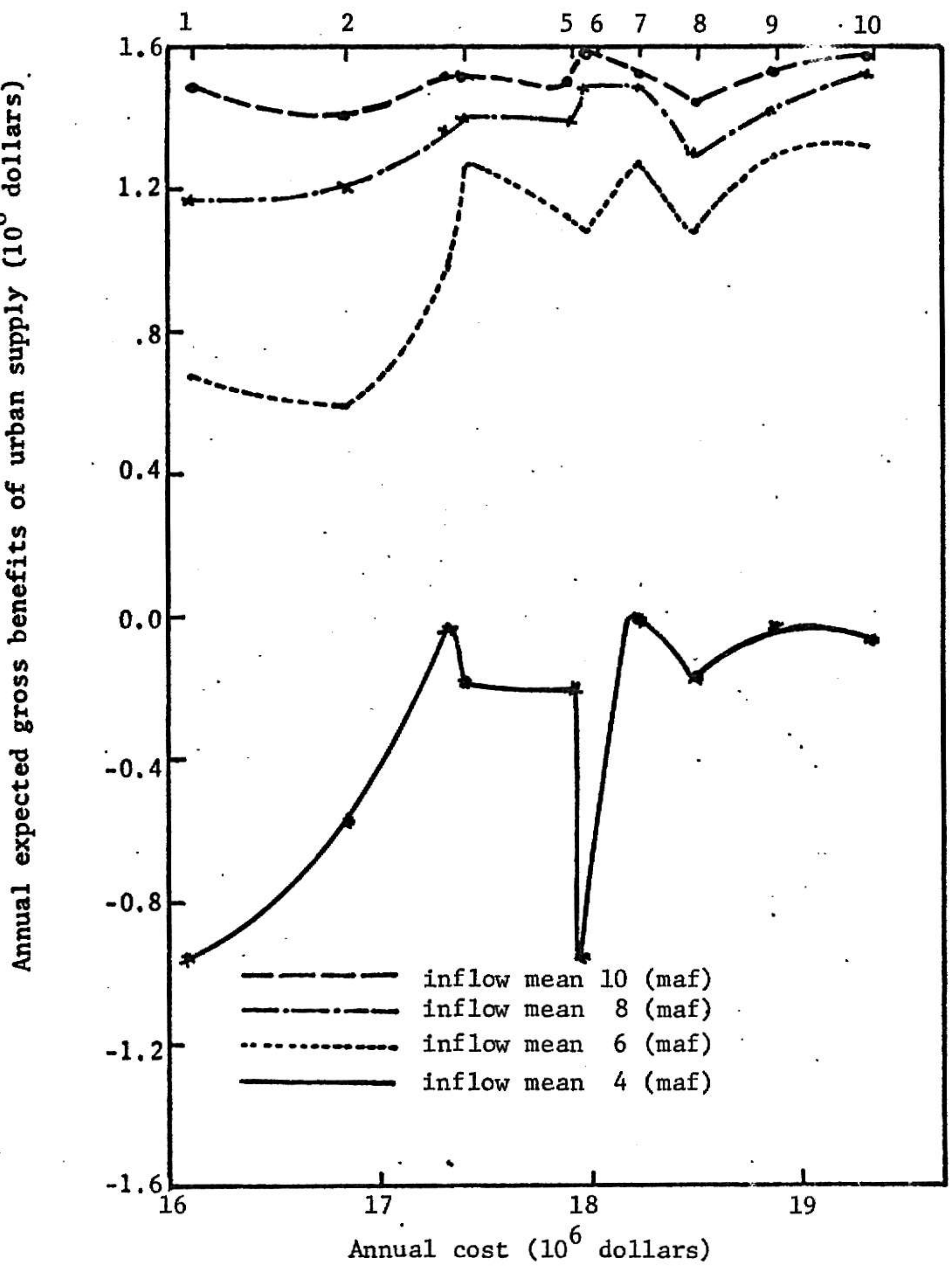


Fig. 5.5 Annual expected gross benefits of urban supply for all combinations at the four inflow means

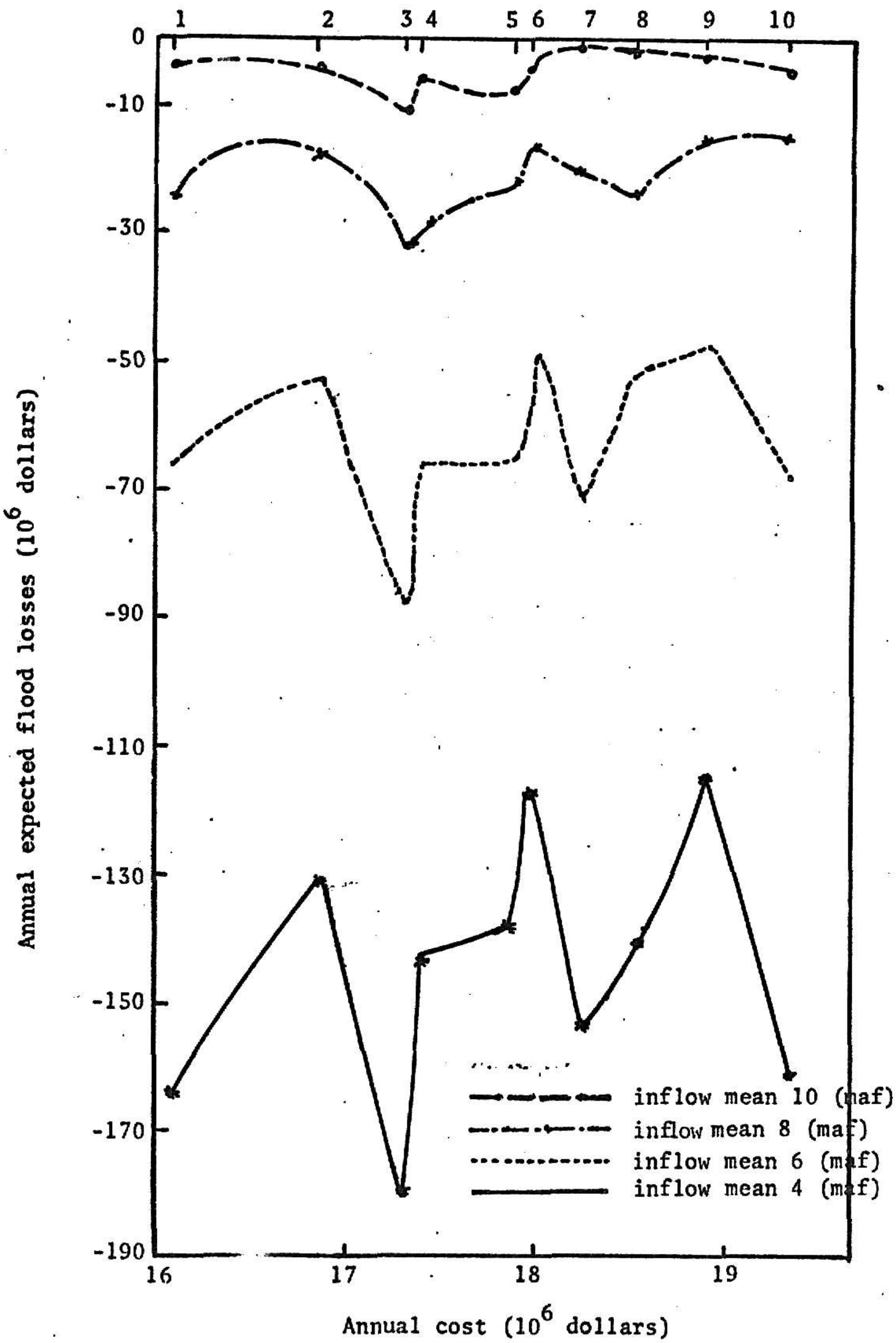


Fig. 5.6 Annual expected flood losses for all combinations at the four inflows.

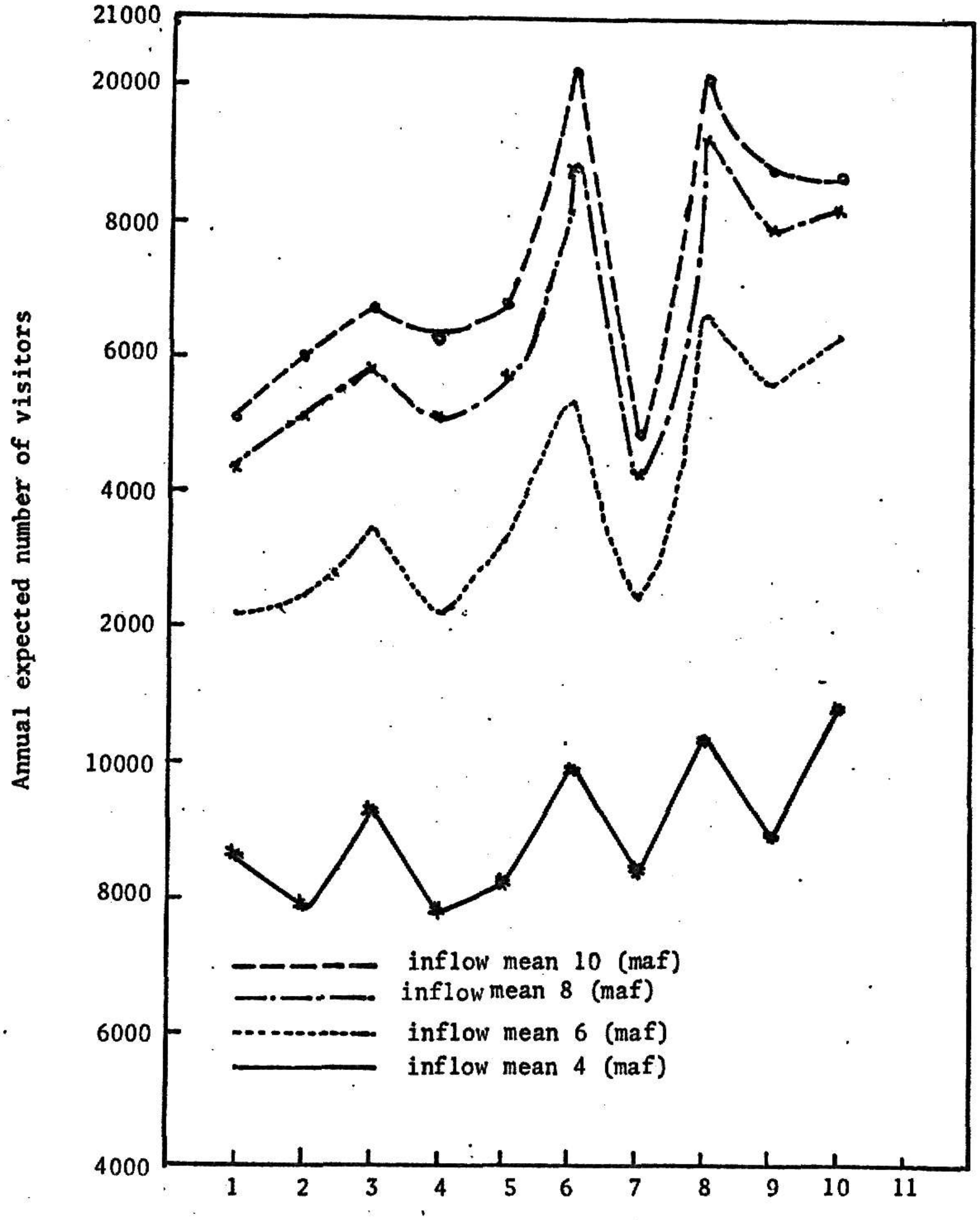


Fig. 5.7 Annual expected number of visitors of reservoirs B and C for all combinations at the four inflow means.

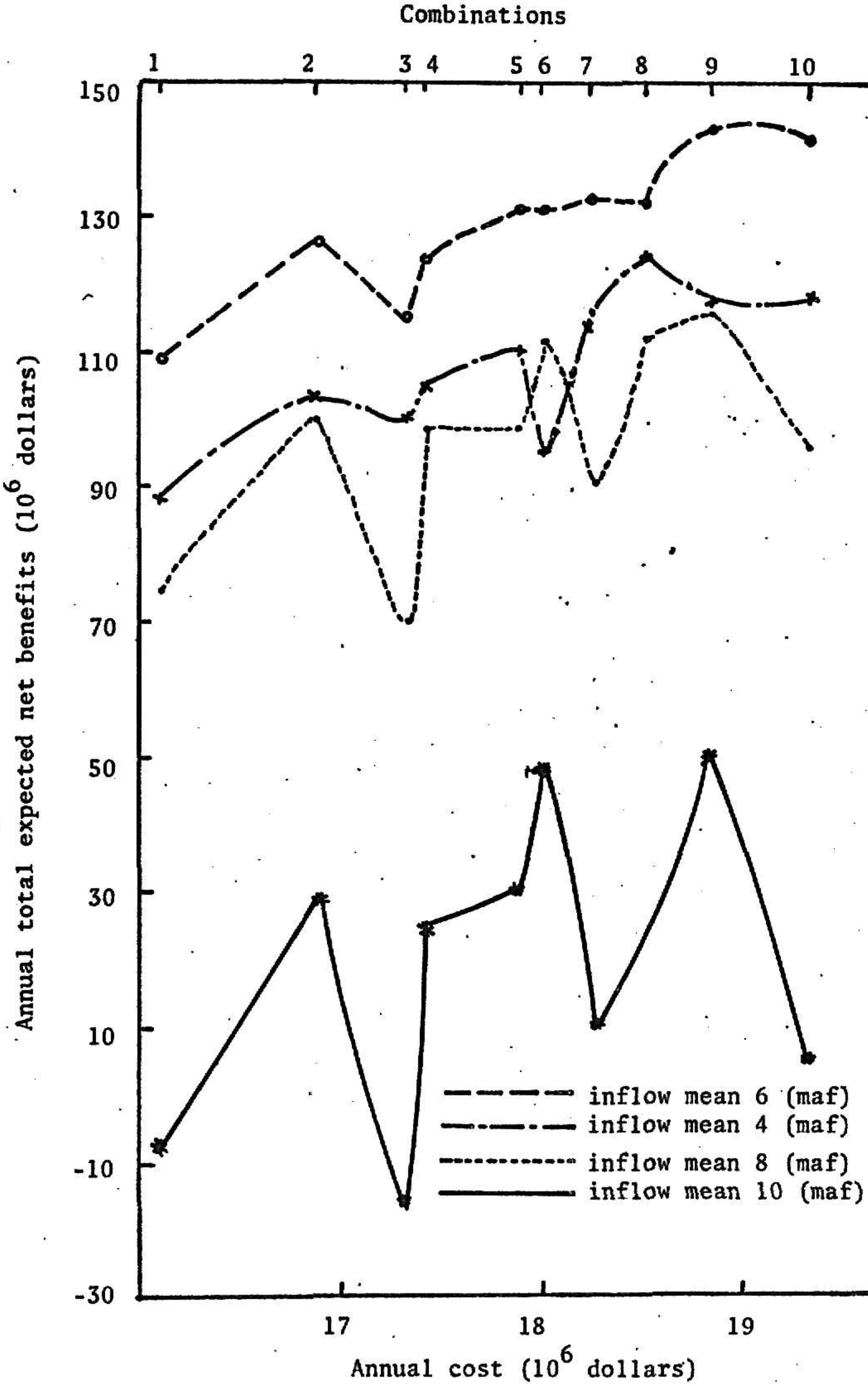


Fig. 5.8 Annual total expected net benefits for all combinations at the four inflow means

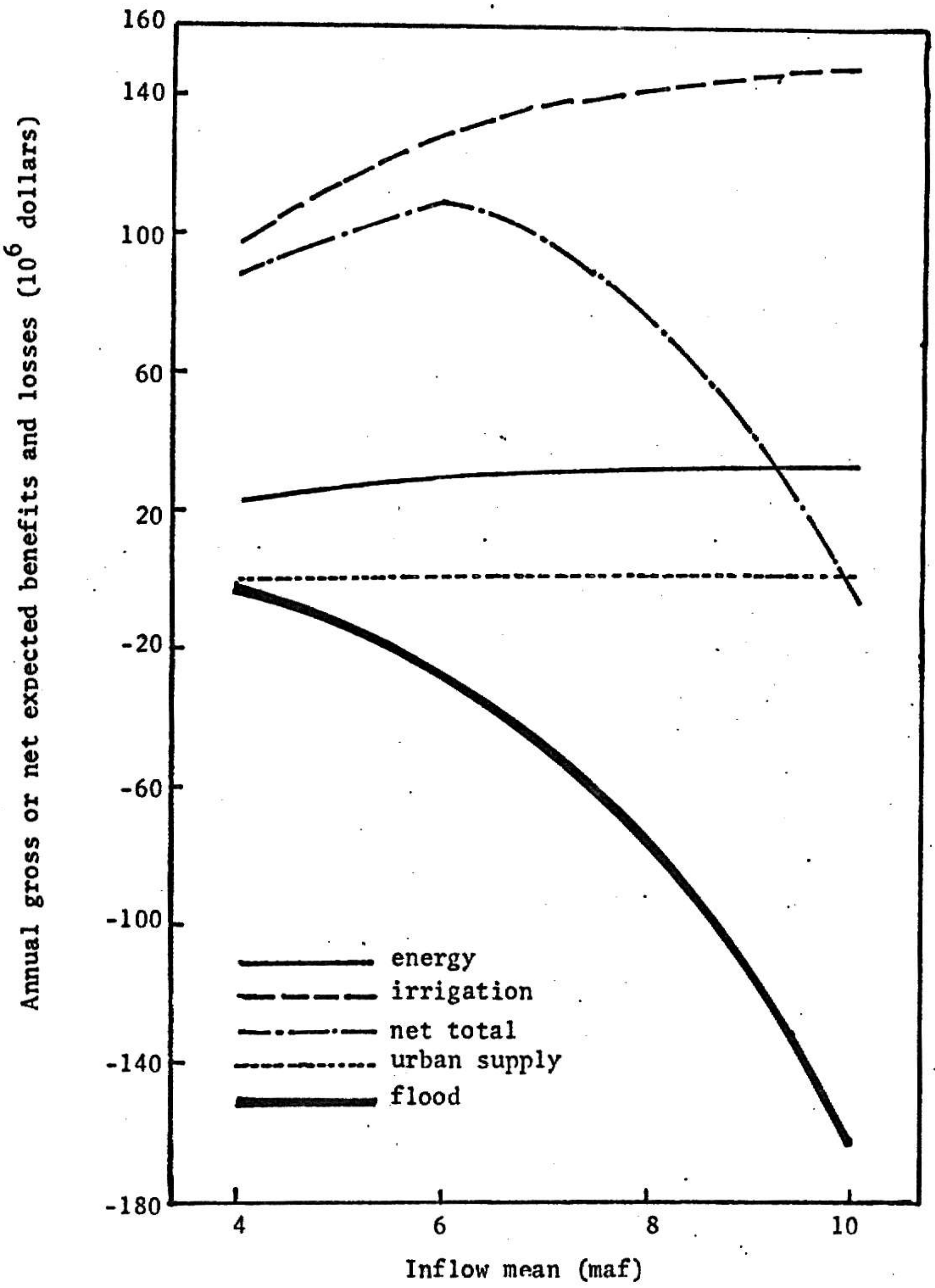
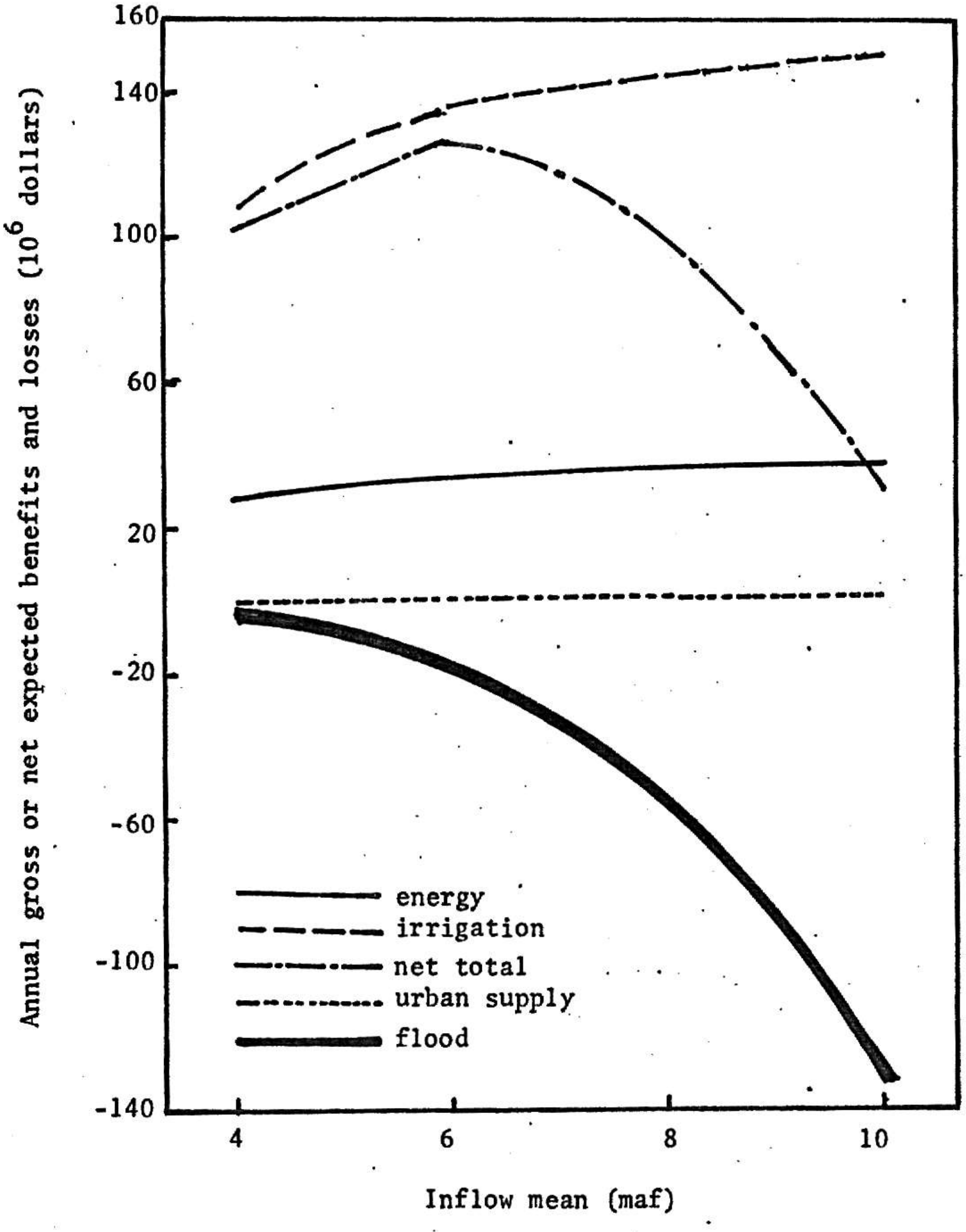


Fig. 5.9 Annual gross or net expected benefits and losses and inflow means for combination 1



'ig. 5.10 Annual gross or net expected benefits and losses and inflow means for combination 2.

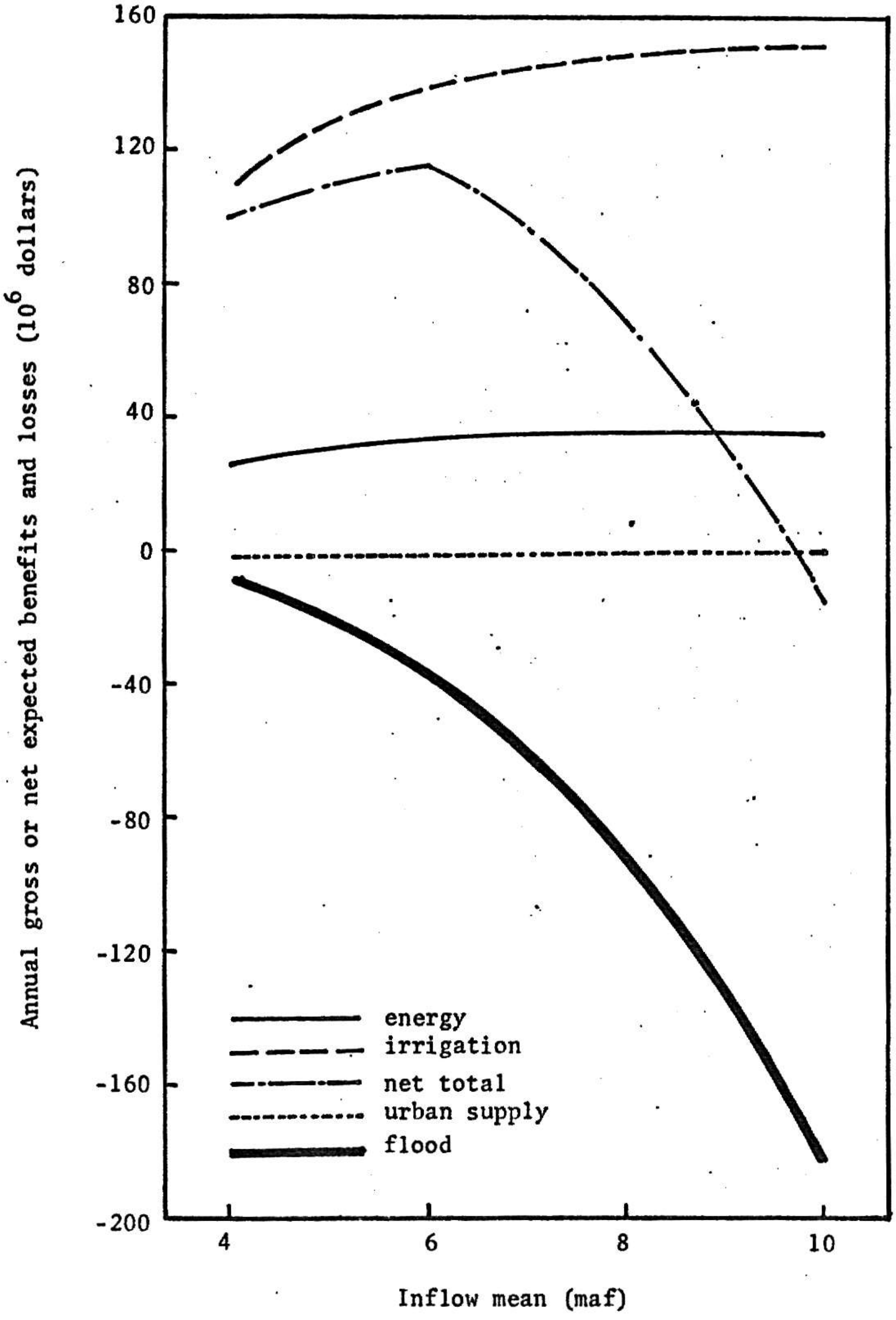


Fig. 5.11 Annual gross or net expected benefits and losses and inflow means for combination 3.

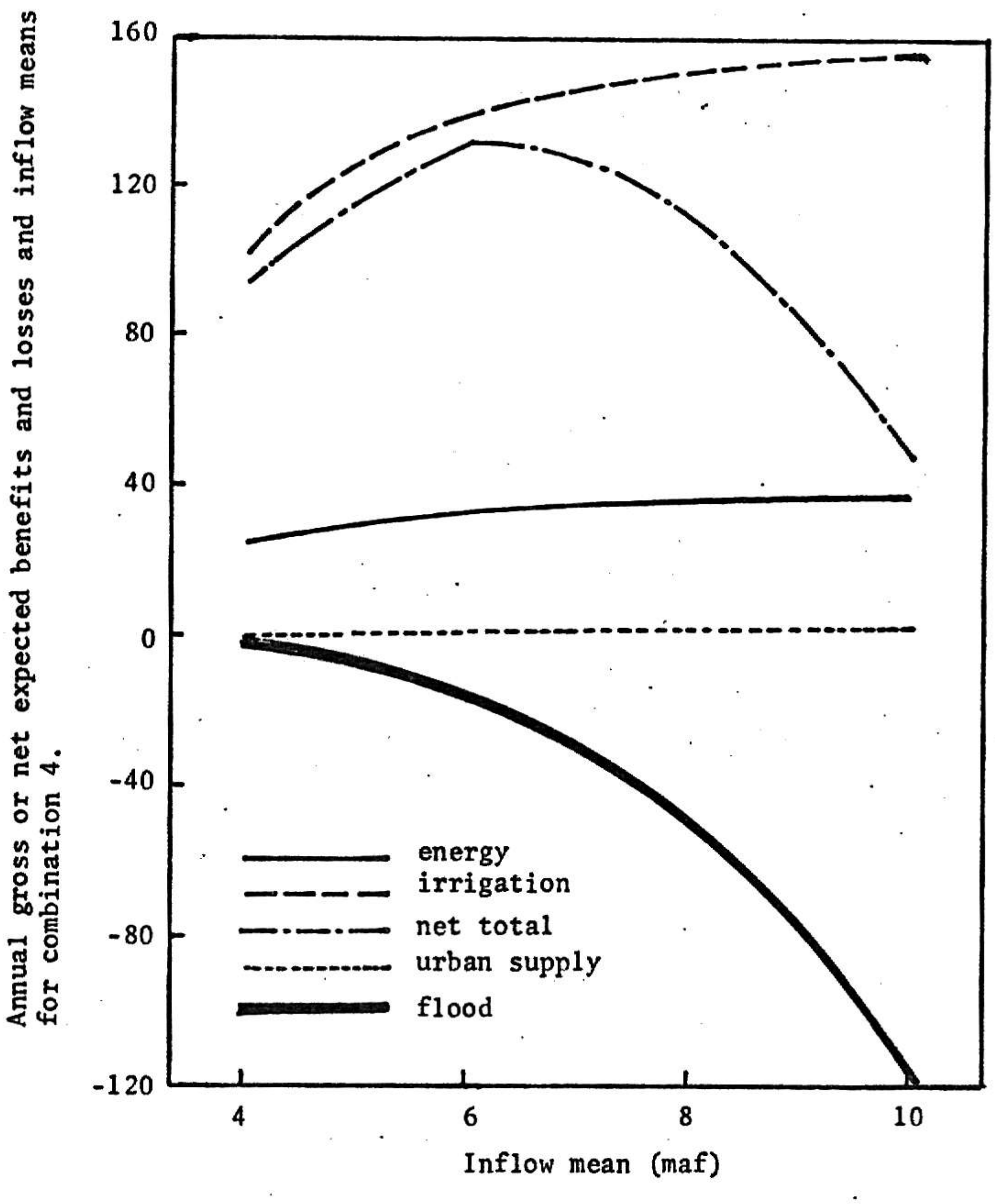


Fig. 5.12 Annual gross or net expected benefits and losses and inflow means for combination 4.

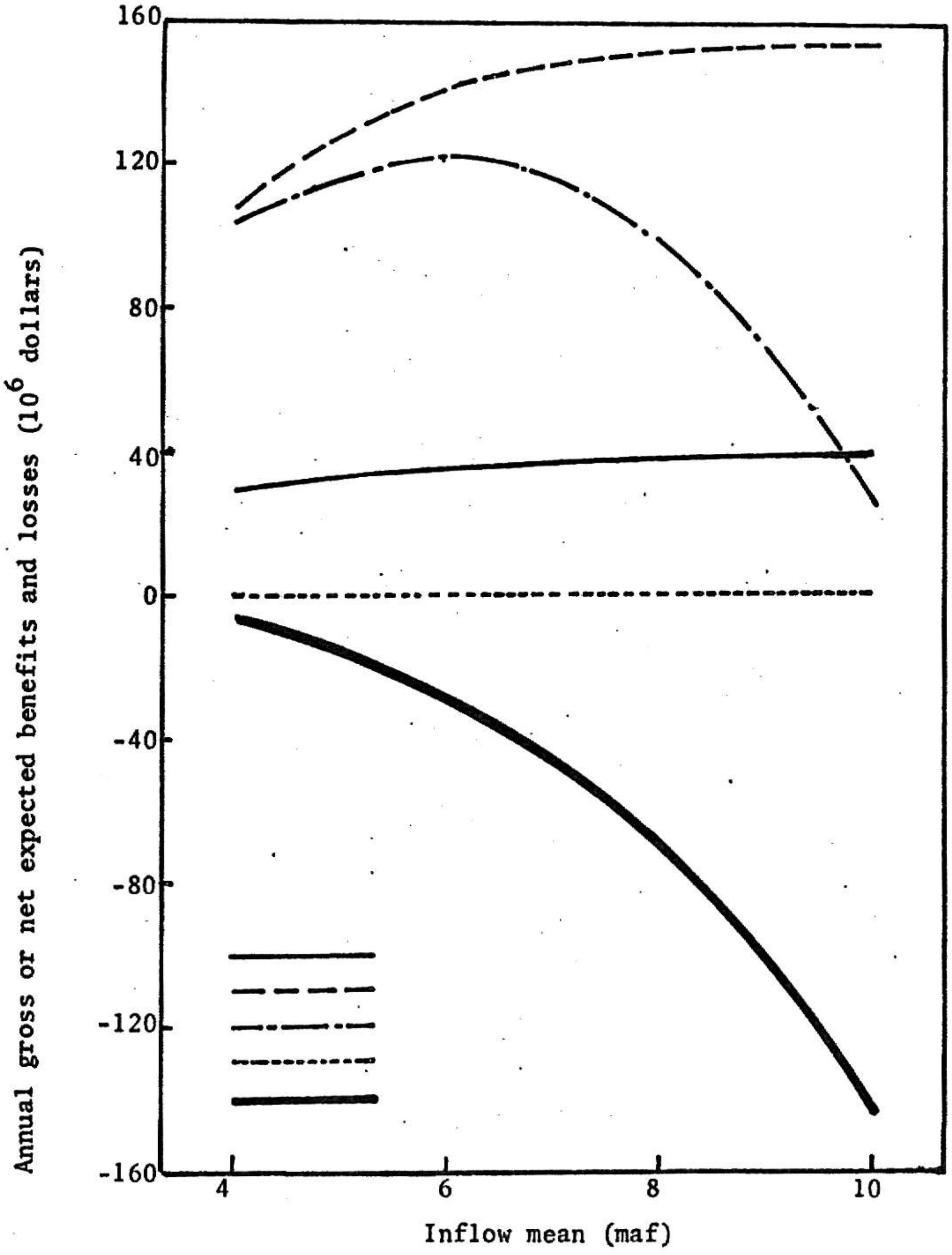


Fig. 5.13. Annual gross or net expected benefits and losses and inflow means for combination 5.

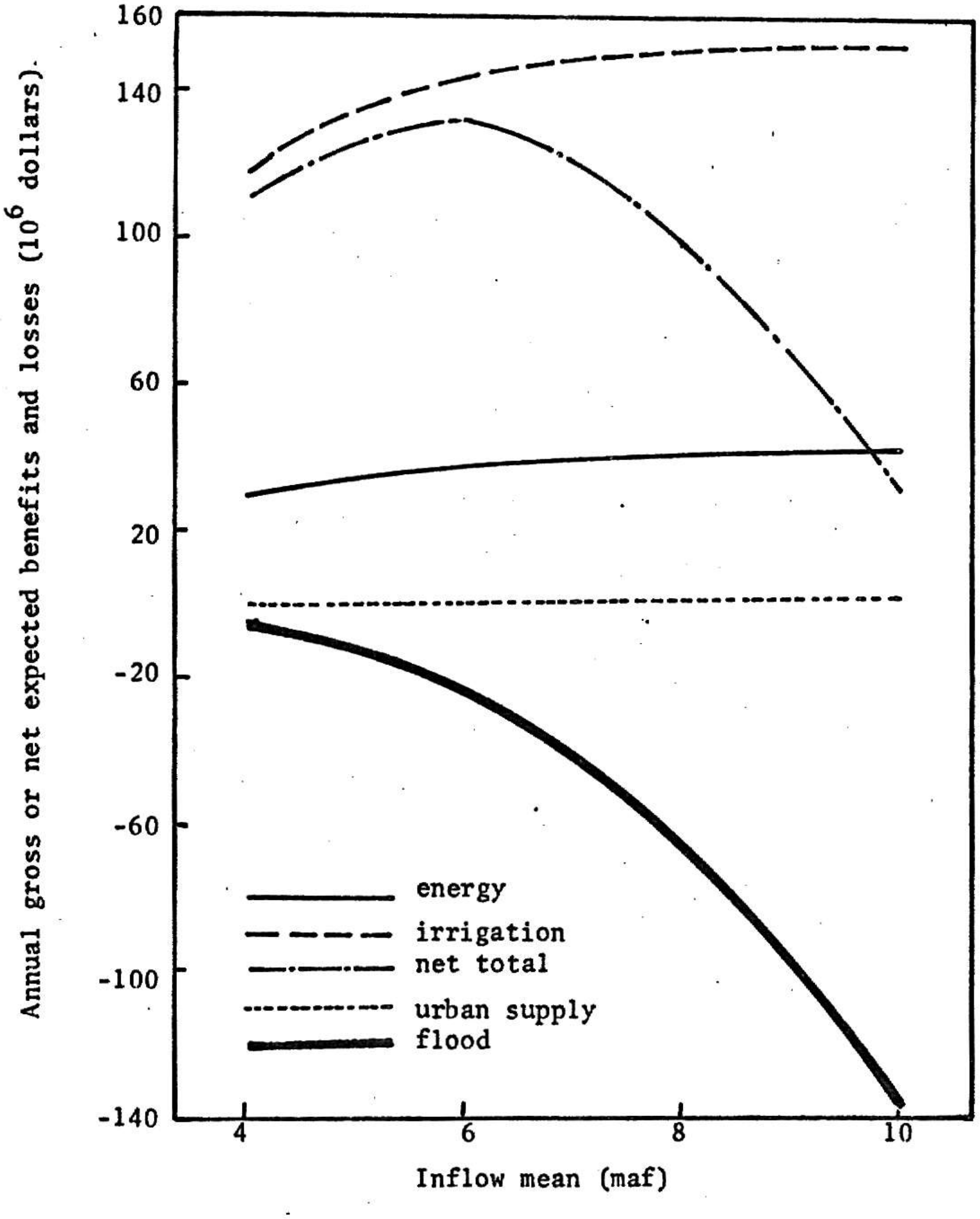


Fig. 5.14. Annual gross or net expected benefits and losses and inflow means for combination 6.

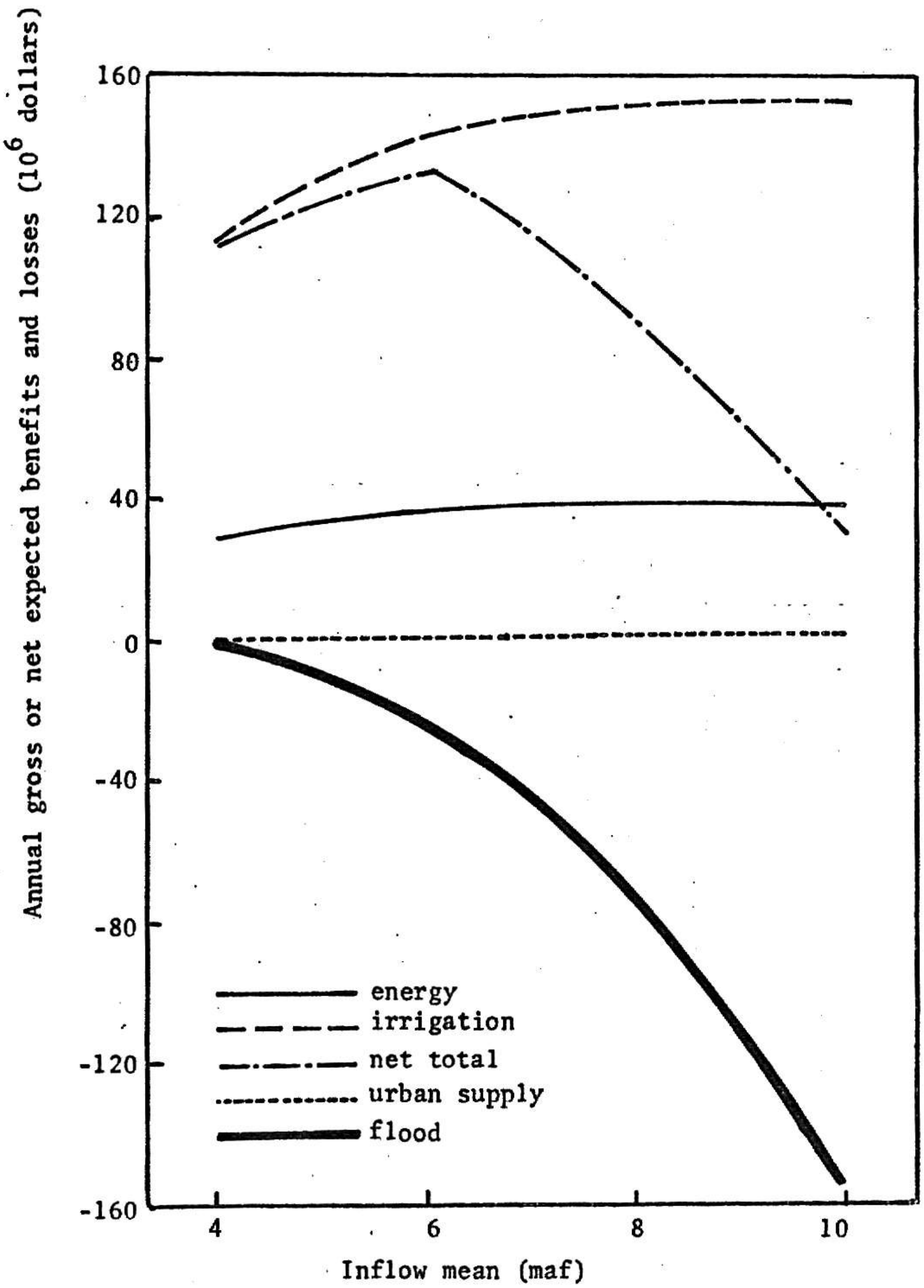


Fig. 5.15 Annual gross or net expected benefits and losses and inflow means for combination 7.

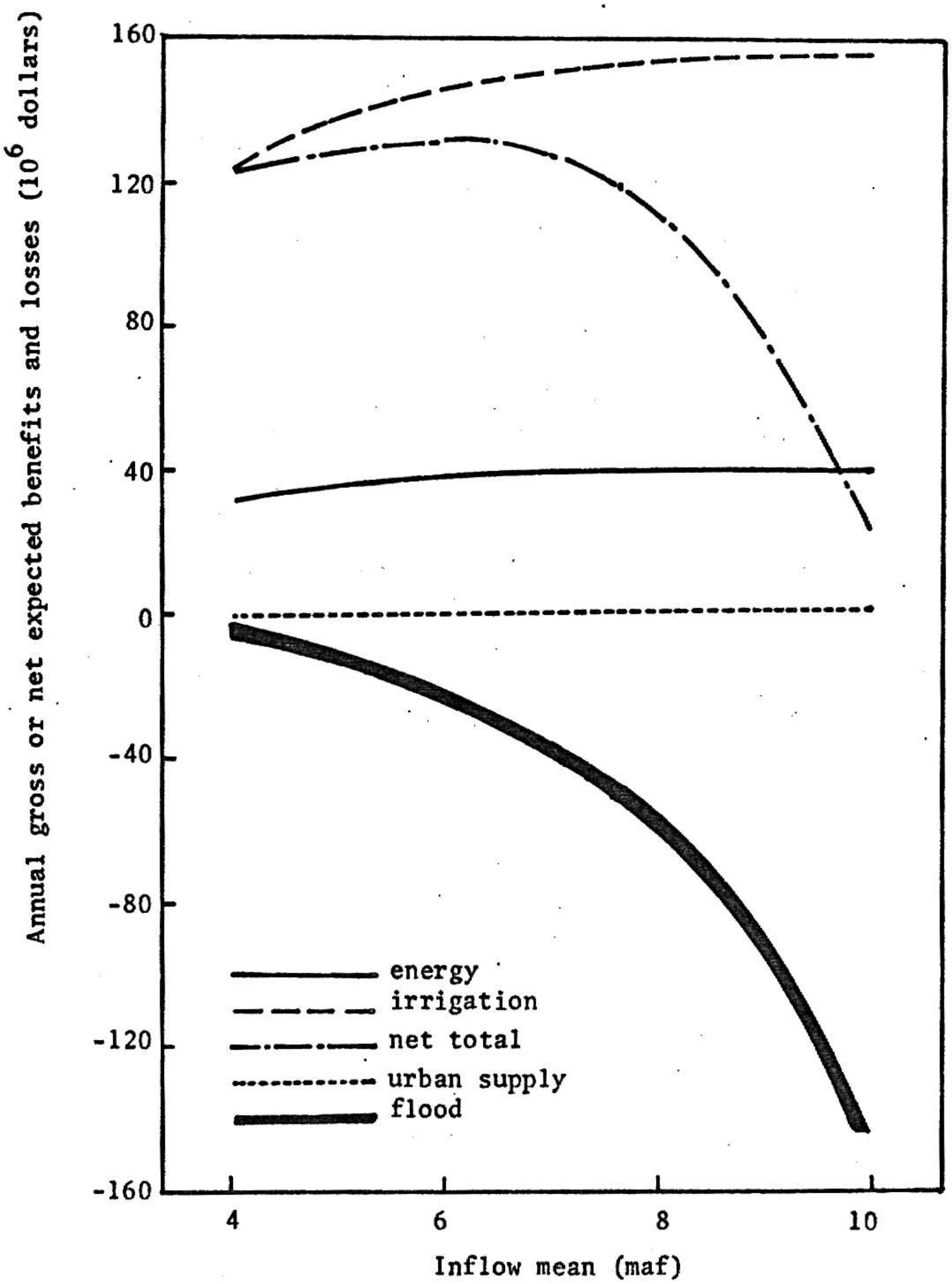


Fig. 5.16 Annual gross or net expected benefits and losses and inflow means for combination 8

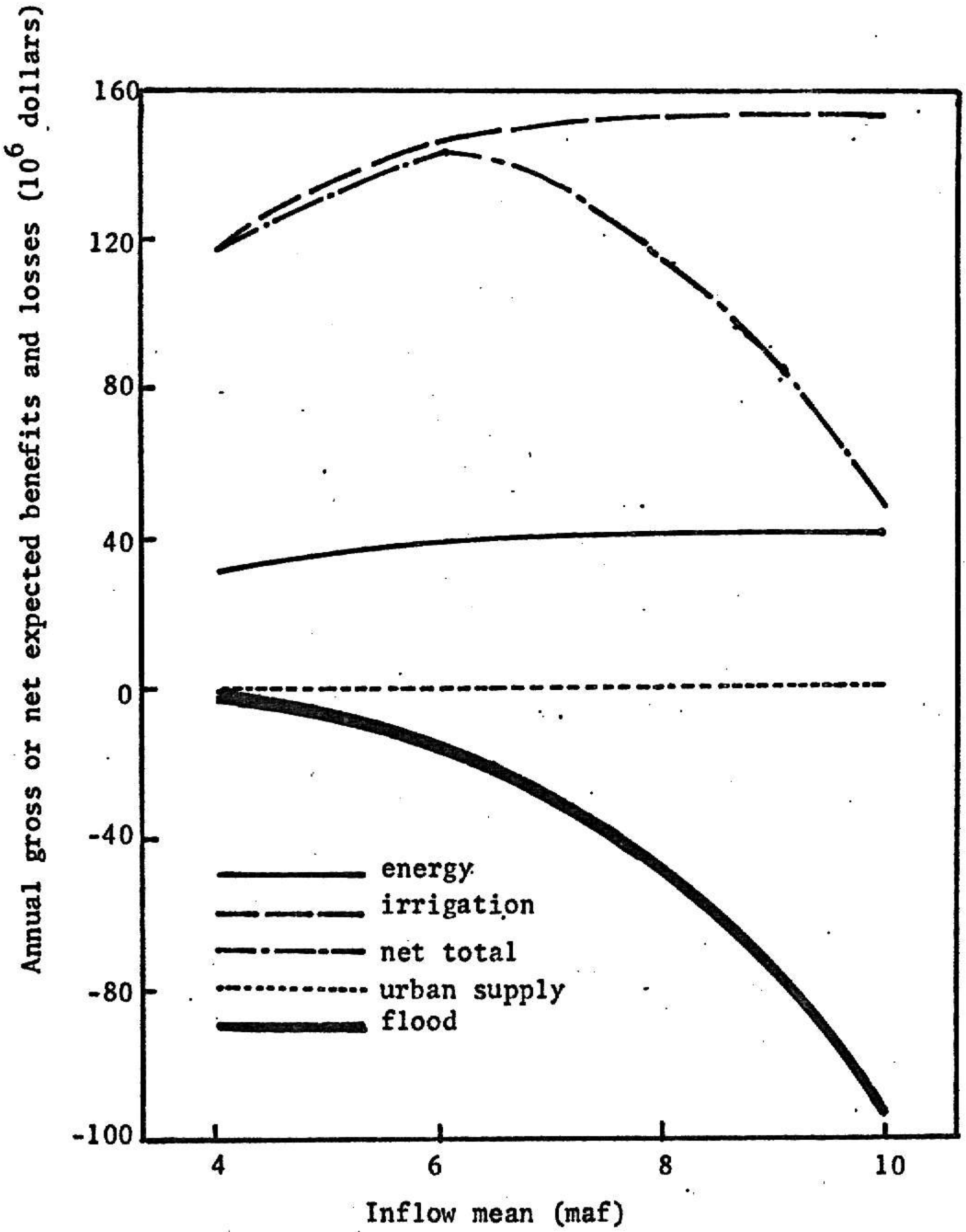


Fig. 5.17 Annual gross or net expected benefits and losses and the inflow means for combination 9

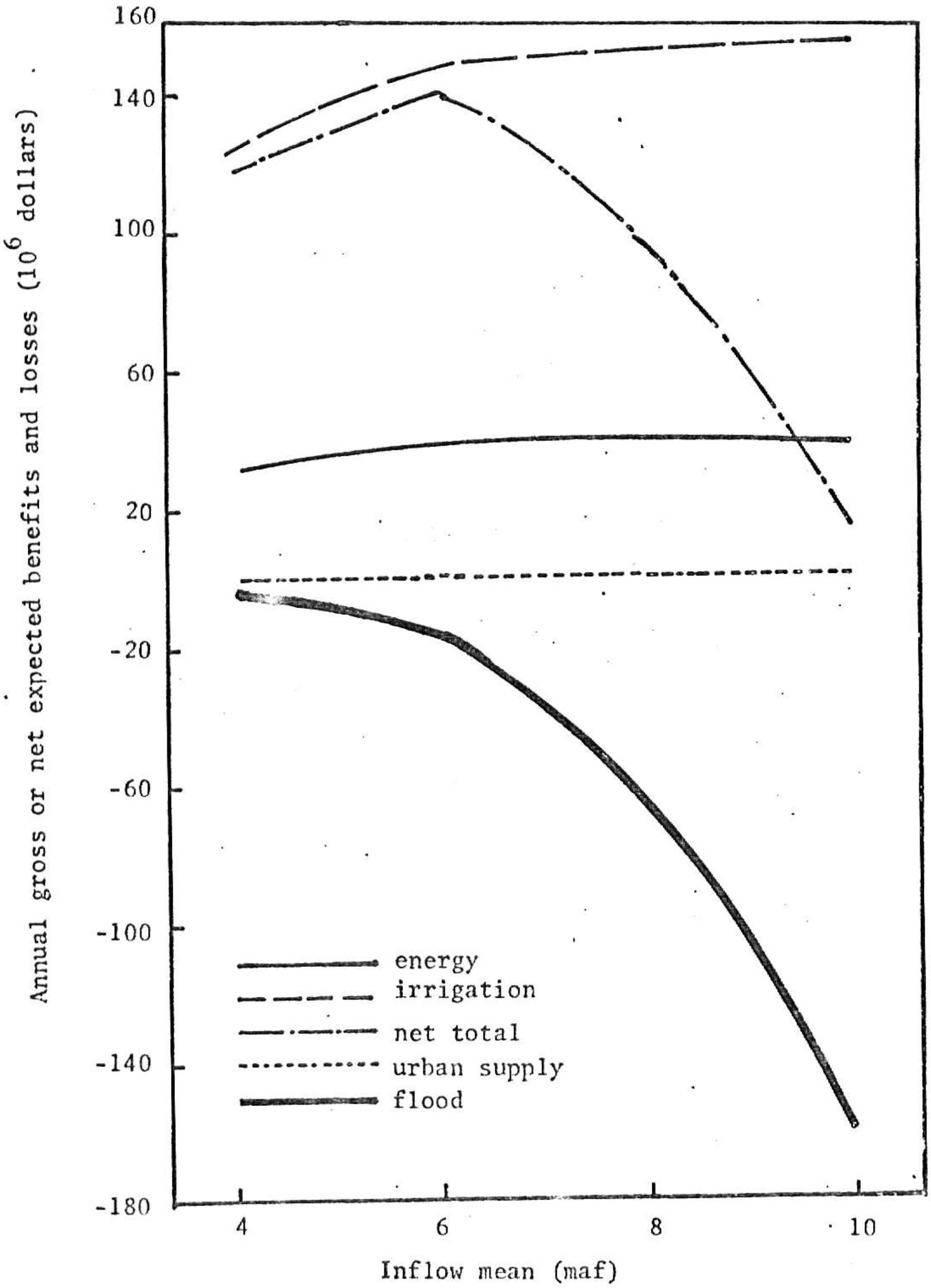


Fig. 5.18 Annual gross or net expected benefits and losses 4 and the inflow means for combination 10.

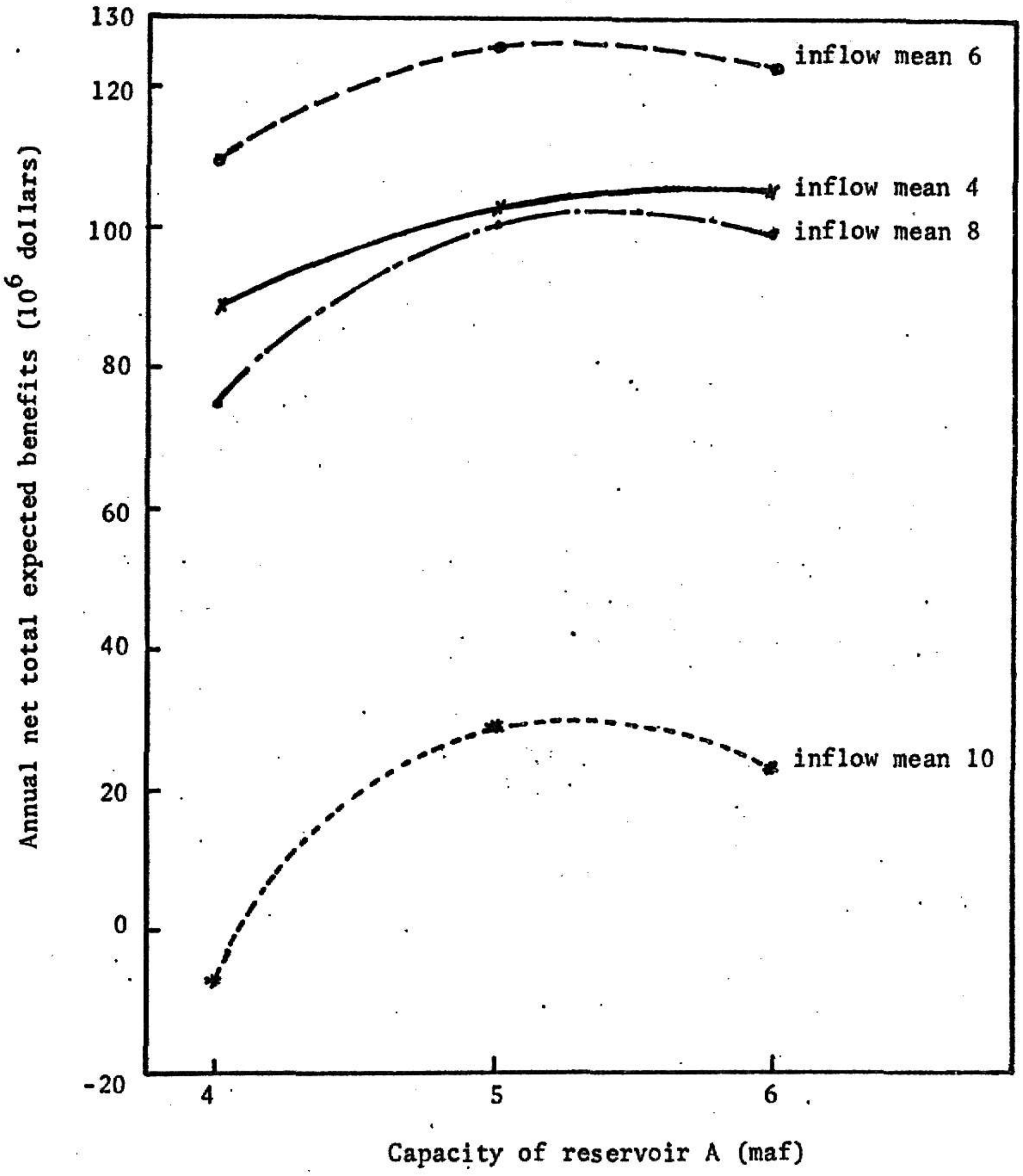


Fig. 5.19 Annual net total expected benefits versus capacity of reservoir A

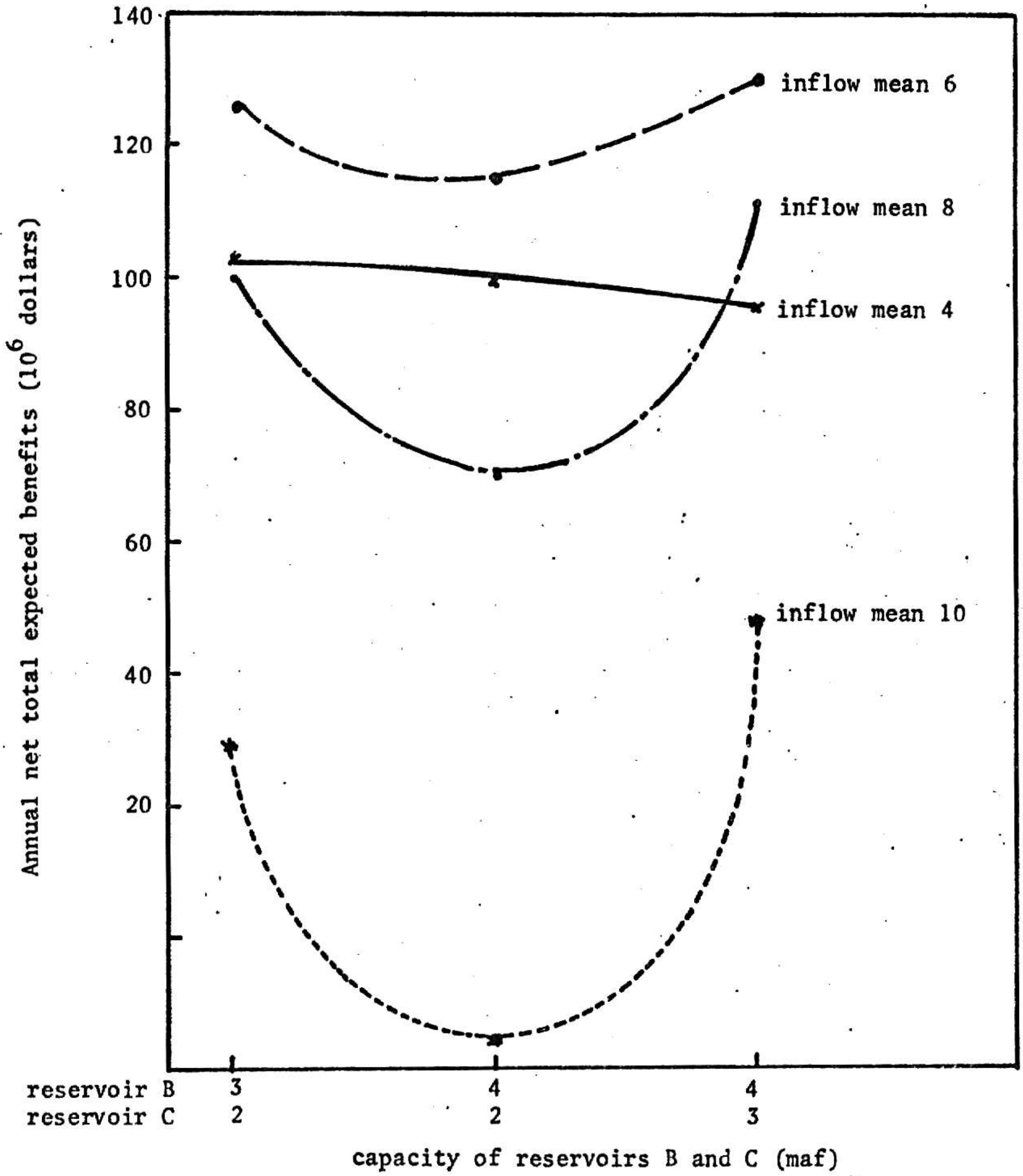


Fig. 5.20 Annual net total expected benefits versus capacities of reservoirs B and C.

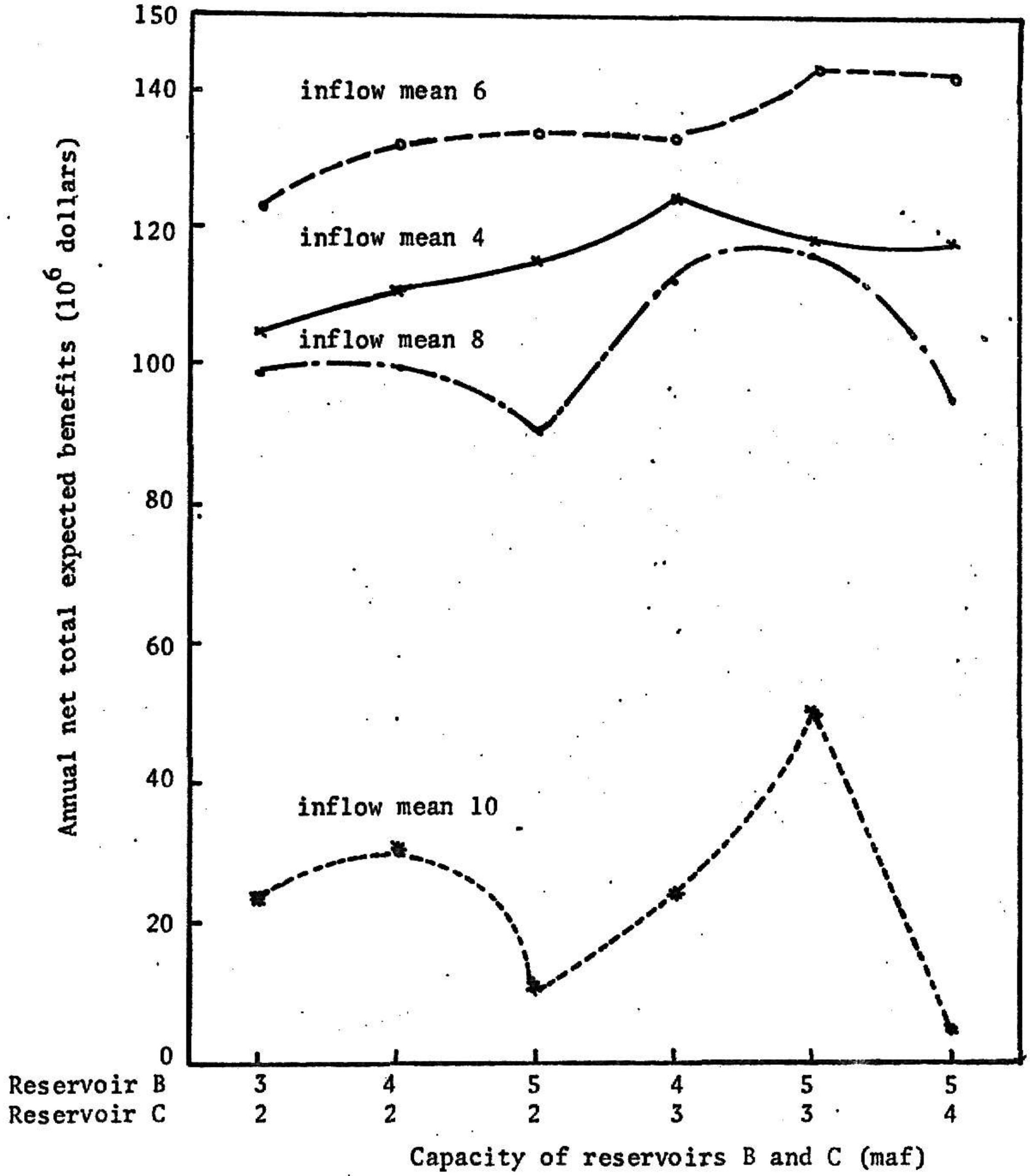


Fig. 5.21 Annual net total expected benefits versus capacities of reservoirs B and C.

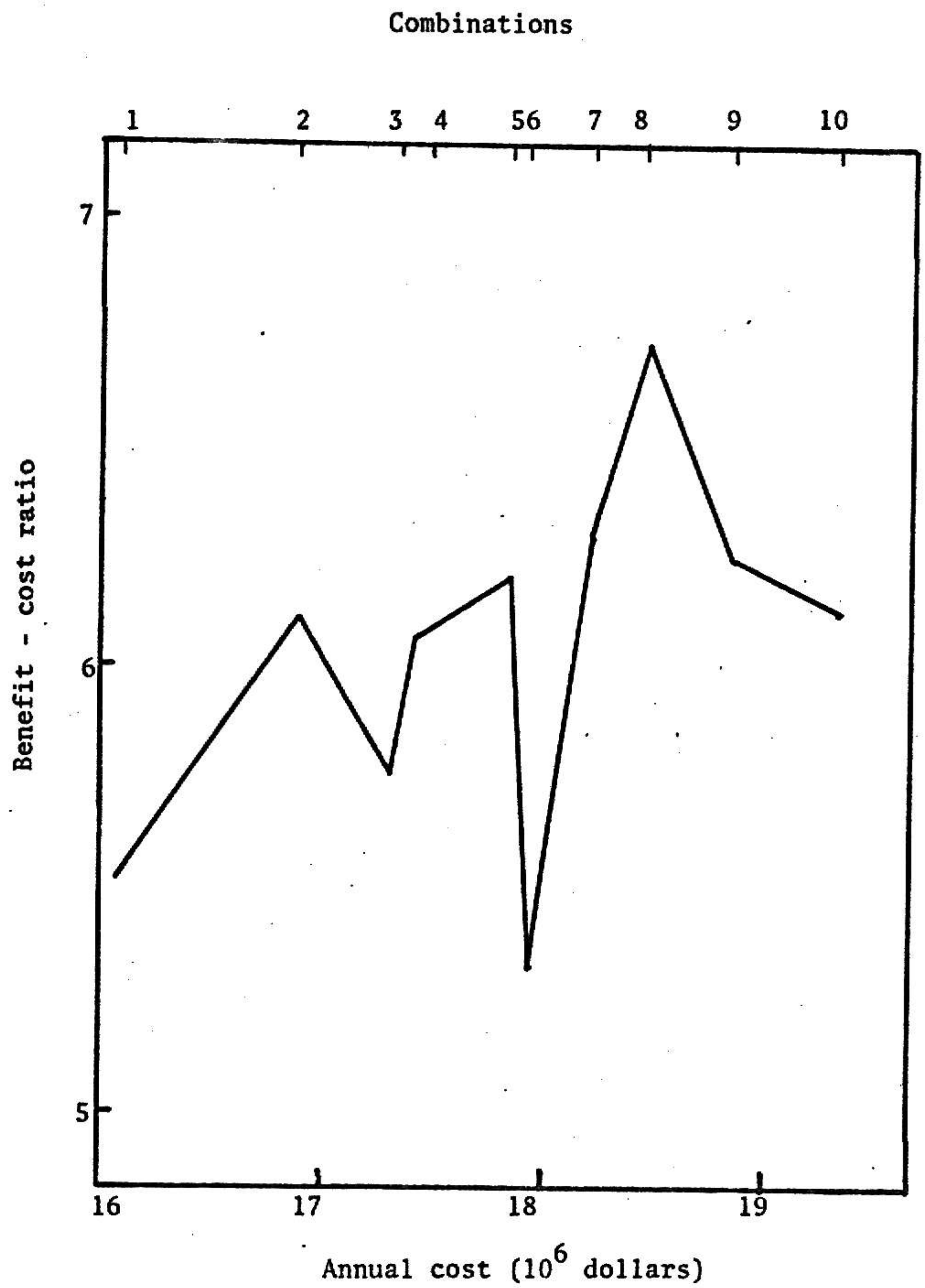


Fig. 5.22 Benefit - cost ratio and annual cost for all combinations at inflow mean 4 (maf).

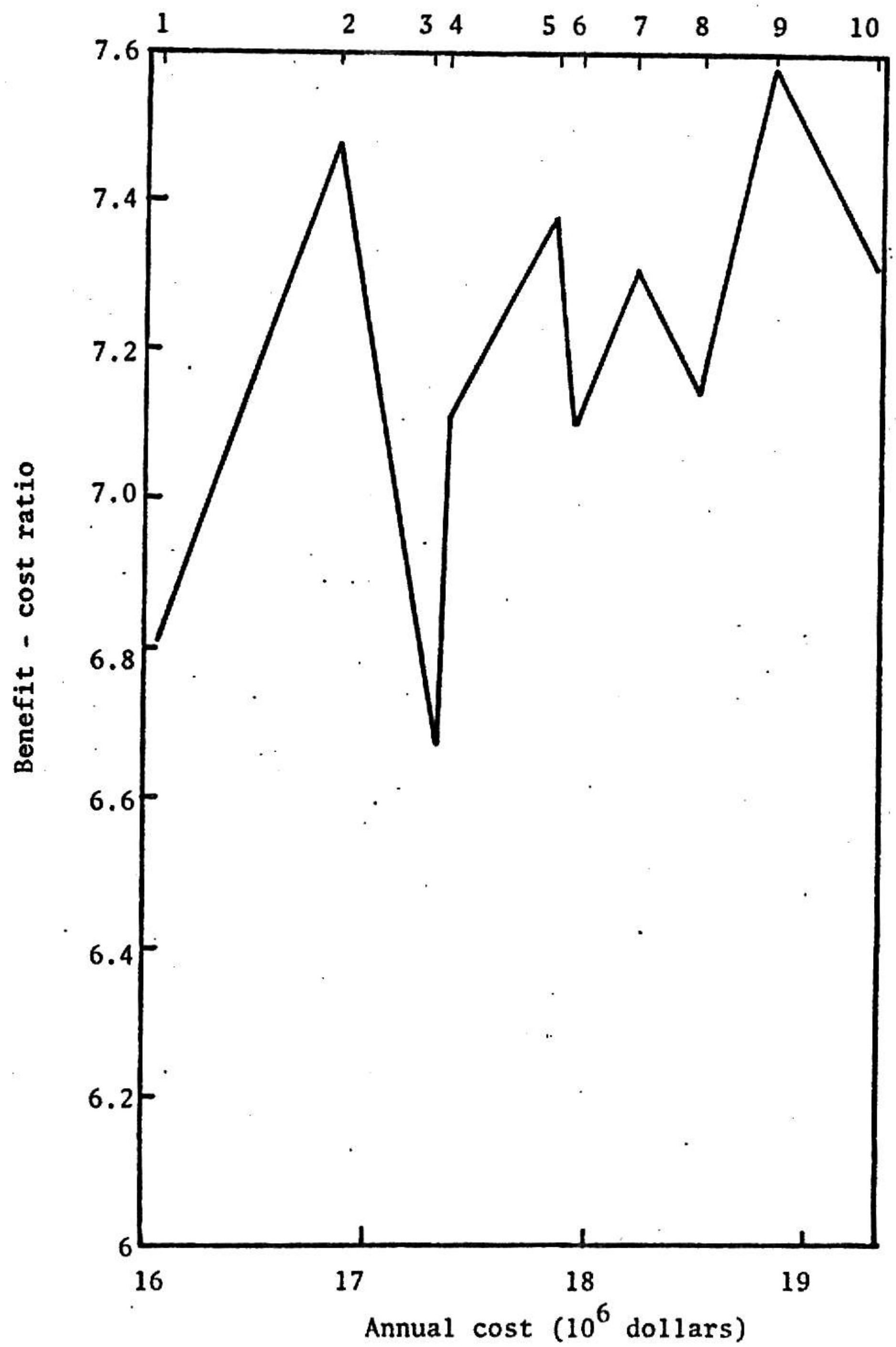


Fig. 5.23 Benefit - cost ratio and annual cost for all combinations at inflow mean 6 (maf).

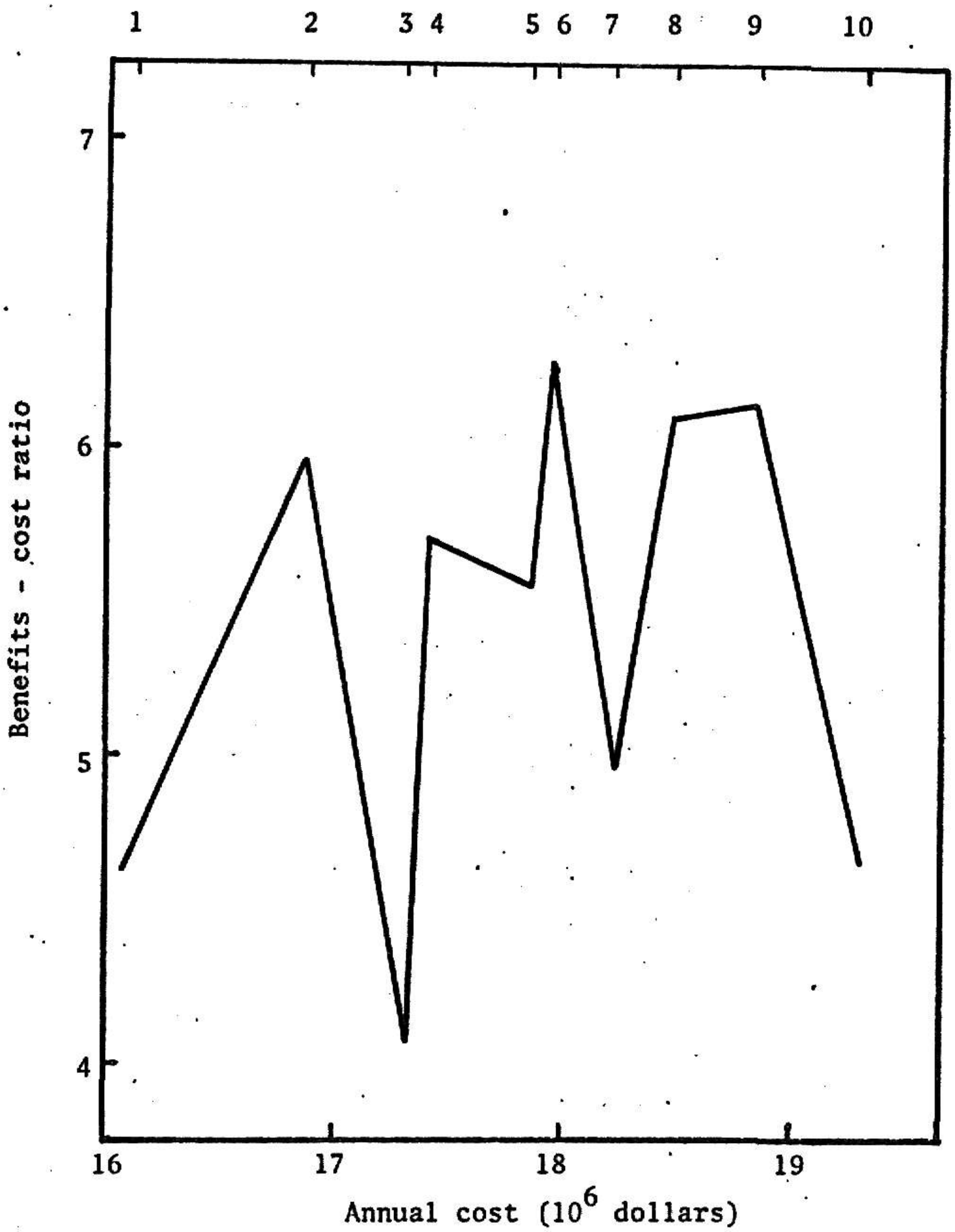


Fig. 5.24 Benefit - cost ratio and annual cost for all combinations at inflow mean 8 (maf).

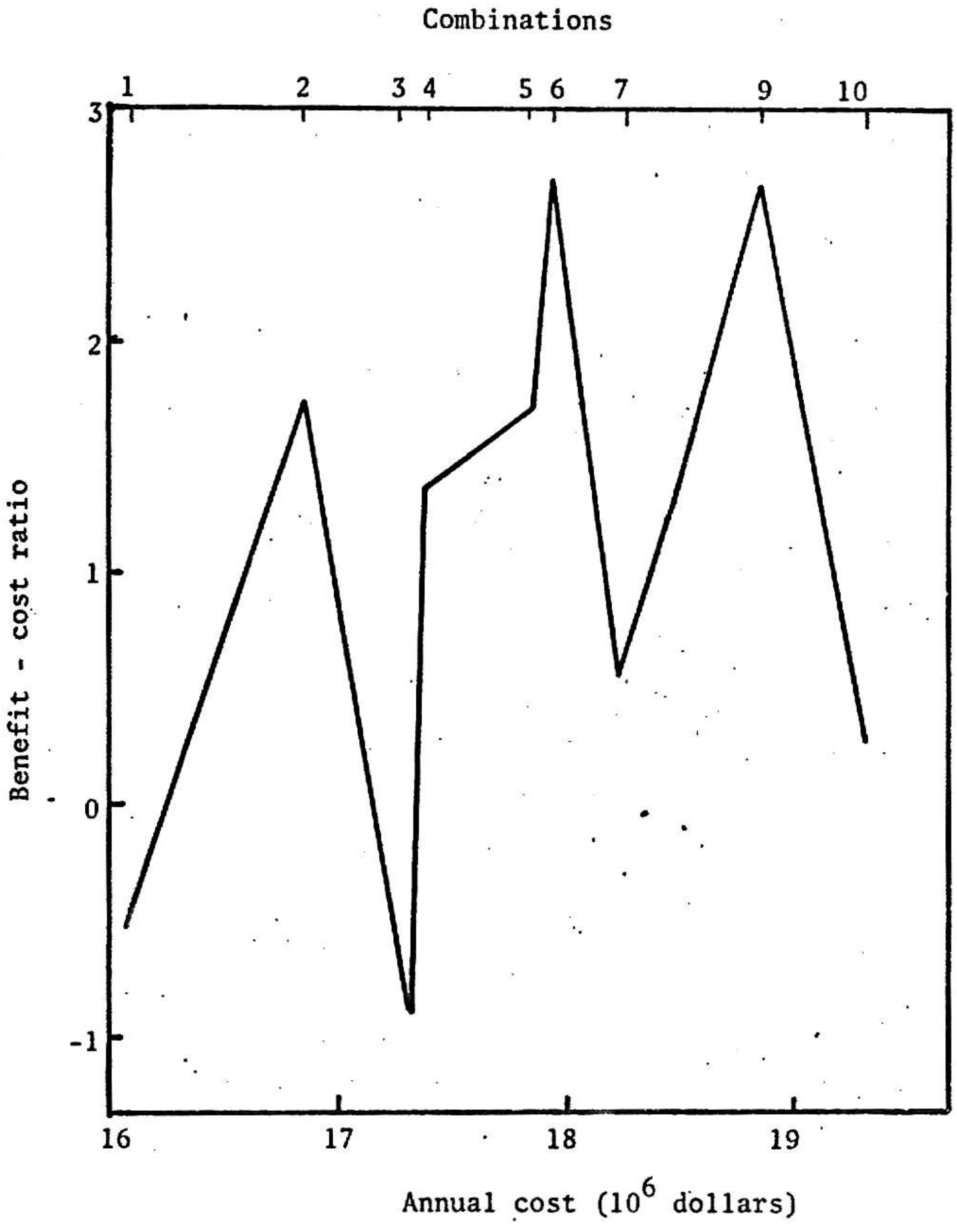


Fig. 5.25 Benefit - cost ratio and annual cost for all combinations at inflow mean 10 (maf).

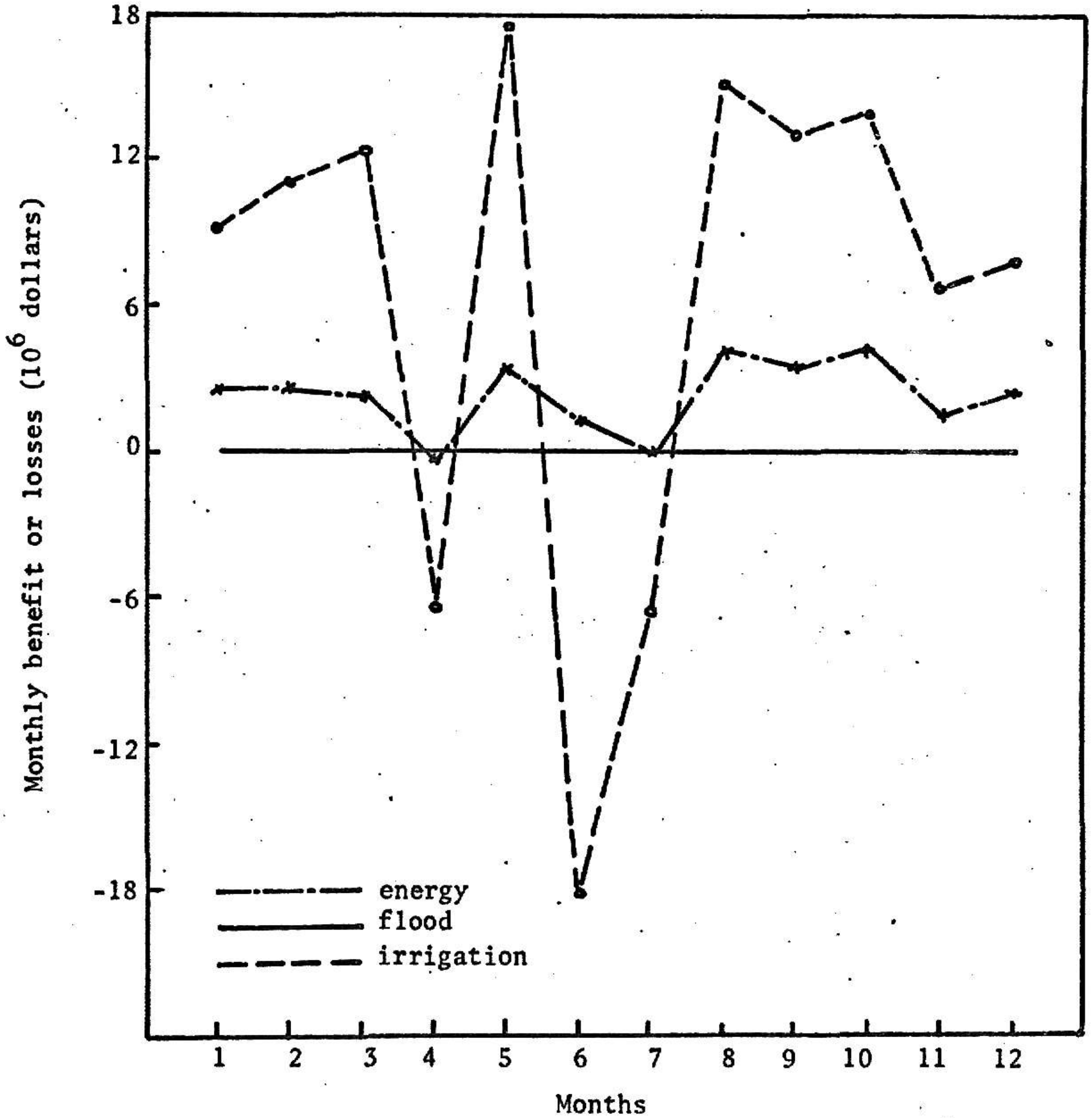


Fig. 5.26 Monthly benefits of irrigation and, power and flood losses for combination 8 at inflow mean 4 (maf) over the 22nd year.

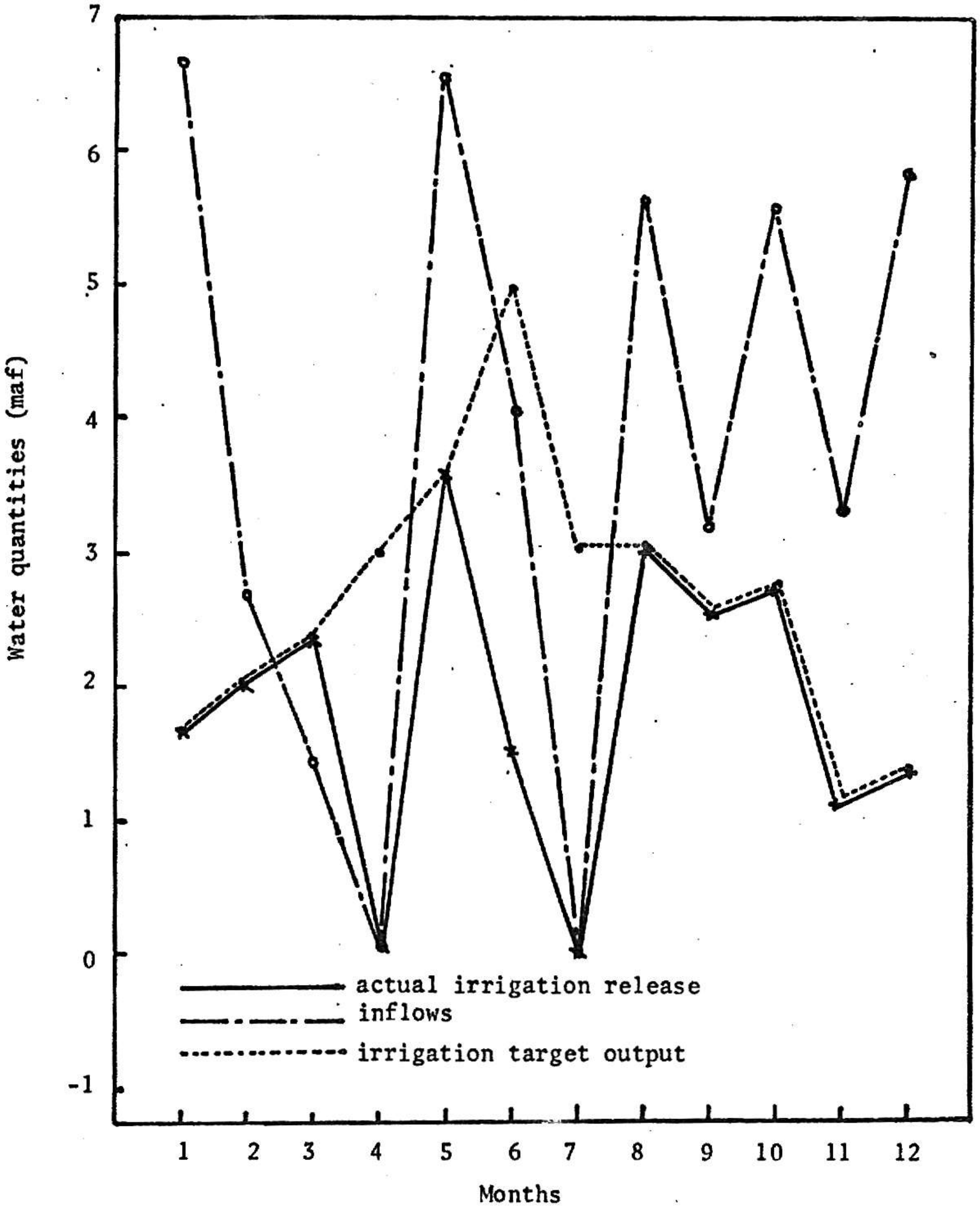


Fig. 5.27 Inflows, actual irrigation release and its target output for combination 8 at inflow mean 4 (maf) over the 22nd year.

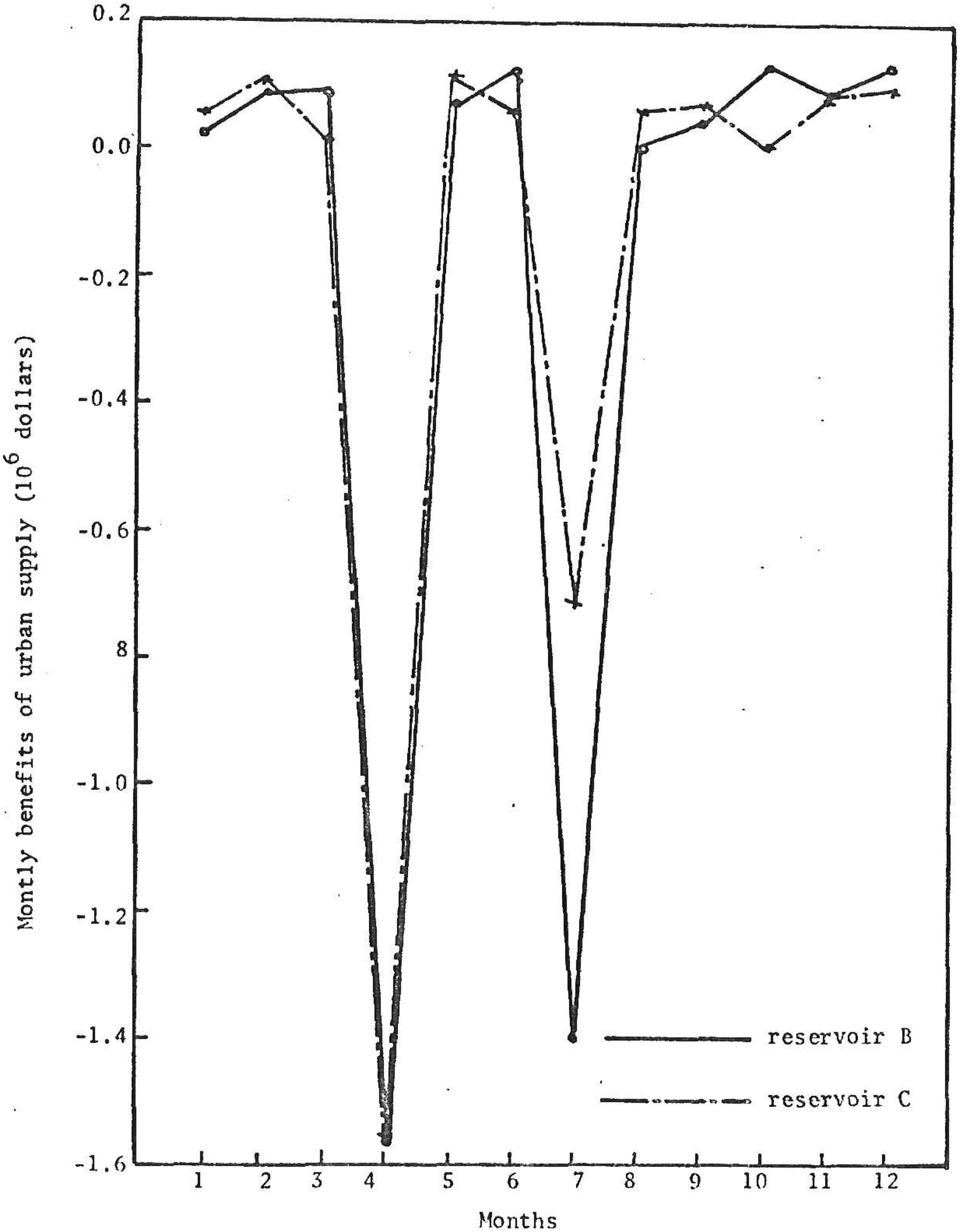


Fig. 5.28 Monthly benefits of urban supply for combination 8 at infow mean 4 (maf) over the 22nd year.

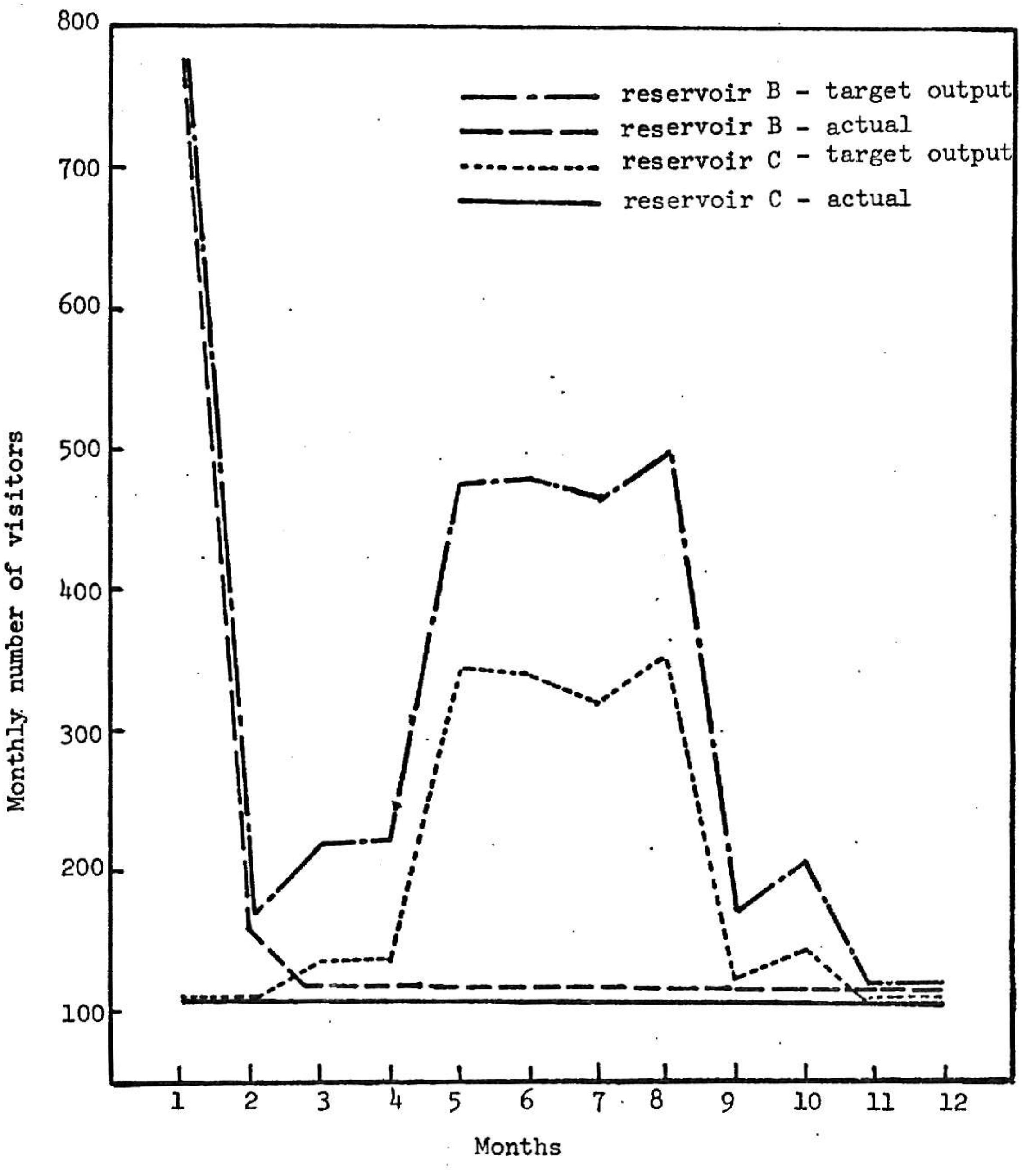


Fig. 5.29 Monthly number of visitors recreated at pools of reservoirs B and C for combination 8 at inflow mean 4 (maf) over the 22nd year.

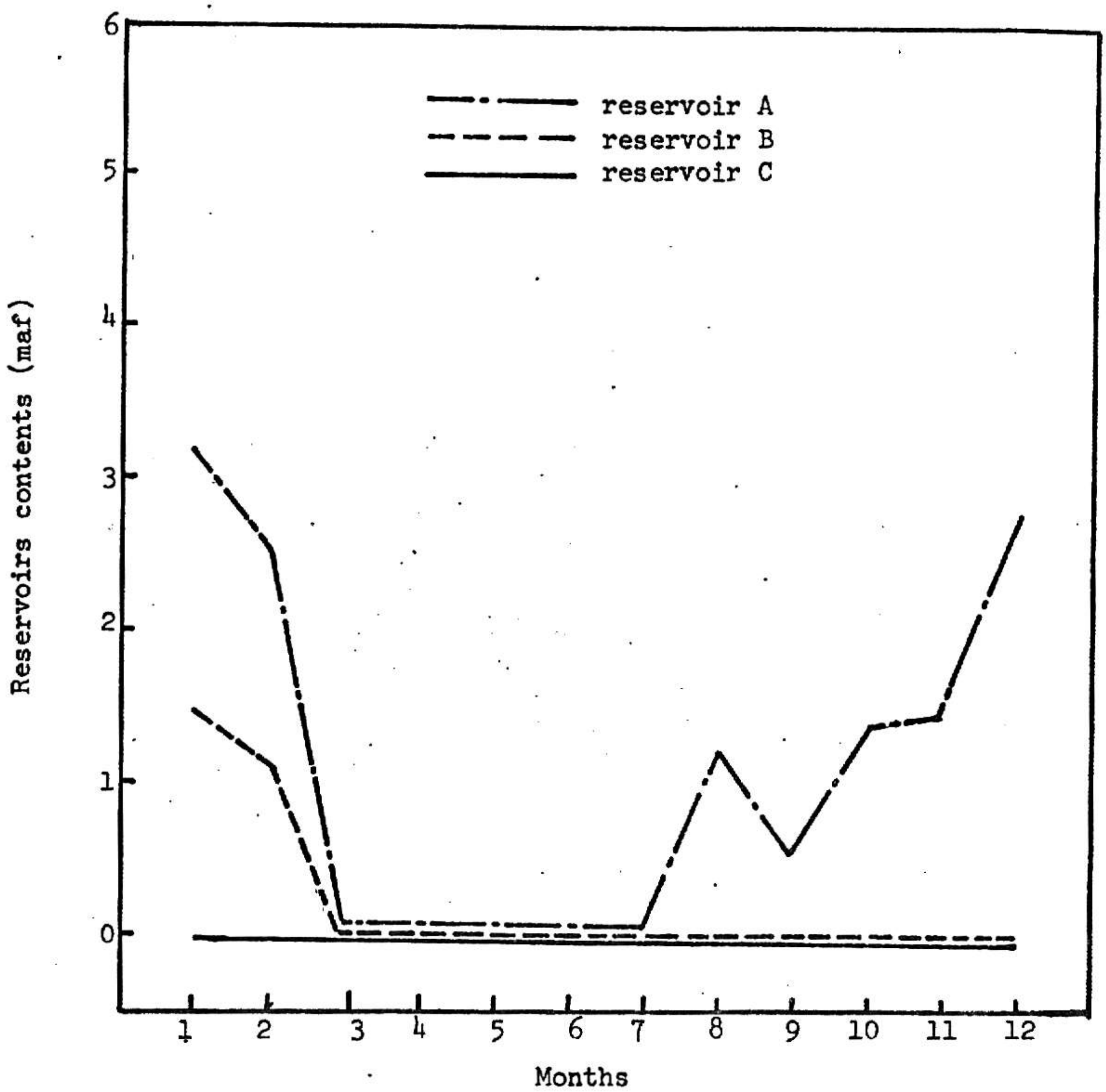


Fig. 5.30 Reservoirs' contents for combination 8 at inflow mean 4 (maf) over the 22nd year.

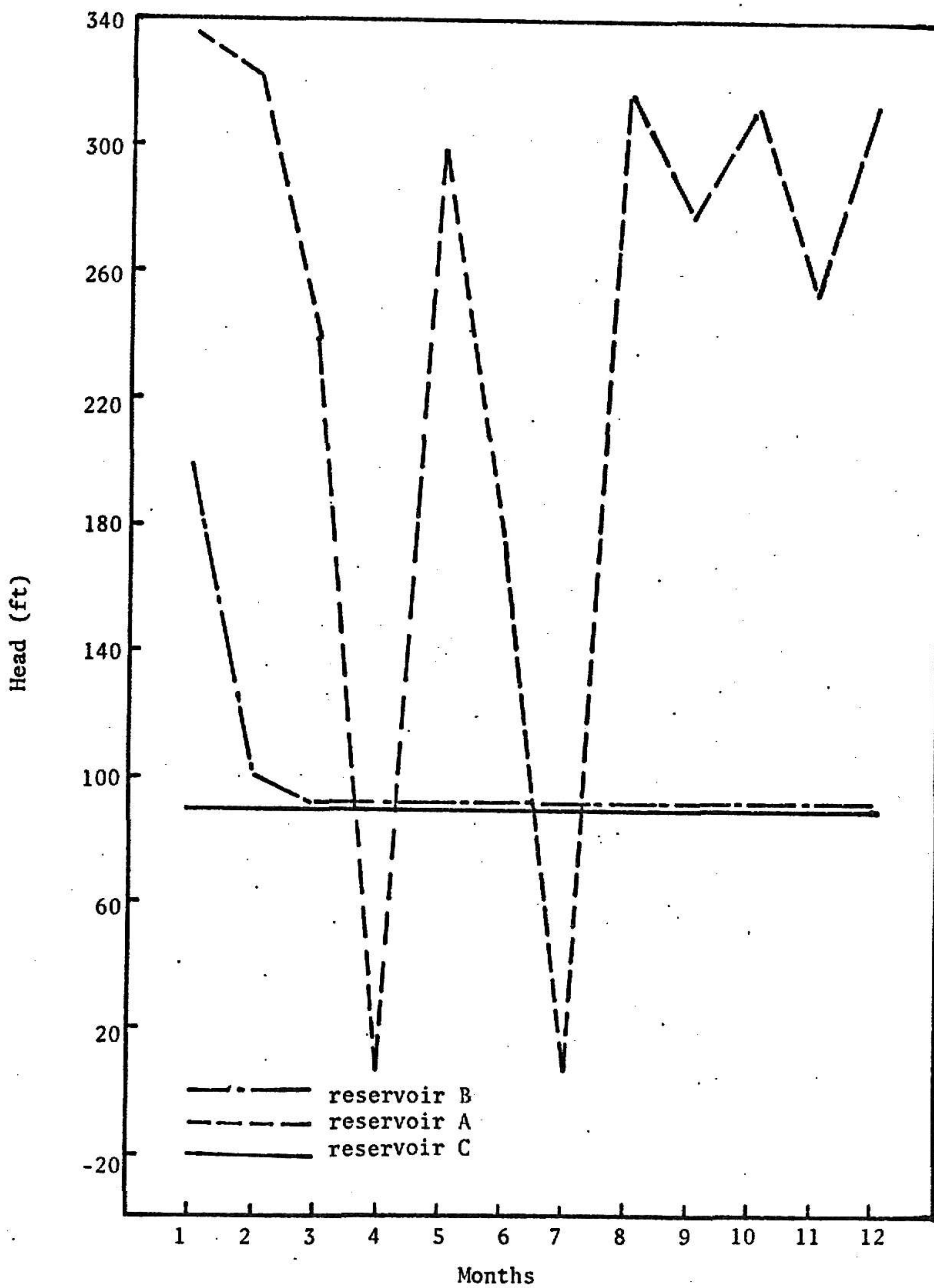


Fig. 5.31 Heads of the three reservoirs for combination 8 at inflow mean 4 (maf) over the 22nd year.

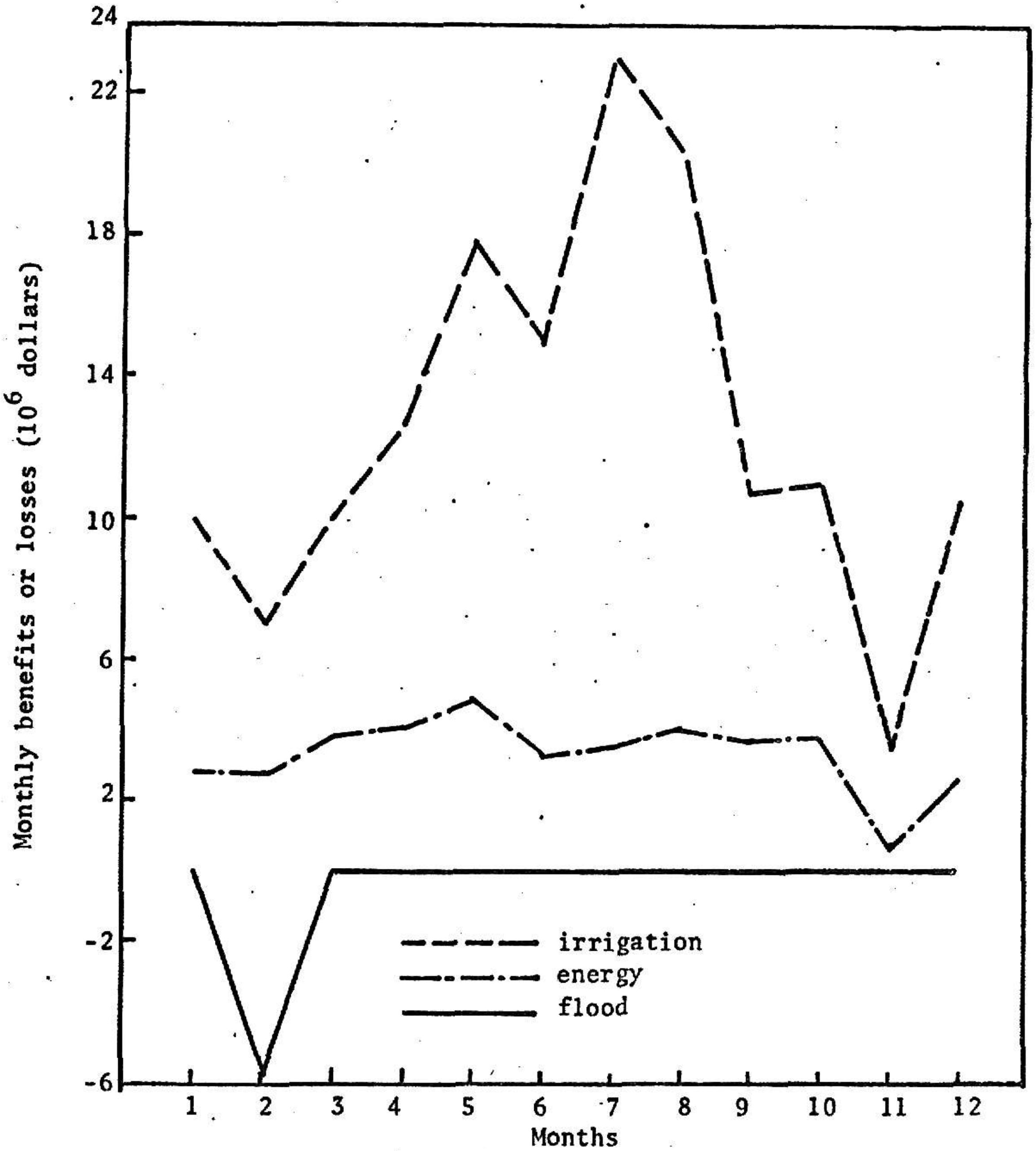


Fig. 5.32 Monthly benefits of irrigation and power, and flood losses for combination 9 at inflow mean 6 maf over the 22nd year.

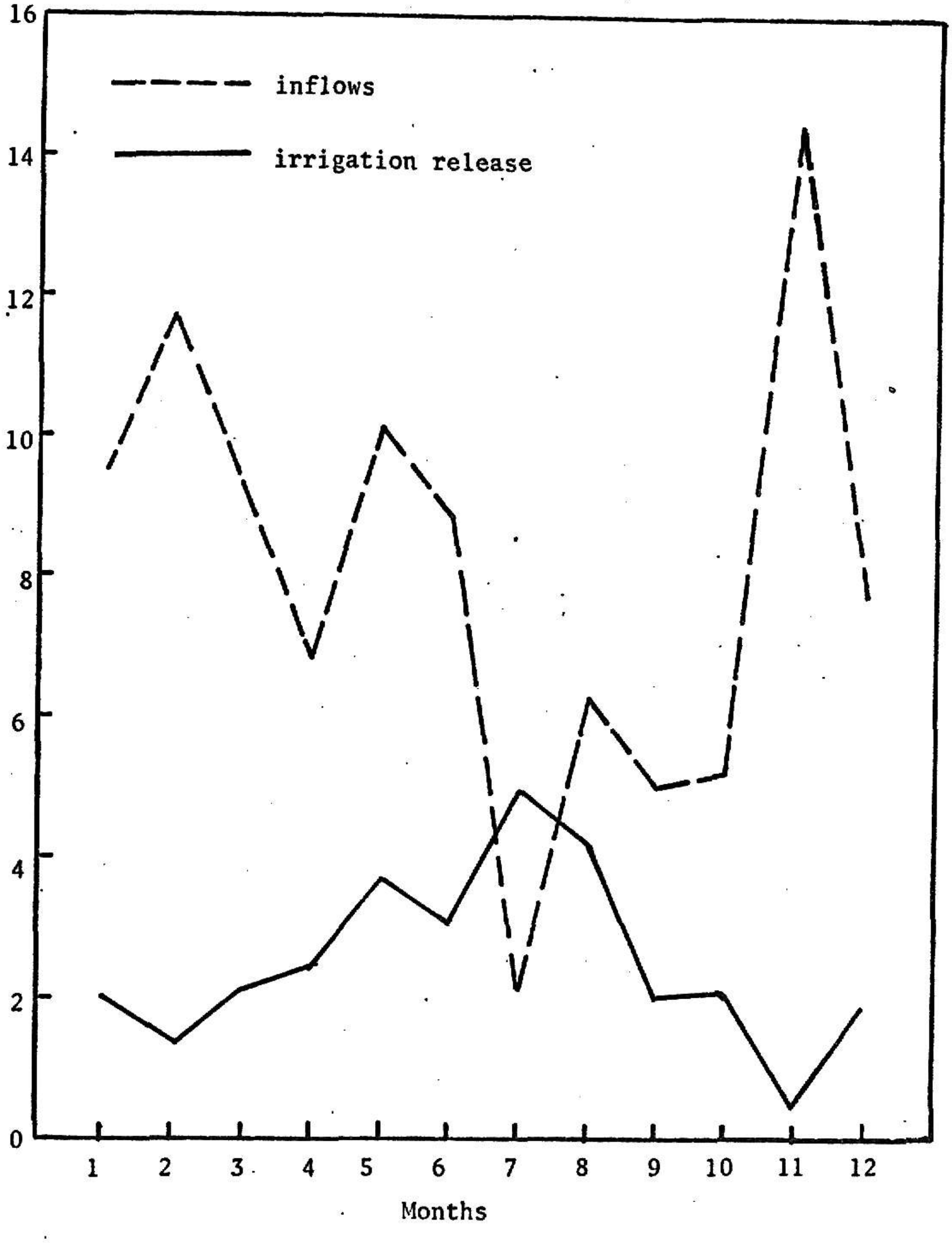


Fig. 5.33 Inflows and irrigation release for combination 9 at inflow mean 6 (maf) over the 22nd year.

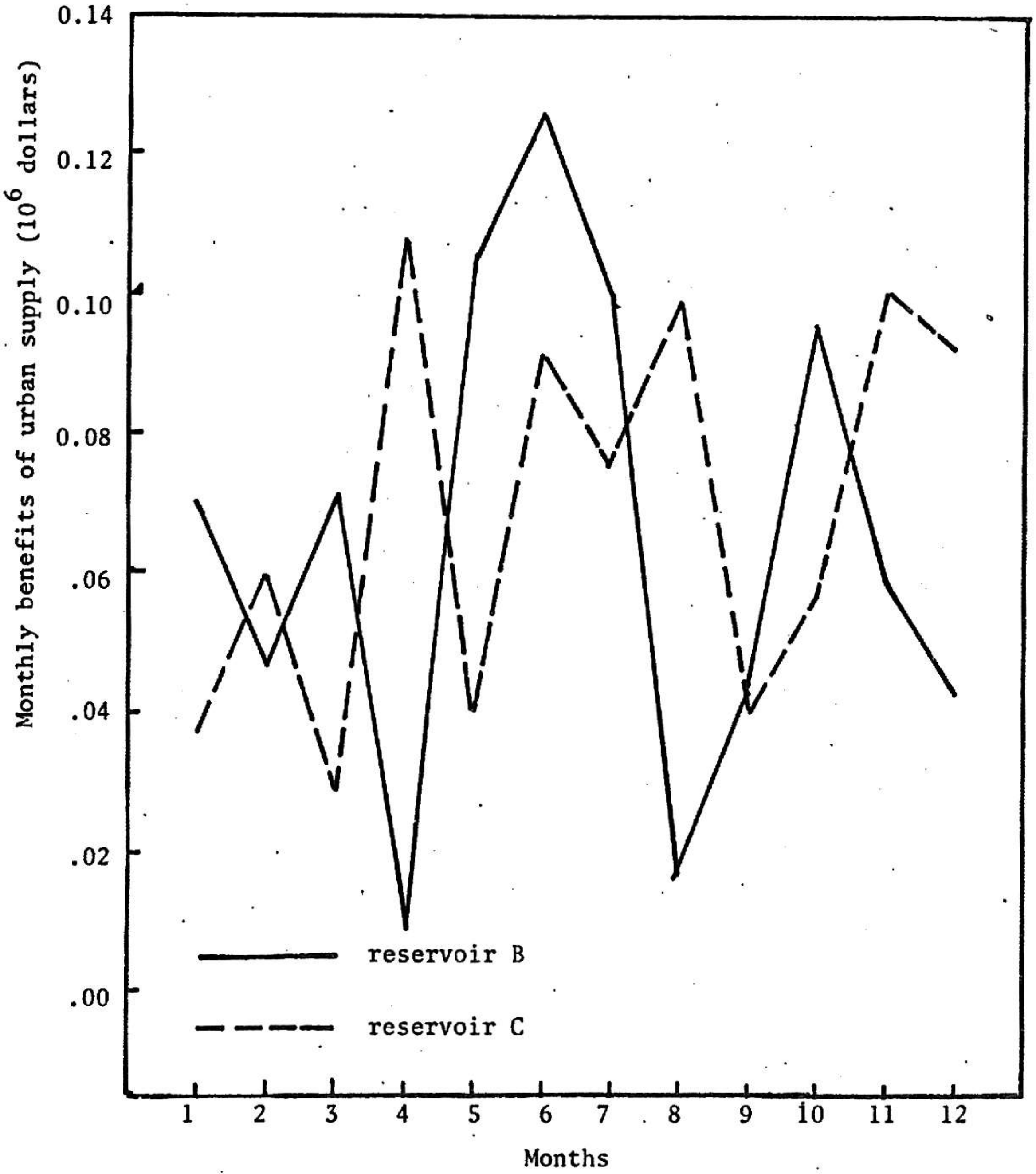


Fig. 5.34 Monthly benefits of urban supply for combination 9 at inflow mean 6 (maf) over the 22nd year.

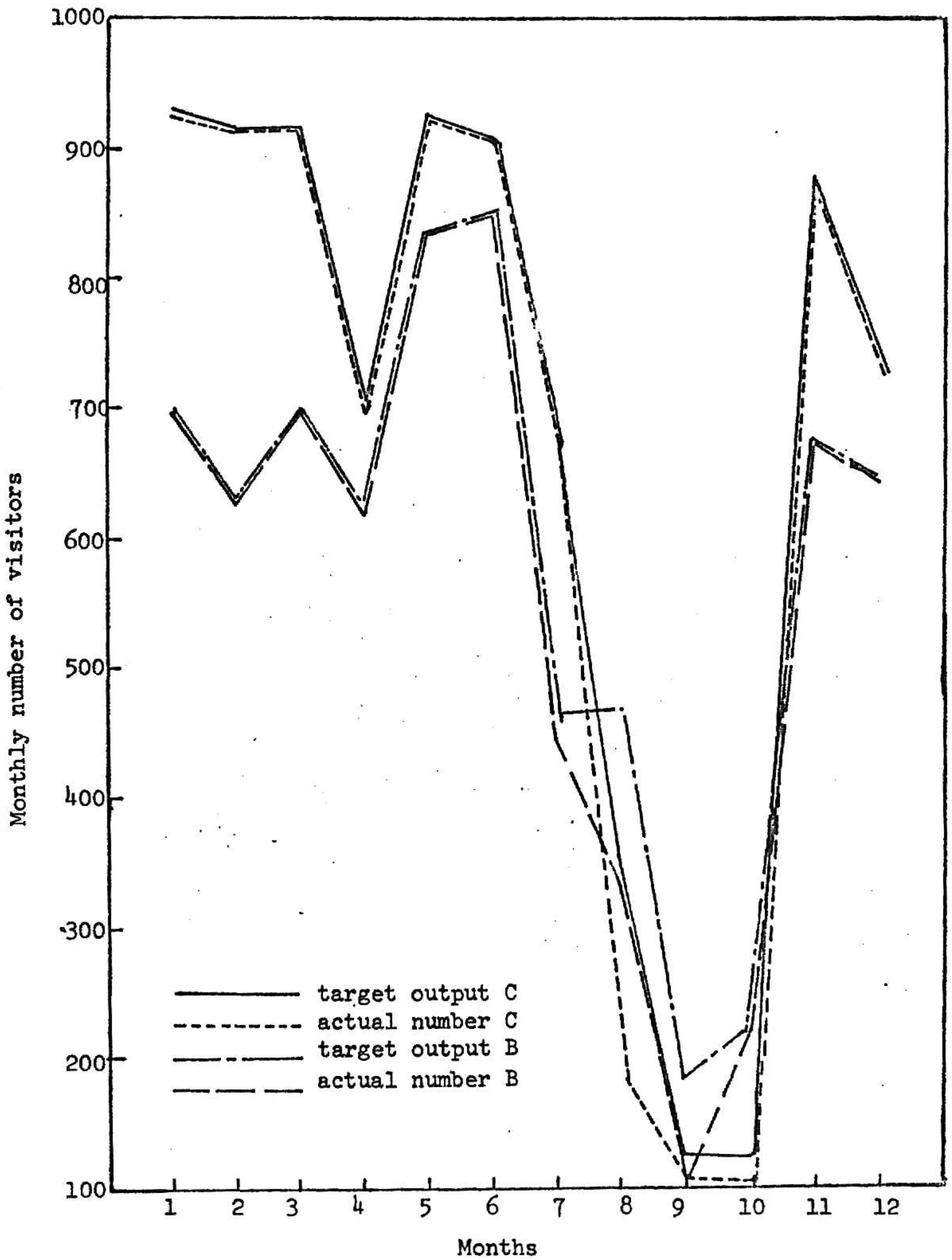


Fig. 5.35 Monthly visitors recreated at pools of reservoir's B and C for combination 9 at inflow mean 6 (maf) over the 22nd year.

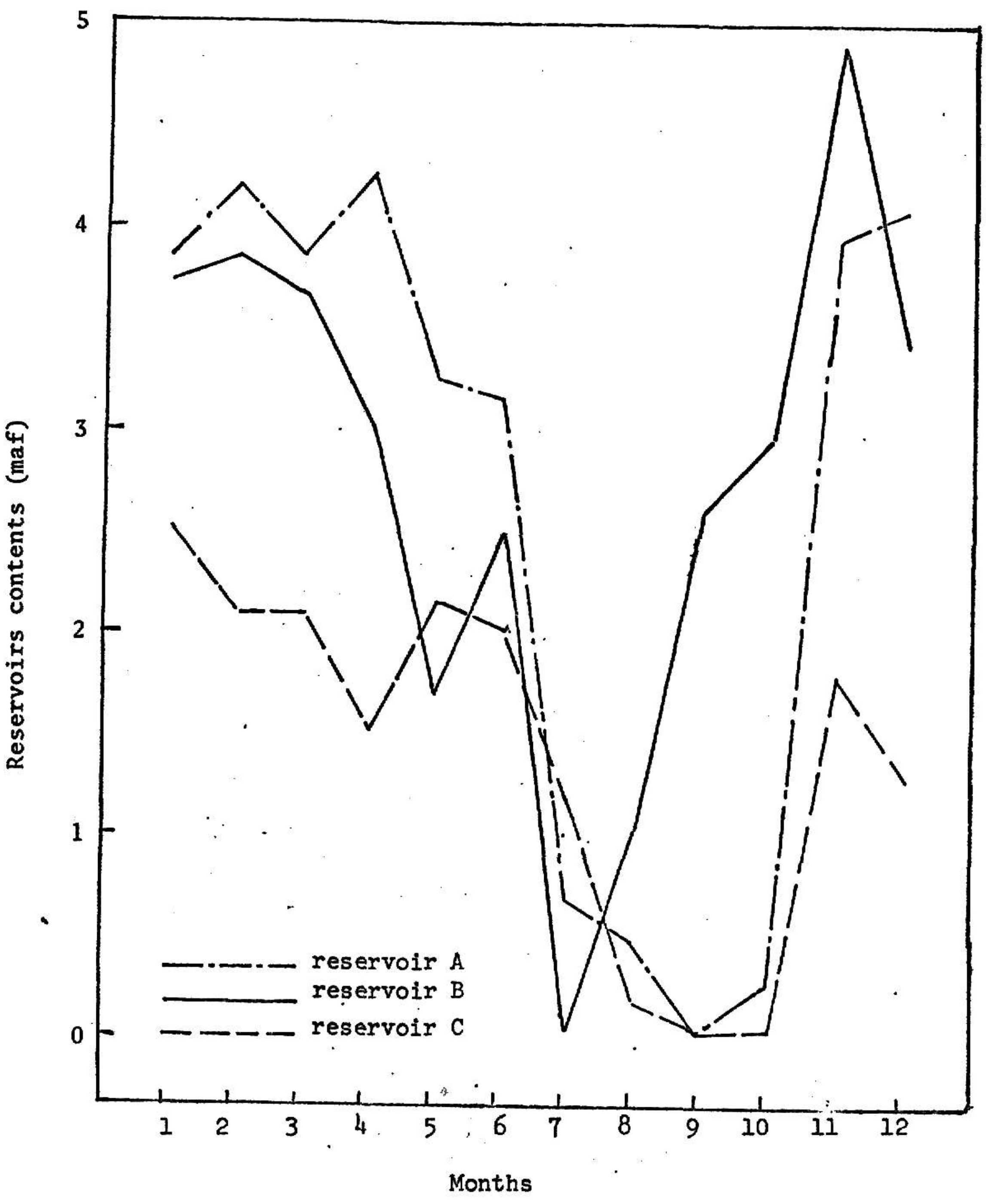


Fig. 5.36 Reservoirs contents for combination 9 at inflow mean 6 (maf) over the 22nd year.

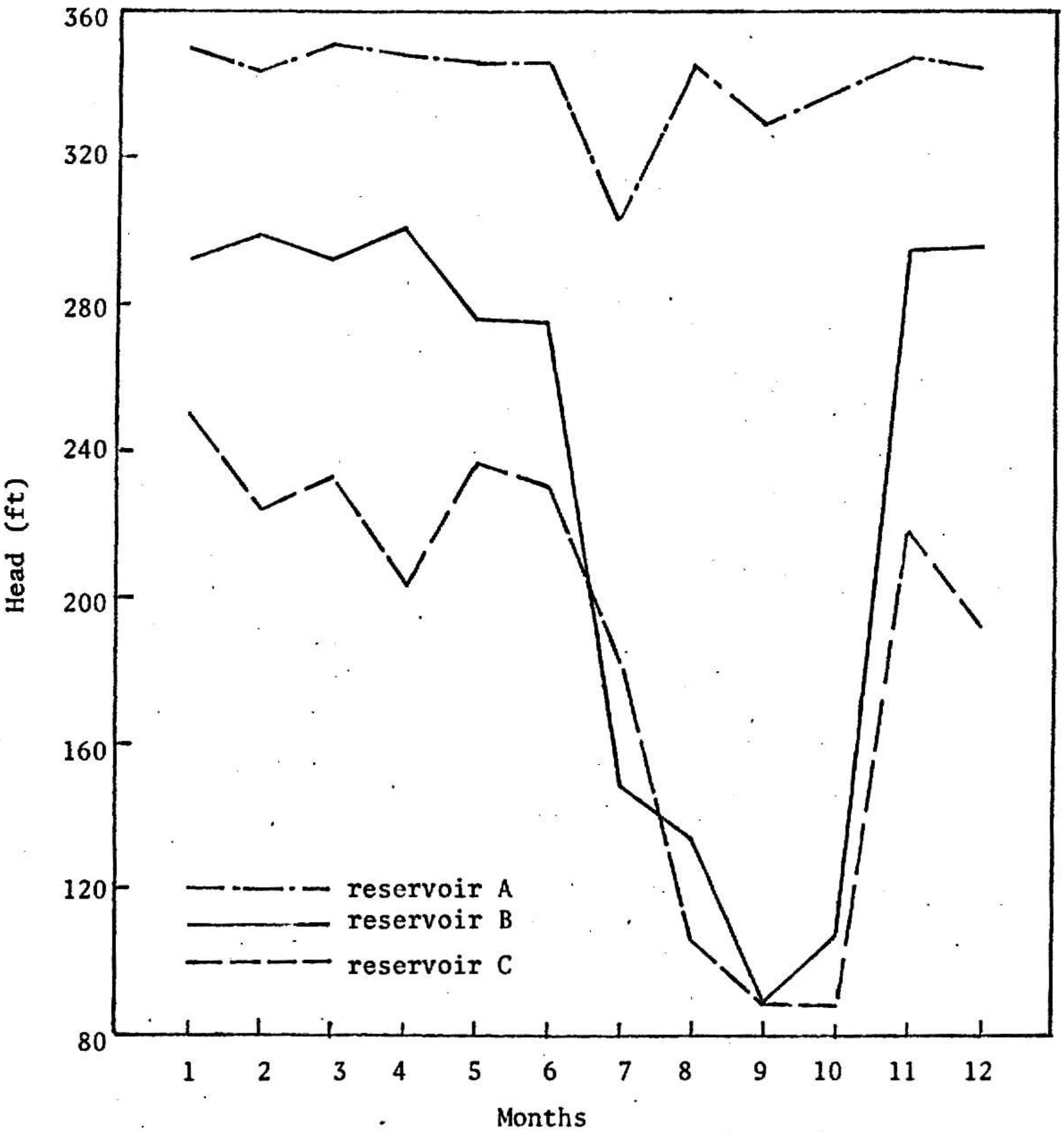


Fig. 5.37 Heads of the three reservoirs for combination 9 at inflow mean 6 (maf) over the 22nd year.

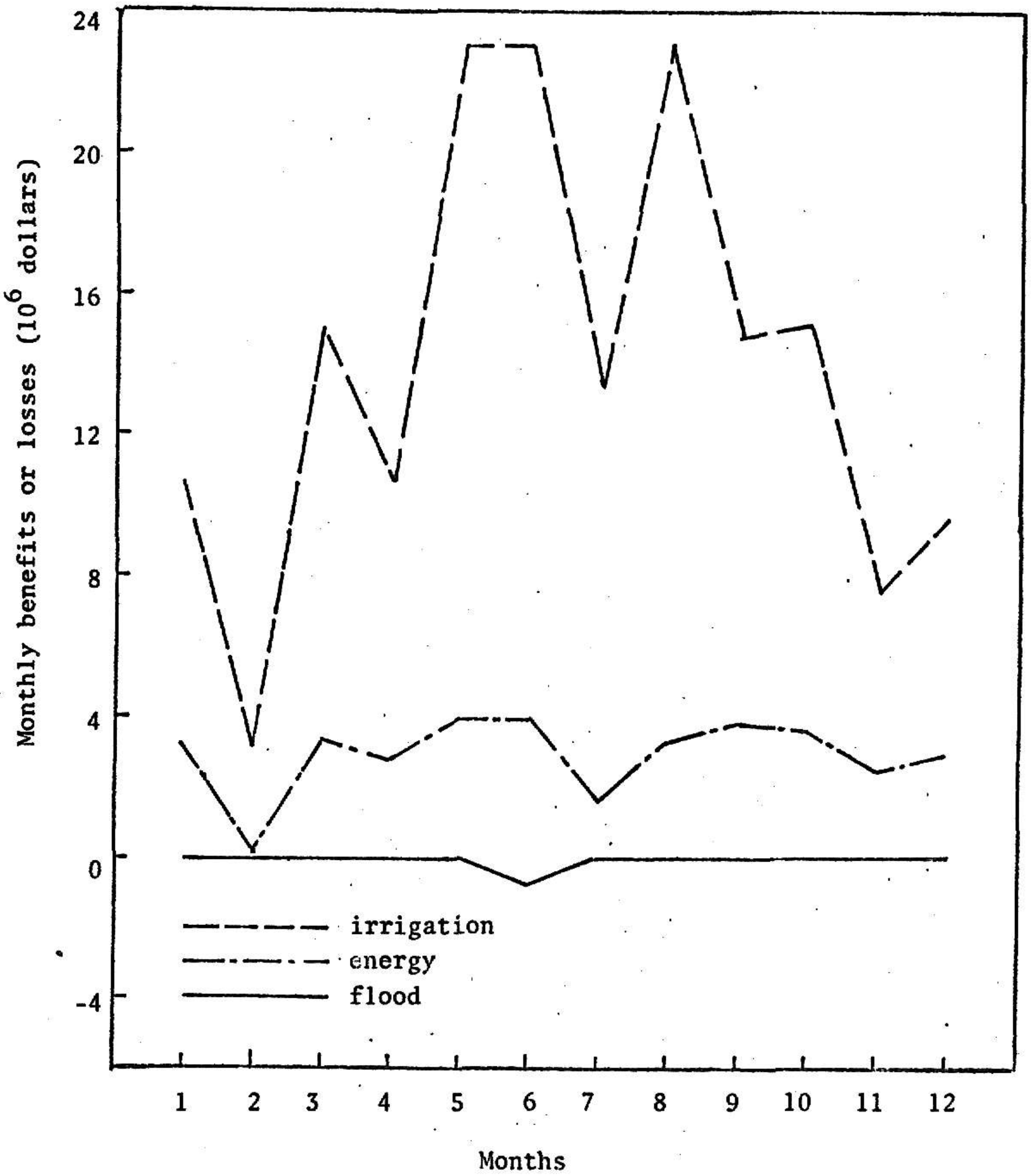


Fig. 3.38 Monthly benefits of irrigation and energy and flood losses for combination 6 at inflow mean 8 (maf) over the 22nd year

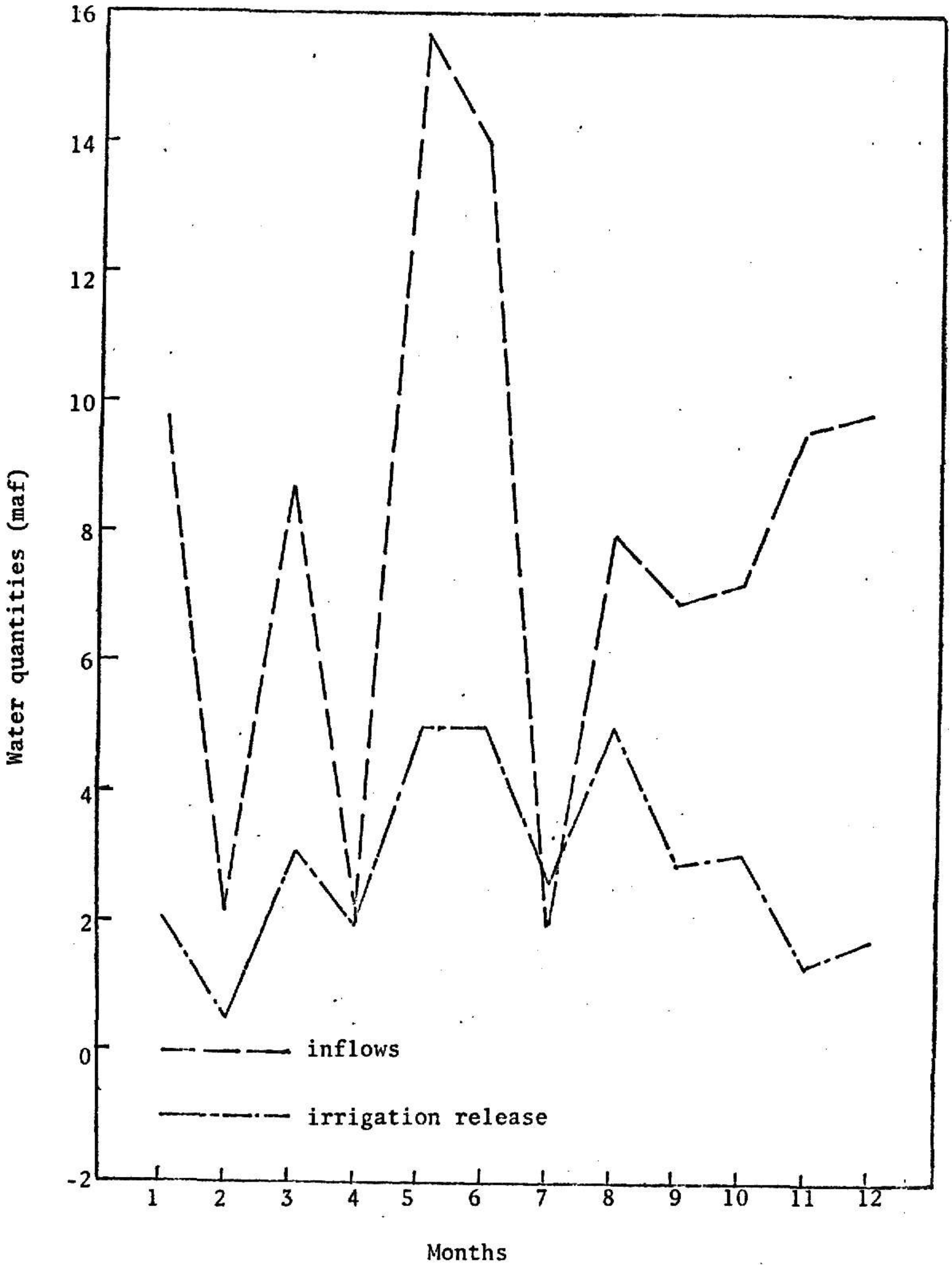


Fig. 5.39 Inflows and irrigation release for combination 6 at inflow mean 8 (maf) over the 22nd year.

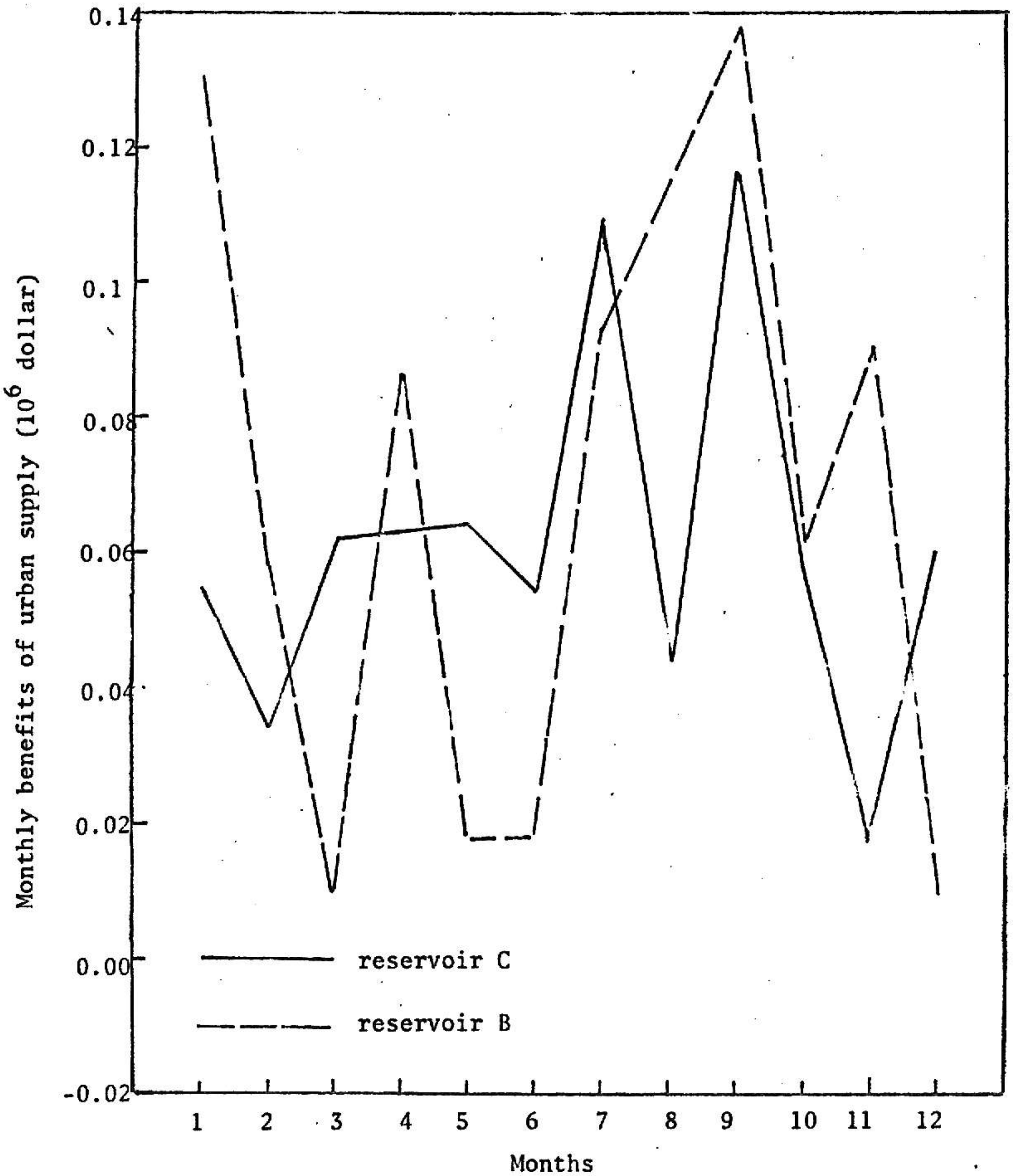


Fig. 5.40 Monthly benefits of urban supply for combination 6 at inflow mean 8 (maf) over the 22nd year

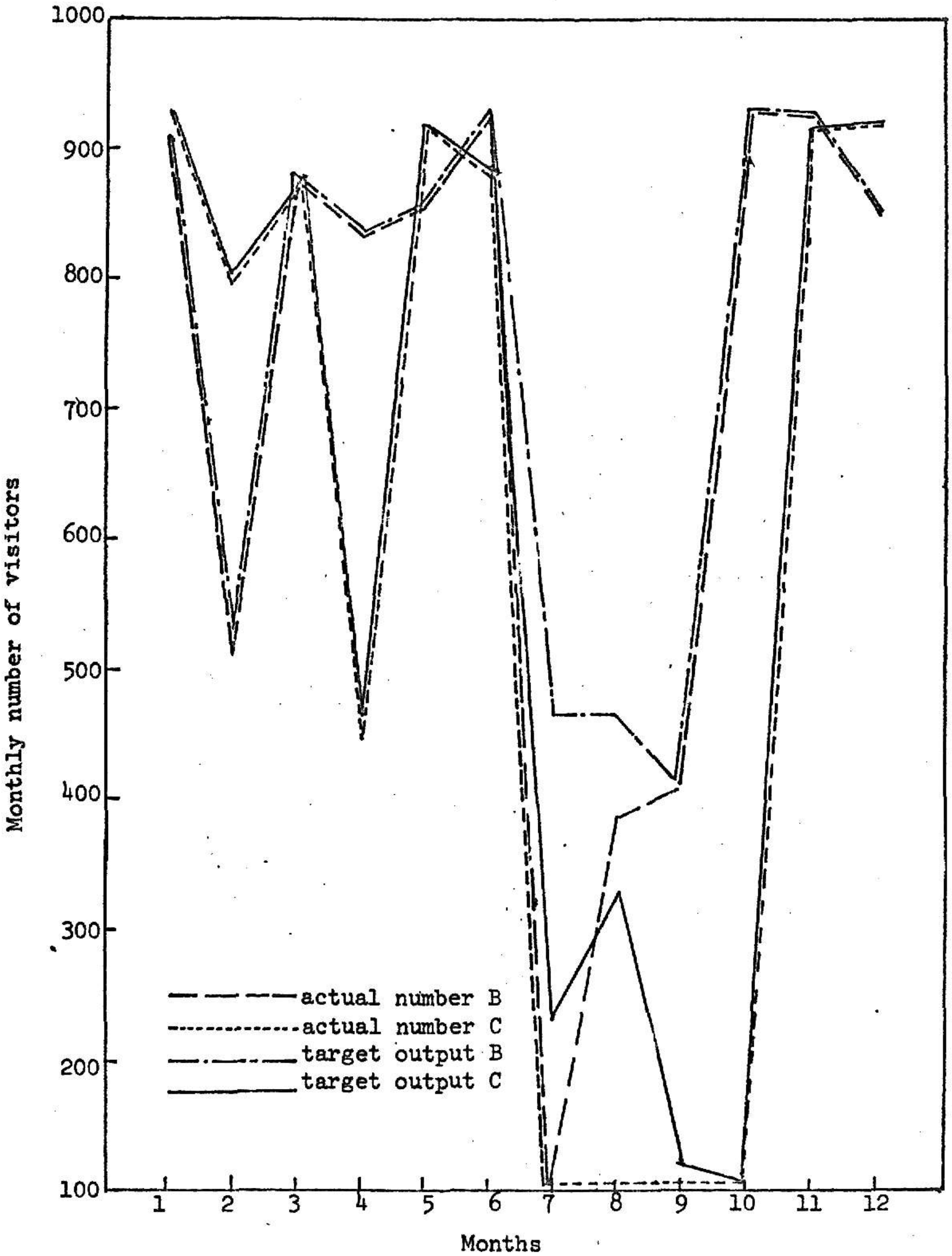


Fig. 5.41 Monthly number of visitors recreated at pools of reservoirs B and C for combination 6 at inflow mean 8 (maf) over the 22nd year.

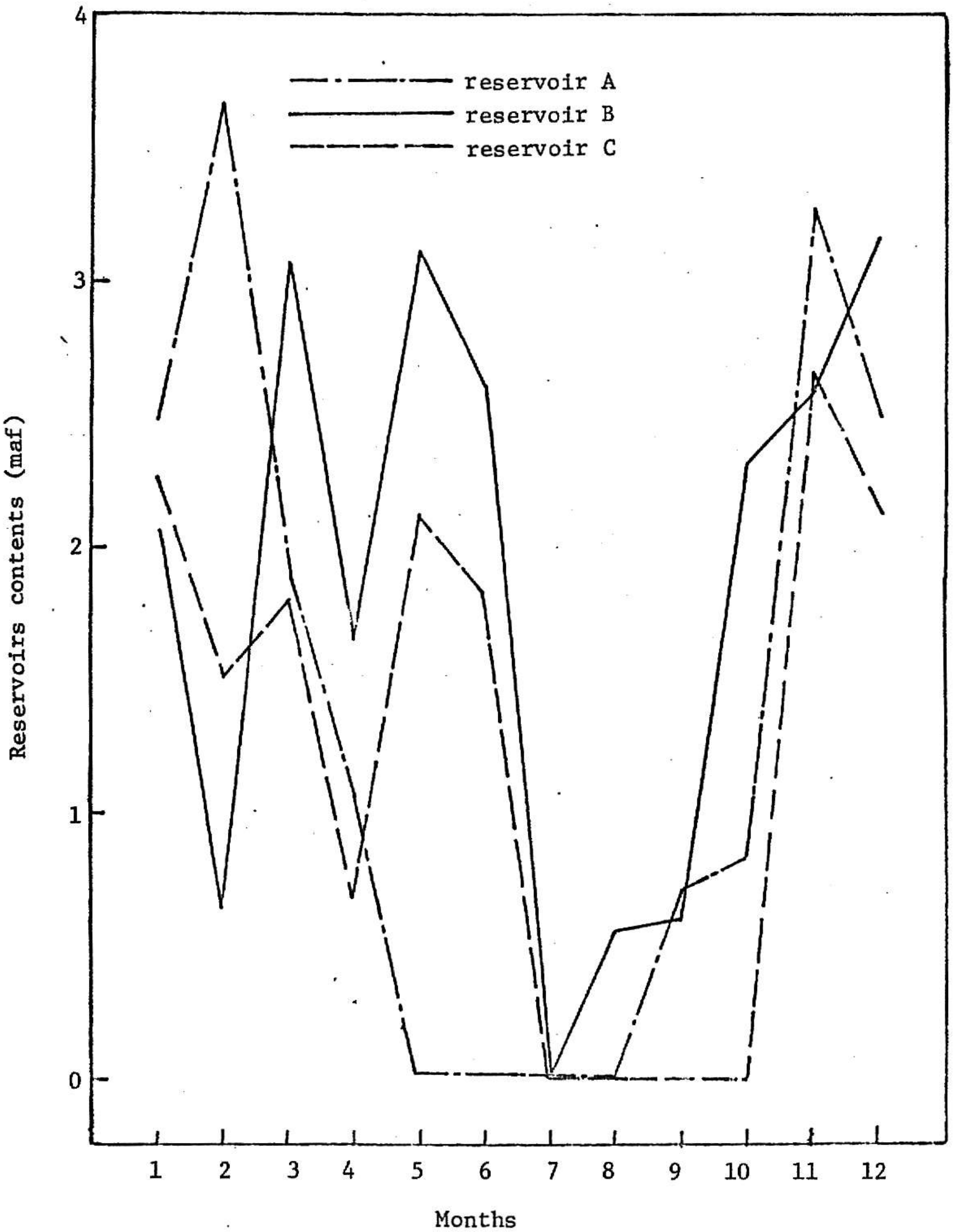


Fig. 5.42 Reservoirs' contents for combination 6 at inflow mean 8 (maf) over the 22nd year.

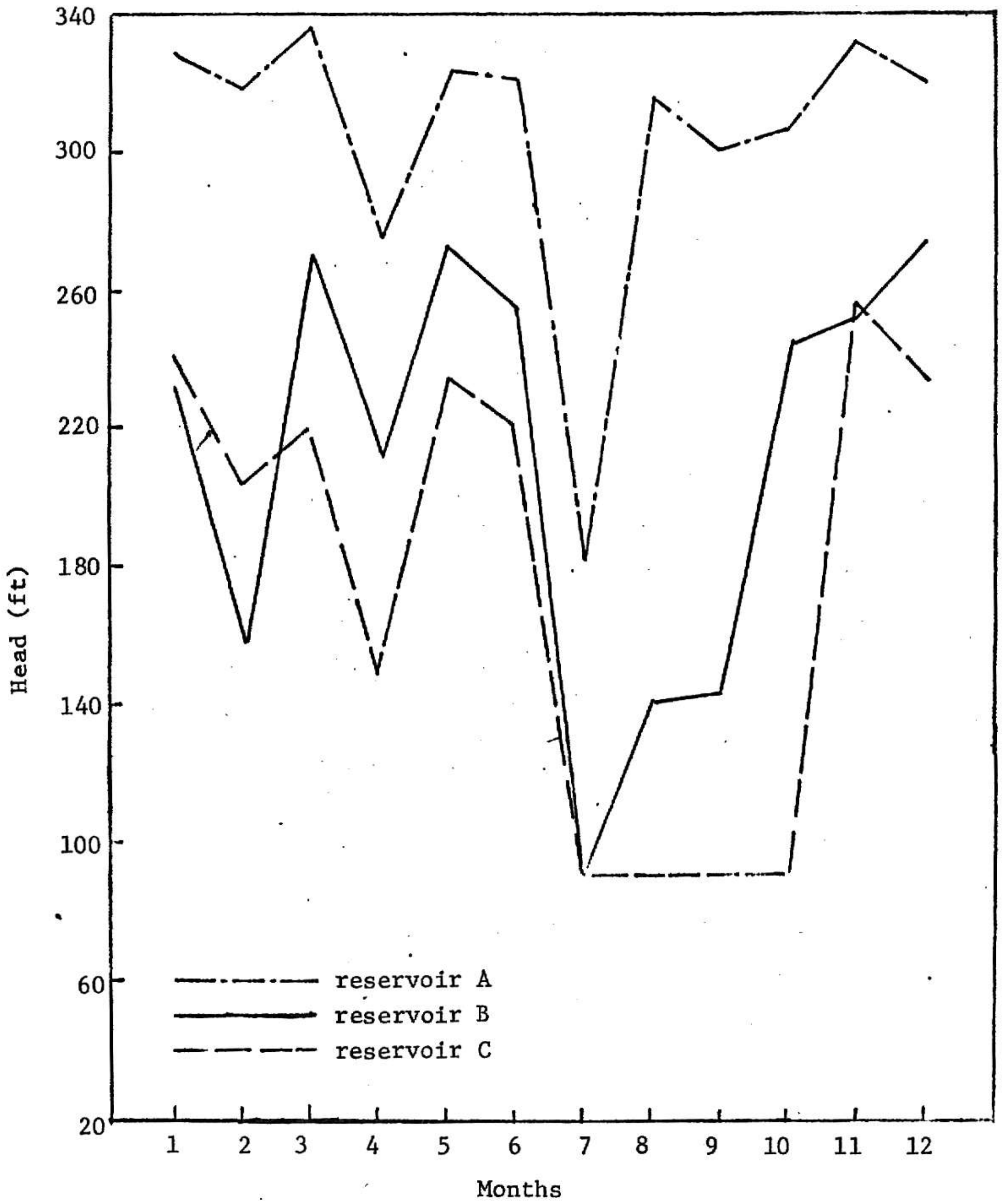


Fig. 5.43 Heads of the three reservoirs for combination 6 at inflow mean 8 (maf) over the 22nd year.

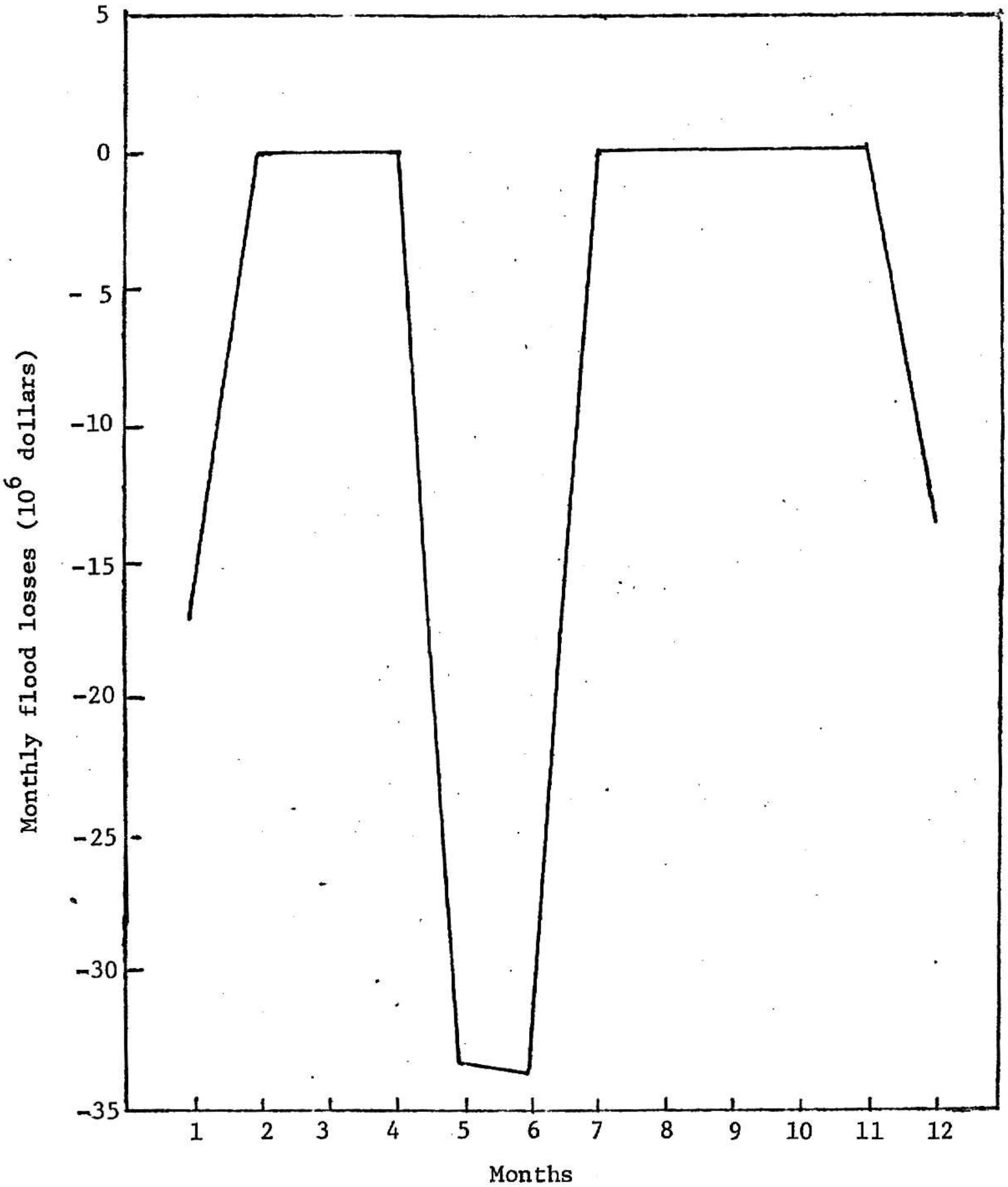


Fig. 5.44 Monthly flood losses for combination 6 at inflow mean 10 maf over the 22nd year.

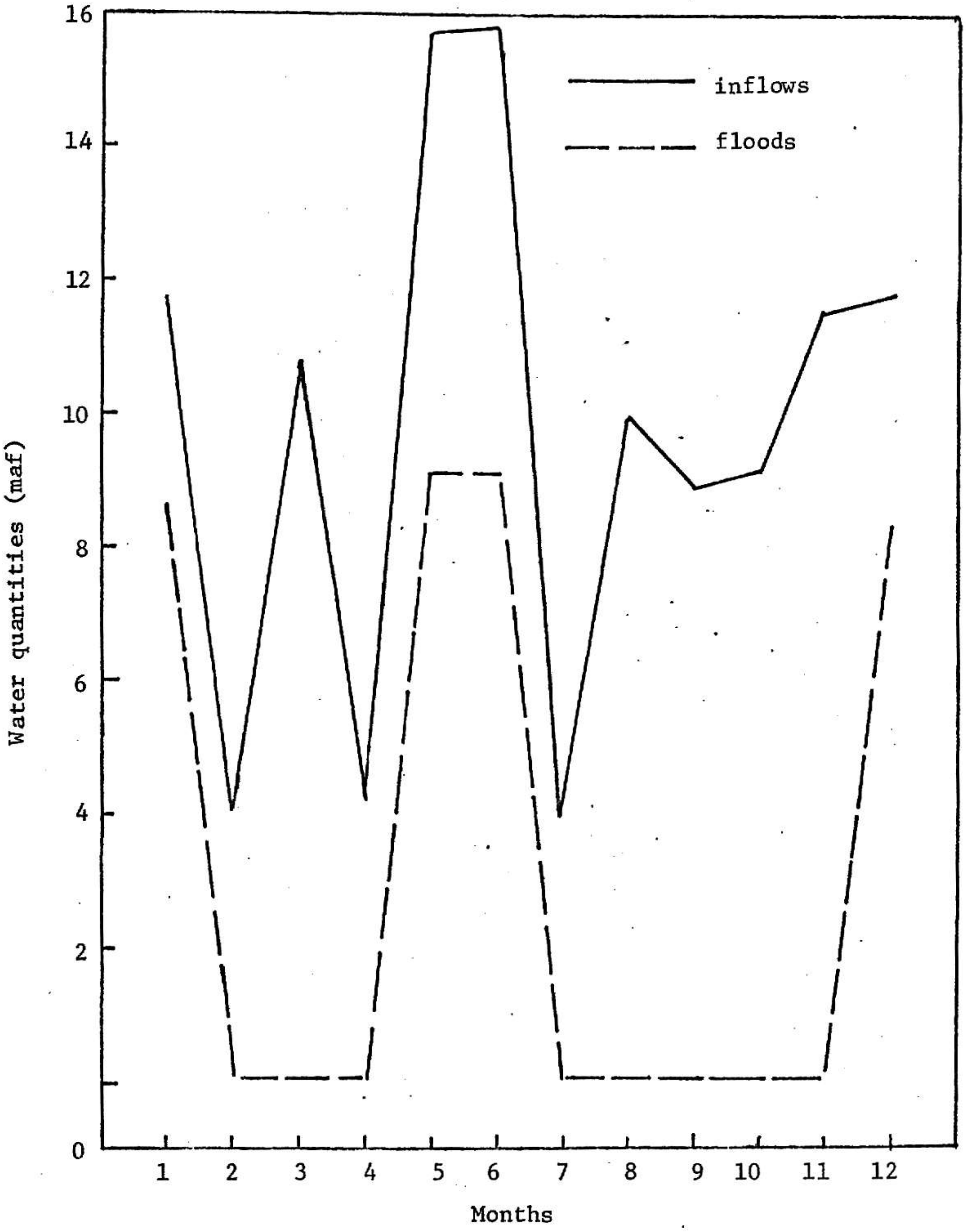


Fig. 5.45 Inflows and floods for combination 6 at inflow mean 10 (maf) over the 22nd year.

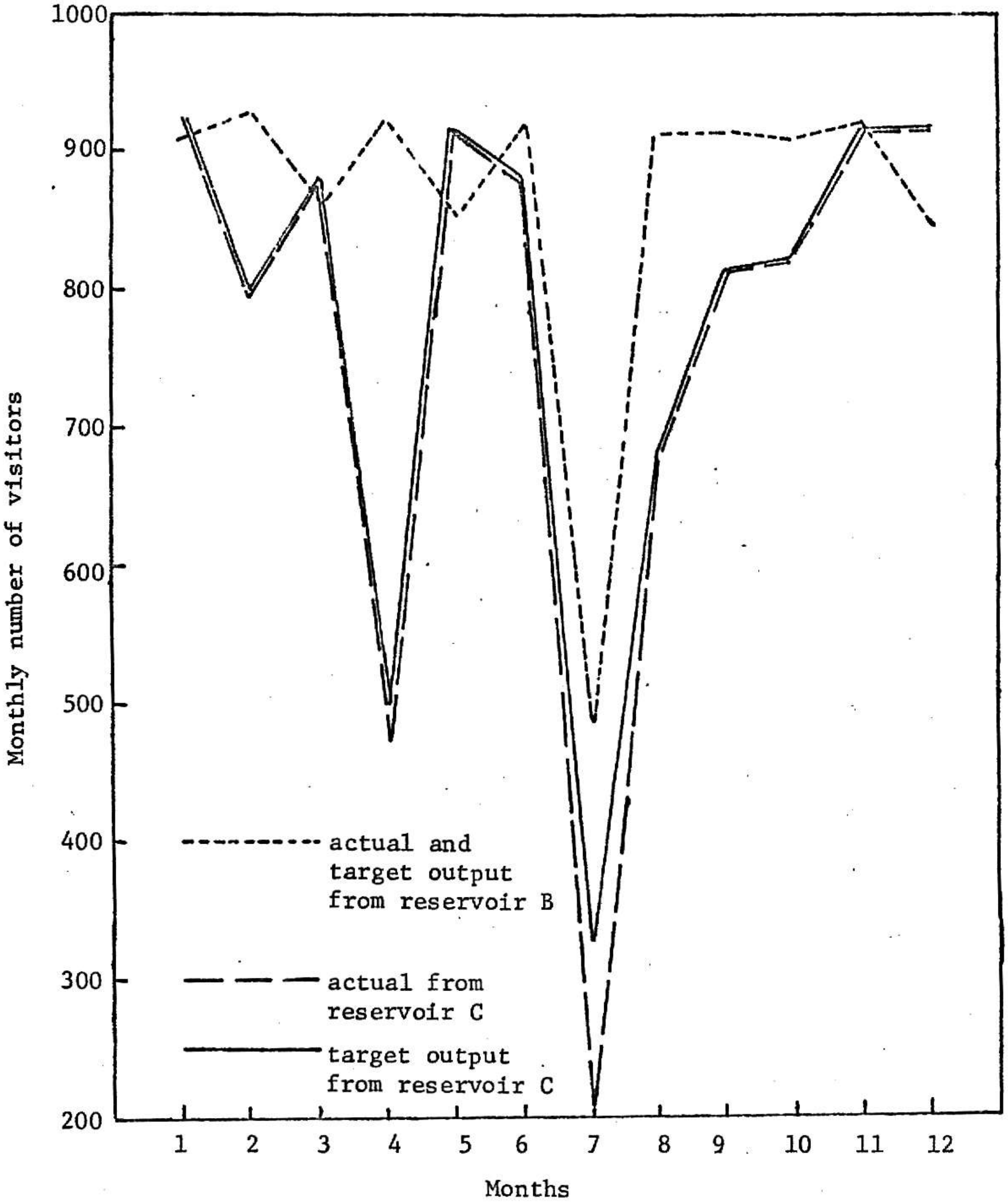


Fig. 5.46 Monthly visitors recreated at pools of reservoirs B and C for combination 6 at inflow mean to (maf) over the 22nd year.

CHAPTER VI

SUMMARY AND CONCLUSIONS

A stochastic model of, three multi-purpose reservoirs, one power plant, and a flood damage zone was developed. The variables of concern have been, capacity of reservoir A, capacity of reservoir B, capacity of reservoir C, and mean inflow mean. The capacity of each reservoir was altered to form ten alternatives. The mean inflow was uncontrollable; however; it has been altered as an attempt to give a future expectation of the system performance under sudden and uncontrolled changes in the coming inflows. Because of the limited computer time, three values for the capacity of each reservoir have been chosen based on some limiting assumptions. Furthermore, four values for the inflow mean have been used. Accordingly, forty experiments have been conducted. Several variables, such as power plant capacity and target outputs of the system could have been considered. Due to the large computation time involved in conducting the experiments, these variables have been excluded. Irrigation and recreation target outputs have been assumed to vary within limited range specified according to certain seasonal patterns. Power generation and urban supply target outputs have been assumed to be uniform throughout the year. In addition to the preceding target outputs flood damage reduction has been considered.

Economic analysis of the system alternative has been performed. Benefits of the system target outputs have been evaluated in terms of expectation. The annual expected net profit of each combination under various inflow means has been obtained. The benefits - cost ratio of all the system alternatives has been determined and used, in addition to the expected net benefits, as criteria to measure the system performance.

The technique of digital simulation of stochastic system has been employed in the study of the current model. This technique has been proved to be promising particularly if the physical characteristics and the assumed functions of the simulated model are very close to reality. The degree of accuracy of the simulation study is dependent on how good is the theoretical approximation to the real world situation. Moreover, it is dependent on the input data and its handling. The latter statement has not been considered in the current model since no data were available. However; some drawbacks of simulation technique has to'be stated. These are; 1) The impossibility of examining all feasible combinations to get the optimal solution; 2) The large computation time involved especially if the system is very complicated; and 3) The slight effect of seed numbers on the outcome of the experiments.

Through the use of digital simulation for the study of the proposed model, some results have been obtained in section 5.2. From these results, the following conclusions are reached.

1. The expected net benefits are found to be much more sensitive to the combination of reservoirs' capacities than to the sum of the total capacity of the system.

2. The different combinations behave in the same manner and have the same trend under the various magnitudes of mean inflows. The explanation of this consistency might be; a) the fixed operating policy followed during all the simulation runs; b) the use of the same mathematical functions all over the experiments; and c) the unchanged initial inputs to the system

such as, the seed numbers, and the parameters of the distribution.

3. The expected benefits may not increase as the cost rises because of the stochastic behavior of the system; however; the general trend goes upward as cost increases.

4. The maximum expected benefits of irrigation, energy, and urban supply are associated with high inflows. On the contrary, the maximum expected flood losses are usually accompanied by high inflows. As a result, the total expected profits are influenced by positive target outputs such as irrigation, energy, and urban supply at the low inflows while they are affected by the flood losses at the high inflows. Accordingly, all the examined combinations are inefficient, within the specified magnitudes of reservoirs' capacities.

5. Irrigation and urban supply shortages are caused by either seasonal pattern of irrigation and the operating policy, or water shortage.

6. At very low inflows, the urban supply losses exist regardless of the capacities of the reservoirs.

7. As expected the frequency of flood occurrence is affected by the capacities of reservoirs and the inflows. At high inflows this frequency is very large, and the severity of flood increases while both of the frequency and the severity decrease at low inflows.

The maximum benefit - cost ratio might be obtained while the expected net benefits are not maximum. This means that the most profitable project may not be the one that give rise to maximum return on the investment. This was found to be true for some of the examined designs. Also, this case might arise in any project other than water resources projects.

APPENDIX A

RANDOM NUMBER GENERATION

Appendix A

Random Number Generation

The current appendix includes the standardization process for the regression coefficients used for the generation of monthly inflows. Moreover, the generation of the other statistical parameters used for the same purpose are discussed. The system target outputs have been randomly generated. The distributions used for this purpose are Uniform, Normal, Erlang, and Poisson. The procedures followed for the generation of those random number are introduced. Furthermore the probability density functions and their graphical illustration are given. The flow charts of the routines used for the generation of random numbers from the various distributions are also presented.

Generation of Inflows. To generate the inflows, many statistical parameters have to be determined from historic records. Since these historic records are not available, the parameters are randomly generated. Specifically, these parameters are monthly mean inflows, monthly standard deviations, correlation coefficients, and regression coefficients. The monthly mean inflows and standard deviations are generated from normal distributions with certain mean and variance for each. Also, certain ranges have been specified for the numbers generated. The correlation coefficients have been generated from an Erlang distribution with specific mean and variance, within the range (0-1). No negative serial correlation coefficients were generated.

Concerning the regression coefficients, a problem of specifying certain range, for ghe generated numbers, arises. As a solution for this problem a standardization process* has taken place, as follows.

let

$\hat{y}$ = the estimate of the dependent variable

X = the independent variable

b = the regression coefficient

a = the intercept

$$\hat{y} = a + bX \tag{1}$$

and

$$x = (X - \bar{x}), \qquad y = (Y - \bar{y})$$

where

$\bar{X}$ = the mean of the dependent variable

$\bar{Y}$ = the mean of the independent variable.

In order to standardize the regression coefficient b, define certain limits, the terms in equation (1) are multipled by the quantity

$\frac{\sum x^2}{\sum y^2}$. Accordingly,

$$\hat{Y} \frac{\sum x^2}{\sum y^2} = a \frac{\sum x^2}{\sum y^2} + b \frac{\sum x^2}{\sum y^2} X$$

$$\hat{Y}' = a' + r' X$$

*According to a discussion with Dr. Waller in statistics department, Kansas State University.

where r' is a standardized regression coefficient (correlation coefficient) and the same limits specified for correlation coefficients can be assigned for the generation of regression coefficients. Of course, all the other values $\hat{Y}$, a, $\dot{X}$ are multiplied by the factors $\frac{\sum x^2}{\sum y^2}$. This change is of no concern for the simulation performed in the current work. The procedure just stated can be extended to modify equation (3.2).

The target outputs of the system are randomly generated. Monthly irrigation targets have been assumed to be Gamma distribution with certain mean and variance within a certain range. Furthermore, the water release for power generation; domestic supply from reservoir B; and domestic supply from reservoir C have been assumed to be uniform random numbers. The recreation target output has been assumed to be a poisson random variable. The procedures followed in the generation of system parameters and target outputs are discussed below. The distributions from which the random numbers are generated are uniform, Normal, Gamma and Exponential.

Generation of Uniform Random Number.

The probability density function is defined as

$$f(x) = \frac{1}{B-A} \quad A < x < B$$

where X is a random variable defined over the interval (A,B), the cumulative distribution function F(x) is

$$F(x) = \int_a^x \frac{1}{B-A}\, dt = \frac{x-A}{B-A} \quad 0 \leq F(X) \leq 1.$$

The mean and the variance of this distribution are

The mean and the variance of this distribution are

$$E(X) = \frac{B+A}{2}$$

$$V(X) = \frac{(B-A)^2}{12} \quad .$$

The method followed to generate uniform random number uses the equation:

$$X_{i+1} = K\ x_i$$

$K = 8j \pm 3,$ $\qquad$ j is an integer

X_0 = any odd number not more than nine digits

X_i = is the least significant part of X_{i-1}.

The above procedure holds only for a random variable over the interval (0-1). If any further modification for this interval are required, the following relation is used

$$X_i = A + R_i(B-A)$$

where R_i is a random variable over the interval (0,1). A detailed flow chart of the discussed procedure is furnished below.

Generation of Normal Random Number.

The normal probability density function is defined as

$$f(x) = \frac{1}{\sigma_x\sqrt{2\Pi}}\ e^{-1/2\left(\frac{x-\mu_x}{\sigma_x}\right)^2} \qquad -\infty < x < \infty$$

where μ_x is the mean and σ_x is the standard deviation which must be positive. If the parameters of the normal distribution μ_x and σ_x have the values 0,1 respectively, the distribution is known as the standard normal distribution. The direct approach, obtained from Martin [27], has been used in order to generate a random normal variate. Let v_{u_1}, v_{u_2} be two random variates over the interval [0,1], then

$$x_{ns} = (-2 \log_e v_{u_1})^{1/2} \cos 2\Pi v_{u_2}$$

where x_{ns} is a normal random variates with zero mean and unit variance. In order to generate a normal random number with different parameters, X_n, the following equation is employed:

$$X_n = X_{ns} \cdot \sigma_x + \mu_X .$$

This method gives exact results with a reasonable speed of calculation.

Generation of the Erlang Random Number.

The Erlang probability density function is defined as

$$f(x) = \frac{\alpha^K x^{(K-1)} e^{-\alpha x}}{(K-1)!} \qquad X > 0$$

where α, and K are the parameters of the Erlang distribution and have to be larger than zero. Furthermore, the parameter K has to be an integer. The expected value and the variance are given by

$$EX = \frac{K}{\alpha}$$

$$VX = \frac{K}{\alpha^2} .$$

The Erlang distribution becomes an exponential one when K = 1. As K increases the Erlang distribution, approaches a normal distribution. Any value for K larger than one and not very large produces a Gamma distribution.

In order to generate Exponential variates, X_e, the following identity is used:

$$X_e = -1/\alpha \ln r_v$$

where $1/\alpha$ is the expected value and r_v is a random variate. A Gamma distribution random variable is the sum of K independent exponential random variables with identical expected value $1/\alpha$. Accordingly, the Gamma variate, X_g, can be expressed as

$$X_g = \frac{-1}{\alpha} \sum_{i=1}^{k} \ln r_i$$

$$X_g = \frac{-1}{\alpha} (\log \prod_{i=1}^{K} r_i \quad)$$

where the last form is computationally faster.

Generation of Poisson Random Number:

The probability density function of the poisson distribution is defined as

$$f(n) = e^{-\lambda} \frac{\lambda^n}{n!} \qquad n = 0, 1, 2, \ldots$$

$$\lambda > 0 \quad .$$

Mathematically, the poisson random deviate n is determined by the inequality

$$\prod_{i=1}^{n} v_i \geq \mathrm{EXP}\ (-\lambda) > \prod_{i=1}^{n+1} v_i$$

where $_v$ is random numbers. The product of these numbers has to be less than the term EXP $(-\lambda)$ in order to obtain the poisson random variate n, if the number of random numbers required is (n+1).

The random number generation performed in this thesis is based upon the discussions presented in Martin [29], Naylor and others [34], and Pritsker and Kiviat [35].

The coding of the generation of random numbers of these distributions is presented in appendix B.

Appendix B

COMPUTER PROGRAM AND FLOW CHARTS

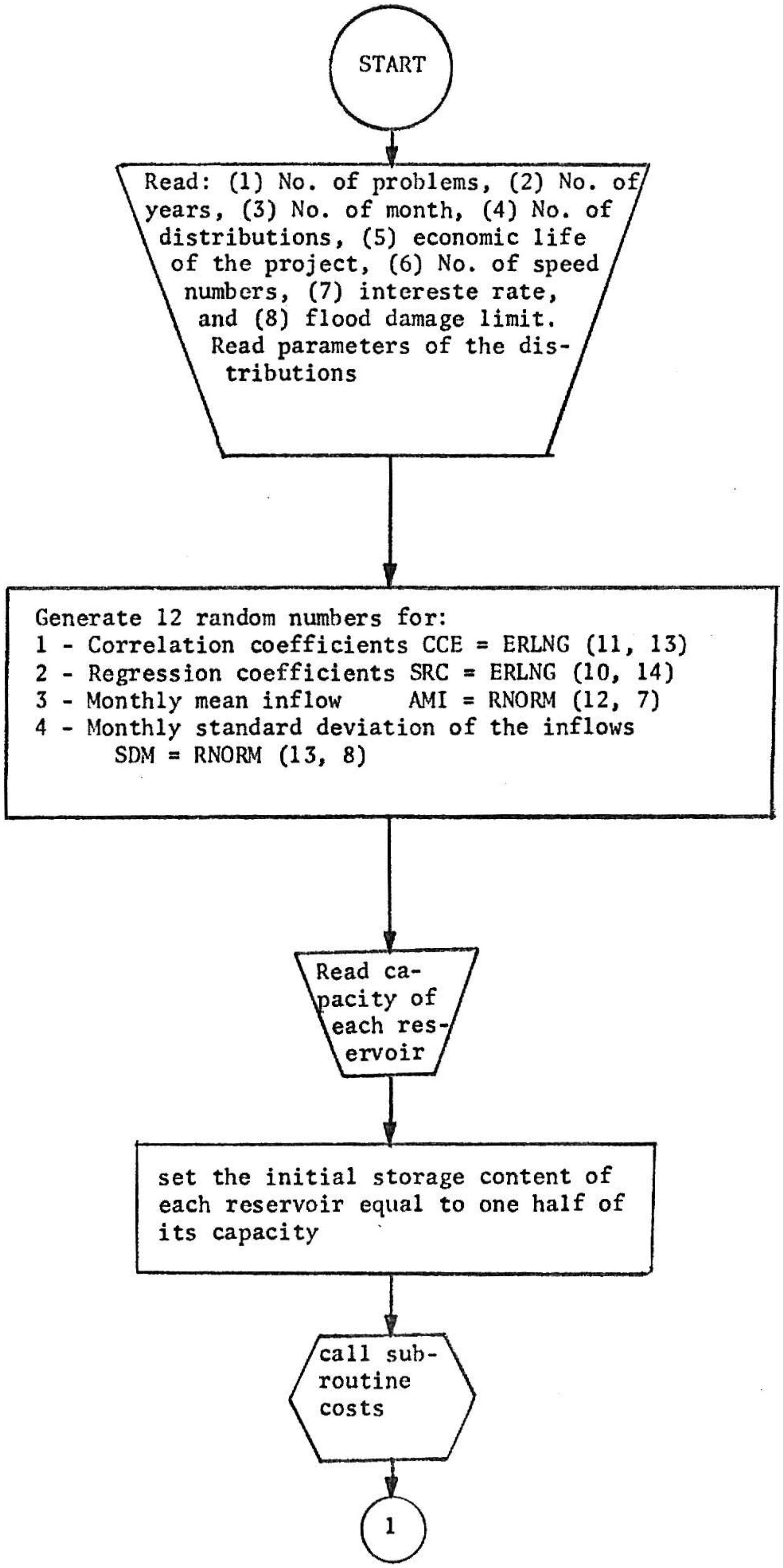
APPENDIX B

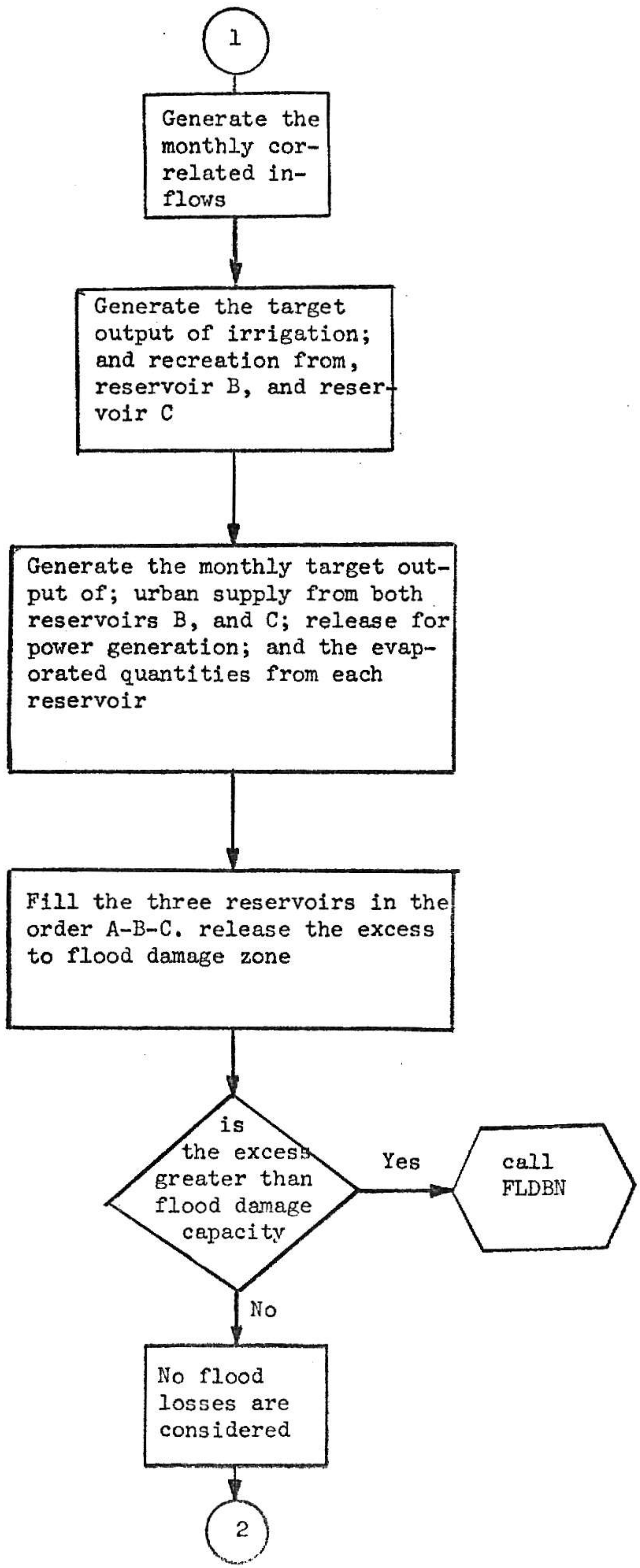
COMPUTER PROGRAM

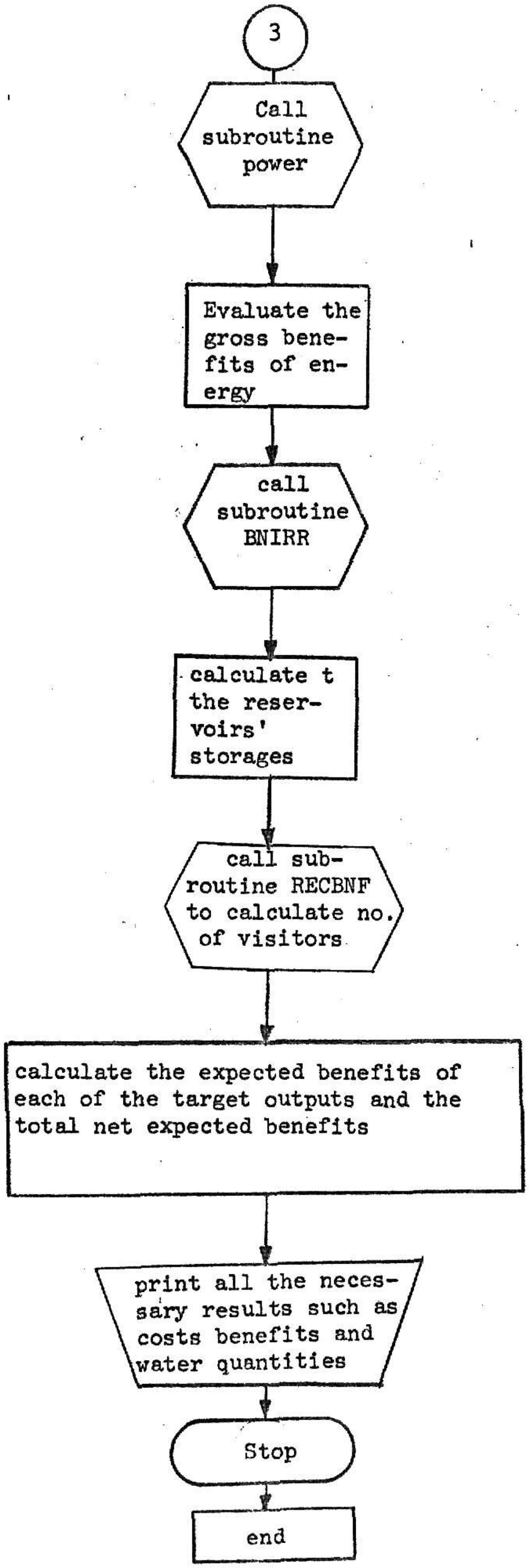
In this appendix, all the computer coding is presented and the flow charts of these codings are included. For the three-reservoir model, the flow charts of the main program, subroutine Costs, subroutine FLDBN, subroutine DOSPN, subroutine Power, and subroutine BNIRR are given. In additon to the main program coding of the one-reservoir model, the codings of these routines are introduced.

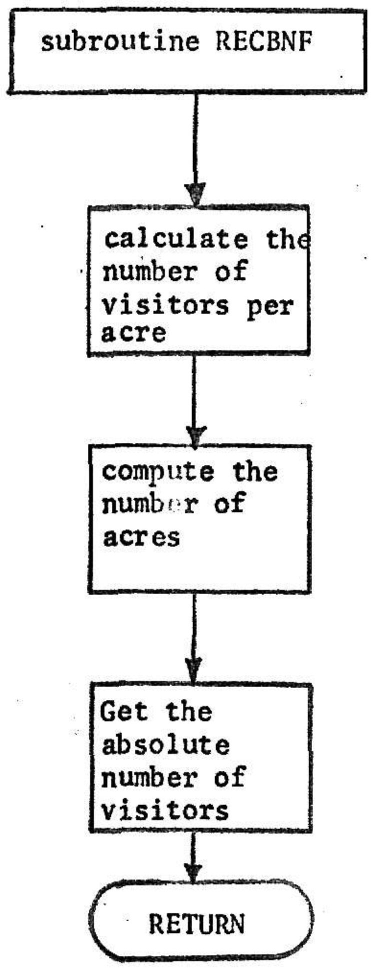
It should be pointed out that all the routines used in the coding of one-reservoir model are exactly the same as those of the three-reservoir model with exception of routine costs where the calculation of capital and OMR costs of reservoirs B and C are excluded.

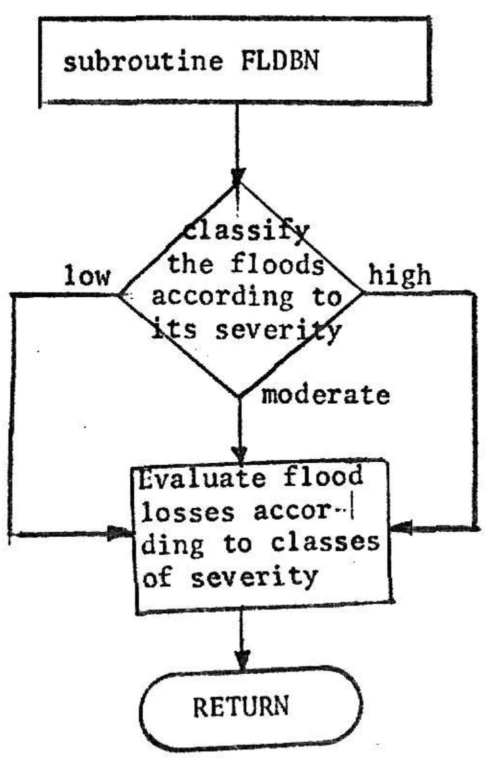
All the function subroutines used for the generation of random numbers are coded according to the logic discussed in appendix A. The coding of these function subroutines are also included in the current appendix.

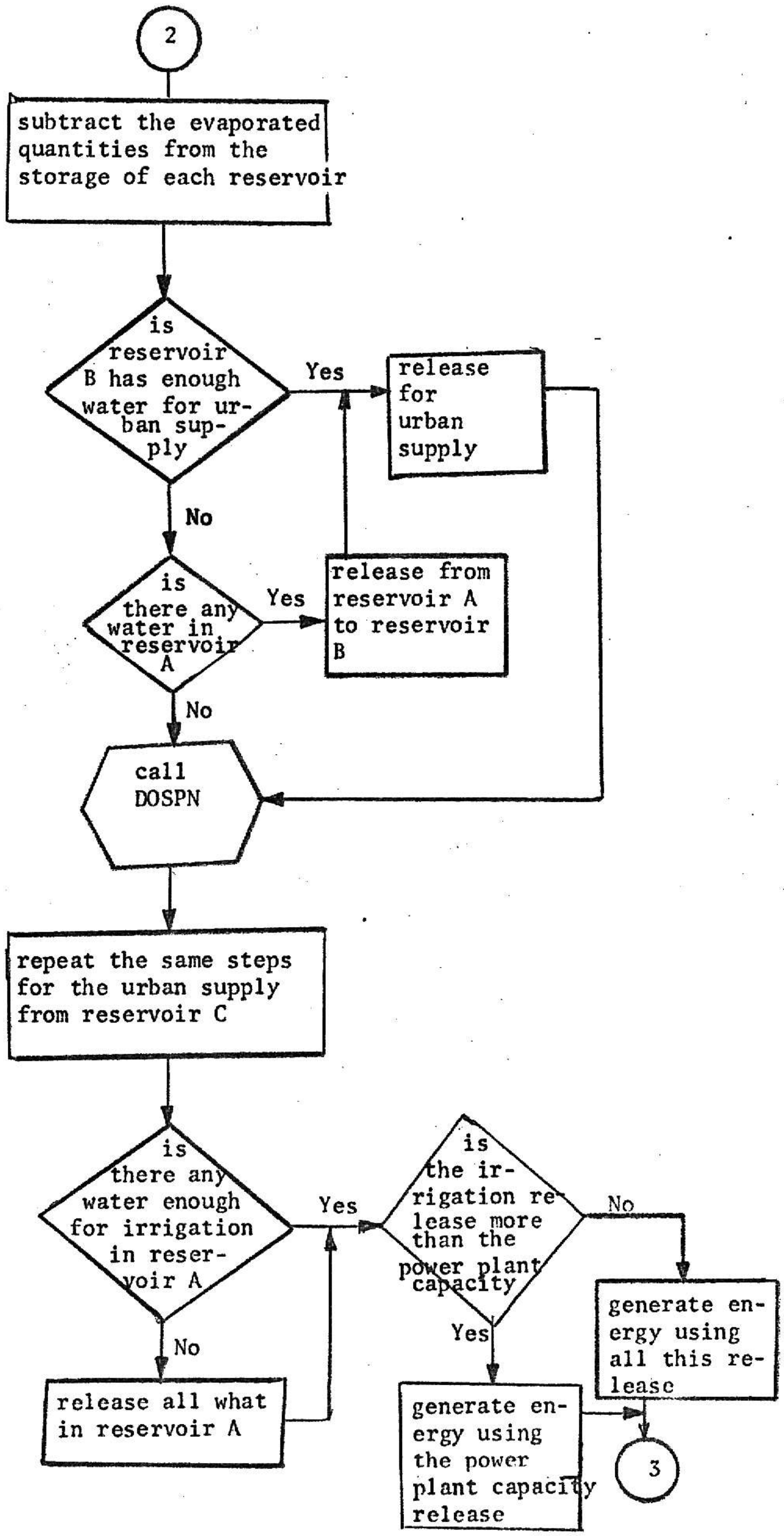

START
Read: (1) No. of problems, (2) No. of years, (3) No. of month, (4) No. of distributions, (5) economic life of the project, (6) No. of speed numbers, (7) intereste rate, and (8) flood damage limit. Read parameters of the distributions
Generate 12 random numbers for:
1 - Correlation coefficients CCE = ERLNG (11, 13)
2 - Regression coefficients SRC = ERLNG (10, 14)
3 - Monthly mean inflow AMI = RNORM (12, 7)
4 - Monthly standard deviation of the inflows SDM = RNORM (13, 8)
Read capacity of each reservoir
set the initial storage content of each reservoir equal to one half of its capacity
call subroutine costs
1

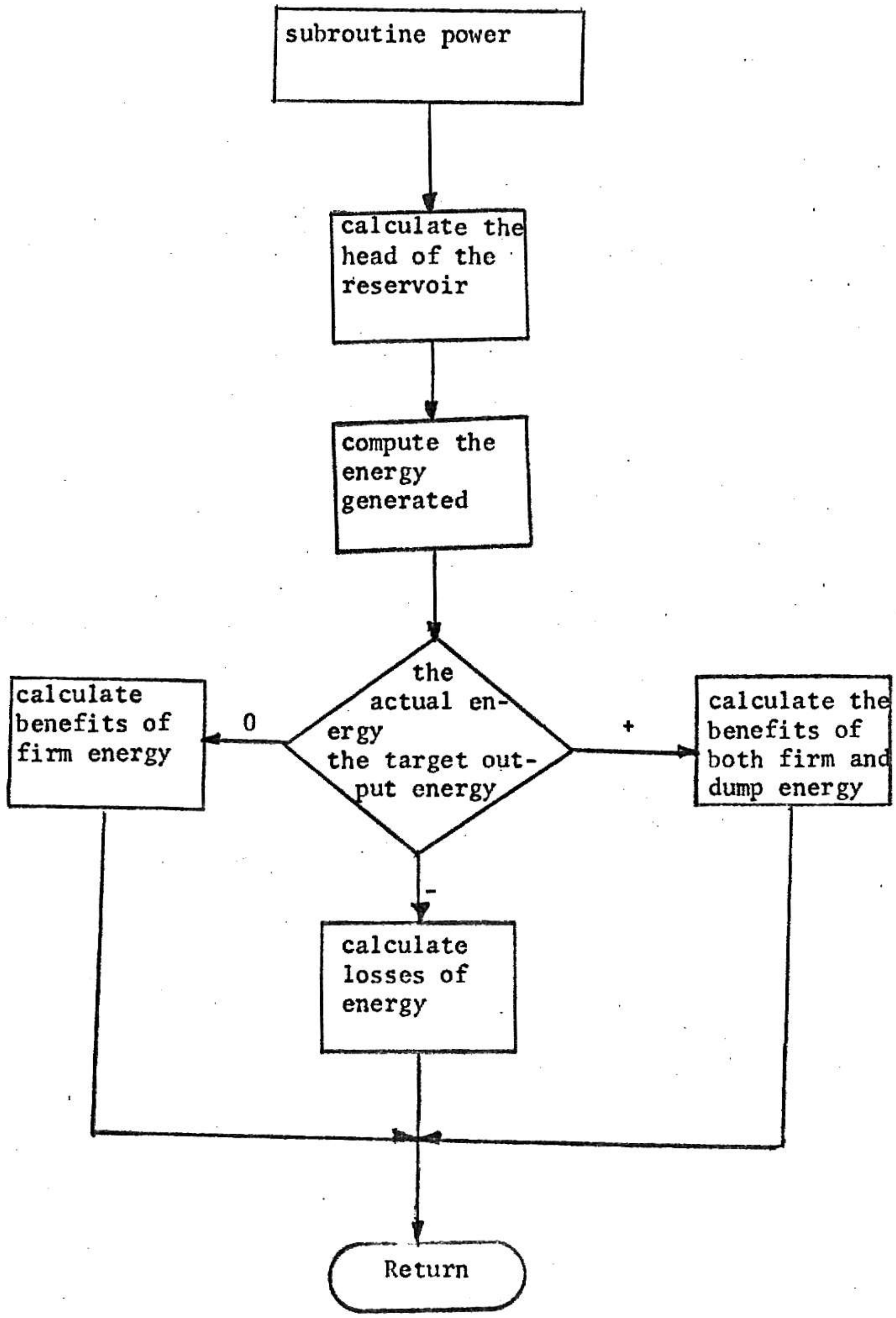

1
Generate the monthly correlated inflows
Generate the target output of irrigation; and recreation from, reservoir B, and reservoir C
Generate the monthly target output of; urban supply from both reservoirs B, and C; release for power generation; and the evaporated quantities from each reservoir
Fill the three reservoirs in the order A-B-C. release the excess to flood damage zone
is the excess greater than flood damage capacity
Yes
call FLDBN
No
No flood losses are considered
2

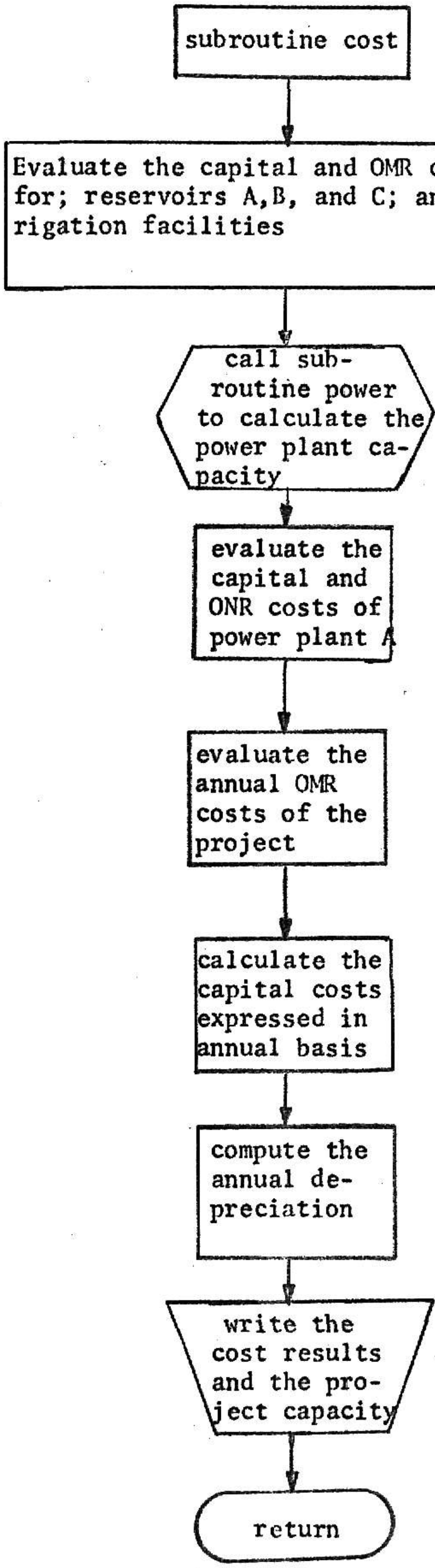

3
Call subroutine power
Evaluate the gross bene- fits of en- ergy
call subroutine BNIRR
calculate t the reser- voirs' storages
call sub- routine RECBNF to calculate no. of visitors
calculate the expected benefits of each of the target outputs and the total net expected benefits
print all the neces- sary results such as costs benefits and water quantities
Stop
end


subroutine RECBNF
calculate the number of visitors per acre
compute the number of acres
Get the absolute number of visitors
RETURN

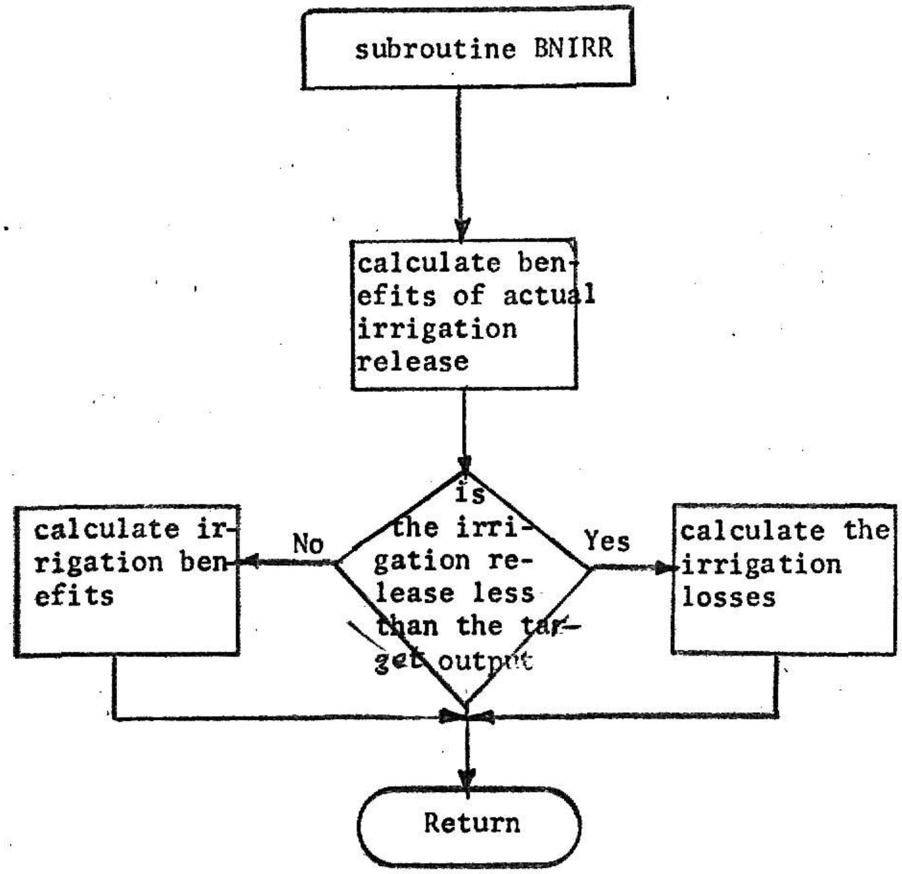

subroutine FLDBN
classify the floods according to its severity
low
high
moderate
Evaluate flood losses according to classes of severity
RETURN

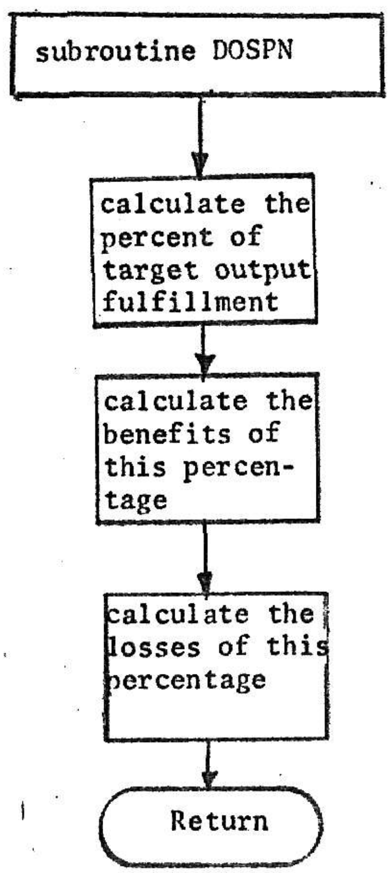

2
subtract the evaporated quantities from the storage of each reservoir
is reservoir B has enough water for urban supply
Yes
release for urban supply
No
is there any water in reservoir A
Yes
release from reservoir A to reservoir B
No
call DOSPN
repeat the same steps for the urban supply from reservoir C
is there any water enough for irrigation in reservoir A
Yes
is the irrigation release more than the power plant capacity
No
generate energy using all this release
Yes
generate energy using the power plant capacity release
No
release all what in reservoir A
3


subroutine power
calculate the head of the reservoir
compute the energy generated
the actual energy
the target output energy
0
+
-
calculate benefits of firm energy
calculate the benefits of both firm and dump energy
calculate losses of energy
Return



subroutine cost
Evaluate the capital and OMR costs for; reservoirs A,B, and C; and irrigation facilities
call subroutine power to calculate the power plant capacity
evaluate the capital and ONR costs of power plant A
evaluate the annual OMR costs of the project
calculate the capital costs expressed in annual basis
compute the annual depreciation
write the cost results and the project capacity
return


subroutine BNIRR
calculate benefits of actual irrigation release
is the irrigation release less than the target output
No
Yes
calculate irrigation benefits
calculate the irrigation losses
Return


subroutine DOSPN
calculate the percent of target output fulfillment
calculate the benefits of this percentage
calculate the losses of this percentage
Return

```
C*************************************************************
C
C
C              I. E. 896 RESEARCH IN INDUSTRIAL ENGINEERING
C                 SIMULATION IN WATER RESOURCES SYSTEM.
C
C
C*************************************************************
C
C
C    PROGRAMMED BY
C
C               A. ELIMAM
C         INDUSTRIAL ENGINEERING DEPARTMENT
C         KANSAS STATE UNIVERSITY
C
C
C*************************************************************
C
C    THIS PROGRAM FOR THE STUDY OF THREE RESERVOIR MODEL WITH
C    ONE POWER PLANT AND ONE FLOOD DAMAGE ZONE. THE MODEL HAS
C    BEEN EVALUATED IN TERMS OF COSTS AND ANNUAL EXPECTED BE-
C    NEFITS.
C
C    THE FOLLOWING ARE THE DEFINITIONS OF THE MAIN VARIABLES.
C
C    VARIABLE      DEFINITION
C    NOPRB         NUMBER OF PROBLEMS
C    NYEAR         NUMBER OF YEARS OVER WHICH THE STUDY IS PE-
C                  RFORMED.
C    MONTH         NUMBER OF MONTHES
C    NDIST         NUMBER OF SEED NUMBERS USED FOR THE RANDOM
C                  NUMBER GENERATION.
C    LP            ECONOMIC LIFE OF THE PROJECT.
C    MDISTU        NUMBER OF STATISTICAL DISTRIBUTIONS.
C    PRC           VALUE OF LOSSES DUE TO EVAPORATION
C    RI            INTEREST RATE.
C    FLTL          FLOOD DAMAGE LIMIT.
C    PARAM         THE PARAMETERS OF THE DISTRIBUTIONS FROM W-
C                  HICH THE RANDOM VARIABLES IN THE SYSTEM ARE
C                  GENERATED
C    CCE           CORRELATION COEFFICIENT .
C    SRC           REGRESSION COEFFICIENT.
C    AMI           MEAN MONTHLY INFLOWS.
C    SDM           STANDARD DEVIATION OF THE INFLOWS PER MONTH
C    CAPA          PREDETERMINED CAPACITY OF RESERVOIR A.
C    CAPB          PREDETERMINED CAPACITY OF RESERVOIR B.
C    CAPC          PREDETERMINED CAPACITY OF RESERVOIR C.
C    RSA,RNA       STORAGE CONTENT OF RESREVOIR A.
C    RSB,RNB       STORAGE CONTENT OF RESREVOIR B.
```

```
C    RSC,RNC         STORAGE CONTENT OF RESREVOIR C.
C    AR              MONTHLY INFLOWS TO THE SYSTEM.
C    WIR             IRRIGATION TARGET OUTPUT PER MONTH.
C    RCB             RECREATION TARGET OUTPUT FROM RESERVOIR B .
C    RCC             RECREATION TARGET OUTPUT FROM RESERVOIR C .
C    DMB             DOMESTIC SUPPLY TARGET OUTPUT FROM RESERVO-
C                    IR B PER MONTH.
C    DMC             DOMESTIC SUPPLY TARGET OUTPUT FROM RESERVO-
C                    IR C PER MONTH
C    PG              RELEASE TARGET OUTPUT FOR POWER GENERATION
C                    PER MONTH.
C    EA              EVAPORATED QUANTITIES FROM RESERVOIR A.
C    EB              EVAPORATED QUANTITIES FROM RESERVOIR B .
C    EC              EVAPORATED QUANTITIES FROM RESERVOIR C .
C
C***********************************************************************
      COMMON PARAM(50,50),IS(50)
      DIMENSION SRC(20),CCE(20),AMI(20),SDM(20),W(20),EA(20)
      DIMENSION EB(20),EC(20),DMB(20),DMC(20),WIR(20),PG(20)
      DIMENSION RSA(80,15),RSB(80,15),RSC(80,15),AR(80,15)
      DIMENSION RCB(20),RCC(20)
    1 FORMAT(8I10)
    2 FORMAT(3F15.4)
    3 FORMAT(14I5)
    4 FORMAT(4F10.4)
    6 FORMAT(1H0,'CAPACITY OF RESERVOIRS ',3F18.2)
    7 FORMAT(1H0,' NO. OF YEARS',I10,'  NO. OF MONTHS',I10)
    8 FORMAT(1H0,' SEED NUMBERS ',//,12I7)
    9 FORMAT(1H0,T40,' DISTRIBUTION PARAMETERS ')
   10 FORMAT(1H0,4F15.4)
   12 FORMAT(1H0,4F30.4)
   13 FORMAT(1H1,T40,' AVERAGE RESERVOIRS TARGET OUTPUTS ')
   15 FORMAT(1H0,8F15.5)
   16 FORMAT(1H0,6F20.4)
   17 FORMAT(1H1)
   30 FORMAT(1H0,I7,I10,5F16.4)
   50 FORMAT(1H ,T2,'IRRIGATION',4F20.4)
   60 FORMAT(1H ,T2,'ENERGY',4X,4F20.4)
   70 FORMAT(1H ,T2,'URBAN SUPPLY B',F16.4,3F20.4)
   80 FORMAT(1H ,T2,'URBAN SUPPLY C',F16.4,3F20.4)
   90 FORMAT(1H ,T2,'RECREATION B',F18.4,F20.4)
  101 FORMAT(1H ,T2,'RECREATION C',F18.4,F20.4)
  102 FORMAT(1H ,T2,'FLOOD CONTROL',F17.4,3F20.4)
  103 FORMAT(1H0,T40,'TOTAL BENEFITS=',F20.4)
  104 FORMAT(1H0,T40,' ANNUAL EVAPORATION LOSSES=',F20.4)
  105 FORMAT(1H0,T20,'RESERVOIR B',T40,'RESERVOIR C')
  106 FORMAT(1H0,'SURFACE AREA',F18.4,T40,F10.4)
  107 FORMAT(1H0,'HEAD',F26.4,T40,F10.4)
  108 FORMAT(8F15.4)
  109 FORMAT(1H0,T40,'TOTAL ANNUAL BENEFITS')
```

```
  112 FORMAT(1H0,T40,'EXPECTED BENEFITS PER YEAR')
  113 FORMAT(1H0,T20,' RATIO OF BENEFITS TO COSTS',F20.4)
  610 FORMAT(1H0,T6,'DUMP',F22.4,40X,F20.4)
C
C   READ DATA AND GIVE THE ECHO-CHECK
C
      READ(1,1) NOPRB
      READ (1,1) NYEAR,MONTH,NDIST,LP,MDISTU
      READ (1,3) (IS(I),I=1,MDISTU)
      READ(1,4) PRC,RI,FLTL
      DO 100  I=1,NDIST
      READ (1,4) (PARAM(I,J) ,J=1,4)
  100 CONTINUE
      WRITE(3,7) NYEAR,MONTH
      WRITE(3,8) (IS(I) ,I=1,MDISTU)
      WRITE(3,9)
      DO  110  I=1,NDIST
      WRITE(3,10) (PARAM(I,J),J=1,4)
  110 CONTINUE
C
C   GENERATE THE STASTICAL PARAMETERS, CORRELATION COEFFICI-
C   ENTS ,REGRESSION COEFFICIENTS , MEAN MONTHLY INFLOWS AND
C   MONTHLY STANDERED DEVIATIONS OF THE INFLOWS .
C
      YEAR=NYEAR
      NMONTH=MONTH+1
      DO  130 J=2,NMONTH
      CCE(J)=ERLNG(11,13)
      SRC(J)=ERLNG(10,14)
      AMI(J)=RNORM(12,7)
      SDM(J)=RNORM(13,8)
  130 CONTINUE
      WRITE(3,12)(SRC(J),CCE(J),AMI(J),SDM(J) ,J=2,NMONTH)
      DO 1234 JK=1,NOPRB
      READ (1,2) CAPA,CAPB,CAPC
      WRITE(3,6) CAPA,CAPB,CAPC
C
C   INITIALIZE THE STORAGES
C
      RSA(1,1)=CAPA/2.
      RSB(1,1)=CAPB/2.
      RSC(1,1)=CAPC/2.
      RNA=CAPA/2.
      RNB=CAPB/2.
      RNC=CAPC/2.
C
C   EVALUATE CAPITAL COSTS FOR RESERVOIRS A,B,C
C   EVALUATE OMR COSTS FOR THE SAME THREE RESERVOIRS
C   EVALUATE CAPITAL COSTS FOR THE IRRIGATION FACILITIES
C   EVALUATE OMR COSTS FOR THE IRRIGATION FACILITIES
```

```
C    EVALUATE POWER PLANT INSTLLATION CAPITAL COSTS
C    EVALUATE OMR COSTS FOR POWER PLANT.
C    GIVE THE PRINTOUT OF THE OBTAINED COSTS.
C
      CALL COSTS(CAPA,CAPB,CAPC,RI,LP,YY)
C
C    GENERATE THE MONTHLY CORRELATED INFLOWS(STANDEREDIZED)
C
      DO  140 L=1,NYEAR
      AR(L,2)=AMI(2)+SDM(2)*RNORM(14,12)
      DO  140 M=3,NMONTH
      K=M-1
      IF(AR(L,K) .LT. 0.0)  AR(L,K)=0.0
      W(M)=SDM(M)*RNORM(14,12)*SQRT(1.-CCE(K)**2)
      AR(L,M)=AMI(M)+SRC(K)*(AR(L,K)-AMI(K))+W(M)
      IF(AR(L,M)  .LT.  0.0)       AR(L,M)=0.0
  140 CONTINUE
      TAN=0.0
      TAP=0.
      TAF=0.0
      TAD=0.0
      TAV=0.0
      TEL=0.0
      DO  150  L=1,NYEAR
      ETEV=0.0
      WRITE(3,13)
C
C    GENERATE THE TARGET OUTPUT FOR IRRIGATION AND RECREATIO-
C    N FROM RESERVOIRS B,C ACCRODING TO SEASONAL PATTERN .
C
      J=2
      DO 212  KM=1,6
      MN=KM
      IF( KM .GT. 3) MN=7-KM
      KL=MN+3
      KN=KL+3
      DO 313 KK=1,2
      WIR(J)=ERLNG(MN,1)
      RCB(J)=NPOSN(KL,2)
      RCC(J)=NPOSN(KN,3)
      J=J+1
  313 CONTINUE
  212 CONTINUE
C
C    GENERATE THE TARGET OUTPUT YIELD FOR DOMESTIC SUPPLY FR-
C    OM RESERVOIRS B, C , POWER SUPPLY , AND THE EVAPORATED
C    QUANTITIES FROM EACH RESERVOIR .
C
      DO 145 M=2,NMONTH
      DMB(M) =UNFRM(0.008,1.392,4)
```

```
      DMC(M)= UNFRM(0.004,1.192,5)
      PG(M)=UNFRM(1.0,2.0,6)
      EA(M)=RNORM(15,9)
      EB(M)=RNORM(16,10)
      EC(M)=RNORM(17,11)
  145 CONTINUE
      ABN=0.0
      APN=0.0
      AND=0.0
      AFB=0.0
      ARV=0.0
      ATBOP=0.
      DO  155  M=2,NMONTH
      WRI=0.0
      DC=DMC(M)
      DB=DMB(M)
      K=M-1
C
C    DISTRIBUTE THE INFLOW SO THAT NO OVERFLOW OCCURS ACCORD-
C    ING TO THE PRIORITY (FILL RESERVOIRS A,B,C RESPECTIVELY)
C    SCHEDULE FLOOD CONTROL PROCEDURE
C
      FLB=0.
      CAPS=CAPA+CAPB+CAPC
      TWM=AR(L,M)+RNA+RNB+RNC
      RAN=TWM-CAPS
      IF( RAN .GT. FLTL)  GO TO 61
      FLD=0.
      TWA=0.
      GO TO 71
   61 CALL FLDBN(RAN,FLD)
      TWA=RAN
   71 FBM=FLB-FLD
      CHKA=CAPA-RNA
      IF(AR(L,M) .LE. CHKA)  GO TO 11
      RSA(L,M)=CAPA
      BR=AR(L,M)-CHKA
      CHKB=CAPB-RNB
      IF(BR .LE. CHKB)   GO TO 22
      RSB(L,M)=CAPB
      CR=BR-CHKB
      CHKC=CAPC-RNC
      IF(CR .LE. CHKC)    GO TO 33
      RSC(L,M)=CAPC
C
C    RELEASE TO THE FLOOD DEMAGE ZONE
C
      REST=CR-CHKC
      GO TO 45
   11 RSA(L,M)=RNA+AR(L,M)
```

```
      RSB(L,M)=RNB
      RSC(L,M)=RNC
      GO TO 44
   22 RSB(L,M)=RNB+BR
      RSC(L,M)=RNC
      GO TO 44
   33 RSC(L,M)=RNC+CR
   44 REST=0.0
   45 APG=PG(M)
C
C    UPDATE ALL YHE STORAGES AFTER EVAPORATED QUANTITIES HAVE
C    BEEN REDUCED.
C
      RSA(L,M)=RSA(L,M)-EA(M)
      RSB(L,M)=RSB(L,M)-EB(M)
      RSC(L,M)=RSC(L,M)-EC(M)
      IF(RSA(L,M)  .LT.  0.0)  RSA(L,M)=0.0
      IF(RSB(L,M)  .LT.  0.0)  RSB(L,M)=0.0
      IF(RSC(L,M)  .LT.  0.0)  RSC(L,M)=0.0
C
C    RELEASE FOR THE DOMESTIC SUPPLY FROM RESERVOIRS B AND C
C    IF THEY ARE EMPTY ,RELEASE FROM RESERVOIR A TO EACH ONE.
C    FURTHER MORE CALCULATE BENEFITS AND LOSSES .
C
      IF(RSB(L,M)-DMB(M))  55,56,57
   55 ADR=RSB(L,M)
      RSB(L,M)=0.0
      DRL=DMB(M)-ADR
      IF(RSA(L,M) .LT. DRL)  GO TO 58
      ADR=DMB(M)
      RSA(L,M)=RSA(L,M)-DRL
      DRL=0.0
      GO TO 59
   58 ADR=RSB(L,M)+RSA(L,M)
      RSA(L,M)=0.0
      DRL=DRL-RSA(L,M)
      GO TO 59
   56 ADR=DMB(M)
      RSB(L,M)=0.0
      DRL=0.0
      GO TO 59
   57 ADR=DMB(M)
      RSB(L,M)=RSB(L,M)-DMB(M)
      DRL=0.
   59 CALL DOSPN(ADR,DRL,DB,BND,UBB,ULB)
      ADB=ADR
      IF(RSC(L,M)-DMC(M))  65,66,67
   65 ADR=RSC(L,M)
      RSC(L,M)=0.0
      DRL=DMC(M)-ADR
```

```
      IF(RSA(L,M) .LT. DRL)  GO TO 68
      ADR=DMC(M)
      RSA(L,M)=RSA(L,M)-DRL
      DRL=0.0
      GO TO 69
   68 ADR=RSC(L,M)+RSA(L,M)
      RSA(L,M)=0.0
      DRL=DRL-RSA(L,M)
      GO TO 69
   66 ADR=DMC(M)
      RSC(L,M)=0.0
      DRL=0.0
      GO TO 69
   67 ADR=DMC(M)
      RSC(L,M)=RSC(L,M)-DMC(M)
      DRL=0.0
   69 CALL DOSPN(ADR,DRL,DC,CND,UBC,ULC)
      ADC=ADR
C
C    RELEASE FROM RESERVOIR A FOR IRRIGATION AND POWER GENER-
C    ATION AND FROM RESERVOIRS B AND C FOR IRRIGATION ONLY.
C    FURTHER MORE CALCULATE BENEFITS AND LOSSES .
C
      RNA=RSA(L,M)
      IF(RSA(L,M) .GT. WIR(M))  GO TO 77
      OIA=WIR(M)-RSA(L,M)
      WRI=WRI+RSA(L,M)
      RSA(L,M)=0.0
      IF(WRI .GT. 2.00)  WRP=2.0
      WRP=WRI
      CALL POWER(WRP,APG,RNA,ENR,0,PLL,PPD,HD,DUM,EDY)
      PNB=PPD-PLL
      IF(RSB(L,M) .GT. OIA)  GO TO 88
      OIB=OIA-RSB(L,M)
      WRI=WRI+RSB(L,M)
      RSB(L,M)=0.0
      IF(RSC(L,M) .GT. OIB)   GO TO 99
      OIC=OIB-RSC(L,M)
      WRI=WRI+RSC(L,M)
      RSC(L,M)=0.0
      GO TO  222
   77 RSA(L,M)=RSA(L,M)-WIR(M)
      IF(WIR(M) .GT. 2.0)  WRP=2.0
      WRP=WIR(M)
      CALL POWER(WRP,APG,RNA,ENR,0,PLL,PPD,HD,DUM,EDY)
      PNB=PPD-PLL
      GO TO 111
   88 RSB(L,M)=RSB(L,M)-OIA
      GO TO 111
   99 RSC(L,M)=RSC(L,M)-OIB
```

```
  111 WRI=WIR(M)
      OIC=0.0
  222 CALL BNIRR(WRI,OIC,BNI,BNL,BNN)
      RNA=RSA(L,M)
      RNB=RSB(L,M)
      RNC=RSC(L,M)
      TB=RCB(M)
      TC=RCC(M)
      CALL RECBNF(RNB,TB,VB,VLB,AB,HB)
      CALL RECBNF(RNC,TC,VC,VLC,AC,HC)
C
C   THIS PART GIVES ALL THE PRINTOUT REQUIRED.
C
      WRITE(3,30) L,K,RSA(L,M),RSB(L,M),RSC(L,M),AR(L,M),HD
      WRITE(3,105)
      WRITE(3,106)AB,AC
      WRITE(3,107)HB,HC
      WRITE(3,50) WRI,BNL,BNI,BNN
      WRITE(3,60) ENR,PLL,PPD,PNB
      WRITE(3,610) EDY,DUM
      WRITE(3,70) ADB,ULB,UBB,BND
      WRITE(3,80) ADC,ULC,UBC,CND
      WRITE(3,90) VB,VLB
      WRITE(3,101) VC,VLC
      WRITE(3,102) TWA,FLD,FLB,FBM
      ATBOP=ATBOP+BNN+PNB+BND+CND+FBM
      ABN=ABN+BNN
      APN=APN+PNB
      AND=AND+BND+CND
      AFB=AFB+FBM
      ARV=ARV+VB+VC
      ETEV=ETEV+EA(M)+EB(M)+EC(M)
      IF(M .NE. NMONTH)    GO TO 155
      L1=L+1
      M12=M-12
      RSA(L1,M12)=RSA(L,M)
      RSB(L1,M12)=RSB(L,M)
      RSC(L1,M12)=RSC(L,M)
  155 CONTINUE
C
C   CALCULATE EVAPORATION LOSSES
C
      EL=ETEV*PRC
      ATBOP=ATBOP-EL
      WRITE(3,104) EL
      WRITE(3,109)
      WRITE(3,108) ABN,APN,AND,AFB,ARV,ATBOP
      TAN=TAN+ABN
      TAP=TAP+APN
      TAD=TAD+AND
```

```
      TAF=TAF+AFB
      TAV=TAV+ARV
      TEL=TEL+EL
  150 CONTINUE
C
C   CALCULATE THE YEARLY EXPECTED BENEFITS .
C
      EP=TAP/YEAR
      ED=TAD/YEAR
      EF=TAF/YEAR
      EI=TAN/YEAR
      EV=TAV/YEAR
      VK=TEL/YEAR
      EXC=EP+ED+EF+EI
      TANB=EXC-YY-VK
      WRITE(3,112)
      WRITE(3,108) EI,EP,ED,EF,EV,TANB
      WRITE(3,104) VK
      RBTC=TANB/YY
      WRITE(3,113) RBTC
C
C   CHECK FOR THE HIGHEST CAPACITY UTILIZED IN RESERVOIRS
C
      RSAM=RSA(1,1)
      RSBM=RSB(1,1)
      RSCM=RSC(1,1)
      DO  160 I=1,NYEAR
      DO 160 J=2,NMONTH
      IF(RSA(I,J) .GE.RSAM)  RSAM=RSA(I,J)
      IF(RSB(I,J) .GE.RSBM)  RSBM=RSB(I,J)
      IF(RSC(I,J) .GE.RSCM)  RSCM=RSC(I,J)
  160 CONTINUE
      WRITE(3,12) RSAM,RSBM,RSCM
 1234 CONTINUE
      STOP
      END
```

```
      SUBROUTINE COSTS(A,B,C,RI,N,TAC)
C***********************************************************
C
C   THIS SUBROUTINE TO EVALUATE THE CAPITAL COSTS OMR COSTS
C   FOR THE THREE RESERVOIRS -POWER PLANT INSTALLATION-IRRI-
C   GATION . MOREOVER THE ANNUAL VALUES OF THESE COSTS ARE
C   OBTAINED AND DEPRECIATION HAS BEEN CALCULATED FOR THE
C   PROJEY BY THE SINKING FUND METHOM.
C
C***********************************************************
      COMMON PARAM(50,50),IS(50)
   10 FORMAT(1H1,T50,' PROJECT COSTS ')
   30 FORMAT(1H0,T5,'RESERVOIR A',3F20.4)
   40 FORMAT(1H0,T5,'RESERVOIR B',3F20.4)
   50 FORMAT(1H0,T5,'RESERVOIR C',3F20.4)
   60 FORMAT(1H0,T5,'IRRIGATION ',3F20.4)
   70 FORMAT(1H0,T5,'POWER PLANT A',F18.4,2F20.4)
   80 FORMAT(1H0,T5,'TOTAL',26X,2F20.4)
   90 FORMAT(1H0,2F20.6)
  100 FORMAT(1H0,'TOTAL ANNUAL COST OF THE PROJECT= ',F20.6)
C
C   EVALUATE CAPITAL COST OF RESERVOIR A WHICH IS FUNCTION
C   OF ITS CAPACITY A.
C
      AS=A*A
      AQ=A*AS
      AF=A*AQ
      CA=-2.6664+38.8582*A-4.7017*AS+0.2729*AQ-0.004483*AF
C
C   EVALUATE THE CAPITAL COST OF RESERVOIR B AS WAS FOR A
C
      BS=B*B
      BQ=B*BS
      CB=0.5349+31.8345*B-3.1238*BS+0.1145*BQ
C
C   EVALUATE THE CAPITAL COST OF RESERVOIR C AS IT WAS FOR A
C
      CS=C*C
      CQ=C*CS
      CF=CQ*C
      CC=0.5349+31.8345*C-3.1238*CS+0.1145*CQ
C
C   EVALUATE ANNUAL OMR COST OF RESERVOIRS A,B AS FUNCTION
C   OF CAPACITY WHILE FOR C AS AFUNCTION OF CAPITAL COST
C
      OMRA=1.5479+11.8057*A-0.7442*AS+0.02412*AQ
      OMRA=OMRA*.001
      BF=B*BQ
      OMRB=0.1748+13.55586*B-1.6208*BS+0.1559*BQ-0.006265*BF
      OMRB=OMRB*.001
```

```
      OMRC=0.1748+13.55586*C-1.6208*CS+0.1559*CQ-0.006265*CF
      OMRC=OMRC*.001
C
C   EVALUATE THE POWER PLANT CAPITAL COST
C
      LL=1
      Y=PARAM(3,3)
      OMRI=0.
      CALL POWER(2.,2.,A,EGR,LL,RW,WQ,WE,UU,GG)
      PCA=EGR/720.
      PAS=PCA*PCA
      IF(PCA  .LT.  600.)   GO TO 11
      CPP=4.18+0.138*PCA
      GO TO 22
   11 CPP=2.9973+0.1628*PCA-0.00006975*PAS
   22 PP=.000000000890424*PCA*PAS-.000000000001588 *PAS*PAS
      OMRP=0.001931+0.001876*PCA-0.000001294*PAS+PP
C
C   EVALUATE THE IRRIGATION CAPITAL COST AND THE OMR COST
C
      YS=Y*Y
      CI=-77.7242+37.8731*Y-0.6645*YS
      IF(Y  .LT.  4.2)  GO TO 33
      OMRI=.14*Y
   33 OMRI=OMRI+(Y/14.)
C
C   CALCULATE THE FUTURE VALUES FOR THE CAPITAL COSTS
C   CALCULATE THE DEPRECIATION OF THE CAPITAL COST
C   OBTAIN THE ANNUAL COST OF THE PROJECT
C
      N1=N-1
      TOMR=OMRA+OMRB+OMRC+OMRI+OMRP
      TCC=CA+CB+CC+CPP+CI
      AVL=TCC*RI*((1+RI)**N)/((1+RI)**N1)
      ADS=TCC*RI/((1+RI)**N1)
      TAC=AVL+ADS+TOMR
C
C   GIVE THE PRINTOUT OF THE RESULTS.
C
      WRITE(3,10)
      WRITE(3,30)A,CA,OMRA
      WRITE(3,40)B,CB,CMRB
      WRITE(3,50)C,CC,OMRC
      WRITE(3,60) Y,CI,OMRI
      WRITE(3,70)PCA,CPP,OMRP
      WRITE(3,80)TCC,TOMR
      WRITE(3,90) AVL,ADS
      WRITE(3,100) TAC
      RETURN
      END
```

```
      SUBROUTINE POWER(AW,TW,RS,AE,LL,PLL,PPD,HEAD,PDB,ED)
C*************************************************************
C
C    THIS ROUTINE TO CALCULATE THE GENERATED POWER FROM POWE-
C    R PLANT A - ALSO TO CALCULATE THE BENFITS OF THE ENERGY
C    OBTAINED IN DOLLARS .
C
C*************************************************************
      COMMON PARAM(50,50),IS(50)
C
C    FROM THE RESERVOIR CAPACITY CALCULATE THE HEAD.
C
      FDT=135.753000*RS
      SDT=-20.65669*RS*RS
      TDT=1.4875770*RS*RS*RS
      RDT=-0.039119*RS*RS*RS*RS
      HEAD=15.12986+FDT+SDT+TDT+RDT
C
C    DETERMINE THE GENERATED ENERGY AND CHECK FOR THE FULFIL-
C    LMENT OF THE ENERGY TARGET OUTPUT.
C
      AE=00.0871*HEAD*AW*10000.
      TENRGY=00.0871*HEAD*TW*10000.
      IF(LL  .EQ.  1)   GO TO 55
      IF(AE    -TENRGY)   11,22,33
   33 EF=TENRGY
      ED=AE    -TENRGY
      EL=0.0
      GO TO 44
   22 EF=AE
      ED=0.0
      EL=0.0
      GO TO 44
   11 EF=AE
      ED=0.0
      EL=TENRGY-AE
C
C    CALCULATE THE BENEFITS OR/AND LOSSES OF THE GENERATED E-
C    NERGY -ALSO EVALUATETHE NET BENEFITS .
C
   44 PGB=7.0*EF*.000001
      PLL=2.0*EL*.000001
      PDB=1.5*ED*.000001
      PNB=PGB+PDB-PLL
      PPD=PGB+PDB
   55 RETURN
      END
```

```
      SUBROUTINE BNIRR(W,TO,TBI,BLI,BNIR)
C***********************************************************
C
C   THIS ROUTINE FOR THE EVALUATION OF THE BENIFITS AND LOS-
C   SES OF IRRIGATION
C
C***********************************************************
      COMMON PARAM(50,50),IS(50)
      TS=TO*TO
      TQ=TO*TS
      WS=W*W
      WQ=WS*W
C
C   CALCULATE THE BENIFITS PER UNIT ACRE OF WATER FOR IRRIG-
C   ATION
C
      BTI=6.4945-0.71272*TO+0.08989*TS-0.004522*TQ
      BOI=6.4945-0.71272*W +0.08989*WS-0.004522*WQ
      TBI=BOI*W
C
C   CALCULATE THE LOSSES DUE TO THE WATER SHORTAGE FOR IRRI-
C   GATION.
C
      IF(W .LT. TO)   GO TO 11
      BLI=0.0
      GO TO 44
   11 WL=TO-W
      PD=WL/TO
      IF(PD .GT. 0.1)    GO TO 22
      BLI=0.7*WL
      GO TO 44
   22 IF(PD .GT. 0.7)   GO TO 33
      BLI=((2.0*BTI-0.07)/0.6)*(WL-0.1*TO)+0.07*TO
      GO TO 44
   33 BLI=0.2*(WL-0.7*TO)+0.07*TO*(2.*BTI-0.07)*TO
   44 BNIR=TBI-BLI
      RETURN
      END
```

```
      SUBROUTINE DOSPN(ADR,ADL,DMT,BND,BG,FL)
C**********************************************************
C
C   THIS ROUTINE TO CALCULATE THE BENIFITS AND LOSSES OF THE
C   DOMESTIC SUPPLY IN DOLLARS
C
C**********************************************************
      COMMON PARAM(50,50),IS(50)
      DSO=ADR/DMT
      DS=DSO*DSO
      DQ=DSO*DS
C
C   CALCULATE THE UNIT BENIFIT AS PERCENTAGE OF THE TARGET.
C
      UP=300.6462-981.5522*DSO+1286.391*DS-595.4962*DQ
      BG=UP*ADR*.01
      FL=0.0
      IF(DMT .LE. ADR)  GO TO 11
      PL=ADL/DMT
      PS=PL*PL
      PQ=PL*PS
C
C   CALCULATE THE LOSSES AS APERCENTAGE OF THE TARGET OUTPUT
C
      UL=-.119+98.2937*PL-269.0476*PS+361.111*PQ
      FL=UL*ADL*.01
   11 BND=BG-FL
      RETURN
      END
```

```
      SUBROUTINE FLDBN(Y,FD)
C***********************************************************
C
C   THIS ROUTINE FOR THE EVALUATION OF THE FLOOD DAMAGES OR
C   FLOOD BENEFITS OF THE SYSTEM.
C
C***********************************************************
      COMMON PARAM(50,50),IS(50)
      R=Y*16.8
      IF(R .GT.  260.)  GO TO 33
      IF(R  .GT.  150.0)   GO TO 22
      FD=-80.0+0.66666667*R
      RETURN
   33 FD=R/2.
      RETURN
   22 RS=R*R
      RQ=RS*R
      RF=R*RQ
      FM=-0.000010322*RF
      FD=-15093.71+308.208*R-2.358589*RS+0.0080524*RQ+FM
      RETURN
      END
```

```
      SUBROUTINE RECBNF(B,TR,PVB,PVL,A,H)
C**********************************************************
C
C   THIS ROUTINE FOR THE EVALUATION OF THE BENIFITS AND LOS-
C   SES OF RECREATION FCR RESERVOIRS B,C IN NUMBER OF VISITORS.
C
C**********************************************************
      COMMON PARAM(50,50),IS(50)
      BS=B*B
      BQ=B*BS
      VPA=182.87+252.70955*B-105.4714*BS+10.7334*BQ
      H=91.8701+92.1178*B-12.9916*BS+0.6707*BQ
C
C   CALCULATE THE SURFACE AREA AS AFUNCTION OF HEAD
C
      A=-0.8524+0.01592*H-0.00000456*H*H
      PVB=VPA*A
      IF(PVB  .GE.  TR )     GO TO 11
      PVL=TR-PVB
      GO TO 22
   11 PVL=0.0
   22 RETURN
      END
```

```
      FUNCTION RANDOM(I)
C*************************************************************
C
C   THIS ROUTINE FOR THE GENERATION OF RANDOM NUMBERS (0-1)
C
C*************************************************************
      COMMON PARAM(50,50),IS(50)
      IS(I)=IS(I)*65539
      IF(IS(I) .LT. 0)   IS(I)=IS(I)+2147483647+1
      RANDOM =IS(I)*0.4656613D-9
      RETURN
      END
      FUNCTION UNFRM(A,B,I)
C*************************************************************
C
C   THIS ROUTINE FOR THE GENERATION OF UNIFORM RANDOM NUMBE-
C   RS
C
C*************************************************************
      COMMON PARAM(50,50),IS(50)
      UNFRM=A+(B-A)*RANDOM(I)
      RETURN
      END
      FUNCTION ERLNG(J,I)
C*************************************************************
C
C   THIS ROUTINE FOR THE GENERATION OF ERLNG RANDOM NUMBERS
C
C*************************************************************
      COMMON PARAM(50,50),IS(50)
      K=PARAM(J,4)
      TR=1
      DO 10 L=1,K
      TR=TR*RANDOM(I)
   10 CONTINUE
      ERLNG=-PARAM(J,1)*ALOG(TR)
      IF(ERLNG-PARAM(J,2))   7,5,6
    7 ERLNG=PARAM(J,2)
    5 RETURN
    6 IF(ERLNG - PARAM(J,3)) 5,5,4
    4 ERLNG=PARAM(J,3)
      RETURN
      END
```

```
      FUNCTION RNORM(J,I)
C************************************************************
C
C   THIS ROUTINE FOR THE GENERATION OF NORMAL RANDOM NUMBERS
C
C************************************************************
      COMMON PARAM(50,50),IS(50)
      RV1=RANDOM(I)
      RV2=RANDOM(I)
      V=(-2.0*ALOG(RV1))**0.5*COS(6.283*RV2)
      RNORM=V*PARAM(J,4)+PARAM(J,1)
      IF(RNORM-PARAM(J,2))  6,7,8
    6 RNORM=PARAM(J,2)
    7 RETURN
    8 IF(RNORM-PARAM(J,3))  7,7,9
    9 RNORM=PARAM(J,3)
      RETURN
      END
      FUNCTION NPOSN(J,I)
C************************************************************
C
C   THIS ROUTINE FOR THE GENERATION OF DISCRETE -POISSON-
C   RANDOM VARIABLE.
C
C************************************************************
      COMMON PARAM(50,50),IS(50)
      NPOSN=0
      P=PARAM(J,1)
      IF(P-6.) 2,2,4
    2 Y=EXP(-P)
      X=1.
    3 X=X*RANDOM(I)
      IF(X-Y)  6,8,8
    4 T=PARAM(J,4)
      PARAM(J,4)=SQRT(PARAM(J,1))
      NPOSN=RNORM(J,I)+0.5
      PARAM(J,4)=T
      IF(NPOSN)   4,6,6
    6 KK=PARAM(J,2)
      KF=PARAM(J,3)
      NPOSN=NPOSN+KK
      IF(NPOSN-KF)  7,7,9
    7 RETURN
    8 NPOSN=NPOSN+1
      GO TO 3
    9 NPOSN=PARAM(J,3)
      RETURN
      END
```

```
C***********************************************************
C
C   THIS PROGRAM FOR THE STUDY OF ONE RESERVOIR
C
C***********************************************************
      COMMON PARAM(20,20),IS(20)
      DIMENSION GE(80,20)
      DIMENSION SRC(20),CCE(20),AMI(20),SDM(20),W(20)
      DIMENSION AR(80,15),STCP(80,15)
      DIMENSION WIR(20),PGW(20),EVQ(20)
    1 FORMAT(5I10)
    2 FORMAT(10I8)
    3 FORMAT(4F10.2)
    4 FORMAT(10F13.4)
    5 FORMAT(1H1)
   14 FORMAT(4F20.4)
   15 FORMAT(2F20.4)
C
C   READ THE INPUT - GIVE TNE ECHO CHECK
C
      READ(1,1) NPRB
      READ(1,3) RI,FLTL
      READ  (1,1) NYEARS,NMONTH,NDIST,NDATA,NN
      READ (1,2) (IS(I), I=1,NDIST)
      WRITE(3,2) (IS(I), I=1,NDIST)
      DO 100 I=1,NDIST
      READ (1,3) (PARAM(I,J) ,J=1,4)
      WRITE(3,3) (PARAM(I,J) ,J=1,4)
  100 CONTINUE
C
C   GENERATE THE STATISTICAL PARAMETERS NECESSARY TO GENERA-
C   TE THE MONTHLY INFLOWS.
C
      YEAR=NYEARS
      DO 110 J=2,NMONTH
      SRC(J)=ERLNG(4,1)
      CCE(J)=ERLNG(5,2)
      AMI(J)=RNORM(6,3)
      SDM(J)=RNORM(7,4)
  110 CONTINUE
      DO  1111 KL=1,NPRB
      READ(1,3) CAP
C
C   EVALUATE THE VARIOUS COSTS OF THE PROJECT.
C
      CALL COSTS(CAP,RI,NN,TC)
      WRITE(3,5)
      RCP=CAP/2.
      BIT=0.0
      BPT=0.0
```

```
      TFL=0.0
      DO 130 L=1,NYEARS
      FBY=0.0
      BOI=0.0
      BOP=0.0
C
C   GENERATE THE IRRIGATION TARGET OUTPUT ACCORDING TO SEAS-
C   ONAL PATTERN .
C
      J=2
      DO 212  KM=1,6
      MN=KM
      IF( KM .GT. 3) MN=7-KM
      DO 313 KK=1,2
      WIR(J)=ERLNG(MN,1)
      J=J+1
  313 CONTINUE
  212 CONTINUE
C
C   GENERATE THE MONTHLY AND SERIALLY CORRELATED INFLOWS .
C
      AR(L,1)=AMI(2)+SDM(2)*RNORM(8,5)
      IF(AR(L,1)  .LT. 0.0) AR(L,1)=0.0
      DO 120 M=2,NMONTH
      W(M)=SDM(M)*SQRT(1.-CCE(M)**2)
      K=M-1
      STCP(L,K)=RCP
C
C   GENERATE THE TARGET OUTPUT OF POWER AND THE EVAPORATED -
C   QUANTITIES.
C
      PGW(M)=UNFRM(0.,2.,7)
      EVQ(M)=RNORM(9,8)
      AR(L,M)=AMI(M)+SRC(M)*(AR(L,K)-AMI(M))+RNORM(8,5)*W(M)
      IF(AR(L,M) .LT. 0.0)  AR(L,M)=0.
      RCP=RCP-EVQ(M)
      WRI=WIR(M)
      PGR=PGW(M)
C
C   SCHEDULE FLOOD CONTROL
C
      CHK=CAP-RCP
      FB=0.0
      IF(CHK-AR(L,M))  21,31,41
   21 RCP=CAP
      RAN=AR(L,M)-CHK
      IF(RAN  .GT. FLTL)  GO TO 51
      FL=0.0
      GO TO 61
   31 RCP=CAP
```

```
      FL=0.0
      GO TO 61
   41 RCP=RCP+AR(L,M)
      FL=0.0
      GO TO 61
   51 CALL FLDBN(RAN,FL)
   61 FBM=FB-FL
      RS=RCP
C
C    RELEASE FOR IRRIGATION AND POWER GENERATION .
C
      IF(WIR(M)-RCP) 11,22,33
   11 AWI=WIR(M)
      RCP=RCP-WIR(M)
      ALI=0.0
      GO TO 44
   22 AWI=WIR(M)
      RCP=0.0
      ALI=0.0
      GO TO 44
   33 AWI=RCP
      RCP=0.0
      ALI=WIR(M)-AWI
   44 CALL BNIRR(AWI,WRI,TBI,BLI,BNIR)
      IF(PGW(M)-WIR(M)) 55,66,77
   55 APR=PGW(M)
      APL=0.0
      GO TO 88
   66 APR=WIR(M)
      APL=0.0
      GO TO 88
   77 APR=WIR(M)
      APL=PGW(M)-WIR(M)
   88 CALL POWER(APR,PGR,RS,ENR,0,PL,PB,PH)
      GE(L,M)=ENR
      BPM=PB-PL
      STCP(L,M)=RCP
      WRITE(3,4) AR(L,M),RCP,AWI,TBI,BLI,BNIR,ENR,FBM,BPM,PH
C
C    CALCULATE AND PRINT THE EXPECTED BENEFITS OF IRRIGATION
C    POWER, AND THE TOTAL BENEFITS .
C
      BOI=BOI+BNIR
      BOP=BOP+BPM
      FBY=FBY+FBM
      TB=BOI+BOP+FBY
  120 CONTINUE
      WRITE(3,14)    BOI,BOP,FBY,TB
      BIT=BIT+BOI
      BPT=BPT+BOP
```

```
      TFL=TFL+FBY
  130 CONTINUE
      EBI=BIT/YEAR
      EPP=BPT/YEAR
      EFL=TFL/YEAR
      TEB=EBI+EPP+EFL
      ENP=TEB-TC
      RPC=ENP/TC
      WRITE(3,14) EBI,EPP,EFL,TEB
      WRITE(3,15) ENP,RPC
 1111 CONTINUE
      STOP
      END
```

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DIGITAL SIMULATION OF WATER RESOURCES SYSTEMS

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AN ABSTRACT OF A MASTER'S THESIS

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The main objective of this research was to study a multi-purpose three-reservoir model with one power plant. The stochastic behavior of the monthly inflows has been included. Correlation among these inflows has been also considered. Some of the target output of the system has followed certain seasonal pattern. The effect of changing the inflows on the system performance has been considered. Emphasis has been given to the influences of individual reservoirs' capacities than to the total capacity of the system. Evaporation effect on the reservoirs' storage has also been also included.

Costs and benefits of the proposed system have been evaluated. Benefits are expressed in terms of expectation. In addition to expected net benefits, benefit-cost ratio has been also obtained and used to measure the system performance. Optimal combinations of reservoir capacities have been obtained. Digital simulation has been used in designing and operating the system.

It has been concluded that the system is much more sensitive to the individual reservoirs' capacities than to the total capacity of the system. Further the total expected net benefits have been found to be more influenced by the expected flood losses for the high mean inflows while they have the same pattern as the expected benefits of irrigation and energy for the low mean inflows. Moreover, the maximum expected benefits of irrigation, energy, and urban supply are associated with high mean inflows. Finally the expected benefits of the system may not increase as its cost rises because of stochastic variation; however, the general trend of this relation goes upward as cost increases. These results and conclusions have been reached by limiting the normal random deviate, which influences the variation of the inflow, within ± three standard deviation.