INTEGRATED PLANNING AND OPERATION OF A RESERVOIR

A THESIS

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in
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By

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Gratis

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled "**INTEGRATED PLANNING AND OPERATION OF A RESERVOIR**" in fulfillment of the requirement for the award of the Degree of **Doctor of Philosophy**, and submitted in the **Department of Hydrology, University of Roorkee, Roorkee** is an authentic record of my own work carried out during a period from July 1991 to June 1995 under the supervision of **Dr. D.K Srivastava.**

The matter embodied in this thesis has not been submitted by me for the award of any other degree.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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ABSTRACT

Isolated studies on various aspects of planning/operation of a reservoir have been carried out and presented in various studies, using systems analysis techniques. A few studies on combined planning and operation of a reservoir are available in literature. Systematic studies towards the various water resources planning and management aspects of integrated planning and operation of a reservoir, i.e., determination of (i) conservation/flood control storages (ii) annual firm/targeted/secondary requirements for irrigation and hydropower (iii) seasonal/year to year or over-year carry-over reservoir capacity/storages and (iv) annual reservoir operation rules, all using systems analysis and (v) selection of annual flow of a given dependability for project planning depending on water use have not been presented.

The specific decision problem under consideration is to solve the integrated planning and operation of a reservoir (single purpose and/or multipurpose) using systems analysis techniques. For this four different single reservoir projects have been selected on different rivers and are located at different locations in India, these are (i) Badanala irrigation project under normal hydrological conditions (ii) Kalluvodduhalla irrigation project under drought conditions (iii) Bodhghat hydroelectric project and (iv) Bargi multipurpose project.

The approach now is to formulate suitable models for various aspects of planning and operation of a reservoir. Often these problems are very complex with different objective, scope, and scale. In such case, there is usually no unique model for the problem. Then a set of linked models may be used. These models may be nested in such a fashion that outputs of one models are inputs to another or two models are run in tandem. Although, the answer to how the model links should be arranged is problem specific. Such use of nested models may be often quite useful. The use of optimization-simulation techniques as nested models is envisaged here to solve these integrated planning and operation problems of a reservoir. It is proposed to use linear programming and dynamic programming as optimization techniques.

The preparation of input data for computation of linear programming by computer are data-intensive and a Herculean task. To overcome this difficulty a suitable computer software for generating the input data matrix for linear programming optimization problems applicable to reservoir planning and operation, called MATGEN PACKAGE has been developed.

Two categories of optimization models were used for reservoir planning as follows:

Category-I Models: These models were used to account for short term variations in the river inflows. They used river flow data of one year length only.

A concept of using annual flows of a probability of given occurrence was introduced in these models to account for the long term variations in the inflows.

Category-II Models: These models were used to account for long term variations in the river inflows. They used river flow data of the entire length of the recorded historical flows.

Reservoir operation was carried out using multi-rule curves based of the actual monsoon flows and the state of the reservoir at the end of monsoon period. In one of the rule curves a new concept of available over-year carry-over reservoir storage at the end of the year (non-monsoon period) is introduced. These rule curves were (i) Variable Upper Rule Curve to provide over-year carry-over reservoir storage at the end of a year and the targeted demand in the non-monsoon period (ii) Middle Rule Curve to provide targeted demand in the non-monsoon period and (iii) Lower Rule Curves to provide firm demands in non-monsoon period.

Category-I models require less computer memory and reasonably less computation time. Also, these models use river flow data of same length, i.e, of one year length only depending upon type of project, which makes this approach more uniform in terms of the length of data used.

Category-II models require large computer memory and large computation time. These models use river flow data of different lengths, which makes this approach non-uniform in terms of the length of data used.

The multi-rule curves operation of a reservoir project with irrigation with the help of Variable Upper Rule Curve reduces water use deficits in early monsoon and the later non-monsoon periods. However, for a single purpose hydropower reservoir operation, use of only Lower Rule Curve is recommended.

On the basis of the experience of applying the above models, a suitable and uniform methodology for integrated planning and operation of a reservoir using Category-I models with the help of nested models for planning and multi-rule curves for operation has been finally suggested. Also use of annual flows of probabilities of given occurrences is recommended.

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CHAPTER 1

INTRODUCTION

Chapter-1

INTRODUCTION

The prime objective of a water resources development project is generally concerned as maximizing the national or regional welfare. Modern water resources projects are mostly planned to satisfy the needs of more than one purposes. The type of works and measures to be adopted will depend upon the purposes to be served and the extent of services to be provided by the project. A reservoir is one of those structures needed. To fulfill these needs, the size of the reservoir should be carefully planned (Chow, 1988). Sufficient storages should be provided in a reservoir, firstly, to cater the needs of water supply during normal water requirements and during droughts by ascertaining dependable flows, secondly, to absorb a considerable portion of the flood waters during extreme flood events. It is obvious that planning must precede design and construction not only in discussion but also in actual practice.

The mass diagram analysis to estimate the active reservoir capacity is one of the earliest method given by Rippl (Rippl, 1883). Over the past 30 years analytical techniques have evolved from a nearly exclusive reliance on narrowly defined engineering design studies to wide spread use of some form of systems analysis. Modeling provides a way, perhaps the principal way, of predicting the future behaviour of existing or proposed water resources system. Applications of models to real systems have improved our understanding of such systems, and hence have often contributed to improved systems design, management and operation. Evaluating the applications of numerous types of models has also taught us how limited our modeling skills remain (Loucks, 1992).

1.1.0 PROBLEM IDENTIFICATION

Isolated studies on various aspects of planning/operation of a reservoir have been carried out and presented in various studies, using systems analysis techniques. A few studies on combined planning and operation of a reservoir are available in literature (Loucks et al., 1981; Yakowtiz, 1982; Stedinger, 1984; and Rogers and Fiering, 1986). Systematic studies towards the various water resources planning and management aspects of integrated planning and operation of a reservoir, i.e., determination of (i) conservation/flood control storages (ii) annual firm/targeted/secondary requirements for irrigation and hydropower (iii) seasonal/year to year or over-year carry-over reservoir capacity/storages and (iv) annual reservoir operation rules, all using systems analysis and (v) selection of annual flow of a given dependability for project planning depending on water use have not been presented.

The specific decision problem under consideration is to solve the integrated planning and operation of a reservoir (single purpose or multipurpose) using systems analysis techniques. For this four different single reservoir projects have been selected on different rivers and are located at different locations in India, these are (i) Badanala irrigation project under normal hydrological conditions (ii) Kalluvodduhalla irrigation project under drought conditions (iii) Bodhghat hydroelectric project and (iv) Bargi multipurpose project.

Keeping in mind the above considerations and recognizing the need of suitable approach, the following objectives were set as the scope of this work.

1.2.0 OBJECTIVES OF PRESENT STUDY

The basic objectives in the present thesis can be defined as under:

(i) To develop optimization-simulation models for integrated planning and operation of a reservoir (single purpose and/or multipurpose). It is proposed to use linear programming and dynamic programming as optimization techniques.

(ii) To determine various reservoir capacities (i.e., conservation storage, flood control storage) for given hydrological conditions and water use aspects.

(iii) To determine annual project requirements for irrigation and hydropower (i.e., firm, targeted, and secondary) which can be delivered from a reservoir.

(iv) To determine reservoir carry-over capacity/storages (i.e., seasonal, and year to year or over-year which will be required or made available during various periods) for a reservoir for given annual project requirements.

(v) To determine reservoir operation policy.

(vi) Since, the preparation of input data for computation of linear programming by computer are data-intensive and a Herculean task (Razavian et al., 1990), it is proposed to develop a suitable computer software for generating the input data matrix for linear programming optimization problems applicable to reservoir planning and operation.

(vii) While using these models it is to determine that how effectively they can be used together in reservoir project planning and operation. Further, how much realistic they are when compared in terms of reasonableness with values determined by conventional methods.

(viii) To draw suitable conclusions from the above results and the experience of applying the above optimization-simulation models on to a reservoir in order to utilize its full developmental potential in the best possible manner.

(ix) The final aim of the study is to develop and recommend a suitable and uniform methodology for integrated planning and operation of a reservoir using systems analysis.

methodology

1.3.0 THE APPROACH

The approach now is to formulate suitable models for various aspects of planning and operation of a reservoir. Often these problems are very complex with different objective, scope, scale and timing considerations. In such case, there is usually no unique model for the problem. Then a set of linked models may be used. These models may be nested in such a fashion that outputs of one model are inputs to another or two models are run in tandem. Although, the answer to how the model links should be arranged is problem specific. Such use of nested models may be often quite useful. The use of optimization-simulation techniques as nested models is envisaged here to solve these integrated planning and operation problems.

1.4.0 THE CHAPTER WISE PLANNING OF THE THESIS REPORT

With respect to the said objectives, this research work is reported in eleven chapters.

CHAPTER-2

In this chapter **"Literature Review"** a literature review is presented related to the topics of planning and operation of reservoir using linear programming, dynamic programming and simulation. The literature survey has been done in the Journals of Water Resources Research; Water Resources Planning and Management, ASCE; Water Resources Bulletin; Water Resources Management and some text books related to the topics. A description of the approach/model developed by different researchers is presented in chronological order as far as possible.

CHAPTER-3

This chapter is devoted towards **"Linear Programming Models"** formulation in the context of the various planning aspects of a reservoir.

CHAPTER-4

This chapter is devoted towards **"Dynamic Programming Model"** formulation.

CHAPTER-5

This chapter deals with **"Simulation Model"** formulation.

CHAPTER-6

In this chapter **"Linear Programming Model - Software Development for Input Data Matrix (Matgen Package)"** development of a computer software package called **(Matgen Package)** to generate required input data matrix for L.P. model is presented.

CHAPTER-7

In **"The River Systems"** a brief introduction of various reservoirs and their river basins have been presented on which the proposed models were applied.

CHAPTER-8

Deals with **"Application of Models, Computation and Results for Reservoir Planning"**. The proposed models have been applied onto various single purpose/multipurpose reservoirs keeping in mind the objectives mentioned in **Chapter-1.** The results and discussions are also presented in this chapter.

CHAPTER-9

A brief introduction of reservoir operation is presented in the chapter **"Reservoir Operation"**.

CHAPTER-10

This chapter **"Application of Models, Computation and Results for Reservoir Operation"** deals with computations for reservoir operation.

CHAPTER-11

Based on the results and experience of the computation carried out analysis is done and suitable conclusions have been drawn, and suggestions for future work are presented in the chapter **"Analysis and Conclusion"**.

CHAPTER 2

REVIEW OF LITERATURE

Chapter-2

REVIEW OF LITERATURE

2.1.0 INTRODUCTION

Perhaps one of the earliest methods used to calculate the active reservoir storage capacity required to meet a specified reservoir release in sequence of periods was developed by Rippl in 1883 (Rippl, 1883; and Fair et al., 1966). His Mass diagram analysis is still used today by many water resource planners. A modification of the cumbersome mass curve method was the sequent-peak procedure, a well-known simplistic algorithm for determining the storage capacity requirement for reservoir (Thomas and Burden, 1963). Potter (1977) used the sequent peak procedure to size a reservoir. Two cycles of inflows and drafts were analyzed. The use of two cycles resulted in the identification of the minimum reservoir capacity which, when simulated with the design inflows and drafts, would not only meet demands but would also result in a final storage which equals or exceeds the initial storage. Demonstration of optimality followed from consideration of method which was equivalent to the sequent peak procedure.

The incentive to plan for better use of any water resource has stimulated the development, over the last several decades, of improved analytical tools and methodologies for defining and evaluating alternatives for managing such systems. The systems analysis is one of the such tools. Water resources systems analysis has now been generally accepted to provide an efficient way of answering the numerous questions regarding planning of large scale water resources systems for which the conventional methods of analysis will be inadequate. The approach and appropriate technique will naturally vary from problem to problem as the configuration, state of development of the system, and stage of decision making is likely to vary over a vast range (Mass et al., 1962; Hufschmidt and Fiering, 1966; Hall and Dracup, 1970;

Haimes, 1977; Loucks et al., 1981; Chaturvedi, 1987; and Wurbs, 1993).

Several mathematical programming techniques (optimization or analytical) have been used, these are (1) linear programming (Young, 1967; Loucks, 1968; Srivastava and Tiwari, 1978; Datta and Burges, 1984; Srivastava and Uddihal, 1985; and Rogers and Fiering, 1986), and (2) dynamic programming (Hall and Dracup, 1970; Haimes, 1977; Yakowitz, 1982; Fontane, 1982; Buras, 1985; Rogers and Firing, 1986; and Karamouz and Houck, 1987). These methods can be used for optimization of water resources systems.

The above optimization methods may only serve as the preliminary design models as they may not be able to describe a system completely due to the complexity either in formulating the model constraints or in making the problem too unmanageable in size for handling very large complex systems. To overcome this difficulty simulation model has to be used for further screening, by using the results of the optimization models (Hufschmidt and Fiering, 1966; Proceedings of a Seminar on Reservoir System Analysis, 1969; System Analysis in Water Resources Planning, 1975; Stedinger, 1984; Rogers and Fiering, 1986; Karamouz and Houck, 1987; and Piper and Knott, 1989). Preliminary design by mathematical programming technique on the basis of which simulation could be planned has often been recommended (Jacoby and Loucks, 1972; Srivastava, 1976; Uddihal, 1979; Chaturvedi and Srivastava, 1981; Ejor, 1985; Karamouz et al., 1992; Bony, 1993; & Sadeghian, 1995). On the other hand, firstly a simulation model and then subsequently an optimization model were used to analyze multipurpose, multi reservoir river basin (Lall and Miller, 1988; & Razavian et al., 1990).

Various applications of above techniques are also presented in Loucks (1969), Yaron and Tapiero (1979) and Simonovic (1992); and for Indian rivers, in Chaturvedi and Rogers (1985), Application of Systems Analysis for Water Resources Development (1987), and Mohan and Raman (1992).

In this chapter some of the studies on reservoir planning and operation problems using systems analysis and available in literature have been presented. As far as possible the presentation has been limited to the cases of a **single** (single/and or multipurpose) **reservoir studies**. To keep the uniformity, the cases presented have been sequenced in three broad categories, i.e., studies on reservoir planning, studies on reservoir operation, and studies on joint reservoir planning and operation problems. Further, these have been sub-categorized depending upon the systems analysis techniques used, i.e., isolated studies, using linear programming (LP), dynamic programming (DP) and simulation techniques; and then studies using combined LP and DP techniques; and cases with combined use of optimization-simulation models. At the end a few studies which used other techniques like non-linear and goal programming are also presented.

2.2.0 STUDIES ON PLANNING OF A RESERVOIR

In Sheer (1979) the basic method of solving linear programming problems have been described, and various simple linear programming applications to reservoir problems have been developed.

The reservoir yield models for single reservoir planning using linear programming were discussed in Loucks et al. (1981). The approach for reservoir planning emphasized the yields that can be achieved, and their reliabilities, with a given stream flow sequence.

A linear optimization model for planning the management of Irrigation District No. 38, in the State of Sonora, Mexico, is presented (Chavez-Morales et al., 1987). The model considers the yield, price, and production cost of twelve primary crops; the land restriction on cropped areas; the storage capacity of the existing reservoir and aquifer; the reservoir net inflows; the evaporation, releases, and spillages from the reservoir; the surface water and groundwater requirements of the crops; the quality of the mix of surface water and groundwater; and the requirements of other resources, such as fertilizer, pesticide, seed, equipment, and labor. The model gives the cropping pattern and the monthly schedule of reservoir releases and aquifer withdrawals that maximize the annual profit in the district. Solutions to the model facilitate an evaluation of the effects of net annual inflows on profits and cropped areas, and provide an indication of the levels of inflow that can be used for planning the operation of the irrigation district.

Lele (1987) presented the improved sequent-peak algorithm for incorporating storage-dependent losses which was tested on a real 50 years and 12 months inflow sequence and was found to give the same results as those obtained by using linear programming formulation to the last significant digit. The second procedure was also implemented as a computer programme; it provided a very quick and flexible way of accurately determining the effect of changes in the reliability norm, including in the percentage shortfall allowed, on the storage capacity requirement.

Dynamic programming has been used to study several types of problems related to water resources systems. Hall and Buras (1969) were the first to propose that dynamic programming be applied to determine the optimal return from reservoir systems. They studied the problem of allocating stored water to various purposes. Hall (1964) reported a study to determine the optimal reservoir size.

Planning of surface water storage (Buras, 1985) is based on the concept of reservoir yield which is derived from the analysis of three basic items of information: the hydrologic regime, the active storage volume, and the release policy. The stochastic dynamic programming model formulated for the derivation of yield functions of the reservoir used as optimization (minimizing) criterions, the sum of squares of deviations of actual releases, and final storages from their respective targets. The algorithm produced a set of curves, one curve for each season, relating optimal total releases from the Navagam reservoir with their probabilities. In addition the probabilities of initial storage volumes were estimated for each of three seasons under steady-state conditions.

Rydzewski and Nairizi (1979) established computer simulation model to search for irrigation project design capacity and area to maximize the net present value in the benefit-cost analysis for the development proposed.

Maji and Heady (1980) constructed a simulation model to estimate the physical and economic performance of alternative river basin development. The paper tells how the problems of large scale water resources developments were confronted and solved. Also a set of general guidelines which may be helpful in other simulation studies have been derived.

Srivastava and Sundar (1985) showed the importance of simulation in reservoir planning by studying an existing irrigation reservoir. The study showed that the existing reservoir capacity is larger than required to serve the useful purposes.

Garudkar (1991) studied an existing reservoir with water supply and multi irrigation demands and showed the feasibility of simulation for reservoir planning.

The linear programming and the simulation techniques (Nadkarni, 1986; and Kar, 1991) for irrigation reservoir and (Sadeghian, 1991) for multipurpose reservoir were used for planning purposes for testing the project provisions.

Both static and dynamic optimization models have been used to reduce the range of possible alternative capacities, targets, and operating rules for further more detailed evaluation by static and dynamic simulation techniques (Jacoby and Loucks, 1972). Without the information provided by screening models it would have been both impractical and prohibitively expensive to simulate enough planning and policy alternatives to conclude with reasonable confidence that an optimal or near optimal set of alternatives had been found. Yet without the ability to simulate the results derived from the solution of screening model there would be little opportunity to test the effect of many limiting assumptions that must often be made when a mathematically tractable optimization model of a complex river system is structured. On the basis of the limited results of this Delaware River basin study, the combined screening simulation method of analysis appears to be both practicable and an efficient means of defining and evaluating alternative designs and operating rules for large river basin systems.

Ejor (1985) and Panigrahi (1990) used linear and dynamic programmings and simulation technique for single purpose irrigation reservoir to show the use of optimization-simulation models for reservoir design purposes.

Optimization-simulation models (Srivastava and Patel, 1992) were used for the systems analysis of a water resources system. The Karjan Irrigation reservoir project in India was taken as the system. Two types of optimization models, i.e., linear programming, and dynamic programming (continuous and discontinuous) were used for preliminary planning purposes. The simulation technique was used for further screening.

The Table 2.1 gives a brief review of the various aspects considered and methodologies used for studies on planning of a reservoir for the cases presented in this section.

2.3.0 STUDIES ON OPERATION OF A RESERVOIR

Short term operation policy for multipurpose reservoirs can be derived from an optimization model with the objective of minimizing short term losses (Datta and Burges, 1984). Also, the aim was to explore the sensitivity of various performance criteria for reservoir operation to the accuracy of forecasted streamflow volumes. For single reservoir the sensitivity of these criteria to meeting conflicting storage and release targets was examined. When a tradeoff is made between incurring one unit of storage deviation and one unit of release deviation from respective target values, the compromise solution depends on uncertain future streamflow as well as the shapes of loss functions, reservoir release was affected according to the solution for the optimization model conditional upon the forecasted streamflow volumes for given time.

Algorithm presented in the paper (Simonovic, 1979) was developed for solving the problem of long term control or planning the functioning of a multipurpose reservoir pool. It is a stochastic problem involving random parameters in equation by which the control is defined. The complexity of the problem is imposed by the two-step algorithm for solving the long-term optimal control: (1) application of all chance constraints on the state and control coordinates is being done at the first step (2): The choice of optimum control is being done in the second step. The method of iterative convolution was chosen for the first and method of linear programming for the second step.

Successive linear programming (SLP) is supposed to reach the optimum of a problem by introducing step bounds to all variables involved and reducing their sizes along the search path through the interior of the feasible region (Tao and Lennox, 1991). Since all variables in a reservoir system are associated with each other through continuity equations, the introduction of step bounds to storages and releases at the same time may violate those equalities if the search is started from the lower bounds of the variables involved. The feasible solutions of a reservoir system lie on the hyperplane determined by continuity equations. The global optimum is most likely given by a nonextreme point on hyperplane if the performance index is nonlinear and monotonic over the region defined by the bounds of storages and releases.

Young (1967) and Hall et al. (1968) were first to study the problem of finding optimal operating rules for a single reservoir using dynamic programming.

A dynamic programming approach (Su and Deininger, 1974) with a Markovian streamflow model has been presented to determine optimal rule curves for Lake Superior.

In Trezos and Yeh (1987) three main issues are addressed: the potential of increasing the output from existing hydropower plants, the alleviation of dimensionality problems for multistate dynamic programming and the use of probabilistic forecast in the decision-making process.

In Helweg et al. (1982) use of optimization model for real time operation. Of the many existing reservoir systems, the Center Valley project in California, and Tennessee Valley Authority project in Tennessee were examined as representive systems. Though the TVA is actively engaged in developing optimization models, the reasons neither is presently using optimization model are summarized as lack of upper management support, and lack of qualified personnel in the development and use.

The operation of reservoirs often requires frequent updating of the results of the operation model (Marino and Mohammadi, 1983). This is mainly because of errors involved in forecasting the natural inflows to the reservoirs or demands for water and energy both. Current model used for operation usually require the use of large computers because of their core-storage and computation-time requirements. Frequent use of such models for the purpose of updating will often result in high computation cost and usually involves long turnaround times. This paper presents an efficient algorithm for the monthly operation of a system of two parallel multipurpose reservoirs that is solved with a minicomputer. The operation model is applied to Shasta and Folsom reservoirs of the California Central Valley Project, and the result are reviewed.

The operation model maximizes the water and energy output of a reservoir system (Marino and Mohammadi, 1984). The model is a combination of parametric linear programming (used for month-by-month optimization) and dynamic programming (used for optimization over the 1-yr. operation period). The resulting operating policy is updated as new monthly inflow forecasts become available, thus incorporating the stochasticity of inflows. An iterative procedure is used to reduce the computation time and computer storage requirements. This efficiency allows the use of minicomputers which are less expensive than mainframe computers. The use of the model is illustrated for the Shasta reservoir (California Central Valley Project).

An efficient algorithm for the real-time monthly operation of a multipurpose reservoir is presented (Mohammadi and Marino,1984). The model is a combination of linear programming (used for month-by-month optimization) and dynamic programming (used for annual optimization). The use of parametric linear programming minimum required beginning of month storages, and an iterative solution procedure result in low computer time and computer storages requirements. Low computer storage requirements allow the model to be run on minicomputers. Water and energy maximization water and energy maximization with food control considerations, and water and energy maximization for peak demand months are considered. Thus the model provides the reservoir operator with different choices for annual optimization. The model is applied to poisom reservoir of the California Central Valley Project and the results are discussed.

Use of single rule curve (defining ideal storage target levels) for reservoir operation depending upon the type of reservoir regulations were presented in Kuiper (1965). Sometimes, operation rules are often defined to include not only storage target levels, but also various storage allocation zones. These storage zones may vary throughout the year. A paper by Loucks and Sigvaldason (1980) and course manual (Watershed Resources Management and Environmental Monitoring, 1981) have discussed the principles involved in reservoir operation by zoning or partitioning.

A model for the optimal operating policy of a reservoir for irrigation under a multiple crops scenario using stochastic dynamic programming (SDP) was developed (Vedula and Mujumdar, 1992). Intraseasonal periods smaller than the crop growth stage durations form the decision intervals of the model to facilitate irrigation decisions in real situations. Reservoir storage, inflow to the reservoir, and the soil moisture in the irrigated area are treated as state variables. An optimal allocation process is incorporated in the model to determine the allocations to individual crops when a competition for water exists among them. The model also serves as an irrigation scheduling model in that at any given intraseason period it specifies whether irrigation is needed and, if it is, the the amount of irrigation to be applied to each crop. The impact on crop yield due to water deficit and the effect of soil moisture dynamics on crop water requirements are taken into account. A linear root growth of the crop is assumed until the end of the vegetative stage, beyond which the root depth is assumed to be constant. The applicability of the model is demonstrated through a case study of an existing reservoir in India.

A study by Orlovski et al. (1984) tells that all efficient operating rules for real time operation of a multipurpose reservoir can simply be obtained by off-line repetitive simulations of the reservoir behaviour for different values of the initial storage (the selection of these values is guided by a one dimensional searching method). These efficient operation rules can be interpreted in terms of storage allocation zones which are not predetermined but depend upon the forecast of inflows. Moreover, when the reservoir is not to full or to empty, the method suggests a whole range of possible release instead of single value, thus introducing some flexibility into the decision-making process.

In many real-world situation operation of water resources systems are subjected to constraints which are formulated on a daily basis. However, in optimization and simulation models, these constraints are generally written on monthly basis. A methodology was developed to include daily constraints on monthly reservoir operation models (Harboe, 1988). It is based on results obtained through simulations with historical daily streamflow data. If the daily constraints are part of the constraint set a simple approximation was possible; however, if the daily constraint involves the objective function, a more complex approximation including interpolation was necessary.

In Karamouz and Houck (1972) an algorithm to generate annual and monthly reservoir operating rules has been proposed and tested in 48 cases. The algorithm is easy to use, and each component of the algorithm (deterministic dynamic programme, multiple regression, simulation) is relatively simple.

In another study by Karamouz and Houck (1987) two algorithms to generate monthly reservoir operating rules by deterministic and stochastic optimization for single reservoir sites have been tested and compared. The deterministic model is called DPR and comprises a deterministic dynamic programme, regression analysis and simulation. The stochastic model is stochastic dynamic programme (SDP). The principal measure of the quality of each operating rule is the loss incurred in simulated reservoir operation. The test cases include small, medium, large, and very large capacity, reservoirs located on rivers, with different streamflow characteristics. Based on the results, SDP model performed better for small reservoir and DPR model for large reservoirs.

A real-time operational methodology (Vedula and Mohan, 1990) has been developed for multipurpose reservoir operation for irrigation and hydropower generation with application to the Bhadra reservoir system in the state of Karnataka, India. The methodology consists of three phases of computer modelling. In the first phase, the optimal release policy for a given initial storage and inflow is determined using a stochastic dynamic programming (SDP) model. Streamflow forecasting using an adaptive AutoRegressive Integrated Moving Average (ARIMA) model constitutes the second phase. A real-time simulation model is developed in the third phase using the forecast inflows of phase 2 and the operating policy of phase 1. A comparison of the optimal monthly real-time operation with the historical operation demonstrates the relevance, applicability and the relative advantage of the proposed methodology.

The planning of reservoir operation presents decision makers with a trade-off between competing functions, which are energy production and flood control (Loaiciga and Marino, 1986). To optimally resolve the trade-off between maximization of energy revenues and minimization of downstream losses, the interaction between the expected value and variance of revenues (accruing from the reservoir operation) is included in a stochastic daily reservoir operation planning model. By parametrically varying the expected value and variance of the objective function, the risk-averse nature of decision makers is incorporated, resulting in a range of feasible alternative policies that reflect the decision maker's attitude towards revenue maximization and poor performance of the reservoir operation.

Yeh (1985) reviewed the state-of-the art of mathematical models developed for reservoir operations, including simulation. Algorithms and methods surveyed include linear programming (LP), dynamic programming (DP), non-linear programming (NLP), and simulation. The general overview is first presented. The historical development of each key model is initially reviewed. The Table 2.1 gives a brief review of the various aspects considered and methodologies used for studies on operation of a reservoir for the cases presented in this section.

2.4.0 STUDIES ON INTEGRATED PLANNING AND OPERATION OF A RESERVOIR

Isolated studies on single reservoir planning or reservoir operation are available in large numbers as presented above, but integrated studies on reservoir planning and operation are not much available in literature.

Loucks et al. (1981) showed the use of linear programming for single reservoir design and operation using yield models. The models estimated the storage capacity required to deliver various yields with given probabilities. Reservoir rules developed for operation were only guidelines, and once developed they should be simulated, evaluated and refined prior to their actual adoption.

Since their introduction, linear decision rules (LDR) chance constrained reservoir models have held out promise of developing into simple reservoir screening models and of producing reasonable operating policies. Single and multiple (LDR) models using two release rule structure are examined in the context of a multiple purpose reservoir operating problem (Stedinger, 1984).The (LDR) models were of questionable value for screening purposes in this instance. As operating policies, computed (LDR) policies were found to be less efficient than simple alternative at meeting water supply and minimum storage targets when subject to constraint on available active or control storage capacity.

The central intention of the survey (Yakowitz, 1982) was to review dynamic programming models for water resource problems and to examine computational techniques which have been used to obtain solutions to these problems. Problem areas served here include planning, irrigation system control, project development, water quality maintenance, and reservoir operation analysis.

A peaking storage tank (Sabet and Helweg, 1989) is used for storing water that is pumped from wells or other sources of supply during off-peak periods when energy cost are less for use during period of on peak water demand. The optimal size of peaking storage tank is that which results in minimum cost, which includes both the storage construction cost and cost of operation of the pumps. The operational cost for a given time-of-use rate is determined by help of a pipe network simulation model solved by the Newton-Raphson technique and a dynamic programming optimization model. Analysis show that low off-peak energy costs make the construction of peaking storage tanks economically attractive and reduce on-peak energy use, which results in electric load levelling.

Klemes (1979) put storage mass-curve analysis into a proper perspective rather than to criticise the dynamic and linear programming techniques whose usefulness and problem-solving power in water resources planning and management problems need no defences.

Over the past 30 years systems analysis applied to the planning and operation of water resources systems has grown from a mathematical curiosity to the major speciality (Rogers and Fiering, 1986). System analysis is that set of mathematical planning and design techniques which includes at least some formal optimization procedure. If used to identify a range of acceptable options, and then to examine these closely under stochastic influences, the techniques of systematic analysis have the potential of significantly improving water resources planning and management.

A simulation model is presented for planning the conjunctive use of irrigation water from a single multipurpose reservoir and an aquifer, and the allocation of cropped areas within an irrigation district (Chavez-morales et al., 1992). The model considers cropping patterns, profits for the farmers in the irrigation district, monthly reservoir and aquifer operating schedules for a one-year planning horizon, and hydropower generation. The model reproduces the performance of the irrigation system under the management policies specified by the planners themselves, given certain initial conditions, hydrological and economic input parameters, cropping patterns, reservoir and aquifer releases, and structural characteristics. Solution to the irrigation planning simulation model is obtained through the use of a computer program module developed for a microcomputer. The capability of the simulation model is illustrated by applying it to planning the management of an irrigation district in northern Mexico. The model permits the study of alternative cropping patterns in the irrigation district and yields the monthly schedule of reservoir storages and releases and aquifer withdrawals as well as the annual profit in the district.

The Table 2.1 gives a brief review of the various aspects considered and methodologies used for studies on integrated planning and operation of a reservoir for the cases presented in this section.

2.5.0 STUDIES USING OTHER TECHNIQUES

A general non-linear mathematical model (Najmaii and Movaghar, 1992) is used for an overall design optimization of run-of-river power plants. The design criteria for such power plants are fundamentally based on some important and initial cost-effective parameters such as discharge design, penstock or tunnel diameter, turbine capacity, number of units and type of turbines.

The optimization of real-time operation for single reservoir system was studied (Chu and Yeh, 1978). The objective was to maximize the sum of hourly power generation over a period of one day subject to constraints of hourly schedules, daily flow requirement for water supply and other purposes and limitation of the facilities. The problem has nonlinear concave objective function with nonlinear concave and linear constraints. Non linear duality theorems and Lagrangian procedures were applied to solve the problem where the minimization of Lagrangian is carried out by a modified gradient projection technique along with optimal step size determination routine. The dimension of the problem in terms of the number of variables and constraints is reduced by eliminating the 24 continuity equations with a special implicit routine.

In (Mohand and Keskar, 1991) the use of goal programming for multipurpose reservoir operation has been proposed and applied to the Bhadra Reservoir system in India. Two different types of models, one with the objective of minimizing the deviations from storage targets and the other with the objective of minimizing the deviations from release targets, have been formulated and applied to the reservoir system. The model with release targets performed better in comparison with the model with storage targets. In Laufer and Morel-Seytoux (1979) a technique was developed to maximize the returns from the operation of a seasonal alpine reservoir for the production of electrical energy. The emphasis rests on a comprehensive approach to the problems and the following fields were considered; hydropower economics, operation research and decision theory. The solution technique to determine the optimal releases strategy is developed for deterministic case. It is based on the solution of the system of equations given by the Kuhn-Tucker conditions. As the direct solution of this system is complicated a Kin to Masse's constrained calculation of variations is applied.

A mixed integer linear optimization model for river basin development for irrigation is presented (Afshar et.al., 1991). The model is a change-constrained optimization model that considers the interactions between design and operation parameters (reservoir capacity, delivery system capacity, hectares of land to be developed and planted to different crops, etc.). The model is capable of integrating all decision variables in the phase, thus accounting directly for any interdependency between the design variables. The model uses a mixed integer technique to linearize the nonlinear cost functions and is applicable to concave and convex cost functions.

Solution of the model provides the optimum extent of the land development for irrigation, cropping pattern, reservoir and canal capacities, as well as the necessary linear decision rule operational parameters. Also, solution of the model reveals the importance of direct inclusion of the reservoir cost in the model in comparison to only minimizing the reservoir capacity under an assumed demand distribution.

The Table 2.1 gives a brief review of the various aspects considered and methodologies used on studies using other techniques for the cases presented in this section.

Table 2.1 Various aspects & techniques for planning and operation of a reservoir considered by authors

Name of Authors	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)
STUDIES ON PLANNING OF A RESERVOIR															
Sheer (1979)	+		+			+									
Loucks et al.(1981)	+		+			+			+						
Chavez-Morales et al.(1987)	+		+			+					+				
Lele (1987)	+		+			+			+	+	+	+			
Hall and Buras (1969), Hall (1964)				+		+	+								
Buras (1985)	+			+		+		+		+	+	+	+		
Rydzewski and Nairizi (1979)	+				+	+	+		+		+				
Maji and Heady (1990)	+				+				+		+				
Srivastava and Sunder (1985)	+				+	+	+		+		+				
Garudkar (1991)	+				+						+			+	+
Nadkarni (1986) and Kar (1991)	+		+		+				+	+	+				
Jacoby and Loucks (1972)	+		+		+	+		+		+	+	+			
Ejor (1985) and Panigrahi (1990)	+		+	+	+				+		+				
Srivastava and Patel (1992)	+		+	+	+		+		+		+				+

Table 2.1 Continued

STUDIES ON OPERATION OF A RESERVOIR															
Datta and Burges (1984)		+	+			+	+		+	+	+	+	+		
Simonovic (1979)	+	+	+					+		+	+	+	+	+	+
Tao and Lennox (1991)		+	+			+	+		+	+	+	+			
Young (1967) and Hall e al.(1968)		+		+		+			+						
Su and Deininger (1974)		+		+		+	+					+			
Trezos and Yeh (1987)		+		+		+						+			
Helweg et al. (1982)		+				+									
Marino and Mohammadi (1983)		+	+	+						+	+				
Mohammadi and Marino (1984)		+	+	+						+	+	+	+		
Marino and Mahammadi (1984)		+	+	+				+		+	+	+			
Loucks and Sigvaldason 1980)		+					+			+					
Vedula and Mujumdar (192)		+		+				+	+		+				+
Orlovski et al. (1984)		+			+	+	+			+					
Harboe (1988)		+			+	+									
Karamouz and Houck (197)		+		+	+		+	+	+						
Karamouz and Houck (198)		+		+	+	+	+	+							
Vedula and Mohan (1990)		+		+	+			+	+	+					
Yeh (1985)	+	+	+	+	+										

Table 2.1 Continued

STUDIES ON INTEGRATED PLANNING AND OPERATION OF A RESERVOIR												
Stedinger (1984)		+	+			+				+	+	+
Yakowitz (1982)	+	+		+			+	+		+	+	+
Sabet and Helewg (1989)	+	+		+	+							
Klemes (1979)	+	+	+	+		+	+	+	+	+	+	+
Rogers and Fiering (1986)	+	+	+	+	+			+		+	+	+
Chavez-Morles et al. (1992)	+	+			+					+	+	+
STUDIES USING OTHER TECHNIQUE												
Najmaii and Movaghar (1992)		+				+		+				
Chu and Yeh (1978)		+				+	+		+			
Mohand and Keskar (1991)		+				+	+			+	+	+
Laufer and Morel-Seytoux (1979)		+				+	+					+
Afshar et al. (1991)	+	+				+		+			+	

(a) = Design; (b) = Operation; (c) = Linear programming; (d) = Dynamic programming;

(e) = Simulation; (f) = Other methods; (g) = Deterministic; (h) = Stochastic;

(i) = Single purpose, (j) = Multipurpose; (k) = Irrigation; (l) Hydroelectric energy;

(m) = Flood control; (n) = Municipal and industrial; and (o) = Other uses.

CHAPTER 3

LINEAR PROGRAMMING MODELS

Chapter-3

LINEAR PROGRAMMING MODELS

3.1.0 INTRODUCTION

The multipurpose use of water in all types of human activities, irrigation, hydroelectric power generation and urbanization of settlements have resulted in a considerable increase in water demand. This is why it is necessary to build complex, spatially scattered multipurpose water resources system. It is also necessary to ensure flood control because of many valuable structures built in river valleys and safety of possible damage sites.

Planning is an integral part of water resources development and management. Whether or not a particular plans or programmes are eventually implemented; the planning process itself forces us to think about what we are or should be doing to address a particular set of problems or needs. The planning should lead to a better understanding of what will happen if we do or do not act, and, if we decide to do something which of many possible actions is likely to be the best. Such planning requires information; thus models are increasingly important source of information. Modelling provides a way, perhaps, the principal way of predicting the future behaviour of an existing or proposed water resources system.

Reservoir are the most important elements of complex water resources system. There is a variety of reservoir analysis problems. The conflicting and complementary multiple purposes served, require complex mathematical formulations. The decision variables, objective functions, and constraints vary for different types of reservoir analysis problems.

Linear programming has been considered as one of the most widely used techniques in water resources and one of the most important scientific advances in recent history. However, this technique is limited to solving only linear problem, i.e., problems with the objective function and constraints in linear form. The first Linear Programming application in deterministic reservoir problem date back to 1962 (Dorfman, 1962).

In this chapter linear programming models to determine various reservoir storages and reservoir yields have been presented. A simple reservoir is shown in Figure 3.1 and various reservoir storages are depicted in Figure 3.2.

General features of the reservoir planning models are described below:

3.2.0 RESERVOIR DESIGN MODEL (Max.Z_{nb})

3.2.1 Reservoir Constraints

(i) The continuity equation for the reservoir is defined as:

$$S_t = S_{t-1} + I_t + P_t + \bar{I}_t - El_t - O_t - \left[O_t^d + O_t^m \right] \text{ for all } t \qquad (3.2.1.1)$$

Where,

t = 1,...,N. For evaporation consideration the above equation can be modified as below.

$$K'_t . S_t = S_{t-1} + I_t + P_t + \bar{I}_t - O_t - \left[O_t^d + O_t^m \right] \text{ for all } t \qquad (3.2.1.1')$$

where,

S_t = gross/live reservoir storage at the end of time t,

S_{t-1} = gross/live reservoir storage at the beginning of time t,

I_t = catchment inflow to the reservoir in time t,

P_t = precipitation directly upon reservoir in time t,

$\bar{I}_t$ = local inflow to the reservoir from surrounding area in time t,

O_t^d = release for water supply from reservoir in time t,

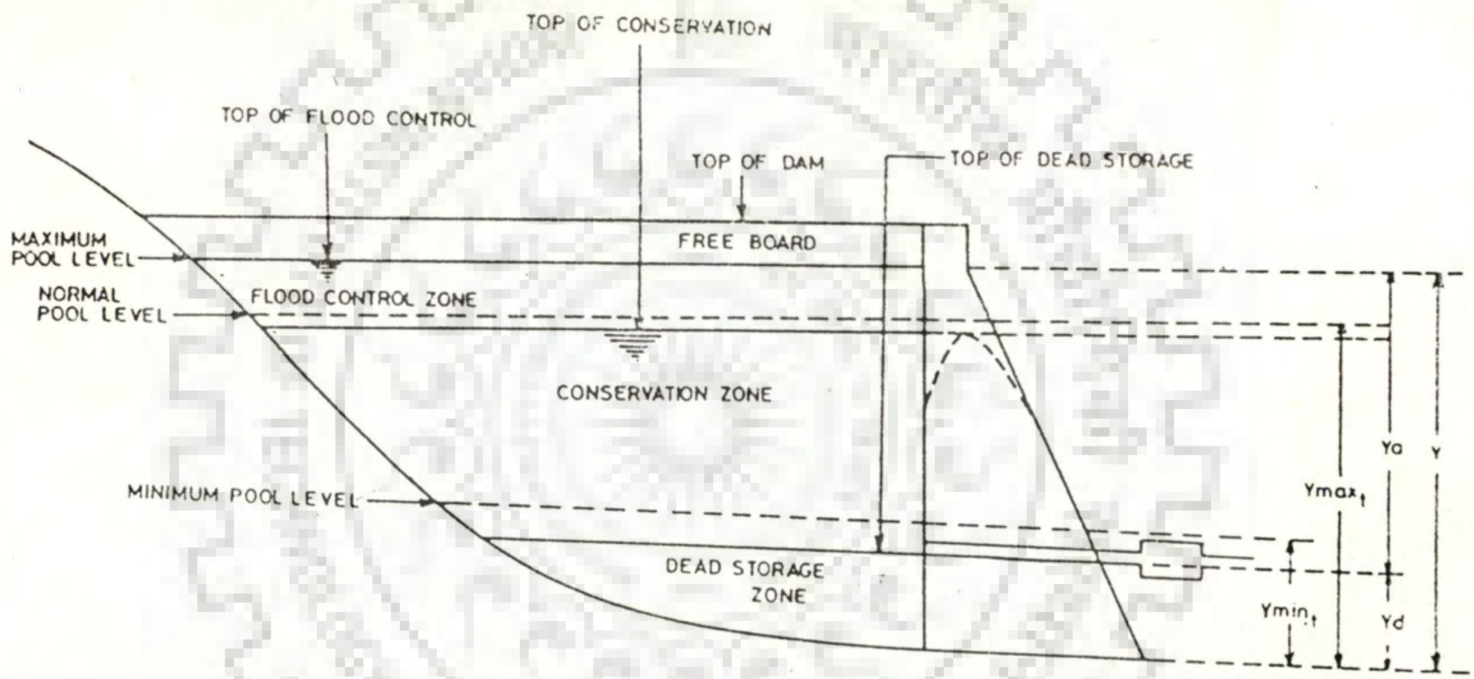


Fig. 3·2–Various reservoir storage & variables related to a reservoir

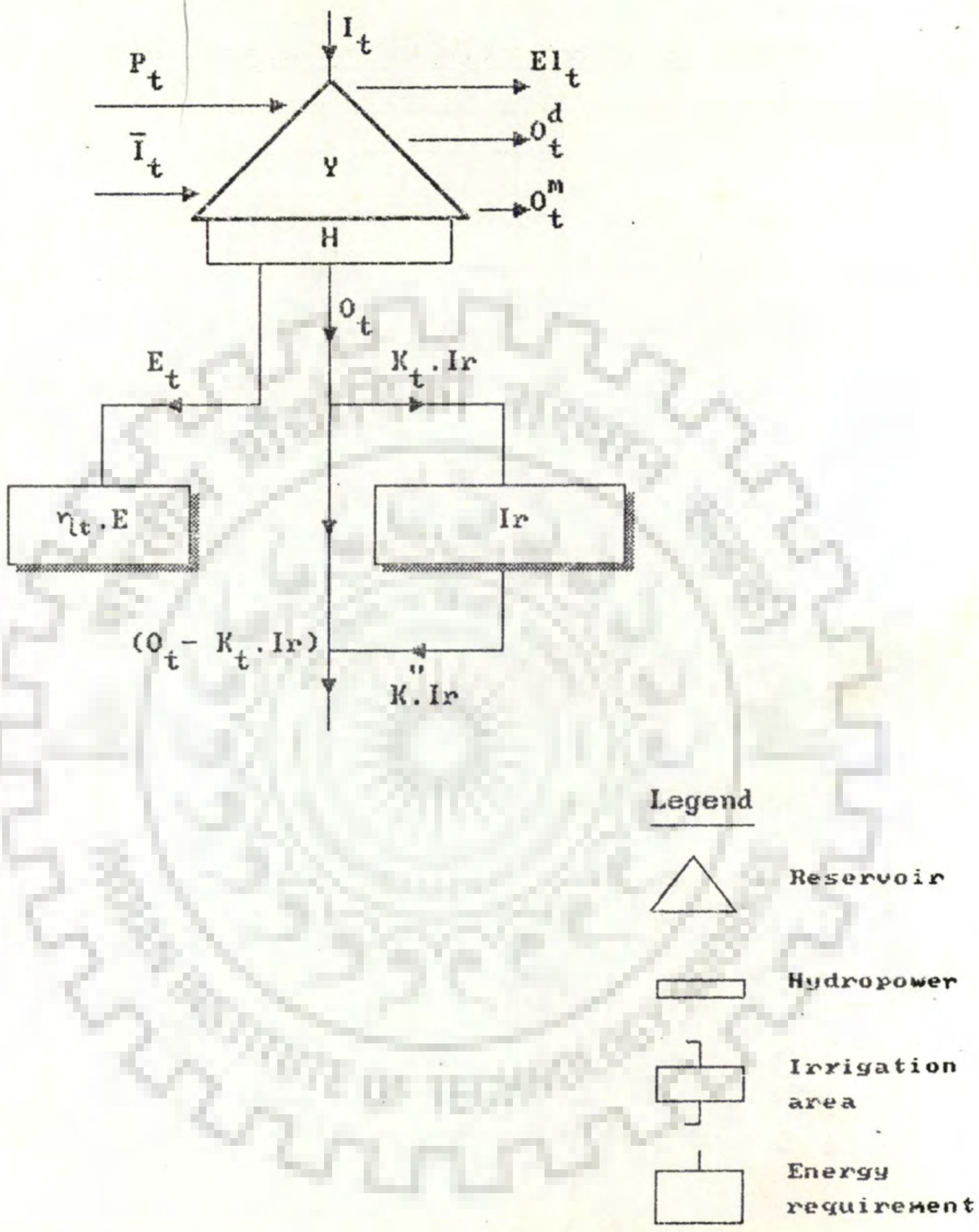


Fig. 3.1 Schematic diagram of reservoir system

O_t^m = release from reservoir to keep minimum flow on dowrstream in time t,

El_t = evaporation from reservoir in time t,

K'_t = amount by which K'_t exceeds unity is the fraction of the end storage which is assigned to reservoir evaporation loss computed from two trial working tables, prepared with and without evaporation losses respectively, and.

N = number of time periods in the planning horizon.

(ii) The dead storage of the reservoir puts a lower limit on the reservoir storage, i.e.,

$$S_{t-1} \geq Yd \qquad \text{for all } t \qquad (3.2.1.2)$$

Here,

S_{t-1} = gross initial reservoir storage in time t, and

Yd = dead storage capacity of reservoir.

or

$$0 \leq S_{t-1} \qquad \text{for all } t \qquad (3.2.1.2')$$

Here,

S_{t-1} = live initial reservoir storage in time t.

(iii) The contents of the reservoir at any time cannot exceed the capacity of the reservoir, i.e.,

$$S_{t-1} \leq Y \qquad \text{for all } t \qquad (3.2.1.3)$$

Here,

S_{t-1} = gross initial reservoir storage in time t, and

Y = total gross reservoir capacity.

or

$$S_{t-1} \leq Ya \qquad \text{for all } t \qquad (3.2.1.3')$$

Here,

S_{t-1} = live initial reservoir storage in time t, and

Ya = total live capacity of reservoir.

3.2.2 Irrigation Constraints

3.2.2.1 Lumped model

The value of water released from the reservoir must be sufficient to meet irrigation demand in that period, i.e.,

$$O_t + I''_t = K_t.Ir + Sp_t \qquad \text{for all } t \qquad (3.2.2.1)$$

Where,

O_t = total water release from reservoir in time t,

I''_t = water that joins the main stream just above irrigation diversion canal in time t,

Ir = annual irrigation water target,

K_t = proportion of annual irrigation target Ir to be diverted for irrigation in time t, and

Sp_t = secondary water release (spill) from reservoir in time t.

3.2.2.2 Consideration of crops

The individual crops can be introduced in the model in place of lumped irrigation in the following manner by putting basic crop constraints.

(i) The constraint (3.2.2.1) is modified by introducing the crops, thus

$$O_t + I''_t = \left(\sum_{k=1}^{m} A_k.W_{t,k} \right) + \overline{O}_t \qquad \text{for all } t \ \& \ k \qquad (3.2.2.2)$$

(ii) Area under various crops in a month cannot exceed total area for irrigation, i.e.,

$$\sum_{k=1}^{m} X_{t,k}.A_k \leq CCA \qquad \text{for all t \& k} \qquad (3.2.2.3)$$

Where,

A_k = crop area for the k^{th} crop,

$W_{t,k}$ = water requirement for crop k in time t,

$X_{t,k}$ = land use coefficient for crop k in time t,

CCA = culturable command area, and

m = number of crops.

3.2.3 Hydropower Constraints

(i) The energy production is governed by

$$E_t = C_f.O_t.Ha_t.e.h_t \qquad \text{for all t for storage projects} \qquad (3.2.3.1)$$

$$E_t = C_f.O_t.\overline{Ha}.e.h_t \qquad \text{for all t for run-of-river project} \qquad (3.2.3.1')$$

Where,

E_t = energy generated in time t,

$\overline{Ha}$ = constant power head in case of run-of-river plant,

Ha_t = average reservoir head in reservoir during time t,

h_t = number of hours in time period t,

C_f = a conversion factor for energy generation = $\frac{(9.8)C_t.C_v}{C_p}$

C_t = $\frac{1}{h_t(3600)}$,

C_v = 1, if O_t is in m^3 in h_t hours,

= 10^4, if O_t is in ha-m (10^4 m^3) in h_t hours,

= 10^6, if O_t is in MCM (10^6 m^3) in h_t hours,

= 10^9, if O_t is in TMC (10^9 m^3) in h_t hours,

h_t = number of hours in time t,

C_p = 1, if power is in KW,

= 10^3, if power is in MW, and

= 10^9, if power is in 10^6 MW. and

e = overall efficiency of turbine.

(ii) Total energy is defined by

$$E_t = \eta_t.E + \bar{E}_t \qquad \text{for all t} \qquad (3.2.3.2)$$

Where,

E = annual energy target,

$\bar{E}_t$ = secondary energy generated in time t, and

η_t = % of annual energy target to be supplied in time t.

(iii) Total energy governed by the load factor

$$E_t = \alpha_t.H.h_t \qquad \text{for all t} \qquad (3.2.3.3)$$

Where,

H = hydroplant capacity, and

α_t = load factor in time t.

For run-of-river plants the following constraints may be added:

(iv) Total annual energy is governed by

$$\sum E_t \leq C_f.I_{av}.\bar{H}a.e.(8760.0) \qquad (3.2.3.4)$$

Where,

I_{av} = average annual river discharge and is given by,

$$I_{av} = 0.175\ I_{15} + 0.075\ I_{20} + 0.10\left(I_{30} + I_{40} + I_{50} + I_{60} + I_{70} + I_{80} + I_{90}\right) + 0.05\ I_{100}\text{, and} \qquad (3.2.3.5)$$

$I_{15},...,I_{100}$ = river inflow of a given dependability.

(v) The power plant capacity is governed by

$$H \leq C_f.I_{15}.\overline{H}a.e \qquad (3.2.3.6)$$

Where,

I_{15} = 15 % exceedence discharge in cumecs.

For plants with storage schemes the following constraints may be added:

(vi) Total annual energy is governed by

$$\sum E_t \geq C_f.I_{av}.\overline{H}a.e.(8760.0) \qquad (3.2.3.7)$$

(vii) The power plant capacity is governed by

$$H \geq C_f.I_{15}.\overline{H}a.e \qquad (3.2.3.8)$$

(viii) Total reservoir release is governed by

$$O_t \geq I_{100} \qquad \text{for all } t \qquad (3.2.3.9)$$

Further, in special cases the following constraints may also be considered.

(ix) In case of a single turbine

$$O_t \geq \frac{0.3H}{C_f.Ha_t.e} \qquad \text{for all } t \qquad (3.2.3.10)$$

3.2.4 Flood Control Constraints

The flood control through a reservoir may be taken in to account by considering a flood control reserve in the reservoir. The flood control reserve Yf_t for time t is defined as the total capacity of the reservoir Y, minus the maximum capacity of the reservoir usable for conservation purposes, $Ymax_t$, i.e.,

$S_t \geq Ymax_t$ for $t = 1,.., t_1$ months of flood provision (3.2.4.1)

and

$Ymax_t \leq Y$ for $t = 1,.., t_1$ months of flood provision (3.2.4.2)

where,

S_t = gross final reservoir storage in time t,

t_1 = number of flood months, and

$Ymax_t$ = gross capacity of reservoir up to normal pool level (top of conservation) of the reservoir in time t.

In case of live reservoir storages S_{t-1}, the above equations are.

$S_t \leq Ymax'_t$ for $t = 1,...., t_1$ (3.2.4.1′)

and

$Ymax'_t \leq Ya$ for $t = 1,...., t_1$ (3.2.4.2′)

Where,

$Ymax'_t$ = live capacity of reservoir up to normal pool level (top of conservation) of the reservoir in time t.

3.2.5 Objective Function

The objective function is to maximize the total annual net benefits from various water purposes which a reservoir is going to serve.

3.2.5.1 Reservoir costs

The cost of reservoir can be calculated as follows:

$$\text{Annual cost of reservoir} = C_1 + Om_1 = \left(C'_1 + Om'_1 \right) Y$$

Where,

C_1 = annual capital cost of reservoir,

C'_1 = annual capital cost function for reservoir capacity,

Om_1 = annual OM (operation and maintenance) cost for reservoir capacity, and

Om'_1 = annual OM cost function for reservoir capacity.

3.2.5.2 Irrigation benefits and costs

3.2.5.2.1 Lumped model:

The benefits from irrigation are initially calculated at the farmers level and are then converted at the project level. The annual irrigation benefits are calculated below:

Gross annual irrigation benefits = $B_2 = a_2 . Ir$

Annual cost of irrigation = $C_2 + Om_2 = \left[C'_2 + Om'_2 \right] Ir$

Where,

B_2 = gross annual irrigation benefits,

C_2 = annual capital cost of irrigation,

C'_2 = annual capital cost function for irrigation,

Om_2 = annual OM cost of irrigation,

Om'_2 = annual OM cost function for irrigation,

a_2 = benefit function for irrigation, and

Ir = annual irrigation water target.

3.2.5.2.2 Consideration of crops:

In case of crops the term B_2, C_2 and Om_2 can be replaced by

$$B_2 = \sum_{k=1}^{m} A_k . Cb_k \quad ; \quad C_2 = \sum_{k=1}^{m} \sum_{t=1}^{N} C'_2 . A_k . W_{t,k} \text{ ; and}$$

$$Om_2 = \sum_{k=1}^{m} \sum_{t=1}^{N} Om'_2 . A_k . W_{t,k}$$

Where,

Cb_k = unit benefit from crop k.

3.2.5.3 Hydropower benefits and costs

The hydropower benefits can be calculated as below:

$$\text{Gross annual energy benefits} = B_3 = a_3 . E$$

$$\text{Annual cost of hydropower} = C_3 + Om_3 = \left(C'_3 + Om'_3 \right) H$$

Where,

B_3 = gross annual energy benefits,

a_3 = benefit per unit of energy,

E = yearly energy target,

C_3 = annual capital cost of hydropower,

Om_3 = annual OM cost of hydropower,

C'_3 = annual capital cost function for hydropower,

Om'_3 = annual OM cost function for hydropower, and

H = hydropower plant capacity.

3.2.5.4 Flood control benefits

The flood control benefits are calculated as a function of the flood control reserve for the period t, and are

$$\text{Annual flood control benefits} = B_4 = \sum_{t=1}^{t_1} a_4 \left(Y - Ymax_t \right) = \sum_{t=1}^{t_1} a_4 . Yf_t$$

Where,

a_4 = unit flood control benefits, and

Yf_t = flood storage capacity or reserve in time t.

3.2.6 Integration into a Complete Optimization Model

The different sets of equations (constraints) and various benefits and costs can be combined together to get a complete model of optimization depending upon the types of water uses from a reservoir.

The complete optimization model becomes,

MAXIMIZE : Annual net benefits from water use

SUBJECT TO : Various constraints of reservoir and water uses.

The details of various complete integrated optimization models depending upon water uses are given in Table 3.1.

3.2.7 Computation of Reservoir Evaporation Losses

The evaporation from a reservoir can also be considered in different ways in the model, as described below:

3.2.7.1 Direct use of reservoir storage surface area curve

The reservoir evaporation (Loucks et al., 1981), El_t, in equation (3.2.1.1) may be written, (refer Figure 3.3),

$$El_t = A_a.e_t \left[\frac{S_{t-1} + S_t}{2}\right] + A_o.e_t \qquad (3.2.7.1)$$

Let

$$a_t = 0.5(A_a.e_t) \qquad (3.2.7.2)$$

Now combine equations (3.2.1.1), (3.2.7.1), and (3.2.7.2) and rewrite the terms which yields.

Table 3.1 Integrated optimization models for reservoir design depending upon water uses

Water use	Objective function MAXIMIZE : Z_{nb}	Subject to constraints (equation number)
(A) Single Purpose (i) Irrigation	$B_2 - \left[(C_1 + Om_1) + (C_2 + Om_2) \right]$ (3.2.6.1)	(a) Lumped – 3.2.1.1′, 3.2.1.2, 3.2.1.3, & 3.2.2.1, (b) With crops – 3.2.1.1, 3.2.1.2, 3.2.1.3, 3.2.2.2 & 3.2.2.3
(ii) Hydropower	$B_3 - \left[(C_1 + Om_1) + (C_3 + Om_3) \right]$ (3.2.6.2)	3.2.1.1′, 3.2.1.2, 3.2.1.3 & 3.2.3.1 to 3.2.3.10
(B) Multipurpose (i) Irrigation & hydropower	$B_2 + B_3 - \left[(C_1 + Om_1) + (C_2 + Om_2) + (C_3 + Om_3) \right]$ (3.2.6.3)	(a) Lumped – 3.2.1.1′, 3.2.1.2, 3.2.1.3, 3.2.2.1 & 3.2.3.1 to 3.2.3.10 (b) With crops – 3.2.1.1′ 3.2.1.2, 3.2.1.3, 3.2.2.2, 3.2.2.3, and 3.2.3.1 and 3.2.3.10
(ii) Irrigation and flood control	$B_2 + B_4 - \left[(C_1 + Om_1) + (C_2 + Om_2) \right]$ (3.2.6.4)	(a) Lumped – 3.2.1.1′, 3.2.1.2, 3.2.1.3, 3.2.2.1, 3.2.4.1 & 3.2.4.2 (b) With crops– 3.2.1.1′, 3.2.1.2, 3.2.1.3, 3.2.2.2, 3.2.2.3, 3.2.4.1 & 3.2.4.2
(iii) Hydropower and flood control	$B_3 + B_4 - \left[(C_1 + Om_1) + (C_3 + Om_3) \right]$ (3.2.6.5)	3.2.1.1′, 3.2.1.2, 3.2.1.3, 3.2.3.1 to 3.2.3.10, 3.2.4.1 & 3.2.4.2
(iv) Irrigation, hydropower and flood control	$B_2 + B_3 + B_4 - \left[(C_1 + Om_1) + (C_2 + Om_2) + (C_3 + Om_3) \right]$ (3.2.6.6)	(a) Lumped – 3.2.1.1′, 3.2.1.2, 3.2.1.3, 3.2.2.1, 3.2.3.1 to 3.2.3.10, 3.2.4.1 & 3.2.4.2 (b) With crops – 3.2.1.1′ 3.2.1.2, 3.2.1.3, 3.2.2.2, 3.2.2.3, 3.2.3.1, to 3.2.3.10, 3.2.4.1 & 3.2.4.2

Note: (1) For hydropower choose appropriate constraints depending on the type of scheme/design criterion, and
(2) For crops use appropriate costs & benefit functions.

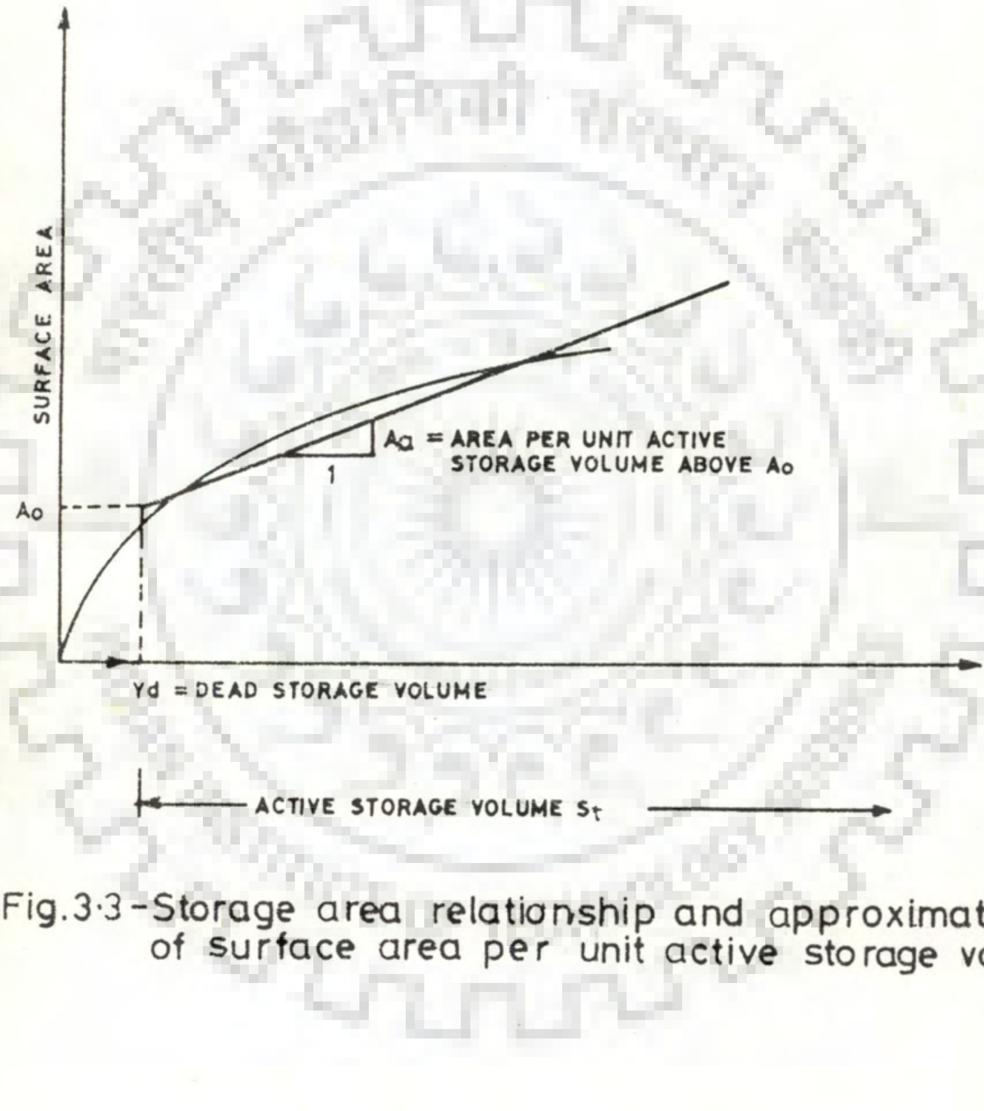


Fig.3·3 - Storage area relationship and approximation of surface area per unit active storage volume

$$\left(1 + a_t\right)S_t - \left(1 - a_t\right)S_{t-1} = I_t - O_t - A_0.e_t + P_t + \bar{I}_t - \left(O_t^d + O_t^m\right) \text{ for all t} \quad (3.2.7.3)$$

where,

A_a = area per unit active storage volume above dead storage, Yd,

A_o = reservoir surface area corresponding to the dead storage of reservoir, and

e_t = average reservoir evaporation rate in time t.

3.2.7.2 Use of evaporation loss adjustment coefficients

The continuity equation (3.2.1.1) in this case can be written as given below:

$$b_t.S_t - b_t'.S_{t-1} = I_t - O_t + P_t + \bar{I}_t - \left[O_t^d + O_t^m\right] \text{ for all t} \quad (3.2.7.4)$$

Where,

b_t and b_t' are called evaporation loss adjustment coefficient given by

$$b_t = \left[1 + 0.5.e_t.k_t''\right] ; b_t' = \left[1 - 0.5.e_t.k_t''\right]; k_t'' = \left[\Delta A_t/\Delta s_t\right]$$

Where,

ΔA_t = the change in the reservoir surface are in time t, and

Δs_t = the change in reservoir storage in time t. The value of k_t'' are calculated from a trial working table.

3.2.8 Annual Cost Discounting Technique

The procedure in which discounting factors may be systematically applied to compare alternatives (either different projects or different sizes of the same project) is called a discounting technique (James and Lee, 1971). In the linear programming models the Annual-Cost method of discounting is used. The annual-cost method converts all benefits and costs into equivalent uniform annual figures.

Annual cost of a project consists of

(i) annual interest on the initial capital cost, K,

(ii) annual depreciation using sinking fund factor on the initial capital cost, K, and

(iii) annual operation and maintenance cost.

Then uniform annual net benefits $B = \left(B' - C' \right)$.

Here,

B' = uniform annual benefits from project, and

C' = uniform annual costs of project.

The present worth (PW_{nb}) of the annual net benefits is obtained by applying the formula for the present value of annuity.

$$PW_{nb} = \left(\frac{P}{A}, i_f \text{ percent}, N \right) B \qquad (3.2.8.1)$$

or

$$PW_{nb} = \frac{\left[\left(1 + i_f \right)^N - 1 \right] B}{i_f \left(1 + i_f \right)^N} \qquad (3.2.8.2)$$

In equation (3.2.8.1) the bracketted term is the abbreviation of the present worth factor of annuity.

Here,

i_f = the annual discount rate, and

N = the economic life of the system.

The unit annual capital costs and the unit annual OM costs are calculated by:

$$C_1 = i_1^i \, CC_1 + \left[A/F, \, i_1^d \, , \, N \right] CC_1$$

$$Om_1' = i_1^o \, CC_1$$

$$C_2' = i_2^i \, CC_2 + \left[A/F, \, i_2^d, \, N \right] CC_2$$

$$Om_2' = i_2^o \, CC_2$$

$$C_3' = i_3^i \, CC_3 + \left[A/F, \, i_3^d, \, N \right] CC_3$$

$$Om_3' = i_3^o \, CC_3$$

Where,

CC_1 = unit capital cost of reservoir (slope of the linearised reservoir capital cost curve),

CC_2 = unit capital cost of irrigation works (slope of the linearised irrigation works capital cost curve),

CC_3 = unit capital cost of hydropower (slope of the linearised hydropower capital cost curve),

i_1^i, i_2^i, and i_3^i = annual rate of interest for calculating annual interest on capital cost for reservoir, irrigation works, and hydropower respectively,

i_1^d, i_2^d, and i_3^d = annual rate of discounting for calculating annual depreciation for reservoir, irrigation works, and hydropower respectively, and

i_1^o, i_2^o, and i_3^o = annual rate for operation and maintenance for reservoir, irrigation works and hydropower respectively.

3.3.0 ESTIMATION OF ANNUAL SAFE YIELDS FROM A RESERVOIR OF KNOWN SIZE (Max.Z_{sy})

Sometimes, reservoirs are operated to even out the flow of a stream, and the term safe yield is often called as the maximum even release that a reservoir of a known size could provide in all the months. On the other hand seasonal or variable monthly releases from a known size of a reservoir to give the annual safe firm and targeted yields are also desired (Loucks et al., 1981). Define O^* to be the annual safe yield from the reservoir, which could be maximized, i.e.,

$$\text{Maximize} : Z_{sy} = O^* \qquad (3.3.0)$$

Subject to:

(i) Reservoir continuity equation

$$K'_t.S_t = S_{t-1} + I_t + P_t + \bar{I}_t - \left[\delta_t.O^* + Sp_t \right] - \left[O_t^d + O_t^m \right] \text{ for all } t \qquad (3.3.1)$$

(ii) Limits on reservoir storages

$$S_{t-1} \geq Yd \qquad \text{for all } t \qquad (3.3.2)$$

$$S_{t-1} \leq Y^g \qquad \text{for all } t \qquad (3.3.3)$$

Where,

S_{t-1} = initial gross reservoir storage in time t,

S_t = final gross reservoir storage in time t,

I_t = catchment inflow to the reservoir in time t,

El_t = evaporation from reservoir in time t,

O^* = annual safe yield from the reservoir,

Sp_t = secondary water release (spill) from reservoir in time t,

Yd = dead storage capacity of reservoir,

Y^g = known gross reservoir capacity,

δ_t = proportion of the annual safe yield needed in time t,

$\delta_t = \frac{1}{12}$ for monthly even releases, and

$\delta_t \neq \frac{1}{12}$ for variable monthly releases.

3.4.0 DISCONTINUOUS MODEL FOR ESTIMATION OF OVER-YEAR CARRY-OVER STORAGES FOR A KNOWN RESERVOIR CAPACITY AND ANNUAL TATGETTED DEMAND ($Max.Z_{tr}$)

The over-year carry-over reservoir storages available/required for known reservoir size and annual targeted demand can be obtained as follows:

$$\text{Maximize : } Z_{tr} = \sum_{t=1}^{12} Va_t.O_t \qquad (3.4.0)$$

Subject to:

(i) Continuity equation

$$K'_t.S_t = S_{t-1} + I_t + P_t + \bar{I}_t - El_t - O_t - Sp_t - \left[O_t^d + O_t^m \right] \text{ for all t} \qquad (3.4.1)$$

Since, the model is to consider monthly flows for one year only, the discontinuous model condition gives that $S_o \neq S_{12}$, which is a measure of carry-over storages. For other months of the year it is a continuous model.

(ii) Limits on reservoir storages

$$Yd \le S_{t-1} \qquad \text{for all t} \qquad (3.4.2)$$

$$\text{and } S_{t-1} \le Y^g \qquad \text{for all t} \qquad (3.4.3)$$

(iii) Upper bounds on reservoir releases

$$O_t \le O_t^g \qquad \text{for all t} \qquad (3.4.4)$$

(iv) Reservoir full condition

$$S_t = Y^g, \qquad \text{for t at the end of the monsoon period} \qquad (3.4.5)$$

Where,

O^g_t = known targeted release from reservoir in time t,

S_o = reservoir storage at the beginning of the year,

S_{12} = reservoir storage at the end of the year,

Va_t = the value of reservoir release in time t, and

Y^g = known gross reservoir capacity.

3.5.0 ESTIMATION OF RESERVOIR CAPACITIES FOR A KNOWN ANNUAL DEMAND

3.5.1 Total Gross Reservoir Capacity for a Known Annual Targeted Demand (Min.Z_{gc})

The total gross reservoir capacity can be obtained for a known annual targeted demand from the following model:

$$\text{Minimize : } Z_{gc} = Y \qquad (3.5.1)$$

Subject to:

(i) Reservoir continuity equation

$$K'_t . S_{j,t} = S_{j,t-1} + I_{j,t} - \left[\delta'_t . Oy^g + Sp_{j,t} \right] \qquad \text{for all j and t} \qquad (3.5.1.1)$$

(ii) Limits on reservoir storages

$$Yd \leq S_{j,t-1} \qquad \text{for all j and t} \qquad (3.5.1.2)$$

$$\text{and } S_{j,t-1} \leq Y \qquad \text{for all j and t} \qquad (3.5.1.3)$$

Where,

$S_{j,t-1}$ = initial gross reservoir storage in time t in year j,

$S_{j,t}$ = final gross reservoir storage in time t in year j,

$I_{j,t}$ = reservoir inflow in time t in year j,

Oy^g = known annual targeted demand from reservoir,

δ'_t = proportion of the annual targeted demand needed in time t, and

$Sp_{j,t}$ = reservoir spill in time t in year j.

3.5.2 Over-year Carry-over Reservoir Capacity for a Known Annual Targeted Demand (Min.Z_{oc})

A reservoir with over-year carry-over storage capacity provides a means of increasing the magnitude and/or reliabilities of various annual yields (Loucks et al., 1981). The over-year carry-over reservoir storage can be obtained for a known annual targeted demand from the following model:

Minimize : $Z_{oc} = Y^o$ (3.5.2)

Subject to:

(i) Reservoir continuity equation

$$K'_j.S_j = S_{j-1} + I_j + P_j + \bar{I}_j - \left[Oy^g + Sp_j \right] - \left[O^d_j + O^m_j \right] \text{for all j} \quad (3.5.2.1)$$

(ii) Limits on reservoir storages

$$S_{j-1} \leq Y^o \quad \text{for all j} \quad (3.5.2.2)$$

$$Yd \leq S_{j-1} \quad \text{for all j} \quad (3.5.2.3)$$

Where,

Y^o = over-year carry-over reservoir capacity,

S_{j-1} = initial reservoir storage in the beginning of year j,

S_j = final reservoir storage at the end of year j,

El_j = reservoir evaporation in year j,

Oy^g = known annual targeted demand from reservoir,

Sp_j = reservoir spill in year j, and

I_j = inflow in year j.

3.5.3 Within-year Active Reservoir Capacity for a Known Annual Targeted Deman

Any distribution of within-year yields that differ from the distribution of the inflow may require additional active reservoir capacity. The difference between the total active reservoir capacity and the over-year carry-over active reservoir capacity is equal to the within-year active reservoir capacity, Ya^w.

3.6.0 LIST OF VARIABLES

A_o = reservoir surface area corresponding to the dead storage of reservoir, .Yd,

A_a = area per unit active storage volume above dead storage, Yd,

A_k = crop area for the k^{th} crop,

a_2 = benefit function for irrigation,

a_3 = benefit per unit of energy,

a_4 = unit flood control benefits,

a_t = a constant for reservoir evaporation in time t,

B = the uniform annual net benefits,

B′ = uniform annual benefits from project,

B_2 = gross annual irrigation benefits,

B_3 = gross annual energy benefits,

b_t, and b'_t = reservoir evaporation loss adjustment coefficient in time t,

C_1 = annual capital cost of reservoir,

C_2 = annual capital cost of irrigation,

C_3 = annual capital cost of hydropower,

C' = uniform annual costs of project,

C'_1 = annual capital cost function for reservoir capacity,

C'_2 = annual capital cost function for irrigation,

C'_3 = annual capital cost function for hydropower,

Cb_k = unit benefit from crop k,

CC_1 = unit capital cost of reservoir (slope of the linearised reservoir capital cost curve),

CC_2 = unit capital cost of irrigation works (slope of the linearised irrigation works capital cost curve),

CC_3 = unit capital cost of hydropower (slope of the linearised hydropower capital cost curve),

CCA = culturable command area,

C_f = a conversion factor for energy generation $= \dfrac{(9.8)C_t.C_v}{C_p}$

C_p = 1, if power is in KW,
= 10^3, if power is in MW, and
= 10^9, if power is in 10^6 MW or (GW),

C_v = 1, if O_t is in m^3 in h_t hours,
= 10^4, if O_t is in ha-m (10^4 m^3) in h_t hours,
= 10^6, if O_t is in MCM (10^6 m^3) in h_t hours,
= 10^9, if O_t is in TMC (10^9 m^3) in h_t hours,

C_t $= \dfrac{1}{h_t.3600}$

E = yearly energy target,

El_j = reservoir evaporation in year j,

El_t = evaporation from reservoir in time t,

E_t = energy generated in time t,

$\overline{E}_t$ = secondary energy generated in time t,

e = overall efficiency of turbine,

e_t = average reservoir evaporation rate in time t,

H = hydropower plant capacity,

$\overline{Ha}$ = constant power head in case of run-of-river plant,

Ha_t = average reservoir head in reservoir during time t,

h_t = number of hours in time t,

I_{av} = average annual river discharge in cumecs,

I_j = inflow in year j,

$I_{j,t}$ = reservoir inflow in time t in year j,

I_{15} = 15 % exceedence discharge in cumecs,

$I_{15},...,I_{100}$ = river inflow of a given dependability,

I_t = catchment inflow to the reservoir in time t,

$\overline{I}_t$ = local inflow to the reservoir from surrounding area in time t,

I''_t = water that joins the main just above irrigation diversion canal in time t ,

Ir = annual irrigation water target,

i_f = the annual discount rate,

i_1^i, i_2^i, and i_3^i = annual rate of interest for calculating annual interest on capital cost for reservoir, irrigation works, and hydropower respectively,

i_1^d, i_2^d, and i_3^d = annual rate of discounting for calculating annual depreciation for reservoir, irrigation works, hydropower respectively,

i_1^o, i_2^o, and i_3^o = annual rate for operation and maintenance for reservoir, irrigation works and hydropower respectively,

K_t = proportion of annual irrigation target Ir to be diverted for irrigation in time t,

K'_t = amount by which K'_t exceeds unity is the fraction of the end storage which is assigned to reservoir evaporation loss computed from two trial working tables, prepared with and without evaporation losses respectively,

m = number of crops,

N = number of time periods in the planning horizon,

O^d_t = release for water supply from reservoir in time t,

O^m_t = release from reservoir to keep minimum flow on downstream in time t,

O_t = total water release from reservoir in time t,

Om_1 = annual OM cost for reservoir capacity,

Om'_1 = annual OM cost function for reservoir capacity,

Om_2 = annual OM (Operation and maintenance) cost of irrigation,

Om'_2 = annual OM cost function for irrigation,

Om_3 = annual Om cost of hydropower,

Om'_3 = annual OM cost function for hydropower,

O^* = annual safe yield from the reservoir,

Oy^g = known annual targeted demand from reservoir,

O^g_t = known targeted release from reservoir in time t,

P_t = precipitation directly upon reservoir in time t,

PW_{nb} = present worth of net benefits,

S_t = gross/live reservoir storage at the end of time t,

S_{t-1} = gross/live reservoir storage at the beginning of time t,

Sp_t = secondary water release (spill) from reservoir in time t,

S_{j-1} = initial live reservoir storage in the beginning of year j,

S_j = final live reservoir storage at the end of year j,

Sp_j = reservoir spill in year j,

$S_{j,t-1}$ = initial gross reservoir storage in time t in year j,

$S_{j,t}$ = final gross reservoir storage in time t in year j,

$Sp_{j,t}$ = reservoir spill in time t in year j,

S_o = reservoir storage at the beginning of the year,

S_{12} = reservoir storage at the end of the year,

t_1 = number of flood months,

Va_t = the value of reservoir release in time t,

$W_{t,k}$ = water requirement for crop k in time t,

$X_{t,k}$ = land use coefficient for crop k in time t,

Y = total gross reservoir capacity,

Ya = total live capacity of reservoir,

Yd = dead storage of reservoir,

Y^g = known gross reservoir capacity,

Yf_t = flood storage capacity or reserve in time t,

$Ymax_t$ = gross capacity of reservoir up to normal pool level (top of conservation) of the reservoir in time t,

$Ymax'_t$ = live capacity of reservoir up to normal pool level (top of conservation) of the reservoir in time t,

Y^o = over-year carry-over reservoir capacity,

ΔA_t = the change in the reservoir surface are in time t,

Δs_t = the change in reservoir storage in time t,

δ_t = proportion of the annual safe yield needed in time t,

δ_t = for monthly even releases,

= for variable monthly releases,

δ'_t = proportion of the annual targeted demand needed in time t,

α_t = load factor in time t, and

η_t = % of annual energy target to be supplied in time t.

CHAPTER 4

DYNAMIC PROGRAMMING MODEL

Chapter-4

DYNAMIC PROGRAMMING MODEL

4.1.0 INTRODUCTION

Dynamic programming is a simple procedure from the computational point of view and that can treat nonconvex, nonlinear, discontinuous objective and constraint functions. It is an iterative procedure and requires a relatively small number of computer instructions. It is limited, however, to problems that can be formulated with only a few state variables at each stage. Dynamic programming has been used to study several types of water resources system. Hall and Buras (1969) were the first to propose that dynamic programming be applied to determine the optimal return from reservoir system. They studied the problem of allocating stored water to various purposes. Hall (1964) reported a study to determine the optimal reservoir size.

4.2.0 THE MODEL

A design and operation problem using Dynamic Programming, similar to the procurement problem (Haimes, 1977), for the reservoir system is formulated. The objective is to maximize the total return (net benefits) from meeting water demands as far as possible for all periods in the planning horizon, subject to certain constraints.

Let,

N = the number of time periods in the planning horizon,

S_t = live reservoir storage during period t, assumed as storage at the end of period t (a state variable),

S_{t-1} = live reservoir storage during period (t–1) assumed as storage at the beginning of period t (a state variable),

I_t = catchment inflow into the reservoir in period t,

O_t = total water release from the reservoir in period t (a decision variable), and

$g_t(S_t,O_t)$ = the return function (net benefits from meeting water demands) for period t; t = 1,2,..., N.

Note that the number of stages in the dynamic programming formulation coincides with the number of periods, N, of the planning horizon.

Since, this reservoir problem involves time, it is beneficial to formulate and solve the dynamic programming problem using backward multistage approach. Therefore, the various variables and parameters are redefined below:

N = the total number of stages to go,

r = r number of stages to go ; r = 1,2, ..., N.

S_r = live reservoir storage at the beginning of r stages to go (a state variable),

S_{r-1} = live reservoir storage at the end of r stages to go (a state variable),

I_r = catchment inflow into the reservoir in r stages to go,

O_r = total water release from the reservoir in r stages to go (a decision variable), and

$g_r(S_r, O_r)$ = the return function (net benefits from meeting water demands) for r stages to go.

The overall objective function is:

$$\text{Max} \sum g_r (S_r, O_r)$$

Where,

$g_r(S_r, O_r)$ = (gross benefit, in r stages to go-fraction of annual OM costs, in r stages to go).

or

$$g_r (S_r, O_r) = \left[\left(B_{2,r} + B_{3,r} + B_{4,r}\right) - \left(Om_{1,r} + Om_{2,r} + Om_{3,r}\right)\right] \quad (4.1)$$

Where,

$B_{2,r}$ = gross benefit from irrigation, in r stages to go,

$B_{3,r}$ = gross benefit from energy, in r stages to go,

$B_{4,r}$ = benefit from flood control, in r stages to go, and

$Om_{1,r}$, $Om_{2,r}$, and $Om_{3,r}$ = fractions of annual OM cost of reservoir, irrigation works, and hydroplant respectively, in r stages to go.

The constraints are:

(a) $O_r \geq 0$, for all r stages to go; r = 1,2,...., N. (4.2)

(b) The continuity equation for the reservoir is

$$S_{r-1} = S_r + I_r + P_r + \bar{I}_r - El_r - \left[O_r + O'_r \right] \quad \text{for all r stages to go} \qquad (4.3)$$

Where,

P_r = precipitation directly upon reservoir in r stages to go,

$\bar{I}_r$ = local inflow to the reservoir from the surrounding area in r stages to go,

El_r = reservoir evaporation in r stages to go, and

O'_r = reservoir release to the natural channel in r stages to go.

Thus,

$$S_{r-1} = Tr_r(S_r, O_r) = S_r + I_r - O_r + \left[P_r + \bar{I}_r - El_r - O'_r \right] \quad \text{for all r stages to go} \qquad (4.4)$$

Put $X_r = P_r + \bar{I}_r - El_r - O'_r$ then equation (4.4) becomes

$$S_{r-1} = S_r + I_r - O_r + X_r \quad \text{for all r stages to go} \qquad (4.4a)$$

Where,

$Tr_r(S_r,O_r)$ = the transformation function.

(c) The maximum live storage can not exceed the live storage capacity of the reservoir Ya, hence,

$$0 \le Ymin'_r \le S_{r-1} \le Ymax'_r \le Ya$$

Where,

Ya = active (live) capacity of the reservoir,

$Ymax'_r$ = live capacity up to the normal pool level of the reservoir in r stages to go, and

$Ymin'_r$ = live capacity upto the minimum pool level of the reservoir in r stages to go.

or

$$0 \le Ymin'_r \le S_r + I_r - O_r + X_r \le Ymax'_r \le Ya$$

Rearranging the above constraints in terms of Ya yields the lower and upper bounds on O_r:

$$S_r + I_r + X_r - Ya \le O_r \le S_r + I_r + X_r \quad \text{for all r stages to go.}$$

Define a new function $f_1(S_1)$ as the maximum benefit from meeting water demands at the first stage to go with a water storage level at S_1.

Mathematically, the optimization problem for the first stage to go can be written as:

$$f_1(S_1) = \max_{O_1} \left[g_1 (S_1, O_1) \right] \tag{4.5}$$

Subject to

$$S_1 + I_1 + X_1 - Ya \le O_1 \le S_1 + I_1 + X_1, \tag{4.6}$$

Similarly, define the general function $f_r(S_r)$ to be the maximum benefit from meeting water demands from all r stages to go with a water storage level S_r during r stages to go.

Mathematically, therefore, the general recursive equation for all r stages to go for the dynamic programming can be written as:

$$f_r(S_r) = \max_{O_r} \left[g_r\left(S_r, O_r \right) + f_{r-1} \left(S_{r-1} \right) \right] \tag{4.7}$$

Subject to

$$S_r + I_r + X_r - Ya \leq O_r \leq S_r + I_r + X_r, \tag{4.8}$$

The value of S_{r-1} can be put in equation (4.7) from equation (4.4a). The above recursive equation can be solved for all possible stock levels (stages or storages) S_r for all r planning stages to go. Then, the optimal release policy O_r^* for all r stages to go can be determined using the state equation.

$$S_{r-1} = S_r + I_r - O_r + X_r$$

The steps involved in the process are shown in Figure 4.1. The dynamic programming computer program is given in Appendix-1. The various terms in $g_r(S_r,O_r)$ were calculated as below:

$$B_{2,r} = a_2.O_r - Lf_{2,r} \left[Od_{2,r} - O_r \right] \qquad \text{if } O_r < Od_{2,r},$$

$$B_{2,r} = a_2.Od_{2,r}, \qquad \text{if } O_r \geq Od_{2,r},$$

Where,

$Od_{2,r} = K_r.Ir,$

K_r = % of irrigation required in r stage to go, and

Ir = annual irrigation target.

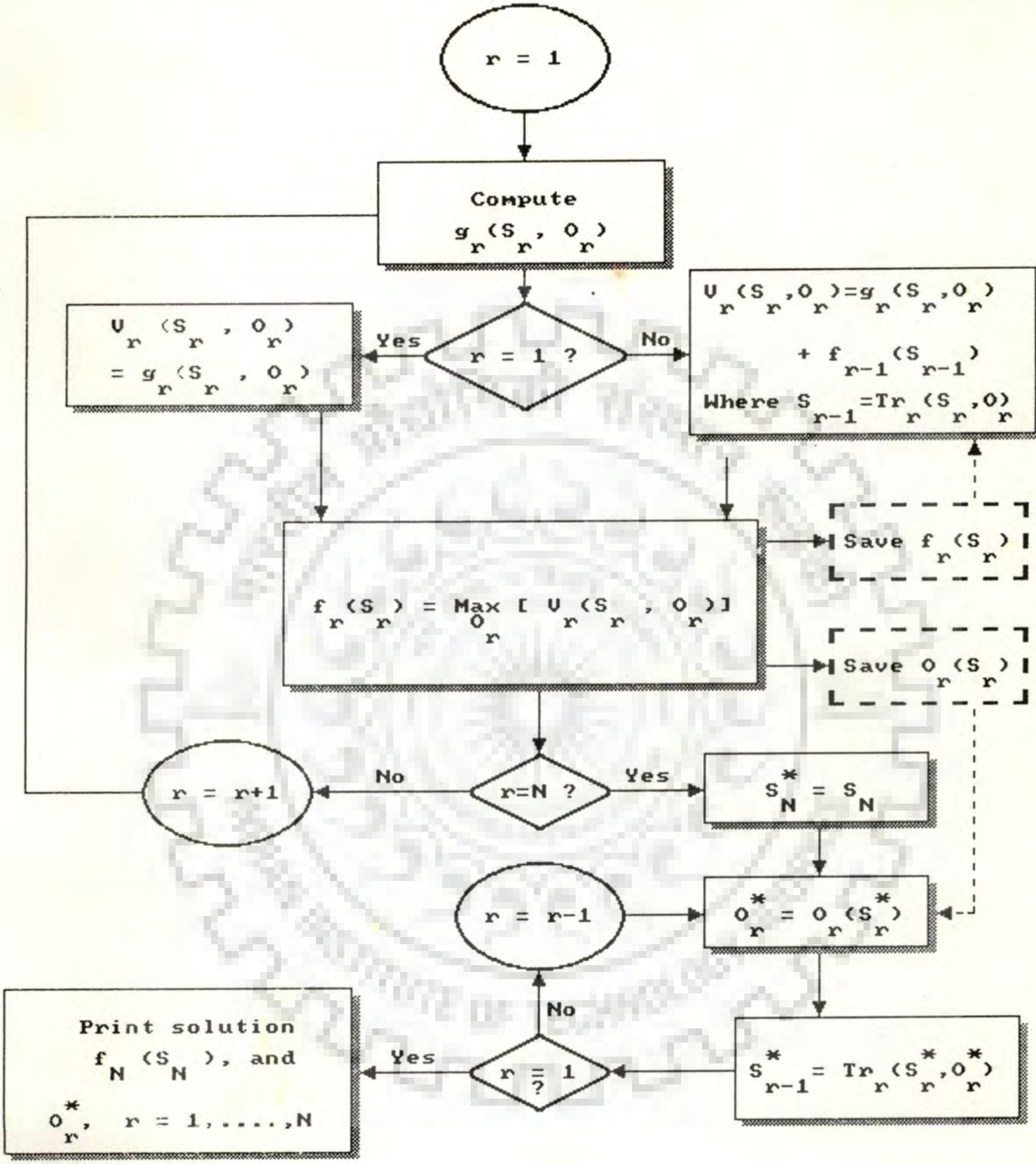


Fig. 4.1 Flow chart for dynamic programming

$$B_{3,r} = a_3.E_r - Lf_{3,r}\left[\eta_r.E - E_r\right] \qquad \text{if } E_r < \eta_r.E,$$

$$B_{3,r} = a_3\left[\eta_r.E\right] + Df_{3,r}\left[E_r - \eta_r.E\right] \qquad \text{if } E_r \geq \eta_r.E,$$

$$B_{4,r} = a_4\left[Ya - Ymax'_r\right]$$

$$Om_{1,r} = \left[Om'_1/12\right]*Ya,$$

$$Om_{2,r} = \left[Om'_2/12\right]*O_r \qquad \text{if } O_r < Od_{2,r},$$

$$Om_{2,r} = \left[Om'_2/12\right]*Od_{2,r}, \text{ and} \qquad \text{if } O_r \geq Od_{2,r},$$

$$Om_{3,r} = \left[Om'_3/12\right]*H.$$

Where,

a_2 = unit irrigation benefit,
a_3 = unit energy benefit,
a_4 = unit flood control benefit in r stages to go,
E = annual energy target,
η_r = % of energy required in r stages to go,
E_r = energy generated in r stages to go,
$Lf_{2,r}$ = loss in irrigation benefits per unit deficit in supply in r stages to go,
$Lf_{3,r}$ = loss in energy benefits per unit deficit in supply in r stages to go, and
H = hydroplant capacity.

4.3.0 LIST OF VARIABLES

a_2 = unit irrigation benefit,

a_3 = unit energy benefit,

a_4 = unit flood control benefit in r stages to go,

$B_{2,r}$ = gross irrigation benefit in r stages to to,

$B_{3,r}$ = gross energy benefit in r stages to go,

$B_{4,r}$ = benefit from flood control in r stages to go,

$Df_{3,r}$ = unit dump energy benefits,

E = annual energy target,

El_r = reservoir evaporation in r stages to go,

E_r = energy generated in r stages to go,

f_r = optimal return from r stages to go,

$g_r(S_r,O_r)$ = the return function (net benefit from meeting water demands) for r stages to go,

$g_t(S_t,O_t)$ = the return function (net benefits from meeting water demands) for period t; t = 1,2,..., N.

H = hydroplant capacity,

Ir = annual irrigation target,

I_r = catchment inflow into the reservoir in r stages to go,

$\bar{I}_r$ = local inflow to the reservoir from the surrounding area in r stages to go,

I_t = catchment inflow into the reservoir in period t,

$Lf_{2,r}$ = loss in irrigation benefits per unit deficit in supply in r stages to go,

$Lf_{3,r}$ = loss in energy benefits per unit deficit in supply in r stages to go,

N = number of stages to go in the planning horizon,

O_r = total water release from the reservoir in r stages to go,

O_r^* = the optimal total water release from the reservoir in r stages to go,

O'_r = reservoir release to the natural channel in r stages to go,

O_t = total water release from the reservoir in period t (a decision variable),

$Od_{2,r}$ = irrigation demand in r stages to go,

$Od_{3,r}$ = energy demand in r stages to go,

Om'_1 = annual OM cost function for reservoir,

$Om_{1,r}$ = fraction of annual OM cost for reservoir in r stages to go,

Om'_2 = annual OM cost function for irrigation,

$Om_{2,r}$ = fraction of annual OM cost for irrigation in r stages to go,

Om'_3 = annual OM cost function for hydropower,

$Om_{3,r}$ = fraction of annual OM cost for hydropower in r stages to go,

P_r = precipitation directly upon reservoir in r stages to go,

r = r stages to go; r = 1,2, ..., N,

S_r = live reservoir storage at the beginning of r stages to go,

S_{r-1} = live reservoir storage at the end of r stages to go,

S_t = live reservoir storage during period t, assumed as storage at the end of period t (a state variable),

S_{t-1} = live reservoir storage during period (t-1) assumed as storage at the beginning of period t (a state variable),

$Tr_r(S_r,O_r)$ = transformation function,

Ya = active (live) capacity of the reservoir,

$Ymax'_r$ = live capacity upto the normal pool level of the reservoir in r stages to go,

$Ymin'_r$ = live capacity upto the minimum pool level of the reservoir in r stages to go, and

η_r = % of energy required in r stages to go.

CHAPTER 5

SIMULATION MODEL

Chapter-5

SIMULATION MODEL

5.1.0 INTRODUCTION

Simulation can be stated as a technique for describing the system behaviour under the action of a particular input, when it is operated under a certain set of procedures. Simulation is basically a trial and error procedure which duplicates the essence of the system and its activity without attaining the reality (Hufschmidt & Fiering, 1966). It is a tool to study effectively any complex problems.Simulation can be done by having physical models, digital or analog models.

Estimation of the storage capacity of a reservoir and the yield from it are major problems and require a thorough study and analysis in water resources planning. The storage does the function of changing the natural flow hydrology into a particular outflow pattern commensurate with the actual demand for beneficial purposes. Though, there are various methods of estimation of storage capacity requirements, simulation is the most widely used method. The reason lies in its mathematical simplicity and versatility. The advent of high-speed computers had enabled the planners to write very detailed simulation programmes to describe the operation of water resources system.

Simulation is not an optimizing procedure, but for any set of design and operation policy parameter values, it merely provides a rapid means for evaluating the anticipated performance of the system. Simulation does not identity the optimal design and operating policy, but it is an excellent means of evaluating those designs and operation policies defined by simpler optimization model (Loucks et al., 1981).

5.2.0 THEORY

For a single reservoir the simulation problem (System Analysis in Water Resources Planning, 1975) is defined below:

author?

(1) Determine sizes of reservoir, irrigation diversion and distribution facility, and power plant,

(2) Determine firm, targeted and secondary annual demand levels of irrigation and energy outputs, and

(3) Determine allocations of reservoir capacity to active, dead, and flood storages, so as to get maximum present value of net benefits. Given (1) monthly run off values, and (2) an operating procedure for reservoir.

5.2.1 System Design Variables, Parameters and Constants

In general, there are two classes of system components and constants:

(1) design variables, which are free to change from one simulation run to the next, and

(2) invariant physical functions, parameters, and constants of the water resources system under study.

The design variables, parameters, and constants are:

5.2.1.1 Major design variables

1. Major Physical Design variables in terms of their assumed ranges and unit of measurements:

(i) Components of System:

(a) Gross and live capacities of reservoir, and

(b) Power plant capacity of power plant.

(ii) Allocation of Reservoir Capacity:

(a) Dead storage in reservoir where energy is generated,

(b) Flood storage in reservoir, and

(c) 12-element vector of flood storage allocation for reservoir (monthly values).

(iii) Demand Outputs:

(a) Firm and targeted annual demand outputs for irrigation for the command area (yearly),

(b) Firm, targeted and secondary annual demand outputs for energy (yearly), and

(c) 12-element vector of annual demand outputs for irrigation and energy (monthly percent of the annual values).

2. Variables, Functions and Constants relating to power generation:

(i) Equation used for energy generation

(ii) Pen stock capacity

(iii) Maximum head for power plant, and

(iv) Turbine and generator efficiencies.

5.2.1.2 Cost and benefit functions

1. For irrigation area:

(i) Annual target output for irrigation vs. unit gross irrigation benefit relationship,

(ii) Annual irrigation shortage vs. irrigation loss relationship,

(iii) Annual target output for irrigation vs. capital cost of irrigation diversion, distribution and pumping works relationship, and

(iv) Annual target output for irrigation vs. annual OM cost of irrigation diversion, distribution and pumping works relationship.

2. For power plant:

(i) Installed capacity of power plant vs. capital cost of power plant relationship,

(ii) Installed capacity of power plant vs. annual OM cost of power plant relationship,

(iii) Reservoir capacity vs. net effective power head,

(iv) Firm energy benefit or unit firm energy benefit,

(v) Dump price for energy, or unit-dump energy benefit, and

(vi) Energy loss, or unit loss from energy deficit.

3. For reservoir:

(i) Capacity of reservoir vs. capital cost of reservoir relationship, and

(ii) Capacity of reservoir vs. annual OM cost of reservoir relationship.

4. Others:

(i) Interest rate and formula used for present worth method of discounting.

5.2.1.3 Streamflow data

(i) Monthly river flows for reservoir site.

5.3.0 OPERATION OF RESERVOIR

Since the performance of the river basin system is studied for many different combinations of system variables, performance in terms of physical outputs and economic benefits achieved is being measured by simulating the behaviour of the system on a digital computer, it is necessary to construct an operating procedure (a set of rules for storing and releasing water in reservoir in a given period) in a form suitable for the computer (Srivastava, 1992).

5.3.1 Individual Reservoir Operation

The reservoir will operate under the following basic constraints:

1. The volume of water released during any period can not exceed the contents of the reservoir at the beginning plus the flow into the reservoir during the period, i.e.,

$$O_t \leq S_{t-1} + I_t + P_t + \bar{I}_t - \left(O_t^d + O_t^m \right) - El_t - Ymin_t \text{ for all } t \qquad (5.1)$$

2. The reservoir continuity equation is

$$S_t = S_{t-1} + I_t + P_t + \bar{I}_t - O_t - El_t - \left(O_t^d + O_t^m \right) \text{ for all } t \quad (5.2)$$

3. The contents of the reservoir at any period can not exceed the capacity of the reservoir (or the gross reservoir storage capacity up to the top of conservation during floods), as well as the dead storage of the reservoir puts a lower limit on the reservoir storage, such that

$$Yd \leq Ymin_t \leq S_{t-1} \leq Ymax_t \leq Y \qquad \text{for all } t \quad (5.3)$$

Where,

El_t = reservoir evaporation from reservoir in time t,

I_t = river inflow to reservoir in time t,

$\bar{I}_t$ = local inflow to reservoir from surrounding areas in time t,

O_t = total reservoir release from reservoir in time t,

P_t = precipitation effect directly upon reservoir in time t,

S_{t-1} = initial gross reservoir content or storage of reservoir in time t,

S_t = gross reservoir storage or content of reservoir at the end of the time t,

t = any time,

Y = gross storage capacity of reservoir,

Yd = dead storage capacity of reservoir,

$Ymin_t$ = gross capacity of reservoir up to minimum pool level of reservoir in time t.

$Ymax_t$ = gross capacity of reservoir upto normal pool level (top of the conservation) of reservoir in time t,

O_t^d = release for water supply from reservoir in time t, and

O_t^m = release from reservoir to keep minimum flow on downstream in time t.

5.4.0 DISCOUNTING TECHNIQUE

The procedure in which discounting factors may be systematically applied to compare alternatives (either different projects or different sizes of same project) in terms of the extent of serving the economic objectives is called a discounting technique (James and Lee, 1971). In the simulation the present worth method of discounting is used. The present worth method selects the projects with the largest present worth of net benefits, PW_{nb}, of the discounted algebraic sum of the benefits minus costs over its life.

In simulation the initial capital costs (initial first costs) of reservoir, K_1, of irrigation, K_2, and of hydropower, K_3, are calculated. The gross benefits in time j (usually a year), from irrigation, $B_{2,j}$, and from energy, $B_{3,j}$, are calculated. The net benefits B'_j, from irrigation and hydropower in time j is given by:

$$B'_j = \left(B_{2,j} + B_{3,j}\right) - \left(Om_{1,j} + Om_{2,j} + Om_{3,j}\right)$$

Where,

$Om_{1,j}$ = Operation and maintenance (OM) cost of reservoir in time j,

$Om_{2,j}$ = OM cost of irrigation works in time j, and

$Om_{3,j}$ = OM cost of hydropower in time j.

Then,

$$PW_{nb} = -\left(K_1 + K_2 + K_3\right) + \sum_{j=1}^{N} \left(\frac{P}{F}, i_f\ \%, j\right) B'_j \tag{5.4}$$

$$= -K + \sum_{j=1}^{N} \left[1/\left(1 + i_f/100\right)^j\right] B'_j \tag{5.5}$$

Where,

K $= K_1 + K_2 + K_3$,

i_f = the discount rate for finding present worth,

N = the economic life of the project, and

j = any time period (usually a year).

In equation (5.4) the bracketted term is the abbreviation of the present worth factor. In equation (5.5) the term in the bracket is the actual present worth factor.

5.5.0 SAMPLING TECHNIQUES

The net benefit from river basin system in response to various simulating combinations of many system variables, say n, represents an n dimensional surface (System Analysis in Water Resources Planning, 1975).

This surface may be called the net benefit response surface. On this surface, there may be several points at which the net benefits are maximum. Among these points there is at least one point which locates the maximum of all maxima, or the greatest net benefits.

Because of the enormous number of possible combinations of the system variables, the point of greatest net benefits cannot be easily determined even with the use of high speed computers. Many combinations and points of maximum net benefits, however, can be eliminated from consideration on account of certain site conditions and the limitations in the range of and due to the nature of the variables. The only time saving practical method of locating the point of optimality or points of local maxima is to sample the variables and thereby explore the response surface and eliminate undesirable combinations from the computations.

There are two broad categories of sampling methods: random and systematic sampling. All the sampling methods may be used either separately or in combination. The selection mainly depends on the nature of the response surface under investigation.

5.5.1 Random Sampling

In random sampling the values of the system variables for each combination are selected purely by chance from an appropriate population of values of the variables (using rectangularly distributed random numbers between 0–1). These selected values should be within their respective ranges and subject to whatever site conditions or limitations may be associated with the different variables. The maximum benefit for each combination is then determined by carrying out simulation. The combination with greatest benefit may be very nearly the maximum of maxima.

5.5.2 Systematic Sampling

In systematic sampling the values of system variables are selected in accordance with some ordering principle and the entire range of combinations of the variables is systematically examined. The methods of systematic sampling particularly applicable to river-basin system designs are the uniform grid method, and incremental analysis method.

In the uniform grid method (also known as factorial method) the values of variables are taken at uniform intervals or grids over the entire range of each variables. The finer the grid the larger will be the number of combinations of variables to be considered. Hence, this method may usually be applied in two steps. In the first step a coarse grid is used to determine the region of local maxima or summits. This is followed by a second step, in which a finer grid is used to analyze the benefit functions around the local summits. From the local summits, the optimal one can be found. In this method a greater number of grid nodes is used only for more important variables. Thus the entire response surface of the system can be mapped with a small number of variables.

5.6.0 RESULTS FROM SIMULATION

Each simulation run (say for monthly operation) gives the following results and statistics for behaviour analysis of the system, other than the present worth of net benefits obtained, during the period of analysis.

5.6.1 Reservoir Behaviour

1. Minimum monthly active content of reservoir in a calendar month (12 element vector),
2. Maximum monthly active content of reservoir in a calendar month (12 element vector),
3. Number of times reservoir was full in a calendar month (12 element vector),
4. Number of times reservoir was empty in a calendar month (12 element vector), and
5. Final reservoir content at the end of the analysis period (single value).

5.6.2 Irrigation Analysis

1. Maximum monthly irrigation deficit in a calendar month (12 element vector),
2. Number of monthly irrigation deficits in a calendar month (12 element vector), and
3. Average annual irrigation deficit (single value).

5.6.3 Energy Analysis

1. Average annual energy deficit (single value),
2. Average annual energy surplus (single value),
3. Maximum monthly energy deficit in a calendar month (12 element vector),

4. Maximum monthly energy surplus in a calendar month (12 element vector),
5. Number of monthly energy deficits in a calendar month (12 element vector), and
6. Number of monthly energy surpluses in a calendar month (12 element vector).

5.7.0 GENERATION OF RECTANGULARLY DISTRIBUTED VARIATIES: CONGRUENTIAL METHODS

These methods have been developed from one originally proposed by (Clarke, 1993). His original multiplicative congruence method used the recurrence relation.

$$X_i = aX_{i-1} \left(\text{modulo } m\right) \tag{5.6}$$

meaning that X_i is the remainder when (aX_{i-1}) is divided by m,and this has been generalized to the relation

$$X_i = \left(aX_{i-1} + C\right) \left(\text{modulo } m\right) \tag{5.7}$$

meaning that X_i is the remainder when $(aX_{i-1} + c)$ is divided by m. In equations (5.6) and (5.7), m is a large integer determined by the design of the computer (usually a large power of 2 or 10), and a, c, X_i are integers between 0 and (m - 1). The number X_i/m then form a sequence having a rectangular distribution.

Much care is necessary in the choice of values a, c and m used; the sequence $\left\{X_1, X_2 \ldots\right\}$ must eventually repeat itself, so that it is preferable to describe it as a sequence of pseudo-random numbers rather than a sequence of random numbers. If the sequence repeats itself after X_p (that is, after p pseudo-random numbers have been generated), the p will depend upon the choice of a, c and m; it is therefore particularly important to choose these integers to make p as large as possible. Rules governing their choice are given by Hammersley and Handscomb (1965).

5.8.0 RANDOM NUMBER FUNCTION

This random number function (HEC-4, Monthly Streamflow Simulation, 1971) is for a binary machine and three constants a, c and m must be computed according to the number of bits in an integer word. The numbers generated are uniformly distributed in interval 0 to 1.

Three constants must be computed by the following equations:

Constant one, $a = \left[2^{(B+1)/2} + 3 \right]$

Constant two, $c = \left[2^{B} - 1 \right]$

Constant three, $m = \left[1./2.^{B} \right]$

Where,

B = Number of bits in an integer word, for a particular machine.

The constants for the IBM 360 computer are listed in Table 5.1.

Table 5.1 The constants for random number function

COMPUTER	SIZE OF INTEGER WORD	a	c	m
IBM 360 SERIES	31	65539	2147483647	0.465661287E–09

5.9.0 COMPUTER PROGRAMME

The computer programme consists of main programme, (SIMF) subroutine sub-programmes and function subprogrammes (Mohanthy, 1992). A general flow chart for simulation/operation computation steps are shown in Figure 5.1. The computer programme is given in Appendix-2. The functions of the various subprogrammes are described below:

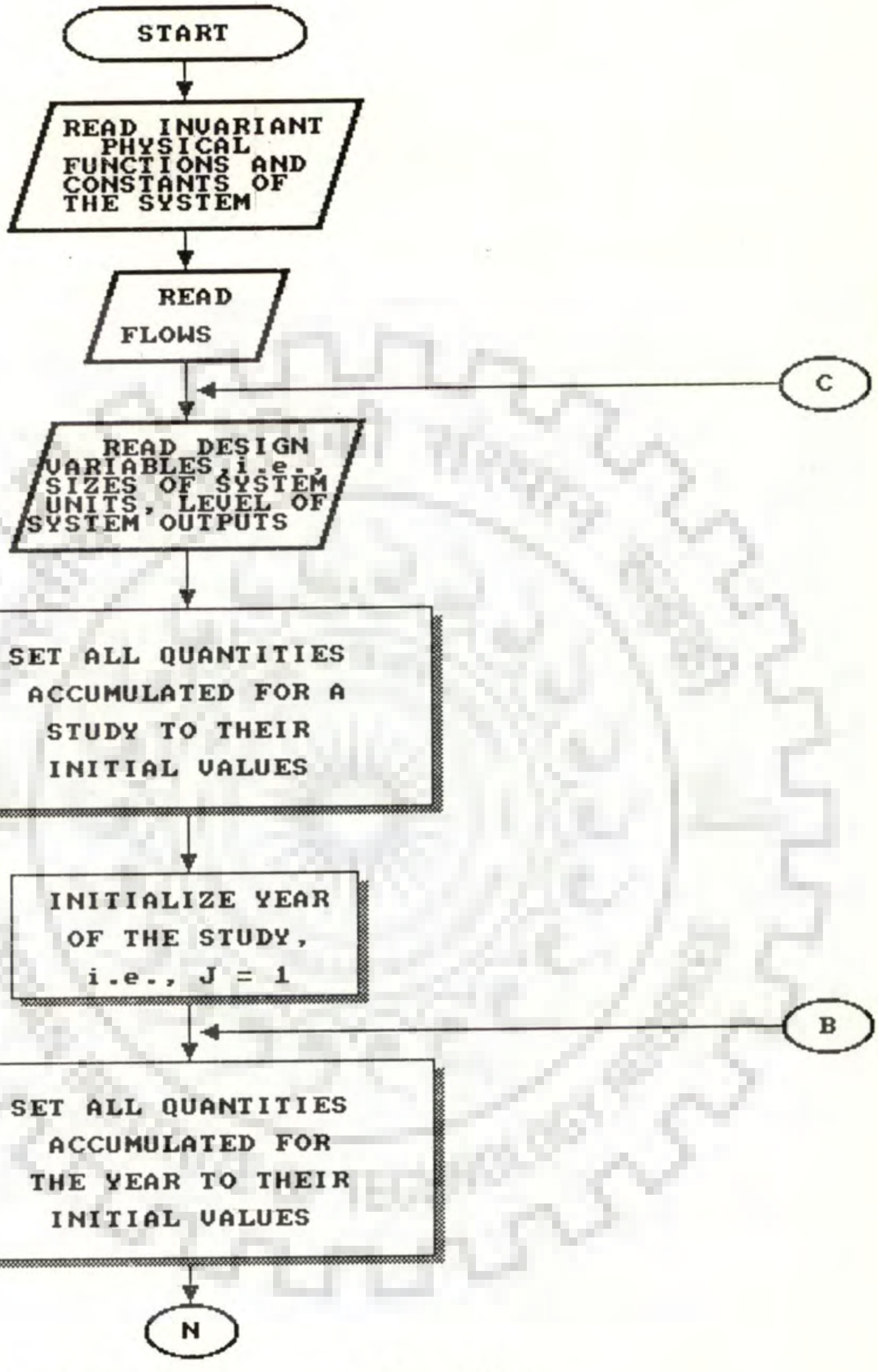


Fig. 5.1 A general flow chart for reservoir simulation/ operation

Fig. 5.1 Continued

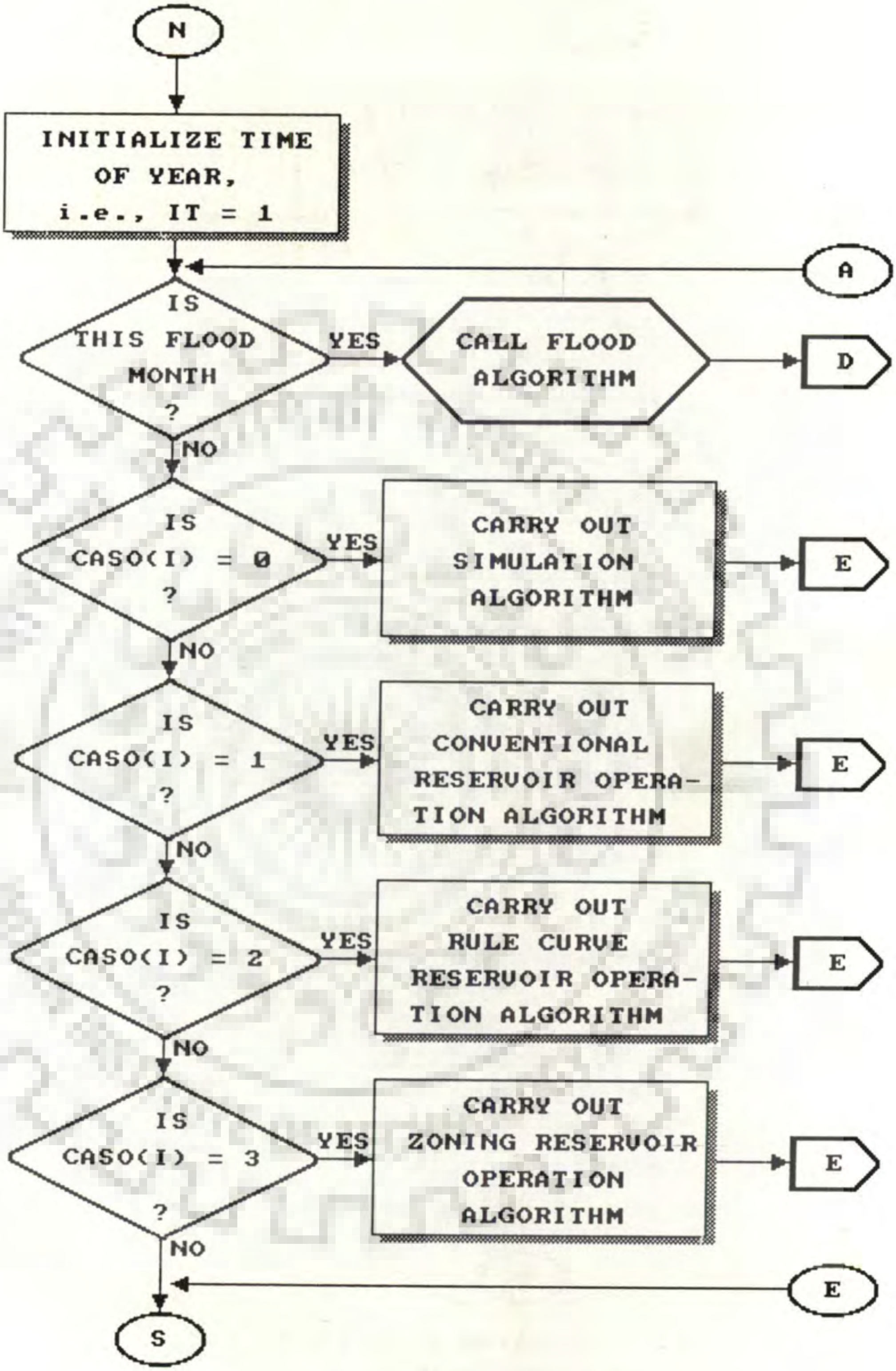
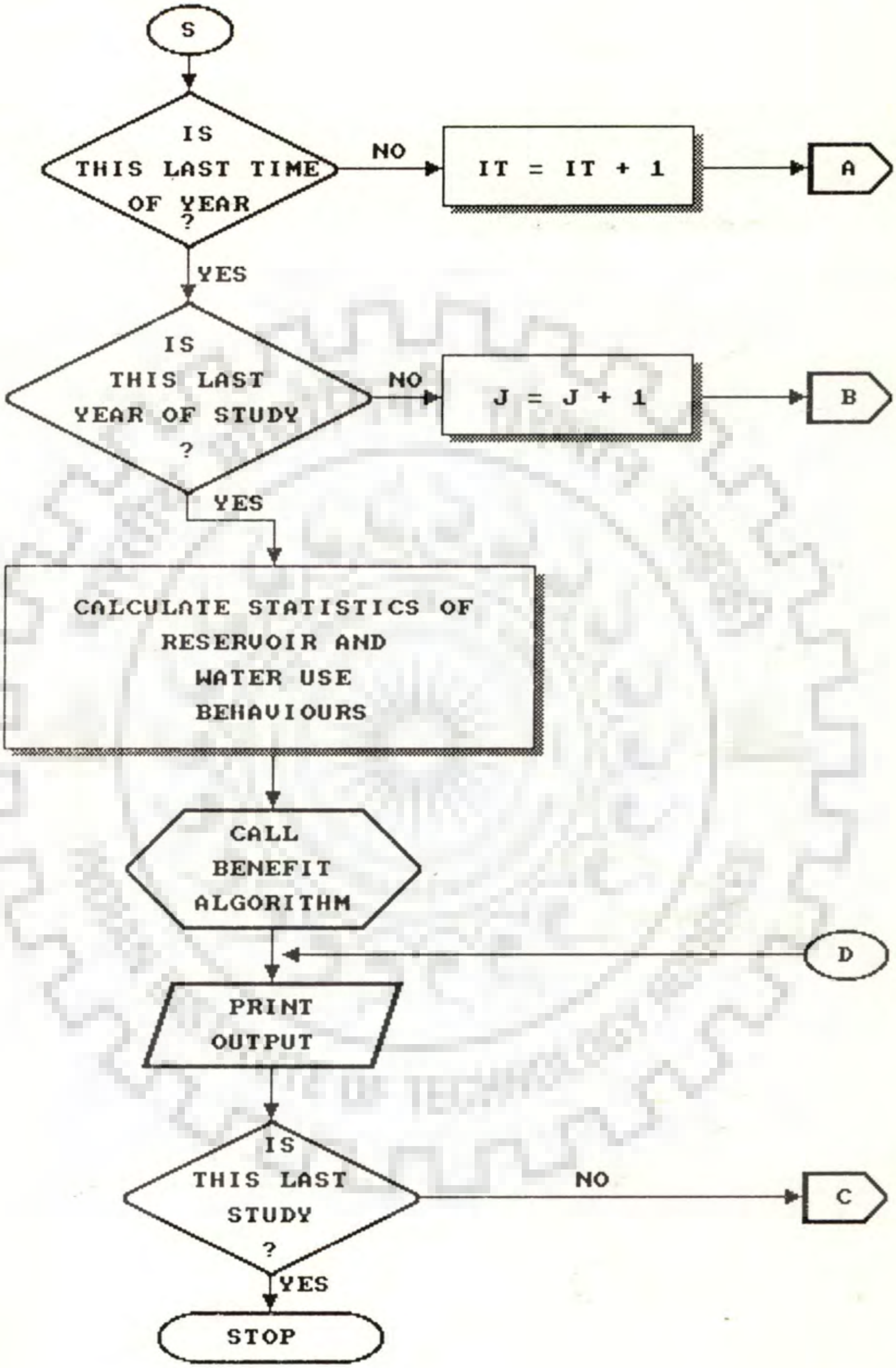


Fig. 5.1 Continued



1. **Subroutine BENFT :**

   This subroutine computes the present worth of net benefits.

2. **Function AREA :**

   This function computes the reservoir water spread area.

3. **Function ELEVAT :**

   This function computes the reservoir water elevation.

4. **Function ABFD :**

   This function computes annual benefit.

5. **Function ALFD :**

   This function computes annual loss in benefit.

6. **Function ADFD :**

   This function computes annual dump energy benefit.

7. **Function AOFR :**

   This function computes annual OM cost of reservoir.

8. **Function AOFP :**

   This function computes annual OM cost of hydropower.

9. **Function AOFD :**

   This function computes annual OM cost of irrigation.

10. **Function CFRE :**

    This function computes capital cost of reservoir.

11. **Function CFPP :**

    This function computes capital cost of hydropower.

12. **Function CFWD :**

    This function computes capital cost of irrigation.

5.10.0 LIST OF VARIABLES

$B_{2,j}$ = gross benefit from irrigation in time j,

$B_{3,j}$ = gross benefit from hydropower in time j,

B'_j = gross benefit from irrigation and hydropower in time j,

a = an integer between 0 and (m–1),

B = number of bits in an integer word, for a particular machine,

c = an integer between 0 and (m–1),

El_t = reservoir evaporation from reservoir in time t,

I_t = river inflow to reservoir in time t,

$\bar{I}_t$ = local inflow to reservoir from surrounding areas in time t,

i_f = the discount rate for finding present worth,

j = any time period (usually a year),

K = total initial capital cost of the project,

K_1 = initial capital cost of reservoir,

K_2 = initial capital cost of irrigation,

K_3 = initial capital cost of hydropower,

m = a large integer determined by the design of computer (usually a large power of 2 or 10),

N = the economic life of the project,

O_t = total reservoir release from reservoir in time t,

O_t^d = release for water supply from reservoir in time t,

O_t^m = release from reservoir to keep minimum flow on downstream in time t,

$Om_{1,j}$ = operation and maintenance (OM) cost of reservoir in time j,

$Om_{2,j}$ = OM cost of irrigation works in time j,

$Om_{3,j}$ = OM cost of hydropower in time j,

P_t = precipitation effect directly upon reservoir in time t,

PW_{nb} = present worth of net benefits,

S_{t-1} = initial gross reservoir content or storage of reservoir in time t,

S_t = gross reservoir storage or content of reservoir at the end of the time t,

t = any time,

X_i = ith random number between 0 and 1, having rectangular distribution,

X_{i-1} = seed value to find X_i,

Y = gross storage capacity of reservoir,

Yd = dead storage capacity of reservoir,

$Ymax_t$ = gross capacity of reservoir upto normal pool level (top of the conservation) of reservoir in time t, and

$Ymin_t$ = gross capacity of reservoir up to minimum pool level of reservoir in time t.

CHAPTER 6

LINEAR PROGRAMMING MODEL-SOFTWARE DEVELOPMENT FOR INPUT DATA MATRIX (MATGEN PACKAGE)

Chapter-6

LINEAR PROGRAMMING MODEL-SOFTWARE DEVELOPMENT FOR INPUT DATA MATRIX (MATGEN PACKAGE)

6.1.0 INTRODUCTION

After a linear programming model is formulated for a real life problem, the solution of the problem requires a Standard Linear Programming Package. These packages are not generally easily available to every user. On the other hand several computer programmes on linear programming appear in various literature. However, these computer packages are not very efficient and the input data feeding is very extensive (Razavian, 1990). Since, the planning and operation problem of a reservoir involves considerable amount of computations and needs extensive data feeding, it may be a worthwhile exercise to evolve a technique to create the Input Data Matrix for the problem in hand. To deal with such a situation, a generalized computer algorithm is presented here in order to create the non-zero coefficients of the matrices resulting from the linear programming model. This in turn will be the pregenerated Input Data Matrix created through a subroutine subprogramme for main linear programme routine (Sadeghian, 1995). This subroutine subprogramme can be appended to a linear programming computer programme available in literature. A linear programming computer programme using simple algorithm is given in Appendix-3.I.

6.2.0 MATRIX FORM OF INPUT DATA

The modeled constraint equations and the objective function of Chapter-3 can be rewritten by rearranging the variables in the sequence O_t, S_{t-1}, S_t, Y, $Ymax_t$, Sp_t, O^*, Ir, H, E, E_t, and $\overline{E}_t$. For explanation this has been shown for a multipurpose reservoir for model $Max.Z_{nb}$ below:

6.2.1 Reservoir Constraints

$$O_t - S_{t-1} + K'_t . S_t = I_t + P_t + \bar{I}_t - \left(O_t^d + O_t^m \right) \quad \text{for all t} \qquad (3.2.1.1')$$

$$S_{t-1} \geq Yd \quad \text{for all t} \qquad (3.2.1.2)$$

$$S_{t-1} - Y \leq 0 \quad \text{for all t} \qquad (3.2.1.3)$$

6.2.2 Irrigation Constraint

$$-O_t + Sp_t + K_t . Ir = I''_t \quad \text{for all t} \qquad (3.2.2.1)$$

6.2.3 Hydropower Constraints

$$-C_f . O_t . Ha_t . e . h_t + E_t = 0 \quad \text{for all t} \qquad (3.2.3.1)$$

$$-\eta_t . E + E_t - \bar{E}_t = 0 \quad \text{for all t} \qquad (3.2.3.2)$$

$$-\alpha_t . H . h_t + E_t = 0 \quad \text{for all t} \qquad (3.2.3.3)$$

$$\sum E_t \geq C_f . I_{av} . \overline{Ha} . e . 8760 \qquad (3.2.3.7)$$

$$H \geq C_f . I_{15} . \overline{Ha} . e \qquad (3.2.3.8)$$

$$O_t \geq I_{100} \quad \text{for all t} \qquad (3.2.3.9)$$

6.2.4 Flood Control Constraints

$$S_t - Ymax_t \leq 0 \text{ for } t = 1,....,t_1 \text{ months of flood provision} \qquad (3.2.4.1)$$

$$-Y + Ymax_t \leq 0 \text{ for } t = 1,....,t_1 \text{ months of flood provision} \qquad (3.2.4.2)$$

We can also put

$$R_t = I_t + P_t - \bar{I}_t - \left(O_t^d + O_t^m \right)$$

$D_t = C_f.Ha_t.e.h_t$

$G_t = \eta_t$

$L_t = \alpha_t.h_t$

$T = C_f.I_{av}.\overline{H}a.e.8760$

$Q = C_f.I_{15}.\overline{H}a.e$

6.2.5 Objective Function

$$\text{Maximize } Z_{nb} = B_2 + B_3 + B_4 - \left[\left(C_1 + Om_1\right) + \left(C_2 + Om_2\right) + \left(C_3 + Om_3\right)\right] \quad (3.2.6.6)$$

$$= a_2.Ir + a_3.E + \left[\sum_{t=1}^{t_1} a_4\left(Y - Ymax_t\right)\right] - \left[\left(C'_1 + Om'_1\right)Y + \left(C'_2 + Om'_2\right)Ir\right.$$

$$\left. + \left(C'_3 + Om'_3\right)H\right] = \left[\left(\sum_{t=1}^{t_1} a_4\right) - \left(C'_1 + Om'_1\right)\right]Y - \left[\sum_{t=1}^{t_1}\left(a_4.Ymax_t\right)\right]$$

$$+ \left[a_2 - \left(C'_2 + Om'_2\right)\right] Ir - \left[\left(C'_3 + Om'_3\right)H\right] + \left[a_3.E\right]$$

Where,

$$U = \left(\sum_{t=1}^{t_1} a_4\right) - \left(C'_1 + Om'_1\right), \quad W = a_2 - \left(C'_2 + Om'_2\right),$$

and $X = \left(C'_3 + Om'_3\right)$

6.2.6 The Data Matrix in Detached Coefficient Form

The above constraint equations can be written for all time periods t, and a matrix in Detached Coefficient Form can be prepared, for explanation this has been shown for two time periods below:

6.2.6.1 Reservoir Constraints

$O_1 - S_0 + K_1'.S_1 = R_1$ for t = 1 (6.2.1.1'-1)

In continuity equation for t = 2, $S_2 = S_0$, as the model is continuous.

$O_2 + K_2'.S_0 - S_1 = R_2$ for t = 2 (6.2.1.1'-2)

$S_0 \geq Yd$ for t = 1 (6.2.1.2-1)

$S_1 \geq Yd$ for t = 2 (6.2.1.2-2)

$S_0 - Y \leq 0$ for t = 1 (6.2.1.3-1)

$S_1 - Y \leq 0$ for t = 2 (6.2.1.3-2)

6.2.6.2 Irrigation Constraints

$-O_1 + Sp_1 + K_1.Ir = I_1''$ for t = 1 (6.2.2.1-1)

$-O_2 + Sp_2 + K_2.Ir = I_2''$ for t = 2 (6.2.2.1-2)

6.2.6.3 Hydropower Constraints

$-D_1.O_1 + E_1 = 0$ for t = 1 (6.2.3.1-1)

$-D_2.O_2 + E_2 = 0$ for t = 2 (6.2.3.1-2)

$-G_1.E + E_1 - \bar{E}_1 = 0$ for t = 1 (6.2.3.2-1)

$-G_2.E + E_2 - \bar{E}_2 = 0$ for t = 2 (6.2.3.2-2)

$-L_1.H + E_1 = 0$ for $t = 1$ (6.2.3.3-1)

$-L_2.H + E_2 = 0$ for $t = 2$ (6.2.3.3-2)

$E_1 + E_2 \geq T$ (6.2.3.7)

$H \geq Q$ (6.2.3.8)

$O_1 \geq I_{100}$ for $t = 1$ (6.2.3.9-1)

$O_2 \geq I_{100}$ for $t = 2$ (6.2.3.9-2)

6.2.6.4 Flood Control Constraints

Flood control is only for $t = 1$, hence

$S_1 - Ymax_1 \leq 0$ for $t = 1$ (6.2.4.1)

$-Y + Ymax_1 \leq 0$ for $t = 1$ (6.2.4.2)

6.2.6.5 Objective Function

Maximize $Z_{nb} = U.Y - a_4.Ymax_1 + W.Ir - X.H + a_3.E$ (6.2.6.6)

6.3.0 THE MATGEN ALGORITHM FOR CREATION OF DATA MATRIX

Looking at Coefficients in Detached Matrix Form, it is found that almost in every constraint equation, the non-zero coefficients of variables generally are appearing by shifting themselves diagonally/vertically with time increments. For example, in the irrigation equation the variables O_t, Sp_t, and Ir and parameter I''_t have this property, as seen from Table 6.1 (refer Equations 6.2.2.1-1, and 6.2.2.1-2).

Based on the Detached Coefficients in Matrix Form of Table 6.1 the property shown above can be easily programmed, hence a computer algorithm is presented to create the desired Input Data for the Linear Programming Model. This computer algorithm based computer programme can be appended as a subroutine subprogramme to a available computer programme on Linear Programming. For the algorithm, the following variables are defined below (Table 6.2).

ICOLR or $C_r^R 1$ = a Column Index Number (CIN), defining the location of a particular design variable (Y and O^*) and/or starting location of a set of series of time variant variables (O_t, S_{t-1}, S_t, $Ymax_t$, and Sp_t) concerning reservoir,

ICOLI or $C_r^I 2$ = a Column Index Number (CIN), defining the location of design variable, Ir, concerning irrigation,

ICOLP or $C_r^P 3$ = a Column Index Number (CIN), defining the location of a particular design variable (H,E) and/or starting location of a set of series of time variant variables (E_t , $\bar{E}_t$) concerning hydropower.

A = the Coefficient Matrix,

B = the Right Hand Side Matrix,

C = the Objective Function Matrix,

CODE = the variable defining the nature of a constraint equation,

NCOLR = number of CIN 's for reservoir , i.e., r^1 = 1,...,NCOLR,

NCOLI = number of CIN 's for irrigation, i.e., r^2 = 1,...,NCOLI and

NCOLP = number of CIN 's for power , i.e., r^3 = 1,...,NCOLP.

A general flowchart for generation of non-zero coefficients of Input Data Matrix for the algorithm is shown in Figure 6.1. Also, a detailed flowchart for generation of non-zero coefficients for irrigation constraint (3.2.2.1) is given in Figure 6.2.

The main features of this computer algorithm (computer programme given in Appendix-3.I.A), now named as **MATGEN** are as follows.

(1) The computer programme is very general and can be applied to any single or multipurpose reservoir.

(2) CIN's have been separated for variables relating to reservoir, irrigation and hydropower. Any number of new sets of variables can be added at the end of the existing sets of CIN's. Hence, the developed algorithm is very flexible and any number of new system constraints and, thereupon, system variables can be added according to the problem to be formulated, and the computer programme be suitably modified.

(3) The upper and lower bounds (limits) can be put on any variable, if desired.

(4) The entire sets of input data A, B, C, CODE, M and K etc. required for a L.P. software package are generated by the algorithm.

In order to explain the input data for **MATGEN** computer package on linear programming a sample input data for multipurpose reservoir with water supply, irrigation, hydropower and flood control, i.e., model Max.Z_{nb} is given below.

(i) Matrices [A], [B] and [C] in Detached Coefficient Form: The coefficients of matrices [A], [B] and [C] for multipurpose reservoir with water supply, irrigation, hydropower and flood control are given in (Table 6.1).

(ii) A Sample Input Data for **MATGEN** : The sample input data for the computer package, **MATGEN**, on linear programming for the above problem are given in Table 6.3.

For other models Max.Z_{sy}, Max.Z_{tr}, Min.Z_{gc}, and Min.Z_{oc}, the Detached Coefficient Matrix and the corresponding Input Data are given in Appendices 4.I, 4.II, 4.III and 4.IV respectively.

The sample input data for model Min.Z_{oc} for MPS and LINGO are given in Appendices 4.V and 4.VI respectively.

Table 6.1 Coefficients of the matrices [A], [B] and [C] for multipurpose reservoir with water supply, irrigation, hydropower and flood control for two time periods

COL.NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
VAR.	O_1	O_2	S_0	S_1	Y	$Ymax_1$	Sp_1	Sp_2	Ir	H	E	E_1	E_2	$\overline{E}_1$	$\overline{E}_2$	SIGN (CODE)	RHS [B]
CIN	c_1^R		c_2^R		c_3^R	c_4^R	c_5^R		c_1^I	c_1^P	c_2^P	c_3^P		c_4^P			
VCIN	1		3		5	6	7		9	10	11	12		14			
Equation							Coefficient Matrix [A]										
6.2.1.1′-1	1	0	-1	K_1'	0	0	0	0	0	0	0	0	0	0	0	=	R_1
6.2.1.1′-2	0	1	K_2'	-1	0	0	0	0	0	0	0	0	0	0	0	=	R_2
6.2.1.2-1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	≥	Yd
6.2.1.2-2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	≥	Yd
6.2.1.3-1	0	0	1	0	-1	0	0	0	0	0	0	0	0	0	0	≤	0
6.2.1.3-2	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	≤	0
6.2.2.1-1	-1	0	0	0	0	0	1	0	K_1	0	0	0	0	0	0	=	I_1^*
6.2.2.1-2	0	-1	0	0	0	0	0	1	K_2	0	0	0	0	0	0	=	I_2^*
6.2.3.1-1	$-D_1$	0	0	0	0	0	0	0	0	0	0	1	0	0	0	=	0
6.2.3.1-2	0	$-D_2$	0	0	0	0	0	0	0	0	0	0	1	0	0	=	0
6.2.3.2-1	0	0	0	0	0	0	0	0	0	0	$-G_1$	1	0	-1	0	=	0
6.2.3.2-2	0	0	0	0	0	0	0	0	0	0	$-G_2$	0	1	0	-1	=	0
6.2.3.3-1	0	0	0	0	0	0	0	0	0	$-L_1$	0	1	0	0	0	=	0
6.2.3.3-2	0	0	0	0	0	0	0	0	0	$-L_2$	0	0	1	0	0	=	0
6.2.3.7	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	≥	T
6.2.3.8	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	≥	Q
6.2.3.9-1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	≥	I_{100}
6.2.3.9-2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	≥	I_{100}
6.2.4.1	0	0	0	1	0	-1	0	0	0	0	0	0	0	0	0	≤	0
6.2.4.2	0	0	0	0	-1	1	0	0	0	0	0	0	0	0	0	≤	0
							Coefficient Matrix [A]										
6.2.6.6	0	0	0	0	U	$-a_4$	0	0	W	-X	a_3	0	0	0	0		

CIN = Column Index Number, VCIN = Value of CIN, SIGN represents CODE, M = Number of constraint equations in Matrix [A], and K = Number of variables. Here, M=20 & K=15. Note: all parameters, R_1, R_2, D_1, D_2, G_1, G_2, L_1, L_2, T, Q, U, W, and X in the Matrices [A], [B] and [C] are known quantities and computed from the Basic Input Data by the computer programme, MATGEN.

Table 6.2 Definition of Column Index Number

Variable	O_1	S_0	Y	$Ymax_1$	Sp_1	O^*
CIN	ICOLR(1) C_1^R	ICOLR(2) C_2^R	ICOLR(3) C_3^R	ICOLR(4) C_4^R	ICOLR(5) C_5^R	ICOLR(6) C_6^R

Variable	Ir
CIN	ICOLI(1) C_1^I

Variable	H	E	E_1	E_1
CIN	ICOLP(1) C_1^P	ICOLP(2) C_2^P	ICOLP(3) C_3^P	ICOLP(4) C_4^P

CIN - Column Index Number

Table 6.3 Sample input data file for multipurpose reservoir with water supply, irrigation, hydropower and flood control for MATGEN.

Input parameter/variable read statement	Input parameter/variable to be given
IGEN	1
IPRNT1	0
NTYPE NOPT	1 0
MM	2
NVAR	15
YD	0
OBJR OBJI OBJP OBJF	1 1 4 5
Y	-
FLOW	I_1 I_2
WS	O_1^d O_2^d
IEVAP	1
XK2 XK3	K_1' K_2' 0 0
EV	-
A0 AS	-
NCOLR	6
ICOLR	1 3 5 6 7 0
NEQR	9

Table 6.3 continued

EQR	1 -1 -1 -1 -1 -1 1 1 -1
C11 OM11	C_1' Om_1'
DELT	-
CC	-
OUTF	-
NCOLI	1
ICOLI	9
NEQI	2
EQI	1
A2 C21 OM21	a_2 C_2' Om_2'
XK1	K_1 K_2
NCOLP	4
ICOLP	10 11 12 14
NEQP	12
EQP	1 -1 1 1 -1 -1 1 1 1 -1 -1 -1
A3 C31 OM31	a_3 C_3' Om_3'
XNETA	η_1 η_2
ALPHA	α_1 α_2
PR1 PR2 I100	0 0 I_{100}
QAV Q15 AHEAD AVHR	I_{av} I_{15} $\overline{Ha}$ 8760
EFFCI CV CP	e C_v C_p
HEAD	Ha_1 Ha_2
TIME	h_1 h_2
POWPF	0 0
A4	a_4
IPRNT	0
IPRT1	0
ISAL	-1
NVAAL	-
IUP ILO IEQ	-
UL LM EQU	-
IFL MMF	1 2
YF2	0.34

Note: The single sign '-' means that the data is not to be given.

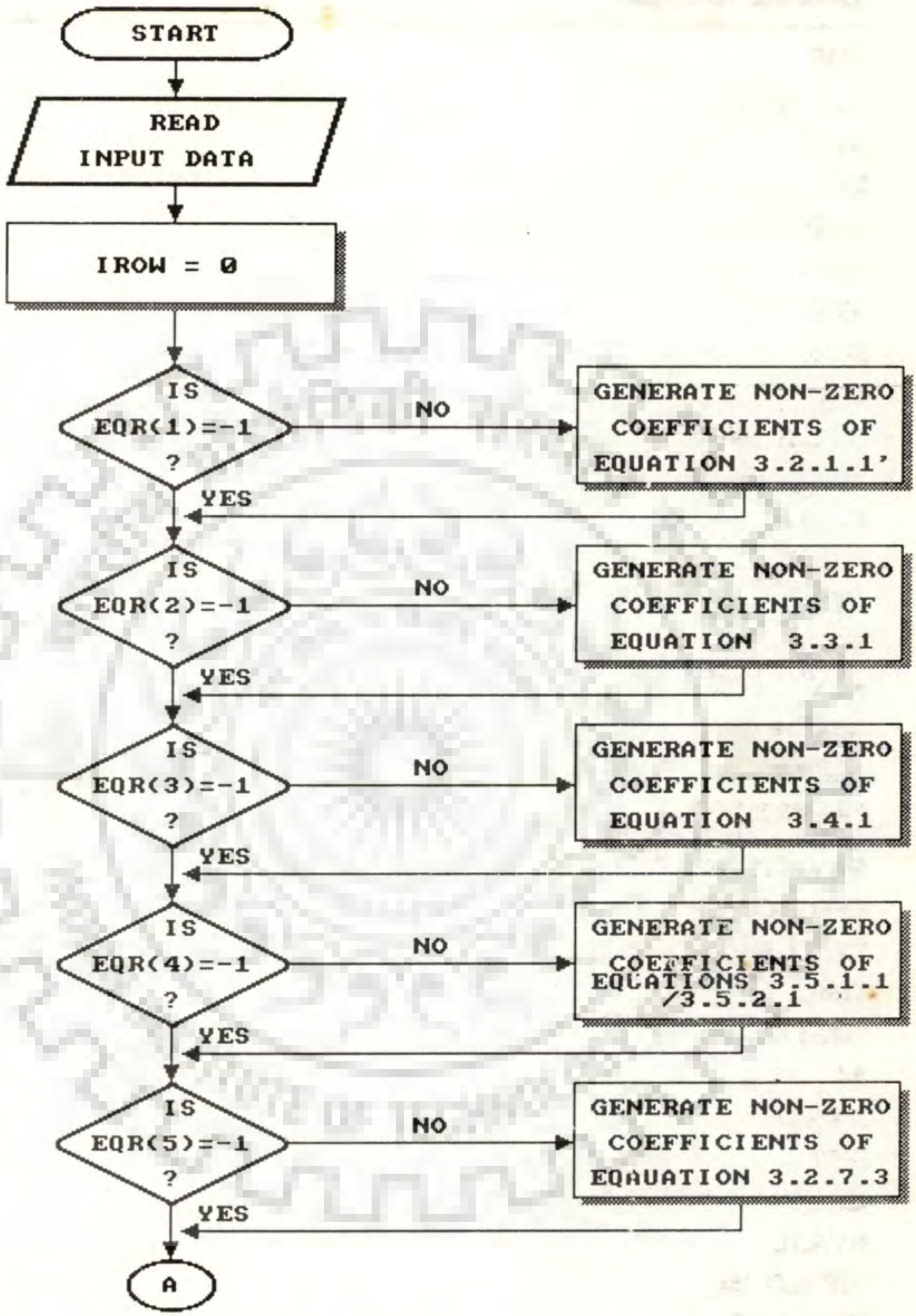


Fig. 6.1 General flow chart for generation of non-zero coefficient of input data matrix for linear programming model (MATGEN PACKAGE)

Fig. 6.1 Continued

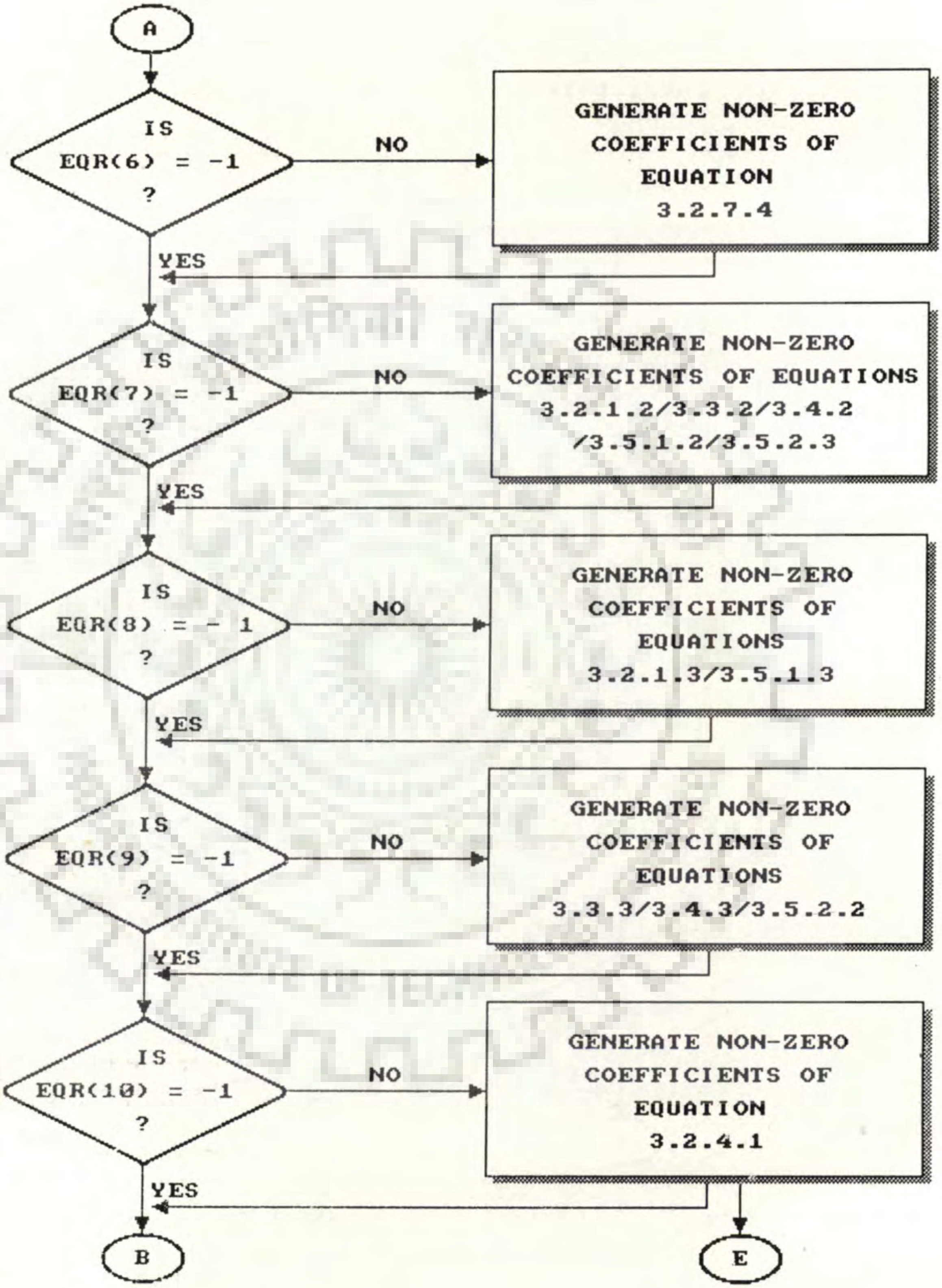


Fig. 6.1 Continued

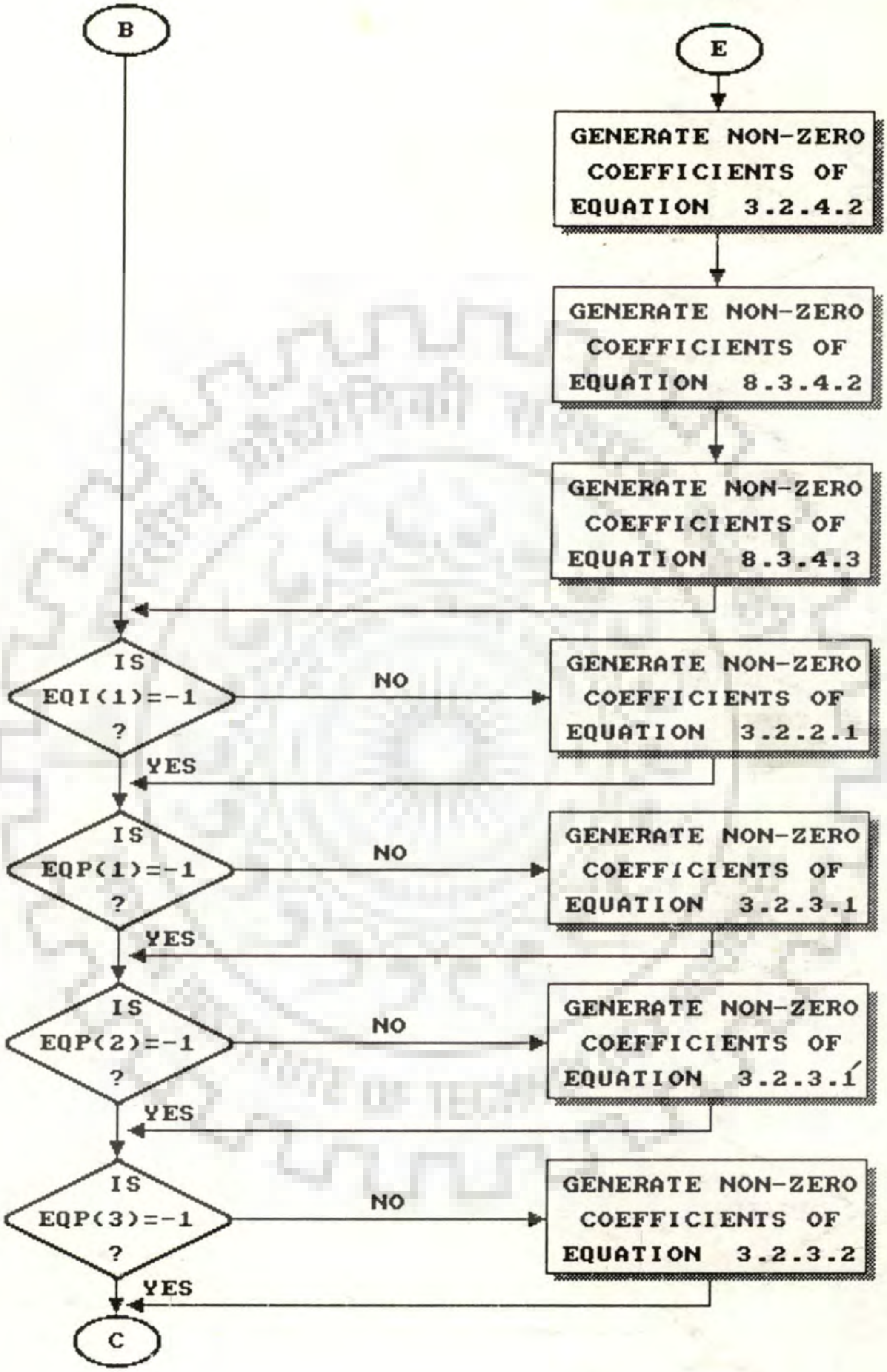


Fig. 6.1 Continued

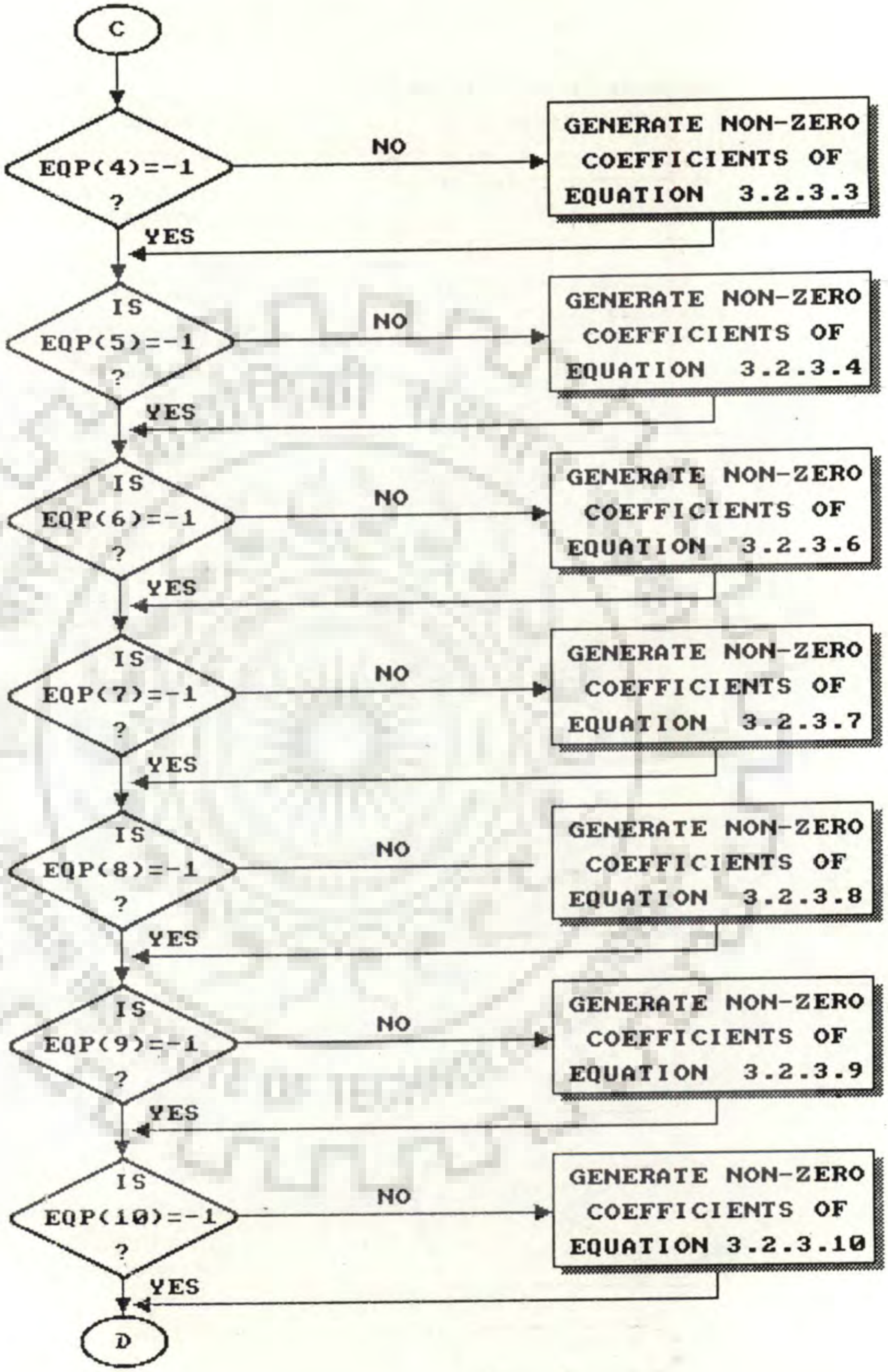
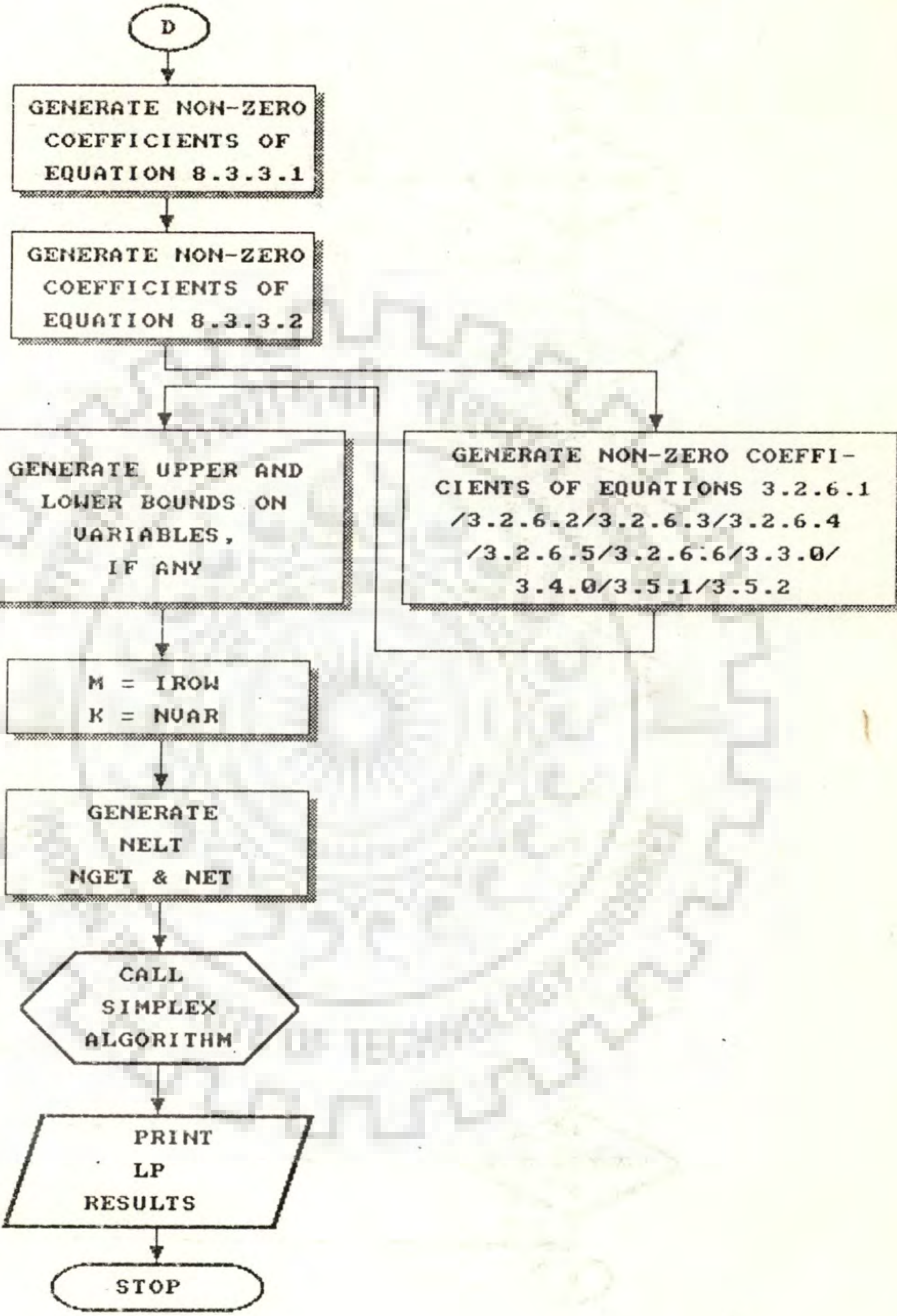


Fig 6.1 Continued



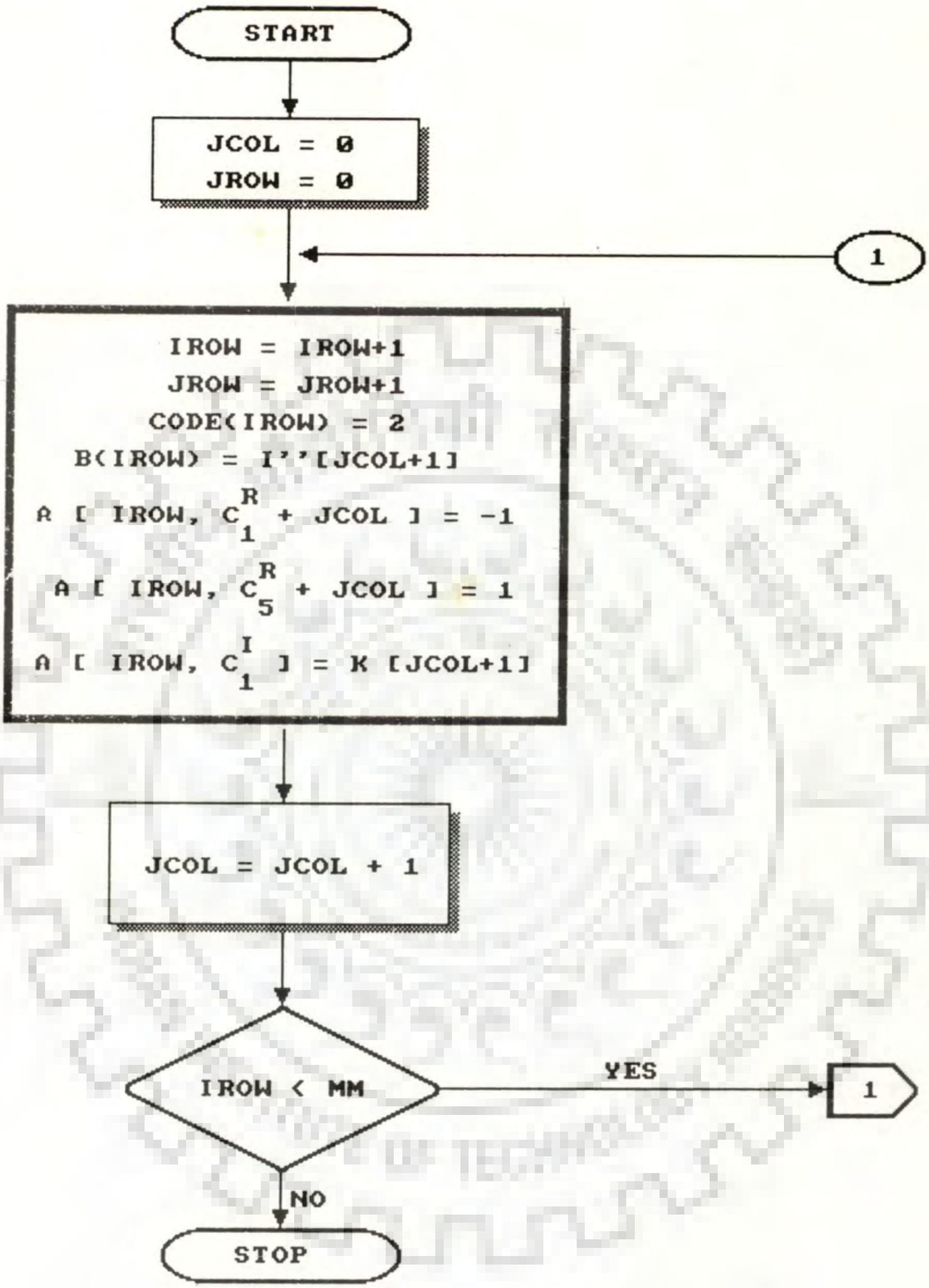


Fig. 6.2 Detailed flow chart for generation of non-zero coefficients for irrigation constraint (Equation 3.2.2.1)

CHAPTER 7

THE RIVER SYSTEMS

Chapter-7

THE RIVER SYSTEMS

7.1.0 BADANALA IRRIGATION PROJECT

The river Badanala is a tributary of the river Gangud which itself is a tributary of river Vansadhara (Badanala Project Report, 1979). The river has its origin from the Ramgiri hills in Ganjam district at an altitude of 900 m. The river after transversing about 48 km from source in hill range emerges down to an altitude of 152 m. The topography of the project command is undulating and moderately sloping with occasional rock out crops of granite and dolorite nature. The ayacut (agricultural area) is very futile due to denudation of forest from year to year. The catchment of river is covered with thick vegetation and is of fan shape and is bounded on either side by steep hill ranges. It has a geographical area of 352 sq.km. There are three raingauge stations in and around the catchment area. The average annual rainfall on the catchment is 1230 mm.

The dam, (gross reservoir capacity of 7564 ha-m with an annual irrigation of 14569 ha-m) is an earthen cum masonry dam near the village of Kenguda in the Koraput district, Orissa State, see Figure 7.1.1. The monthly river flow data for the period of 26 years (1953-1979) are given in Table 7.1.1. Annual losses due to reservoir evaporation are taken as 1.896 m and the monthly break-down is shown in Table 7.1.2. Monthly irrigation water requirements, for proposed irrigation of 9800 ha and net utilization of 14569 ha-m are also given in Table 7.1.2. The reservoir in this region would generally fill during the monsoon period from June to October and would be depleted from November to the following May. The reservoir capacity-area and reservoir capacity-elevation curves are given in Figures 7.1.2 and 7.1.3 respectively. The salient features are given in Annexure-1.

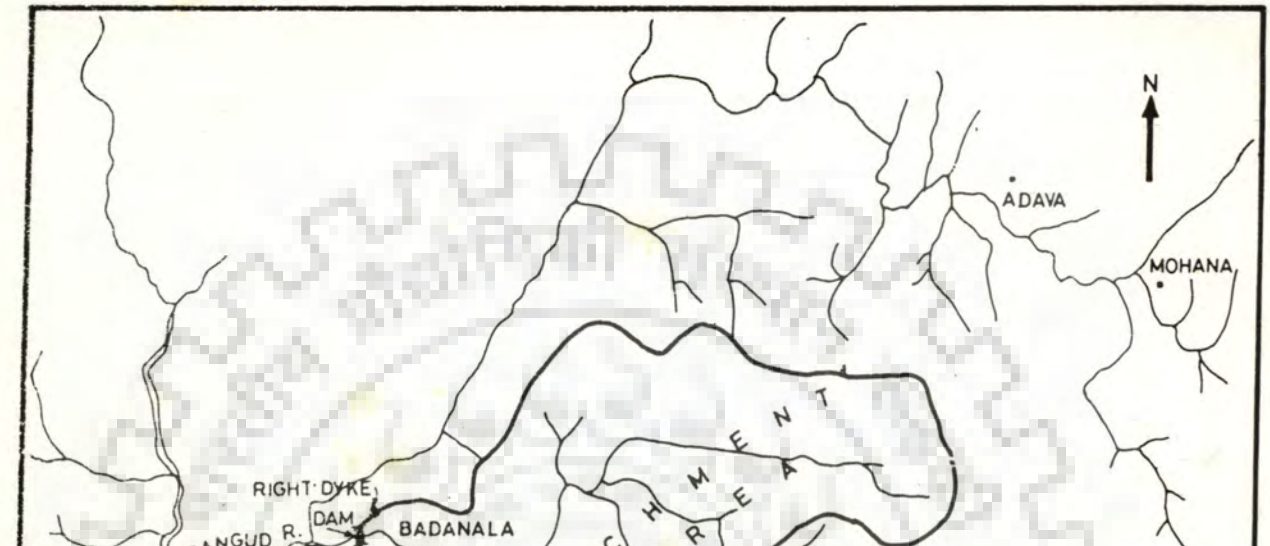


Fig. 7·1·1. Plan showing the Badanala irrigation project.

Table 7.1.1 Monthly river flows from (1953-1979) at Badanala irrigation project, in ha-m

Year	Jun	Jul	Aug	Sep	Oct	Total monsoon	Nov
1953-54	1889	2682	7185	7130	3530	22416	1582
1954-55	1504	2831	6387	6794	5374	22890	1615
1955-56	263	2085	3508	5786	4907	16549	1168
1956-57	558	3309	7407	6083	7353	24710	1744
1957-58	232	2016	3963	2382	3980	12573	877
1958-59	458	1730	3433	4640	10811	21072	1487
1959-60	2072	2742	5580	5085	4413	19892	1404
1960-61	907	5580	5457	4103	1485	17532	1237
1961-62	265	1747	4473	4822	5963	17270	1219
1962-63	759	2504	4797	2060	3773	13893	980
1963-64	218	2774	3731	6212	6615	19550	1379
1964-65	160	2119	7247	5970	5930	21426	1512
1965-66	103	1747	2538	4092	1459	9939	701
1966-67	438	1853	3578	4952	1553	12374	873
1967-68	1290	6026	2142	2666	313	12437	877
1968-69	147	212	381	7490	8310	16540	2130
1969-70	94	3700	5640	5420	1240	16094	439
1970-71	320	1180	4480	2675	3075	11730	540
1971-72	177	375	1792	3620	3095	9059	848
1972-73	72	192	1266	7940	5526	14996	2776
1973-74	272	1624	1836	1074	1837	6643	1410
1974-75	1814	2173	1282	1703	5508	12480	633
1975-76	2397	4886	13363	10500	8310	39456	2514
1976-77	266	2065	6472	5280	580	14663	465
1977-78	233	1793	2302	1702	1304	7334	376
1978-79	1185	4801	9969	5073	2558	23586	1606
Average	696	2490	4623	4818	4185	16812	1246

Dec. Flows?

Table 7.1.1 continued

Dec	Jan	Feb	Mar	Apr	May	Total non-monsoon	Total annual yield	Total annual yield in descending order	Dependable year, m/(n+1)
533	287	165	147	165	252	3131	25547	43696	4
545	293	169	150	169	257	3198	26088	28098	7
394	212	122	109	122	186	2313	18862	27299	11
588	316	119	162	182	277	3388	28098	26088	15
299	161	93	83	93	141	1747	14320	25547	19
501	270	155	136	155	236	2940	24012	24417	22
473	255	146	131	140	223	2772	22664	24012	26
417	224	129	115	139	197	2458	19990	22664	30
414	21	135	114	127	194	2424	19694	22268	33
331	178	101	91	103	156	1940	15833	19990	37
465	250	144	128	133	219	2718	22268	19752	41
510	274	156	141	158	240	2991	24417	19694	44
236	127	72	64	67	112	1379	11318	19084	48
294	158	97	81	90	139	1732	14106	18862	52
296	159	91	82	80	140	1725	14162	17127	56
421	163	112	105	233	48	3212	19752	15833	59
219	177	83	50	14	51	1033	17127	15726	63
104	106	40	70	18	23	901	12631	14320	67
232	156	82	49	46	254	1667	10726	14162	70
011	112	81	47	32	29	4088	19084	14106	75
333	481	326	317	204	352	3423	10066	13878	78
187	185	109	99	74	111	1398	13878	12631	81
956	86	145	89	49	401	4240	43696	11318	85
58	319	64	51	45	61	1063	15726	10726	89
242	32	18	16	115	201	1000	8334	10066	93
190	170	153	156	143	295	3713	27299	8334	96
433	207	120	107	111	184	2408	19220	19220	
								S.D. =7378	

Table 7.1.2 Average flow, reservoir evaporation, and irrigation water requirements at Badanala

Month	Average flow	Reservoir evaporation		Irrigation water requirements	
	ha - m	m	K'_t	ha - m	K_t
Jun	696	0.2028	1.065	1191	8.175
Jul	2490	0.1569	1.051	3702	25.410
Aug	4623	0.1406	1.016	3026	20.770
Sep	4818	0.1399	1.011	2320	15.924
Oct	4185	0.1524	1.014	988	6.782
Nov	1246	0.1208	1.013	1141	7.832
Dec	433	0.1121	1.014	1115	7.653
Jan	207	0.1179	1.016	877	6.020
Feb	120	0.1282	1.016	141	0.968
Mar	107	0.1912	1.024	42	0.288
Apr	111	0.2017	1.025	26	0.178
May	184	0.2315	1.025	0	0.000
Total	19220	1.8960		14569	100.000

Note:

The values of K'_t were estimated by preparing working tables with and without reservoir evaporation. This was done individually for 26 years flow and an average value of K'_t is used.

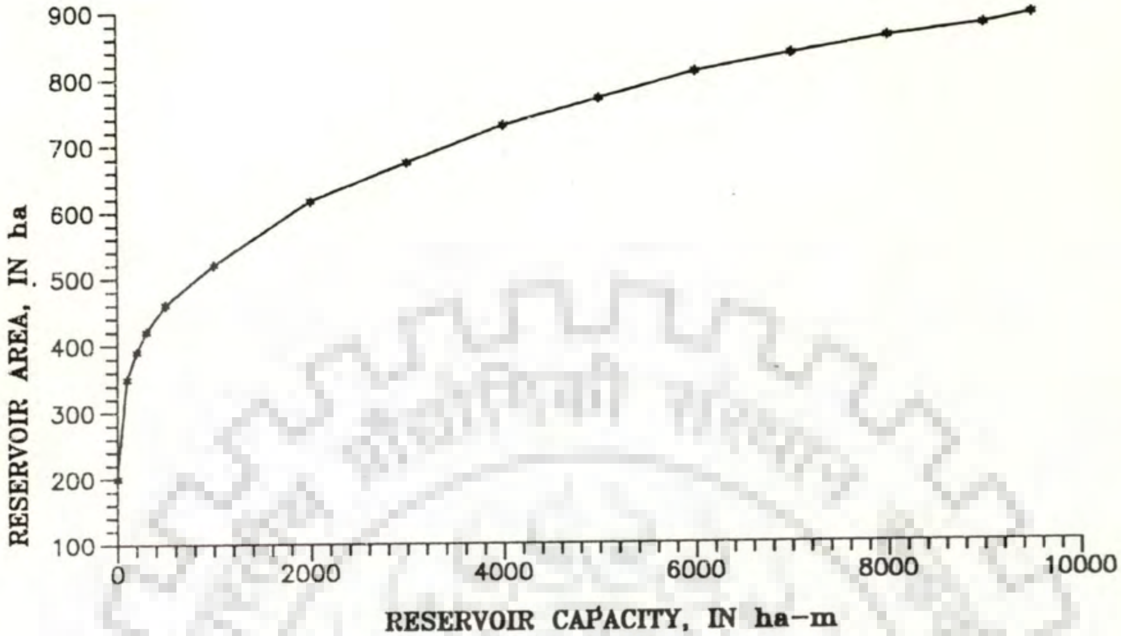


Fig. 7.1.2 Reservoir capacity vs area for Badanala

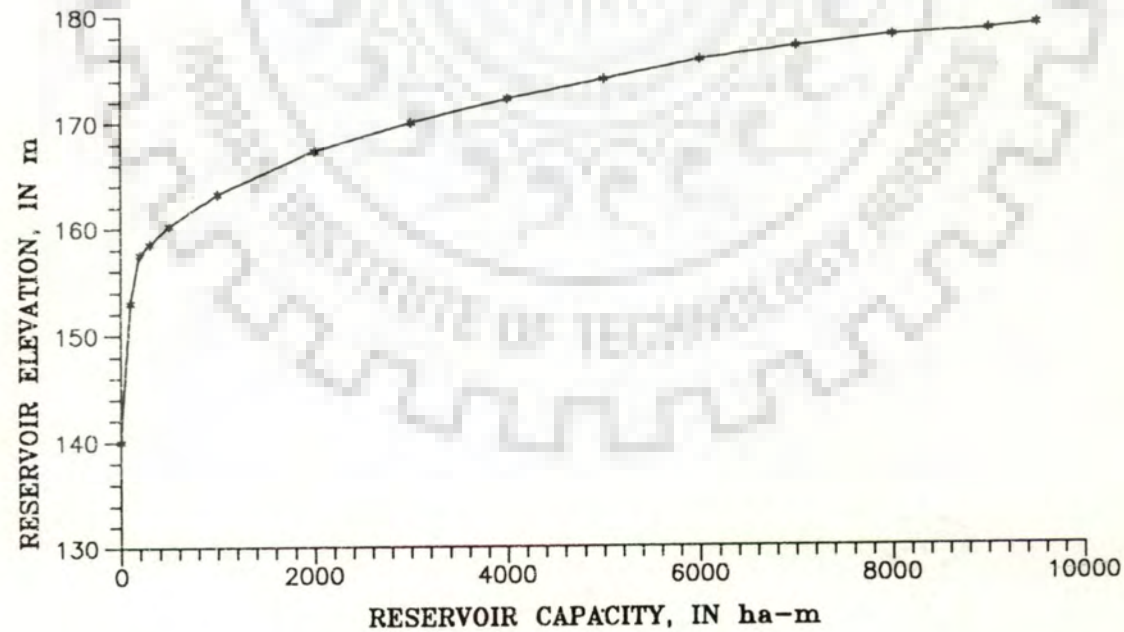


Fig. 7.1.3 Reservoir capacity vs elevation for Badanala

7.2.0 KALLUVODDUHALLA IRRIGATION PROJECT

The river Kalluvodduhalla is one of the tributary in sub-basin of Kumudwati river which in turn is a tributary to Tungabhadra river. (Kalluvodduhalla Project Report, 1984). The topography of command area is plain in most part of the project area, but undulating in few places. General slope of the area varies from 0 to 3% . The total catchment area of the project is 41 sq.km. This nalla (stream) rises at an altitude of about 700 m. The lowest river bed level at the site is about 614.17 m. Upper most catchment area is hilly and thickly forested and lower reaches are in moderate country. There are two raingauges in and around the catchment. The average annual rainfall on the catchment is 1305 mm.

Kalluvodduhalla is a project situated in Shikaripura Taluk, Shimoga district of Karnataka State, see Figure 7.2.1. The dam with gross reservoir capacity of 12.176 MCM (million cubic meters) and annual irrigation of 17.549 MCM is an earthen cum masonry dam. Present study deals with monthly discharges from (1950-1980). The monthly river flow data for the above period are given in Table 7.2.1. The yearly losses due to evaporation are taken as 1.3739 m and monthly break-down is shown in Table 7.2.2. The monthly irrigation water requirements for proposed irrigation of 1450 ha and net utilization of 17.549 MCM are also given in Table 7.2.2. The reservoir in this region would generally fill during the monsoon period from June to October and would be depleted from November to the following May. The reservoir capacity-area and reservoir capacity-elevation curves are given in Figures 7.2.2 and 7.2.3 respectively. The salient features are given in Annexure-2.

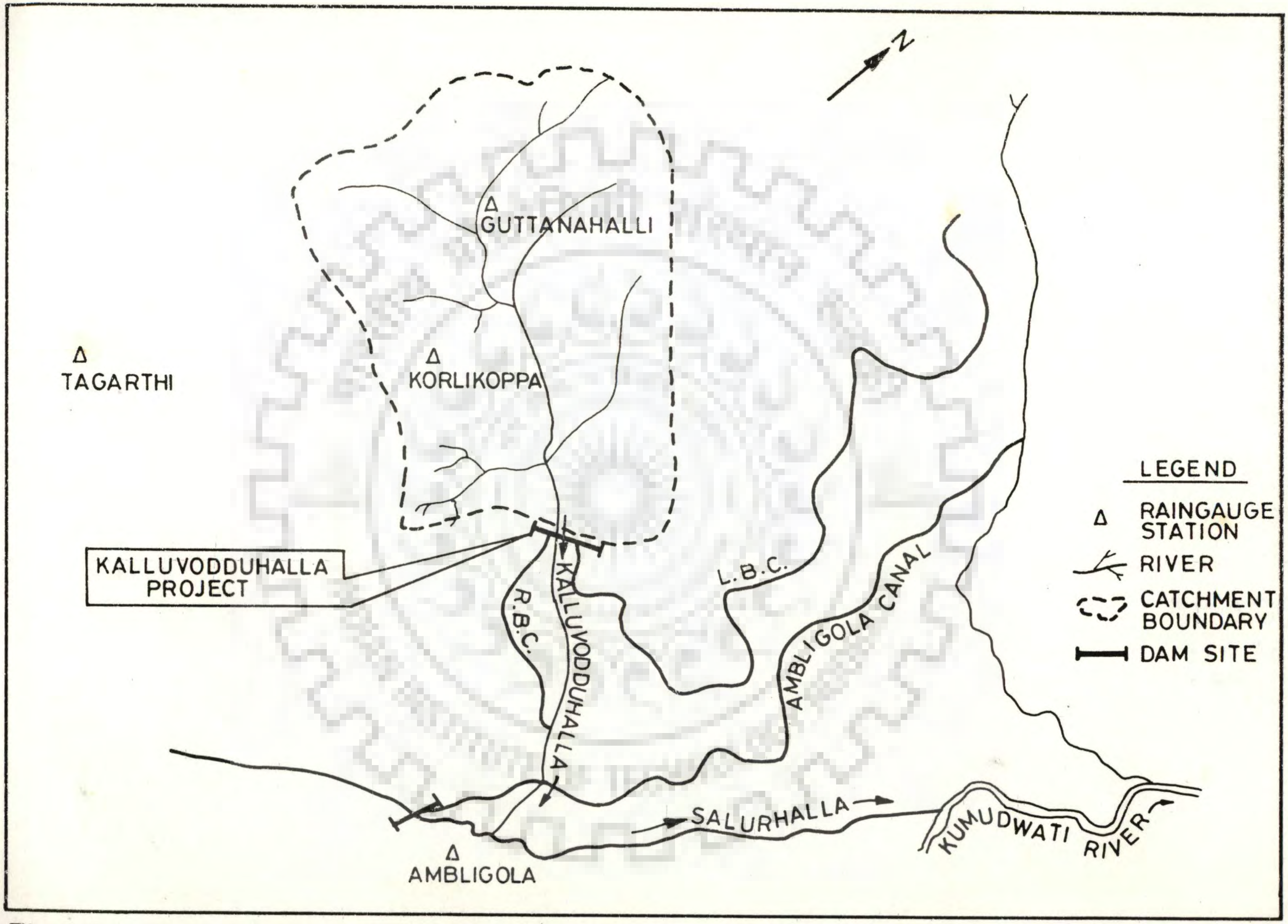


Fig.7·2·1 Plan showing the Kalluvodduhalla irrigation project.

Table 7.2.1 Monthly river flows from (1950-1980) at Kailuvodduhalla irrigation project, in MCM

Year	Jun	Jul	Aug	Sep	Oct	Total mon-soon	Nov	May	Tot. non-mon-soon	Total annual yield	Total annual yield de.or.	Dependable year m/(n+1)
1950	0.28	17.11	8.20	1.60	1.54	28.73	0.71	0.11	0.82	29.55	38.36	3
1951	1.08	6.54	2.67	3.56	8.54	22.39	0.00	0.00	0.00	22.39	36.40	6
1952	0.00	0.31	1.27	1.77	3.30	6.65	0.00	0.00	0.00	6.65	32.06	10
1953	2.33	2.86	12.31	0.00	0.00	17.50	0.00	0.00	0.00	17.50	31.53	13
1954	1.08	9.83	7.91	2.71	5.09	26.62	0.00	0.36	0.36	26.98	29.66	16
1955	2.05	1.78	6.05	6.00	8.50	24.38	0.00	0.00	0.00	24.38	29.55	19
1956	2.55	12.53	11.24	1.29	1.89	29.50	1.77	0.26	2.03	31.53	29.49	23
1957	2.56	8.21	6.27	3.20	4.68	24.92	2.82	0.00	2.82	27.74	28.72	26
1958	1.15	14.25	9.93	0.86	1.30	27.49	0.18	0.06	0.24	27.73	27.93	29
1959	3.83	21.88	4.35	5.85	0.62	36.53	1.83	0.00	1.83	38.36	27.74	32
1960	0.27	5.20	6.40	7.98	6.63	26.48	0.05	2.96	3.01	29.49	27.73	35
1961	7.77	20.14	5.19	2.09	1.17	36.36	0.00	0.04	0.04	36.40	26.98	39
1962	0.20	8.17	18.14	1.30	3.96	31.77	0.19	0.10	0.29	32.06	26.43	42
1963	0.34	2.92	7.12	0.70	4.07	15.15	2.16	0.00	2.16	17.31	24.47	45
1964	0.18	2.22	12.05	3.05	4.22	27.70	2.76	0.00	2.77	24.47	24.38	48
1965	0.41	6.97	4.97	1.61	1.65	15.16	0.00	0.15	0.15	15.76	23.42	50
1966	0.16	5.64	0.76	3.73	5.84	16.13	3.92	0.02	3.94	20.07	22.45	55
1967	0.59	10.51	9.57	1.68	1.07	23.42	0.00	0.00	0.00	23.42	22.39	58
1968	0.42	13.36	2.54	3.92	0.00	20.24	1.31	0.00	1.31	21.55	22.01	61
1969	0.04	6.12	4.62	4.46	5.98	21.22	1.13	0.10	1.23	22.45	21.55	65
1970	1.07	5.03	14.14	7.21	0.48	29.93	0.00	0.00	0.00	27.93	20.07	67
1971	2.43	5.64	2.76	1.88	0.55	13.26	0.10	0.05	0.15	13.41	18.73	71
1972	2.11	9.81	5.97	2.27	1.51	21.67	0.34	0.00	0.34	22.01	17.50	75
1973	2.32	9.59	12.30	0.69	1.48	26.36	0.05	0.00	0.05	26.43	17.31	77
1974	0.09	3.12	5.91	3.00	2.51	14.63	0.00	0.00	0.00	14.63	15.76	81
1975	2.97	6.74	10.98	5.85	1.55	28.09	1.57	0.00	1.57	29.66	14.63	84
1976	1.48	2.69	1.06	0.64	3.93	9.80	0.00	0.00	0.00	9.80	13.41	87
1977	0.57	5.18	2.73	4.33	2.34	15.15	3.53	0.05	3.58	18.73	10.32	90
1978	3.00	9.73	13.06	1.14	1.08	28.01	0.71	0.00	0.71	28.72	9.80	94
1979	0.75	2.01	6.44	0.46	0.22	9.88	0.44	0.00	0.44	10.32	6.65	97
Aver	1.47	7.87	7.23	2.83	2.85	22.25	0.85	0.14	1.00	23.25	23.25	
										S.D.	7.62	

MCM-Ha-m ?

Other month's values?

Table 7.2.2 Average flow, reservoir evaporation, and irrigation water requirements at Kalluvodduhalla

Month	Average flow MCM	Reservoir evaporation		Irrigation water requirements	
		m	K'_t	MCM	K_t
Jun	1.47	0.1104	1.0637	4.280	24.40
Jul	7.87	0.0954	1.0080	0.796	4.50
Aug	7.23	0.0975	1.0163	1.318	7.50
Sep	2.83	0.1008	1.0177	2.498	14.20
Oct	2.86	0.1011	1.0172	2.600	14.80
Nov	0.85	0.0986	1.0189	0.929	5.30
Dec	0.00	0.0921	1.0179	0.347	2.00
Jan	0.00	0.1090	1.0258	0.700	4.00
Feb	0.00	0.1180	1.0289	1.701	9.70
Mar	0.00	0.1530	1.0490	2.098	11.60
Apr	0.00	0.1530	1.0400	0.298	1.70
May	0.14	0.1450	1.0365	0.050	0.30
Total	23.25	1.3739		17.549	100.00

Note:

The values of K'_t were estimated by preparing working tables with and without reservoir evaporation. This was done individually for 30 years flow and an average value of K'_t is used.

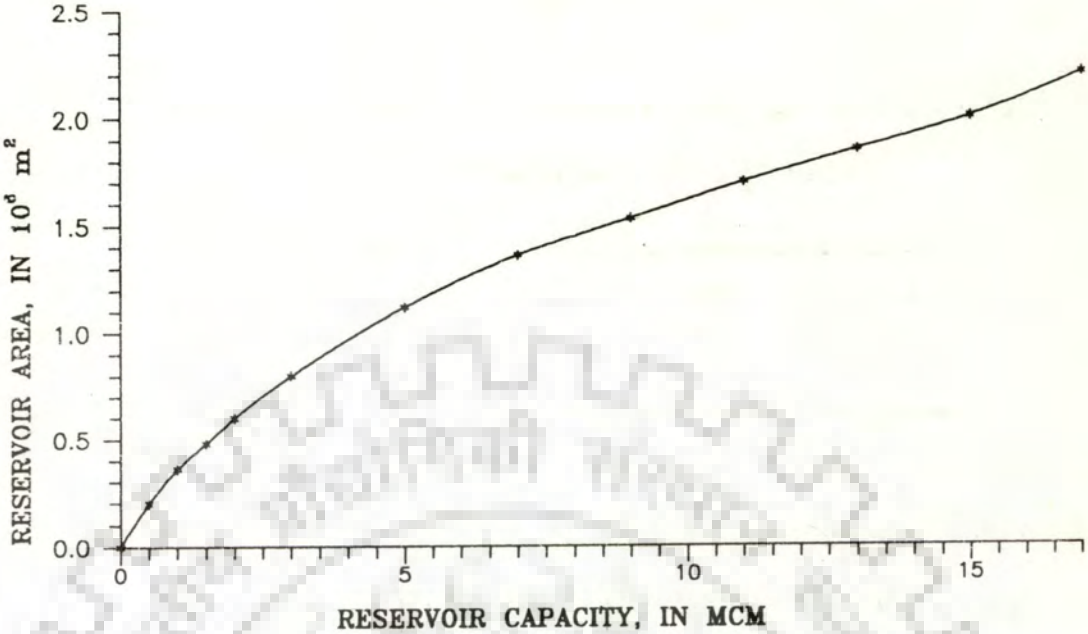


Fig. 7.2.2 Reservoir capacity vs area for Kalluvodduhalla

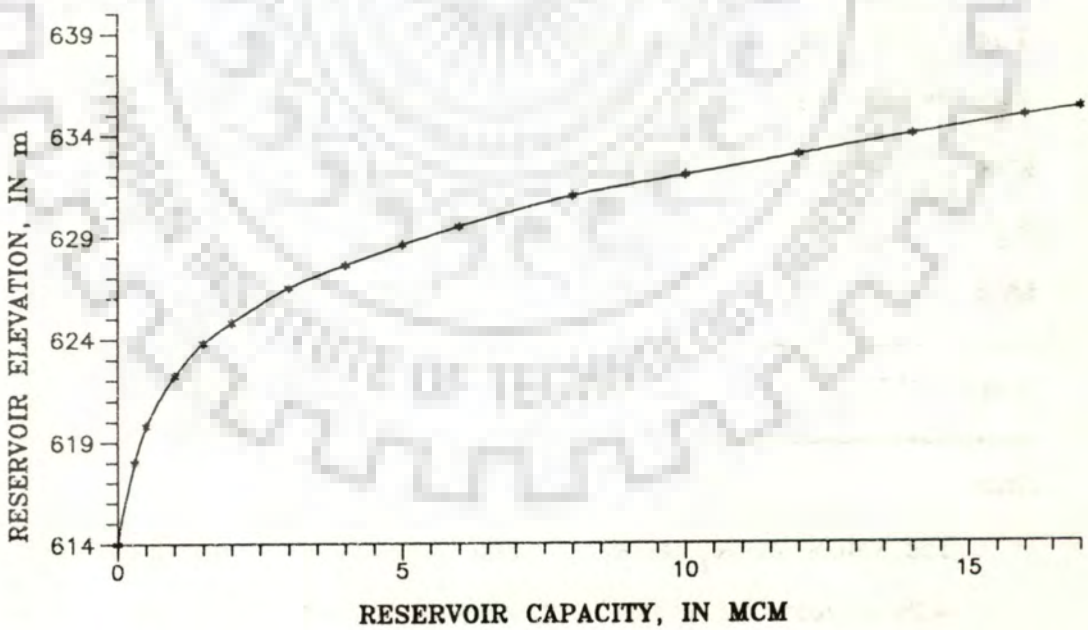


Fig. 7.2.3 Reservoir capacity vs elevation for Kalluvodduhalla

7.3.0 BODHGHAT HYDROELECTRIC PROJECT

The River Indravati is a right bank tributary of the river Godavari, on which the Bodhghat project is situated [Bodhghat Project Report (M.P.), 1980]. The delta of river consists of wide belt of river borne alluvium and gradually extending into the sea. It passes through the Eastern Ghats flowing through a narrow gorge 130 km, from the sea.

Bodhghat hydroelectric project contemplate utilization of waters of Indravati river by constructing a dam across Indravati and a power house near Bodhghat village in Bastar district in the State of Madhya Pradesh, see Figure 7.3.1.

The gross capacity of reservoir is 4458 MCM. The proposed installed capacity of the scheme is 500 MW with 5 units of 100 MW each. The monthly river flow data for the Bodhghat site for a period of 10 years from (1966-1976) are given in Table 7.3.1. The monthly average flow data for the above period, the losses due to evaporation of 1.599 m and its monthly break-down, and the monthly energy requirements are given in Table 7.3.2. The reservoir in this region would generally fill during the monsoon period from June to October and would be depleted from November to the following May. The reservoir capacity-area and reservoir capacity-elevation curves are given in Figures 7.3.2 and 7.3.3 respectively. The salient features are given in Annexure-3.

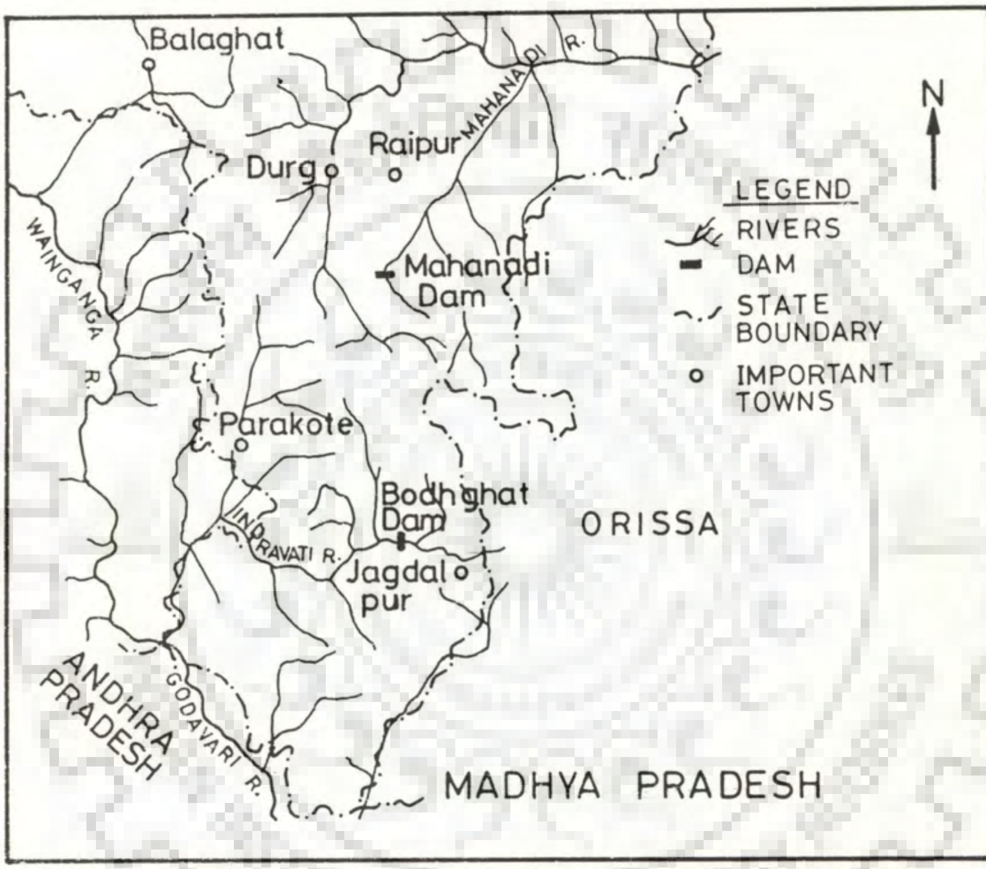


Fig. 7·3·1 Plan showing the Bodhghat hydropower project.

State Boundary unclear ?

Table 7.3.2 Average flow, reservoir evaporation, and energy requirements at Bodhghat

Month	Average flow	Reservior evaporation		Energy requirements	
	MCM	m	K'_t	MWhr	η_t
Jun	282	0.121	1.00389	85 430	0.075
Jul	1138	0.114	1.00299	85 430	0.075
Aug	1453	0.095	1.00336	102 510	0.090
Spt	1200	0.076	1.00292	102 510	0.090
Oct	532	0.076	1.00302	108 210	0.095
Nov	198	0.057	1.00241	108 210	0.095
Dec	115	0.076	1.00311	108 210	0.095
Jan	123	0.095	1.00371	108 210	0.095
Feb	68	0.156	1.00640	85 430	0.075
Mar	113	0.216	1.00785	85 430	0.075
Apr	48	0.305	1.01108	79 730	0.070
May	50	0.203	1.00738	79 730	0.070
Total	5320	1.599		1139 000	1.000

Note:

The values of K'_t were estimated by preparing working tables with and without reservoir evaporation. This was done individually for 10 years flow and an average value of K'_t is used.

Table 7.3.1 Monthly river flows from (1966-1976) at Bodhghat hydroelectric project, in MCM

Year	Jun	Jul	Aug	Sep	Oct	Total monsoon	Nov	Dec	Jan	Feb	Mar	Apr	May	non-	Total annual yield	Total annual yield in descending order	Dependable Year m/n+1
1966-67	250	762	1152	1241	265	3670	42	31	35	67	135	69	44	423	4093	7108	10
1967-68	492	1231	2672	826	757	5978	52	232	255	74	132	78	35	858	6836	6973	20
1968-69	151	624	501	1171	655	3102	105	124	345	59	57	30	17	737	3839	6836	30
1969-70	199	1889	1900	1890	728	6606	47	93	100	70	68	59	65	502	7108	6408	40
1970-71	222	1124	2165	1084	518	5113	159	114	51	65	577	77	64	1107	6220	6220	50
1971-72	255	644	1369	822	402	3492	163	112	91	139	52	10	47	614	4106	4739	60
1972-73	100	1367	676	1354	549	4046	302	118	97	78	26	21	51	693	4739	4106	70
1973-74	135	2233	1775	1008	640	5791	209	132	93	63	10	54	56	617	6408	4093	80
1974-75	532	442	629	419	266	2288	273	77	77	20	48	41	48	584	2872	3839	90
1975-76	486	1068	1687	2183	540	5964	632	114	88	40	21	41	73	1009	6973	2872	100
Average	282	1138	1453	1200	532	4605	198	115	123	68	11	48	50	715	5320	5320 S.D. =1474	

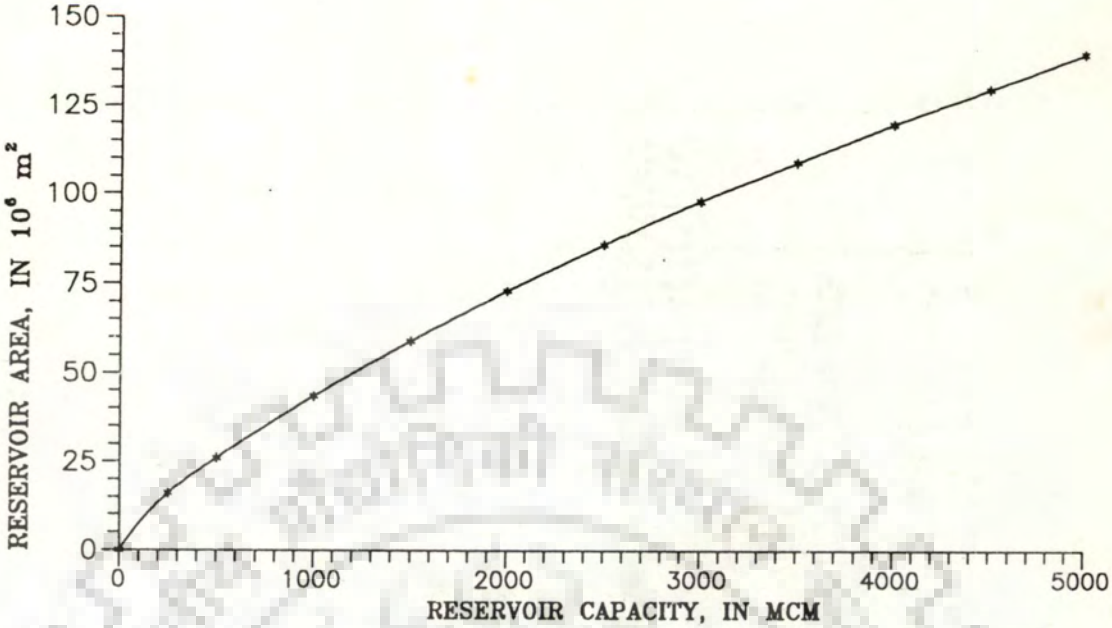


Fig. 7.3.2 Reservoir capacity vs area for Bodhghat

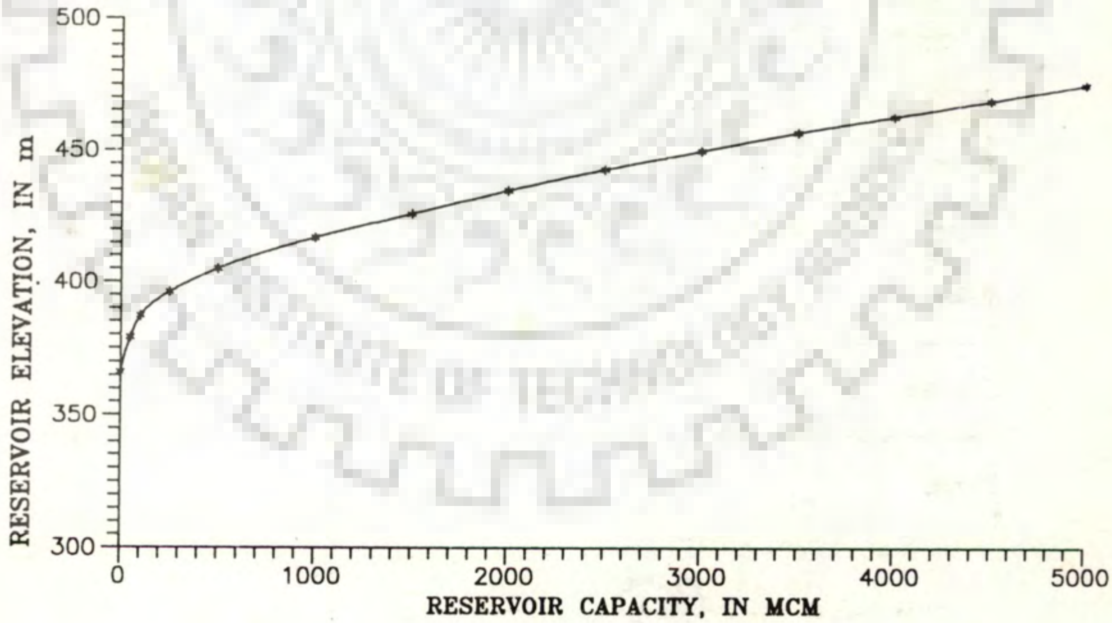


Fig. 7.3.3 Reservoir capacity vs elevation for Bodhghat

7.4.0 BARGI MULTIPURPOSE PROJECT

Bargi is a multipurpose project constructed at village Bargi near Jabalpur in the State of Madhya Pradesh, see Figure 7.4.1, across the river Narmada approximately 35 km from the source of the river (Bargi Project Report, 1968). It has a catchment area up to the dam site equal to 14556 sq.km. The average annual rainfall in the catchment is 1148 mm. It will provide irrigation, power and flood control benefits to vast areas of madhya Pradesh.

The dam has a gross reservoir capacity of 3.932 TMC (thousand million cubic meters) with annual irrigation of 3.947 TMC and power plant capacity of 90 MW with 2 unit of 45 MW each. The regular observation of river flows in Narmada is available from 1948 onwards.The monthly river flow data from (1948-1970) are given Table 7.4.1. The annual losses due to evaporation are taken as 0.221 TMC and the monthly break-down is shown in Table7.4.2. The proposed irrigation is 402000 ha and net utilization of 3.947 TMC and monthly percent energy requirements, are also given in Table 7.4.2. The reservoir would generally fill during July to October and would be depleted from November to the following June. The reservoir capacity-area and reservoir capacity-elevation curves are given in Figures 7.4.2 and 7.4.3 respectively. The salient features are given in Annexure-4.

Basin Boundary ↓ at what point

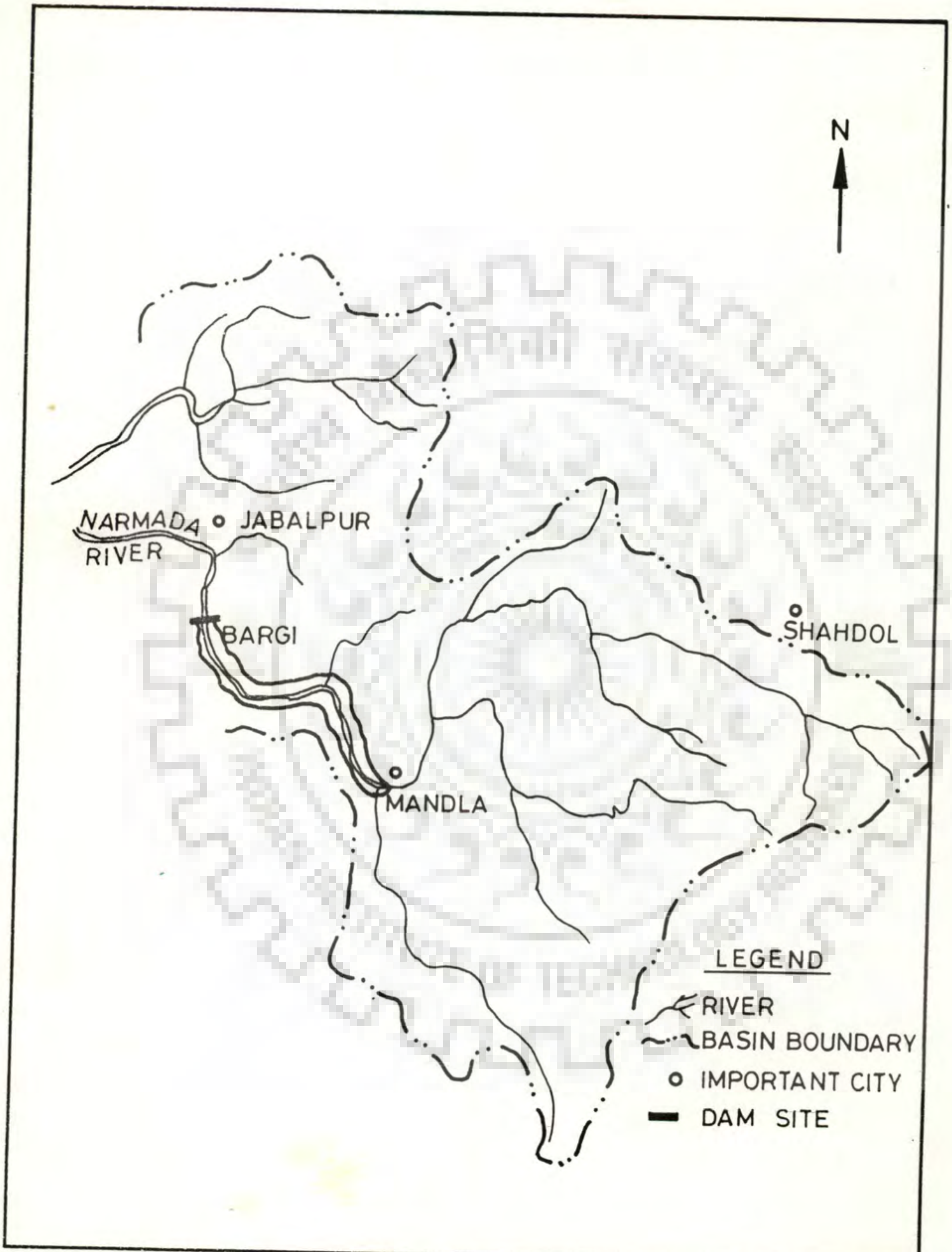


Fig. 7·4·1 Plan showing the Bargi multipurpose project.

Table 7.4.1 Monthly river flows from (1948-1970) at Bargi multipurpose project, in TMC

Year	Jul	Aug	Sep	Oct	Nov	Total monsoon	Dec
1948-49	1.518	2.938	1.869	0.363	0.230	6.918	0.093
1949-50	0.392	1.119	1.055	0.693	0.154	3.413	0.052
1950-51	1.862	2.902	0.884	0.153	0.049	5.850	0.045
1951-52	0.066	1.470	0.662	0.338	0.052	2.588	0.032
1952-53	1.383	2.735	1.433	0.216	0.062	5.829	0.033
1953-54	1.039	1.675	0.691	0.213	0.065	3.683	0.036
1954-55	0.669	1.139	1.413	0.301	0.076	3.598	0.028
1955-56	0.915	2.389	2.565	1.280	0.220	7.369	0.086
1956-57	3.169	4.838	1.189	0.701	0.289	10.186	0.095
1957-58	1.235	2.513	0.934	0.202	0.062	4.946	0.032
1958-59	1.203	1.107	0.969	1.132	0.185	4.596	0.065
1959-60	2.058	3.172	2.239	0.542	0.125	8.136	0.062
1960-61	0.943	2.416	0.556	0.750	0.127	4.792	0.064
1961-62	4.474	3.994	4.124	0.957	0.222	13.771	0.133
1962-63	0.458	1.183	0.978	0.258	0.085	2.962	0.301
1963-64	0.629	1.716	1.751	0.248	0.104	4.448	0.053
1964-65	1.917	3.270	1.111	0.459	0.109	6.866	0.059
1965-66	0.251	0.330	0.614	0.109	0.036	1.340	0.021
1966-67	0.736	1.552	0.202	0.059	0.025	2.574	0.023
1967-68	2.087	4.118	2.087	0.345	0.091	8.728	0.134
1968-69	0.781	2.121	0.362	0.211	0.068	3.543	0.041
1969-70	1.045	3.343	0.899	0.221	0.088	5.596	0.042
Average	1.310	2.365	1.299	0.444	0.115	5.533	0.069

Table 7.4.1 Continued

Jan	Feb	Mar	Apr	May	Jun	Total non-monsoon	Total annual yield	Total annual yield in descending order	Dependable year, m/(n+1)
0.062	0.058	0.037	0.011	0.004	0.027	0.292	7.210	14.152	4
0.044	0.046	0.056	0.025	0.005	0.023	0.251	3.664	10.527	9
0.035	0.022	0.012	0.051	0.007	0.036	0.208	6.058	9.256	13
0.015	0.009	0.006	0.002	0.001	0.111	0.176	2.764	8.427	17
0.035	0.021	0.007	0.002	0.001	0.000	0.099	5.928	7.700	22
0.021	0.010	0.004	0.002	0.001	0.017	0.091	3.774	7.210	26
0.025	0.019	0.009	0.004	0.001	0.452	0.538	4.136	7.135	30
0.041	0.023	0.011	0.006	0.002	0.162	0.331	7.700	6.058	35
0.101	0.037	0.054	0.032	0.007	0.015	1.341	10.527	5.995	39
0.020	0.012	0.026	0.007	0.001	0.005	0.103	5.049	5.928	43
0.052	0.041	0.012	0.007	0.004	0.004	0.185	4.781	5.227	48
0.068	0.031	0.021	0.019	0.005	0.085	0.291	8.427	5.049	52
0.049	0.047	0.019	0.006	0.001	0.246	0.432	5.227	4.781	56
0.073	0.042	0.031	0.019	0.007	0.076	0.381	14.152	4.639	61
0.056	0.021	0.015	0.009	0.009	0.118	0.529	3.491	4.136	66
0.032	0.022	0.015	0.005	0.002	0.063	0.191	4.639	3.774	70
0.039	0.025	0.015	0.025	0.004	0.102	0.269	7.135	3.664	75
0.020	0.011	0.005	0.001	0.001	0.241	0.300	1.640	3.640	78
0.014	0.009	0.033	0.028	0.004	0.101	0.212	2.786	3.491	83
0.200	0.074	0.044	0.011	0.007	0.058	0.528	9.256	2.786	87
0.032	0.011	0.006	0.004	0.001	0.002	0.097	3.640	2.764	91
0.037	0.019	0.046	0.009	0.007	0.239	0.399	5.995	1.640	96
0.049	0.027	0.024	0.012	0.004	0.099	0.284	5.817	5.817 S.D. =2.85	

Table 7.4.2 Average flow, reservoir evaporation, irrigation water requirements, and energy requirements at Bargi

Month	Average flow	Reservoir evaporation		Irrigation water requirements		Energy requirements
	TMC	TMC	K'_t	TMC	K_t	η_t
Jul	1.310	0.031	1.0351	0.195	4.940	7
Aug	2.365	0.031	1.0226	0.156	3.952	8
Sep	1.299	0.021	1.0189	0.509	12.896	9
Oct	0.444	0.021	1.0199	0.460	11.655	9
Nov	0.115	0.021	1.0225	0.421	10.919	9
Dec	0.069	0.021	1.0178	0.305	7.727	10
Jan	0.049	0.011	1.0219	0.441	11.173	10
Feb	0.027	0.014	1.0197	0.294	7.449	9
Mar	0.024	0.014	1.0280	0.282	7.146	8
Apr	0.012	0.014	1.0300	0.267	6.765	7
May	0.004	0.011	1.0550	0.347	8.791	7
Jun	0.099	0.011	1.0645	0.260	6.587	7
Total	5.817	0.221		3.947	100.000	100

Note:

The values of K'_t were estimated by preparing working tables with and without reservoir evaporation. This was done individually for 22 years flow and an average value of K'_t is used.

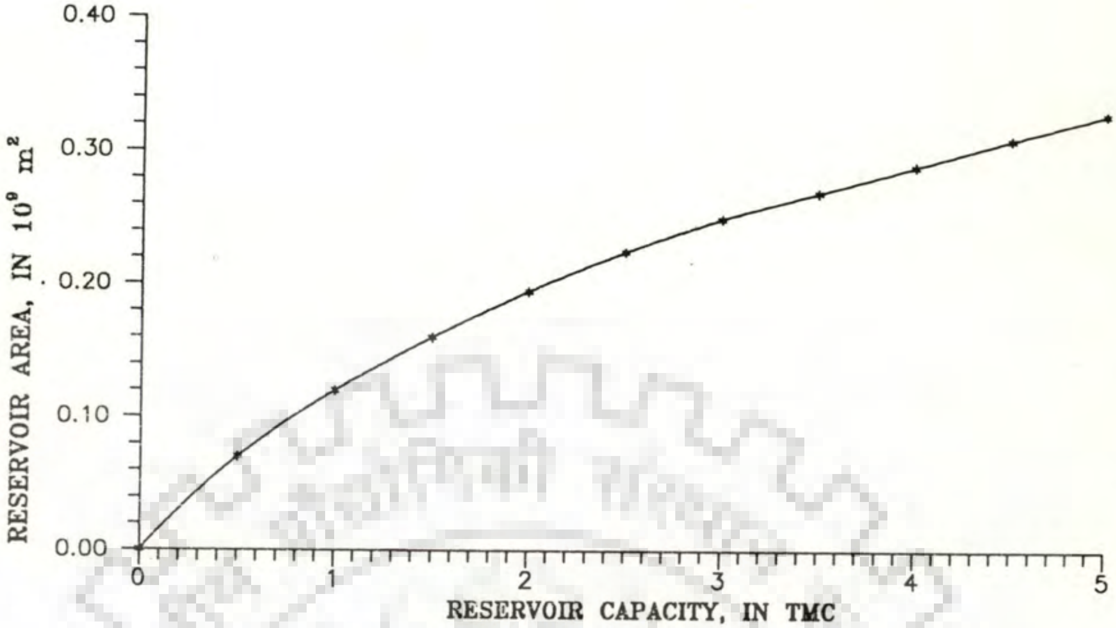


Fig. 7.4.2 Reservoir capacity vs area for Bargi

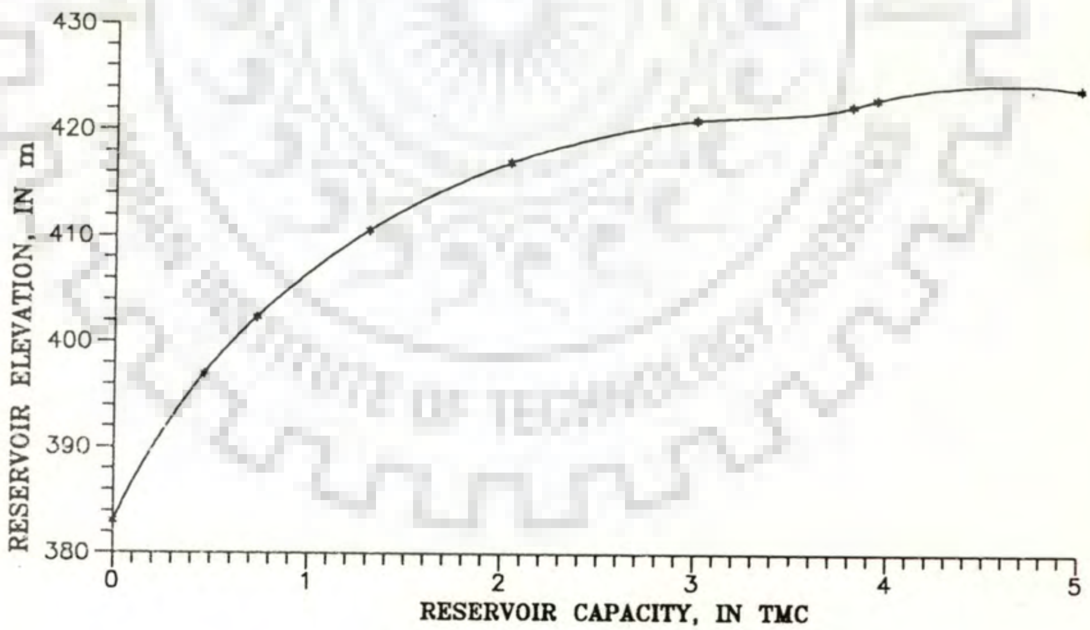


Fig. 7.4.3 Reservoir capacity vs elevation for Bargi

CHAPTER 8

APPLICATION OF MODELS, COMPUTATION AND RESULTS FOR RESERVOIR PLANNING

Chapter-8

APPLICATION OF MODELS, COMPUTATION AND RESULTS FOR RESERVOIR PLANNING

Various models for reservoir planning were discussed in Chapter-3, 4 and 5. For applying these models, four reservoirs given in Chapter-7 are to be considered. Keeping in mind the objectives of this study as mentioned in Chapter-1, the following approach may be used for computing various planning aspects of a reservoir. The computation were done on TATA ELXSI Power Series 3220 Computer and PC (GENIUS 386).

8.1.0 THE APPROACH FOR RESERVOIR PLANNING

The various models for reservoir planning may be nested as follows:

Step-I: Since, the reservoir capacity and annual water use targets are unknown, it is worthwhile to use linear programming model Max.Z_{nb} to determine their initial estimates in order to regulate given annual flows and to maximize the net annual benefits. A number of yearly river flows of different dependabilities would be used depending upon type of the project. The model was run for one year with 12 monthly periods.

Step-II: The reservoir capacities obtained from model Max.Z_{nb} can be simulated to estimate (i) the annual water use targets for a given project dependability, and (ii) the water utilization factor.

Step-III: The linear programming annual safe yield model Max.Z_{sy} will be used to revise and refine the annual water use targets from the reservoir capacity obtained from model Max.Z_{nb}. Different dependable year's from would be used depending upon type of the project, and the model was run for one year with 12 monthly periods.

Step-IV: The over-year carry-over storages in a reservoir for a known annual safe targeted yield/demand (earlier determined from model Max.Z_{sy}) are proposed to be obtained as follows:

(i) Use of linear programming discontinuous model Max.Z_{tr}: the model is to be used to determine variations in over-year carry-over storage for a known reservoir capacity and annual targeted demand. The model will be run for one year only with 12 months period. A selected number of annual flows would be considered and the model would be run independently for each annual flow. The annual safe yield was taken from model Max.Z_{sy}.

(ii) Use of dynamic programming model: this model is to be run similar to model Max.Z_{tr}.

Step-V: The linear programming model Max.Z_{gc} will be used in order to obtain the reservoir capacity to account for long term variations in the storage requirements for a known annual targeted demand taken equal to the project provision. The model would be run for the entire length of the historical data with bi-seasonal and multi-seasonal periods independently.

Step-VI: The linear programming model Max.Z_{oc} will be used to determine over-year carry-over reservoir capacity to account for its long term variations for a known annual targeted demand taken equal to the project provision. The model would be run for the entire length of the historical data with one time period in a year.

Step-VII: The project provisions can be tested by simulation in order to compare them with the above modeled results.

8.2.0 COST, BENEFIT AND LOSS FUNCTIONS

8.2.1 General

In every optimization model cost, benefit and loss functions,as a continuous function of inputs and outputs, such as stored volumes, targets, capacities, flows, and allocations etc, are required. These functions were developed from the data obtained from the reports of various projects.

The systems analysis was used to determine as best as possible those sets of design variables that maximized the values of the net benefit derived from conservation uses (mainly irrigation, and hydroelectric energy) and flood control. In linear programming and dynamic programming models annual cost method was used as the economic objective and all capital costs were converted to annual values. In simulation the economic objective was to determine the present worth of net benefits.

8.2.2 Cost, Benefit and Loss Functions for L.P. and D.P. Models

The detailed calculation for cost and benefit functions for the Bargi multi-purpose project are given in Appendix-5. These values for all the projects are given in Table 8.2.1. No losses were considered in L.P. models due to short falls in water targets, but were not neglected in D.P. model. These unit loss functions are given at a later stage in the computations.

Table 8.2.1 Costs and benefits used for optimization models

Project	C'_1	Om'_1	a_2	C'_2	Om'_2	a_3	C'_3	Om'_3	a_4
Badanala	0.0375	0.0042	0.3125	0.0081	0.0009	—	—	—	—
Kalluvo-dduhalla	4.2670	0.5096	7.1910	1.5903	1.8990	—	—	—	—
Bodhghat	0.1686	0.0051	—	—	—	0.0000030	0.5179	0.0156	—
Bargi	1.8085	0.0995	54.089	4.5460	0.5000	0.0000002	0.0087	0.0005	1.90

Note:

(i) For Badanala all the costs and irrigation benefits are in Rs.10^5/ha-m.

(ii) For Kalluvodduhalla all the costs and irrigation benefits are in Rs.10^5/MCM.

(iii) For Bodhghat all the costs are in Rs.10^6/MCM.

(iv) For Bargi all the costs and irrigation benefits are in Rs.10^7/TMC.

(v) The energy benefits for Bodhghat is in Rs.10^6/Mwhr.

(vi) The energy benefits for Bargi is in Rs.10^7/Mwhr.

8.2.3 Cost, Benefit and Loss Functions for Simulation Model

The design values for cost and benefit for each project were available at least for a certain size of each facility. The project design cross section of each dam and the cost of each item, involved are given, Based on these, calculations are done for estimation of the costs, for different capacities of reservoirs, irrigation works and power plants. In this regard estimation for different possible ranges for each project is considered on the basis of appropriate engineering approaches. The cost of auxiliary works for reservoir were developed on a unit basis. The cost of the hydropower plant and equipment and auxiliary works and the cost of irrigation and diversion works were developed on a unit basis. These were estimated for 1994 prices. Although they involved considerable work, it must be understood that the estimates are for a methodological study rather than for detailed design. On the basis of calculation of costs for different capacities of reservoirs, irrigation works and power plants suitable curves were developed. The Tables 8.2.2 to 8.2.5, and also Figures from 8.2.1.1 to 8.2.1.5; 8.2.2.1 to 8.2.2.5; 8.2.3.1 to 8.2.3.4, and 8.2.4.1 to 8.2.4.7 for Badanala, Kalluvodduhalla, Bodhghat and Bargi show respectively the functional relationships of the data used in this study.

The present value of net annual benefits extending over the period of study for system is calculated by applying the formula for the present value of annuity given below:

$$P = A \frac{\left[\left(1 + i_f\right)^n - 1 \right]}{i \left(1 + i_f\right)^n}$$

Where,

P = the present value of annuity (the present value of net annual benefits),

A = the value of annuity (the value of net annual benefit),

i_f = the discount rate, and

n = the economic life of the project.

In simulation the present value of net benefits extending over the economic life of the system at a given rate of discount was calculated as given in Chapter-5.

8.2.4 Reservoir Volume vs. Reservoir Elevation and Reservoir Volume vs. Reservoir Area Curves for Simulation

Relationships of volume vs. elevation and area of reservoir were developed and were given for the projects in Tables 8.2.2 to 8.2.5.

Table 8.2.2 Functional relationships developed for Badanala irrigation project

Sl. No.	Independent variable	Dependent variable	Coefficients
1	Reservoir capacity	Reservoir area	a0 = 298.8906 a1 = 0.2962799 a2 = $-0.82038*10^{-4}$ a3 = $0.10625*10^{-7}$ a4 = $-0.48396*10^{-12}$
2	Reservoir capacity	Reservoir elevation	a0 = 149.4092 a1 = $0.196743*10^{-1}$ a2 = $-0.632926*10^{-5}$ a3 = $0.865211*10^{-9}$ a4 = $-0.406341*10^{-13}$
3	Reservoir capacity	Capital cost of reservoir	a0 = 1956.047 a1 = 0.2393951 a2 = $-0.14212*10^{-5}$ a3 = $0.35903*10^{-9}$
4	Reservoir capacity	OM cost of reservoir	a0 = 9.969238 a1 = $0.11212*10^{-2}$ a2 = $-0.40496*10^{-7}$
5	Annual irrigation requirement	Capital cost of irrigation works	a0 = 737.4063 a1 = 0.1493530 a2 = $-0.19614*10^{-4}$ a3 = $0.83401*10^{-9}$
6	Annual irrigation requirement	OM cost of irrigation works	a0 = 8.906260 a1 = $0.25365*10^{-3}$ a2 = $0.31961*10^{-8}$
7	Annual irrigation requirement	Irrigation benefits	a0 = 14.22331 a1 = 0.3006858 a2 = $0.18959*10^{-5}$ a3 = $-0.80215*10^{-10}$

Where, a0, a1, a2, a3, and a4 are the coefficients of polynomial equations.
All costs and benefits are in Rs. 10^5. All volumetric units are in ha-m.

Table 8.2.3 Functional relationships developed for Kalluvodduhalla irrigation project

Sl. No.	Independent variable	Dependent variable	Coefficients
1	Reservoir capacity	Reservoir area	a0 = $0.24539*10^{-1}$ a1 = 0.3442577 a2 = $-0.32033*10^{-1}$ a3 = $0.16515*10^{-2}$ a4 = -0.30379470^{-4}
2	Reservoir capacity	Reservoir elevation	a0 = 617.0784 a1 = 3.989698 a2 = -0.3616289 a3 = $0.113088*10^{-1}$
3	Reservoir capacity	Capital cost of reservoir	a0 = 70.64508 a1 = 75.38718 a2 = -3.910439 a3 = $0.98003*10^{-1}$
4	Reservoir capacity	OM cost of reservoir	a0 = 0.532640 a1 = 0.2725958 a2 = $-0.90700*10^{-2}$ a3 = $0.15192*10^{-3}$
5	Annual irrigation requirement	Capital cost of irrigation works	a0 = 20.00000 a1 = 17.84945
6	Annual irrigation requirement	OM cost of irrigation works	a0 = 0.1400001 a1 = 0.1819135
7	Annual irrigation requirement	Irrigation benefits	a0 = 9.000000 a1 = 6.677988

Where, a0, a1, a2, a3, and a4 are the coefficients of polynomial equations.
All costs and benefits are in Rs. 10^5. All volumetric units are in MCM.

Table 8.2.4 Functional relationships developed for Bodhghat hydroelectric project

Sl. No.	Independent variable	Dependent variable	Coefficients
1	Reservoir capacity	Reservoir area	a0 = 0.9824219 a1 = $0.56269*10^{-1}$ a2 = $-0.16421*10^{-4}$ a3 = $0.37416*10^{-8}$ a4 = $-0.32107*10^{-12}$
2	Reservoir capacity	Reservoir elevation	a0 = 376.6777 a1 = $0.573120*10^{-1}$ a2 = $-0.200644*10^{-4}$ a3 = $0.378349*10^{-8}$ a4 = $-0.252243*10^{-12}$
3	Reservoir capacity	Capital cost of reservoir	a0 = 191.125 a1 = 1.381348 a2 = $-0.246882*10^{-3}$ a3 = $0.537256*10^{-7}$ a4 = $-0.509459*10^{-11}$
4	Reservoir capacity	OM cost of reservoir	a0 = 1.434326 a1 = $0.57933*10^{-2}$ a2 = $-0.37171*10^{-6}$ a3 = $0.13088*10^{-10}$
5	Power plant capacity	Capital cost of power plant	a0 = 150.00000 a1 = 2.82800
6	Power plant capacity	OM cost of power plant	a0 = 0.799996 a1 = $0.14040*10^{-1}$

Where, a0, a1, a2, a3, and a4 are the coefficients of polynomial equations.
All costs and benefits are in Rs. 10^6. All volumetric units are in MCM.

Table 8.2.5 Functional relationships developed for Bargi multipurpose project

Sl. No.	Independent variable	Dependent variable	Coefficients
1	Reservoir capacity	Reservoir area	a0 = $0.22733*10^{-1}$ a1 = $-0.55317*10^{-1}$ a2 = 0.1838010 a3 = $-0.610036*10^{-1}$ a4 = $0.57745*10^{-2}$
2	Reservoir capacity	Reservoir elevation	a0 = 383.9257 a1 = 29.54465 a2 = -7.765953 a3 = 0.694165
3	Reservoir capacity	Capital cost of reservoir	a0 = 10.33859 a1 = 59.54181 a2 = -20.12424 a3 = 2.766336
4	Reservoir capacity	OM cost of reservoir	a0 = $0.57422*10^{-1}$ a1 = 0.2859806 a2 = $-0.947122*10^{-1}$ a3 = $0.129649*10^{-1}$
5	Annual irrigation requirement	Capital cost irrigation works	a0 = 19.00000 a1 = 50.20611 a2 = -1.463681
6	Annual irrigation requirement	OM cost of irrigation works	a0 = 0.190009 a1 = 0.502069 a2 = $-1.46368*10^{-1}$

Table 8.2.5 Continued

7	Annual irrigation requirement	Irrigation benefits	a0 = 13.75299 a1 = 57.55832 a2 = -1.094980
8	Power plant capacity	Capital cost of power plant	a0 = 3.104462 a1 = 0.912830^{-1} a2 = $-0.89809*10^{-5}$
9	Power plant capacity	OM cost of power plant	a0 = $0.15222*10^{-1}$ a1 = $0.45642*10^{-3}$ a2 = $0.44904*10^{-7}$

Where, a0, a1, a2, a3, and a4 are the coefficients of polynomial equations.

All costs and benefits are in Rs. 10^7. All volumetric units are is TMC.

Power plant capacity is in MW.

8.3.0 LINEAR PROGRAMMING COMPUTATIONS

Five types of models were used for L.P computations for planning as discussed in the approach earlier.

8.3.1 Computation for Badanala Irrigation Project

The monthly river flows are given in Table 7.1.1. The monthly values of irrigation requirements (K_t) and monthly evaporation coefficients (K'_t) are given in Table 7.1.2. All the costs and benefits were linearized.

8.3.1.1 Use of model Max.Z_{nb}

Since, both the reservoir capacity and annual irrigation target are unknown, it is worthwhile to use this model to determine their initial estimates in order to maximize net annual benefits.

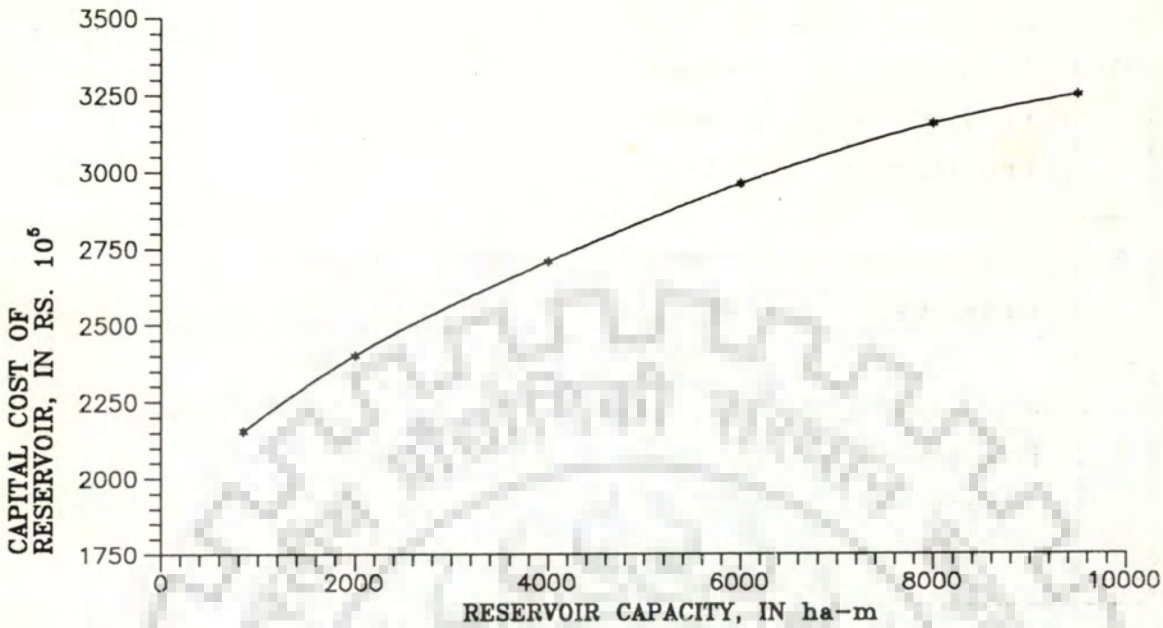


Fig. 8.2.1.1 Reservoir capacity vs capital cost for Badanala

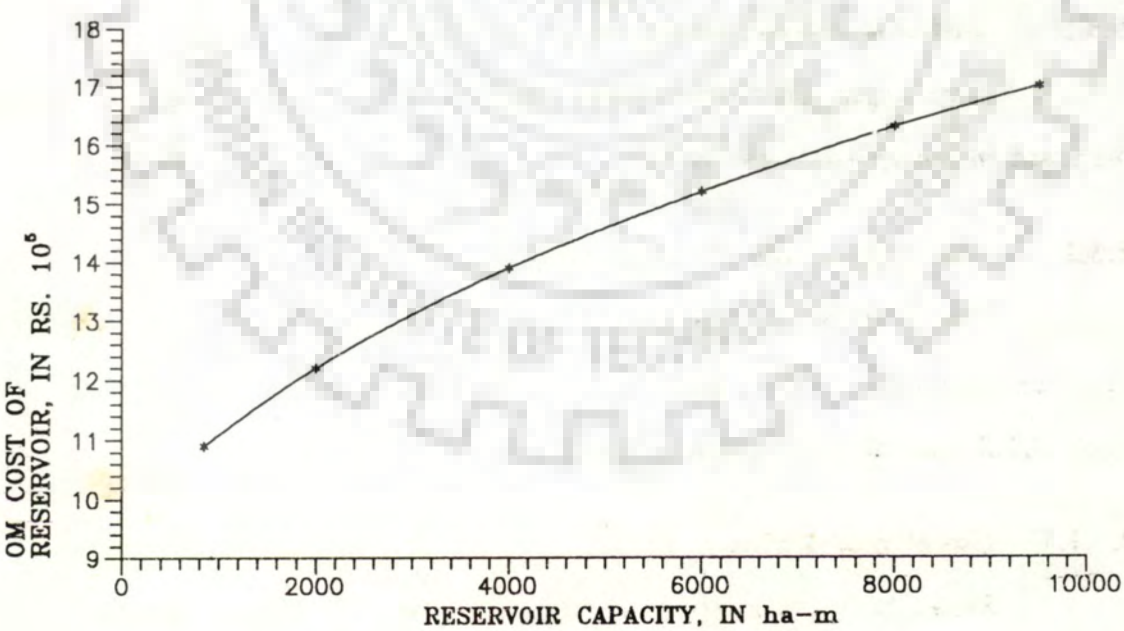


Fig. 8.2.1.2 Reservoir capacity vs OM cost for Badanala

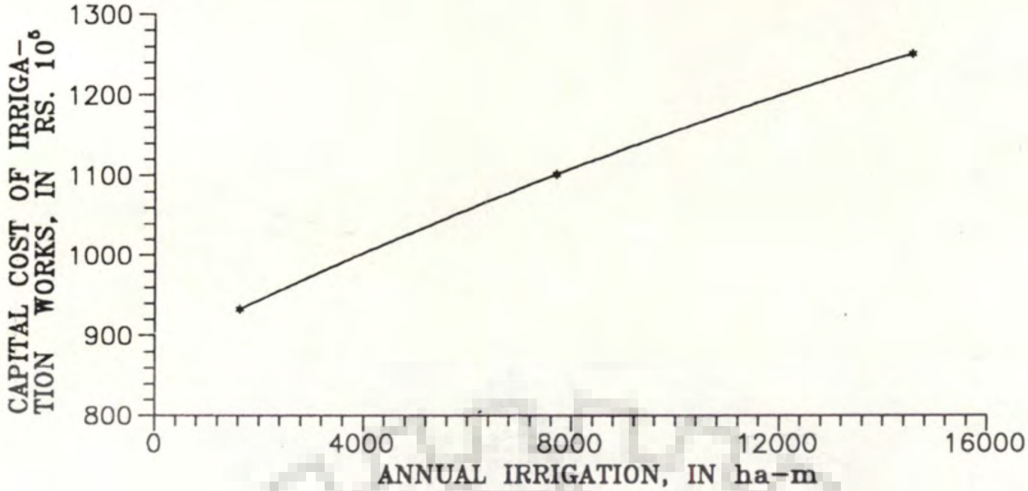


Fig. 8.2.1.3 Annual irrigation vs capital cost for Badanala

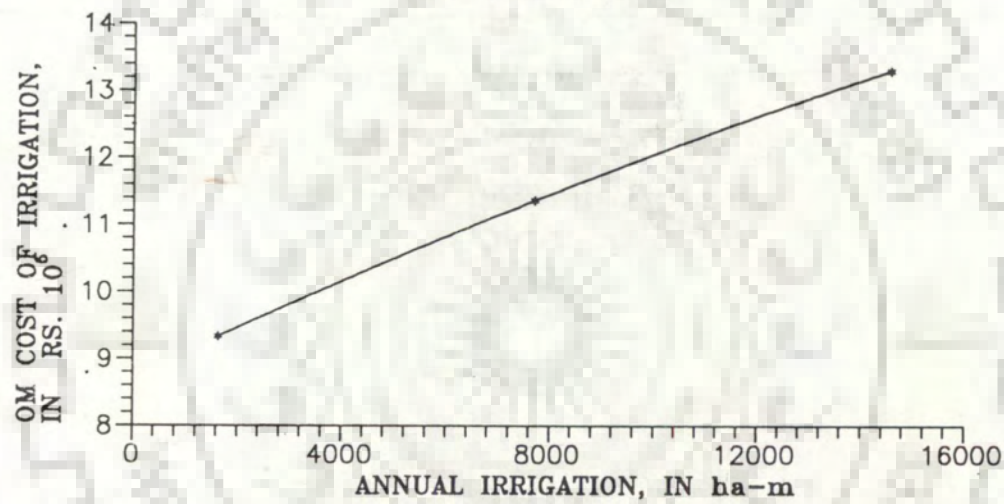


Fig. 8.2.1.4 Annual irrigation vs OM cost for Badanala

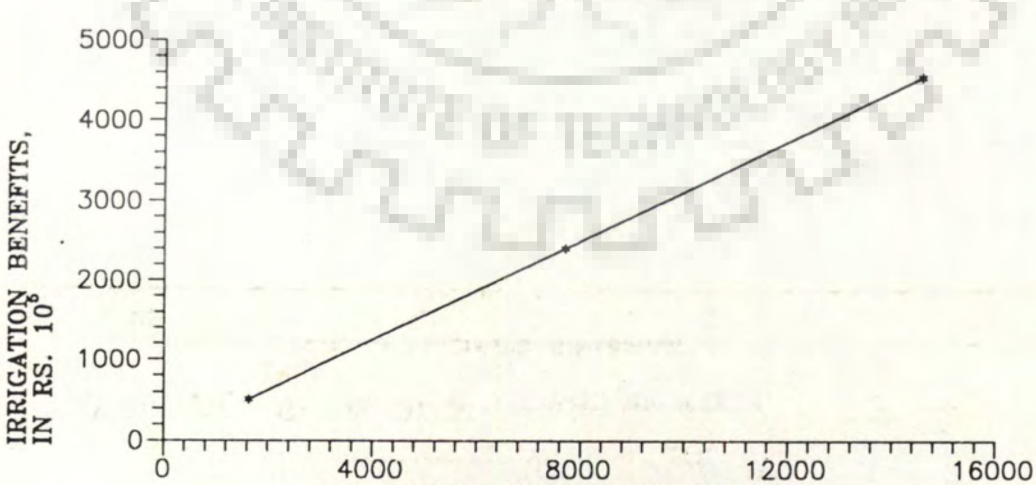


Fig. 8.2.1.5 Annual irrigation vs benefits for Badanala

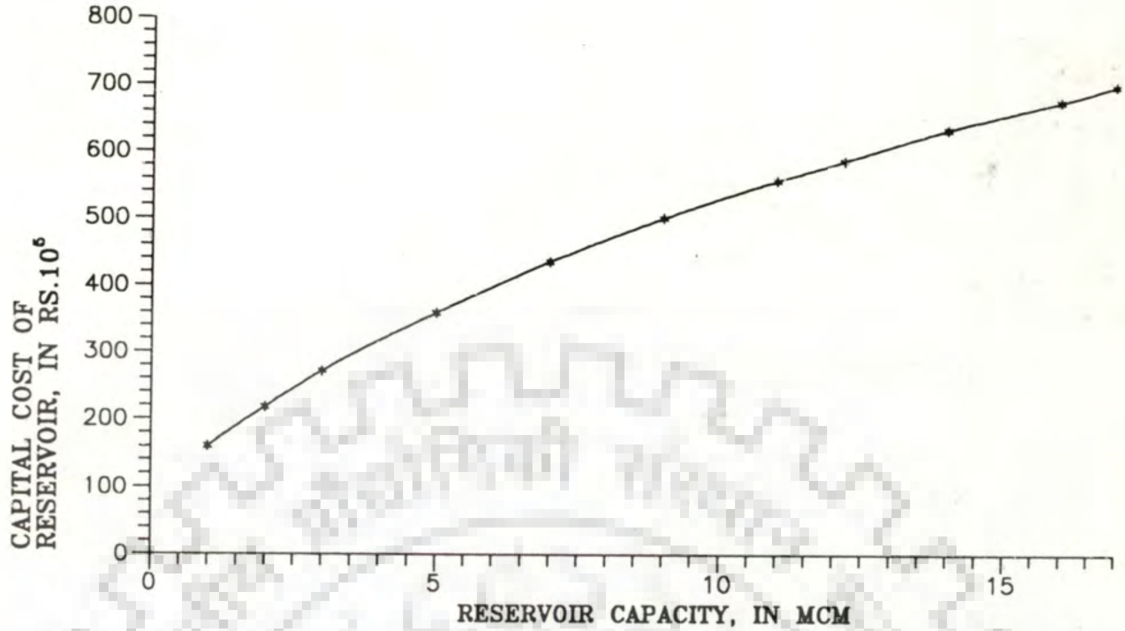


Fig. 8.2.2.1 Reservoir capacity vs capital cost for Kalluvodduhalla

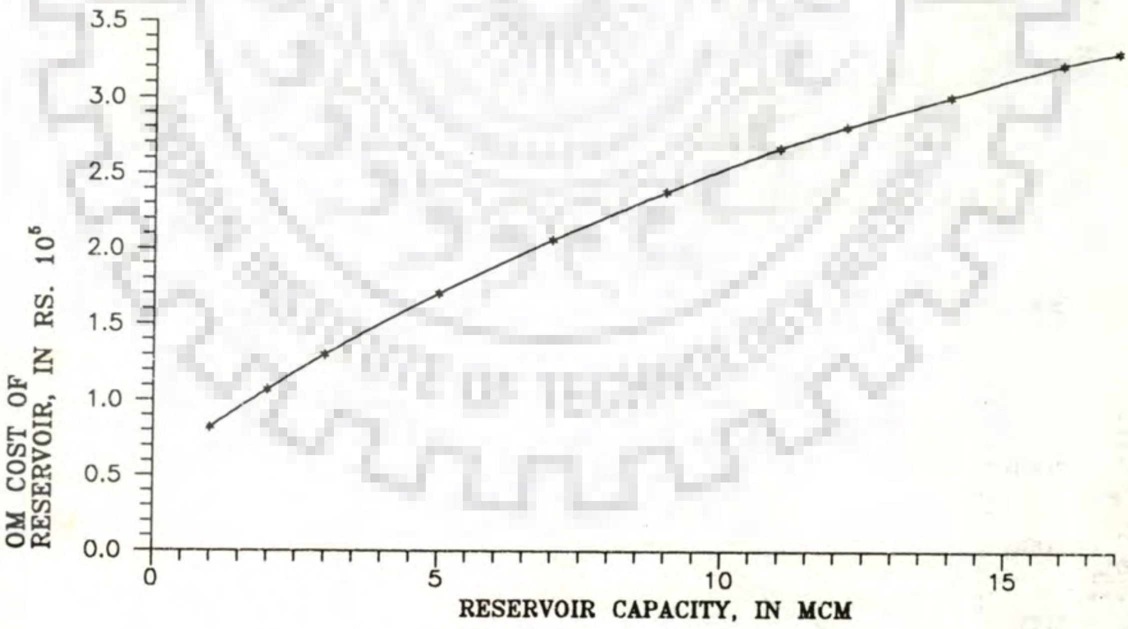


Fig. 8.2.2.2 Reservoir capacity vs OM cost for Kalluvodduhalla

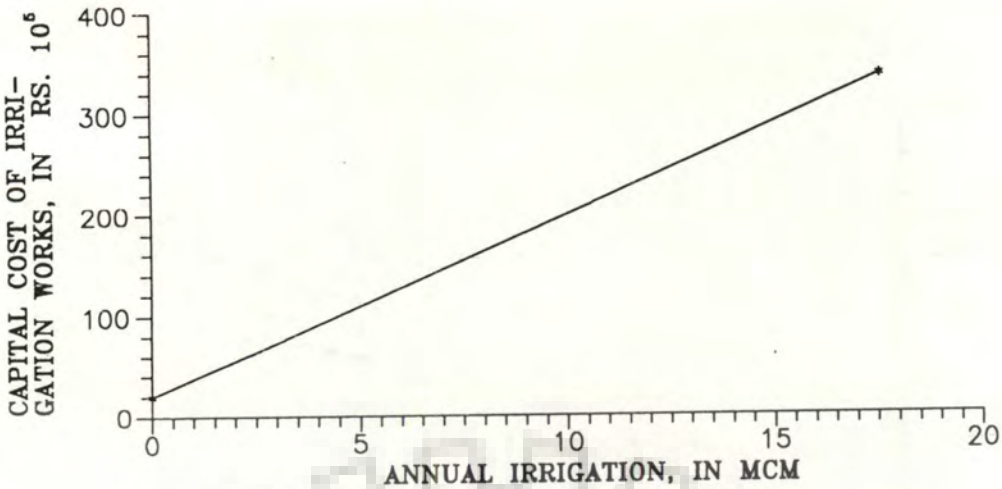


Fig. 8.2.2.3 Annual irrigation vs capital cost for Kalluvodduhalla

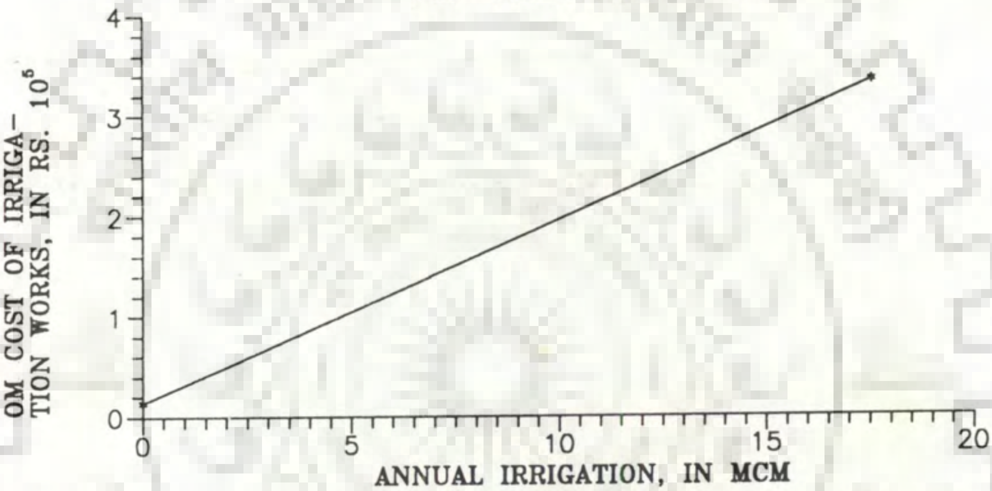


Fig. 8.2.2.4 Annual irrigation vs OM cost for Kalluvodduhalla

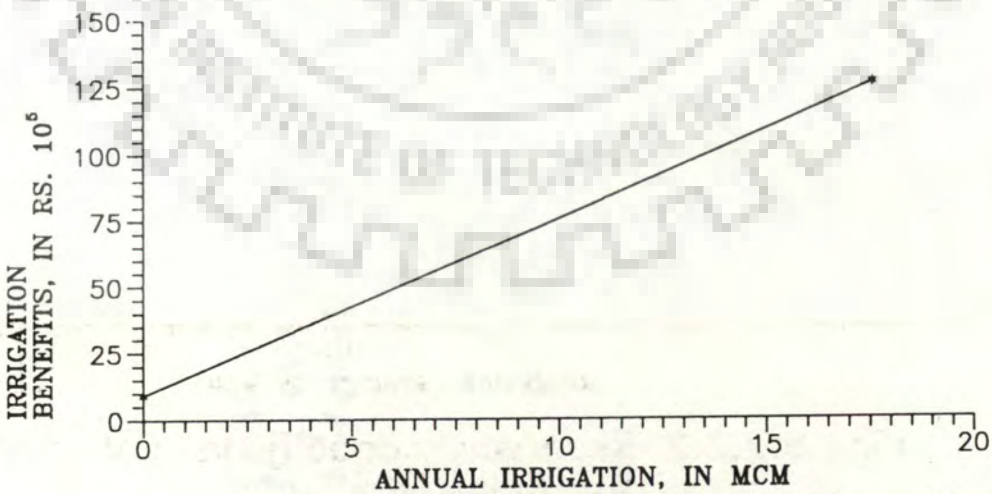


Fig. 8.2.2.5 Annual irrigation vs benefits for Kalluvodduhalla

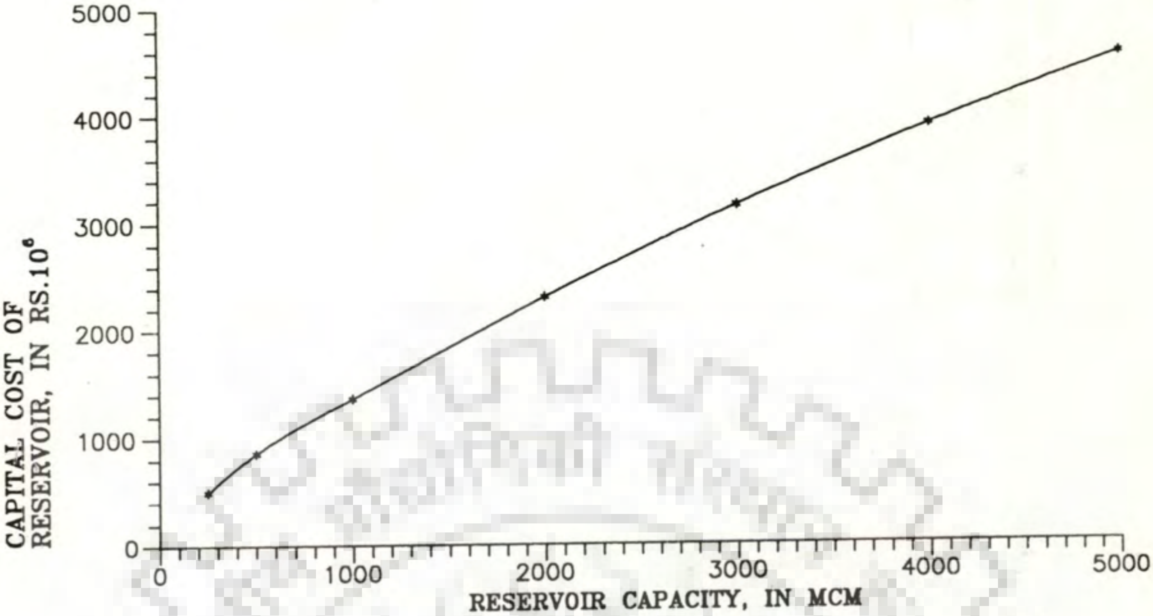


Fig. 8.2.3.1 Reservoir capacity vs capital cost for Bodhghat

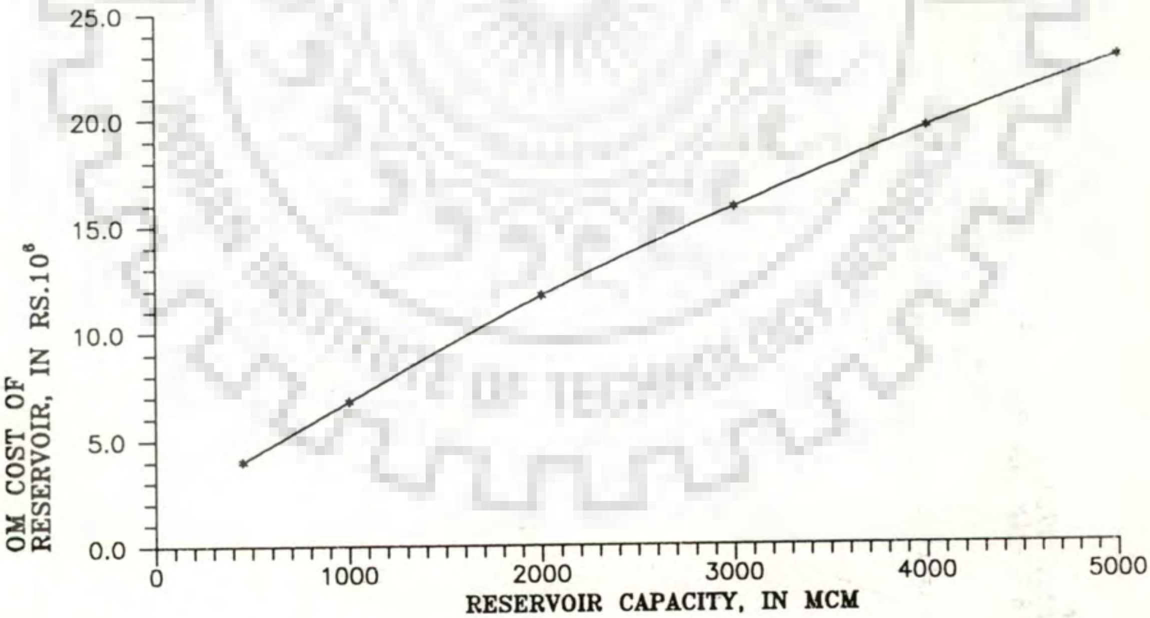


Fig. 8.2.3.2 Reservoir capacity vs OM cost for Bodhghat

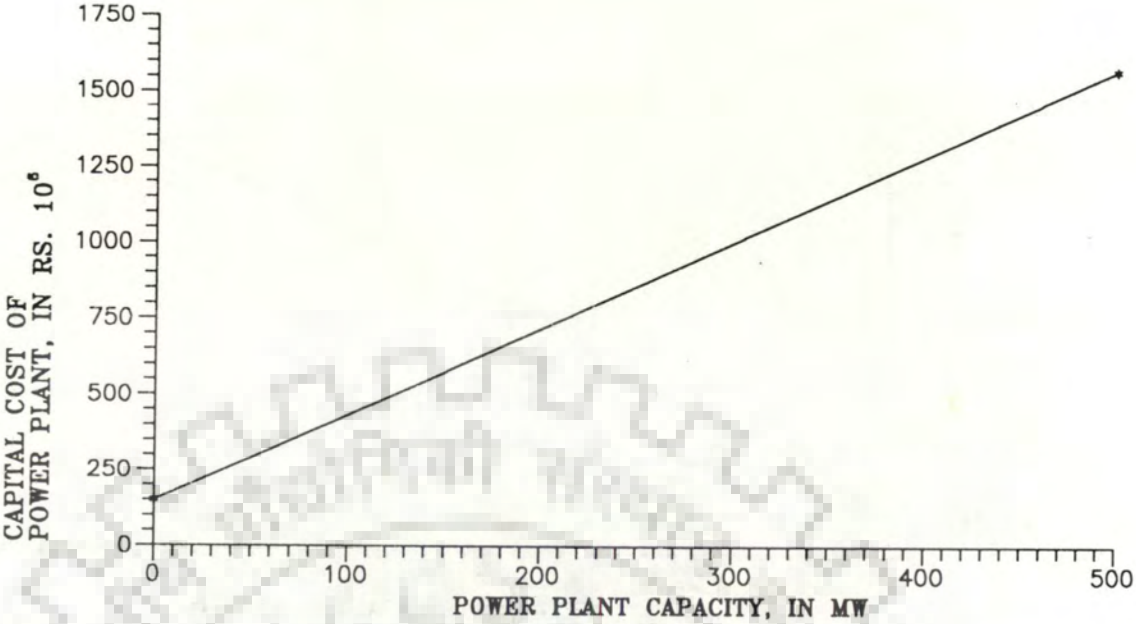


Fig. 8.2.3.3 Power plant capacity vs capital cost for Bodhghat

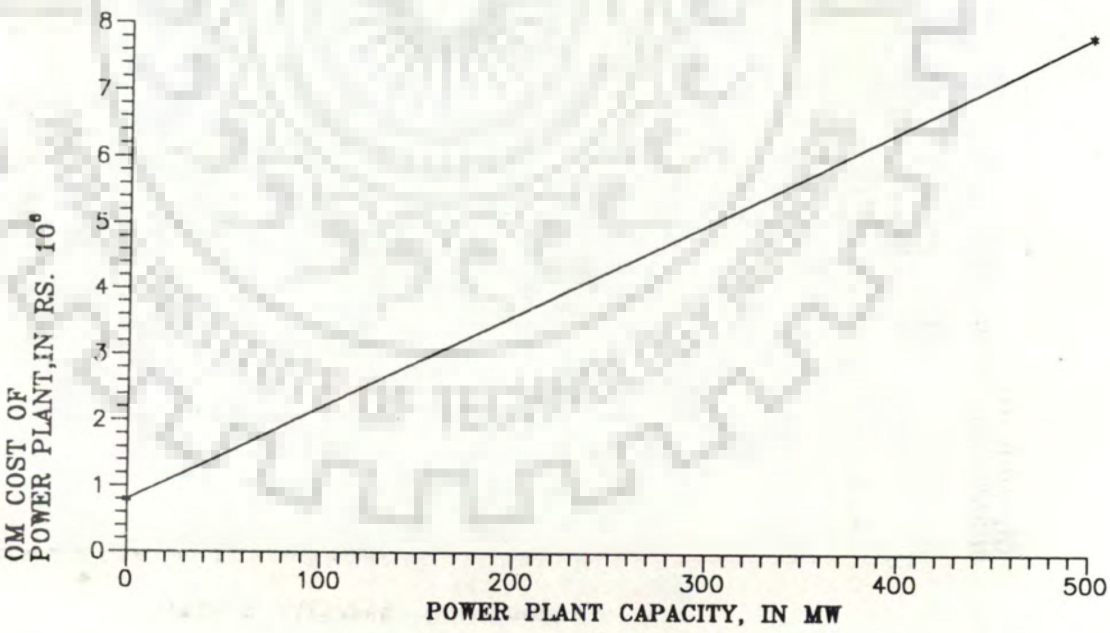


Fig. 8.2.3.4 Power plant capacity vs OM cost for Bodhghat

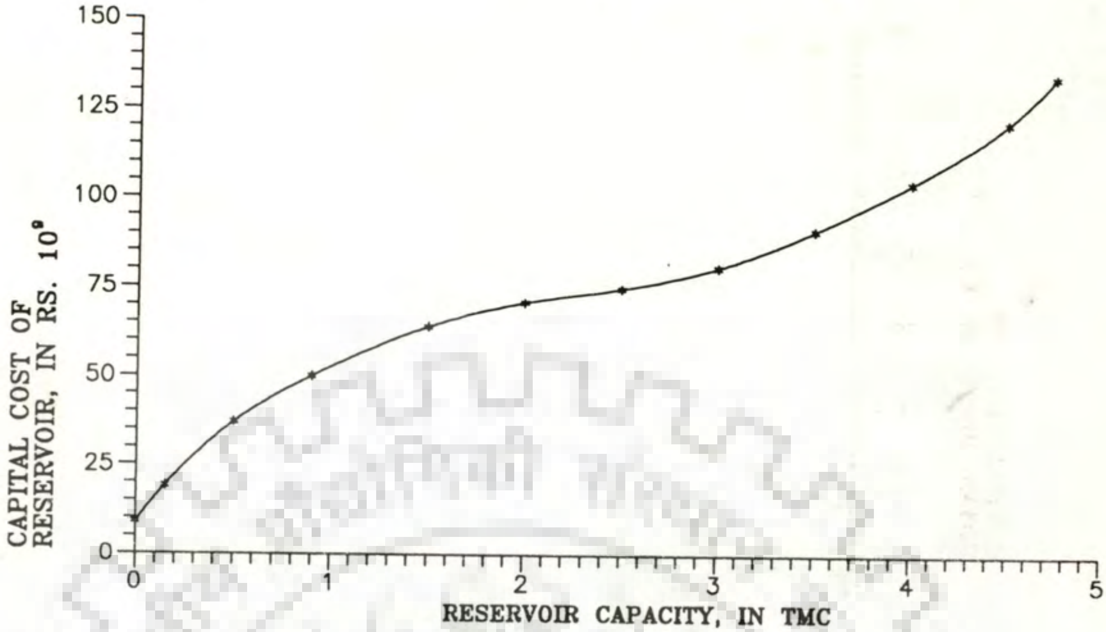


Fig. 8.2.4.1 Reservoir capacity vs capital cost for Bargi

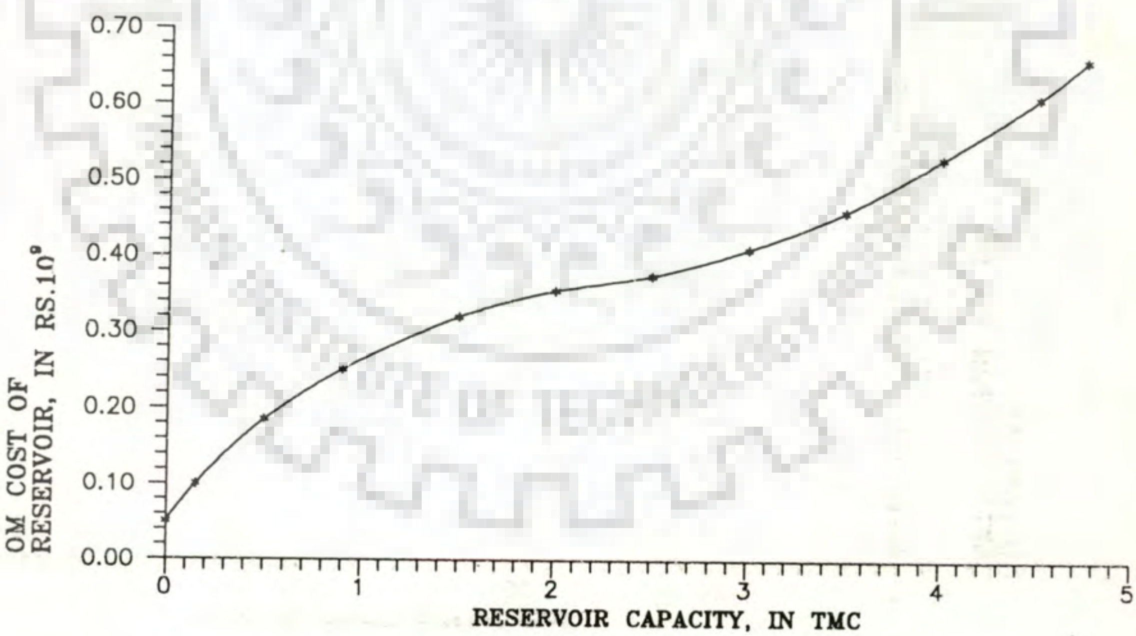


Fig. 8.2.4.2 Reservoir capacity vs OM cost for Bargi

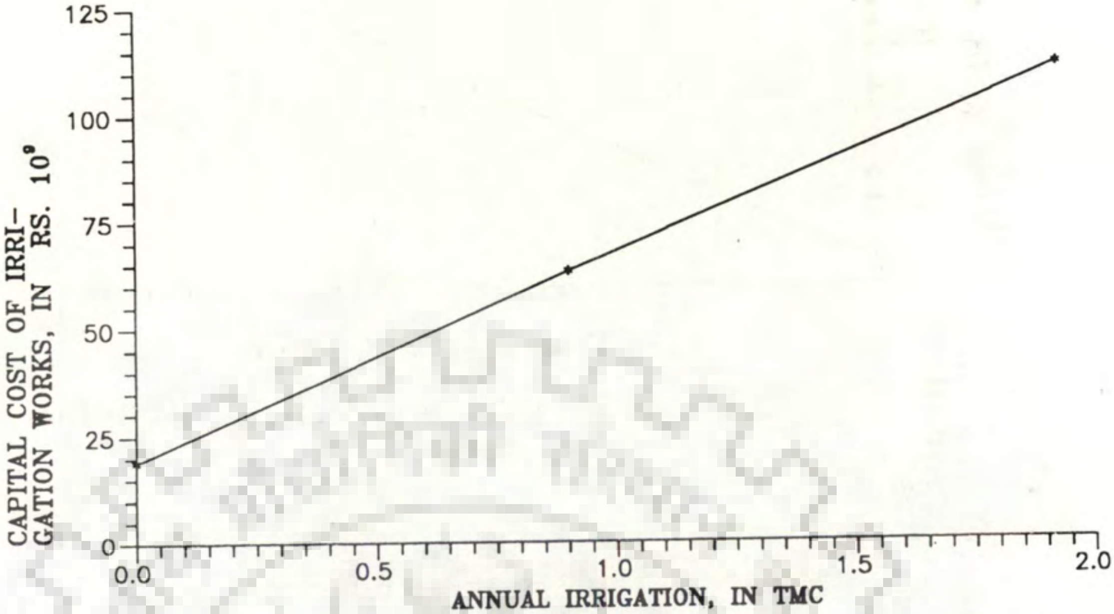


Fig. 8.2.4.3 Annual irrigation vs capital cost for Bargi

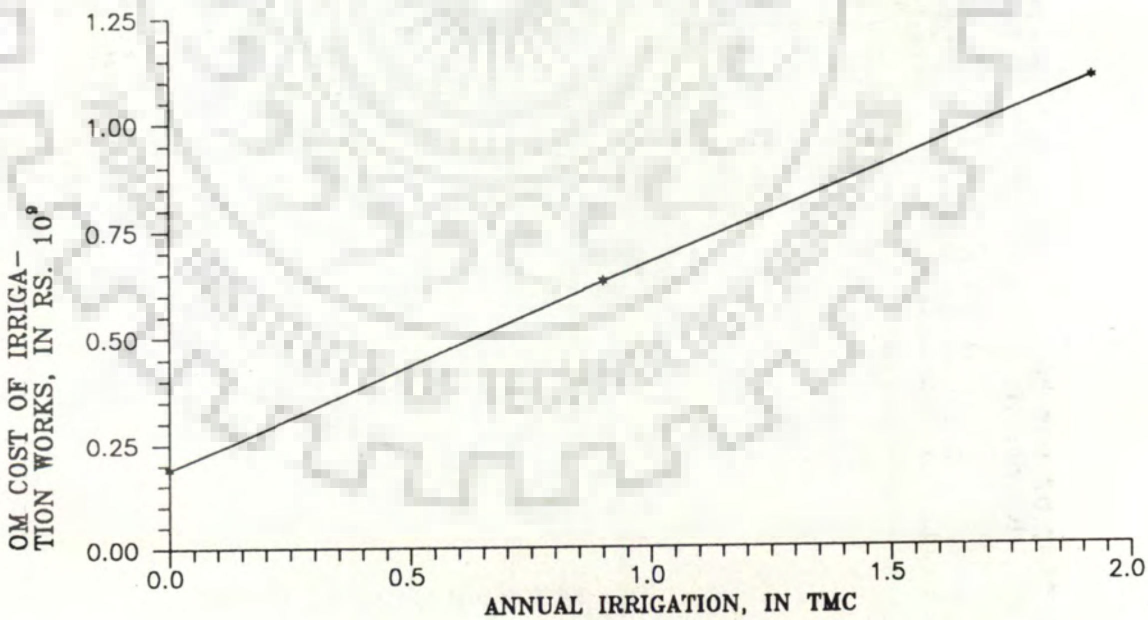


Fig. 8.2.4.4 Annual irrigation vs OM cost for Bargi

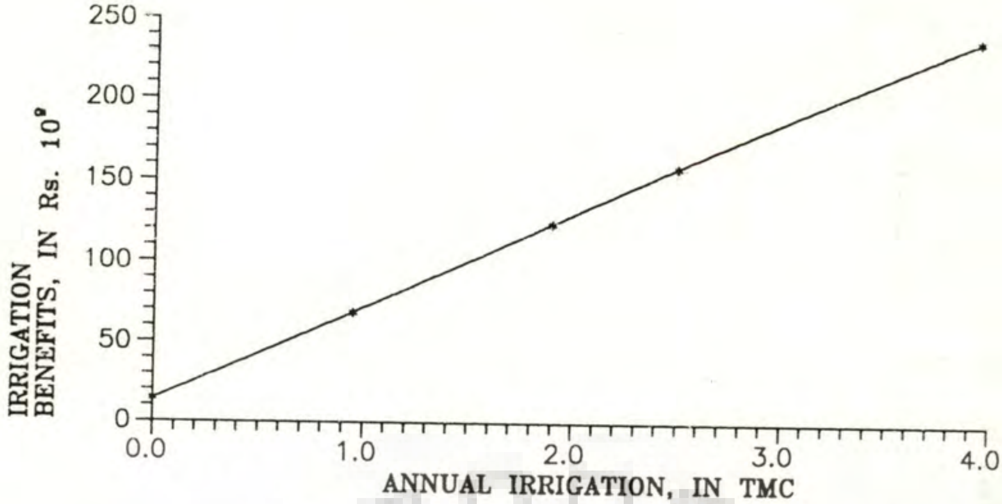


Fig. 8.2.4.5 Annual irrigation vs benefits for Bargi

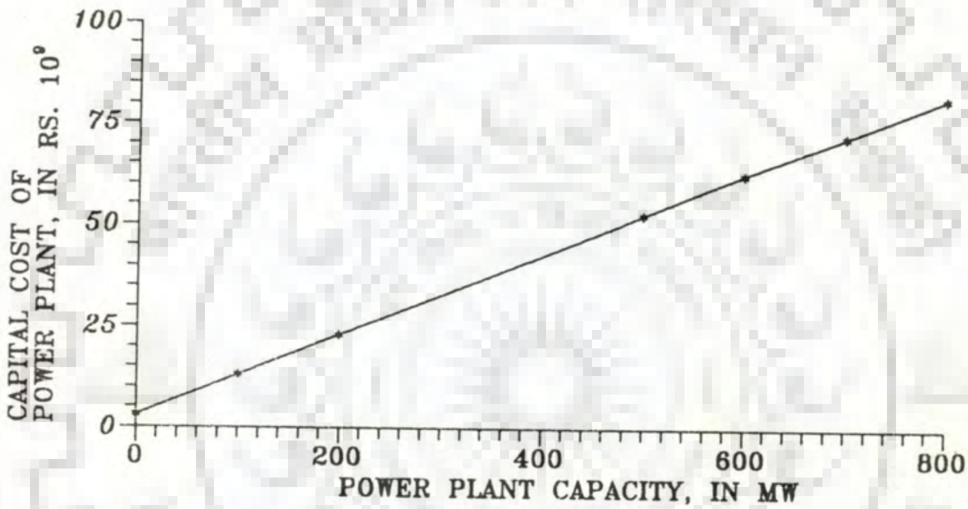


Fig.8.2.4.6 Power plant capacity vs capital cost for Bargi

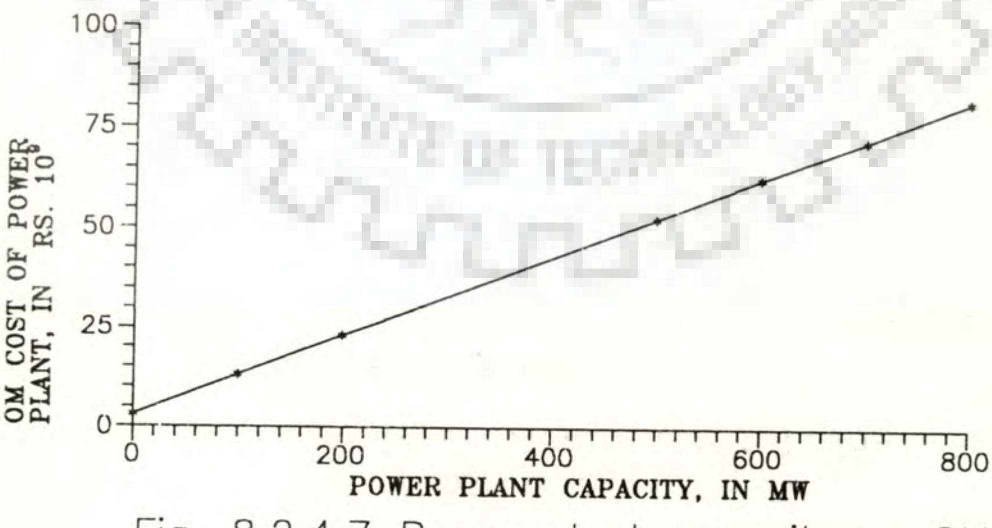


Fig. 8.2.4.7 Power plant capacity vs OM cost for Bargi

To make the problem more realistic a few additional design constraints were added on the basis of project design criterias for this model as follows:

(1) The reservoir submergence ratio should be less than 0.2, i.e.,

$$\frac{\text{Reservoir submerged area}}{\text{Culturable commanded area}} \leq 0.2$$

$$\text{or} \quad \frac{\left[As.Ya + Ao \right]}{\left[r/d \right]} \leq 0.2$$

$$\text{or} \quad 0.2 \frac{Ir}{d} - As.Ya \geq Ao \qquad (8.3.1.1)$$

Where,

d = annual depth of irrigation.

(2) The annual water utilization factor should be more then equal to 80 % for a project with irrigation, i.e.,

$$\frac{\text{Total water utilization}}{\text{Total inflow}} \geq 0.8$$

$$\text{or} \quad \frac{\text{Total reservoir spill}}{\text{Total inflow}} \leq 0.2$$

$$\text{or} \sum Sp_t \leq 0.2 \sum I_t \qquad (8.3.1.2)$$

For a single purpose hydroelectric project utilization factor should be 90%.

(3) The benefit-cost ratio should be more than a given value, i.e., for an irrigation project.

$$\frac{\text{Gross annual benefit from project}}{\text{Total annual cost of project}} \geq 1.5 \qquad (8.3.1.3)$$

For a hydropower project this value is 1.3 and for a multipurpose project this value is 1.1. To obtain better estimates of the variables, the model was run for 12 time periods for one year only. The reservoir storage at the end of year was assumed to be the same as in the beginning of the year (in other words, no over-year carry-over storage).

For Badanala project, the end of the year month is May and the beginning of the year month is the month of June of the previous year. The Badanala project lies under normal hydrological conditions. In India under normal irrigation conditions a project is designed on the 75 % project dependability criteria. Therefore, monthly river flows of three different dependable yearly flows, i.e., 4 % (highest), 75 %, 96% (lowest), and also average monthly flows were considered. In this model the equations (3.2.1.1′), (3.2.1.2′), (3.2.1.3′), and (3.2.2.1) were used. The dead storage is 850 ha-m. The computation have been done for live capacity/storages because working with gross capacity/storages gave infeasible solutions. The model results are given in Table 8.3.1.1.

8.3.1.2 Testing of Max.Z_{nb} model results by simulation

The reservoir capacities obtained from model Max.Z_{nb} in (Table8.3.1.1) were simulated individually. It is found from the simulated results (Table 8.3.1.2) that for the 75 % project dependability the highest annual flow gave a large utilization factor of 91 % (i.e., for highest recorded flow) whereas, the lowest annual flow gave a small utilization factor of a bout 48 % (i.e., for lowest recorded flow). On the other hand most of the projects with irrigation in India are designed on the basis of at least about 80 % utilization factor. Keeping this is mind even 75 % dependable flow year giving a smaller utilization factor of 65 % may be left out. This brings out the fact of the preference of using the average annual flows in the model Max.Z_{nb}. However, model Max.Z_{nb} estimates (Table 8.3.1.1) smaller live capacity of reservoir, Ya (a live capacity of 5464 ha-m) as compared to the project design value of 6714 ha-m. Since average flows are used, the reservoir capacity obtained may be only to regulate average flows and is an estimate of short term flow variations, in order to maximize the net annual benefits. As ascertained from simulation the annual irrigation target, Ir, for 75 % project dependability for a live reservoir capacity of 5464 ha-m (gross capacity of 6314 ha-m) is 12740 ha-m against a value of 18054 ha-m as obtained from the model Max.Z_{nb} (Table 8.3.1.1). Whereas, the project provision of, Ir, is 14569 ha-m. Hence, it may be useful to use annual safe yield model Max.Z_{sy} to obtain a better estimate of, Ir.

8.3.1.3 Use of model Max.Z_{sy}

This model is used to revise and refine the annual irrigation target, Ir. It also calculates the annual firm demand which can be made available throughout the year at 100 % dependability. This model was run for 12 time periods for one year only, and monthly inflows were taken from 75 % dependable flow year (in India the annual irrigation target is generally taken as the 75 % dependable year's flow). The values of δ_t were taken as K_t values. The reservoir storage at the end of year, i.e., in the month of May, was assumed to be the same as in the beginning of the year, i.e., in the month of previous June (in other words, no over-year carry-over storage). The live reservoir capacity was taken from earlier model results of Max.Z_{nb}, and for this model for the average flows the value of Ya, was estimated as 5464 ha-m. No dead storage was considered and the estimate of Ir (which is termed as safe yield O^*), from annual safe yield model is 13445 ha-m (Table 8.3.1.3). This value is close to the value obtained from simulation 12740 ha-m for 75 % project dependability.

For finding the annual firm demand the lowest recorded annual flow was used in the model. The value of annual firm demand obtained was 8256 ha-m.

8.3.1.4 Use of model Max.Z_{tr}

The linear programming model Max.Z_{tr} was used to find the range of over-year carry-over storages available and required for highest and lowest observed flows respectively for a known reservoir capacity and annual targeted demand. The reservoir capacity was taken form model Max.Z_{nb} for average flow. The annual targeted demand was taken from model Max.Z_{sy}. This model requires many trials to find these storages as the discontinuous problem is to be solved for different initial and final storages. To study the maximum likely over-year carry-over storage available at the end of year the highest recorded flow was used which gave a value of carry-over storage available as 5120 ha-m. Similarly, the lowest recorded flow gave a value of 5875 ha-m as the maximum likely over-year carry-over storage required.

8.3.1.5 Use of model Min.Z_{gc}

In order to obtain the reservoir capacity to account for the long term variations in the storage requirements the model Min.Z_{gc} to minimize the reservoir capacity was used. The value of annual irrigation requirement was taken from the project provision of 14569 ha-m. This model was run for multi-bi-seasonal period (model Min.Z_{gcs}) and for multi-crop-seasonal period (model Min.Z_{gcc}). The models were run for 26 years of available flows.

(I) Multi-bi-seasonal model Min.Z_{gcs}

The model was run for two time periods in a year for 26 years. The first time period was monsoon (June to October) and second time period was non-monsoon (November to May). The result (Table 8.3.1.4) of bi-seasonal model indicates a value of gross capacity, Y, of 10795 ha-m as compared to the project provision of 7564 ha-m. The value of annual irrigation requirement was taken as project provision and was equal to 14569 ha-m.

(II) Multi-crop-seasonal model Min.Z_{gcc}

The model was run for three time periods in a year for 26 years. The first time period was Kharif (June to October), second time period was Rabi (November to February) and third time period was Til or Perennials (March to May). The result (Table 8.3.1.4) of this model gave a value of gross reservoir capacity, Y, of 11636 ha-m as compared with project provision of 7564 ha-m. The value of annual irrigation requirement was taken as project provision equal to 14569 ha-m.

8.3.1.6 Use of model Min.Z_{oc}

The over-year carry-over reservoir capacity was estimated using the model Min.Z_{oc} in order to account for the possible excess capacity required over and above the within the year capacity requirements to provide increased water yields. The model was run for one time period in a year for 26 years. The result (Table 8.3.1.5) of this model gave a value of over-year reservoir capacity, Y^{o} equal to 7691 ha-m. The value of annual irrigation requirement was taken as project provision equal to 14569 ha-m.

8.3.1.7 Testing of project provisions by simulation

It now becomes necessary to check the project provisions by simulation in order to compare them with the modeled results. It was done in three steps. Firstly, for the project provision of gross capacity of 7564 ha-m (live capacity of 6714 ha-m), how much annual irrigation is possible with 75 % project dependability was ascertained ? For this, the value of Ir, was found to be 13770 ha-m (Table 8.3.1.6) Secondly, for the project provision of annual irrigation of 14569 ha-m how much reservoir capacity is needed for a project dependability of 75% was also ascertained ? For this, the value of Y, 9550 ha-m (live capacity, Ya, of 8700 ha-m) was obtained. Thirdly, the project provisions of both reservoir capacity and annual irrigation target were simulated. It gave a project dependability of only 70 % which is below the desired project dependability of 75 %.

From simulation the values of over-year carry-over storages are S_0^o = 6371 ha-m, and S_{12}^o = 6730 ha-m, for existing reservoir capacity; and S_0^o = 3890 ha-m, and S_{12}^o = 8594 ha-m for proposed reservoir capacity.

The results show that in this project the provision of either the reservoir capacity is inadequate or the annual irrigation target is higher for this capacity. This shows that the project provisions are not properly designed for a project dependability of 75 % .

Table 8.3.1.1 Results of model Max.Z_{nb} for Badanala

Annual flow	Ya	Ir	Annual net benefit, in Rs.10^5
Highest	13604	41893	12147
Average	5464	18504	5388
75 % execeedence	4081	13557	3944
Lowest	1708	8178	2411

Note: All volumetric values are in ha-m.

Table 8.3.1.2 Simulation results-testing of Max.Z_{nb} model values for Badanala

Annual flow	Ya (Y)	Ir for 75 % project dependability	PW_{nb}, in Rs. 10^5	Utilization factor, in %
Highest	13604** (14454)	16010	65739	91
Average	5464** (6314)	12740	52289	71
75% exceedence	4081** (4931)	11630	47340	65
Lowest	1708** (2558)	8910	34804	48

Note: All volumetric values are in ha-m. ** Modeled.

Table 8.3.1.3 Results of model Max.Z_{sy} for Badanala

Ya	O^*
5464**	13445

Note: All volumetric values are in ha-m.
** Modeled.

Table 8.3.1.4 Results of model Min.Z_{gc} for Badanala

Model	Number of sub periods in a year	Ir	K'_t	Y
Min.Z_{gcs}	2 (Monsoon non-monsoon)	14569*	1.0314, 1.0190	10795
Min.Z_{gcc}	3 (Crop-seasons)	14569*	1.0314,1.0148,1.0247	11636

Note: All volumetric values are in ha-m.
* Given.

Table 8.3.1.5 Results of model Min.Z_{oc} for Badanala

Ir	K'_t	Y^o
14569*	1.0240	7691

Note: All volumetric values are in ha-m.
* Given.

Table 8.3.1.6 Simulation results-testing of project provisions for Badanala

Y (Ya)	Ir	% Project dependability (success)	Utilization factor, in %	PW_{nb}, in Rs. 10^5
7564* (6714)	13770	75	75	5 6294
9550+ (8700)	14569*	75	80	5 9728
7564* (6714)	14569*	70	78	5 8990

Note: All volumetric values are in ha-m.
* Given.
\+ The would be proposed reservoir capacity for desired project success for existing project annual targeted demand of 14569 ha-m.

8.3.2 Kalluvodduhalla Irrigation Project

Similar linear programming computations were done for Kalluvodduhalla irrigation reservoir as carried out for Badanala and the details are given below:
The monthly river flows are given in Table 7.2.1. The values of K_t and K'_t are given in Table 7.2.2.

This project is under drought prone area and in India under these conditions an irrigation project is designed on the basis of 50 % project dependability. Hence, for this project for model Max.Z_{nb} the 50% dependable year's flow was considered in place of 75 % dependable year's flow, along with highest and lowest yearly observed flows and average annual flow. The dead storage is 0.874 MCM. The model results are given in Table 8.3.2.1. Here, also the highest flow and the lowest flow give utilization factors of 93 % and 40 % respectively from simulation (Table 8.3.2.2), and are deviating very much from 80 % . Therefore, it further shows the importance of using the average annual flows in the model Max.Z_{nb}. The value of Ya from this model is 12.29 MCM which is very near and the value of Ir is 21.26 MCM which is very large as compared to the project provisions of 12.176 MCM and 17.549 MCM respectively. For Ya equal to 12.29 MCM (Y = 13.17 MCM) for 50 % project dependability the value of Ir from simulation works out to be 16.90 MCM. Then, the model Max.Z_{sy} was used to find the revised Ir (or O^* here). For this model 75% dependable year's flow was used as mentioned earlier. For Ya equal to 12.29 MCM the value of Ir (or O^*) was found to be 15.52 MCM (Table 8.3.2.3), which is also very close to the value of Ir 16.90 MCM obtained from simulation for 50 % project dependability and as that of the project provision of 17.549 MCM.

The annual firm demand using the lowest recorded annual flow with this model comes to be 6.21 MCM.

For this project using the model Max.Z_{tr} the maximum over-year carry-over storage available and required were 7.7 MCM and 4.7 MCM for highest and lowest observed flows respectively.

Using the models Min.Z_{gcs} and Min.Z_{gcc}, the values of Y, for Ir equal to project provision of17.549 MCM obtained were 18.67 and 19.35 MCM respectively (Table 8.3.2.4).The models were run for 30 years of available flows.

The value of Y^o equal to 11.87 MCM was obtained from Min.$Z_{oc}$for Ir equal to 17.549 TMC (Table 8.3.2.5). The model was run for 30 years.

Similarly, the project provisions were tested by simulation and the results are given in Table 8.3.2.6 This shows that project provisions are not properly designed.

From simulation the values of over-year carry-over storages are $S_0^o = 6.82$ MCM, and $S_{12}^o = 7.89$ MCM, for existing reservoir capacity; and $S_0^o = 4.10$ MCM, and $S_{12}^o = 10.10$ MCM for proposed reservoir capacity.

Table 8.3.2.1 Results of model Max.Z_{nb} for Kalluvodduhalla

Annual flow	Ya	Ir	Annual net benefit, in Rs. 10^6
Highest	21.94	35.25	86
Average	12.29	21.26	56
50 % execeedence	12.20	21.01	55
Lowest	4.06	6.05	13

Note: All volumetric values are in MCM.

Table8.3.2.2 Simulation results-testing of Max.Z_{nb} model values for Kalluvodduhalla

Annual flow	Ya (Y)	Ir for 50 % project dependability	PW_{nb}, in Rs. 10^6	Utilization factor, in %
Highest	21.94** (22.81)	20.95	382	93
Average	12.29** (13.17)	16.90	458	77
50% exceedence	12.20** (13.07)	16.85	456	77
Lowest	4.06** (4.93)	7.51	85	40

Note: All volumetric values are in MCM, ** Modeled.

Table 8.3.2.3 Results of model Max.Z_{sy} for Kalluvodduhalla

Ya	O*
12.29**	15.52

Note: All volumetric values are in MCM.
** Modeled.

Table 8.3.2.4 Results of model Min.Z_{gc} for Kalluvodduhalla

Model	Number of sub periods in a year	Ir	K'_t	Y
Min.Z_{gcs}	2 (Monsoon non-monsoon)	17.549*	1.0245, 1.0311	18.67
Min.Z_{gcc}	3 (Crop-seasons)	17.549*	1.0245,1.0231,1.0481	19.35

Note: All volumetric values are in MCM.
* Given.

Table 8.3.2.5 Results of model Min.Z_{oc} for Kalluvodduhalla

Ir	K'_t	Y^o
17.549*	1.0283	11.87

Note: All volumetric values are in MCM.
* Given.

Table 8.3.2.6 Simulation results-testing of project provisions for Kalluvodduhalla

Y (Ya)	Ir	% Project dependability (success)	Utilization factor, in %	PW_{nb}, in Rs. 10^6
12.176* (11.302)	16.220	50	72	431
14.500+ (13.626)	17.549*	50	79	482
12.176* (11.302)	17.549*	42	75	461

Note: All volumetric values are in MCM.
* Given.
\+ The would be proposed reservoir capacity of desired project success for existing project annual targeted demand of 17.549 MCM.

8.3.3 Computation for Bodhghat Hydroelectric Project

For single purpose hydropower project Bodhghat was chosen. The data used are given in Table 7.3.1 and 7.3.2 respectively. In India a hydroelectric project is designed on a project dependability of 90 %, therefore, for model Max.Z_{nb}, the 90 % dependable year's flow was considered along with highest and lowest recorded annual flows, and average annual flows. The flow duration curve at the project site is given in Figure 8.3.3.1. The runoff-the-river head available is 30 m. For hydropower the equations 3.2.1.1′, 3.2.1.2′, 3.2.1.3′ and 3.2.3.1 to 3.2.3.10 were used in the model. The dead storage is 740 MCM. The results of model Max.Z_{nb} are shown in Table 8.3.3.1, with similar outcomes after simulation (Table 8.3.3.2) and also as found for earlier

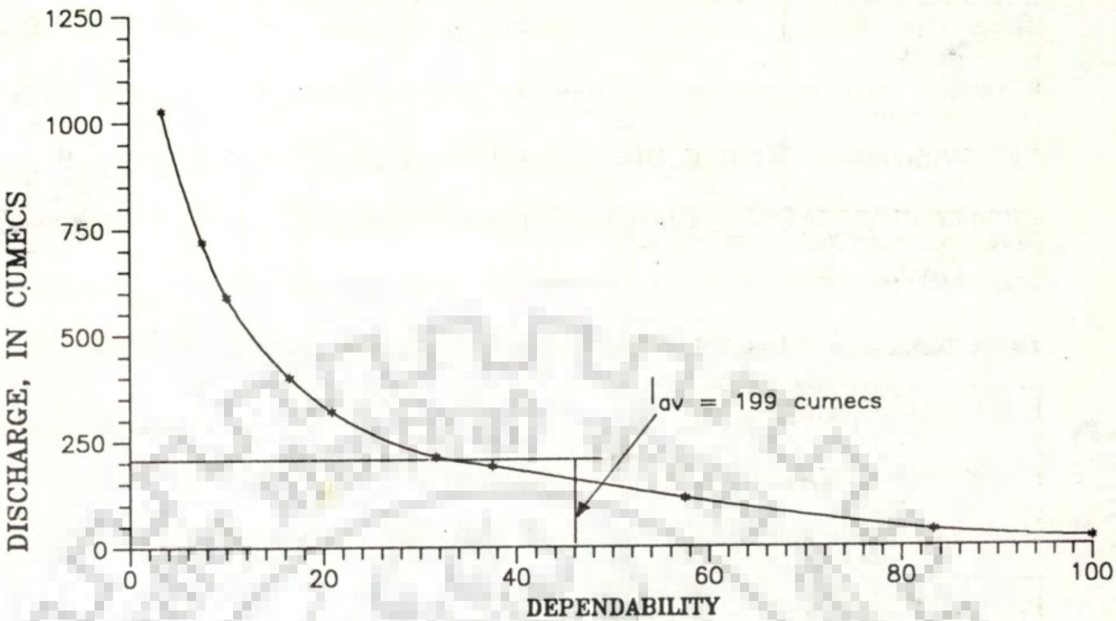


Fig. 8.3.3.1 Flow–duration curve for Bodhghat

projects (Tables 8.3.1.2 and 8.3.2.2) showing importance of the use of the average flows for finding reservoir capacity to account for short term flow variations. However, in India a single hydropower project is designed for about 90 % annual water utilization factor. Keeping this in mind the highest recorded annual flow gives a good estimate of the reservoir capacity. For model Max.Z_{sy}, the 90 % dependable year's flow and reservoir capacity of Ya of 2818 MCM from model Max.Z_{nb} obtained from average flows were used. The following two equations were used.

$$0.6H - O^{*}.C_f.Ha_t.e \leq 0 \qquad (8.3.3.1)$$

$$-C_f.Ha_t.\delta_t.O^{*}.h_t.e + E_t = 0 \qquad (8.3.3.2)$$

The values of δ_t were taken as the ratio of $(O_t/\Sigma O_t)$ from model Max.Z_{nb}. The results are shown in Table 8.3.3.3.

The annual firm demand using the lowest recorded annual flow with this model comes to 450520 MWhr.

For this project using the model Max.Z_{tr} the maximum over-year carry-over storage available and required were 2020 MCM and 3300 MCM for highest and lowest observed flows respectively.

For this project (hydropower) model Min.Z_{gcs} was only used for calculating Y for accounting long term flow variations. For water demands, the value of O^{*} from model Max.Z_{sy} was broken into monsoon and non-monsoon values as the energy demand in volumetric units are not generally available. The model was run for 10 years of data available. The results are given in Table 8.3.3.4. To calculate Y^{o} in model Min.Z_{oc}, 10 years flows were used and annual water demand was taken as O^{*}, the result is given in Table 8.3.3.5. The project provisions were tested as earlier and the results are given in Table 8.3.3.6.

From simulation the values of over-year carry-over storages are S_0^o = 1859 MCM, and S_{12}^o = 2471 MCM, for existing reservoir capacity; and S_0^o = 1493 MCM, and S_{12}^o = 2625 MCM for proposed reservoir capacity.

Table 8.3.3.1 Results of model Max.Z_{nb} for Bodhghat

Annual flow	Ya	H	E	$\bar{E}$	Annual net benefit, in Rs.10^6
Highest	4394	690	1491000	70000	2003
Average	2818	520	1119000	57000	1585
90 % exceedence	1868	370	807000	40000	1173
Lowest	1211	280	605000	29000	912

Note: All volumetric values are in MCM, H in MW, E and $\bar{E}$ are in MWhr.

Table 8.3.3.2 Simulation results-testing of Max.Z_{nb} model values for Bodhghat

Annual flow	Ya (Y)	H	E for 90 % project dependability	$\bar{E}$	PW_{nb}, in Rs.10^6	Utilization factor, in %
Highest	4394** (5134)	690	1139100	93969	10241	95
Average	2818** (3558)	520	954100	165430	9094	86
90 % exceedence	1868** (2608)	370	654300	33933	7580	63
Lowest	1211** (1951)	280	448100	39040	6109	48

Note: All volumetric values are in MCM, H in MW, E and $\bar{E}$ are in MWhr.
** Modeled.

Table 8.3.3.3 Results of model Max.Z_{sy} for Bodhghat

Ya	O*	E
2818**	3802	881899

Note: All volumetric values are in MCM and E in MWhr,
** Modeled.

Table 8.3.3.4 Results of model Min.Z_{gcs} for Bodhghat

Number of sub periods in a year	O^*	K'_t	Y
2 (Monsoon and non-monsoon)	3802^{**}	1.00323, 1.00600	3276

Note: All volumetric values are in MCM.
** Modeled.

Table 8.3.3.5 Results of model Min.Z_{oc} for Bodhghat

Ir	K'_t	Y^o
3802^{**}	1.00458	1673

Note: All volumetric values are in MCM.
** Modeled.

Table 8.3.3.6 Simulation results-testing of project provisions for Bodhghat

Y (Ya)	H	E	$\bar{E}$	% Project dependability (success)	Utilization factor, in %	PW_{nb}, in Rs. 10^6
4458^* (3718)	500^*	1120196	33590	90	94	10956
4565^+ (3825)	500^*	1139000^*	30530	90	92	11107
4458^* (3718)	500^*	1139000^*	30090	80	92	10825

Note: All volumetric values are in MCM, H in MW, E and $\bar{E}$ are in MWhr.
* Given.
+ The would be proposed reservoir capacity for desired project success for existing annual targeted demand of 1139000 MWhr.

8.3.4 Computation for Bargi Multipurpose Project

For multipurpose project Bargi project was analyzed. The data used are given in Table 7.4.1 and 7.4.2 respectively. The flow-duration curve at site is given in Figure 8.3.4.1. The dead storage is 0.742 TMC. For model Max.Z_{nb} only average flows were considered because of irrigation. The equations 3.2.1.1′, 3.2.1.2′, 3.2.1.3′, 3.2.2.1 and 3.2.3.1 to 3.2.3.10 were used.

In order to consider the flood control storage space in a multipurpose reservoir it is desirable that some over-year carry-over storage be considered as available at the beginning of a year so that most critical conditions may be available at the time when a reservoir is likely to attain high levels during its filling period. As found from simulation studies for some of the projects in India that about 10-25 % of the live reservoir capacity is available as over-year carry-over storage on an average basis. Keeping this is mind about 10-25 % of the reservoir capacity was taken as the available over-year carry-over reservoir storage at the beginning of a year in model Max.Z_{nb}. Similarly, the expected flood control requirements in this reservoir as per project reports was in the range of 0.2 TMC and 0.34 TMC. Also the flood months are July and August. From the above two considerations following three limits were put on reservoir storages, i.e.,

$S_0 \geq$ (A given over-year carry-over storage) at the beginning a year (8.3.4.1)

$S_2 \leq (Ya - Yf_2)$ for reservoir storage at the end of August (8.3.4.2)

$Ya - Ymax_2 = Yf_2$ for flood storage at the end of August (8.3.4.3)

Where,

Yf_2 = flood storage during the time period t = 2.

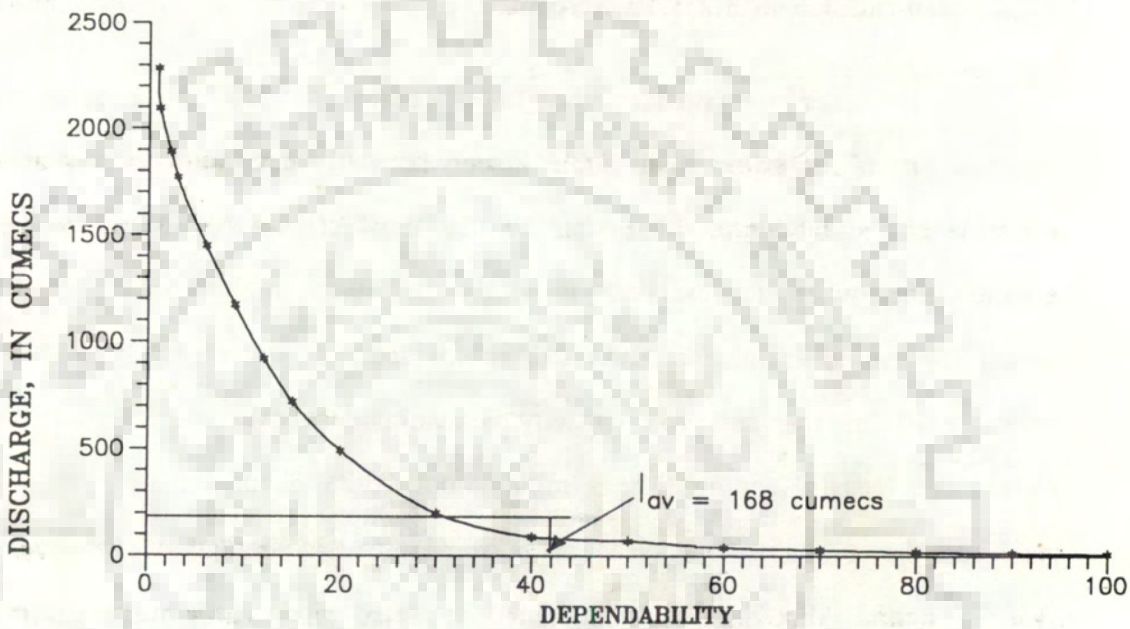


Fig. 8.3.4.1 Flow–duration curve for Bargi

The values of over-year carry-over storage, S_0, and Yf_2 were changed in the above ranges and the optimal values in terms of objective function were obtained. The results are given in Table 8.3.4.1. The testing of model Max.Z_{nb} by simulation are given in Table 8.3.4.2. For model Max.Z_{sy} 75 % dependable year's flow was used. The values of δ_t were taken as K_t values and the results are given in Table 8.3.4.3.
The annual firm demand for irrigation and hydropower using lowest recorded annual flow with this model comes to 2.5 TMC and 264000 MWhr respectively.

For this project using the model Max.Z_{tr} maximum over-year carry-over storage available and required were 2.5 TMC and 3 TMC for highest and lowest recorded flows respectively.

The results of models Min.Z_{gcs} and Min.Z_{gcc} are given in Table 8.3.4.4. The result of model Min.Z_{oc} is given 8.3.4.5.

The results of testing project provisions by simulation are given in Table 8.3.4.6. From simulation the values of over-year carry-over storages are S_0^o = 1.96 TMC, and S_{12}^o = 1.70 TMC, for existing reservoir capacity; and S_0^o = 1.20 TMC, and S_{12}^o = 2.42 TMC for proposed reservoir capacity.

Table 8.3.4.1 Results of model Max.Z_{nb} for Bargi

Annual flow	Ya	Ir	WS	H	E	$\bar{E}$	Annual net benefit, in Rs. 10^7
Average	3.37	3.71	0.2*	100	426000	43200	254

Note: All volumetric values are in TMC, H in MW E and $\bar{E}$ are in MWhr.
* Given

Table 8.3.4.2 Simulation results-testing of Max.Z_{nb} model values for Bargi

Annual flow	Ya (Y)	WS	Ir	H	E	$\overline{E}$	PW_{nb}, in Rs. 10^7	Utilization factor, in %
Average	3.37** (4.112)	0.2*	3.791	100	310000	161219	3284	77

Note: All volumetric values are in TMC, H in MW E and $\overline{E}$ are in MWhr.
** Modeled.
* Given
Ir and E for 70 % , and 90 % project dependabilities respectively.

Table 8.3.4.3 Results of model Max.Z_{sy} for Bargi

Ya	O*	WS	E
3.37**	3.77	0.2	385000

Note: All volumetric values are in TMC and E in MWhr.
** Modeled.

Table 8.3.4.4 Results of model Min.Z_{gc} for Bargi

Model	Number of sub periods in a year	Ir	K'_t	Y
Min.Z_{gcs}	2 (Monsoon non-monsoon)	3.947*	1.0351 1.0226	6.30
Min.Z_{gcc}	3 (crop-seasons)	3.947*	1.0351 1.0226 1.0189	6.65

Note: All volumetric values are in TMC.
* Given.

Table 8.3.4.5 Results of model Min.Z_{oc} for Bargi

Ir	K'_t	Y^o
3.947*	1.0297	4.06

Note: All volumetric values are in TMC.
* Given.

Table 8.3.4.6 Simulation results-testing of project provisions for Bargi

Y (Ya)	WS	Ir	H	E	$\overline{E}$	% Project dependability (success) for			Utilization factor, in %	PW_{nb}, in Rs. 10^7
						WS	Ir	E		
3.932*(3.19)	0.2*	3.947*	90*	329000	147974	74	65	65	73	3203
3.932*(3.19)	0.2*	3.947*	90*	259000	207568	74	70	70	71	3258
3.932*(3.19)	0.2*	3.681	90*	329000*	133907	83	70	74	70	3211
4.310(3.568)	0.2*	3.947*	90*	329000*	157472	78	74	74	80	3272

Note: All volumetric values are in TMC, H in MW E and $\overline{E}$ are in MWhr.

* Given.

\+ The would be proposed reservoir capacity for desired project success for existing annual targeted demand of 3.947 TMC and 276000 MWhr.

8.3.5 Use of Concept of Probability Flows in Model Max.Z_{nb}

The model Max.Z_{nb} used average flows to find initial estimates of project size and project targets, specially the reservoir capacity. Further, simulation studies were carried out at different stages to ascertain a desired project dependability. It is found from simulation, that for the reservoir capacity obtained from model Max.Z_{nb}, and to obtain the annual project target of a given project dependability (success), the average annual reservoir spill was more and the utilization factor was quite less than the desired. Hence, a reservoir capacity greater than to accommodate average flows is required to reduce the reservoir spills, increase the utilization factor and take into account the long term variations in the river inflows. This is possible only by storing (regulating) an annual flow of a value higher than the average annual flow. Since the average flow has a probability of 50 % occurrence, therefore, we can set the annual inflow equal to any desired probability of less than equal to 50 % occurrence depending upon type of project. Then, the reservoir capacity should be such that it should be able to store the annual flow as high as possible and which has a desired probability or chances of occurrence, such that a portion of the annual flow less than this occurrence would be spilled.

Therefore, the reliability of the model solution will only depend on the correct selection of inflow data. It is a fact that monthly and annual runoff are additive in nature. The variables for which the causative factors are additive in nature, will follow normal distribution.

Hence, assuming that the set of annual inflow data will follow normal distribution, the annual inflow which has a given probability of less than equal to 50 % occurrence can be evaluated. This is in relation to the concept of a desirable project success (dependability) in case of simulation studies.

From the standard table of normal distribution, the inflow Q_T, having probability of given occurrence is given by

$$Q_T = \mu + K_T.\sigma.$$

Where,

Q_T = inflow of probability of given occurrence,

μ = mean,

K_T = frequency factor, and

σ = standard deviation.

The annual inflow having probability of a given occurrence is given in Table 8.3.5.1 with reference to various project dependabilities depending upon the type of project as per project practices in India.

Table 8.3.5.1 Annual inflow having probability of a given occurrence

S.N	Type of project	Project dependability in terms of % success	Probability of given occurrence in %	Annual inflow ($\mu + K_T.\sigma$)
1	Irrigation project under normal conditions	75	100 - 75 = 25	$\mu + 0.675\sigma$
2	Irrigation project under drought conditions	50	100 - 50 = 50	μ
3	Hydropower project	90	100 - 90 = 10	$\mu + 1.285\sigma$
4	Multipurpose project	70	100 - 70 = 30	$\mu + 0.525\sigma$

With this thinking a better estimate of reservoir capacity may be obtained by using an annual flow of, $\mu + K_T.\sigma$, in the model Max. Z_{nb}.

The probability annual flows of Table 8.3.5.1 were used in the model Max.Z_{nb} for each reservoir. For finding monthly flows from the annual flow, the annual flow was distributed in the ratio of average monthly flows. The model was run for one year only for monthly periods and the results are given in Table 8.3.5.2. The results of this model were tested by simulation and the same are given in Table 8.3.5.3.

8.3.6 Computation Time

The computation time for each model is given in Table 8.3.6.

Table 8.3.6 Computation time

Model	Computation time in seconds
Max.Z_{nb}	0.2
Max.Z_{sy}	0.1
Max.Z_{tr}	0.1
Min.Z_{oc}	0.9
Min.Z_{gcs}	1.4
Min.Z_{gcc}	3.9

Table 8.3.5.2 Results of model Max.Z_{nb} for annual flow of desired probability of a given occurrence

S.N.	Type of project	Project dependability (probability of given occurrence for inflow)	μ	σ	K_T	$\mu+K_T\sigma$	Ya	Ir	H	E	$\bar{E}$	Z_{nb}
1	Badanala (Normal irrigation)	75 (25)	19220	7378	0.675	24205	6880	23302	-	-	-	6786
2	Kalluvoddu-halla (Drought irrigation)	50 (50)	23.25	7.62	0.0	23.25	12.20	21.26	-	-	-	67.28
3	Bodhghat (Hydropower)	90 (10)	5320	1474	1.286	7221	3818	-	700	1516000	74000	2147
4	Bargi (Multi-purpose)	70 (30)	5.817	2.85	0.525	7.313	3.820	4.160	120	507160	51680	303

Note: All volumetric values for Babanala at Sl. No.1 are in ha-m, Z_{nb} in Rs.10^5.

All volumetric values for Kalluvodduhalla at Sl. No.2 are in MCM, Z_{nb} in Rs.10^6.

All volumetric values for Bodhghat at Sl. No.3 are in MCM, H in MW, E and $\bar{E}$ are in MWhr, Z_{nb} in Rs.10^6.

All volumetric values for Bargi at Sl. No.4 in TMC, H in MW, E and $\bar{E}$ are in MWhr, Z_{nb} in Rs.10^7.

Table 8.3.5.3 Simulation results-testing of model Max.Z_{nb} results for desired probability annual flows

S.N.	Project type	Ya (Y)	Ir	H	E	E	% Project dependability			Utilization factor, in %	PW_{nb}
							WS	Ir	E		
1	Normal irrigation (Badanala project)	6800** (7730)	13910	-	-	-	-	75	-	77	56829
2	Drought irrigation (Kalluvoduhalla project)	12.29** (13.17)	18.90	-	-	-	-	50	-	82	514
3	Hydropower (Bodhghat project)	3818** (4558)	-	700	1134300	130777	-	.	90	91	10603
4	Multipurpose (Bargi project)	3.820** (4.562)	4.250	120	330000	181685	78	70	74	80	3559

Note: For units see Table 8.3.5.2.

** Modeled

8.4.0 PLANNING FOR OVER-YEAR CARRY-OVER STORAGES FOR RESERVOIR OPERATION

The computations for reservoir operation will be carried out in Chapter-10. Since, the reservoirs are already existing, two cases, one for the existing reservoir capacity and another for the reservoir capacity proposed here are to be considered for reservoir operation. The estimation of the over-year carry-over storages is carried out for these two cases using the linear programming models Max.Z_{sy} and Max.Z_{tr} and the dynamic programming model.

8.4.1 Use of Model Max.Z_{sy} for Existing Reservoir Capacity

The linear programming model Max.Z_{sy} was used to revise and refine the annual target for a known reservoir capacity. This model was run for 12 time periods for one year only.

8.4.1.1 Computation for Badanala

The monthly inflows were taken from 75 % dependable year's flow. The estimate of Ir which was termed as the annual safe targeted yield O^* is 13445 ha-m from the reservoir of capacity 7564 ha-m.

8.4.1.2 Computation for Kalluvodduhalla

The monthly inflows were taken from 75 % dependable year's flow. The estimate of annual safe targeted yield O^* is 15.41 MCM from the reservoir of capacity 12.176 MCM.

8.4.1.3 Computation for Bodhghat

The monthly inflows were taken from 90 % dependable year's flow and the annual safe targeted yield is 3802 MCM and corresponding annual safe targeted energy is 881899 MWhr. The reservoir capacity was 4458 MCM.

8.4.1.4 Computation for Bargi

The monthly inflows were taken from 70 % dependable year's flow. The estimate of annual safe targeted yield O^* is 3.77 TMC and annual safe energy is 385000 MWhr. The reservoir capacity was 3.932 TMC.

8.4.2 Use of Model Max.Z_{tr} for Existing Reservoir Capacity

The linear programming model Max.Z_{tr} was used to find the ranges of over-year carry-over storages available and required for lowest and highest probability flows respectively for a known reservoir capacity and annual targeted demand. The annual targeted demand was taken from the annual safe model (Max.Z_{sy}). This model requires many trials to find these storages as the discontinuous problem is to be solved for different initial and final storages.

8.4.2.1 Computation for Badanala

To study the maximum likely over-year carry-over storage available at the end of year the 5 % probability flow was used which gave a value of carry-over storage available as 61 10^2ha-m. Similarly, 95 % probability flow gave a value of 54 10^2ha-m as the maximum likely over-year carry-over storage required. The value of Y was 75.64 10^2ha-m and of Ir was 134.45 10^2ha-m.

8.4.2.2 Computation for Kalluvodduhalla

For this project the maximum over-year carry-over storage available and required were 62 10^{-1}MCM and 50 10^{-1}MCM for 5 % and 95 % probability flows respectively. The value of Y was 121.76 10^{-1}MCM and of Ir was 155.20 10^{-1}MCM.

8.4.2.3 Computation for Bodhghat

For this project the maximum over-year carry-over storage available and required were 32 10^2MCM and 31 10^2MCM for 5% and 95 % probability flows respectively. The value of Y was 44.58 10^2MCM. The total release was taken from model Max.Z_{sy} equal to 3802 MCM.

8.4.2.4 Computation for Bargi

For this project the maximum over-year carry-over storage available and required were 21 10^{-1}TMC and 32 10^{-1}TMC for 5 % and 95 % probability flows respectively. The value of Y was 39.32 10^{-1}TMC and of Ir was 3.77 TMC.

8.4.3 Dynamic Programming Computation for Existing Reservoir Capacity

The dynamic programming model was run on monthly basis to determine various over-year carry-over storages using the backward multistage approach. The period of analysis was one year only. The reservoir storage at the end of a year is not same as at the beginning of same year. This model is called discontinuous model, (S_0 is not equal to S_{12}). Different probability flows were used in the model, i.e., from lowest probability flows to highest probability flows for finding over-year carry-over storage available and over-year carry-over storage required. The model was run by considering evaporation loss and loss in benefits due to deficits.

8.4.3.1 Carry-over storages by dynamic programming for Badanala

Knowing the ranges of carry-over storages from the model Max.Z_{tr}, the dynamic programming discontinuous model was then used to find over-year carry-over storages available and required. The live reservoir capacity, the dead storage and annual irrigation target were taken equal to the project provision of 67 10^2ha-m, 9 10^2ha-m and 146 10^2ha-m. Different probability flows were used, i.e., 5 %, 10 %, 25%, 30 %, 50 %, 60 %, and 65 % to find carry-over storage available, see Table 8.4.1. In the runs various trials were made by changing final storage (carry-over storage available) within the range of 0 to 60 10^2ha-m with increments of 1 10^2ha-m. The results are given in Table 8.4.1. For finding the carry-over storage required, 80 %, 85%, 88 %, 89 %, 90 %, 92 %, and 93 %, probability flows were used. The carry-over storage required for the above probability flows are given in Table 8.4.1.

8.4.3.2 Testing of carry-over storages by simulation for Badanala

These results were tested with simulation model. The results of dynamic programming are very close to the results of simulation. Simulation gave maximum available carry-over storage of 67.30 10^2ha-m where as dynamic programming gave 69 10^2ha-m. For case of carry-over storage required simulation gave a maximum value of 63.71 10^2ha-m and dynamic programming gave 54 10^2ha-m. Dynamic programming does not require many trials as all the possibilities of carry-over storages can be determined in one run.

8.4.3.3 Carry-over storages by dynamic programming for Kalluvodduhalla

Similar calculations were done for Kalluvodduhalla reservoir for finding various over-year carry-over storages using dynamic programming. The results are given in Table 8.4.2. The increments were 1 10^{-1}MCM.

8.4.3.4 Testing of carry-over storages by simulation for Kalluvodduhalla

From simulation results the maximum over-year carry-over storages available was equal 78.90 10^{-1}MCM and the required was 68.20 10^{-1}MCM.

8.4.3.5 Carry-over storages by dynamic programming for Bodhghat

The results of various carry-over storages are given in Table 8.4.3. The increments were 1 10^2MCM.

8.4.3.6 Testing of carry-over storages by simulation for Bodhghat

From simulation results the maximum over-year carry-over storage available was equal 24.71 10^2MCM and the required was 18.59 10^2MCM.

8.4.3.7 Carry-over storages by dynamic programming for Bargi

The results of various carry-over storages are given in Table 8.4.4. The increments were 1 10^{-1}TMC.

8.4.3.8 Testing of carry-over storages by simulation for Bargi

From simulation results the maximum over-year carry-over storage available was equal 17.0 10^{-1}TMC and the required was 19.6 10^{-1}TMC.

8.4.4 Use of Model Max.Z_{sy} for Proposed Reservoir Capacity

The annual safe targeted yields from various reservoirs are given in Table 8.4.5.

8.4.5 Use of Model Max.Z_{tr} for Proposed Reservoir Capacity

The values of maximum likely over-year carry-over storages available and required are given in Table 8.4.6 for different reservoirs.

8.4.6 Carry-over Storages by Dynamic Programming for Proposed Reservoir Capacity

The values of likely available and required over-year carry-over storages are given in Table 8.4.7 to 8.4.10 for reservoirs Badanala, Kalluvodduhalla, Bodhghat, and Bargi respectively.

8.4.7 Testing of Carry-over Storages by Simulation for Proposed Reservoir Capacity

The results of simulation are given in Table 8.4.11.

Table 8.4.1 Dynamic programming results for over-year carry-over storages for existing reservoir capacity for Badanala

Probability in %	Monsoon flow 10^2ha-m	Non-monsoon flow 10^2ha-m	Over-year carry-over storage available 10^2ha-m	Over-year carry-over storage required 10^2ha-m
5	274	40	60	-
10	251	36	59	-
25	212	30	55	-
30	202	29	53	-
50	186	24	48	-
60	152	22	42	-
65	143	21	34	-
80	114	16	-	5
85	101	15	-	10
88	92	14	-	11
89	89	13.5	-	15
90	85	13	-	20
91	81	12	-	27
92	77	11	-	33
93	73	10	-	45

Existing reservoir capacity Ya = 67 10^2ha-m,

Ir = 135 10^2ha-m.

Table 8.4.2 Dynamic programming results for over-year carry-over storages for existing reservoir capacity for Kalluvodduhalla

Probability in %	Monsoon flow 10^{-1}MCM	Non-monsoom flow 10^{-1}MCM	Over-year carry-over storage available 10^{-1}MCM	Over-year carry-over storage required 10^{-1}MCM
5	251	107	58	—
25	202	82	56	—
40	179	73	54	—
60	152	61	52	—
65	145	58	50	—
70	137	56	48	—
75	129	52	40	—
92	89	36	—	5
94	109	33	—	7
95	76	31	—	10
96	71	28	—	15
97	63	26	—	25
98	54	22	—	40

Existing reservoir capacity Ya = 112 10^{-1}MCM,

Ir = 155 10^{-1}MCM.

Table 8.4.3 Dynamic programming results for over-year carry-over storages for existing reservoir capacity for Bodhghat

Probability in %	Monsoon flow 10^2MCM	Non-Monsoon flow 10^2MCM	Over-year carry-over storage available 10^2MCM	Over-year carry-over storage required 10^2MCM
5	42	35	11	—
10	39	33	9	—
25	34	29	8	—
50	27	24	6	—
60	29	22	4	—
70	25	21	2	—
91	18	15	—	1
93	17.5	14.5	—	2
94	16	14	—	3
95	15	13	—	5
96	14	12	—	6
97	13	11	—	8

Existing reservoir capacity Ya = 37 10^2MCM,

H = 500 MW, and E = 881899 MWhr.

Table 8.4.4 Dynamic programming results for over-year carry-over storages for existing reservoir capacity reservoir for Bargi

Probability in %	Monsoon flow 10^{-1}TMC	Non-Monsoon flow 10^{-1}TMC	Over-year carry-over storage available 10^{-1}TMC	Over-year carry-over storage required 10^{-1}TMC
5	90	15	14	–
25	66	12	12	–
40	52	11	10	–
50	50	8	9	–
60	44	7	7	–
70	37	6	6	–
82	28	5	–	5
84	26	4	–	8
86	24	3	–	10
88	22	2.5	–	12
90	21	2	–	14
92	16	1.5	–	16
95	9	1	–	19

Existing reservoir capacity Ya = 32 10^{-1}TMC,

Ir = 35 10^{-1}TMC, H = 90 MW, and E = 329000 MWhr.

Table 8.4.5 Results of model Max.Z_{sy} for Proposed reservoir capacity

Name of Project	Reservoir capcity	% Project dependability	Ir or O*	Annual safe energy
Badanala	9550	75 %	13445	–
Kalluvodduhalla	14.50	75 %	16.28	–
Bodhghat	4565	90 %	3802	881899
Bargi	4.31	70 %	3.77	385000

Note: Units for Badanala, Kalluvodduhalla, Bodhghat and Bargi are ha-m, MCM, MCM and TMC respectively and for annual safe energy are in MWhr.

Table 8.4.6 Results of model Max.Z_{tr} for proposed reservoir capacity

Name of Project	Reservoir capacity, Y	Annual safe yield or (O*)	Flow Probability, in %	Over-year carry-over storage available	Over-year carry-over storage required
Badanala	95.50	134.45*	5	77.00	–
			95	—	44.60
Kalluvo-dduhalla	145.0	152.20*	5	89.00	–
			95	—	38.00
Bodhghat	45.65	38.02*	5	35.20	–
			95	—	30.00
Bargi	48.20	35.20*	5	33.20	–
			95	—	18.00

Note: Units for Badanala, Kalluvodduhalla, Bodhghat and Bargi are 10^2ha-m, 10^{-1}MCM, 10^2MCM and 10^{-1}TMC respectively.

* From model Max.Z_{sy}.

Table 8.4.7 Dynamic programming results for over-year carry-over storages for proposed reservoir capacity for Badanala

Probability in %	Monsoon flow 10^2ha-m	Non-monsoon flow 10^2ha-m	Over-year carry-over storage available 10^2ha-m	Over-year carry-over storage required 10^2ha-m
5	274	40	72	-
10	251	36	68	-
25	212	30	62	-
30	202	29	57	-
50	186	24	52	-
60	152	22	47	-
65	143	21	40	-
89	89	13.5	-	21
90	86	13	-	23
91	82	12	-	29
92	77	11	-	30
93	73	10	-	40

Proposed reservoir capacity Ya = 87 10^2ha-m,

Ir = 135 10^2ha-m.

Table 8.4.8 Dynamic programming results for over-year carry-over storages for proposed reservoir capacity for Kalluvodduhalla

Probability in %	Monsoon flow 10^{-1}MCM	Non-monsoom flow 10^{-1}MCM	Over-year carry-over storage available 10^{-1}MCM	Over-year carry-over storage required 10^{-1}MCM
5	251	107	76	–
25	202	82	70	–
40	179	73	65	–
60	152	61	62	–
65	145	58	58	–
70	137	56	55	–
75	129	52	50	–
95	76	31	—	4
96	71	28	—	6
97	63	26	—	14
98	54	22	—	19

Proposed reservoir capacity Ya = 136 10^{-1}MCM,

Ir = 155 10^{-1}MCM.

Table 8.4.9 Dynamic programming results for over-year carry-over storages for proposed reservoir capacity for Bodhghat

Probability in %	Monsoon flow 10^2MCM	Non-Monsoon flow 10^2MCM	Over-year carry-over storage available 10^2MCM	Over-year carry-over storage required 10^2MCM
5	42	35	18	–
10	39	33	17	–
25	34	29	15	–
50	29	24	13	–
60	27	22	12	–
70	25	21	9	–
91	18	15	–	1
93	17.5	14.5	–	2
94	16	14	–	3
95	15	13	–	5
96	14	12	–	6
97	13	11	–	7

Proposed reservoir capacity Ya = 39 10^2MCM,

H = 500 MW, and E = 881899 MWhr.

Table 8.4.10 Dynamic programming results for over-year carry-over storages for proposed reservoir capacity for Bargi

Probability in %	Monsoon flow 10^{-1}TMC	Non-Monsoon flow 10^{-1}TMC	Over-year carry-over storage available 10^{-1}TMC	Over-year carry-over storage required 10^{-1}TMC
5	90	15	21	–
25	66	12	17	–
40	52	11	14	–
50	50	8	12	–
60	44	7	10	–
70	37	6	8	–
82	28	5	–	1
84	26	4	–	2
86	24	3	–	6
88	22	2.5	–	8
90	21	2	–	9
82	16	1.5	–	10
95	9	1	–	11

Proposed reservoir capacity Ya = 36 10^{-1}TMC,

Ir = 35 10^{-1}TMC, H = 90 MW, and E = 329000 MWhr.

Table 8.4.11 Results of testing carry-over storage by simulation for proposed reservoir capacity

Name of Project	S_0^o	S_{12}^o
Badanala	3890	8594
Kalluvodduhalla	4.10	10.10
Bodhghat	1493	2625
Bargi	1.20	2.24

Units for Badanala, Kalluvodduhalla, Bodhghat and Bargi are ha-m, MCM, MCM and TMC.

8.4.8 Computation Time

The computation time for dynamic programming is given in Table 8.4.12.

Table 8.4.12 Computation time

Model	Computation time in seconds
D.P.	0.4

CHAPTER 9

RESERVOIR OPERATION

Chapter-9

RESERVOIR OPERATION

9.1.0 RESERVOIR OPERATION PROBLEM

The efficient use of water resources requires not only judicious design but also proper management after construction. Once a reservoir comes into being, the benefits depend, to a large extent, upon how well it is managed. The conservation demands are best served when the reservoir is full at the end of filling period. The flood control purpose, on the other hand, requires empty storage space so that the incoming floods get absorbed and moderated to permissible limits. The conflict between the storage space requirements is resolved through proper operation of reservoirs.

A reservoir operation policy specifies the releases as a function of the current state of the reservoir, time, the size of current and near-term demands and the likely inflows. The releases must be in conformity with the stated objectives. A full reservoir is needed to maximize returns from conservation uses while an empty reservoir gives maximum benefits from flood control. The operation policy should optimally resolve the conflicts among the various purposes.

9.1.1 Characteristics and Requirements of Water Uses

The complexity of the problem of reservoir operation depends upon the extent to which the various purposes which a reservoir is supposed to serve are compatible. The characteristics of various conservation requirements from a reservoir are briefly described below:

(a) Irrigation

The irrigation requirements are seasonal in nature and the variation largely depends upon the cropping pattern in the command area. The irrigation demands are consumptive in nature and a small fraction of the water supplied for irrigation is available to the system as return flow. These requirements have direct correlation with rainfall in the command area.

(b) Hydroelectric Power

The hydroelectric power demands usually vary seasonally and to a lesser extent, daily and hourly too. The degree of fluctuation depends upon the type of load being served, viz., industrial, municipal and agricultural. The hydroelectric power demand is nonconsumptive use of water.

(c) Municipal and Industrial Water Supply

Generally, the water requirements for municipal purposes are quite constant throughout the year, more so when compared with the requirements for irrigation and hydroelectric power. The water requirements increase from year to year due to growth and expansion. The seasonal demand peak is observed in summer. The supply system for such purposes is designed for very high level of reliability.

(d) Miscellaneous

Sometimes, storage reservoirs are designed to make a river-reach navigable by maintaining sufficient depth of flow. Navigation demands show marked seasonal variation and depend on the type and volume of traffic. From environmental considerations, it is also sometimes desirable to maintain some minimum flow in the downstream channel.

9.1.2 Conflicts in Reservoir Operation

While operating a reservoir which serves for more than one purpose, conflicts arise among the demands of various purposes. The conflicts that arise in a multipurpose reservoir are (a) conflict in space, (b) conflict in time, and (c) conflict in discharge.

Conflicts in space occur when a reservoir is required to satisfy divergent purposes like water conservation and flood control. The temporal conflicts occur when the use pattern of water varies with purpose and release for one purpose does not match with other purpose. Conflicts for discharge are experienced in reservoirs serving for consumptive use and hydropower generation such that release for the two purposes may vary considerably within a day.

9.2.0 OPERATION OF RESERVOIR USING RULE CURVES

The reservoirs are frequently operated using the rule curves. A rule curve or a rule level specifies the storage or empty space to be maintained in a reservoir during different times of the year. Here the assumption is that a reservoir can best satisfy its purposes if the storage specified by the rule curve are maintained at different times. The rule curve as such does not give the amount of water to be released from the reservoir. The amount will depend upon the inflows to the reservoir, the storage space available in the reservoir and the demands from the reservoir.

The rule curve is generally derived by operation studies using historic or generated flows. Often, due to various reasons, viz., low inflows, minimum requirements for demands etc., it is not possible to maintain the reservoir levels according to the rule curve. However, it is possible to return to the rule levels in several ways. Some possibilities are; (a) return to the rule curve by curtailing the release beyond the minimum required if the deviation is the negative; (b) make release more than the demand but less than safe carrying capacity, if the deviation is positive. The operation of a reservoir by strictly following a single rule curve becomes quite rigid. Often, to provide flexibility in operation, different rule curves (multi-rule curves) may be followed in different circumstances.

9.3.0 METHODOLOGY ADOPTED IN THE PRESENT STUDY

It is proposed to carry out reservoir operation using multi-rule curves based on the actual monsoon flows and the state of the reservoir at the end of monsoon period. Three conditions have been visualized, i.e, Case-I: when high monsoon flows are above normal monsoon flows; Case-II: when high monsoon flows are below normal monsoon flows; and Case-III: low monsoon flows. In Cases-I and II a reservoir will be full and in Case-III a reservoir will not be full at the end of monsoon period. Also, in Cases-I and II it will be possible to meet the annual targeted demands. The average monsoon flows have been taken as the normal average monsoon flows.

In Case-I during non-monsoon periods exceptionally good inflows are expected and the total water availability including reservoir storage at any time is likely to exceed the water demands in this period. Hence this would provide a reasonable amount of over-year carry-over storage in a reservoir at the end of the non-monsoon period. This amount of available over-year carry-over storage at the end of non-monsoon period can be estimated for various annual flows for known reservoir capacity and annual targeted demand during planning stages using suitable models, i.e., the linear programming model Max.Z_{tr} and the dynamic programming model given in Chapters-3 and 4 respectively.

Use of this information can be made to develop a suitable relationship between the monsoon flows and the corresponding over-year carry-over storage which can be made available in a reservoir at the end of non-monsoon period. This new concept of knowing in advance by the end of monsoon period after reservoir operation is actually carried out in monsoon period about the amount of over-year carry-over storage which can be made available at the end of the year (non-monsoon period) is introduced for Case-I. This carry-over storage could be maintained as a minimum pool throughout during non-monsoon period. These rule curves may look like as shown in Figure 9.1.

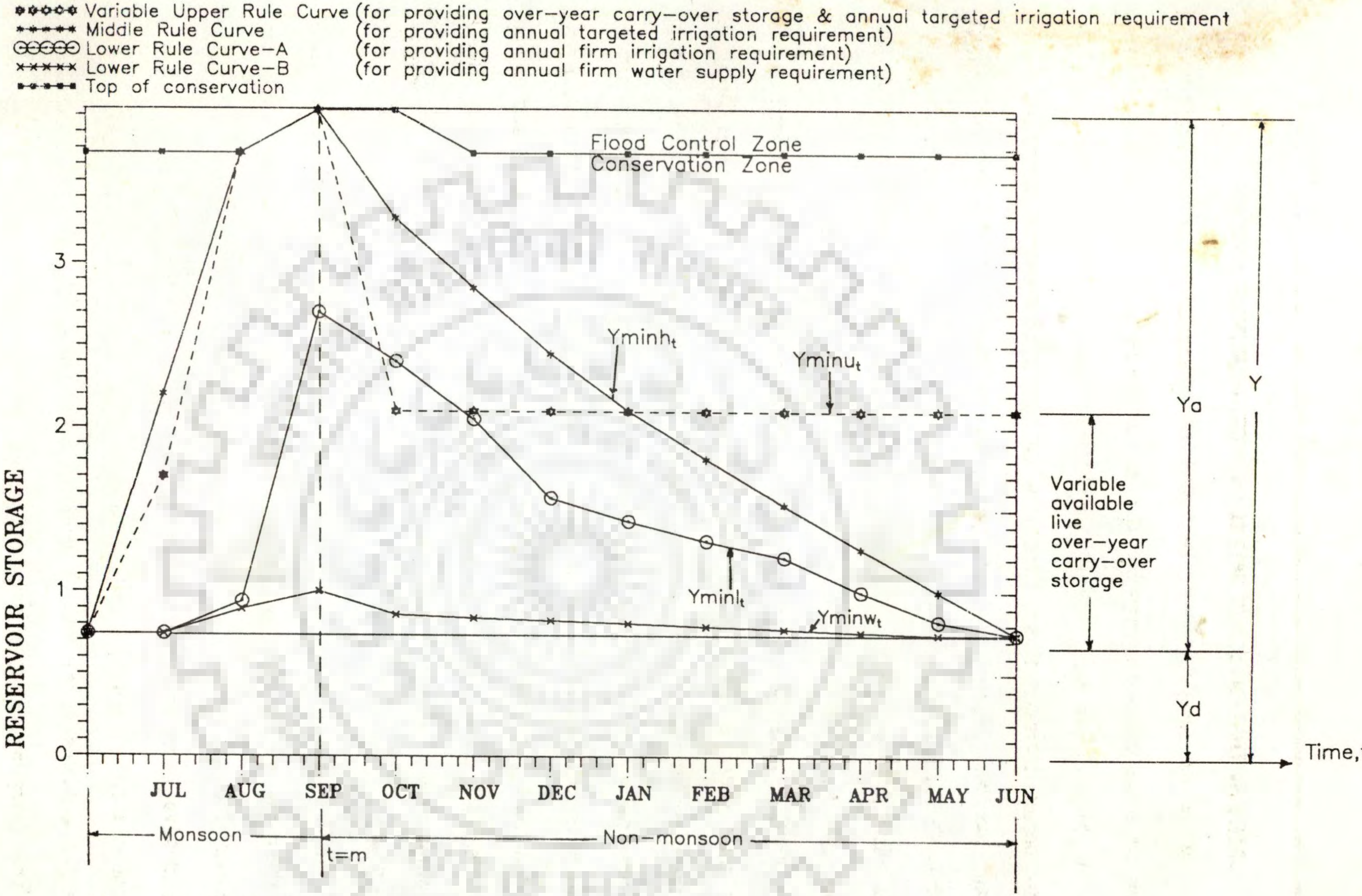


Fig. 9.1 Multi-rule curves

CHAPTER 10

APPLICATION OF MODELS, COMPUTATION AND RESULTS FOR RESERVOIR OPERATION

Chapter-10

APPLICATION OF MODELS, COMPUTATION AND RESULTS FOR RESERVOIR OPERATION

10.1.0 THE APPROACH FOR RESERVOIR OPERATION

The multi-rule curves are proposed to be used for reservoir operation as discussed in Chapter-9. The following approach may be followed for this purpose:

After operating reservoir for monsoon period (for operation the monsoon period is taken as the period at the end of which reservoir is likely to be full most of the times, i.e., the end of the flood season), in Case-I, if reservoir is full at the end of monsoon, the available over-year carry-over storage could be obtained from monsoon flows vs. over-year carry-over storage relationship (the over-year carry-over storages could be obtained for the given size of a reservoir using the results of linear programming model Max.Z_{tr} and dynamic programming model) knowing the monsoon flows which have already occured in the current year, and a rule curve for non-monsoon period can be obtained (i.e., storages are not allowed to go below this available over-year carry-over storage in non-monsoon period) to provide the above available over-year carry-over storage at the end of monsoon period in the current year and the annual targeted requirement, and the reservoir could be operated with this rule curve in non-monsoon period. This rule curve is named as Variable Upper Rule Curve.

In Case-II, if reservoir is full at the end of monsoon, a rule curve for non-monsoon period can be obtained to provide the annual targeted requirement. This rule curve is named as Middle Rule Curve.

In Case-III, if reservoir is not full at the end of monsoon, two rule curves for non-monsoon period can be obtained first one to provide the annual firm requirement and second one to provide annual firm water supply requirement (if water supply is one of the water uses). The first one is named as Lower Rule Curve-A and the second one as Lower Rule Curve-B.

In other words these rule curves can be defined as follows:

(i) When $\sum_{t=1}^{m} I_t \geq Iav_m$ and $S_m = Ymax_m$, follow Variable Upper Rule Curve (i.e., $Yminu_t$)

(ii) When $\sum_{t=1}^{m} I_t < Iav_m$ and $S_m = Ymax_m$, follow Middle Rule Curve (i.e., $Yminh_t$)

(iii) When $S_m < Ymax_m$, and

if (a) $Yminl_m \leq S_m$, follow Lower Rule Curve-A (i.e., $Yminl_t$)

if (b) $Yminw_m \leq S_m < Yminl_m$, follow Lower Rule Curve-B (i.e., $Yminw_t$)

if (c) $Yd = Ymin_m \leq S_m < Yminw_m$, follow $Ymin_t = Yd$.

Where,

m = end of monsoon period,

$Yminu_t$ = value of Variable Upper Rule Curve at time t,

$Yminh_t$ = value of Middle Rule Curve at time t,

$Yminl_t$ = value of Lower Rule Curve-A at time t, and

$Yminw_t$ = value of Lower Rule Curve-B at time t,

Iav_m = average of monsoon flows.

Using the multi-rule curves, the computations were done in two steps as follows:

(i) Reservoir operation with multi-rule curves for existing reservoir capacity and existing requirement.

(ii) Reservoir operation with multi-rule curves for proposed reservoir capacity and existing requirement.

The computer programme for simulation/operation is given in Appendix-2.

10.2.0 RESERVOIR OPERATION COMPUTATION FOR EXISTING RESERVOIRS

10.2.1 Monsoon Flows vs. Over-year Carry-over Storages Relationship

The computation for relationships between ratio of monsoon flow and average monsoon flow vs. ratio of over-year carry-over storage available and gross capacity for reservoir operation for Badanala, Kalluvodduhalla, Bodhghat and Bargi are given in Tables 10.2.1.1, 10.2.1.2, 10.2.1.3, and 10.2.1.4 respectively. These have been obtained from Tables 8.4.1 to 8.4.4. This relationship is shown in Figure 10.1 for existing reservoir capacity.

10.2.2 Computation For Badanala

For Badanala for Case-I, Case-II and Case-III of reservoir operation, the multi-rule curves are given in Table 10.2.2.1. These are also shown in Figure 10.2 for existing reservoir capacity. The results of the computations for simulation and rule curves are given in Tables 10.2.2.2 and 10.2.2.3.

10.2.3 Computation for Kalluvodduhalla

The multi-rule curves are given in Table 10.2.3.1. These are shown in Figure 10.3 for existing reservoir capacity. The results of the computations for simulation and rule curves are given in Tables 10.2.3.2 and 10.2.3.3.

Table 10.2.1.1 Relationship of monsoon flow vs. over-year carry-over storage for Badanala for existing reservoir

Proba-bility flows	Monsoon flows in 10^2ha-m	Monsoon flow / average of monsoon flow	Over-year carry-over storage available from dynamic pro-gramming in 10^2ha-m	Over-year carry-over storage/gross capacity (S^o_{12}/Y)
5 %	274	1.630	69	0.912
10 %	251	1.493	68	0.899
25 %	212	1.261	64	0.846
30 %	202	1.201	62	0.819
50 %	168	1.000	57	0.753
60 %	152	0.904	51	0.674
65 %	143	0.851	43	0.568

Average of monsoon flow for the months of June to October = 168.12 10^2ha-m, and Y = 75.64 10^2ha-m.

Table 10.2.1.2 Relationship of monsoon flow vs. over-year carry-over storage for Kalluvodduhalla for existing reservoir

Proba-bility flows	Monsoon flows in 10^{-1}MCM	Monsoon flow / average of monsoon flow	Over-year carry-over storage available from dynamic pro-gramming in 10^{-1}MCM	Over-year carry-over storage/gross capacity (S^o_{12}/Y)
5 %	255.1	1.539	66	0.542
25 %	202.4	1.221	64	0.525
40 %	179.3	1.082	62	0.509
60 %	151.3	0.874	60	0.493
65 %	144.8	0.650	58	0.476
70 %	137.1	0.827	56	0.460
75 %	129.1	0.579	48	0.394

Average of monsoon flow = 165.7 10^{-1}MCM, and Y = 121.76 10^{-1}MCM.

Table 10.2.1.3 Relationship of monsoon flow vs. over-year carry-over storage for Bodhghat for existing reservoir

Proba-bility flows	Monsoon flows in 10^2MCM	Monsoon flow / average of monsoon flow	Over-year carry-over storage available from dynamic programming in 10^2 MCM	Over-year carry-over storage/gross capacity (S^o_{12}/Y)
5 %	41.82	1.459	19	0.426
10 %	38.92	1.355	17	0.381
25 %	34.11	1.187	16	0.359
50 %	28.73	1.000	14	0.314
60 %	26.66	0.927	12	0.269
70 %	24.55	0.855	10	0.221

Average of monsoon flow for the months June to August = 28.73 10^2MCM, and Y = 44.58 10^2MCM.

Table 10.2.1.4 Relationship of monsoon flow vs. over-year carry-over storage for Bargi for existing reservoir

Proba-bility flows	Monsoon flows in 10^{-1}TMC	Monsoon flow / average of monsoon flow	Over-year carry-over storage available from dynamic programming in 10^{-1}TMC	Over-year carry-over storage/gross capacity (S^o_{12}/Y)
5 %	89.87	1.807	21	0.534
25 %	66.19	1.331	19	0.483
40 %	51.89	1.043	17	0.432
50 %	49.74	0.875	16	0.407
60 %	43.52	0.743	14	0.356
70 %	36.95	0.740	13	0.331

Average of monsoon flow for the months June to September =49.74 10^{-1}TMC, and

Y = 39.32 10^{-1}TMC.

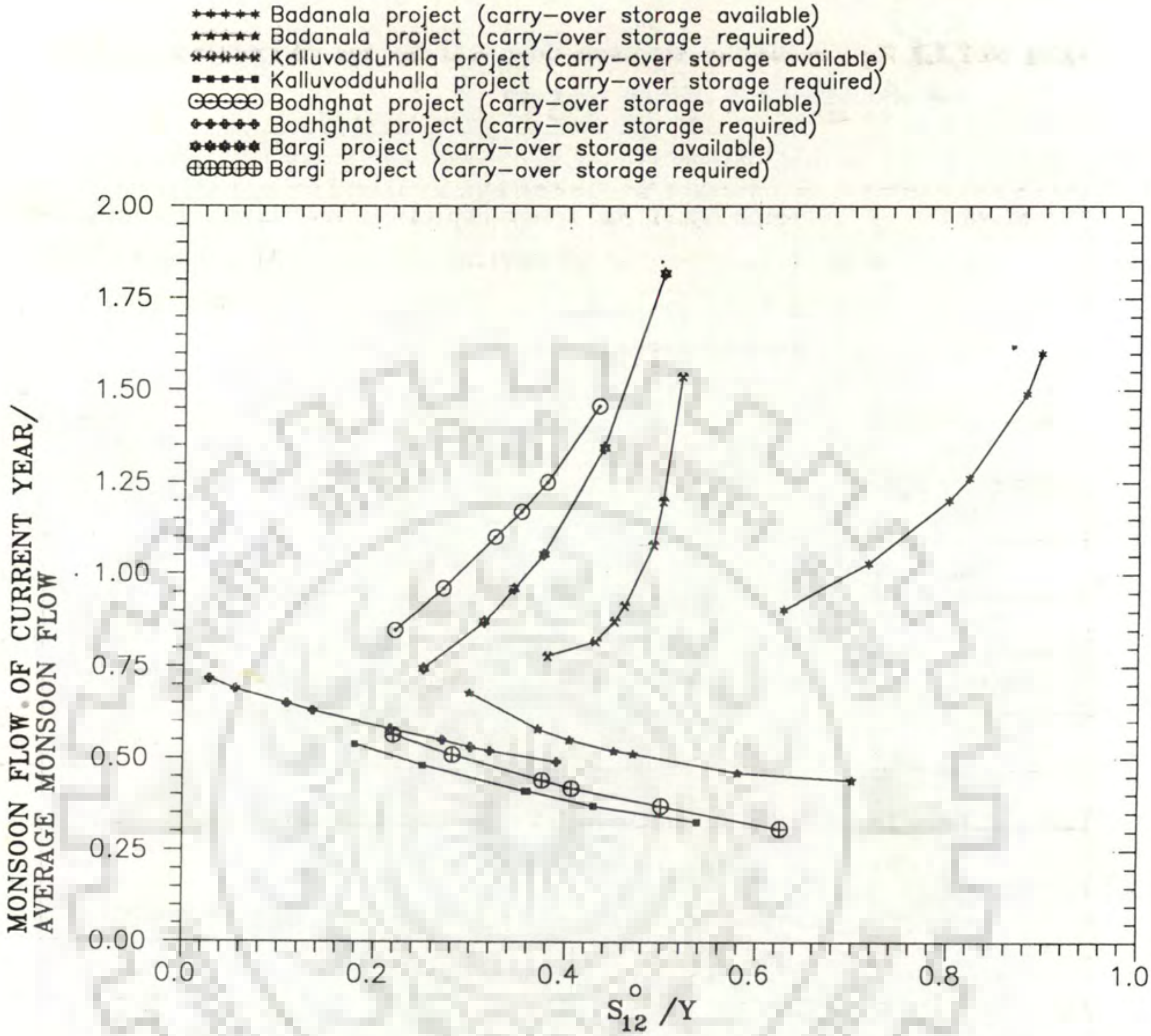


Fig. 10.1 Monsoon flow vs. reservoir over-year carry-over storage available and required for existing reserv

Table 10.2.2.1 Rule curves for reservoir operation for annual targeted and firm requirements for Badanala for existing reservoir

Month	Variable Upper Rule Curve for over-year carry-over storage and annual targeted requirement	Middle Rule Curve for annual targeted requirement	Lower Rule Curve-A for annual firm requirement
Jun	934	850	850
Jul	850	850	850
Aug	2320	850	850
Sep	4590	3285	850
Oct	7564	7564	3116
Nov	S^o_{12}	3059	2343
Dec	S^o_{12}	1936	1587
Jan	S^o_{12}	1059	992
Feb	S^o_{12}	918	898
Mar	S^o_{12}	876	867
Apr	S^o_{12}	850	850
May	S^o_{12}	850	850

S^o_{12} = Variable over-year carry-over storage to be made available at the end of non-monsoon period which is obtained from Figure 10.2, below which reservoir storages are not allowed to go during non- monsoon period.

All values are in ha-m.

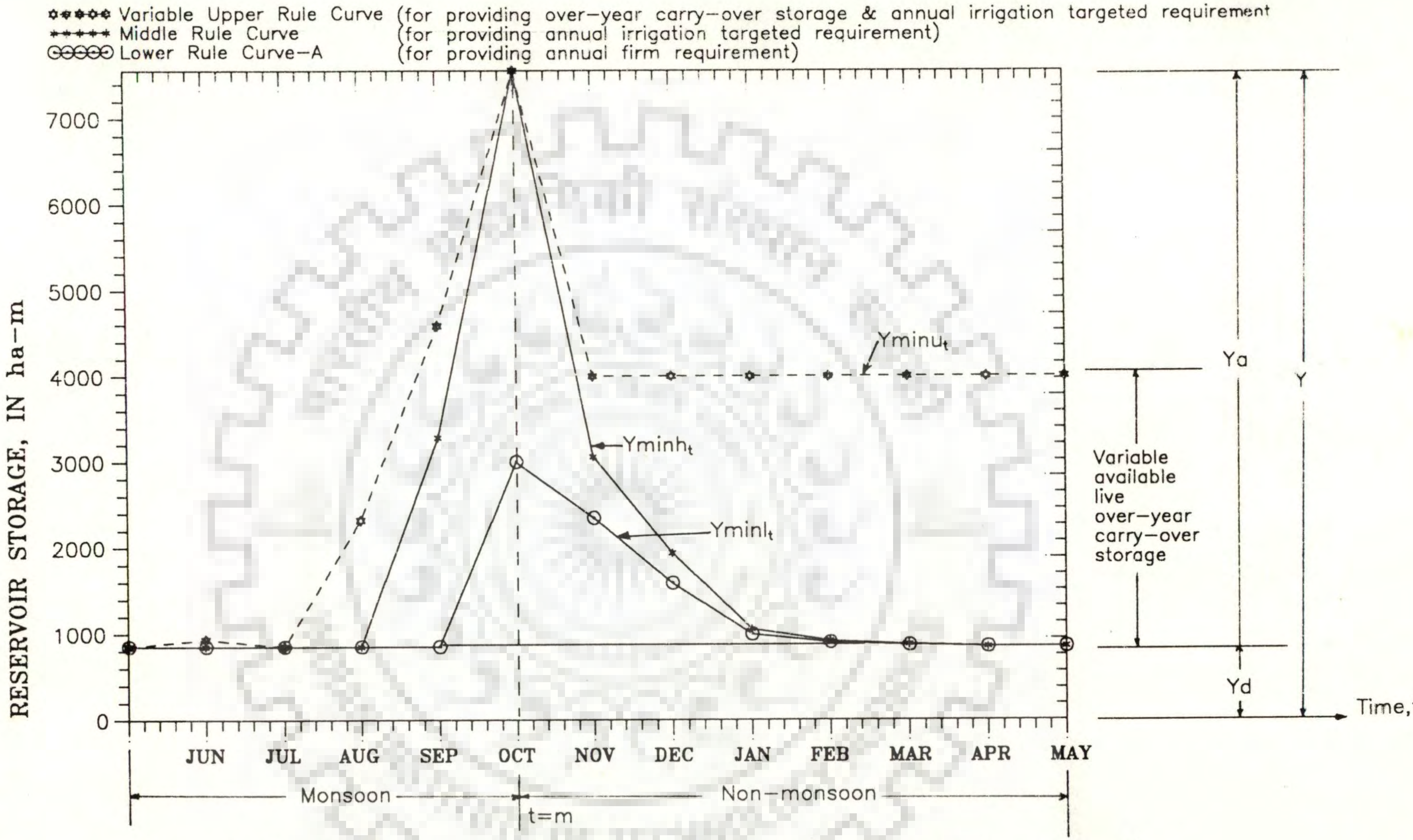


Fig. 10.2 Multi-rule curves for Badanala reservoir operation for existing reservoir

Table 10.2.2.2 Simulation results for existing reservoir capacity and existing irrigation requirement for Badanala

Month	Average irrigation deficit	No. of irrigation deficits	Percentage of irrigation deficit	No. of times reservoir empty	No. of times reservoir full
Jun	29.736	3	2.50	3	0
Jul	484.324	6	13.10	6	0
Aug	310.829	5	10.27	5	6
Sep	75.500	3	3.25	3	11
Oct	0.00	0	0.00	0	16
Nov	19.985	1	1.75	1	11
Dec	34.658	1	3.11	1	0
Jan	41.340	3	4.71	3	0
Feb	5.429	1	3.84	1	0
Mar	1.614	1	3.84	1	0
Apr	0.278	1	1.10	1	0
May	0.000	0	0.00	0	0

Number of annual deficits in irrigation = 9.
Average annual irrigation deficit = 1003.891 ha-m.
Average annual spill = 4240.00 ha-m.
Net present worth of benefits = Rs. $58990 * 10^5$.

Y = 7564 ha-m , Ir = 14569 ha-m.

Table 10.2.2.3 Multi-rule curves operation results for existing reservoir capacity and existing irrigation requirement for Badanala

Month	Average irrigation deficit	No. of irrigation deficits	percentage of irrigation deficit	No. of times reservoir empty (reaches rule curves)	No. of times reservoir full
Jun	0.000	0	0.00	0	0
Jly	479.665	5	12.81	5	0
Aug	292.484	4	9.60	4	6
Sep	72.380	3	3.10	3	11
Oct	44.430	2	4.49	2	16
Nov	19.984	1	1.75	1	11
Dec	64.447	3	5.89	3	0
Jan	37.680	2	4.10	2	0
Feb	0.000	0	0.00	0	0
Mar	0.00	0	0.00	0	0
Apr	0.00	0	0.00	0	0
May	0.00	0	0.00	0	0
Number of annual deficits in irrigation = 9. Average annual irrigation deficit = 1011 ha-m. Average annual spill = 4243.80 h-am. Net present worth of benefits = Rs. 58957 * 10^5.					

Y = 7564 ha-m, Ir = 14569 ha-m.

Table 10.2.3.1 Rule curves for reservoir operation for annual targeted and firm requirements for Kalluvodduhalla for existing reservoir

Month	Variable Upper Rule Curve for over-year carry-over storage and annual targeted requirement	Middle Rule Curve for annual targeted requirement	Lower Rule Curve-A for annual firm requirement
Jun	0.874	0.874	0.874
Jul	11.735	2.279	0.874
Aug	12.176	12.176	0.874
Sep	S^o_{12}	9.596	6.263
Oct	S^o_{12}	6.997	4.635
Nov	S^o_{12}	6.068	4.097
Dec	S^o_{12}	5.721	3.877
Jan	S^o_{12}	5.021	3.437
Feb	S^o_{12}	2.320	2.370
Mar	S^o_{12}	1.222	1.094
Apr	S^o_{12}	0.924	0.904
May	S^o_{12}	0.874	0.874

S^o_{12} is obtained from Figure 10.3.

All values are in MCM.

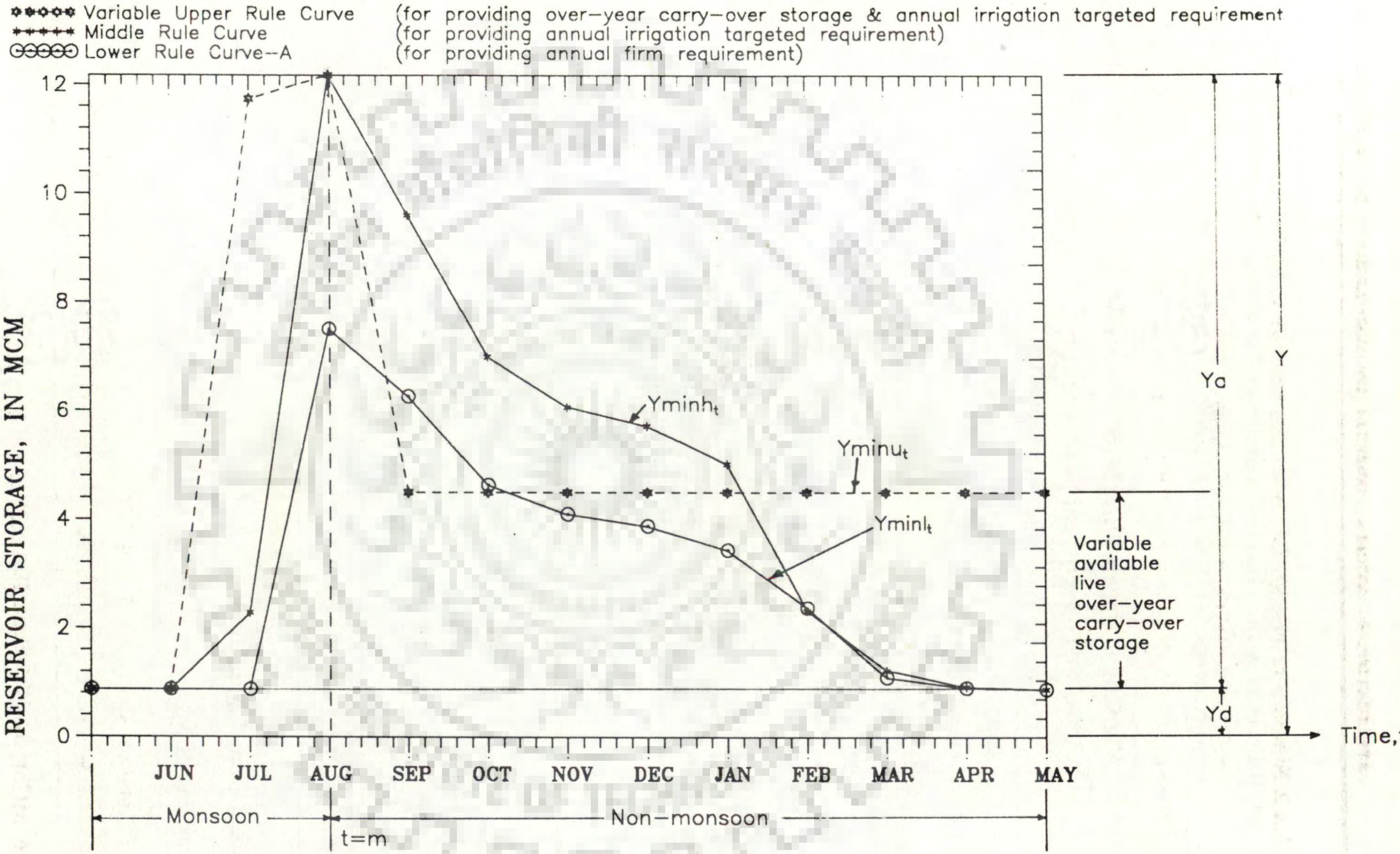


Fig. 10.3 Multi-rule curves for Kalluvodduhalla reservoir operation for existing reservoir

Table 10.2.3.2 Simulation results for existing reservoir capacity and existing irrigation requirement for Kalluvodduhalla

Month	Average irrigation deficit	No. of irrigation deficits	Percentage of irrigation deficit	No. of times reservoir empty	No. of times reservoir full
Jun	1.1330	16	26.47	3	0
Jul	0.0168	1	2.11	1	6
Aug	0.0024	1	0.18	0	17
Sep	0.0250	1	1.00	0	8
Oct	0.0000	0	0.00	0	7
Nov	0.0099	1	0.38	1	3
Dec	0.0117	1	3.37	1	0
Jan	0.0246	2	3.77	2	0
Feb	0.1889	4	11.11	4	0
Mar	0.2849	5	13.58	5	0
Apr	0.0497	5	16.68	5	0
May	0.0087	5	17.40	5	0

Number of annual deficits in irrigation = 18.
Average annual irrigation deficit = 1.7577 MCM.
Average annual spill = 5.911 MCM.
Net present worth of benefits = Rs. $461*10^5$

Y = 12.176 MCM, Ir 17.549 MCM.

Table 10.2.3.3 Multi-Rule curves operation results for existing reservoir capacity and existing irrigation requirement for Kalluvodduhalla

Month	Average irrigation deficit	No. of irrigation deficits	Percentage of irrigation deficit	No. of times reservoir empty (reaches rule curves)	No. of times reservoir full
Jun	0.9996	14	23.34	14	0
Jul	0.0168	1	2.11	1	6
Aug	0.0019	1	0.14	1	17
Sep	0.0210	1	0.84	1	8
Oct	0.2664	2	10.24	2	7
Nov	0.0099	1	0.38	1	4
Dec	0.0117	1	3.37	1	0
Jan	0.0174	1	2.00	1	0
Feb	0.1754	2	10.30	2	0
Mar	0.2799	4	13.34	4	0
Apr	0.0000	0	0.00	0	0
May	0.0000	0	0.00	0	0
Number of annual deficits in irrigation = 19. Average annual irrigation deficit = 1.8100 MCM. Average annual spill = 5.971 MCM. Net present worth benefits = Rs. $452*10^{5}$.					

Y = 12.176 MCM, Ir 17.549 MCM.

10.2.4 Computation for Bodhghat

For single purpose hydropower reservoir, only the Lower Rule Curve-A was found effective and is given in Table 10.2.4.1. and is shown in Figure 10.4 for existing reservoir capacity. The results of the computations for simulation and rule curve are given in Tables 10.2.4.2 and 10.2.4.3.

10.2.5 Computation for Bargi

The multi-rule curves are given in Table 10.2.5.1 and are shown in Figure 10.5 for existing reservoir capacity. The results of the computations for simulation and rule curves are given in Tables 10.2.5.2 and 10.2.5.3.

10.3.0 RESERVOIR OPERATION COMPUTATION FOR PROPOSED RESERVOIRS

10.3.1 Monsoon Flows vs. Over-year Carry-over Storages Relationship

The computation for relationships between ratio of monsoon flow and average monsoon flow vs. ratio of over-year carry-over storage available and gross capacity for reservoir operation for Badanala, Kalluvodduhalla, Bodhghat and Bargi are given in Tables 10.3.1.1, 10.3.1.2, 10.3.1.3, and 10.3.1.4 respectively. These have been obtained from Tables 8.4.7 to 8.4.10. This relationship is shown in Figure 10.6for proposed reservoir capacity.

10.3.2 Computation For Badanala

For Badanala for Case-I, Case-II and Case-III of reservoir operation, the multi-rule curves are given in Table 10.3.2.1. These are also shown in Figure 10.7 for proposed reservoir capacity. The results of the computations for simulation and rule curves are given in Tables 10.3.2.2 and 10.3.2.3.

Table 10.2.4.1 Rule curve for reservoir operation for annual firm requirements for Bodhghat for existing reservoir

Month	Lower Rule Curve-A for annual firm requirement
Jun	1133
Jul	1988
Aug	1871
Sep	3433
Oct	3153
Nov	2846
Dec	2528
Jan	2200
Feb	1855
Mar	1491
Apr	1141
May	740

All values in MCM.

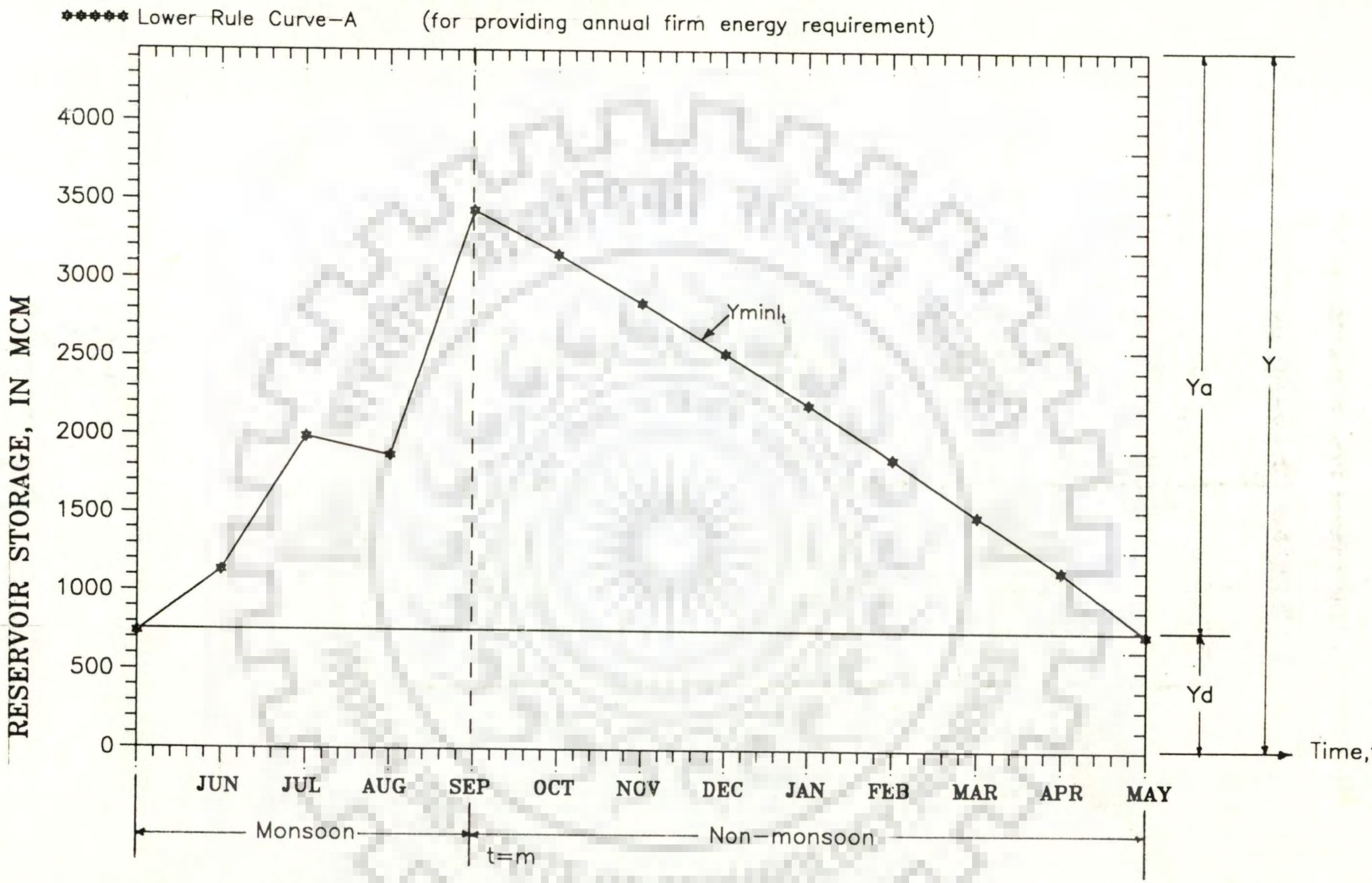


Fig. 10.4 Single-rule curves for Bodhghat reservoir operation for existing reservoir

Table 10.2.4.2 Simulation results for existing reservoir capacity and existing hydropower requirement for Bodhghat

Month	Average energy deficit	No. of energy deficits	Percentage of energy deficit	No. of times reservoir empty	No. of times reservoir full
Jun	0.000	0	0.00	0	1
Jul	0.000	0	0.00	0	1
Aug	0.000	0	0.00	0	4
Sep	3222	1	3.14	1	3
Oct	6808	1	6.29	1	0
Nov	9296	1	8.59	1	0
Dec	9303	1	8.60	1	0
Jan	10035	1	9.29	1	0
Feb	8564	1	10.02	1	0
Mar	8669	1	10.14	2	0
Apr	5761	2	7.22	2	0
May	4670	2	5.87	2	0

Number of annual deficits in energy = 2.
Average annual energy deficit = 66328 MWhr.
Average annual spill = 119 MCM.
Number of annual dump energy = 2.
Average annual dump energy = 30090 MWhr
Net present worth of benefits = Rs.10679*10^{6}

Y = 4458 MCM, H = 500 MW, and E =1139000 MWhr.

Table 10.2.4.3 Single-rule curve operation result for existing reservoir capacity and existing hydropower requirement for Bodhghat

Month	Average energy deficit	No. of energy deficits	Percentage of energy deficit	No. of times reservoir empty (reaches rule curves)	No. of times reservoir full
Jun	0.000	0	0.00	0	1
Jul	0.000	0	0.00	0	1
Aug	0.000	0	0.00	0	5
Sep	3833	1	3.80	1	5
Oct	5187	1	4.79	1	0
Nov	8866	1	8.19	1	0
Dec	8886	1	8.21	1	0
Jan	9083	1	8.39	1	0
Feb	15204	1	17.79	1	0
Mar	8521	2	9.97	2	0
Apr	4958	2	6.21	2	0
May	4389	2	5.50	2	0

Number of annual deficits in energy = 3.
Average annual energy deficit = 69825 MWhr.
Average annual spill = 173 MCM.
Number of annual dump energy = 3.0
Average annual dump energy = 43865 MWhr
Net present worth of benefits = Rs.1074 $3 * 10^{6}$

Y = 4458 MCM, H = 500 MW, and E =1139000 MWhr.

Table 10.2.5.1 Rule curves for reservoir operation for annual targeted and firm requirements for Bargi for existing reservoir

Month	Variable Upper Rule Curve for over-year carry-over storage and annual targeted requirement	Middle Rule Curve for annual targeted requirement	Lower Rule Curve-A for annual firm requirement	Lower Rule Curve-B for annual firm water supply requirement
Jul	1.325	1.301	0.742	0.742
Aug	3.592	3.592	0.941	0.908
Sep	3.932	3.932	0.959	1.000
Oct	S^{o}_{12}	3.272	2.994	0.875
Nov	S^{o}_{12}	2.851	2.754	0.858
Dec	S^{o}_{12}	2.546	1.796	0.841
Jan	S^{o}_{12}	2.105	1.555	0.824
Feb	S^{o}_{12}	1.811	1.386	0.809
Mar	S^{o}_{12}	1.529	1.229	0.792
Apr	S^{o}_{12}	1.262	1.080	0.776
May	S^{o}_{12}	1.002	0.887	0.759
Jun	S^{o}_{12}	0.742	0.742	0.742

S^{o}_{12} is obtained from Figure 10.5.

All values are in TMC.

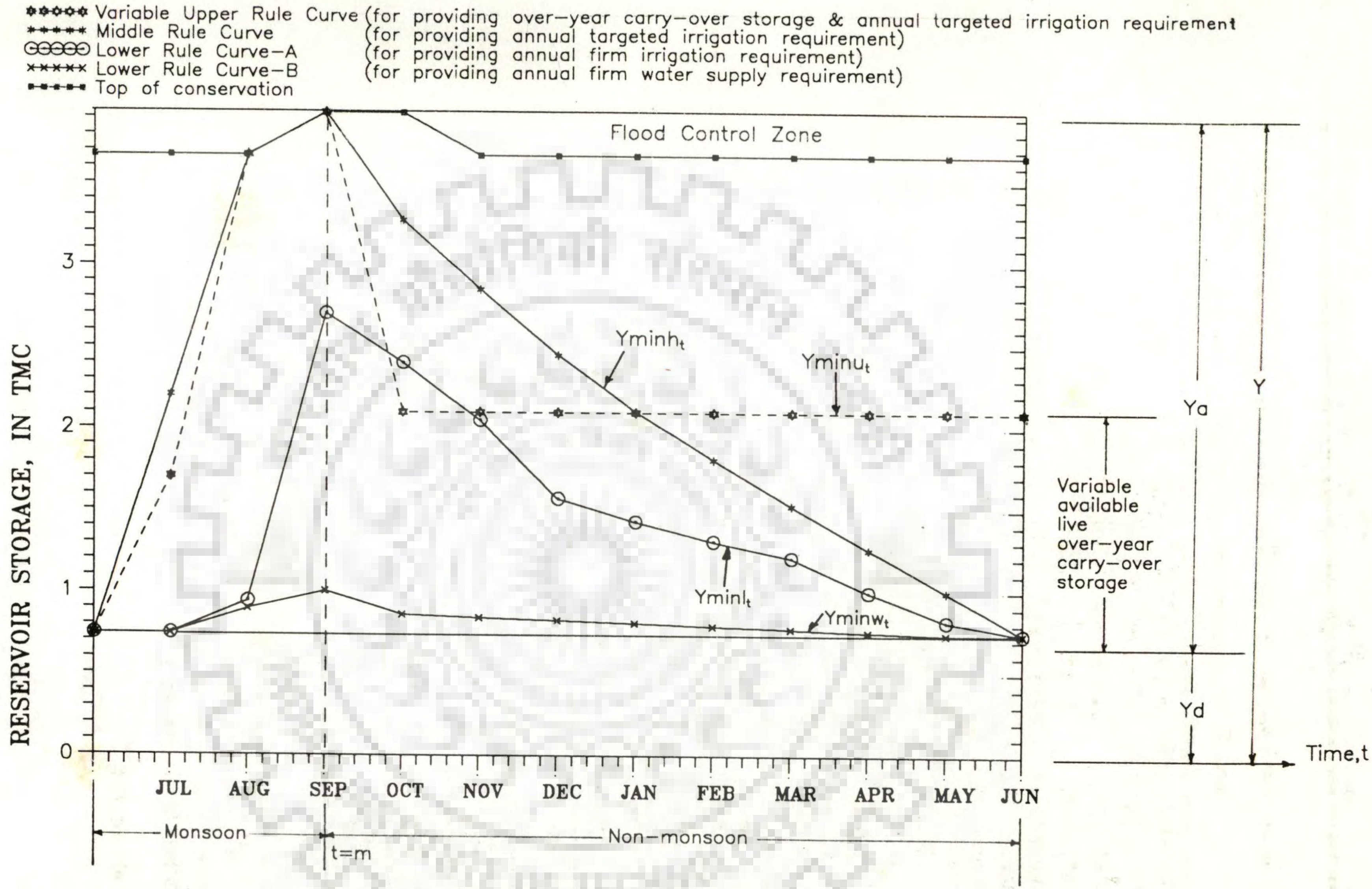


Fig. 10.5 Multi-rule curves for Bargi reservoir operation for existing reservoir

Table 10.2.5.2 Simulation results for existing reservoir capacity and existing irrigation requirement and existing hydropower for Bargi

Month	Water supply deficits			Irrigation deficits			Energy deficits			No. of times reservoir empty	No. of times reservoir full
	Average	No.	Per-centage	Average	No.	Per-centage	Average	No.	Per-centage		
Jul	0.00000	0	0.00	0.00000	0	0.00	0	0	0.00	0	2
Aug	0.00000	0	0.00	0.00000	0	0.00	0	0	0.00	0	12
Sep	0.00000	0	0.00	0.00000	0	0.00	0	0	0.00	0	9
Oct	0.00000	0	0.00	0.00000	0	0.00	0	0	0.00	0	4
Nov	0.00000	0	0.00	0.00582	1	1.30	180	1	0.61	1	0
Dec	0.00077	1	4.53	0.01386	1	4.50	1496	1	4.55	1	0
Jan	0.00071	2	4.18	0.04792	3	10.80	3417	3	10.38	3	0
Feb	0.00210	3	13.62	0.04000	3	13.60	4039	3	13.64	3	0
Mar	0.00168	3	9.88	0.03850	3	13.60	3591	3	12.13	3	0
Apr	0.00236	4	14.30	0.04850	4	18.10	4198	4	18.18	4	0
May	0.00387	5	22.76	0.08101	6	23.30	5244	5	22.77	6	0
Jun	0.00140	2	8.48	0.05263	7	21.60	5209	7	22.83	7	0

Number of annual deficits in water supply = 6.
Average annual deficit in water supply = 0.0129 TMC.
Number of annual deficits in irrigation = 8.
Average annual deficit in irrigation = 0.32824 TMC.
Number of annual deficits in hydropower = 8.
Average annual deficit in hydropower = 27374 MWhr.
Number of dump energy = 22
Average annual dump energy = 147974 MWhr.
Average annual spill = 1.602 TMC, and
Net present worth of benefits = Rs. $3302*10^7$

Y = 3.932 TMC, Ir=3.947 TMC, WS=0.2 TMC, and H=90 MW, E=329000 MWhr.

Table 10.2.5.3 Multi-rule carves operation results for existing reservoir capacity and existing irrigation requirement and existing hydropower or Bargi

Mo-nth	Water supply deficits			Irrigation deficits			Energy deficits			No. of times reservoir empty (reaches rule curves)	No. of times reservoir full
	Average	No.	Percentage	Average	No.	Percentage	Average	No.	Percentage		
Jul	0.00000	0	0.00	0.0000	0	0.00	0	0	0.00	0	2
Aug	0.00000	0	0.00	0.0000	0	0.00	0	0	0.00	0	13
Sep	0.00112	2	6.80	0.0998	4	19.61	4103	3	13.86	4	11
Oct	0.00000	0	0.00	0.0105	1	2.28	0	0	0.00	1	5
Nov	0.00149	3	9.10	0.0860	4	19.95	5286	4	18.18	4	0
Dec	0.00116	3	6.84	0.0543	4	17.80	5547	4	16.86	4	0
Jan	0.00000	0	0.00	0.0291	2	6.60	1804	1	5.48	2	0
Feb	0.00000	0	0.00	0.0059	2	19.72	508	2	1.71	2	0
Mar	0.00000	0	0.00	0.0106	2	3.75	884	2	3.30	2	0
Apr	0.00000	0	0.00	0.0113	2	4.21	782	2	3.39	2	0
May	0.00000	0	0.00	0.0311	3	8.96	147	2	0.63	3	0
Jun	0.00000	0	0.00	0.0071	2	2.71	616	2	2.60	2	0

Number of annual deficits in water supply = 4.
Average annual deficit in water supply = 0.00377 TMC.
Number of annual deficits in irrigation = 8.
Average annual deficit in irrigation = 0.34571 TMC.
Number of annual deficits in hydropower = 7.
Average annual deficit in hydropower = 21149 MWhr.
Number of dump energy = 22.
Average annual dump energy = 148830 MWhr.
Average annual spill = 1.710 TMC, and
Net present worth of benefits = Rs. $3395*10^7$

Y = 3.932 TM, Ir = 3.947 TMC, Ws= 0.2 TMC, and H=90 MW, E=329000 MWhr.

Table 10.3.1.1 Relationship of monsoon flow vs. over-year carry-over storage for Badanala for proposed reservoir

Probability flows	Monsoon flows in 10^2ha-m	Monsoon flow / average of monsoon flow	Over-year carry-over storage available from dynamic programming in 10^2ha-m	Over-year carry-over storage/gross capacity (S^o_{12}/Y)
5 %	274	1.630	81	0.849
10 %	251	1.493	77	0.806
25 %	212	1.261	71	0.743
30 %	202	1.201	66	0.691
50 %	168	1.000	61	0.639
60 %	152	0.904	56	0.586
65 %	143	0.851	49	0.513

Average of monsoon flow for the months of June to October=168.12 10^2ha-m, and Y = 95.50 10^2ha-m.

Table 10.3.1.2 Relationship of monsoon flow vs. over-year carry-over storage for Kalluvodduhalla for proposed reservoir

Probability flows	Monsoon flows in 10^{-1}MCM	Monsoon flow / average of monsoon flow	Over-year carry-over storage available from dynamic programming in 10^{-1}MCM	Over-year carry-over storage/gross capacity (S^o_{12}/Y)
5 %	255 . 1	1.539	85	0.586
25 %	202 . 4	1.221	78	0.538
40 %	179 . 3	1.082	73	0.503
60 %	151 . 3	0.874	70	0.483
65 %	144 . 8	0.650	66	0.455
70 %	137 . 1	0.827	63	0.435
75 %	129 . 1	0.579	56	0.386

Average of monsoon flow = 165.7 10^{-1}MCM, and Y = 145 10^{-1}MCM.

Table 10.3.1.3 Relationship of monsoon flow vs. over-year carry-over storage for Bodhghat for proposed reservoir

Probability flows	Monsoon flows in 10^2MCM	Monsoon flow / average of monsoon flow	Over-year carry-over storage available from dynamic programming in 10^2 MCM	Over-year carry-over storage/gross capacity (S^o_{12}/Y)
5 %	41.82	1.459	26	0.569
10 %	38.92	1.355	25	0.547
25 %	34.11	1.187	23	0.504
50 %	28.73	1.000	21	0.460
60 %	26.66	0.927	20	0.438
70 %	24.55	0.855	17	0.372

Average of monsoon flow for the months June to August = 28.73 10^2MCM and,
Y = 45.65 10^2MCM.

Table 10.3.1.4 Relationship of monsoon flow vs. over-year carry-over storage for Bargi for proposed reservoir

Probability flows	Monsoon flows in 10^{-1}TMC	Monsoon flow / average of monsoon flow	Over-year carry-over storage available from dynamic programming in 10^{-1}TMC	Over-year carry-over storage/gross capacity (S^o_{12}/Y)
5 %	89.87	1.807	28	0.650
25 %	66.19	1.331	24	0.557
40 %	51.89	1.043	21	0.487
50 %	49.74	0.875	19	0.441
60 %	43.52	0.743	17	0.394
70 %	36.95	0.740	15	0.348

Average of monsoon flow for the months June to September =49.74 10^{-1}TMC, and
Y = 43.10 10^{-1}MCM

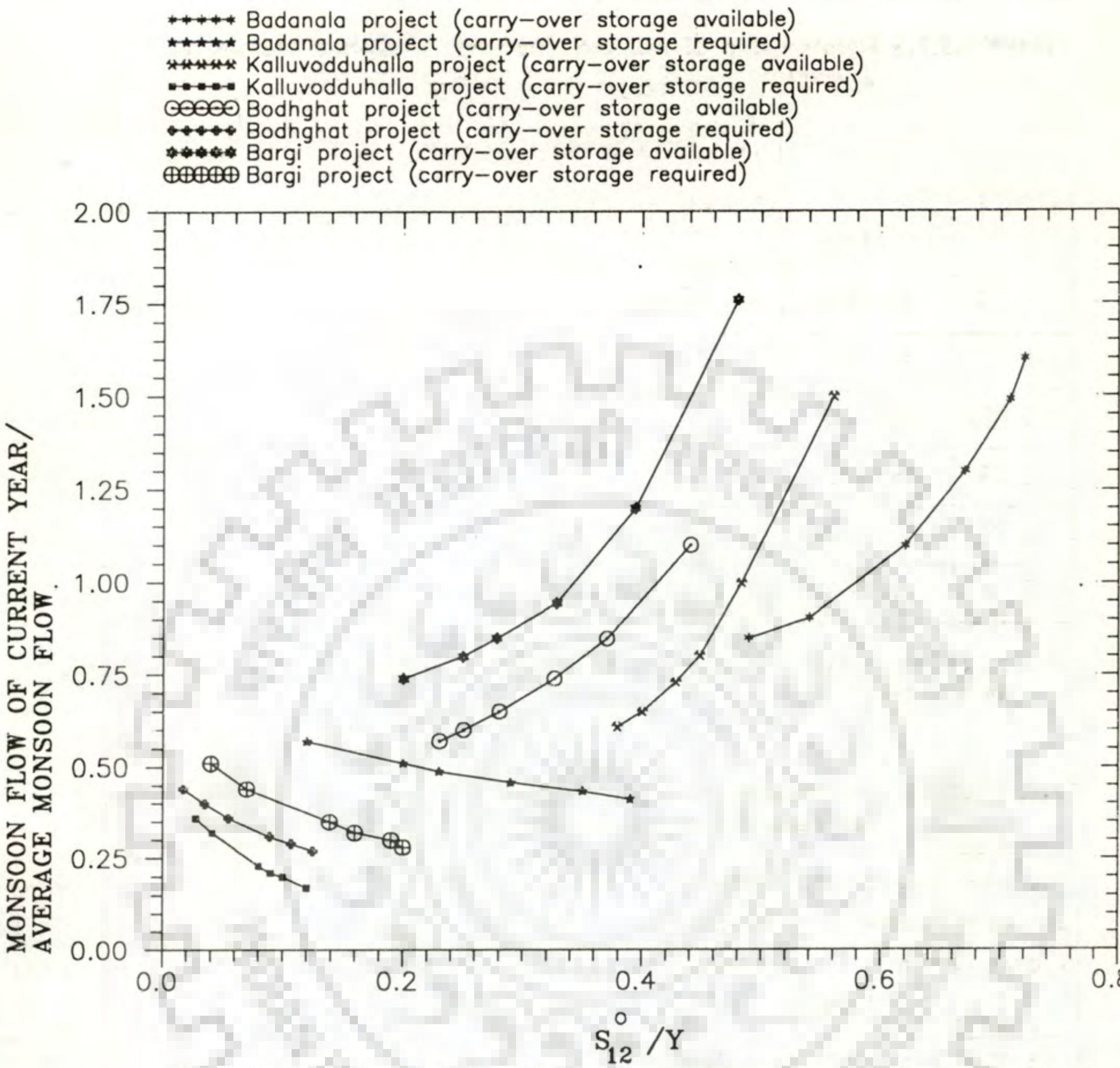


Fig. 10.6 Monsoon flow vs. reservoir over–year carry–over storage available and required for proposed reservoir

Table 10.3.2.1 Rule curves for reservoir operation for annual targeted and firm requirements for Badanala for proposed reservoir

Month	Variable Upper Rule Curve for over-year carry-over storage and annual targeted requirement	Middle Rule Curve for annual targeted requirement	Lower Rule Curve-A for annual firm requirement
Jun	934	850	850
Jul	850	850	850
Aug	3868	850	850
Sep	6116	3285	850
Oct	9550	9550	3268
Nov	S^{o}_{12}	3059	2524
Dec	S^{o}_{12}	1936	1666
Jan	S^{o}_{12}	1059	1007
Feb	S^{o}_{12}	918	901
Mar	S^{o}_{12}	876	869
Apr	S^{o}_{12}	850	850
May	S^{o}_{12}	850	850

S^{o}_{12} = Variable over-year carry-over storage to be made available at the end of non-monsoon period which is obtained from Figure 10.7 below which reservoir storages are not allowed to go during non-monsoon period.

All value are in ha-m.

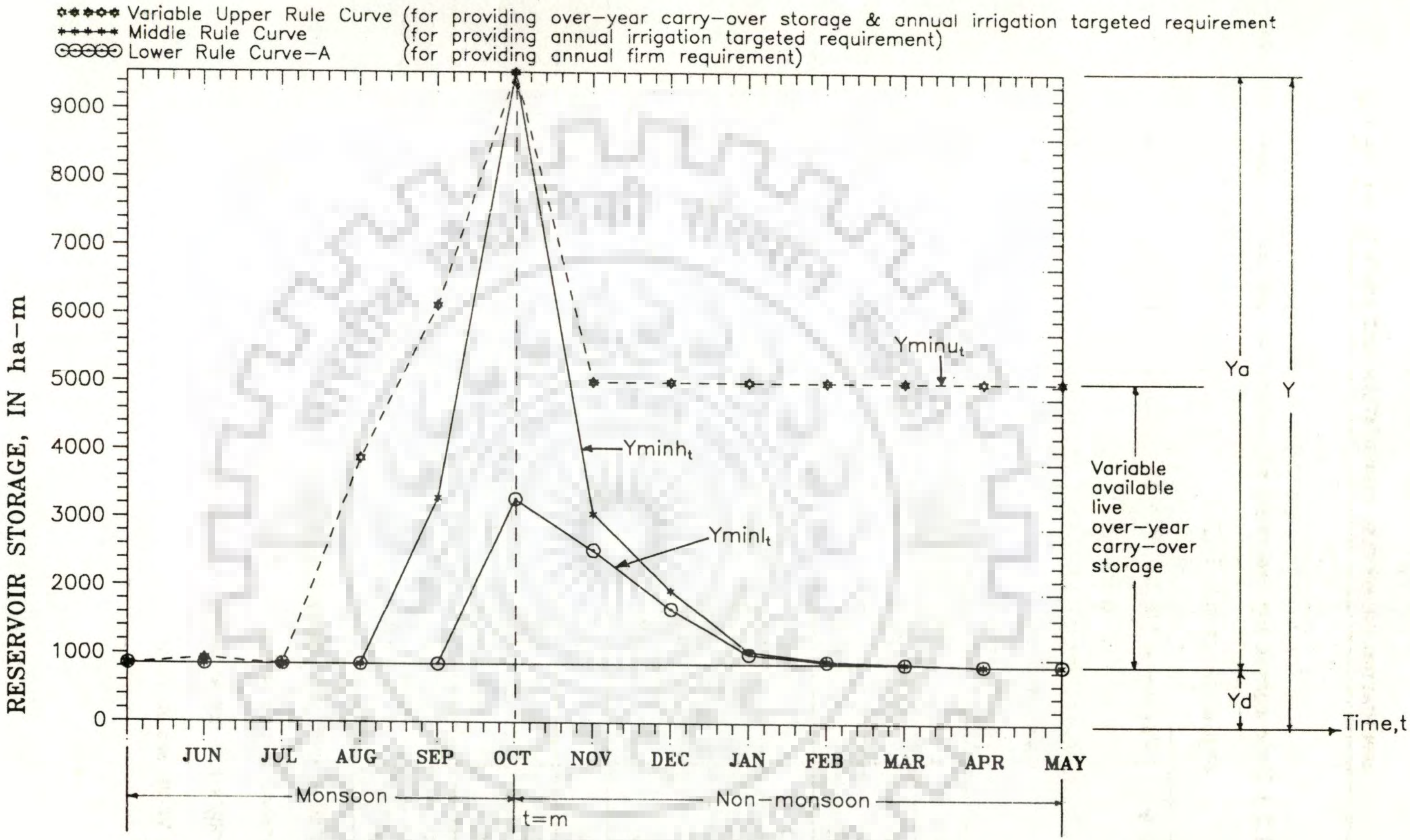


Fig. 10.7 Multi-rule curves for Badanala reservoir operation for proposed reservoir

Table 10.3.2.2 Simulation results for proposed reservoir capacity and existing irrigation requirement for Badanala

Month	Average irrigation deficit	No. of irrigation deficits	Percentage of irrigation deficit	No. of times reservoir empty	No. of times reservoir full
Jun	26.347	1	2.20	1	0
Jul	362.716	5	9.80	5	0
Aug	268.229	5	8.86	5	5
Sep	25.080	2	1.10	2	10
Oct	0.000	0	0.00	0	16
Nov	1.265	1	0.09	1	11
Dec	34.659	1	3.12	1	0
Jan	33.641	2	3.80	2	0
Feb	5.424	1	3.84	1	0
Mar	1.618	1	3.85	1	0
Apr	0.278	1	1.10	1	0
May	0.000	0	0.00	0	0

Number of annual deficits in irrigation = 7.
Average annual irrigation deficit = 759.250 ha-m.
Average annual spill = 37290 ha-m.
Net present worth of benefits = Rs. $59727*10^{5}$.

Y = 9550 ha-m, Ir = 14569 ha-m.

Table 10.3.2.3 Simulation results for proposed reservoir capacity and existing irrigation requirement for Badanala

Month	Average irrigation deficit	No. of irrigation deficits	Percentage of irrigation deficit	No. of times reservoir empty	No. of times reservoir full
Jun	0.000	0	0.08	0	0
Jul	358.590	5	9.65	5	0
Aug	262.376	4	8.67	4	5
Sep	22.803	1	0.98	1	10
Oct	27.960	2	2.80	2	16
Nov	0.000	0	5.40	0	11
Dec	61.820	3	2.69	3	0
Jan	30.210	2	0.00	2	0
Feb	0.000	0	0.00	0	0
Mar	0.000	0	0.00	0	0
Apr	0.000	0	0.00	0	0
May	0.000	0	0.00	0	0

Number of annual deficits in irrigation = 8.
Average annual irrigation deficit = 763.759 ha-m.
Average annual spill = 3740 ha-m.
Net present worth of benefits = Rs. $59709 * 10^5$.

Y = 9550 ha-m, Ir = 14569 ha-m.

10.3.3 Computation for Kalluvodduhalla

The multi-rule curves are given in Table 10.3.3.1. These are shown in Figure 10.8 for proposed reservoir capacity. The results of the computations for simulation and rule curves are given in Tables 10.3.3.2 and 10.3.3.3.

10.3.4 Computation for Bodhghat

For single purpose hydropower reservoir, only the Lower Rule Curve-A was found effective and is given in Table 10.3.4.1. and is shown in Figure 10.9 for proposed reservoir capacity. The results of the computations for simulation and rule curve are given in Tables 10.3.4.2 and 10.3.4.3.

10.3.5 Computation for Bargi

The multi-rule curves are given in Table 10.3.5.1 and are shown in Figure 10.10 for proposed reservoir capacity. The results of the computations for simulation and rule curves are given in Tables 10.3.5.2 and 10.3.5.3.

Table 10.3.3.1 Rule curves for reservoir operation for annual targeted and firm requirements for Kalluvodduhalla for proposed reservoir

Month	Variable Upper Rule Curve for over-year carry-over storage and annual targeted requirement	Middle Rule Curve for annual targeted requirement	Lower Rule Curve-A for annual firm requirement
Jun	0.874	0.874	0.874
Jul	11.735	2.279	0.874
Aug	14.500	14.500	0.874
Sep	S^o_{12}	9.596	6.962
Oct	S^o_{12}	6.997	5.142
Nov	S^o_{12}	6.068	4.490
Dec	S^o_{12}	5.721	4.244
Jan	S^o_{12}	5.021	3.752
Feb	S^o_{12}	2.320	2.559
Mar	S^o_{12}	1.222	1.120
Apr	S^o_{12}	0.924	0.911
May	S^o_{12}	0.874	0.874

S^o_{12} is obtained from Figure 10.8.

All values are in MCM.

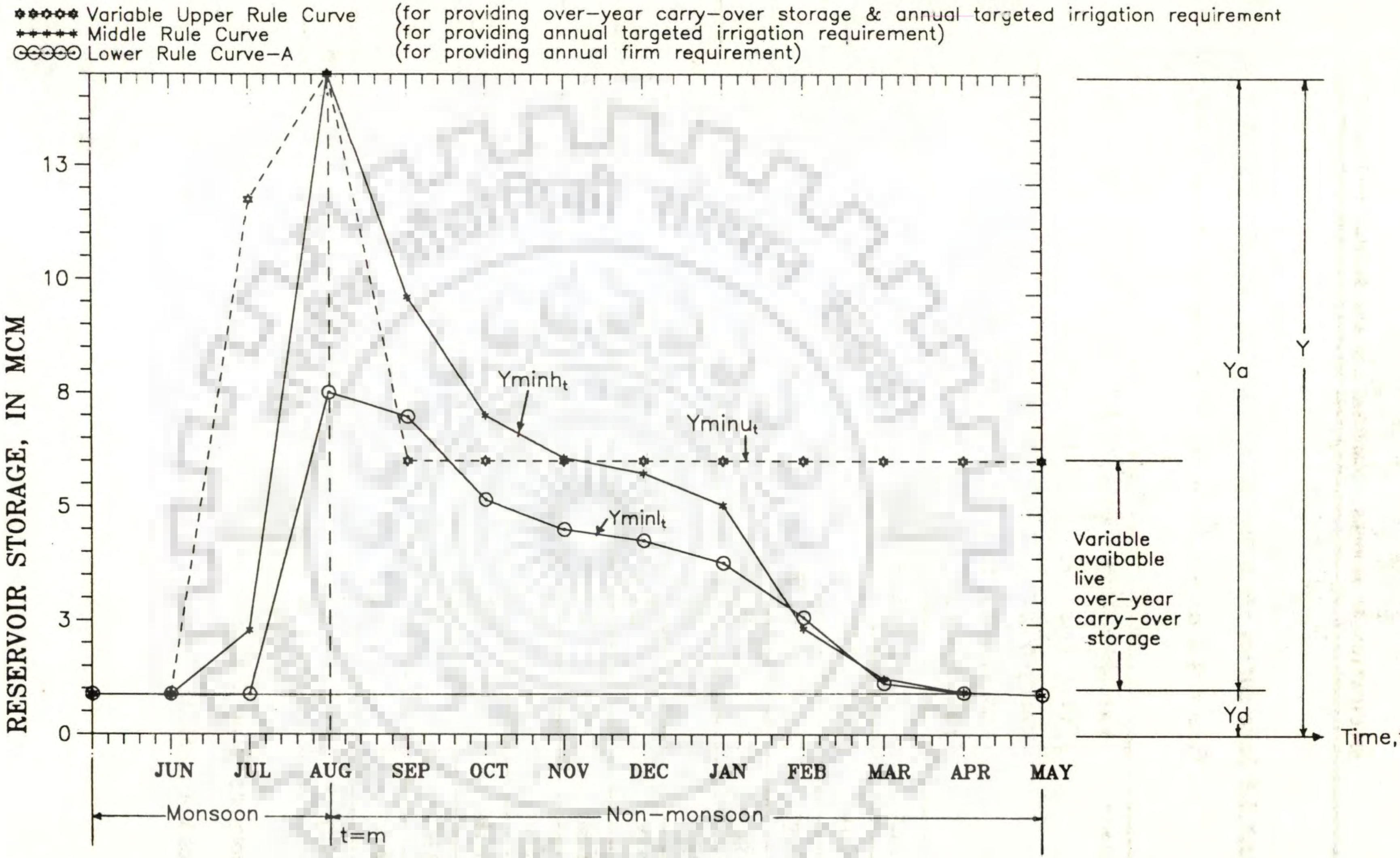


Fig. 10.8 Multi-rule curves for Kalluvodduhalla reservoir operation for proposed reservoir

Table 10.3.3.2 Simulation results for proposed reservoir capacity and existing irrigation requirement for Kalluvodduhalla

Month	Average irrigation deficit	No. of irrigation deficit	Percentage of irrigation deficit	No. of times reservoir empty	No. of times reservoir full
Jun	0.6024	11	14.10	2	0
Jul	0.0000	0	0.00	0	5
Aug	0.0000	0	0.00	0	13
Sep	0.0000	0	0.00	0	7
Oct	0.0000	0	0.00	0	7
Nov	0.0000	0	0.00	0	3
Dec	0.0117	1	3.37	1	0
Jan	0.0234	1	3.43	1	0
Feb	0.1116	2	6.56	2	0
Mar	0.2295	4	10.95	3	0
Apr	0.0398	4	13.35	4	0
May	0.0070	4	14.00	4	0

Number of annual deficits in irrigation = 15.
Average annual irrigation deficit = 1.0255 MCM.
Average annual spill = 4.941 MCM.
Net present worth of benefits = Rs. $482*10^{5}$.

Y = 14.50 MCM, Ir = 17.549 MCM.

Table 10.3.3.3 Multi-rule curves operation results for proposed reservoir capacity and existing irrigation requirement for Kalluvodduhalla

Month	Average irrigation deficit	No. of irrigation deficits	Percentage of irrigation deficit	No. of times reservoir empty (reaches rule curves)	No. of times reservoir full
Jun	0.5000	10	11.68	0	0
Jul	0.0000	0	0.00	0	5
Aug	0.0000	0	0.00	0	13
Sep	0.0000	0	0.00	0	7
Oct	0.1893	3	7.28	3	7
Nov	0.0000	0	0.00	0	3
Dec	0.0117	1	3.37	1	0
Jan	0.0838	2	11.97	2	0
Feb	0.1116	2	6.56	2	0
Mar	0.1930	2	9.19	2	0
Apr	0.0000	0	0.00	0	0
May	0.0000	0	0.00	0	0

Number of annual deficits in irrigation = 16.
Average annual irrigation deficit = 1.0894 MCM.
Average annual spill = 4.941 MCM.
Net present worth of benefits = Rs. $476*10^5$.

Y = 14.50 MCM, Ir = 17.549 MCM.

Table 10.3.4.1 Rule curve for reservoir operation for annual targeted and firm requirements for Bodhghat for proposed reservoir

Month	Lower Rule Curve-A for annual firm energy requirement
Jun	1133
Jul	1988
Aug	1871
Sep	3499
Oct	3212
Nov	2898
Dec	2572
Jan	2273
Feb	1883
Mar	1510
Apr	1155
May	740

All values in MCM.

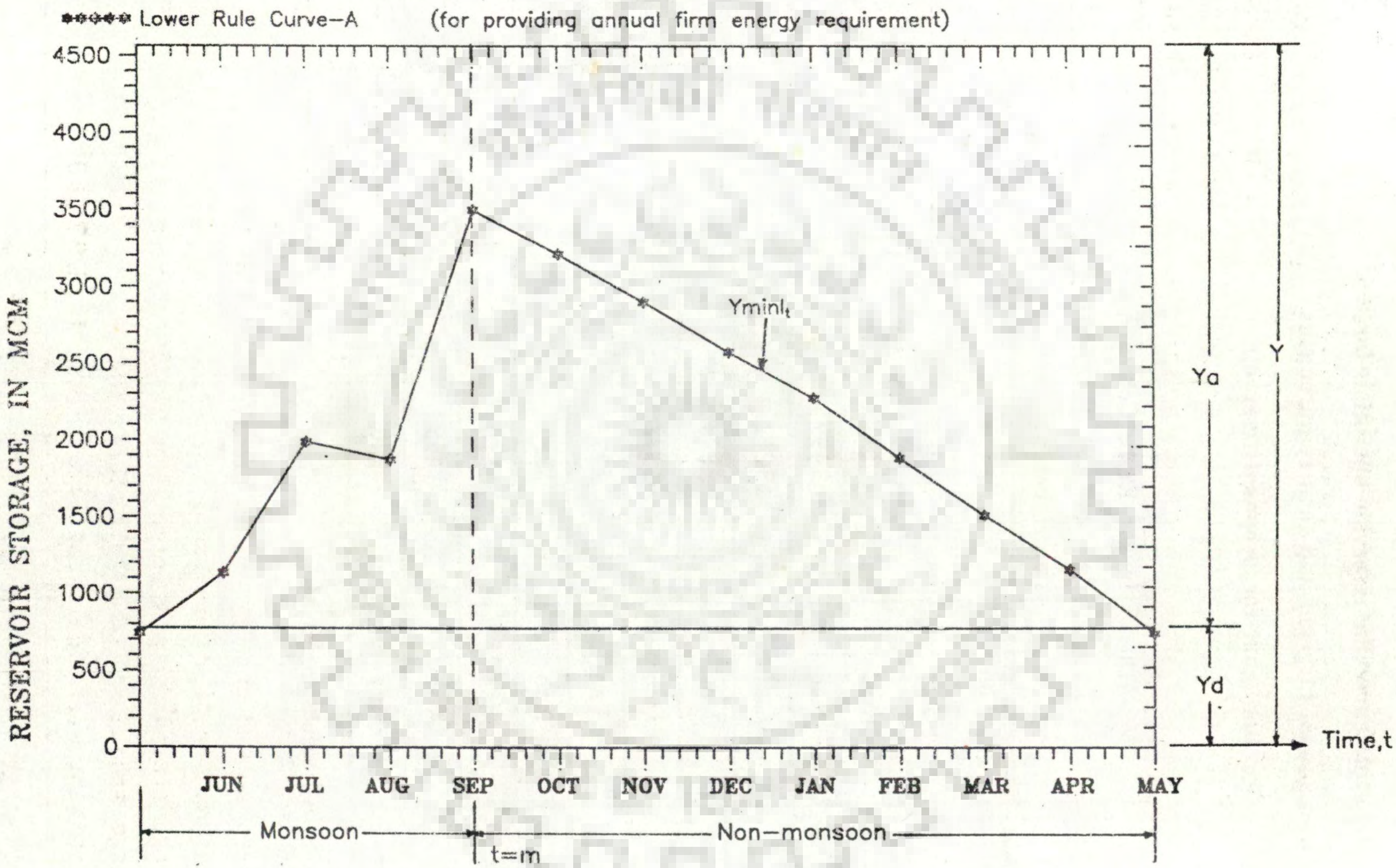


Fig. 10.9 Single–rule curves for Bodhghat reservoir operation for proposed reservoir

Table 10.3.4.2 Simulation results for proposed reservoir capacity and existing hydropower requirement for Bodhghat

Month	Average energy deficit	No. of energy deficits	Percentage of energy deficit	No. of times reservoir empty	No. of times reservoir full
Jun	0	0	0.00	0	1
Jul	0	0	0.00	0	1
Aug	0	0	0.00	0	4
Sep	0	0	0.00	0	4
Oct	6526	1	6.03	1	0
Nov	9039	1	8.35	1	0
Dec	9278	1	8.57	1	0
Jan	9893	1	9.09	1	0
Feb	6834	1	7.99	1	0
Mar	5013	1	5.80	1	0
Apr	3150	1	3.95	1	0
May	2400	2	3.00	2	0

Number of annual deficits in energy = 1.
Average annual energy deficit = 52133 MWhr.
Number of annual dump energy = 2.
Average annual dump energy = 30530 MWhr.
Average annual spill = 117 MCM.
Net present worth of benefits = Rs. $11107*10^6$

Y = 4565 MCM, H = 500 MW, and E = 1139000 MWhr.

Table 10.3.4.3 Single-rule curves operation result for proposed reservoir capacity and existing hydropower requirement for Bodhghat

Month	Average energy deficit	No. of energy deficits	Percentage of energy deficit	No. of times reservoir empty (reaches rule curves)	No. of times reservoir full
Jun	0	0	0.00	0	1
Jul	0	0	0.00	0	2
Aug	0	0	0.00	0	5
Sep	1232	1	1.20	1	5
Oct	4839	1	4.52	1	0
Nov	7832	1	7.23	1	0
Dec	8123	1	8.06	1	0
Jan	7828	1	8.06	1	0
Feb	13906	1	16.27	1	0
Mar	4873	2	5.70	1	0
Apr	2889	1	3.62	1	0
May	1728	1	2.20	1	0

Number of annual deficits in energy = 2.
Average annual energy deficit = 53250 MWhr.
Number of annual dump energy = 3.
Average annual dump energy = 42392 MWhr.
Average annual spill = 162 MCM.
Net present worth of benefits = Rs. $10743*10^6$

Y = 4565 MCM, H = 500 MW, and E = 1139000 MWhr.

Table 10.3.5.1 Rule curves for reservoir operation for annual targeted and firm requirements for Bargi for proposed reservoir

Month	Variable Upper Rule Curve for over-year carry-over storage and annual targeted requirement	Middle Rule Curve for annual targeted requirement	Lower Rule Curve-A for annual firm requirement	Lower Rule Curve-B for annual firm water supply requirement
Jul	1.325	1.301	0.742	0.742
Aug	3.970	3.970	1.229	0.908
Sep	4.310	3.310	1.246	1.000
Oct	S^o_{12}	3.272	3.167	0.875
Nov	S^o_{12}	2.851	2.892	0.858
Dec	S^o_{12}	2.546	1.991	0.841
Jan	S^o_{12}	2.105	1.741	0.824
Feb	S^o_{12}	1.811	1.523	0.809
Mar	S^o_{12}	1.529	1.392	0.792
Apr	S^o_{12}	1.262	1.127	0.776
May	S^o_{12}	1.002	0.894	0.759
Jun	S^o_{12}	0.742	0.742	0.742

S^o_{12} is obtained from Figure 10.10.

All values are in TMC.

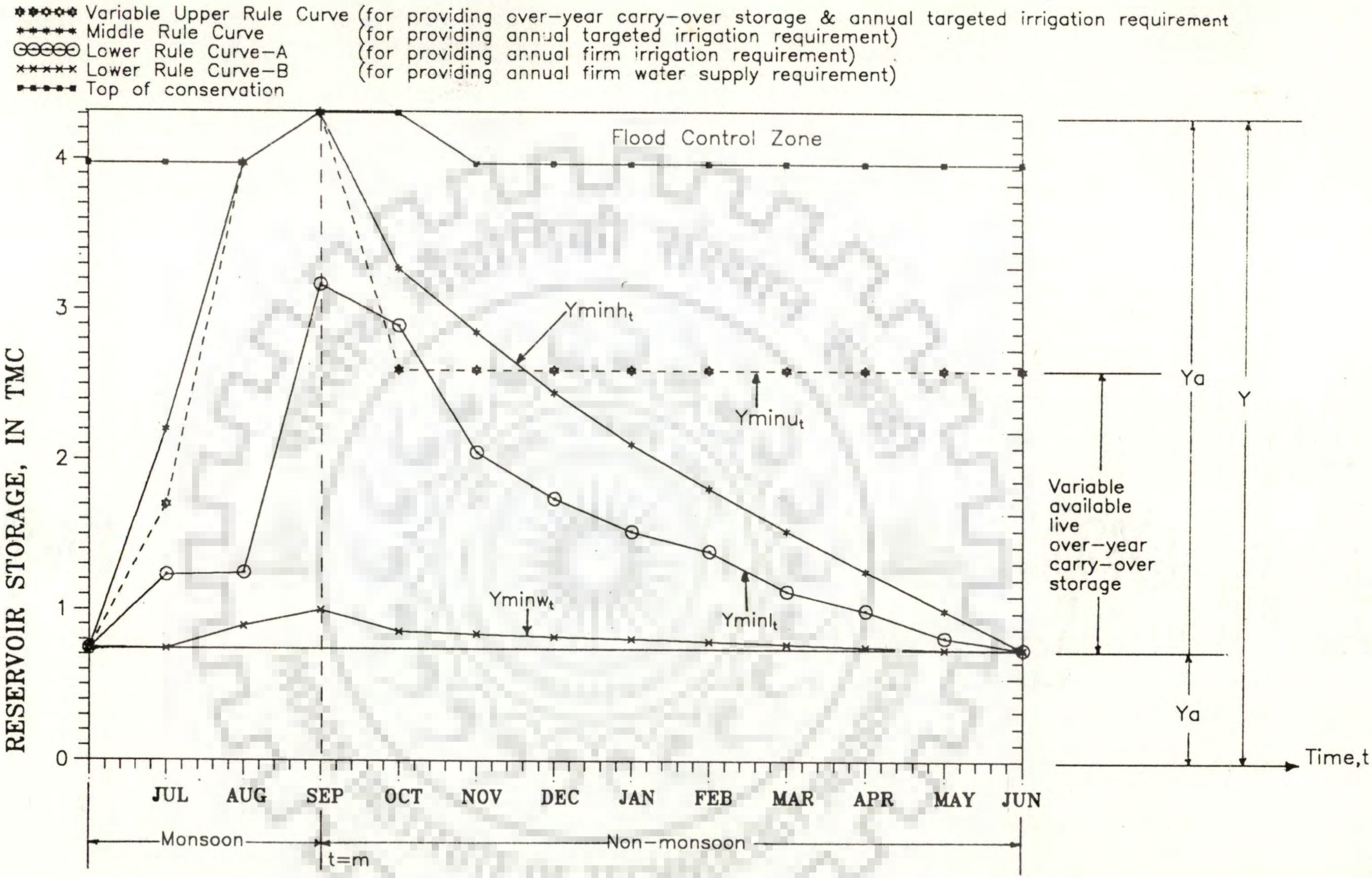


Fig. 10.10 Multi-rule curves for Bargi reservoir operation for proposed reservoir

Table 10.3.5.2 Simulation results for proposed reservoir capacity and existing irrigation requirement and existing hydropower for Bargi

Month	Water supply deficits			Irrigation deficits			Energy deficits			No. of times reservoir empty	No. of times reservoir full
	Average	No.	Percentage	Average	No.	Percentage	Average	No.	Percentage		
Jul	0.00000	0	0.00	0.00000	0	0.00	0	0	0.00	0	2
Aug	0.00000	0	0.00	0.00000	0	0.00	0	0	0.00	0	12
Sep	0.00000	0	0.00	0.00000	0	0.00	0	0	0.00	0	9
Oct	0.00000	0	0.00	0.00000	0	0.00	0	0	0.00	0	4
Nov	0.00000	0	0.00	0.00000	0	0.00	0	0	0.00	0	0
Dec	0.00000	0	0.00	0.00689	1	2.23	870	1	2.6	1	0
Jan	0.00071	2	4.17	0.04002	2	9.10	2992	2	9.1	2	0
Feb	0.00139	2	9.10	0.03410	3	11.50	3537	3	12.0	3	0
Mar	0.00168	3	9.89	0.03846	3	13.60	3591	3	13.6	3	0
Apr	0.00236	4	14.30	0.04860	4	18.20	4190	4	18.2	4	0
May	0.00309	4	18.20	0.06563	5	18.90	4190	4	18.2	5	0
Jun	0.00048	1	2.90	0.03619	5	13.92	3370	5	14.5	5	0

Number of annual deficits in water supply = 5.
Average annual deficit in water supply = 0.00971 TMC.
Number of annual deficits in irrigation = 7.
Average annual deficit in irrigation = 0.26950 TMC.
Number of annual deficits in hydropower = 6.
Average annual deficit in hydropower = 22710 MWhr.
Number of annual dump energy = 22.
Average annual dump energy = 157472 MWhr.
Average annual spill = 1.221 TMC, and
Net present worth of benefits = Rs. $3372*10^7$

Y = 4.310 TMC, Ir = 3.947 TMC, Ws = 0.2 TMC, H=90 MW and E=329000 MWhr.

Table 10.3.5.3 Multi-rule curves operation results for proposed reservoir capacity and existing irrigation requirement and existing hydropower for Bargi

Month	Water supply deficits			Irrigation deficits			Energy deficits			No. of times reservoir empty (reaches rule curves)	No. of times reservoir full
	Average	No.	Percentage	Average	No.	Percentage	Average	No.	Percentage		
Jul	0.00000	0	0.00	0.0000	0	0.00	0	0	0.00	0	2
Aug	0.00000	0	0.00	0.0000	0	0.00	0	0	0.00	0	10
Sep	0.00078	1	4.72	0.0971	3	19.10	403	4	13.69	4	11
Oct	0.00000	0	0.00	0.0105	1	3.25	0	0	0.00	1	5
Nov	0.00112	2	7.45	0.0782	3	18.40	3569	3	18.13	3	0
Dec	0.00077	1	4.53	0.0337	3	11.04	3399	3	10.33	3	0
Jan	0.00000	0	0.00	0.0104	1	2.37	338	1	1.03	1	0
Feb	0.00000	0	0.00	0.0588	1	2.00	508	1	1.72	1	0
Mar	0.00000	0	0.00	0.0105	2	3.75	884	2	3.25	2	0
Apr	0.00000	0	0.00	0.0107	2	4.00	782	2	3.39	2	0
May	0.00000	0	0.00	0.0217	2	8.10	978	2	4.25	2	0
Jun	0.00000	0	0.00	0.0000	0	0.00	0	0	0.00	0	0

Number of annual deficits in water supply = 3.
Average annual deficit in water supply = 0.00260 TMC.
Number of annual deficits in irrigation = 7.
Average annual deficit in irrigation = 0.27873 TMC.
Number of annual deficits in hydropower =5.
Average annual deficit in hydropower = 16315 MWhr.
Number of annual dump energy = 22.
Average annual dump energy = 159139 MWhr.
Average annual spill = 1.474 TMC, and
Net present worth of benefits = Rs. $3454*10^7$

Y = 4.310 TMC, Ir = 3.947 TMC, Ws = 0.2 TMC, and H=90 MW, E=329000 MWhr.

CHAPTER 11

ANALYSIS & CONCLUSION

Chapter-11

ANALYSIS AND CONCLUSION

11.1.0 GENERAL

The analysis in this chapter is based on the models given in Chapters-3, 4, 5 and 9. These models were applied to four reservoirs in India given in Chapter-7. The Chapter-8 gives the computational procedure for reservoir planning and the cost and benefit-loss functions needed. The computed values of costs and benefits are tabulated in Table Nos. from 8.2.2 to 8.2.5. The Chapter-10 dealt with the computational procedure for reservoir operation.

The computations were done basically for integrated planning and operation of a reservoir. The strategies followed were explained in Chapters-8 and 10.

The computer software (MATGEN PACKAGE), given in Appendix-3.I.A for generation of Input Data Matrix coupled with simplex package were used for the linear programming computations. A computer programme given in Appendix-1 was used for the dynamic programming computations. The simulation technique was used for finer screening and testing the results of various models at different stages. The computer programme for simulation in given in Appendix-2 . The average annual flows and the annual flows of various dependabilities were used in optimization models. These optimization models were run for periods ranging from a period of one year only to a period of the entire length of the historical streamflow records. In a year either one or subperiods ranging from seasonal to monthly were considered. In simulation monthly flows for the recorded historical data were used. In optimization models single economic objective criteria was considered, where as in simulation multi-objective criterion consisting of economic, and water use project dependability were used.

11.2.0 ANALYSIS OF RESULTS FOR RESERVOIR PLANNING

The two categories of optimization models were used for reservoir planning as follows:

Category-I Models: These models were used to account for short term variations in the inflows. They used river flow data of one year length only. These included the linear programming models Max.Z_{nb}, Max.Z_{sy}, Max.Z_{tr}, and the dynamic programming model.

Category-II Models: These models were used to account for the long term variations in the inflows. They used river flow data of entire length of the recorded historical flows. These included linear programming models Min.Z_{gc}, and Min.Z_{oc}.

The results of these models are summarized in Tables 11.2.1.1 to 11.2.1.3; Tables 11.2.2.1 to 11.2.2.3; Tables 11.2.3.1 to 11.2.3.3; and Tables 11.2.4.1 to 11.2.4.3 for reservoirs Badanala, Kalluvodduhalla, Bodhghat, and Bargi respectively.

Table 11.2.1.1 Reservoir capacity for Badanala project

Model	Flow	Total number of subperiods	Ya	Y	$\frac{Y}{9550}$
Max.Z_{nb}	Average	12*1 = 12	5464	(6314)	0.661
	25% Probability	12*1 = 12	6880	(7730)	0.809
Min.Z_{gc}	26 years (Min.Z_{gcs})	26*2 = 52	(9945)	10795	1.130
	26 years (Min.Z_{gcc})	26*3 = 78	(10786)	11636	1.218
Proposed from simulation (see Table 11.2.1.3)			8700	(9550)	1.000
Existing (see Table 11.2.1.3)			6714*	7564*	0.792

Note:

* Given.

(i) For model Min.Z_{gc} annual target for irrigation is equal to the project provision of 14569 ha-m.

(ii) All volumetric values are in ha-m.

(iii) The values without brackets were obtained from the models.

(iv) The values within brackets were obtained either by adding or subtracting the dead storage in Ya or from Y respectively as the case may be.

Table 11.2.1.2 Over-year carry-over reservoir capacity for Badanala project

Model	Flow	Total number of subperiods	Y^o	S_0^o	S_{12}^o	carry-over / Y
Min.Z_{oc}	26 years	26*1 = 26	7691	-	-	□ 0.713
Max.Z_{tr}	Highest recorded annual flow	12*1 = 12	-	-	5120	-
	Lowest recorded annual flow	12*1 = 12	-	5875 +	-	□□ 0.930
Proposed from simulation (see Table 11.2.1.3)				3890	8594	□□□ 0.899
Existing from simulation (see Table 11.2.1.3)				6371	6730	-

Note:
(i) For model Min.Z_{oc} the annual irrigation target is equal to project provision of 14569 ha-m.
(i) For model Max.Z_{tr} the annual target for irrigation is from model Max.Z_{sy}, i.e., 13445 ha-m and reservoir capacity was taken from model Max.Z_{nb} for average flow equal to 6314 ha-m.
(iii) All volumetric values are in ha-m,

Y^o = Over-year carry-over capacity,

S_0^o = Maximum gross over-year carry-over storage required at the beginning of a year, and

S_{12}^o = Maximum gross over-year carry-over storage available at the end of a year.

\+ Larger of S_0^o and S_{12}^o is a measure of over-year carry-over capacity.

□ Y is from model Min.Z_{gcs},

□□ Y is from model Max.Z_{nb},

□□□ Y is from proposed.

Table 11.2.1.3 Simulation results for Badanala project

Model		Ya (Y)	Ir	S_0^o	S_{12}^o	% Project dependability
Simulation	Existing	6714* (7564)*	14569*	6371	6730	70
			13770	–	–	75
	Proposed	8700 (9550)	14569*	3890	8594	75

Note: All volumetric values are in ha-m.
* Given.

Table 11.2.2.1 Reservoir capacity for Kalluvodduhalla project

Model	Flow	Total number of subperiods	Ya Y	Y / 14..
$Max.Z_{nb}$	Average	12*1 = 12	12.29 (13.17)	0.90
	50 % Probability	12*1 = 12	12.20 (13.07)	0.90
$Min.Z_{gc}$	30 years ($Min.Z_{gcs}$)	30*2 = 60	(17.796) 18.67	1.28
	30 years ($Min.Z_{gcc}$)	30*3 = 90	(18.476) 19.35	1.33
Proposed from simulation (see Table 11.2.2.3)			13.626 (14.5)	1.00
Existing (see Table 11.2.2.3)			11.302* 12.176*	0.84

Note:

(i) For model $Min.Z_{gc}$ annual target for irrigation is equal to the project provision of 17.547 MCM.

(ii) All volumetric values are in MCM.

Table 11.2.2.2 Over-year carry-over reservoir capacity for Kalluvodduhalla project

Model	Flow	Total number of subperiods	Y^o	S^o_0	S^o_{12}	Car ove Y
$Min.Z_{oc}$	30 years	30*1 = 30	11.87	-	-	0.6
$Max.Z_{tr}$	Highest recorded annual flow	12*1 = 12	-	-	7.70+	0.5
	Lowest recorded annual flow	12*1 = 12	-	4.7	-	-
Proposed from simulation (see Table 11.2.2.3)				4.10	10.1	0.6
Existing from simulation (see Table 11.2.2.3)				6.82	7.89	-

Note:

(i) For model $Min.Z_{oc}$ the annual irrigation target is equal to project provision of 17.549 MCM.

(i) For model $Max.Z_{tr}$ the annual target for irrigation is from model $Max.Z_{sy}$, i.e., 15.52 MCM and reservoir capacity was taken from model $Max.Z_{nb}$ for average flow equal to 13.17 MCM.

(iii) All volumetric values are in ha-m.

Table 11.2.2.3 Simulation results for Kalluvodduhalla project

Model		Ya (Y)	Ir	S_0^o	S_{12}^o	% Project dependability
Simulation	Existing	11.302* (12.176)*	17.549*	6.82	7.89	42
			16.22	–	–	50
	Proposed	13.526 (14.500)	17.549*	4.10	10.10	50

Note: All volumetric values are in MCM.

* Given.

Table 11.2.3.1 Reservoir capacity for Bodhghat project

Model	Flow	Total number of subperiods	Ya	Y	$\frac{Y}{4564}$
Max.Z_{nb}	Average	12*1 = 12	2818	(3558)	0.779
	10 % Probability	12*1 = 12	3818	(4558)	0.998
Min.Z_{gcs}	10 years	10*2 = 20	(2536)	3276	0.718
Proposed from simulation (see Table 11.2.3.3)			3825	(4565)	1.000
Existing (see Table 11.2.3.3)			3718*	4458*	0.976

Note:

(i) For model Min.Z_{gc} water equivalent for annual target for energy was taken from model Max.Z_{sy} equal to 3802 MCM.

(ii) All volumetric values are in MCM.

Table 11.2.3.2 Over-year carry-over reservoir capacity for Bodhghat project

Model		Flow	Total number of subperiods	Y^o	S_0^o	S_{12}^o	Carry-over / Y
$Min.Z_{oc}$		10 years	10*1 = 10	1673	-	-	0.511
$Max.Z_{tr}$		Highest recorded annual flow	12*1 = 12	-	-	2020	-
		Lowest recorded annual flow	12*1 = 12	-	3300 +	-	0.927
Proposed from simulation (see Table 11.2.3.3)					1493	2625	0.575
Existing from simulation (see Table 11.2.3.3)					1859	2471	-

Note:

(i) For model $Min.Z_{oc}$ water equivalent for annual target for energy was taken from model $Max.Z_{sy}$ equal to 3802 MCM.

(i) For model $Max.Z_{tr}$ the annual target was taken from model $Max.Z_{sy}$ equal to 881899 MWhr and reservoir capacity was taken from model $Max.Z_{nb}$ for average flow equal to 3558 MCM.

(iii) All volumetric values are in MCM.

Table 11.2.3.3 Simulation results for Bodhghat project

Model		Ya (Y)	H	E	$\bar{E}$	S_0^o	S_{12}^o	% Project dependability
Simulation	Existing	3718* (4458)*	500*	1139000*	30090	1859	2471	80
			500*	1120000	52624	–	–	90
	Proposed	3825 (4565)	500*	1139000*	30530	1493	2625	90

Note: All volumetric values are in MCM, H in MW, E, and $\bar{E}$ are in MWhr.

* Given.

Table 11.2.4.1 Reservoir capacity for Bargi project

Model	Flow	Number of sub-periods	Ya	Y	$\frac{Y}{4.310}$
$Max.Z_{nb}$	Average	12*1 = 12	3.37	(4.112)	0.954
	30 % Probability	12*1 = 12	3.82	(4.562)	1.058
$Min.Z_{gc}$	22 years ($Min.Z_{gcs}$)	22*2 = 44	(5.558)	6.300	1.462
	22 years ($Min.Z_{gcc}$)	22*3 = 66	(5.908)	6.650	1.543
Proposed from simulation (see Table 11.2.4.3)			3.568	4.310	1.000
Existing (see Table 11.2.4.3)			3.190*	3.932*	0.912

Note:
(i) For model $Min.Z_{gc}$ annual target for irrigation is equal to the project provision of 3.947 TMC.
(ii) All volumetric values are in TMC.

Table 11.2.4.2 Over-year carry-over reservoir capacity for Bargi project

Model	Flow	Total number of subperiods	Y^o	S_0^o	S_{12}^o	$\frac{\text{Carry-over}}{Y}$
$Min.Z_{oc}$	22 years	22*1 = 22	4.06	-	-	0.644
$Max.Z_{tr}$	Highest recorded annual flow	12*1 = 12	-	-	2.50	-
	Lowest recorded annual flow	12*1 = 12	-	3.00+	-	0.729
Proposed from simulation (see Table 11.2.4.3)				1.20	2.24	0.519
Existing from simulation (see Table 11.2.4.3)				1.96	1.70	—

Note:
(i) For model $Min.Z_{oc}$ the annual irrigation target is equal to project provision of 3.947 TMC.
(ii) For model $Max.Z_{tr}$ the annual target for irrigation is from model $Max.Z_{sy}$, i.e., 3.77 TMC and reservoir capacity was taken from model $Max.Z_{nb}$ for average flow equal to 4.102 TMC.
(iii) All volumetric values are in TMC.

Table 11.2.4.3 Simulation results for Bargi project

Model		Ya (Y)	Ws	Ir	H	E	Ē	S_0^o	S_{12}^o	% project dependability		
										Ws	Ir	E
Simulation	Existing	$3.19^*(3.932)^*$	0.2^*	3.947^*	90^*	329000^*	147974	1.96	1.70	74	65	65
			0.2^*	3.947^*	90^*	259000	207568	–	–	74	70	70
			0.2^*	3.681	90^*	329000^*	133907	–	–	83	70	74
	Proposed	3.568 (4.31)	0.2^*	3.947^*	90^*	329000^*	157472	1.20	2.24	78	70	74

Note: All volumetric values are in TMC, H in MW, E and Ē are in MWhr.
* Given.

11.2.1 Analysis for Results of Model Max.Z_{nb}

The linear programming model Max.Z_{nb} was used to estimate the values of reservoir capacity and annual targeted demands in order to regulate the annual flows and to maximize the net annual benefits from various water uses. The model used a number of yearly flows, i.e., highest recorded annual flow, lowest recorded annual flow, average flow, and annual flow of a given dependability (i.e., 75 % dependable year's flow for an irrigation project under normal conditions; 50 % dependable year's flow for an irrigation project under drought conditions; 90 % dependable year's flow for a hydropower project; and 70 % dependable year's flow for a multipurpose project) based on the dependability criterias adopted in India for planning.

The model was made more realistic and practicable by adding some more constraints depicting a few design aspects, like the limiting reservoir submergence ratio criteria, the desired annual water utilization factor criteria, and the minimum benefit-cost ratio criteria. For projects with hydropower additional new constraints on minimum annual energy generation, and minimum hydroplant capacity etc. based on flow-duration curve were also incorporated.

The reservoir continuity equation (3.2.1.1) was non linear and was linearized by assuming and effective head and comparing it with the head specified in the model solution. The solutions were relatively insensitive to changes in assumed heads.

The cost functions in the objective function were assumed to be linear in the model. These assumptions were fairly good in the sense that the values of design variables obtained were within the assumed linear segments.

The results of simulation Tables 8.3.1.2, 8.3.1.6; 8.3.2.2, 8.3.2.6; and 8.3.4.2, 8.3.4.6 for projects with irrigation show that in model Max.Z_{nb} the annual flows of small dependability give very high reservoir capacity and very large annual target, and annual flows of high dependability give small reservoir capacity and small annual target.

For uniformity, 80 % annual utilization factor may be considered for all the projects with irrigation, which happens to be minimum desired value for projects in India. From the results of simulation in the tables mentioned above it is seen that for the reservoir capacity obtained from model Max.Z_{nb}, the annual flows of small dependability give very high annual utilization factor for desired project dependability (success), where as, the annual flows of high dependability give very low annual utilization factor for desired project dependability.

On the other hand the average annual flows give the near desired value of annual utilization factor for desired project dependability (success), and a reasonably good estimate of the reservoir capacity.

However, for a single purpose hydropower project, 90 % annual utilization factor may be chosen. Here, the annual flows of small dependability give the near desired value of the annual utilization factor for desired project dependability (success), and a good estimate of the reservoir capacity.

In general this model estimated reservoir capacities slightly smaller in the range of 0.661 to 0.908 times of the proposed ones by simulation.

The cropping patterns were not considered in the computation as the field level planning is not desired.

11.2.2 Analysis of Model Max.Z_{sy} Results

After deciding the size of the reservoir with average annual flows, the annual water use demands were revised and refined using this model to provide the annual safe targeted and firm yields (demands). For reservoirs with irrigation the 75 % dependable year's flow and for a single purpose hydropower reservoir the 90 % dependable year's flow were taken as the inflows for targeted yield. For annual safe firm yield the lowest recorded annual flows were used. The annual safe yields for projects with irrigation provided by this model were close to the values provided by simulation based on the given project dependability criterias for the same reservoir capacity. Whereas for hydroenergy these variations were large as in model Max.Z_{sy} either the storage heads could not be matched easily or the annual flow was large for a multipurpose reservoir.

11.2.3 Analysis of Model Max.Z_{tr} Results

This model was used to estimate the likely available/required over-year carry-over reservoir storages from the reservoir size and for the annual targeted demand obtained above from models Max.Z_{nb} and Max.Z_{sy} respectively, under the conditions that the reservoir will be full at the end of monsoon period and the annual targeted demand will be met.

For likely maximum available over-year carry-over reservoir storage the highest recorded flow was used and for likely maximum required over-year carry-over storage the lowest recorded flow was used. The larger of this value is a measure of the over-year carry-over reservoir capacity.

11.2.4 Analysis on Using Annual Flows of a Probability of Given Occurrence

The L.P. model Max.Z_{nb} using the average flows estimated a lower reservoir capacity, gave high average annual spill, and the annual water utilization factor quite less the desired. Hence, a reservoir capacity greater than to accommodate average flows was estimated using an annual inflow equal to a desired probability of less than equal to 50% occurrence (the probability of occurrence of average flows) depending upon the type of project, such that a portion of the annual flow of less than this occurrence would be spilled. This desired probability is similar to the concept of a desirable project success (dependability).

The concept of using annual flows of a probability of given occurrence in model Max.Z_{nb} estimated a better reservoir capacity, and was a measure to account for the long term variations in the inflows.

This estimated closer reservoir capacities in the range of 0.809 to 1.058 times the proposed ones by simulation.

11.2.5 General Remarks on Category-I Models

(i) While using average annual flows the model Max.Z_{nb} accounted for short term variations in the river inflows.

(ii) While using annual flows of a desired probability depending upon the type of project the model Max.Z_{nb} accounted for the long term variations in the river inflows.

(iii) They use single objective of maximizing the net annual benefits/ returns.

(iv) They require less computer memory and reasonably less computation time.

(v) These models use river flow data of same length, i.e., of one year length only depending upon the type of project, hence, approach is more uniform in terms of the length of the data used.

11.2.6 Analysis of Model Min.Z_{gc} Results

This model estimated reservoir capacity to provide known annual targeted demand, using the entire length of the historical recorded inflows. It used crop seasons or monsoon and non-monsoon seasons as multi-periods in a year. The known annual targeted demands for project with irrigation was taken equal to the project provision (i.e., 75 % dependable year's flow) and for a single purpose hydropower project (i.e., 90 % dependable year's flow).

This model generally estimated slightly higher values for reservoir capacities in the range of 1.1 to 1.3 times of proposed ones by simulation.

11.2.7 Analysis of Model Min.Z_{oc} Results

This model was run similar the model Min.Z_{gc}, except that no multi-periods were considered in a year. This model also provided a good estimate of the over-year carry-over reservoir capacity.

11.2.8 General Remarks on Category-II Models

(i) These models account for long term variations in the river inflows.

(ii) They use single objective of minimizing the reservoir storage.

(iii) They require large computer memory and large computation time.

(iv) These models use historical river flow data of different lengths, hence, approach is not uniform in terms of the length of the data used.

11.3.0 ANALYSIS OF RESULTS FOR RESERVOIR OPERATION

11.3.1 Planning for Reservoir Operation

For planning for reservoir operation for existing and proposed reservoirs Category-I Models Max.Z_{sy}, Max.Z_{tr}, and dynamic programming model were used as follows:

11.3.1.1 Analysis of model Max.Z_{sy} results

The model provided the annual safe targeted demand for known reservoir capacity to be used further for finding reasonable over-year carry-over storages.

11.3.1.2 Analysis of model Max.Z_{tr} results

This model provided the ranges of over-year carry-over storages available and required for known reservoir capacity and annual safe targeted demand for highest and lowest probability flows. It also gave the reservoir storages at the end of each month which provided the approximate corridors for storage limits in various months.

11.3.1.3 Analysis of dynamic programming model results

The variations in the over-year carry-over reservoir storages available at the end of a year and required at the beginning of a year were estimated for a known reservoir capacity and annual safe targeted demand. The known ranges and the approximate corridors for storage limits obtained from model Max.Z_{tr} helped in reducing the computation time considerably.

11.3.2 Analysis of Reservoir Operation

Reservoir operation was carried out using multi-rule curves based on the actual monsoon flows and the state of the reservoir at the end of monsoon period. Three conditions were visualized, i.e.,

(i) **Case-I** (reservoir operation with Variable Upper Rule Curve): When high monsoon flows were above normal monsoon flows and and reservoir was full at the end of monsoon period. This rule curve provided over-year carry-over storage at the end of a year and which could also provide the targeted demand in the non-monsoon period.

(ii) **Case-II** (reservoir operation with Middle Rule Curve): When high monsoon flows were below normal monsoon flows and reservoir was full at the end of monsoon period. This rule curve provided targeted demand in the non-monsoon period.

(iii) **Case-III** (reservoir operation with Lower Rule Curve): Low monsoon flows when reservoir was not full at the end of monsoon period. Firstly the Lower Rule Curve-A provided firm demand in the non-monsoon period. Secondly, the Lower Rule Curve-B provided the firm water supply requirement in the non-monsoon period. Thirdly, if sufficient water is not available to provide even firm water supply requirements, encroach the top of dead storage.

The outcome of the reservoir operation can be summarized as follows:

(a) In general, it is seen from reservoir operation that the multi-rule curves operation of a reservoir project with irrigation reduces considerably the amount and number of water use deficits in early monsoon period and in the later part of the non-monsoon period, when in early monsoon demands are large and comparatively less storage and flow occur in a year with monsoon flow less than normal, and in non-monsoon demands are smaller and little storage and flow occur in a year with low non-monsoon flow. This guarantees the availability of sufficient water when it is most needed.

However, the water use deficits were increased in the amount and numbers in the early non-monsoon period as was expected as the total water remains the same.

(b) For a single purpose hydropower reservoir the Lower Rule Curve helps in reducing the energy deficits in the non-monsoon period.

11.3.3 Use of Required Over-year Carry-over Reservoir Storage

Further, it is suggested that the use of required over-year carry-over reservoir storage obtained earlier, may also be made for reservoir operation using Variable Upper Rule Curve in the following manner:

(a) Forecast the monsoon river flows.

(b) Obtain available over-year carry-over reservoir storage, $(S^o_{12})_i$, from the relationship in Figures 10.1 or 10.6 after reservoir is operated for the monsoon period in current year, i.

(c) Obtain required over-year carry-over reservoir storage, $(S^o_0)_{i+1}$ for the next year, i+1, from the relationship in Figures 10.1 or 10.6 before operation for non-monsoon period in the current year, i, is carried out.

(d) Select the value of $(S^o_{12})_i$ in the current year i in the following manner:

$$\text{If } \left[S^o_{12} \right]_i > \left[S^o_0 \right]_{i+1} \text{ , then } \left[S^o_{12} \right]_i = \left[S^o_0 \right]_{i+1};$$

$$\text{If } \left[S^o_{12} \right]_i < \left[S^o_0 \right]_{i+1} \text{ , then } \left[S^o_{12} \right]_i = \left[S^o_{12} \right]_i .$$

(e) Now operate the reservoir with the $(S^o_{12})_i$ obtained above in step (d).

Firstly, the Lower Rule Curve-A provided firm demand in the non-monsoon period. Secondly, the Lower Rule Curve-B provided the firm water supply requirement in the non-monsoon period in case Curve-A is not applicable. Thirdly, if sufficient water is not available to provide even firm water supply requirements, encroach the top of dead storage and satisfy the firm water supply requirements as much as possible.

11.4.0 UTILITY OF COMPUTER SOFTWARE MATGEN PACKAGE

The input data matrix of non-zero coefficients of set of constraint equations of L.P. model is fed in a very standard format to the computer in many standard L.P packages like MPS (Mathematical Programming System) of IBM computers and LINGO, of LINDO Systems Inc. etc. The procedure involved is data intensive and a

Herculean task (Razavian, 1990). In this context, to overcome this difficulty, in the present work a generalized computer algorithm (software) has been developed called (MATGEN PACKAGE). The non-zero coefficients of variables generally are appearing by shifting themselves diagonally/vertically with time increments in every constraint equation. This property has been programmed and a computer algorithm is presented to create the desired Input Data Matrix for the Linear Programming Models.

The main features of this computer algorithm (computer programme), MATGEN are as follows:

(1) The computer programme is very general and can be applied to any single or multipurpose reservoir planning and operation problem using the models described herein.

(2) The developed algorithm is very flexible and any number of new system constraints and, thereupon, system variables can be added according to the problem to be formulated, and the computer programme can be suitably modified.

(3) The above package is feasible, efficient, convenient and fool proof as any omission/error can be rectified and correction incorporated easily in comparison to other available packages like, MPS, LINGO and others. Also, it is possible to use it repetitively any number of times without much difficulty and hesitation as input data is very small and its feeding is less time consuming.

11.5.0 CONCLUSION

The objective of the present study was to develop optimization-simulation models for integrated planning and operation of a reservoir (single purpose and/or multi-purpose). Linear programming and dynamic programming were used as optimization techniques. Four reservoirs were considered on which these models were applied.

The following conclusions may be drawn from the above study:

(i) Optimization-simulation techniques using the linked (nested) models were found most suitable for integrated planning and operation of a reservoir.

(ii) Use of Category-I models, i.e., L.P. models Max.Z_{nb}, Max.Z_{sy}, and Max.Z_{tr}, and of D.P. model require less computation memory and reasonable less computation time. Also, these models use river flow data of same length, i.e., of one year length only depending upon type of project. Hence, the approach used here is more uniform in terms of the length of the data used.

(iii) Use of Category-II models, i.e, L.P. models Min.Z_{gc} and Min.Z_{oc} require large computer memory and large computation time. These models use historical river flow data of different lengths. Hence, the approach used here is not uniform in terms of the length of the data used.

(iv) In Max.Z_{nb}, Max.Z_{tr}, and dynamic programming models a concept of using the annual flow of a probability of given occurrence was used to represent the various annual flows of different dependabilities to make the approach more uniform as each project has different length of historical data.

(v) The L.P. model Max.Z_{nb} using the average flows estimates a lower reservoir capacity and gives high spills. Hence, a reservoir capacity greater than to accommodate average flows is required. This can be done by using inflow equal to any desired probability of less than equal to 50 % occurrence depending upon the type of project in order to obtain a better estimate of reservoir capacity.

(vi) In early monsoon demands are large and comparatively less storage and flow occur in a year with monsoon flow less than normal, and in non-monsoon demands are smaller and small storage and flow occur in a year with low non-monsoon flow. In such cases the use of multi- rule curves operation of a reservoir project with irrigation with Variable Upper Rule Curve reduces the water use deficits in the early monsoon and the non-monsoon periods.

(vii) However, for a single purpose hydropower reservoir use of Lower Rule Curve is recommended for reservoir operation.

(viii) The development of **MATGEN** software package for L.P. model made the construction of the optimization models a less data-intensive and a non-Herculean task. "There is no standardized method whose structure conforms to the real world of water resources well enough that it can be taken as a general mathematical model for its optimization. There is not now, and there probably will never be a "library" of computer programmes for the generalized optimization of water resources systems or subsystems (Hall and Dracup, 1970)". However, the approach used in MATGEN PACKAGE is one such step towards preparing a generalized algorithm (computer programme) very well fitting to the basic multipurpose reservoir planning and operation problems in their real life water resources system.

(ix) The provision of reservoir capacities of various projects as given in project reports are smaller in size than required.

(x) On the basis of the experience of applying the above models, the following suitable and uniform methodology for integrated planning and operation of a reservoir using systems analysis with the help of Category-I Models nested together as suggested below is **recommended**:

(a) Use model Max.Z_{nb} to estimate the initial value of the reservoir capacity by taking annual flows of a probability of given occurrence depending upon the type of project as given in Table 8.3.5.1.

(b) Use model Max.Z_{nb} with average flows to estimate the initial value of the hydroplant capacity.

(c) Use model Max.Z_{nb} with the annual flow of the probability of 90 % occurrence for estimating the initial value of the annual targeted demand for hydroenergy.

(d) Select annual flow of the probability of 75 % occurrence as the annual targeted demand for irrigation.

(e) Use simulation to revise the reservoir capacity and the hydroplant capacity and refine the annual targeted demand for hydroenergy obtained above, as per the project dependability (success) criterias as indicated in Table 8.3.5.1.

(f) Use model Max.Z_{sy} and find the annual safe targeted yield from the reservoir capacity obtained in step **(e)**, by taking annual flows of a probability of given occurrence, i.e., 75 % for an irrigation project under normal conditions, 50% for an irrigation project under drought conditions, 90 % for a hydropower project, and 70 % for a multipurpose project.

(g) Use model Max.Z_{sy} and find the annual safe firm yield/yields from the reservoir capacity obtained in step **(e)**, by taking annual flow of the probability of 99 % occurrence.

(h) Use simulation to correctly estimate the annual safe firm yields.

(i) Use model Max.Z_{tr} for finding the ranges of the available and required over-year carry-over reservoir storages for the reservoir capacity obtained in step **(e)** and to provide the annual safe targeted yield obtained in step **(f)**, by taking annual flows of the probabilities of lowest and highest possible occurrences respectively.

(j) Use dynamic programming model to find out the variations in available and required over-year carry-over storages for the reservoir capacity obtained in step (e), by taking annual flows of selected probabilities of occurrences.

(k) Use Multi-Rule Curves for reservoir operation for a reservoir with irrigation.

(l) Use Lower Rule Curve for reservoir operation for a single purpose hydropower reservoir.

11.6.0 SCOPE FOR FUTURE WORK

(1) The integrated planning and operation problems of a reservoir should be attempted under the conditions of uncertainty using the methodology as recommended at the end of the study undertaken above. Further, the multi-objective criteria should be incorporated in the various objective functions.

(2) For better operation of a reservoir, a study on the real time reservoir operation of a multipurpose reservoir should be attempted.

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APPENDICES

```
C*******************************************************************
C              ***********************************
C                   *************************
C                      COMPUTER PROGRAMME FOR
C                      (DYNAMIC PROGRAMMING)
C              DEVELOPED BY : ASSADULLAH KOHISTANI
C               SUPERVOISER : Dr. D.K  SRIVASTAVA
C                   *************************
C              ***********************************
C*******************************************************************
      DIMENSION  GI(12,190)
      DIMENSION  F(12,190),OIMI(12,190,190),PLSTI(12),PLSII(12),
     1           PUSTI(12),PUSII(12),PLSTF(12),PLSIF(12)

      DIMENSION  PUSTF(12),PUSIF(12),FT(12),FLO(12),
     1           PLLOI(12),PULOI(12),NOI(12,190)

      DIMENSION  FOT(190),GIT(12,190),STATI(12,190)
      DIMENSION  STATG(190),STATF(12,190),FO(190)
     1           ,NOINS(12),NOFLS(12),TITLE(80),SIINF(12,190)

      DIMENSION  NCCUI(12,190,190),NCCUF(12,190,190)
     1           ,IFN(190)

      DIMENSION  PLOTG(12),PUOTG(12),PLOIG(12),PUOIG(12)
      DIMENSION  IALT(12),IUPOT(12),ILOOT(12),IEQOT(12),
     1           IALI(12),IUPOI(12),ILOOI(12),IEQOI(12)

      DIMENSION  XX(12), STORE(190),EV(190),YMAX1(12)
      COMMON /BLK1/GI
      COMMON /BLK2/OI
      COMMON /BLK3/YA
      COMMON /BLK4/H,YMAX1,E,XIR
      COMMON /BLK5/IOPTI,IOPTE,IOPTF
      COMMON /BLK6/STORE,EV
      COMMON /BLK7/NPART
      COMMON /BLK8/DISIN
      COMMON /BLK10/SI
      COMMON /BLK13/INFEA
      character*10 file1,file2
      write(*,*)'fileinput='
      read(*,'(a)')file1
```

```
      write(*,*)'fileoutput='
      read(*,'(a)')file2
      open(unit=1,file=file1)
      open(unit=2,file=file2)
      READ(1,101)TITLE
101   FORMAT(80A1)
      WRITE(2,101)TITLE
      READ(1,*)ICAL
      WRITE(2,*)ICAL
      READ(1,*)IWRT
      READ(1,*)IWRT1
      READ(1,*)IWRT3
      READ(1,*)IWRT5
      READ(1,*)N,IOBJ
      READ(1,*)YA,DISIN
      READ(1,*)PLSTI(1),PUSTI(1)
      DO 505 IT=1,N
      READ(1,*)PLSTF(IT),PUSTF(IT)
505   CONTINUE
      IF(N.EQ.1)GO TO 510
      DO 502 IT=2,N
      PLSTI(IT)=PLSTF(IT-1)
      PUSTI(IT)=PUSTF(IT-1)
502   CONTINUE
510   READ(1,*)(FT(IT),IT=1,N)
C     READ(1,*)IFLMX
      DO 503 IT=1,N
      READ(1,*)IALT(IT)
      IF(IALT(IT).NE.1)GO TO 503
      READ(1,*)IUPOT(IT),ILOOT(IT),IEQOT(IT)
      READ(1,*)PLOTG(IT),PUOTG(IT)
503   CONTINUE
      WRITE(2,125)YA
125   FORMAT(15X,28('=')//2X,'THE LIVE STORAGE CAPACITY='F10.3/)
      WRITE(2,126)
126   FORMAT(2X,'THE PERMISSIONS OF STORAGE')
      DO 501 IT=1,N
      WRITE(2,*)PLSTI(IT),PUSTI(IT)
      WRITE(2,*)PLSTF(IT),PUSTF(IT)
501   CONTINUE
      DO 504 IT=1,N
      WRITE(2,*)IALT(IT)
      IF(IALT(IT).NE.1)GO TO 504
      WRITE(2,*)IUPOT(IT),ILOOT(IT),IEQOT(IT)
      WRITE(2,105)PLOTG(IT),PUOTG(IT)
504   CONTINUE
```

```
      WRITE(2,127)(FT(IT),IT=1,N)
127   FORMAT(2X,'MONTHLY INFLOW '/6F10.2/6F10.2//)
105   FORMAT(6F10.2/6F10.2//)
      L=YA
      LL=DISIN
      MAXNS=L/LL+1
      READ(1,*)(FOT(I),I=1,MAXNS)
      WRITE(*,128)(FOT(I),I=1,MAXNS)
128   FORMAT(2X,'THE INITIAL FUNCTION VALUE'/6F10.3/6F10.3/6F10.3
     1 /6F10.3)
      DO 100 I=1,MAXNS
      FO(I)=FOT(I)
100   CONTINUE
      READ(1,*)ISG
      READ(1,*)(STATG(IL),IL=1,ISG)
      WRITE(2,130)(STATG(IL),IL=1,ISG)
130   FORMAT(2X,'THE START ='F10.3)
      IREAD=0
      IT=N
      ISTGO=1
5     WRITE(*,102)ISTGO,STATG(1)
102   FORMAT(2X,70('-')//2X,'STAGE TO GO',I3/F16.17)
C     JLM=(YA+IFLMX)/DISIN
      DO 400 I=1,MAXNS
      F(ISTGO,I)=-1.
C     DO 4 K=1,JLM
      DO 4 K=1,190
      OIMI(ISTGO,I,K)=-1.
4     CONTINUE
400   CONTINUE
      PLSII(ISTGO)=PLSTI(IT)
      PUSII(ISTGO)=PUSTI(IT)
      PLSIF(ISTGO)=PLSTF(IT)
      PUSIF(ISTGO)=PUSTF(IT)
      FLO(ISTGO)=FT(IT)
      LK=111
C     WRITE(2,106)LK,PLSII(ISTGO),PUSII(ISTGO),PLSIF(ISTGO),
C    1 PUSIF(ISTGO),FLO(ISTGO)
106   FORMAT(I4,5F10.2)
      SI=PLSII(ISTGO)
      L=SI
      LL= DISIN
      I=L/LL+1
3     PLLOI(ISTGO)=SI+FLO(ISTGO)-YA
      PULOI(ISTGO)=SI+FLO(ISTGO)
      IF(PLLOI(ISTGO).LT.0.0)PLLOI(ISTGO)=0.0
```

```
      OI=PLLOI(ISTGO)
      NOI(ISTGO,I)=0
      IF(IOBJ.EQ.1)FMIN=0.0
      IF(IOBJ.EQ.(-1))FMAX=0.0
      J=1
      LK=222
      IF(IWRT.EQ.1) WRITE(*,*)LK,SI,PLLOI(ISTGO),PULOI(ISTGO),OI
     1 ,NOI(ISTGO,I),J
C107   FORMAT(I4,3F10.2,I4,I4)
2     IF(PLSIF(ISTGO).NE.PUSIF(ISTGO)) GOTO 20
      SIMI1=PUSIF(ISTGO)
      OI=SI+FLO(ISTGO)-SIMI1
      IF(OI.LT.0)GO TO 1
      IF(ICAL.EQ.1)CALL SUB1(IREAD,N,IT,ISTGO,I)
      IF(ICAL.EQ.2)CALL SUB2(IREAD,N,IT,ISTGO,I,MAXNS)
      IF(ICAL.EQ.3)CALL SUB3(IREAD,N,IT,ISTGO,I)
      IF(INFEA.EQ.-1)GO TO 1
      L=PUSIF(ISTGO)
      LL=DISIN
      IMI1=L/LL+1
      IF(ISTGO.EQ.1)FIMI1=FO(IMI1)
      IF(ISTGO.GT.1)FIMI1=F(ISTGO-1,IMI1)
      X=GI(ISTGO,I)+FIMI1
      LK=333
      IF(IWRT1.EQ.1)WRITE(2,*)LK,X,GI(ISTGO,I),FIMI1
      IF(IWRT.EQ.1) WRITE(*,108)LK,SIMI1,OI,L,LL,IMI1,GI(ISTGO,I)
     1 ,FIMI1,X
108   FORMAT(I4,2F10.2,3I4,3F10.2)
C      IF(X.LT.0.OR.GI(ISTGO,I).LT.0.) GOTO 1
      IF(X.LT.0.0) GOTO 1
      NOI(ISTGO,I)=1
      IF(IOBJ.EQ.1)FMIN=X
      IF(IOBJ.EQ.(-1))FMAX=X
      OIMI(ISTGO,I,NOI(ISTGO,I))=OI
      LK=444
      IF(IWRT.EQ.1) WRITE(*,109)LK,FMIN,FMAX,NOI(ISTGO,I)
     1 ,OIMI(ISTGO,I,NOI(ISTGO,I))
109   FORMAT(I4,2F10.2,I4,F10.2)
      GOTO 1
20    SIMI1=SI+FLO(ISTGO)-OI
      LK=555
      IF(IWRT.EQ.1)WRITE(*,*)LK,SIMI1
C     IF(SIMI1.LT.PLSIF(ISTGO).AND.SIMI1.GT.PUSIF(ISTGO)) GOTO 19
      IF(SIMI1.LT.PLSIF(ISTGO)) GOTO 19
      IF(SIMI1.GT.PUSIF(ISTGO)) GOTO 19
      IF(ICAL.EQ.1)CALL SUB1(IREAD,N,IT,ISTGO,I)
```

```
      IF(ICAL.EQ.2)CALL SUB2(IREAD,N,IT,ISTGO,I,MAXNS)
      IF(ICAL.EQ.3)CALL SUB3(IREAD,N,IT,ISTGO,I)
      IF(INFEA.EQ.-1)GO TO 19
      L=SIMI1
      LL=DISIN
      IMI1=L/LL+1
      IF(ISTGO.EQ.1)FIMI1=FO(IMI1)
      IF(ISTGO.GT.1)FIMI1=F(ISTGO-1,IMI1)
      X=GI(ISTGO,I)+FIMI1
      LK=666
      IF(IWRT1.EQ.1)WRITE(2,*)LK,X,GI(ISTGO,I),FIMI1
      IF(IWRT.EQ.1) WRITE(*,*)LK,L,LL,IMI1,FIMI1,GI(ISTGO,I),X
C      IF(X.LT.0.0.OR.GI(ISTGO,I).LT.0.0)GO TO 19
      IF(X.LT.0.0)GO TO 19
      IF(IOBJ.EQ.1)GO TO 10
      IF(IOBJ.EQ.(-1))GO TO 11
10    IF(J.EQ.1)FMIN=X
      IF(J.EQ.1)OIMIN=OI
      IF(X.LT.FMIN)GO TO 16
      IF(X.EQ.FMIN)GO TO 17
      GOTO 19
16    NN=NOI(ISTGO,I)
      NOI(ISTGO,I)=0
      FMIN=X
      OIMIN=OI
      NOI(ISTGO,I)=NOI(ISTGO,I)+1
      LK=777
      IF(IWRT.EQ.1)WRITE(*,*)LK,NN,NOI(ISTGO,I),FMIN,OIMIN
      DO 18 N1=1,NN
      OIMI(ISTGO,I,N1)=0.0
18    CONTINUE
      OIMI(ISTGO,I,NOI(ISTGO,I))=OIMIN
      LK=888
      IF(IWRT.EQ.1)WRITE(*,*)LK,OIMI(ISTGO,I,NOI(ISTGO,I))
C110   FORMAT(I6,F10.3)
      GO TO 19
17    NOI(ISTGO,I)=NOI(ISTGO,I)+1
      OIMI(ISTGO,I,NOI(ISTGO,I))=OI
      LK=999
      IF(IWRT.EQ.1)WRITE(*,111)LK,NOI(ISTGO,I),OIMI(ISTGO,I
     1 ,NOI(ISTGO,I))
111   FORMAT(2I5,F10.2)
      GO TO 19
11    IF(J.EQ.1)FMAX=X
      IF(J.EQ.1)OIMAX=OI
      IF(X.GT.FMAX)GO TO 30
```

```
      IF(X.EQ.FMAX)GO TO 31
      GOTO 19
 30   NN=NOI(ISTGO,I)
      NOI(ISTGO,I)=0
      FMAX=X
      OIMAX=OI
      NOI(ISTGO,I)=NOI(ISTGO,I)+1
      LK=1111
      IF(IWRT.EQ.1)WRITE(*,*)LK,NN,NOI(ISTGO,I),FMAX,OIMAX
      DO 32 N1=1,NN
      OIMI(ISTGO,I,N1)=0.0
 32   CONTINUE
      OIMI(ISTGO,I,NOI(ISTGO,I))=OIMAX
      LK=2222
      IF(IWRT.EQ.1)WRITE(*,*)LK,OIMI(ISTGO,I,NOI(ISTGO,I))
      GO TO 19
 31   NOI(ISTGO,I)=NOI(ISTGO,I)+1
      OIMI(ISTGO,I,NOI(ISTGO,I))=OI
      LK=3333
      IF(IWRT.EQ.1)WRITE(*,*)LK,NOI(ISTGO,I),OIMI(ISTGO,I,NOI
     1 (ISTGO,I))
 19   OI=OI+DISIN
      J=J+1
      LK=4444
      IF(IWRT.EQ.1)WRITE(*,*)LK,OI,J
      IF(OI.LE.PULOI(ISTGO))GO TO 2
 1    IF(IOBJ.EQ.1)F(ISTGO,I)=FMIN
      IF(IOBJ.EQ.(-1))F(ISTGO,I)=FMAX
      SI=SI+DISIN
      I=I+1
      LK=5555
      IF(IWRT.EQ.1)WRITE(*,*)LK,FMIN,FMAX,SI,I
      IF(SI.LE.PUSII(ISTGO)) GO TO 3
      IT=IT-1
      ISTGO=ISTGO+1
      IF(ISTGO.LE.N) GO TO 5
      ISTGO=0
      SI=0
      DO 40 II=1,N
      ISTGO=ISTGO+1
      IF(IWRT5.EQ.1)WRITE(2,102)ISTGO,DISIN
      IF(IWRT5.EQ.1)WRITE(2,300)
300   FORMAT(2X,70('=')/5X,'SI',10X,'F',12X,'OIMI'/2X,70('-')//)
41    L=SI
      LL=DISIN
      I=L/LL+1
```

```
      IF(NOI(ISTGO,I).EQ.0.AND.IWRT5.EQ.1)WRITE(2,511)SI
511   FORMAT(F10.3,5X,'INFEASIBLE')
      IF(NOI(ISTGO,I).NE.0.AND.IWRT5.EQ.1)WRITE(2,200)SI,F
     1 (ISTGO,I),(OIMI(ISTGO,I,KKK),KKK=1,NOI(ISTGO,I))
200   FORMAT(F10.3,F14.3,5X,6F10.2,/,28X,6F10.2,/,28X,6F10.2)
      IF(IWRT5.EQ.1)WRITE(2,5001)
      SI=SI+DISIN
      IF(SI.LE.YA)GOTO 41
      SI=0.
40    CONTINUE
      DO 33 IL=1,ISG
      IT=1
      ISTGO=N
      K2=0
      K3=1
      K4=0
      STATI(ISTGO,1)=STATG(IL)
      L=STATI(ISTGO,1)
      LL=DISIN
      I=L/LL+1
      IF(IOBJ.EQ.1)FMIN=F(ISTGO,I)
      IF(IOBJ.EQ.(-1))FMAX=F(ISTGO,I)
      IF(NOI(ISTGO,I).NE.0)NOINS(ISTGO)=1
      IF(NOI(ISTGO,I).EQ.0)NOINS(ISTGO)=0
C     NCCUI(ISTGO,1)=K3
      LK=6666
      IF(IWRT3.EQ.1)WRITE(*,*)LK,IT,ISTGO,K2,K3,K4,STATI
     1 (ISTGO,1),L,LL,I,FMIN,FMAX,NOINS(ISTGO)
25    IF(NOINS(ISTGO).EQ.0)GO TO 33
      DO 22 K1=1,NOINS(ISTGO)
      L=STATI(ISTGO,K1)
      LL=DISIN
      I=L/LL+1
      LK=6161
      IF(IWRT3.EQ.1)WRITE(*,*)LK,L,LL,I,NOI(ISTGO,I)
      DO 21 N1=1,NOI(ISTGO,I)
      YY=STATI(ISTGO,K1)+FLO(ISTGO)-OIMI(ISTGO,I,N1)
      IF(K2.EQ.0)GOTO 250
      IF(K2.GT.0)GOTO 201
250   K2=K2+N1
      STATF(ISTGO,K2)=YY
      NOFLS(ISTGO)=K2
      GOTO 202
201   DO 203 IJ=1,K2
      IF(YY.EQ.STATF(ISTGO,IJ))GOTO 202
203   CONTINUE
```

```
      K2=K2+1
      STATF(ISTGO,K2)=YY
      NOFLS(ISTGO)=K2
202   LK=7777
C     IF(IWRT3.EQ.1) WRITE(*,*)LK,NOINS(ISTGO),K1,L,LL,I,N1,K2,
C    1 STATF(ISTGO,K2),STATI(ISTGO,K1),FLO(ISTGO),OIMI(ISTGO,I,N1)
      NOFLS(ISTGO)=K2
      K3=K3+1
      K4=K4+1
C      NCIRF(ISTGO,K1,K4)=K3
C      NCCUF(ISTGO,K2)=K3
      LK=8888
C      IF(IWRT3.EQ.1)WRITE(*,*)LK,NOFLS(ISTGO),K2,NCIRF
C    1 (ISTGO,K1,K4),NCCUF(ISTGO,K2),K3,K4
      IF(IWRT3.EQ.1)WRITE(*,*)LK,NOFLS(ISTGO),K2,K3,K4
21    CONTINUE
      K4=0
22    CONTINUE
      NOINS(ISTGO-1)=NOFLS(ISTGO)
      DO 23 K1=1,NOFLS(ISTGO)
      STATI(ISTGO-1,K1)=STATF(ISTGO,K1)
C     NCCUI(ISTGO-1,K1)=NCCUF(ISTGO,K1)
      LK=9999
C     IF(IWRT3.EQ.1)WRITE(*,*)LK,NOFLS(ISTGO),K1,NOINS
C    1(ISTGO-1),STATI(ISTGO-1,K1),NCCUI(ISTGO-1,K1)
      IF(IWRT3.EQ.1)WRITE(*,*)LK,NOFLS(ISTGO),K1,NOINS
     1(ISTGO-1),STATI(ISTGO-1,K1)
23    CONTINUE
      IT=IT+1
      ISTGO=ISTGO-1
      K2=0
      LK=10000
C     WRITE(*,*)LK,IT,ISTGO,K2
      IF(ISTGO.NE.1)GO TO 25
      IT=1
      ISTGO=N
      WRITE(2,409)STATF(ISTGO,K1)
409   FORMAT(2X,70('-')//15X,'THE OPERATING POLICY OF RESERVOIR'
     1/15X,F34.35//)
      WRITE(2,410)
410   FORMAT(4X,70('=')/4X,'IT',2X,'ISTGO',5X,'STATI',2X,'NCCUI'
     1,6X,'OIMI',5X,'STATF',2X,'NCCUF'/4X,70('-')//)
      K5=0
      K6=MAXNS
      K55=K5
      K66=K6
```

```
      DO 42 II=1,N
      K2=0
      K4=0
      DO 50 K1=1,NOINS(ISTGO)
      L=STATI(ISTGO,K1)
      LL=DISIN
      I=L/LL+1
      K5=K5+I
      WRITE(2,500)IT,ISTGO,STATI(ISTGO,K1)
      IF(NOI(ISTGO,I).EQ.0)WRITE(2,512)
512   FORMAT(23X,'INFEASIBLE')
      DO 51 N1=1,NOI(ISTGO,I)
      K2=K2+N1
      K4=K4+1
      STATF(ISTGO,N1)=STATI(ISTGO,K1)+FLO(ISTGO)-OIMI(ISTGO,I,N1)
      LF=STATF(ISTGO,N1)
      LL=DISIN
      IF=LF/LL+1
      K6=K6+IF
      IFN(N1)=IF
      NCCUI(ISTGO,I,IF)=K5
      NCCUF(ISTGO,I,IF)=K6
      WRITE(2,600)NCCUI(ISTGO,I,IF),OIMI(ISTGO,I,N1),STATF
     1 (ISTGO,N1),NCCUF(ISTGO,I,IF)
      K6=K66
51    CONTINUE
      K2=0
      K4=0
      K5=K55
50    CONTINUE
      K5=IT*MAXNS
      K6=(IT+1)*MAXNS
      K55=K5
      K66=K6
      IT=IT+1
      ISTGO=ISTGO-1
      WRITE(2,5001)
5001  FORMAT(1X,20('*'))
42    CONTINUE
500   FORMAT(I6,I7,F10.3)
600   FORMAT(24X,I6,F10.3,F10.3,I7)
33    CONTINUE
      STOP
      END
```

```
C       ****************************************************************
        OUBROUTINE SUB1 (IREAD,N,IT,ISTGO,I)
C       ****************************************************************
        REAL LF2R,LF3R,LFSP
        DIMENSION FACTR(12)
        DIMENSION RATE(3,3)
        DIMENSION XNETA(12),OD2(12)
        DIMENSION ENER(12),REQE(12)
        DIMENSION C1(12),OM1(12)
        DIMENSION C2(12),OM2(12),B2(12)
        DIMENSION C3(12),OM3(12),B3(12)
        DIMENSION XK1(12),B4(12),YMAX1(12)
        DIMENSION EVDEP(12),OR1(12),XR(12)
        DIMENSION HOURS(12),OD3(12)
C        DIMENSION GI(12,190)
        COMMON /BLK1/GI (12,190)
        COMMON /BLK2/OI
        COMMON /BLK3/YA
        COMMON /BLK4/H,YMAX1,E,XIR
        COMMON /BLK5/IOPTI,IOPTE,IOPTF
        COMMON /BLK8/DISIN
        COMMON /BLK9/LIFE
        COMMON /BLK10/SI
        COMMON /BLK11/RATE
        COMMON /BLK12/IWRT2
        COMMON /BLK13/INFEA
        COMMON /BLK14/ISITE
        IF(IREAD.NE.0)GO TO 50
        READ(1,*)IOPTI,IOPTE,IOPTF
        XN=N
        READ(1,*)IWRT2
        READ(1,*)IWRT4
        READ(1,*)ISITE
        READ(1,*)CONV
        READ(1,*)INON
        READ(1,*)(FACTR(KK),KK=1,N)
        DO 20 KK=1,N
        FACTR(KK)=FACTR(KK)/XN
        WRITE(2,*)FACTR(KK)
20      CONTINUE
        READ(1,*)LIFE
        IF(INON.EQ.1)READ(1,*)(RATE(1,KK),KK=1,3)
        IF(INON.EQ.0)READ(1,*)C11,OM11
        READ(1,*)LFSP
        READ(1,*)IEV
        READ(1,*)(EVDEP(KK),KK=1,N)
```

```
      READ(1,*)(OR1(KK),KK=1,N)
      READ(1,*)DS
C     SS=SI+DS
C     IF(IEV.EQ.1)EVAPO=AREA(SS,CONV)/CONV
C     IF(IEV.EQ.0)EVAPO=1.0
C     XR(IT)=-EVAPO*EVDEP(IT)+OR1(IT)
C     QQ=EVAPO*EVDEP(IT)
C     XR(IT)=QQ+OR1(IT)
C     WRITE(2,*)XR(IT),EVAPO,EVDEP(IT),OR1(IT)
      IF(IOPTI.EQ.1)GO TO 2
5     IF(IOPTE.EQ.1)GO TO 3
6     IF(IOPTF.EQ.1)GO TO 4
      GO TO 50
2     READ(1,*)A2,LF2R
      IF(INON.EQ.1)READ(1,*)(RATE(2,KK),KK=1,3)
      IF(INON.EQ.0)READ(1,*)C21,OM21
      READ(1,*)(XK1(KK),KK=1,N)
      READ(1,*)XIR
      DO 11 KK=1,N
      OD2(KK)=XIR*XK1(KK)
11    CONTINUE
      GO TO 5
3     READ(1,*)A3,LF3R,DF3R
      IF(INON.EQ.1)READ(1,*)(RATE(3,KK),KK=1,3)
      IF(INON.EQ.0)READ(1,*)C31,OM31
      READ(1,*)(XNETA(KK),KK=1,N)
      READ(1,*)H,E
      DO 12 KK=1,N
      REQE(KK)=E*XNETA(KK)
12    CONTINUE
      READ(1,*)(HOURS(KK),KK=1,N)
C     WRITE(2,*)(HOURS(KK),KK=1,N)
      READ(1,*)CV,CP
      READ(1,*)TWL,PPEFF
      GO TO 6
4     READ(1,*)A4
      READ(1,*)(YMAX1(KK),KK=1,N)
50    IF(IOPTI.EQ.1.AND.IOPTE.EQ.1)GO TO 33
      IF(IOPTI.EQ.1) GO TO 7
      IF(IOPTE.EQ.1) GO TO 8
7     SPILL=0
      SS=SI+DS
      IF(IEV.EQ.1)EVAPO=AREA(SS,CONV)/CONV
      IF(IEV.EQ.0)EVAPO=1.0
      XR(IT)=-EVAPO*EVDEP(IT)-OR1(IT)
C     QQ=EVAPO*EVDEP(IT)
```

```
C      XR(IT)=QQ+OR1(IT)
C      WRITE(2,*)XR(IT),EVAPO,EVDEP(IT),OR1(IT)
       INFEA=0
       OIA2=OI+XR(IT)
C      OIA2=OI
       IF(OIA2.GE.0)AOIA2=OIA2
C      IF(OIA2.LT.0)INFEA=-1
C      IF(OIA2.LT.0)RETURN
       IF(OIA2.LT.0)OIA2=0
       IF(OIA2.GE.OD2(IT))GO TO 23
       GO TO 24
23     OIA2=OD2(IT)
       SPILL=AOIA2-OIA2
24     IF(INON.EQ.1)CALL FUN2(C21,OM21,OIA2)
       IF(OIA2.LT.OD2(IT))B2(ISTGO)=A2*OIA2-LF2R*(OD2(IT)-OIA2)
       IF(OIA2.EQ.OD2(IT))B2(ISTGO)=A2*(OD2(IT))-LFSP*SPILL
C      IF(OIA2.LT.OD2(IT))C2 (ISTGO)=(C21*FACTR(IT))*OIA2
C      IF(OIA2.EQ.OD2(IT))C2(ISTGO)=(C21*FACTR(IT))*OD2(IT)
C      IF(OIA2.LT.OD2(IT))OM2(ISTGO)=(OM21*FACTR(IT))*OIA2
C      IF(OIA2.EQ.OD2(IT))OM2(ISTGO)=(OM21*FACTR(IT))*OD2(IT)
       GO TO 10
8      CT=1.0/(3600.0*HOURS(IT))
       SS=SI+DS
       EL=ELEVT(SS,CONV)
       IF(IWRT4.EQ.1)WRITE(2,*)EL
       HEAD=EL-TWL
       CF=CP/(9.8*CV*CT*HEAD*PPEFF)
       OTMAX=H*CF
       OD3(IT)=REQE(IT)*CF/HOURS(IT)
       SPILL=0
       INFEA=0
       SS=SI+DS
       IF(IEV.EQ.1)EVAPO=AREA(SS,CONV)/CONV
       IF(IEV.EQ.0)EVAPO=1.0
       XR(IT)=-EVAPO*EVDEP(IT)-OR1(IT)
C      QQ=EVAPO*EVDEP(IT)
C      XR(IT)=QQ+OR1(IT)
C      WRITE(2,*)XR(IT),EVAPO,EVDEP(IT),OR1(IT)
       OIA3=OI+XR(IT)
C      OIA3=OI
       IF(IWRT4.EQ.1)WRITE(2,*)CT,HEAD,CF,OTMAX,OD3(IT),OIA3,
      1CV,CP,TWL,PPEFF
       IF(OIA3.GE.0)AOIA3=OIA3
C      IF(OIA3.LT.0)INFEA=-1
C      IF(OIA3.LT.0)RETURN
       IF(OIA3.LT.0)OIA3=0
```

```
      IF(OIA3.GE.OD3(IT))GO TO 21
      GO TO 22
21    OIA3=OD3(IT)
      SPILL=AOIA3-OIA3
22    ZZ=OIA3+SPILL
      IF(ZZ.GE.OTMAX)ZZ=OTMAX
      ENER(ISTGO)=ZZ*HOURS(IT)/CF
      IF(INON.EQ.1)CALL FUN3 (C31,OM31,H)
      IF(ENER(ISTGO).LT.REQE(IT))B3(ISTGO)=A3*ENER(ISTGO)-
     1 LF3R*(REQE(IT)-ENER(ISTGO))
      IF(ENER(ISTGO).GE.REQE(IT))B3(ISTGO)=A3*REQE(IT)+
     1 DF3R*(ENER(ISTGO)-REQE(IT))
C     C3(ISTGO)=C31*FACTR(IT)*H
C     OM3(ISTGO)=OM31*FACTR(IT)*H
      GO TO 10
33    SPILL=0
      INFEA=0
      SS=SI+DS
      IF(IEV.EQ.1)EVAPO=AREA(SS,CONV)/CONV
      IF(IEV.EQ.0)EVAPO=1.0
      XR(IT)=-EVAPO*EVDEP(IT)-OR1(IT)
C     QQ=EVAPO*EVDEP(IT)
C     XR(IT)=QQ+OR1(IT)
C     WRITE(2,*)XR(IT),EVAPO,EVDEP(IT),OR1(IT)
      OIA2=OI-XR(IT)
C     OIA2=OI
      IF(OIA2.GE.0)AOIA2=OIA2
C     IF(OIA2.LT.0)INFEA=-1
C     IF(OIA2.LT.0)RETURN
      IF(OIA2.LT.0)OIA2=0
      IF(OIA2.GE.OD2(IT))GO TO 30
      GO TO 31
30    OIA2=OD2(IT)
      SPILL=AOIA2-OIA2
31    SS=SI+DS
      EL=ELEVT(SS,CONV)
      WRITE(2,*)EL
      HEAD=EL-TWL
      CT=1.0/(3600.0*HOURS(IT))
      CF=CP/(9.8*CV*CT*HEAD*PPEFF)
      OTMAX=H*CF
      OD3(IT)=REQE(IT)*CF/HOURS(IT)
      OIA3=0
      IF(OIA2.GE.OD3(IT))GO TO 32
      IF((OD3(IT)-OIA2).LE.SPILL)OIA3=OD3(IT)-OIA2
      IF((OD3(IT)-OIA2).LE.SPILL)SPILL=SPILL-OIA3
```

```
      IF((OD3(IT)-OIA2).GT.SPILL)OIA3=SPILL
      IF((OD3(IT)-OIA2).GT.SPILL)SPILL=0
32    ZZ=OIA2+OIA3+SPILL
      IF(ZZ.GE.OTMAX)ZZ=OTMAX
      ENER(ISTGO)=ZZ*HOURS(IT)/CF
      IF(INON.EQ.1)CALL FUN2(C21,OM21,OIA2)
      IF(OIA2.LT.OD2(IT))B2(ISTGO)=A2*OIA2-LF2R*(OD2(IT)-OIA2)
      IF(OIA2.GE.OD2(IT))B2(ISTGO)=A2*(OD2(IT))-LFSP*SPILL
C     IF(OIA2.LT.OD2(IT))C2 (ISTGO)=(C21*FACTR(IT))*OIA2
C     IF(OIA2.GE.OD2(IT))C2(ISTGO)=(C21*FACTR(IT))*OD2(IT)
C     IF(OIA2.LT.OD2(IT))OM2(ISTGO)=(OM21*FACTR(IT))*OIA2
C     IF(OIA2.GE.OD2(IT))OM2(ISTGO)=(OM21*FACTR(IT))*OD2(IT)
      IF(INON.EQ.1)CALL FUN3 (C31,OM31,H)
      IF(ENER(ISTGO).LT.REQE(IT))B3(ISTGO)=A3*ENER(ISTGO)-
     1 LF3R*(REQE(IT)-ENER(ISTGO))
      IF(ENER(ISTGO).GE.REQE(IT))B3(ISTGO)=A3*REQE(IT)+
     1 DF3R*(ENER(ISTGO)-REQE(IT))
C     C3(ISTGO)=C31*FACTR(IT)*H/XN
C     OM3(ISTGO)=OM31*FACTR(IT)*H/XN
10    IF(IOPTF.EQ.-1) GO TO 9
      B4(ISTGO)=A4*(YA-YMAX1(IT))
9     IF(INON.EQ.1)CALL FUN1(C11,OM11,YA)
      XN=N
C     WRITE(2,*)C11,OM11,C21,OM21,FACTR(IT),YA,XN,ISTGO,IT,I
C     WRITE(2,*)I
C     C1(ISTGO)=C11*FACTR(IT)*YA
C     OM1(ISTGO)=OM11*FACTR(IT)*YA
      GI(ISTGO,I)=0
C     GI(ISTGO,I)=-C1(ISTGO)-OM1(ISTGO)
      IF(IOPTI.EQ.1)GI(ISTGO,I)=GI(ISTGO,I)+B2(ISTGO)
      IF(IOPTE.EQ.1)GI(ISTGO,I)=GI(ISTGO,I)+B3(ISTGO)
      IF(IOPTF.EQ.1)GI(ISTGO,I)=GI(ISTGO,I)+B4(ISTGO)
      IREAD=IREAD+1
      LN=1010
      IF(IWRT2.EQ.1.AND.IOPTI.EQ.1)WRITE(2,*)LN,B2(ISTGO),C2(ISTGO),
     1 OM2(ISTGO),GI(ISTGO,I),OD2(IT),OI,C1(ISTGO),OM1(ISTGO)
      LN=1020
      IF(IWRT2.EQ.1.AND.IOPTE.EQ.1)WRITE(2,*)LN,B3(ISTGO),C3(ISTGO),
     1 OM3(ISTGO),GI(ISTGO,I),OD3(IT),OI,C1(ISTGO),OM1(ISTGO),
     1 ENER(ISTGO),REQE(IT),HEAD,OTMAX,OIA3,SPILL,ZZ,CF
      RETURN
      END
```

```
C     ****************************************************************
      SUBROUTINE FUN1(C11,OM11,X)
C     ****************************************************************
      DIMENSION RATE(3,3)
      COMMON/BLK9/LIFE
      COMMON/BLK11/RATE
      COMMON /BLK12/IWRT2
      COMMON/BLK14/ISITE
      GO TO(1,2,3,4,5)ISITE
1     CCF1=0.1956047E+04+0.2393951E+00*X-0.1421198E-04*X**2+
     1 0.3590230E-09*X**3
      GO TO 77
2     CCF1=0.7064508E+02+0.7538718E+02*X-0.3910439E+01*X**2+
     1 0.9800397E-01*X**3
      GO TO 77
3     CCF1=0.1913125E+03+0.1381348E+01*X-0.2468824E-03*X**2+
     1 0.5372567E-07*X**3-0.5094591E-11*X**4
      GO TO 77
4     CCF1=0
      GO TO 77
5     CCF1=0.1033859E+02+0.5954181E+02*X-0.2012424E+02*X**2+
     1 0.2766336E+01*X**3
77    XX=(1.0+RATE(1,2))**LIFE-1.0
      ANDEF=RATE(1,2)/XX
      C11=(RATE(1,1)+ANDEF)*CCF1/X
      OM11=RATE(1,3)*CCF1/X
      LN=1030
      IF(IWRT2.EQ.1)WRITE(2,*)LN,RATE(1,2),XX,ANDEF,RATE(1,1),CCF1,
     1 RATE(1,3),C11,OM11
      RETURN
      END
C     ****************************************************************
      SUBROUTINE FUN2(C21,OM21,X)
C     ****************************************************************
      DIMENSION RATE(3,3)
      COMMON/BLK9/LIFE
      COMMON/BLK11/RATE
      COMMON /BLK12/IWRT2
      COMMON /BLK14/ISITE
      GO TO(1,2,3,4,5)ISITE
1     CCF2=0.7374063E+03+0.1493530E+00*X-0.1961365E-04*X**2+
     1 0.8340066E-09*X**3
      GO TO 88
2     CCF2=0.2000002E+02+0.1784945E+02*X
      GO TO 88
3     CCF2=0
```

```
      GO TO 88
4     CCF2=0
      GO TO 88
5     CCF2=0.1900008E+02+0.5020611E+02*X-0.1463681E+01*X**2
88    XX=(1.0+RATE(2,2))**LIFE-1.0
      ANDEF=RATE(2,2)/XX
      IF(X.GT.0.)C21=(RATE(2,1)+ANDEF)*CCF2/X
      IF(X.GT.0.)OM21=RATE(2,3)*CCF2/X
      IF(X.LT.0)C21=0
      IF(X.LT.0)OM21=0
      LN=1040
      IF(IWRT2.EQ.1)WRITE(2,*)LN,RATE(2,2),XX,ANDEF,RATE(2,1),CCF2,
     1 RATE(2,3),C21,OM21
      RETURN
      END
C     ***************************************************************
      SUBROUTINE FUN3(C31,OM31,X)
C     ***************************************************************
      DIMENSION RATE(3,3)
      COMMON/BLK9/LIFE
      COMMON/BLK11/RATE
      COMMON /BLK12/IWRT2
      COMMON /BLK14/ISITE
      GO TO(1,2,3,4,5)ISITE
1     CCF3=0
      GO TO 99
2     CCF3=0
      GO TO 99
3     CCF3=0.1499999E+03+0.2828000E+01*X
      GO TO 99
4     CCF3=0
      GO TO 99
5     CCF3=0.3104462E+01+0.9128303E-01*X+0.8980931E-05*X**2
99    XX=(1.0+RATE(3,2))**LIFE-1.0
      ANDEF=RATE(3,2)/XX
      C13=(RATE(3,1)+ANDEF)*CCF3/X
      OM31=RATE(3,3)*CCF3/X
      LN=1050
      IF(IWRT2.EQ.1)WRITE(2,*)LN,RATE(3,2),XX,ANDEF,RATE(3,1),CCF3,
     1 RATE(3,3),C31,OM31
      RETURN
      END
```

```
C     ************************************************************
      FUNCTION AREA(Y,CONV)
C     ************************************************************
      COMMON/BLK14/ ISITE
      GO TO (1,2,3,4,5)ISITE
1     AREA=0.2265317E+03+0.4286903E-02*X+0.3299952E-04*X**2-
     1 0.4754354E-08*X**3+0.2161810E-12*X**4
      RETURN
2     AREA=0.3010366E-01+0.2885666E+00*X-0.1744216E-01*X**2+
     1 0.2336046E-03*X**3+0.1432534E-04*X**4
      RETURN
3     X=Y*CONV
      AREA=0.3887914E+01+0.3291998E-01*X-0.2770826E-05*X**2
     1 +0.3767724E-09*X**3-0.1317866E-13*X**4
      RETURN
4     AREA=0
      RETURN
5     AREA=0.3851403E+03+0.3401476E+03*X-0.1340375E+04*X**2
     1 -0.2174464E+04*X**3
      RETURN
      END
C     ************************************************************
      FUNCTION ELEVT(Y,CONV)
C     ************************************************************
      COMMON/BLK14/ ISITE
      GO TO (1,2,3,4,5)ISITE
1     ELEVT=0.1602608E+03+0.2707258E-02*X-0.1006891E-06*X**2
      RETURN
2     ELEVT=0.6157974E+03+0.6923746E+01*X-0.1310248E+01*X**2+
     1 0.1077476E+00*X**3-0.3007150E-02*X**4
      RETURN
3     X=Y*CONV
      ELEVT=0.3715872E+03+0.6111376E-01*X-0.2155736E-04*X**2
     1 +0.3969155E-08*X**3-0.2531183E-12*X**4
      RETURN
4     ELEVT=0
      RETURN
5     ELEVT=0.3896889E+03+0.2054818E+02*X-0.4854121E+01*X**2
     1 +0.4425995E+00*X**3
      RETURN
      END
C     ************************************************************
      FUNCTION EVAPO(X)
C     ************************************************************
      DIMENSION STORE(190), EV(190)
      COMMON/BLK6/STORE,EV
```

```
      COMMON/BLK7/NPART
      DO 1 LK=1,NPART
      IF(X.NE.STORE(LK))GO TO 1
      EVAPO=EV(LK)
      GO TO 2
1     CONTINUE
2     RETURN
      END
C     ***********************************************************
      SUBROUTINE SUB2(IREAD,N,IT,ISTGO,I)
C     ***********************************************************
      DIMENSION C(12),CC(12),GI(12,190)
      COMMON /BLK1/GI
      COMMON /BLK2/OI
      COMMON /BLK3/YA
      IF(IREAD.NE.0)GOTO 1
      READ(1,*)(C(KK),KK=1,N)
      LKK=1010
      WRITE(2,950)(C(KK),KK=1,N)
950   FORMAT(2X,'THE VALUE OF UNIT RELEASE'/6F11.3/6F11.3)
      READ(1,*)CY
1     CC(ISTGO)=C(IT)
      GI(ISTGO,I)=CC(ISTGO)*OI-CY*YA
      IREAD=IREAD +1
      RETURN
      END
C     ***********************************************************
      SUBROUTINE SUB3(IREAD,N,IT,ISTGO,I,MAXNS)
C     ***********************************************************
      DIMENSION C(190,190),CC(12),GI(12,190)
      COMMON /BLK1/GI
      COMMON /BLK2/OI
      COMMON /BLK3/YA
      IF(IREAD.NE.0)GOTO 1
      DO 2 KK=1,N
      READ(1,*)(C(KK,I1),I1=1,MAXNS)
      WRITE(2,*)(C(KK,I1),I1=1,MAXNS)
2     CONTINUE
      LKK=1010
1     I1=OI+1
      CC(ISTGO)=C(IT,I1)
      GI(ISTGO,I)=CC(ISTGO)
      IREAD=IREAD +1
      RETURN
      END
```

```
C     ***************************************************************
      SUBROUTINE SUB4(IREAD,N,IT,ISTGO,I)
C     ***************************************************************
      DIMENSION C(12),CC(12),GI(12,190)
      COMMON /BLK1/GI
      COMMON /BLK2/OI
      COMMON /BLK3/YA
      IF(IREAD.NE.0)GOTO 1
      READ(1,*)(C(KK),KK=1,N)
      LKK=1010
      WRITE(2,950)(C(KK),KK=1,N)
950   FORMAT(2X,'THE VALUE OF UNIT RELEASE'/6F11.3/6F11.3)
1     CC(ISTGO)=C(IT)
      GI(ISTGO,I)=CC(ISTGO)*OI
      IREAD=IREAD +1
      RETURN
      END
```

APPENDIX 2

```
C***********************************************************************
C             ****************************************
C                  *****************************
C                      COMPUTER PROGRAMME FOR
C                 (RESERVOIR SIMULATION/OPERATION)
C               DEVELOPED BY : ASSADULLAH KOHISTANI
C                SUPERVISOR  : Dr. D.K. SRIVASTAVA
C                  *****************************
C             ****************************************
C***********************************************************************
      DIMENSION S(1,13),FLOW(1,50,12),P(1,50,12)
      DIMENSION YMIN(1,12),EVAPO(1,12),YMAX(1,12),AVQDS(1,12)
      DIMENSION ARQDS(1),PRQDS(1,12),EVPVO(1,12),O(1,12)
      DIMENSION REQIF(1,12),ARQIF(1),PRQIF(1,12),NREMT(1,12)
      DIMENSION REQET(1,12),ARQET(1),PRQET(1,12)
      DIMENSION REQEF(1,12),ARQEF(1),PRQEF(1,12)
      DIMENSION REQIT(1,12),ARQIT(1),PRQIT(1,12)
      DIMENSION AVQI(1,12),NRFUT(1,12),SS(1,32)
      DIMENSION ENER(1,12),REQDS(1,12),VALO2(1,12)
      DIMENSION IENO(12),PPEFF(1),PPC(1),TWL(1)
      DIMENSION RLS1(1),RLS2(1),RLS3(1),RLS4(1),X(12)
      DIMENSION DEFDS(1,12),DEFI(1,12),DEFE(1,12),DUMPE(1,12)
      DIMENSION NMDDS(1,12),NMDI(1,12),NMDE(1,12),NMDUE(1,12)
      DIMENSION CUMF(1),CUMP(1),CUMEL(1),CUMR1(1),CUMR2(1)
      DIMENSION CUMR3(1),CUMR4(1),PHMIN(1,12),MRFUT(1)
      DIMENSION NADEI(1),AADEI(1,50),SUMB(1,50)
      DIMENSION IFIRM(1),WANET(1),AADEE(1,50),NADEE(1)
      DIMENSION CASOC(1),CASO(1),SUM5(1),IFLM(1,12)
      DIMENSION CASOZ(1),YB(1,12),REQI(1,12),REQE(1,12)
      DIMENSION YR(1,12),CASOR(1),IOPTI(1),AADUE(1,50)
      DIMENSION NADDS(1),NADUE(1),AADDS(1,50),IRQDS(1)
      DIMENSION AMDDS(1,12),AMDI(1,12),AMDE(1,12),AMDUE(1,12)
      DIMENSION SUM1(1),SUM2(1),SUM3(1),SUM4(1),MREMT(1)
      DIMENSION STORE(1,50),RAEAC(1,50),ELEVTC(1,50),TLS(31)
      DIMENSION XXX(100),YYY(100),ZZZ(100),AAA(100),BBB(100)
      DIMENSION NDAYS(12),FLOWT(1,50,31),PT(1,50,31),CCC(100)
      DIMENSION ELEV(1,15),SLAB(1,15),DDD(100),EEE(100),IP(1)
      DIMENSION YMAXT(1,31),YBT(1,31),YMINT(1,31),OT(1,31)
      DIMENSION ARD(1,10),AND(1,50,10),IREQ(1,10),NDSRE(1)
      DIMENSION ANLEN(1,50),PEALE(1),PEALD(1),PEALI(1),YMINW(1,12)
      DIMENSION AVSPL(1),ISITE(6),IUSE(6,4),YMIN1(1,12),YMINA(1,12)
      DIMENSION TFMON(100),CSTAV(100),SUMW(1,12),STODI(1,12)
      DIMENSION YMINL(1,12),YMINH(1,12),REQSU(12),YMINU(1,12),IC(5)
```

```
      COMMON/BLK1/TODAM,YD,Y,EVAPO,WAVFU
      COMMON/BLK11/YMAX,YMIN,S
      COMMON/BLK12/FLOW,P,EVPVO
      COMMON/BLK13/YMAXT,YMINT,SS,OT
      COMMON/BLK2/TWL,PPEFF,PPC,PHMIN,CCF
      COMMON/BLK3/NDAYS,IT,NPART,I,J,KPART,IENO,IEVPO
      COMMON/BLK4/REQEF,REQET
      COMMON/BLK41/REQDS,REQIT,REQIF
      COMMON/BLK5/RAEZ1,RAEZ2,RAIZ3,RAEZ3,RAEZ5
      COMMON/BLK6/FLOWT,PT
      COMMON/BLK61/XXX,YYY,ZZZ,AAA,BBB,CCC,DDD,EEE
      COMMON/BLK7/RLS1,RLS2,RLS3,RLS4,ENER
      COMMON/BLK8/IFLM
      COMMON/BLK9/NREMT,NRFUT
      COMMON/BLK10/ELE,WANET
      COMMON/BLK14/ARD,AADEE,AADUE,AND
      COMMON/BLK15/RATE
      COMMON/BLK16/IREQ,NDSRE,NYEAR,NSITE
      COMMON/BLK17/ISITE,IUSE
      character*25 file1,file2,file3,file4,file5
      write(*,*)'fileinput='
      read(*,'(a)')file1
      write(*,*)'fileoutput='
      read(*,'(a)')file2
      write(*,*)'fileoutput='
      read(*,'(a)')file3
      write(*,*)'fileoutput='
      read(*,'(a)')file4
      write(*,*)'fileoutput='
      read(*,'(a)')file5
      open(unit=1,file=file1)
      open(unit=2,file=file2)
      open(unit=3,file=file3)
      open(unit=4,file=file4)
      open(unit=5,file=file5)
      READ(1,101)TITLE
101   FORMAT(80A1)
      WRITE(2,101)TITLE
      READ(1,*) IPRTW,IPRTD,IPRTB,IPRTC,IPRTR,IPRTF
      IF(IPRTD.EQ.1)WRITE(2,*) IPRTW,IPRTD,IPRTB,IPRTC,IPRTR,IPRTF
      READ(1,*)NSITE,NYEAR,NMONT,CCF,HOURS,KYEAR
      IF(IPRTD.EQ.1)WRITE(4,*)NSITE,NYEAR,NMONT,CCF,HOURS,KYEAR
      10 FORMAT(/5X,'NUMBER OF SITE='I3,
     1 /5X,'NUMBER OF YEAR='I3,
     2 /5X,'NUMBER OF MONT='I3,
     3 /5X,'CONVERSION FACTOR='F10.5,
```

```
    4  /5X,'NUMBER OF HOURS  ='F10.3,
    5  /5X,'STARTING YEAR='I4)
       READ(1,*)(NDAYS(IT),IT=1,NMONT)
       WRITE(*,*)(NDAYS(IT),IT=1,NMONT)
       DO 200 I=1,NSITE
       READ(1,*)IFIRM(I)
       IF(IPRTD.EQ.1)WRITE(4,*)IFIRM(I)
       READ(1,*)IRQDS(I)
       IF(IPRTD.EQ.1)WRITE(4,*)IRQDS(I)
       READ(1,*)IEVPO
       IF(IPRTD.EQ.1)WRITE(4,*)IEVPO
       READ(1,*)IOPTI(I),CASO(I)
       IF(IPRTD.EQ.1)WRITE(4,*)IOPTI(I),CASO(I)
       READ(1,*)IP(I)
       IF(IPRTC.EQ.1)WRITE(2,*)IP(I)
       READ(1,*)S(I,1)
       IF(IPRTD.EQ.1)WRITE(4,20)S(I,1)
20     FORMAT(/5X,'INITIAL STORAGE='F10.3)
       DO 1 J=1,NYEAR
       KK=J+KYEAR
       KKK=KK+1-1900
       READ(1,*)(FLOW(I,J,K),K=1,NMONT)
       IF(IPRTD.EQ.1)WRITE(4,30)KK,KKK,(FLOW(I,J,K),K=1,NMONT)
30     FORMAT(/5X,'MONTHLY FLOW DATA, YEAR: 'I4,'-',I2,
    1  /3X,6F10.3/3X,6F10.3)
1      CONTINUE
       IF(IP(I).EQ.0)GO TO 11
       DO 2 J=1,NYEAR
       KK=J+KYEAR
       KKK=KK+1-1900
       READ(1,*)(P(I,J,K),K=1,NMONT)
       IF(IPRTD.EQ.1)WRITE(4,40)KK,KKK,(P(I,J,K),K=1,NMONT)
40     FORMAT(/5X,'MONTHLY PRECIPITATION ,YEAR:'I4,'-'I2,
    1  /3X,6F10.3/3X,6F10.3)
2      CONTINUE
11     READ(1,*)(YMIN(I,J),J=1,NMONT)
       IF(IPRTD.EQ.1)WRITE(4,50)(YMIN(I,J),J=1,NMONT)
50     FORMAT(/5X,'MINIMUM CAPACITY:',
    1  /3X,6F10.3/3X,6F10.3)
       READ(1,*)(YMAX(I,J),J=1,NMONT)
       IF(IPRTD.EQ.1)WRITE(4,60)(YMAX(I,J),J=1,NMONT)
60     FORMAT(/5X,'MAXIMUM CAPACITY:'
    1  /3X,6F10.3/3X,6F10.3)
       IF(IOPTI(I).EQ.0) GO TO 8000
       IF(IOPTI(I).EQ.1) GO TO 8001
       IF(IOPTI(I).EQ.2) GO TO 8002
```

```
      IF(IOPTI(I).EQ.3) GO TO 8003
 8001 READ(1,*) ARQIF(I)
      IF(IPRTD.EQ.1)WRITE(4,*)ARQIF(I)
      READ(1,*)(PRQIF(I,J),J=1,NMONT)
      IF(IPRTD.EQ.1)WRITE(4,*)(PRQIF(I,J),J=1,NMONT)
      READ(1,*) PEALI(I)
      IF(IPRTD.EQ.1)WRITE(4,*) PEALI(I)
      GO TO 8000
 8002 READ(1,*)ARQIT(I)
      IF(IPRTD.EQ.1)WRITE(4,*)ARQIT(I)
      READ(1,*)(PRQIT(I,J),J=1,NMONT)
      IF(IPRTD.EQ.1)WRITE(4,*)(PRQIT(I,J),J=1,NMONT)
      READ(1,*) PEALI(I)
      IF(IPRTD.EQ.1)WRITE(4,*) PEALI(I)
      GO TO 8000
 8003 READ(1,*)ARQIF(I)
      IF(IPRTD.EQ.1)WRITE(4,*)ARQIF(I)
      READ(1,*)(PRQIF(I,J),J=1,NMONT)
      (IF IPRTD.EQ.1)WRITE(4,*)(PRQIF(I,J),J=1,NMONT)
      READ(1,*)PEALI(I)
      IF(IPRTD.EQ.1)WRITE(4,*) PEALI(I)
      READ(1,*)ARQIT(I)
      IF(IPRTD.EQ.1)WRITE(4,*)ARQIT(I)
      READ(1,*)(PRQIT(I,J),J=1,NMONT)
      IF(IPRTD.EQ.1)WRITE(4,*)(PRQIT(I,J),J=1,NMONT)
      READ(1,*) PEALI(I)
      IF(IPIRTD.EQ.1)WRITE(4,*) PEALI(I)
 8000 IF(IFIRM(I).EQ.0) GO TO 4000
      IF(IFIRM(I).EQ.1) GO TO 4001
      IF(IFIRM(I).EQ.2) GO TO 4002
      IF(IFIRM(I).EQ.4) GO TO 4003
      GO TO 4000
 4001 READ(1,*)ARQEF(I)
      IF(IPRTD.EQ.1)WRITE(4,*)ARQEF(I)
      READ(1,*)(PRQEF(I,J),J=1,NMONT)
      IF(IPRTD.EQ.1)WRITE(4,*)(PRQEF(I,J),J=1,NMONT)
      READ(1,*)PEALE(I)
      IF(IPRTD.EQ.1)WRITE(4,*)PEALE(I)
      GO TO 4000
 4002 READ(1,*)ARQET(I)
      IF(IPRTD.EQ.1)WRITE(4,*)ARQET(I)
      READ(1,*)(PRQET(I,J),J=1,NMONT)
      IF(IPRTD.EQ.1)WRITE(4,*)(PRQET(I,J),J=1,NMONT)
      READ(1,*)PEALE(I)
      IF(IPRTD.EQ.1)WRITE(4,*)PEALE(I)
      GO TO 4000
```

```
4003   READ(1,*)ARQEF(I)
       IF(IPRTD.EQ.1)WRITE(4,*)ARQEF(I)
       READ(1,*)(PRQEF(I,J),J=1,NMONT)
       IF(IPRTD.EQ.1)WRITE(4,*)(PRQEF(I,J),J=1,NMONT)
       READ(1,*)PEALE(I)
       IF(IPRTD.EQ.1)WRITE(4,*)PEALE(I)
       READ(1,*)ARQET(I)
       IF(IPRTD.EQ.1)WRITE(4,*)ARQET(I)
       READ(1,*)(PRQET(I,J),J=1,NMONT)
       IF(IPRTD.EQ.1)WRITE(4,*)(PRQET(I,J),J=1,NMONT)
       READ(1,*)PEALE(I)
       IF(IPRTD.EQ.1)WRITE(4,*)PEALE(I)
4000   READ(1,*)NDSRE(I)
       READ(1,*)(IREQ(I,II1),II1=1,NDSRE(I))
       READ(1,*)(ARD(I,II1),II1=1,NDSRE(I))
       READ(1,*)RATE
       READ(1,*)ISITE(I)
       READ(1,*)(IUSE(I,II1),II1=1,NDSRE(I))
       IF(IRQDS(I).NE.1)GO TO 1020
       READ(1,*)ARQDS(I)
       IF(IPRTD.EQ.1)WRITE(4,*)ARQDS(I)
       READ(1,*)(PRQDS(I,J),J=1,NMONT)
       IF(IPRTD.EQ.1)WRITE(4,*)(PRQDS(I,J),J=1,NMONT)
       READ(1,*)PEALD(I)
       IF(IPRTD.EQ.1)WRITE(4,*)PEALD(I)
1020  IF(CASO(I).EQ.0.0)GO TO  1021
       IF(CASO(I).NE.1)GO TO 1023
       READ(1,*)REC1,RIC2,REC2,RDC3
       IF(IPRTD.EQ.1)WRITE(4,*)REC1,RIC2,REC2,RDC3
       1023 IF(CASO(I).NE.2)GO TO 1024
       READ(1,*)RER1,RIR2,RER2,RIR3,RER3,RDR4
       IF(IPRTD.EQ.1)WRITE(4,*)RER1,RIR2,RER2,RIR3,RER3,RDR4
1024   IF(CASO(I).NE.3)GO TO 1021
       READ(1,*)REZ1,REZ2,RIZ3,REZ3,REZ5
       IF(IPRTD.EQ.1)WRITE(4,*)REZ1,REZ2,RIZ3,REZ3,REZ5
1021   DO 3 J=1,NMONT
       IF(IRQDS(I).NE.0)REQDS(I,J)=ARQDS(I)*PRQDS(I,J)/100.0
       IF(IOPTI(I).NE.1.AND.IOPTI(I).NE.3)GO TO 12
       REQIF(I,J)= ARQIF(I)*PRQIF(I,J)/100.0
12     IF(IOPTI(I).NE.2.AND.IOPTI(I).NE.3)GO TO 13
       REQIT(I,J)=ARQIT(I)*PRQIT(I,J)/100.0
13    IF(IFIRM(I).NE.1.AND.IFIRM(I).NE.4)GO TO  14
       REQEF(I,J)=ARQEF(I)*PRQEF(I,J)/100.0
14     IF(IFIRM(I).NE.2.AND.IFIRM(I).NE.4)GO TO 3
       REQET(I,J)=ARQET(I)*PRQET(I,J)/100.0
3      CONTINUE
```

```
      READ(1,*)(EVAPO(I,IT),IT=1,NMONT)
      IF(IPRTD.EQ.1)WRITE(4,*)(EVAPO(I,IT),IT=1,NMONT)
      IF(IFIRM(I).EQ.0.)GO TO 15
      READ(1,*)IENO(I),PPEFF(I),PPC(I),TWL(I)
      IF(IPRTD.EQ.1)WRITE(4,*)IENO(I),PPEFF(I),PPC(I),TWL(I)
      READ(1,*)(PHMIN(I,IT),IT=1,NMONT)
      IF(IPRTD.EQ.1)WRITE(4,*)(PHMIN(I,IT),IT=1,NMONT)
15    READ(1,*)TODAM,Y,YD
      IF(IPRTD.EQ.1)WRITE(4,*)TODAM,Y,YD
      IF(CASO(I).EQ.2)READ(1,*)(YR(I,IT),IT=1,NMONT)
      IF(CASO(I).EQ.2)WRITE(4,*)(YR(I,IT),IT=1,NMONT)
      IF(CASO(I).EQ.3)READ(1,*)(YB(I,IT),IT=1,NMONT)
      IF(CASO(I).NE.3)WRITE(4,*)(YB(I,IT),IT=1,NMONT)
      IF(CASO(I).EQ.0)GO TO 200
      READ(1,*)IMONT
      IF(IPRTD.EQ.1)WRITE(4,*)IMONT
      READ(1,*)(EVPVO(I,IT),IT=1,NMONT)
      IF(IPRTD.EQ.1)WRITE(4,*)(EVPVO(I,IT),IT=1,NMONT)
      READ(1,*)NPART
      IF(IPRTD.EQ.1)WRITE(4,*)NPART
      READ(1,*)(VALO2(I,IT),IT=1,NMONT)
      IF(IPRTD.EQ.1)WRITE(4,*)(VALO2(I,IT),IT=1,NMONT)
      READ(1,*)(STORE(I,KC),KC=1,NPART)
      IF(IPRTD.EQ.1)WRITE(4,*)(STORE(I,KC),KC=1,NPART)
      READ(1,*)(ELEVTC(I,KC),KC=1,NPART)
      IF(IPRTD.EQ.1)WRITE(4,*)(ELEVTC(I,KC),KC=1,NPART)
      READ(1,*)(RAEAC(I,KC),KC=1,NPART)
      IF(IPRTD.EQ.1)WRITE(4,*)(RAEAC(I,KC),KC=1,NPART)
      READ(1,*)KPART
      IF(IPRTD.EQ.1)WRITE(4,*)KPART
      READ(1,*)(ELEV(I,KC),KC=1,KPART)
      IF(IPRTD.EQ.1)WRITE(4,*)(ELEV(I,KC),KC=1,KPART)
      READ(1,*)(SLAB(I,KC),KC=1,KPART)
      IF(IPRTD.EQ.1)WRITE(4,*)(ELEV(I,KC),KC=1,KPART)
      WRITE(*,*)(SLAB(I,KC),KC=1,KPART)
200   CONTINUE
      IF(IOPIT(I).EQ.0.AND.IRQDS(I).EQ.0) GO TO 556
      READ(1,*) LMONM,NFLO,AVFMO
      READ(1,*) CSLIM
      READ(1,*) (TFMON(IL),IL=1,NFLO)
      READ(1,*) (CSTAV(IL),IL=1,NFLO)
      READ(1,*) YA,DS
      IF(IRQDS.EQ.1)READ(1,*)(YMINW(I,IL),IL=1,NMONT)
      READ(1,*)(YMINL(I,IL),IL=1,NMONT)
      READ(1,*)(YMINH(I,IL),IL=1,NMONT)
      READ(1,*)(YMINU(I,IL),IL=1,LMONM)
```

```
      WRITE(4,*) LMONM,NFLO,AVFMO
      WRITE(4,*) CSLIM
      WRITE(4,*) (TFMON(IL),IL=1,NFLO)
      WRITE(4,*) (CSTAV(IL),IL=1,NFLO)
      WRITE(4,*) Y,DS
      IF(IRQDS.EQ.1)WRITE(4,*)(YMINW(I,IL),IL=1,NMONT)
      WRITE(4,*)(YMINL(I,IL),IL=1,NMONT)
      WRITE(4,*)(YMINH(I,IL),IL=1,NMONT)
      WRITE(4,*)(YMINU(I,IL),IL=1,LMONM)
556   DO 4 I=1,NSITE
      NADDS(I)=0
      NADEI(I)=0
      NADEE(I)=0
      NADUE(I)=0
      AVSPL(I)=0
      DO 4 IT=1,NMONT
      NMDDS(I,IT)=0.0
      NMDI(I,IT)=0.0
      NMDE(I,IT)=0.0
      NMDUE(I,IT)=0
      AAA(IT)=YMAX(I,IT)
      BBB(IT)=YB(I,IT)
      CCC(IT)=YMIN(I,IT)
4     CONTINUE
      DO 201 I=1,NSITE
      IF(CASO(I).EQ.0)GO TO 16
      DO 5 KC=1,NPART
      XXX(KC)=STORE(I,KC)
      YYY(KC)=ELEVTC(I,KC)
      ZZZ(KC)=RAEAC(I,KC)
5     CONTINUE
      DO 6 KC=1,KPART
      DDD(KC)=ELEV(I,KC)
      EEE(KC)=SLAB(I,KC)
6     CONTINUE
16    SUM1(I)=0
      SUM2(I)=0
      SUM3(I)=0
      SUM4(I)=0
      SUM5(I)=0
      DO 204 IC1=1,5
      IC(IC1)=0
204   CONTINUE
      DO 202 J=1,NYEAR
      IF(CASO(I).EQ.0)GO TO 17
      READ(1,*)(IFLM(I,IT),IT=1,NMONT)
```

```
      WRITE(*,*)(IFLM(I,IT),IT=1,NMONT)
17    IF(CASO(I).NE.0)CALL RATI(RATIO,ISTRT,IMONT,I,J,NMONT,NDAYS,
      AADDS(I,J)=0
      AADEI(I,J)=0
      AADEE(I,J)=0
      AADUE(I,J)=0.0
      DO 500 II1 =1,NDSRE(I)
      AND(I,J,II1)=0
500   CONTINUE
      SUMB(I,J)=0.0
      CUMF(I)=0.0
      CUMP(I)=0.0
      CUMEL(I)=0.0
      CUMR1(I)=0.0
      CUMR2(I)=0.0
      CUMR3(I)=0.0
      CUMR4(I)=0.0
      KK=J+KYEAR
      KKK=KK+1-1900
      IF(IPRTW.NE.0)WRITE(2,61)KK,KKK
61    FORMAT(110('*'),//25X,'RESERVOIR OPERATION TABLE; YEAR:',I4,
     1 '-'I2,//110('*'))
      IF(IPRTW.NE.0)WRITE(2,777)
      INOT=1
      TMONF=0
      DO 203 IT=1,NMONT
      IF(IT.GT.1) GO TO 7009
      DO 7008 IL=1,NMONT
      YMINA(I,IL)=YMIN(I,IL)
7008  CONTINUE
7009  II1=0.0
      RLS1(I)=0
      RLS2(I)=0
      RLS3(I)=0
      RLS4(I)=0
      REQV=0
      REQA=0
      ADNLV=0
      ADNLC=0
      ADNLD=0
      REGEN=0
      ENERG=0
      AVANW=0
      DEFDS(I,IT)=0.0
      DEFI(I,IT)=0.0
      DEFE(I,IT)=0.0
```

```
      DUMPE(I,IT)=0.0
      ENER(I,IT)=0.0
      IF(IFLM(I,IT).NE.0)CALL FLOOD(S)
      IF(IFLM(I,IT).NE.0)GO TO 9999
C     CALCULATE WATER SPREAD,AS
      IF(CASO(I).EQ.0)AS=AREA(I,S(I,IT))
      IF(CASO(I).NE.0)CALL INTPO(S(I,IT),XXX,ZZZ,AS,NPART,IUP)
      IF(IEVPO.EQ.0)AS=1.0
C     CALCULATE RESERVOIR EVAPORATION,EL
      EL=AS*EVAPO(I,IT)
C     CALCULATE RESERVOIR ELEVATION,ELE
      IF(CASO(I).EQ.0)ELE=ELEVAT(I,S(I,IT))
      IF(CASO(I).NE.0)CALL INTPO(S(I,IT),XXX,YYY,ELE,NPART,IUP)
      HE=ELE-TWL(I)
      IF(IFIRM(I).EQ.0) GO TO 9009
      CF=3600.*24*365/(12.0*CCF)
      FACTR=9.8*HE*PPEFF(I)*24*30.4
      QMAX=PPC(I)*1000*CF/(9.8*HE*PPEFF(I))
9009  IF(CASO(I).EQ.0.0)GO TO 1016
      REQVF=CF*(REQEF(I,IT)*1000.)/FACTR
      REQVT=CF*(REQET(I,IT)*1000.)/FACTR
      GO TO 1015
1016  IF(IFIRM(I).EQ.0)GO TO 9000
      IF(IFIRM(I).EQ.1)REQVF=CF*(REQEF(I,IT)*1000.)/FACTR
      IF(IFIRM(I).EQ.2)REQVT=CF*(REQET(I,IT)*1000.)/FACTR
      IF(IFIRM(I).EQ.3)REQVM=QMAX
      IF(IFIRM(I).EQ.1)REQV=REQVF
      IF(IFIRM(I).EQ.2)REQV=REQVT
      IF(IFIRM(I).EQ.3)REQV=REQVM
9000  IF(IOPTI(I).EQ.0) GO TO 9001
      IF(IOPTI(I).EQ.1)REQI(I,IT)=REQIF(I,IT)
      IF(IOPTI(I).EQ.2)REQI(I,IT)=REQIT(I,IT)
      MMM=110
      WRITE(4,*)MMM,REQI(I,IT)
C     CALCULATE NET WATER  AVAILABLE,AVANW
9001  AVANW=S(I,IT)+FLOW(I,J,IT)+P(I,J,IT)-EL-YMIN(I,IT)
      IF(AVANW.LT.0.0)AVANW=0.0
      WANET(I)=AVANW
      IF(AVANW.EQ.0.0)GO TO 81
      LLL=10
      IF(IPRTC.EQ.1)WRITE(2,*)LLL,IT,S(I,IT),AS,EL,ELE,FLOW(I,J,IT),
     1 P(I,J,IT),AVANW
70    FORMAT(//3X,I2,7F8.3)
      IF(IRQDS(I).EQ.0)GO TO 9002
C     CALCULATE D/S RIPARIAN RIGHTS/M&I RELEASES,RLS1
      IF(AVANW.LT.REQDS(I,IT))RLS1(I)=AVANW
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```
      IF(AVANW.GE.REQDS(I,IT))RLS1(I)=REQDS(I,IT)
C     CALCULATE BALANCE WATER
      AVANW=AVANW-RLS1(I)
9002  IF(IOPTI(I).EQ.0)GO TO 9003
      IF(INOT.EQ.0) GO TO 9003
C     CALCULATE IRRIGATION  RELEASES,RLS2(I)
      IF(AVANW.LT.REQI(I,IT))RLS2(I)=AVANW
      IF(AVANW.GE.REQI(I,IT))RLS2(I)=REQI(I,IT)
C     CALCULATE BALANCE  WATER
      AVANW=AVANW-RLS2(I)
      WAVFU=AVANW
      9003 LLL=20
      IF(IPRTC.EQ.1)WRITE(2,*)LLL,IT,REQDS(I,IT),RLS1(I),
    1 REQI(I,IT),RLS2(I)
      WAVFU=AVANW
      GO TO 2000
1015  NOW=0
      IF(CASO(I).EQ.1.AND.IT.LE.ISTRT)RAIC2=RIC2
      IF(CASO(I).EQ.2.AND.IT.LE.ISTRT)RAIR2=RIR2
      IF(CASO(I).EQ.3.AND.IT.LE.ISTRT)RAIZ3=RIZ3
      IF(CASO(I).EQ.1.AND.IT.GT.ISTRT)RAIC2=RATIO
      IF(CASO(I).EQ.2.AND.IT.GT.ISTRT)RAIR2=RATIO
      IF(CASO(I).EQ.3.AND.IT.GT.ISTRT)RAIZ3=RATIO
      IF(CASO(I).EQ.1)GO TO 1000
      IF(CASO(I).EQ.2)GO TO 1001
      IF(CASO(I).EQ.3)GO TO 1002
C     RESERVOIR OPERATION WITH CONVENTIONAL RULE
1000  IF(S(I,IT).LE.TODAM.AND.S(I,IT).GT.Y)GO TO 1003
      IF(S(I,IT).LE.Y.AND.S(I,IT).GT.YMIN(I,IT))GO TO 1004
      IF(S(I,IT).LE.YMIN(I,IT).AND.YMIN(I,IT).EQ.YD)GO TO 1005
1003  AVANW=S(I,IT)+FLOW(I,J,IT)+P(I,J,IT)-EL-Y
      WANET(I)=AVANW
      CASOC(I)=1
      NOW=1
      RLS1(I)=REQDS(I,IT)
      RLS2(I)=REQIT(I,IT)
      REQV=REQVT*(RAEC1/100.)
      LLL=1110
      IF(IPRTC.EQ.1)WRITE(2,*)LLL,WANET(I),RLS1(I),RLS2(I),REQV
      GO TO 2000
1004  AVANW=S(I,IT)+FLOW(I,J,IT)+P(I,J,IT)-EL-YMIN(I,IT)
      WANET(I)=AVANW
      CASOC(I)=2
      NOW=2
      RLS1(I)=REQDS(I,IT)
      RLS2(I)=REQIF(I,IT)+(REQIT(I,IT)-REQIF(I,IT))*(RAIC2/100.)
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      REQV=REQVF+(REQVT-REQVF)*(RAEC2/100.)
      LLL=1112
      IF(IPRTC.EQ.1)WRITE(2,*)LLL,WANET(I),RLS1(I),RLS2(I),REQV
      GO TO 2000
 1005 AVANW=S(I,IT)+FLOW(I,J,IT)+P(I,J,IT)-EL-YMIN(I,IT)
      WANET(I)=AVANW
      CASOC(I)=3
      NOW=3
      RLS1(I)=REQDS(I,IT)*(RADC3/100.)
      RLS2(I)=0
      REQV=0
      LLL=1113
      IF(IPRTC.EQ.1)WRITE(2,*)LLL,WANET(I),RLS1(I),RLS2(I),REQV
      GO TO 2000
C     RESERVOIR OPERATION WITH RULE CURVE
 1001 IF(S(I,IT).LE.TODAM.AND.S(I,IT).GT.Y)GO TO 1006
      IF(S(I,IT).LE.Y.AND.S(I,IT).GT.YR(I,IT))GO TO 1007
      IF(S(I,IT).LE.YR(I,IT).AND.S(I,IT).GT.YMIN(I,IT).
     1 AND.YMIN(I,IT).EQ.YD)GO TO 1008
      IF(S(I,IT).LE.YMIN(I,IT).AND.YMIN(I,IT).EQ.YD)GO TO 1009
 1006 AVANW=S(I,IT)+FLOW(I,J,IT)+P(I,J,IT)-EL-Y
      WANET(I)=AVANW
      CASOR(I)=1
      NOW=1
      RLS1(I)=REQDS(I,IT)
      RLS2(I)=REQIT(I,IT)
      REQV=REQVT*(RAER1/100.)
      LLL=1114
      IF(IPRTC.EQ.1)WRITE(2,*)LLL,WANET(I),RLS1(I),RLS2(I),REQV
      GO TO 2000
 1007 AVANW=S(I,IT)+FLOW(I,J,IT)+P(I,J,IT)-EL-YR(I,IT)
      WANET(I)=AVANW
      CASOR(I)=2
      NOW=2
      RLS1(I)=REQDS(I,IT)
      RLS2(I)=REQIF(I,IT)+(REQIT(I,IT)-REQIF(I,IT))*(RAIR2/100.)
      REQV=REQVF+(REQVT-REQVF)*(RAER2/100.)
      LLL=1115
      IF(IPRTC.EQ.1)WRITE(2,*)LLL,WANET(I),RLS1(I),RLS2(I),REQV
      GO TO 2000
 1008 AVANW=S(I,IT)+FLOW(I,J,IT)+P(I,J,IT)-EL-YMIN(I,IT)
      WANET(I)=AVANW
      CASOR(I)=3
      NOW=3
      RLS1(I)=REQDS(I,IT)
      RLS2(I)=REQIF(I,IT)*(RAIR3/100.)
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      REQV=REQVF*(RAER3/100.)
      LLL=1116
      IF(IPRTC.EQ.1)WRITE(2,*)LLL,WANET(I),RLS1(I),RLS2(I),REQV
      GO TO 2000
1009  AVANW=S(I,IT)+FLOW(I,J,IT)+P(I,J,IT)-EL
      WANET(I)=AVANW
      CASOR(I)=4
      NOW=4
      RLS1(I)=REQDS(I,IT)*(RADR4/100.)
      RLS2(I)=0
      REQV=0
      LLL=1117
      IF(IPRTC.EQ.1)WRITE(2,*)LLL,WANET(I),RLS1(I),RLS2(I),REQV
      GO TO 2000
C     RESERVOIR OPERATION WITH ZONING(PARTITIONING)
1002  IF(S(I,IT).LE.TODAM.AND.S(I,IT).GT.Y)GO TO 1010
      IF(S(I,IT).LE.Y.AND.S(I,IT).GT.YMAX(I,IT))GO TO 1011
      IF(S(I,IT).LE.YMAX(I,IT).AND.S(I,IT).GT.YB(I,IT))GO TO 1012
      IF(S(I,IT).LE.YB(I,IT).AND.S(I,IT).GT.YMIN(I,IT).AND.
     1 YMIN(I,IT).GE.YD)GO TO 1013
      IF(S(I,IT).LE.YMIN(I,IT).AND.YMIN(I,IT).GE.YD)GO TO 1014
1010  AVANW=S(I,IT)+FLOW(I,J,IT)+P(I,J,IT)-EL-Y
      WANET(I)=AVANW
      CASOZ(I)=1
      NOW=1
      RLS1(I)=REQDS(I,IT)
      RLS2(I)=REQIT(I,IT)
      REQV=REQVT*(RAEZ1/100.)
      LLL=1118
      IF(IPRTC.EQ.1)WRITE(2,*)LLL,WANET(I),RLS1(I),RLS2(I),REQV
      GO TO 2000
1011  AVANW=S(I,IT)+FLOW(I,J,IT)+P(I,J,IT)-EL-YMAX(I,IT)
      WANET(I)=AVANW
      CASOZ(I)=2
      NOW=2
      RLS1(I)=REQDS(I,IT)
      RLS2(I)=REQIT(I,IT)
      REQV=REQVT*(RAEZ2/100.)
      LLL=1119
      IF(IPRTC.EQ.1)WRITE(2,*)LLL,WANET(I),RLS1(I),RLS2(I),REQV
      GO TO 2000
1012  AVANW=S(I,IT)+FLOW(I,J,IT)+P(I,J,IT)-EL-YB(I,IT)
      WANET(I)=AVANW
      CASOZ(I)=3
      NOW=3
      RLS1(I)=REQDS(I,IT)
```

```
      RLS2(I)=REQIF(I,IT)+(REQIT(I,IT)-REQIF(I,IT))*(RAIZ3/100.)
      REQV=REQVF+(REQVT-REQVF)*(RAEZ3/100.)
      LLL=1120
      IF(IPRTC.EQ.1)WRITE(2,*)LLL,WANET(I),RLS1(I),RLS2(I),REQV
      GO TO 2000
1013  AVANW=S(I,IT)+FLOW(I,J,IT)+P(I,J,IT)-EL-YMIN(I,IT)
      CASOZ(I)=4
      NOW=4
      RLS1(I)=REQDS(I,IT)
      RLS2(I)=0.0
      REQV=0.
      LLL=1122
      IF(IPRTC.EQ.1)WRITE(2,*)LLL,WANET(I),RLS1(I),RLS2(I),REQV
      GO TO 2000
1014  AVANW=S(I,IT)+FLOW(I,J,IT)+P(I,J,IT)-EL
      CASOZ(I)=5
      NOW=5
      RLS1(I)=REQDS(I,IT)*(RAEZ5/100.)
      RLS2(I)=0.0
      REQV=0.
      LLL=1123
      IF(IPRTC.EQ.1)WRITE(2,*)LLL,WANET(I),RLS1(I),RLS2(I),REQV
2000  IF(IFIRM(I).EQ.0)GO TO 9005
      IF(ELE.LE.PHMIN(I,IT))ENERG=0
      IF(ELE.LE.PHMIN(I,IT))RLS3(I)=0
      IF(ELE.LE.PHMIN(I,IT))ADNLC=0
      IF(ELE.LE.PHMIN(I,IT))GO TO 991
C     CALCULATE ENERGY GENERATED FROM RLS1 OR /AND RLS2
      IF(IENO(I).EQ.1)REGEN=RLS1(I)
      IF(IENO(I).EQ.2)REGEN=RLS2(I)
      IF(IENO(I).EQ.3)REGEN=RLS1(I)+RLS2(I)
      IF(IENO(I).EQ.4)REGEN=0.00
C     CALCULATE ADDITIONAL POWER RELEASES,RLS3
      IF(REQV.GE.QMAX)REQA=QMAX
      IF(REQV.GE.QMAX)ADNLC=0
      IF(REQV.LT.QMAX)REQA=REQV
      IF(REQV.LT.QMAX)ADNLC=QMAX-REQV
      IF(REGEN.GE.REQA)ENERG=REQA
      IF(REGEN.GE.REQA)ADNLV=0
      IF(REGEN.LT.REQA)ENERG=REGEN
      IF(REGEN.LT.REQA)ADNLV=REQA-REGEN
      LLL=1111
      IF(IPRTC.EQ.1)WRITE(2,*)LLL,REQV,QMAX,REQA,ADNLV,ADNLC,
     1 ENERG,WAVFU
      IF(INOT.EQ.0) GO TO 991
      IF(ADNLV.NE.0.0)GO TO 701
```

```
      IF(ADNLV.EQ.0.0.AND.ADNLC.NE.0.0.AND.(REGEN-REQA).LE.
     1 ADNLC)GO TO 9004
      ENERG=REQA+ADNLC
      ADNLC=0
      GO TO 991
 9004 ENERG=REGEN
      ADNLC=QMAX-REGEN
      GO TO 991
 701  IF(WAVFU.EQ.0)GO TO 991
      IF(WAVFU.LT.ADNLV)ADNLD=WAVFU
      IF(WAVFU.GE.ADNLV)ADNLD=ADNLV
      ADNLV=ADNLV-ADNLD
      WAVFU=WAVFU-ADNLD
      ENERG=ENERG+ADNLD
      IF(ADNLV.NE.0.)ADNLC=0
      RLS3(I)=ADNLD
 9005 LLL=40
      IF(IPRTC.EQ.1)WRITE(2,*)LLL,ADNLC,ENERG,ADNLV,ADNLD,
     1 WAVFU,RLS3(I)
 991  IF(CASO(I).EQ.0)AVANW=AVANW-RLS3(I)
      IF(CASO(I).NE.0)AVANW=(S(I,IT)+FLOW(I,J,IT)+P(I,J,IT)-EL)-
     1 (RLS1(I)+RLS2(I)+RLS3(I))
      IF(CASO(I).EQ.0)RLS4(I)=(YMIN(I,IT)+AVANW)-YMAX(I,IT)
      IF(CASO(I).NE.0.AND.AVANW.LE.YMAX(I,IT))RLS4(I)=0.
      IF(CASO(I).NE.0.AND.AVANW.GT.YMAX(I,IT))RLS4(I)=AVANW-
     1 YMAX(I,IT)
      IF(RLS4(I).LT.0.0)RLS4(I)=0
      IF(IFIRM(I).EQ.0)GO TO 9006
      IF(RLS4(I).LT.ADNLC)ADNLC=RLS4(I)
      ENERG=ENERG+ADNLC
      ENERG=ENERG/CF
      ENERG=ENERG*9.8*HE*PPEFF(I)
      ENERG=ENERG*24*365.0/12.0
      ENER(I,IT)=ENERG/1000
 9006 LLL=60
      IF(IPRTC.EQ.1)WRITE(2,*)LLL,AVANW,ADNLC,RLS4(I),ENERG,
     1 ENER(I,IT),Y
      LLL=70
      IF(IPRTC.EQ.1)WRITE(2,*)LLL,REQDS(I,IT),RLS1(I),REQI(I,IT),
     1 RLS2(I),REQV,REGEN,
     1 RLS3(I),ENER(I,IT)
      IF(IPRTC.EQ.1)WRITE(2,992)
 992  FORMAT(1X,30('-'))
 80   FORMAT(//3X,7F8.3,F10.2)
C     CALCULATE TOTAL RELEASES
 81   O(I,IT)=RLS1(I)+RLS2(I)+RLS3(I)+RLS4(I)
```

```
C       CALCULATE FINAL RESERVOIR CONTENT
        IF(RLS4(I).NE.0.0)S(I,IT+1)=YMAX(I,IT)
        IF(RLS4(I).LE.0.0)S(I,IT+1)=S(I,IT)+FLOW(I,J,IT)+P(I,J,IT)-EL
     1  -O(I,IT)
        IF(S(I,IT+1).LT.0.0)S(I,IT+1)=0.0
        IF(S(I,IT+1).LE.YMIN(I,IT))NREMT(I,IT)= NREMT(I,IT)+1
        IF(S(I,IT+1).EQ.YMAX(I,IT))NRFUT(I,IT)= NRFUT(I,IT)+1
C       CALCULATE D/S OR M&I USE,IRRIGATION & ENERGY DEFICIT
9999   IF(CASO(I).EQ.0)GO TO  89
        REQI(I,IT)=REQIT(I,IT)
        REQE(I,IT)=REQET(I,IT)
        GO TO 92
89      IF(IFIRM(I).NE.0) REQE(I,IT)=REQV*9.8*HE*PPEFF(I)*24*365.0
     1  /(CF*12.*1000.)
        IF(IRQDS(I).EQ.0)GO TO 86
92      IF(RLS1(I).LT.REQDS(I,IT))GO TO 82
        IF(IOPTI(I).EQ.0) GO TO 87
86      IF(RLS2(I).LT.REQI(I,IT))GO TO 83
        IF(IFIRM(I).EQ.0)GO TO 88
87      ZP=(ENER(I,IT)/REQE(I,IT))*100.0
        ZPA=100.0-PEALE(I)
        IF(INT(ENER(I,IT)).LT.INT(REQE(I,IT))) GO TO 84
        IF(INT(ENER(I,IT)).GT.INT(REQE(I,IT))) GO TO 85
        IF(INT(ENER(I,IT)).EQ.INT(REQE(I,IT))) GO TO 90
C      IF(ZP.LT.ZPA)GO TO  84
C       IF(ZP.GT.ZPA)GO TO 85
C       IF(ZP.EQ.ZPA)GO TO 90
82      DEFDS(I,IT)=REQDS(I,IT)-RLS1(I)
        AMDDS(I,IT)=AMDDS(I,IT)+DEFDS(I,IT)/FLOAT(NYEAR)
        NMDDS(I,IT)=NMDDS(I,IT)+1
        AADDS(I,J)=AADDS(I,J)+DEFDS(I,IT)
        II1=II1+1
        AND(I,J,II1)=AADDS(I,J)
        GO TO 86
83      DEFI(I,IT)=REQI(I,IT)-RLS2(I)
        AMDI(I,IT)=AMDI(I,IT)+DEFI(I,IT)/FLOAT(NYEAR)
        NMDI(I,IT)=NMDI(I,IT)+1
        AADEI(I,J)=AADEI(I,J)+DEFI(I,IT)
        II1=II1+1
        AND(I,J,II1)=AADEI(I,J)
        GO TO 87
84      DEFE(I,IT)=REQE(I,IT)-ENER(I,IT)
        AMDE(I,IT)=AMDE(I,IT)+DEFE(I,IT)/FLOAT(NYEAR)
        NMDE(I,IT)=NMDE(I,IT)+1
        AADEE(I,J)=AADEE(I,J)+DEFE(I,IT)
        LLL=111
```

```
      WRITE(5,*)LLL,ENER(I,IT),REQE(I,IT)
      ANLEN(I,J)=ANLEN(I,J)+ENER(I,IT)
      GO TO 88
85    DUMPE(I,IT)=ENER(I,IT)-REQE(I,IT)
      AMDUE(I,IT)=AMDUE(I,IT)+DUMPE(I,IT)/FLOAT(NYEAR)
      NMDUE(I,IT)=NMDUE(I,IT)+1
      AADUE(I,J)=AADUE(I,J)+DUMPE(I,IT)
      ANLEN(I,J)=ANLEN(I,J)+REQE(I,IT)
      GO TO 88
90    ANLEN(I,J)=ANLEN(I,J)+REQE(I,IT)
C     RESERVOIR WATER BALANCE
C     CUMULATIVE RESERVOIR INPUT
88    CUMF(I)=CUMF(I)+FLOW(I,J,IT)
      CUMP(I)=CUMP(I)+P(I,J,IT)
C     CUMULATIVE RESERVOIR OUTPUT
      CUMEL(I)=CUMEL(I)+EL
      CUMR1(I)=CUMR1(I)+RLS1(I)
      CUMR2(I)=CUMR2(I)+RLS2(I)
      CUMR3(I)=CUMR3(I)+RLS3(I)
      CUMR4(I)=CUMR4(I)+RLS4(I)
      IF(IPRTW.EQ.0) GO TO 3021
      WRITE(2,888)IT,S(I,IT),FLOW(I,J,IT),EL,ELE,
     1 WANET(I),REQI(I,IT),RLS2(I),REQV,RLS3(I),RLS4(I),REQET(I,IT
     1 ENER(I,IT),S(I,IT+1)
777   FORMAT(/2X,'TIME',3X,'OPBAL',2X,'INFLOW',2X,'EVAPON',3X,
     1 'ELEVN',2X,'NETWAT',2X,'IR.REQ',2X,'IR.RLS',5X,'EN.VOL',5X,
     2 EN.RLS',3X,'SPILL',3X,'EN.REQ',4X,'EN.GEN',4X,'FNL.ST')
888   FORMAT(/I6,10F8.2,2E9.3,3X,F10.3)
3021  SUMB(I,J)=SUMB(I,J)+RLS2(I)*VALO2(I,IT)
      IF(IOPIT(I).EQ.0.AND.IRQDS(I).EQ.0) GO TO 556
      MMM=10
      WRITE(4,*)MMM,TMONF
      IF(IT.LE.LMONM)TMONF=TMONF+FLOW(I,J,IT)/AVFMO
      MMM=20
      WRITE(4,*) MMM,TMONF,FLOW(I,J,IT),S(I,IT+1),AVFMO
      IF(IT.LT.LMONM)GO TO 203
      IF(IT.EQ.LMONM.AND.S(I,IT+1).EQ.YMAX(I,IT)
     1 .AND.TMONF.GE.CSLIM)GO TO 7001
      IF(IT.EQ.LMONM.AND.S(I,IT+1).EQ.YMAX(I,IT)
     1 .AND.TMONF.LT.CSLIM)GO TO 7020
      IF(IT.EQ.LMONM.AND.S(I,IT+1).LT.YMAX(I,IT).AND.S(I,IT+1).
     1 GE.YMINL(I,LMONM))GO TO  7021
      IF(IRQDS.NE.1) GO TO 555
      IF(IT.EQ.LMONM.AND.S(I,IT+1).LT.YMINL(I,LMONM).AND.S(I,IT+1)
     1 GE.YMINW(I,LMONM)) GO TO  7040
      IF(IT.EQ.LMONM.AND.S(I,IT+1).LT.YMINW(I,LMONM))GO TO 7041
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555     IF(IT.GT.LMONM)GO TO 203
7001    CALL INTPO (TMONF,TFMON,CSTAV,S12,NFLO,IVP)
        MMM=30
        WRITE(4,*) MMM,TMONF,S12
        DO 7005 IL=LMONM+1,NMONT
        SUMW(I,IL)=0
        REQSU(IL)=0
7005    CONTINUE
        IF(IFIRM(I).EQ.2.AND.IRQDS(I).EQ.0.AND.IOPTI(I).EQ.0)
     1  GO TO 7027
        IF(IFIRM(I).EQ.2.AND.IRQDS(I).NE.0.AND.IOPTI(I).EQ.0)
     1  GO TO 7027
        IF(IFIRM(I).EQ.2.AND.IOPTI(I).EQ.2)GO TO 7028
7027    ELL=ELEVAT(I,S12)
        HEL=ELL-TWL(I)
        CFT=3600.*24/CCF
        FACT=9.8*HEL*PPEFF(I)*24
        REQVV=CFT*(REQET(I,NMONT)*1000.0)/FACT
        IK=NMONT
        DO 7025 IL = LMONM+1,NMONT
        REQSU(IK) = REQSU(IK)+REQVV
        WRITE(4,*)S12,ELL,FACT,REQVV,REQSU(IK),IK
        ELL=ELEVAT(I,S12+REQVV)
        FACT=9.8*HEL*PPEFF(I)*24
        IK=IK-1
        REQVV=REQVV+CFT*(REQET(I,IK)*1000.0)/FACT
7025    CONTINUE
7028    YMS12=Y-S12*Y
        NONMM=NMONT-LMONM
        SUMT=0
        DO 7002 IL=LMONM+1,NMONT
        MMM=100
        IF(IOPTI(I).EQ.1)REQI(I,IL)=REQIF(I,IL)
        IF(IOPTI(I).EQ.2)REQI(I,IL)=REQIT(I,IL)
        WRITE(4,*)MMM,REQI(I,IL),I,IL
        IF(IFIRM(I).EQ.2.AND.IRQDS(I).EQ.0.AND.IOPTI(I).EQ.0)
     1  GO TO 7029
        IF(IFIRM(I).EQ.2.AND.IRQDS(I).NE.0.AND.IOPTI(I).EQ.0)
     1  GO TO 7030
        IF(IFIRM(I).EQ.2.AND.IOPTI(I).EQ.2)GO TO 7031
7029    SUMW(I,IL)=SUMW(I,IL)+REQSU(IL)
        GO TO 7002
7030    SUMW(I,IL)=SUMW(I,IL)+REQDS(I,IL)+REQSU(IL)
        GO TO 7002
7031    IF(IRQDS(I).NE.0)SUMW(I,IL)=SUMW(I,IL)+REQDS(I,IL)
        IF(IOPTI(I).NE.0)SUMW(I,IL)=SUMW(I,IL)+REQI(I,IL)
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      SUMT=SUMT+SUMW(I,IL)
      MMM=40
      WRITE(4,*) MMM,SUMT,SUMW(I,IL),REQI(I,IL),IL,I
 7002 CONTINUE
      MMM=50
      WRITE(4,*) MMM,SUMT
      DO 7003 IL=LMONM+1,NMONT
      STODI(I,IL)=(SUMW(I,IL)/SUMT)*YMS12
      MMM=60
      WRITE(4,*) MMM,STODI(I,IL)
 7003 CONTINUE
      IK=NMONT
      WRITE(4,*)S12,Y,DS
      CUMST=S12*Y
      DO 7004 IL=LMONM+1,NMONT
      YMIN1(I,IK)= CUMST
      MMM=70
      WRITE(4,*) MMM,YMIN1(I,IK)
C     CUMST=CUMST+STODI(I,IK)
      MMM=80
      WRITE(4,*) MMM,CUMST
      IK=IK-1
 7004 CONTINUE
      DO 7007 IL= LMONM+1,NMONT
      YMIN(I,IL)=YMIN1(I,IL)
      MMM=90
      WRITE(4,*) MMM,YMIN(I,IL)
 7007 CONTINUE
      DO 7034 IL=1,LMONM
      YMINA(I,IL)=YMINU(I,IL)
 7034 CONTINUE
      DO 7035 IL=LMONM+1,NMONT
      YMINA(I,IL)=YMIN(I,IL)
 7035 CONTINUE
      ICC=1
      WRITE(4,*)ICC,S(I,IT+1),TMONF,YMINL(I,LMONM),YMINW(I,LMONM)
      IC(1)=IC(1)+1
      GO TO 203
 7020 DO 7022 IL=LMONM+1,NMONT
      YMIN(I,IL)=YMINH(I,IL)
 7022 CONTINUE
 DO   7032 IL=1,NMONT
      YMINA(I,IL)=YMINH(I,IL)
 7032 CONTINUE
      ICC=2
      WRITE(4,*)ICC,S(I,IT+1),TMONF,YMINL(I,LMONM),YMINW(I,LMONM)
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      IC(2)=IC(2)+1
      GO TO 203
7021  DO 7023 IL=LMONM+1,NMONT
      YMIN(I,IL)=YMINL(I,IL)
7023  CONTINUE
      DO 7033 IL=1,NMONT
      YMINA(I,IL)=YMINL(I,IL)
      7033 CONTINUE
      ICC=3
      WRITE(4,*)ICC,S(I,IT+1),TMONF,YMINL(I,LMONM),YMINW(I,LMONM)
      IC(3)=IC(3)+1
      GO TO 203
7040  DO 7042 IL= LMONM+1,NMONT
      YMIN(I,IL)=YMINW(I,IL)
7042  CONTINUE
 DO   7043 IL =1,NMONT
      YMINA(I,IL)=YMINW(I,IL)
7043  CONTINUE
      ICC=4
      WRITE(4,*)ICC,S(I,IT+1),TMONF,YMINL(I,LMONM),YMINW(I,LMONM)
      IC(4)=IC(4)+1
      GO TO 203
7041  INOT=0
      DO 7044 IL=1,NMONT
      YMIN(I,IL) = DS
      YMINA(I,IL) = DS
7044  CONTINUE
      ICC=5
      WRITE(4,*)ICC,S(I,IT+1),TMONF,YMINL(I,LMONM),YMINW(I,LMONM)
      IC(5)=IC(5)+1
203   CONTINUE
      INOT=1
      DO 7012 IL=1,NMONT
      YMIN(I,IL)=YMINA(I,IL)
7012  CONTINUE
      TE=0.0
      TIR=0.0
      TDS=0.0
      DO 95 IT=1,NMONT
      TE=TE+REQE(I,IT)
      TIR=TIR+REQI(I,IT)
      TDS=TDS+REQDS(I,IT)
95    CONTINUE
      ZP=(AADEE(I,J)/TE)*100.0
      ZDS=(AADDS(I,J)/TDS)*100.0
      ZIR=(AADEI(I,J)/TIR)*100.0
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      IF(ZDS.GT.PEALD(I))NADDS(I)=NADDS(I)+1
      IF(ZIR.GT.PEALI(I))NADEI(I)=NADEI(I)+1
      IF(ZP.GT.PEALE(I))NADEE(I)=NADEE(I)+1
      IF(AADUE(I,J).NE.0)NADUE(I)=NADUE(I)+1
      XX=CUMF(I)+CUMP(I)
      YY=CUMEL(I)+CUMR1(I)+CUMR2(I)+CUMR3(I)+CUMR4(I)
C     CHECK WATER BALANCE OF RESERVOIR
      T=S(I,NMONT+1)-S(I,1)
      B=XX-YY
      IF((T-B).GE.(-0.00001).OR.(T-B).LE.0.00001)GO TO 400
      IF(IPRTC.EQ.1)WRITE(2,96)
96    FORMAT(/5X,'WATER BALANCE FOUND INCORRECT')
      STOP
400   IF(IPRTC.EQ.1)WRITE(2,91)
91    FORMAT(/5X,'WATER BALANCE FOUND OK'//)
      S(I,1)=S(I,NMONT+1)
      AVSPL(I)=AVSPL(I)+CUMR4(I)/FLOAT(NYEAR)
202   CONTINUE
      WRITE(4,*)(IC(IC1),IC1=1,5)
      IF(IOPTI(I).NE.0)WRITE(2,*)(AADEI(I,J),J=1,NYEAR)
      IF(IFIRM(I).NE.0)WRITE(2,*)(ANLEN(I,J),J=1,NYEAR)
      IF(IFIRM(I).NE.0)WRITE(2,*)(AADEE(I,J),J=1,NYEAR)
      IF(IFIRM(I).NE.0)WRITE(2,*)(AADUE(I,J),J=1,NYEAR)
 DO   5000 J=1,NYEAR
      IF(IRQDS(I).NE.0) SUM1(I)=SUM1(I)+AADDS(I,J)/FLOAT(NYEAR)
      IF(IOPTI(I).NE.0) SUM2(I)=SUM2(I)+AADEI(I,J)/FLOAT(NYEAR)
      IF(IFIRM(I).EQ.0)GO TO 9007
      SUM3(I)=SUM3(I)+AADEE(I,J)/FLOAT(NYEAR)
      SUM4(I)=SUM4(I)+AADUE(I,J)/FLOAT(NYEAR)
9007  IF(IOPTI(I).NE.0) SUM5(I)=SUM5(I)+SUMB(I,J)
5000  CONTINUE
201   CONTINUE
 DO   3005 I=1,NSITE
      IF(CASO(I).EQ.0)WRITE(3,6000)
6000  FORMAT(110('*'),//45X,'SIMULATION',//110('*'))
      IF(CASO(I).EQ.1)WRITE(3,6001)
6001  FORMAT(110('*'),//45X,'CONVENTIONAL',//110('*'))
      IF(CASO(I).EQ.2)WRITE(3,6002)
6002  FORMAT(110('*'),//45X,'RULE CURVE',//110('*'))
      IF(CASO(I).EQ.3)WRITE(3,6003)
6003  FORMAT(110('*'),//45X,'ZONING',//110('*'))
      IF(IRQDS(I).NE.0) WRITE(3,3007)NADDS(I),SUM1(I)
3007  FORMAT(1X,'NO. OF ANNUAL DEFICIET IN D/S=',I4,4X,
     1 'AVE.ANNUAL DEFICIET IN D/S=',F10.9)
      IF(IOPTI(I).NE.0) WRITE(3,5001)NADEI(I),SUM2(I)
5001  FORMAT(1X,'NO.OF ANNUAL DEFICIT IN IRRIGATION=',I4,4X,'AVE.
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     1  ANNUAL DEFICIT IN IRRIGATION=',F10.5/)
        IF(IFIRM(I).EQ.0)GO TO 9008
        WRITE(3,5006)NADEE(I),SUM3(I)
 5006   FORMAT(1X,'NO.OF ANNUAL DEFICIT IN ENERGY=',I4,4X,'AVE.ANNUAL
     1  DEFICIT IN ENERGY=',F10.1/)
        WRITE(3,5007)NADUE(I),SUM4(I)
 5007   FORMAT(1X,'NO.OF ANNUAL DUMP IN ENERGY=',I4,4X,'AVE. ANNUAL
     1  DUMPE IN ENERGY=',F10.1/)
 9008   WRITE(3,3000)
 3000   FORMAT(1X,3X,'AVE.DOWN/S',1X,'NO. OF DOWN/S',3X,'AVE.IRRIGA',
     1  1X,'NO. OF IRRIGA',3X,'AVE. ENERGY',1X,'NO. OF ENERGY',3X,
     2 'AVE. DUMPEN',1X,'NO. OF DUMPEN')
        WRITE(3,3001)
 3001   FORMAT(1X,6(7X,'DEFICIT'),2(7X,'SURPLUS'))
        WRITE(3,3002)
 3002   FORMAT(1X,8(7X,'IN TIME'))
        WRITE(3,3003)
 3003   FORMAT(1X,8(9X,'MONTH'))
        WRITE(3,3004)
 3004   FORMAT(//)
        DO 3009 IT=1,NMONT
        WRITE(3,3006)AMDDS(I,IT),NMDDS(I,IT),AMDI(I,IT),NMDI(I,IT),
     1  AMDE(I,IT),NMDE(I,IT),AMDUE(I,IT),NMDUE(I,IT)
 3006   FORMAT(1X,2(F14.7,I14),2(E14.5,I14))
 3009   CONTINUE
        WRITE(3,3020) AVSPL(I)
 3020   FORMAT(2X,'ANNUAL SPILL=,'F14.3)
        WRITE(3,3010)
 3010   FORMAT(//,7X,'NO.OF.TIMES',2X,'NO.OF.TIMES')
        WRITE(3,3011)
 3011   FORMAT(9X,'RES.EMPTY',4X,'RES.FULL'/)
        DO 5008 IT=1,NMONT
        WRITE(3,3012)NREMT(I,IT),NRFUT(I,IT)
 3012   FORMAT(I14,I13)
 5008   CONTINUE
        WRITE(3,*)SUM5(I)
 3005   CONTINUE
        CALL BENFT(Y,PPC)
        STOP
        END
C       *****************************************************************
        FUNCTION AREA(I,X)
C       *****************************************************************
        DIMENSION ISITE(6),IUSE(6,4)
        COMMON/BLK17/ ISITE,IUSE
        GO TO (1,2,3,4,5)ISITE(I)
```

```
1         AREA=0.2265317E+03+0.4286903E-02*X+0.3299952E-04*X**2-
     1    0.4754354E-08*X**3+0.2161810E-12*X**4
          RETURN
2         AREA=0.3010366E-01+0.2885666E+00*X-0.1744216E-01*X**2+
     1    0.2336046E-03*X**3+0.1432534E-04*X**4
          RETURN
3         AREA=0.3887914E+01+0.3291998E-01*X-0.2770826E-05*X**2
     1    +0.3767724E-09*X**3-0.1317866E-13*X**4
          RETURN
4         AREA=0
          RETURN
5         AREA=0.3851403E+03+0.3401476E+03*X-0.1340375E+04*X**2
     1    -0.2174464E+04*X**3
          END
C         *********************************************************
          FUNCTION ELEVAT(I,X)
C         *********************************************************
          DIMENSION ISITE(6),IUSE(6,4)
          COMMON/BLK17/ ISITE,IUSE
          GO TO (1,2,3,4,5)ISITE(I)
1         ELEVAT=0.1602608E+03+0.2707258E-02*X-0.1006891E-06*X**2
          RETURN
2         ELEVAT=0.6157974E+03+0.6923746E+01*X-0.1310248E+01*X**2+
     1    0.1077476E+00*X**3-0.3007150E-02*X**4
          RETURN
3         ELEVAT=0.3715872E+03+0.6111376E-01*X-0.2155736E-04*X**2
     1    +0.3969155E-08*X**3-0.2531183E-12*X**4
          RETURN
4         ELEVAT=0
          RETURN
5         ELEVAT=0.3896889E+03+0.2054818E+02*X-0.4854121E+01*X**2
     1    +0.4425995E+00*X**3
          END
C         *********************************************************
C         SUBROUTINE RATI TO FIND RATIOS
C         *********************************************************
          SUBROUTINE RATI(RATIO,ISTRT,IMONT,I,J,NMONT,NDAYS,Y)
          DIMENSION FLOWT(1,50,31),PT(1,50,31),NDAYS(12),IFLM(1,12)
          DIMENSION X(12),S(1,13),FLOW(1,50,12),P(1,50,12)
          DIMENSION YMIN(1,12),REQDS(1,12),REQIT(1,12)
          DIMENSION YMAX(1,12),REQIF(1,12),EVPVO(1,12)
          COMMON/BLK12/FLOW,P,EVPVO
          COMMON/BLK11/YMAX,YMIN,S
          COMMON/BLK41/REQDS,REQIT,REQIF
          COMMON/BLK6/FLOWT,PT
          COMMON/BLK8/IFLM
```

```
      IFULL=0
      BIG=0
      IBIG=0
      DO 7000 IL=1,IMONT
      X(IL)=0.
      XX=0
      YY=0
      IF(IFLM(I,IL).NE.1)GO TO 2
      DO 1 ITF=1,NDAYS(IL)
      XX=XX+FLOWT(I,J,ITF)
      YY=YY+PT(I,J,ITF)
1     CONTINUE
      GO TO 3
2     XX=FLOW(I,J,IL)
      YY=P(I,J,IL)
3     WATER=S(I,IL)+XX+YY-EVPVO(I,IL)-
     1 YMIN(I,IL)-(REQDS(I,IL)+REQIT(I,IL))
      IF(WATER.GE.(Y-YMIN(I,IL)))IFULL=IL
      IF(WATER.LT.(Y-YMIN(I,IL)))X(IL)=WATER
      IF(WATER.GE.(Y-YMIN(I,IL)))S(I,IL+1)=Y
      IF(WATER.LT.(Y-YMIN(I,IL)))S(I,IL+1)=X(IL)+YMIN(I,IL)
7000  CONTINUE
      SUM=0.
      IF(IFULL.NE.0)SUM=YMAX(I,IL)-YMIN(I,IL)
      IF(IFULL.NE.0)GO TO 7002
      BIG=X(1)
      IBIG=1
      DO 7001 IL=2,IMONT
      IF(X(IL).LT.BIG)GO TO 7001
      BIG=X(IL)
      IBIG=IL
7001  CONTINUE
      SUM=BIG
7002  IF(IFULL.NE.0)ISTRT=IFULL+1
      IF(IFULL.EQ.0)ISTRT=IBIG+1
      IF(IPRTR.EQ.1)WRITE(5,*)J,IFULL,IBIG,BIG,SUM
      SUM1=0
      SUM2=0
      SUM3=0
      DO 7003 IL=ISTRT,NMONT
      SUM=SUM+FLOW(I,J,IL)+P(I,J,IL)
      SUM1=SUM1+EVPVO(I,IL)+REQDS(I,IL)
      SUM2=SUM2+REQIT(I,IL)
      SUM3=SUM3+REQIF(I,IL)
7003  CONTINUE
      IF(IPRTR.EQ.1)WRITE(5,*)SUM,SUM1,SUM2,SUM3
```

```
      DEFCT=0
      XX=0
      RATIO=0
      IF(SUM.GE.(SUM1+SUM2))GO TO 7004
      DEFCT=SUM1+SUM2-SUM
      XX=SUM2-DEFCT
      RATIO=((XX-SUM3)/(SUM2-SUM3))*100
 7004 IF(IPRTR.EQ.1)WRITE(5,*)DEFCT,XX,RATIO
      RETURN
      END
C     ***********************************************************
C     SUBROUTINE INTPO TO INTERPOLATE BETWEEN CAPACITY-ELEVATION &
C                            AREA-ELEVATION
C     ***********************************************************
      SUBROUTINE INTPO(XG,X,Y,YC,NPART,I)
      DIMENSION X(100),Y(100)
      DO 4 I=2,NPART
      IF (XG.LE.X(I))GO TO 2
      GO TO 4
 2    YC=YINTP(XG,X,Y,I)
      RETURN
 4    CONTINUE
      RETURN
      END
      FUNCTION YINTP(XG,X,Y,I)
      DIMENSION X(100),Y(100)
      X1=XG-X(I-1)
      Z1=X(I)-X(I-1)
      Y1=Y(I)-Y(I-1)
      YINTP=Y(I-1)+(X1/Z1)*Y1
      RETURN
      END
C     ***********************************************************
C     SUBROUTINE FLOOD IN ZONING FOR DAILY FLOWS IN FLOOD MONTH
C     ***********************************************************
      SUBROUTINE FLOOD(S)
C     FLOOD MODERATION FOR ZONING
      DIMENSION RLS1T(31),RLS4T(31),NDAYS(12),SS(1,32),XXX(100)
      DIMENSION YYY(100),ZZZ(100),EVPVO(1,12),TWL(1),PPEFF(1)
      DIMENSION PPC(1),DAYS(12),YBT(1,31),YMAXT(1,31),IENO(12)
      DIMENSION YMINT(1,31),FLOWT(1,50,31),PT(1,50,31)
      DIMENSION REQIT(1,12),REQEF(1,12),REQET(1,12),OT(1,31)
      DIMENSION REQIF(1,12),REQDS(1,12),RLS2T(31),RLS3T(31)
      DIMENSION PHMIN(1,12),EVAPO(1,12),S(1,13),ENER(1,12)
      DIMENSION RLS1(1),RLS2(1),RLS3(1),RLS4(1),TLS(31)
      DIMENSION DDD(100),EEE(100),AAA(100),BBB(100),CCC(100)
```

```
      DIMENSION NREMT(1,12),NRFUT(1,12),MREMT(1),MRFUT(1)
      DIMENSION FLOW(1,50,12),WANET(1),P(1,50,12)
      COMMON/BLK1/TODAM,YD,Y,EVAPO,WAVFU
      COMMON/BLK13/YMAXT,YMINT,SS,OT
      COMMON/BLK2/TWL,PPEFF,PPC,PHMIN,CCF
      COMMON/BLK3/NDAYS,IT,NPART,I,J,KPART,IENO,IEVPO
      COMMON/BLK4/REQEF,REQET
      COMMON/BLK41/REQDS,REQIT,REQIF
      COMMON/BLK5/RAEZ1,RAEZ2,RAIZ3,RAEZ3,RAEZ5
      COMMON/BLK6/FLOWT,PT
      COMMON/BLK61/XXX,YYY,ZZZ,AAA,BBB,CCC,DDD,EEE
      COMMON/BLK7/RLS1,RLS2,RLS3,RLS4,ENER
      COMMON/BLK9/NREMT,NRFUT
      COMMON/BLK10/ELE,WANET
      COMMON/BLK12/FLOW,P,EVPVO
      READ(1,*)(FLOWT(I,J,ITF),ITF=1,NDAYS(IT))
      IF(IPRTD.EQ.1)WRITE(4,*)(FLOWT(I,J,ITF),ITF=1,NDAYS(IT))
      DO 10 ITF=1,NDAYS(IT)
      FLOWT(I,J,ITF)=FLOWT(I,J,ITF)*2.333E-06
      10 CONTINUE
      FLOW(I,J,IT)=0
      WANET(I)=0
      READ(1,*)(PT(I,J,ITF),ITF=1,NDAYS(IT))
      IF(IPRTD.EQ.1)WRITE(4,*)(PT(I,J,ITF),ITF=1,NDAYS(IT))
      MREMT(I)=0
      MRFUT(I)=0
      SS(I,1)=S(I,IT)
      LLL=112
      IF(IPRTF.EQ.1)WRITE(5,*)LLL,SS(I,IT)
      DO 203 ITF=1,NDAYS(IT)
      DAYS(IT)=NDAYS(IT)
      RLS1T(ITF)=0
      RLS2T(ITF)=0
      RLS3T(ITF)=0
      RLS4T(ITF)=0
      REQV=0
      REQA=0
      ADNLV=0
      ADNLC=0
      ADNLD=0
      REGEN=0
      ENERG=0
      AVANW=0
C     CALCULATE WATER SPREAD,AS
C     AS=AREA(I,SS(I,ITF))
      CALL INTPO(SS(I,ITF),XXX,ZZZ,AS,NPART,IUP)
```

```
      IF(IEVPO.EQ.0)AS=1.0
C     CALCULATE RESERVOIR EVAPORATION,EL
      EL=AS*EVAPO(I,IT)/DAYS(IT)
C     CALCULATE RESERVOIR ELEVATION,ELE
C     ELE=ELEVAT(I,SS(I,ITF))
      IF(ITF.EQ.1)ELE1=ELE
      CALL INTPO(SS(I,ITF),XXX,YYY,ELE,NPART,IUP)
      HE=ELE-TWL(I)
C     CF=3600.*24*365/(12.0*CCF)
C     FACTR=9.8*HE*PPEFF(I)*24*30.4
C     QMAX=PPC(I)*1000*CF/(9.8*HE*PPEFF(I))
      CFT=3600.*24/CCF
      FACT=9.8*HE*PPEFF(I)*24
      QMAX=PPC(I)*1000*CFT/(9.8*HE*PPEFF(I))
      REQVF=(CFT*(REQEF(I,IT)*1000.)/FACT)/DAYS(IT)
      REQVT=(CFT*(REQET(I,IT)*1000.)/FACT)/DAYS(IT)
      YMAXT(I,ITF)=CAL(AAA,DAYS,IT,NMONT,ITF)
      YBT(I,ITF)=CAL(BBB,DAYS,IT,NMONT,ITF)
      YMINT(I,ITF)=CAL(CCC,DAYS,IT,NMONT,ITF)
C     RESERVOIR OPERATION WITH ZONING(PARTITIONING)
1002  IF(SS(I,ITF).LE.TODAM.AND.SS(I,ITF).GT.Y)GO TO 1010
      IF(SS(I,ITF).LE.Y.AND.SS(I,ITF).GT.YMAXT(I,ITF))GO TO 1011
      IF(SS(I,ITF).LE.YMAXT(I,ITF).AND.SS(I,ITF)
     1 .GT.YBT(I,ITF))GO TO 1012
      IF(SS(I,ITF).LE.YBT(I,ITF).AND.SS(I,ITF).GT.YMINT(I,ITF).AND
     1 YMINT(I,ITF).GE.YD)GO TO 1013
      IF(SS(I,ITF).LE.YMINT(I,ITF).AND.YMINT(I,ITF).GE.YD)
     1 GO TO 1014
      1010 AVANW=SS(I,ITF)+FLOWT(I,J,ITF)+PT(I,J,ITF)-EL-Y
      TLS(ITF)=AVANW-Y
      REMWA=TLS(ITF)
      DEMND=REQDS(I,IT)/DAYS(IT)
      IF(REMWA.GE.DEMND)RLS1T(ITF)=DEMND
      IF(REMWA.LT.DEMND)RLS1T(ITF)=REMWA
      REMWA=REMWA-RLS1T(ITF)
      DEMND=REQIT(I,IT)/DAYS(IT)
      IF(REMWA.GE.DEMND)RLS2T(ITF)=DEMND
      IF(REMWA.LT.DEMND)RLS2T(ITF)=REMWA
      REMWA=REMWA-RLS2T(ITF)
      REQV=REMWA
      LLL=1118
      IF(IPRTF.EQ.1)WRITE(5,*)LLL,RLS1T(ITF),RLS2T(ITF),REQV,
     1 TLS(ITF),REMWA,DEMND
      GO TO 2000
1011  AVANW=SS(I,ITF)+FLOWT(I,J,ITF)+PT(I,J,ITF)-EL-YMAXT(I,ITF)
C     CALL INTPO(ELE,DDD,EEE,TLS(ITF),KPART,IUP)
```

```
      TLS(ITF)=SLAB(ELE)
      REMWA=TLS(ITF)
      DEMND=REQDS(I,IT)/DAYS(IT)
      IF(REMWA.GE.DEMND)RLS1T(ITF)=DEMND
      IF(REMWA.LT.DEMND)RLS1T(ITF)=REMWA
      REMWA=REMWA-RLS1T(ITF)
      DEMND=REQIT(I,IT)/DAYS(IT)
      IF(REMWA.GE.DEMND)RLS2T(ITF)=DEMND
      IF(REMWA.LT.DEMND)RLS2T(ITF)=REMWA
      REMWA=REMWA-RLS2T(ITF)
      REQV=REMWA
      LLL=1119
      IF(IPRTF.EQ.1)WRITE(5,*)LLL,RLS1T(ITF),RLS2T(ITF),REQV,
     1 SS(I,ITF),
     1 YMAXT(I,ITF),TLS(ITF)
      GO TO 2000
1012  AVANW=SS(I,ITF)+FLOWT(I,J,ITF)+PT(I,J,ITF)-EL-YBT(I,ITF)
      RLS1T(ITF)=REQDS(I,IT)/DAYS(IT)
      RLS2T(ITF)=(REQIF(I,IT)+(REQIT(I,IT)-REQIF(I,IT))
     1 *(RAIZ3/100.))/DAYS(IT)
      REQV=(REQVF+(REQVT-REQVF)*(RAEZ3/100.))/DAYS(IT)
      LLL=1120
      IF(IPRTF.EQ.1)WRITE(5,*)LLL,RLS1T(ITF),RLS2T(ITF),
     1 REQV,SS(I,ITF),YBT(I,ITF)
      GO TO 2000
1013  AVANW=SS(I,ITF)+FLOWT(I,J,ITF)+PT(I,J,ITF)-EL-YMINT(I,ITF)
      RLS1T(ITF)=REQDS(I,IT)/DAYS(IT)
      RLS2T(ITF)=0.0
      REQV=0.
      LLL=1122
      IF(IPRTF.EQ.1)WRITE(5,*)LLL,RLS1T(ITF),RLS2T(ITF),
     1 REQV,SS(I,ITF),YMINT(I,ITF)
      GO TO 2000
1014  AVANW=SS(I,ITF)+FLOWT(I,J,ITF)+PT(I,J,ITF)-EL
      RLS1T(ITF)=(REQDS(I,IT)*(RAEZ5/100.))/DAYS(IT)
      RLS2T(ITF)=0.0
      REQV=0.
      LLL=1123
      IF(IPRTF.EQ.1)WRITE(5,*)LLL,RLS1T(ITF),RLS2(ITF),REQV,SS
     1 (I,ITF)
2000  IF(ELE.LE.PHMIN(I,IT))ENERG=0
      IF(ELE.LE.PHMIN(I,IT))RLS3T(ITF)=0
      IF(ELE.LE.PHMIN(I,IT))ADNLC=0
      IF(ELE.LE.PHMIN(I,IT))GO TO 991
C     CALCULATE ENERGY GENERATED FROM RLS1 OR /AND RLS2
      IF(IENO(I).EQ.1)REGEN=RLS1T(ITF)
```

```
      IF(IENO(I).EQ.2)REGEN=RLS2T(ITF)
      IF(IENO(I).EQ.3)REGEN=RLS1T(ITF)+RLS2T(ITF)
      IF(IENO(I).EQ.4)REGEN=0.00
C     CALCULATE ADDITIONAL POWER RELEASES,RLS3
      IF(REQV.GE.QMAX)REQA=QMAX
      IF(REQV.GE.QMAX)ADNLC=0
      IF(REQV.LT.QMAX)REQA=REQV
      IF(REQV.LT.QMAX)ADNLC=QMAX-REQV
      IF(REGEN.GE.REQA)ENERG=REQA
      IF(REGEN.GE.REQA)ADNLV=0
      IF(REGEN.LT.REQA)ENERG=REGEN
      IF(REGEN.LT.REQA)ADNLV=REQA-REGEN
      LLL=1111
      IF(IPRTF.EQ.1)WRITE(5,*)LLL,REQV,QMAX,REQA,ADNLV,ADNLC,ENERG
     1 WAVFU
      IF(ADNLV.NE.0.0)GO TO 701
      IF(ADNLV.EQ.0.0.AND.ADNLC.NE.0.0.AND.(REGEN-REQA).LE.
     1 ADNLC)GO TO 9001
      ENERG=REQA+ADNLC
      ADNLC=0
      GO TO 991
9001  ENERG=REGEN
      ADNLC=QMAX-REGEN
      GO TO 991
701   IF(WAVFU.EQ.0)GO TO 991
      IF(WAVFU.LT.ADNLV)ADNLD=WAVFU
      IF(WAVFU.GE.ADNLV)ADNLD=ADNLV
      ADNLV=ADNLV-ADNLD
      WAVFU=WAVFU-ADNLD
      ENERG=ENERG+ADNLD
      IF(ADNLV.NE.0.)ADNLC=0
      RLS3T(ITF)=ADNLD
      LLL=40
      IF(IPRTF.EQ.1)WRITE(5,*)LLL,ADNLC,ENERG,ADNLV,ADNLD,WAVFU,
     1 RLS3T(ITF)
991   AVANW=(SS(I,ITF)+FLOWT(I,J,ITF)+PT(I,J,ITF)-EL)-
     1 (RLS1T(ITF)+RLS2T(ITF)+RLS3T(ITF))
      IF(AVANW.LE.Y)RLS4T(ITF)=0.
      IF(AVANW.GT.Y)RLS4T(ITF)=AVANW-Y
      IF(RLS4T(ITF).LT.0.0)RLS4T(ITF)=0
      IF(RLS4T(ITF).LT.ADNLC)ADNLC=RLS4T(ITF)
      ENERG=ENERG+ADNLC
      ENERG=ENERG/CFT
      ENERG=ENERG*9.8*HE*PPEFF(I)
      ENERG=ENERG*24.
      ENERG=ENERG/1000.
```

```
      ENER(I,IT)=ENER(I,IT)+ENERG
      LLL=60
      IF(IPRTF.EQ.1)WRITE(5,*)LLL,AVANW,ADNLC,RLS4T(ITF),ENERG,
     1 ENER(I,IT)
      LLL=70
      IF(IPRTF.EQ.1)WRITE(5,*)LLL,REQDS(I,IT),RLS1T(ITF),RLS2T
     1 (ITF),REQV,REGEN,RLS3T(ITF),ENER(I,IT)
      IF(IPRTF.EQ.1)WRITE(5,992)
992   FORMAT(1X,30('-'))
80    FORMAT(//3X,7F8.3,F10.2)
C     CALCULATE TOTAL RELEASES
81    OT(I,ITF)=RLS1T(ITF)+RLS2T(ITF)+RLS3T(ITF)+RLS4T(ITF)
C     CALCULATE FINAL RESERVOIR CONTENT
      IF(RLS4T(ITF).NE.0.0)SS(I,ITF+1)=Y
      IF(RLS4T(ITF).LE.0.0)SS(I,ITF+1)=SS(I,ITF)+FLOWT(I,J,ITF)
     1 +PT(I,J,ITF)-EL-OT(I,ITF)
      IF(SS(I,ITF+1).LT.0.0)SS(I,ITF+1)=0.0
      IF(SS(I,ITF).LE.YMINT(I,ITF))MREMT(I)=MREMT(I)+1
      IF(SS(I,ITF).EQ.Y)MRFUT(I)=MRFUT(I)+1
      RLS1(I)=RLS1(I)+RLS1T(ITF)
      RLS2(I)=RLS2(I)+RLS2T(ITF)
      RLS3(I)=RLS3(I)+RLS3T(ITF)
      RLS4(I)=RLS4(I)+RLS4T(ITF)
      FLOW(I,J,IT)=FLOW(I,J,IT)+FLOWT(I,J,ITF)
      WANET(I)=WANET(I)+AVANW
203   CONTINUE
      IF(MREMT(I).NE.0)NREMT(I,IT)=NREMT(I,IT)+1
      IF(MRFUT(I).NE.0)NRFUT(I,IT)=NRFUT(I,IT)+1
      S(I,IT+1)=SS(I,NDAYS(IT))
      ELE=ELE1
      RETURN
      END
C     ****************************************************************
      SUBROUTINE BENFT(YYY,PPC)
C     ****************************************************************
      DIMENSION NUSRE(1),NDSRE(1),ARD(1,10),IREQ(1,10),
     1 AADE(1,50),AND(1,50,10),AADU(1,50),Y(1),PPC(1)
      DIMENSION CCRE(1),CCPP(1),AORE(1),AOPP(1),VORE(1),
     1 VOPP(1),TVCC(1),TVBD(1),TVOD(1),AFBD(1,10),
     1 AOWD(1,10),CCWD(1,10),VPBD(1,10),
     1 VDBD(1,10),VOWD(1,10),APBD(1,10,50),ALBD(1,10,50),
     1 ADBD(1,10,50)
      COMMON/BLK14/ARD,AADE,AADU,AND
      COMMON/BLK15/RATE
      COMMON/BLK16/IREQ,NDSRE,NYEAR,NSITE
      TVC=0
```

```
      TVB=0
      TVO=0
      PVNB=0
      DO 16 I=1,NSITE
      Y(I)=YYY
      CCRE(I)=0
      CCPP(I)=0
      AORE(I)=0
      AOPP(I)=0
      VORE(I)=0
      VOPP(I)=0
      TVCC(I)=0
      TVBD(I)=0
      TVOD(I)=0
      DO 16 II=1,NDSRE(I)
      AFBD(I,II)=0
      AOWD(I,II)=0
      CCWD(I,II)=0
      AOWD(I,II)=0
      VPBD(I,II)=0
      VDBD(I,II)=0
      VOWD(I,II)=0
      DO 16 JJ=1,NYEAR
      APBD(I,II,JJ)=0
      ALBD(I,II,JJ)=0
      ADBD(I,II,JJ)=0
16    CONTINUE
      DO 1 I=1,NSITE
      DO 2 II=1,NDSRE(I)
      AFBD(I,II)=ABFD(ARD(I,II),I,II)
      IF(IPRTB.EQ.1)WRITE(2,100)AFBD(I,II)
100   FORMAT(1X,'AFBD',F20.3)
2     CONTINUE
      DO 3 JJ=1,NYEAR
      DO 4 II=1,NDSRE(I)
      IF(IREQ(I,II).EQ.1)ALBD(I,II,JJ)=ALFD(AADE(I,JJ),I,II)
      IF(IREQ(I,II).EQ.0)ALBD(I,II,JJ)=ALFD(AND(I,JJ,II),I,II)
      IF(IPRTB.EQ.1)WRITE(2,99)ALBD(I,II,JJ)
99    FORMAT(1X,'ALBD',F20.3)
4     CONTINUE
3     CONTINUE
      DO 5 JJ=1,NYEAR
      DO 6 II=1,NDSRE(I)
      APBD(I,II,JJ)=AFBD(I,II)-ALBD(I,II,JJ)
      IF(IPRTB.EQ.1)WRITE(2,101)APBD(I,II,JJ)
101   FORMAT(1X,'APBD',F20.3)
```

```
      IF(IREQ(I,II).EQ.1)ADBD(I,II,JJ)=ADFD(AADU(I,JJ),I,II)
      IF(IPRTB.EQ.1)WRITE(2,130)ADBD(I,II,JJ)
130   FORMAT(1X,'ADBD',F20.3)
6     CONTINUE
5     CONTINUE
      CCRE(I)=CFRE(Y(I),I)
      IF(IPRTB.EQ.1)WRITE(2,102)CCRE(I)
102   FORMAT(1X,'CCRE',F20.3)
      CCPP(I)=CFPP(PPC(I),I)
      IF(IPRTB.EQ.1)WRITE(2,103)CCPP(I)
103   FORMAT(1X,'CCPP',F20.3)
      DO 7 II=1,NDSRE(I)
      CCWD(I,II)=CFWD(ARD(I,II),I,II)
      IF(IPRTB.EQ.1)WRITE(2,104)CCWD(I,II)
104   FORMAT(1X,'CCWD',F20.3)
7     CONTINUE
      AORE(I)=AOFR(Y(I),I)
      IF(IPRTB.EQ.1)WRITE(2,105)AORE(I)
105   FORMAT(1X,'AORE',F20.3)
      AOPP(I)=AOFP(PPC(I),I)
      IF(IPRTB.EQ.1)WRITE(2,106)AOPP(I)
106   FORMAT(1X,'AOPP',F20.3)
      DO 8 II=1,NDSRE(I)
      AOWD(I,II)=AOFD(ARD(I,II),I,II)
      IF(IPRTB.EQ.1)WRITE(2,107)AOWD(I,II)
107   FORMAT(1X,'AOWD1',F20.3)
8     CONTINUE
      DO 9 JJ=1,NYEAR
      DO 10 II=1,NDSRE(I)
      PWF=1.0/((1.0+RATE)**JJ)
      IF(IPRTB.EQ.1)WRITE(2,108)PWF
108   FORMAT(1X,'PWF',F20.3)
      VPBD(I,II)=VPBD(I,II)+PWF*APBD(I,II,JJ)
      IF(IPRTB.EQ.1)WRITE(2,109)VPBD(I,II)
109   FORMAT(1X,'VPBD',F20.3)
      IF(IREQ(I,II).EQ.1)VDBD(I,II)=VDBD(I,II)+PWF*ADBD(I,II,JJ)
      IF(IPRTB.EQ.1)WRITE(2,98)VDBD(I,II)
98    FORMAT(1X,'VDBD',F20.3)
10    CONTINUE
9     CONTINUE
      PWFA=((((1.0+RATE)**NYEAR)-1.0)/RATE)/((1.0+RATE)**NYEAR)
      IF(IPRTB.EQ.1)WRITE(2,110)PWFA
      110 FORMAT(1X,'PWFA',F20.3)
      VORE(I)=PWFA*AORE(I)
      IF(IPRTB.EQ.1)WRITE(2,111)VORE(I)
111   FORMAT(1X,'VORE',F20.3)
```

```
      VOPP(I)=PWFA*AOPP(I)
      IF(IPRTB.EQ.1)WRITE(2,112)VOPP(I)
112   FORMAT(1X,'VOPP',F20.3)
      DO 11 II=1,NDSRE(I)
      VOWD(I,II)=PWFA*AOWD(I,II)
      IF(IPRTB.EQ.1)WRITE(2,113)VOWD(I,II)
113   FORMAT(1X,'VOWD',F20.3)
11    CONTINUE
      TVCC(I)=CCRE(I)+CCPP(I)
      IF(IPRTB.EQ.1)WRITE(2,114)TVCC(I)
114   FORMAT(1X,'TVCC',F20.3)
      DO 12 II=1,NDSRE(I)
      TVCC(I)=TVCC(I)+CCWD(I,II)
      IF(IPRTB.EQ.1)WRITE(2,115)TVCC(I)
115   FORMAT(1X,'TVCC',F20.3)
12    CONTINUE
      DO 13 II=1,NDSRE(I)
      TVBD(I)=TVBD(I)+VPBD(I,II)
      IF(IPRTB.EQ.1)WRITE(2,116)TVBD(I)
116   FORMAT(1X,'TVBD',F20.3)
      IF(IREQ(I,II).EQ.1)TVBD(I)=TVBD(I)+VDBD(I,II)
      IF(IPRTB.EQ.1)WRITE(2,97)TVBD(I)
97    FORMAT(1X,'TVBD',F20.3)
13    CONTINUE
      TVOD(I)=VORE(I)+VOPP(I)
      IF(IPRTB.EQ.1)WRITE(2,117)TVOD(I)
117   FORMAT(1X,'TVOD',F20.3)
      DO 14 II=1,NDSRE(I)
      TVOD(I)=TVOD(I)+VOWD(I,II)
      IF(IPRTB.EQ.1)WRITE(2,118)TVOD(I)
118   FORMAT(1X,'TVOD',F20.3)
14    CONTINUE
1     CONTINUE
      DO 15 I=1,NSITE
      TVC=TVC+TVCC(I)
      IF(IPRTB.EQ.1)WRITE(2,119)TVC
119   FORMAT(1X,'TVC',F20.3)
      TVB=TVB+TVBD(I)
      IF(IPRTB.EQ.1)WRITE(2,120)TVB
120   FORMAT(1X,'TVB',F20.3)
      TVO=TVO+TVOD(I)
      IF(IPRTB.EQ.1)WRITE(2,121)TVO
121   FORMAT(1X,'TVO',F20.3)
15    CONTINUE
      PVNB=-TVC+TVB-TVO
      WRITE(2,122)PVNB
```

```
122     FORMAT(1X,'PVNB',F20.3)
        RETURN
        END
C       ************************************************************
        FUNCTION ABFD(X,I,II)
C       ************************************************************
        DIMENSION ISITE(6),IUSE(6,4)
        COMMON/BLK17/ISITE,IUSE
        GO TO(1,2,3,4,5)ISITE(I)
1       GO TO(10)IUSE(I,II)
10      ABFD=0.1423317E+02+0.3006858E+00*X+0.1895906E-05*X**2-
     1  0.8021544E-10*X**3
        RETURN
        2 GO TO (20)IUSE(I,II)
        20 ABFD=0.9000000E+01+0.6677988E+01*X
        RETURN
        3 GO TO (30)IUSE(I,II)
        30 ABFD=0.0021*X
        RETURN
        4 GO TO (40)IUSE(I,II)
40      ABFD=0
        RETURN
5       GO TO(50,51,52,53)IUSE(I,II)
50      ABFD=0
        RETURN
51      ABFD=0.1375299E+02+0.5755832E+02*X-0.1094980E+00*X**2
        RETURN
52      ABFD=0.0002*X
        RETURN
53      ABFD=0
        RETURN
        END
C       ************************************************************
        FUNCTION ALFD(X,I,II)
C       ************************************************************
        DIMENSION ISITE(6),IUSE(6,4)
        COMMON/BLK17/ISITE,IUSE
        GO TO(1,2,3,4,5)ISITE(I)
1       GO TO(10)IUSE(I,II)
10      ALFD=1.2*(0.1423317E+02+0.3006858E+00*X+0.1895906E-05*X**2-
     1  0.8021544E-10*X**3)
        RETURN
2       GO TO (20)IUSE(I,II)
20      ALFD=1.2*(0.9000000E+01+0.6677988E+01*X)
        RETURN
3       GO TO (30)IUSE(I,II)
```

```
30        ALFD=0.0030*X
          RETURN
4         GO TO (40)IUSE(I,II)
40        ALFD=0
          RETURN
5         GO TO(50,51,52,53)IUSE(I,II)
50        ALFD=0
          RETURN
51        ALFD=1.2*(0.1375299E+02+0.5755832E+02*X-0.1094980E+00*X**2
          RETURN
52        ALFD=0.0003*X
          RETURN
53        ALFD=0
          RETURN
          END
C         *************************************************************
          FUNCTION ADFD(X,I,II)
C         *************************************************************
          DIMENSION ISITE(6),IUSE(6,4)
          COMMON/BLK17/ISITE,IUSE
          GO TO(1,2,3,4,5)ISITE(I)
1       GO  TO(10)IUSE(I,II)
10        ADFD=0
          RETURN
2         GO TO (20)IUSE(I,II)
20        ADFD=0
          RETURN
3         GO TO (30)IUSE(I,II)
30        ADFD=0.001*X
          RETURN
4         GO TO (40)IUSE(I,II)
40        ADFD=0
          RETURN
5         GO TO(50,51,52,53)IUSE(I,II)
50        ADFD=0
          RETURN
51        ADFD=0
          RETURN
52        ADFD=0.0001*X
          RETURN
53        ADFD=0
          RETURN
          END
```

```
C     ******************************************************************
      FUNCTION AOFR(X,I)
C     ******************************************************************
      DIMENSION ISITE(6),IUSE(6,4)
      COMMON/BLK17/ISITE,IUSE
      GO TO(1,2,3,4,5)ISITE(I)
1     AOFR=0.9969238E+01+0.1121193E-02*X-0.4049616E-07*X**2
      RETURN
2     AOFR=0.5382640E+00+0.2725958E+00*X-0.9070040E-02*X**2+
     1 0.1519245E-03*X**3
      RETURN
3     AOFR=0.1434326E+01+0.5793333E-02*X-0.3717141E-06*X**2+
     1 0.1308820E-10*X**3
      RETURN
4     AOFR=0
      RETURN
5     AOFR=0.5742246E-01+0.2859806E+00*X-0.9471226E-01*X**2+
     1 0.1296496E-01*X**3
      RETURN
      END
C     ******************************************************************
      FUNCTION AOFP(X,I)
C     ******************************************************************
      DIMENSION ISITE(6),IUSE(6,4)
      COMMON/BLK17/ISITE,IUSE
      GO TO(1,2,3,4,5)ISITE(I)
1     AOFP=0
      RETURN
2     AOFP=0
      RETURN
3     AOFP=0.7999995E+00+0.1404000E-01*X
      RETURN
4     AOFP=0
      RETURN
5     AOFP=0.1552224E-01+0.4564150E-03*X+0.4490396E-07*X**2
      RETURN
      END
C     ******************************************************************
      FUNCTION AOFD(X,I,II)
C     ******************************************************************
      DIMENSION ISITE(6),IUSE(6,4)
      COMMON/BLK17/ISITE,IUSE
      GO TO(1,2,3,4,5)ISITE(I)
1     GO TO(10)IUSE(I,II)
10    AOFD=0.8820311E+01+0.3120175E-03*X-0.4055366E-09*X**2
      RETURN
```

```
 2        GO TO (20)IUSE(I,II)
 20       AOFD=0.1400001E+00+0.1819135E+00*X
          RETURN
 3        GO TO (30)IUSE(I,II)
 30       AOFD=0
          RETURN
 4        GO TO (40)IUSE(I,II)
 40       AOFD=0
          RETURN
 5        GO TO(50,51,52,53)IUSE(I,II)
 50       AOFD=0
          RETURN
 51       AOFD=0.1900009E+00+0.5020609E+00*X-0.1463618E-01*X**2
          RETURN
 52       AOFD=0
          RETURN
 53       AOFD=0
          RETURN
          END
C         ****************************************************************
          FUNCTION CFRE(X,I)
C         ****************************************************************
          DIMENSION ISITE(6),IUSE(6,4)
          COMMON/BLK17/ISITE,IUSE
          GO TO(1,2,3,4,5)ISITE(I)
1         CFRE=0.1956047E+04+0.2393951E+00*X-0.1421198E-04*X**2+
     1    0.3590230E-09*X**3
          RETURN
2         CFRE=0.7064508E+02+0.7538718E+02*X-0.3910439E+01*X**2+
     1    0.9800397E-01*X**3
          RETURN
3         CFRE=0.1913125E+03+0.1381348E+01*X-0.2468824E-03*X**2+
     1    0.5372567E-07*X**3-0.5094591E-11*X**4
          RETURN
4         CFRE=0
          RETURN
5         CFRE=0.1033859E+02+0.5954181E+02*X-0.2012424E+02*X**2+
     1    0.2766336E+01*X**3
          RETURN
          END
C         ****************************************************************
          FUNCTION CFPP(X,I)
C         ****************************************************************
          DIMENSION ISITE(6),IUSE(6,4)
          COMMON/BLK17/ISITE,IUSE
          GO TO(1,2,3,4,5)ISITE(I)
```

```
1       CFPP=0
        RETURN
2       CFPP=0
        RETURN
3       CFPP=0.1499999E+03+0.2828000E+01*X
        RETURN
4       CFPP=0
        RETURN
5       CFPP=0.3104462E+01+0.9128303E-01*X+0.8980931E-05*X**2
        RETURN
        END
C       ***********************************************************
        FUNCTION CFWD(X,I,II)
C       ***********************************************************
        DIMENSION ISITE(6),IUSE(6,4)
        COMMOND/BLK17/ISITE,IUSE
        GO TO(1,2,3,4,5)ISITE(I)
1      GO  TO(10)IUSE(I,II)
10      CFWD=0.7374063E+03+0.1493530E+00*X-0.1961365E-04*X**2+
     1  0.8340066E-09
        RETURN
2      GO TO  (20)IUSE(I,II)
20      CFWD=0.2000002E+02+0.1784945E+02*X
        RETURN
3       GO TO (30)IUSE(I,II)
30      CFWD=0
        RETURN
4       GO TO (40)IUSE(I,II)
40      CFWD=0
        RETURN
5       GO TO(50,51,52,53)IUSE(I,II)
50      CFWD=0
        RETURN
51      CFWD=0.1900008E+02+0.5020611E+02*X-0.1463681E+01*X**2
        RETURN
52      CFWD=0
        RETURN
53      CFWD=0
        RETURN
        END
C       **************************************************************
C       FUNCTION CAL TO INTERPOLATE BETWEEN YMAX,YB & YMIN IN
C                             FLOOD MONTH
C       **************************************************************
        FUNCTION CAL(Y,DAYS,IT,NMONT,ITF)
        DIMENSION Y(100),DAYS(12)
```

```
      IF(IT.NE.1)GO TO 1
      X1=Y(IT)-Y(NMONT)
      CAL=Y(NMONT)+X1*ITF/DAYS(IT)
      GO TO 2
      1 X1=Y(IT)-Y(IT-1)
      CAL=Y(IT-1)+X1*ITF/DAYS(IT)
 2    RETURN
      END
C     ************************************************************
C      FUNCTION SLAB TO MAKE RELEASES AS PER PROPOSED
C                       STEPPED PATTERN
C     ************************************************************
      FUNCTION SLAB(ELE)
      IF(ELE.GE.410.56.AND.ELE.LT.415.00)GO TO 1
      IF(ELE.GE.415.00.AND.ELE.LT.416.00)GO TO 2
      IF(ELE.GE.416.00.AND.ELE.LT.417.00)GO TO 3
      IF(ELE.GE.417.00.AND.ELE.LT.418.00)GO TO 4
      IF(ELE.GE.418.00.AND.ELE.LT.419.00)GO TO 5
      IF(ELE.GE.419.00.AND.ELE.LT.420.00)GO TO 6
      IF(ELE.GE.420.00.AND.ELE.LT.421.00)GO TO 7
      IF(ELE.GE.421.00.AND.ELE.LT.421.50)GO TO 8
      IF(ELE.GE.421.50.AND.ELE.LT.422.00)GO TO 9
      IF(ELE.GE.422.00.AND.ELE.LT.422.50)GO TO 10
      IF(ELE.GE.422.50.AND.ELE.LT.423.00)GO TO 11
      IF(ELE.GE.423.00.AND.ELE.LT.423.50)GO TO 12
      IF(ELE.GE.423.50.AND.ELE.LT.424.00)GO TO 13
      IF(ELE.GE.424.00.AND.ELE.LT.424.28)GO TO 14
 1    SLAB=0.216
      RETURN
 2    SLAB=0.2592
      RETURN
 3    SLAB=0.3456
      RETURN
 4    SLAB=0.432
      RETURN
 5    SLAB=0.5184
      RETURN
 6    SLAB=0.6048
      RETURN
 7    SLAB=0.6912
      RETURN
 8    SLAB=0.7344
      RETURN
 9    SLAB=0.7776
      RETURN
10    SLAB=0.8208
```

```
      RETURN
11    SLAB=0.864
      RETURN
12    SLAB=0.9072
      RETURN
13    SLAB=0.9504
      RETURN
14    SLAB=0.9784
      RETURN
      END
C ************************************************************************
C                         ABBREVIATIONS
C ************************************************************************
C   FLOW=INFLOW TO THE RESERVOIR IN THOUSAND MILLION CUBIC METER
C   P=PRECIPITATION IN THE RESERVOIR
C   S=STORAGE IN THE RESERVOIR (TMCM)
C   O=OUTFLOW FROM THE RESERVOIR
C   AS=WATER SPREAD AREA
C   EL=EVAPORATION
C   ELE=ELEVATION IN METER
C   NSITE=NUMBER OF SITES
C   NYEAR=NUMBER OF YEARS
C   NMONT=NUMBER OF MONTHS CONSIDERED IN A YEAR
C   HOURS=NUMBER OF HOURS CONSIDERED IN A YEAR
C   KYEAR=STARTING YEAR
C   AVANW=NET WATER AVAILABLE
C   ARQDS=ANNUAL REQUIREMENT OF WATER FOR DOWNSTREAM
C   ARQDI=ANNUAL REQUIREMENT OF WATER FOR IRRIGATION
C   ARQDE=ANNUAL REQUIREMENT OF ENERGY (MEGA WATT HOUR)
C   PRQDS=MONTHLY PERCENTAGE REQUIRED FOR DOWNSTREAM
C   PRQI=MONTHLY PERCENTAGE REQUIRED FOR IRRIGATION
C   PRQE=MONTHLY PERCENTAGE REQUIRED FOR ENERGY
C   REQDS=MONTHLY REQUIREMENT OF WATER FOR DOWNSTREAM (M & I USES)
C   REQI=MONTHLY REQUIREMENT OF WATER FOR IRRIGATION
C   REQE=MONTHLY REQUIREMENT OF ENERGY
C   RLS1=RELEASES FOR DOWNSTREAM(M & I USES)
C   RLS2=RELEASES FOR IRRIGATION
C   RLS3=ADDITIONAL RELEASE OF WATER TO MEET THE ENERGY DEMAND
C   RLS4=RELEASE OF WATER THROUGH SPILL
C   IENO=IF 1,
C   DOWNSTREAM (M & I USES) RELEASE CAN BE USED FOR
C   IF  1,   POWER GENERATION
C   IF  2,   IRRIGATION RELEASE CAN BE USED FOR POWER GENERATION
C   IF  3,   BOTH 1 & 2 CAN BE USED FOR POWER GENERATION
C   IF  4,   NONE CAN BE USED FOR POWER GENERATION
C   PPEFF=POWER PLANT EFFICIENCY
```

```
C     PPC=POWER PLANT CAPACITY (MEGA WATT)
C     TWL=TAIL WATER LEVEL IN METER
C     CF=CONVERSION FACTOR
C     DEFDS=DEFICIT FOR DOWNSTREAM USE
C     DEFI=DEFICIT FOR IRRIGATION
C     DEFE=DEFICIT FOR ENERGY
C     NMDDS=NO.OF MONTHS DEFICIT IN DOWNSTREAM
C     NMDI=NO.OF MONTHS DEFICIT IN IRRIGATION
C     NMDE=NO.OF MONTHS DEFICIT IN ENERGY
C     CUMF=CUMULATIVE INFLOW TO THE RESERVOIR
C     CUMP=CUMULATIVE PRECIPITATION
C     CUMEL=CUMULATIVE EVAPORATION
C     CUMR1=CUMULATIVE RELEASE FOR DOWNSTREAM
C     CUMR2=CUMULATIVE RELEASE FOR IRRIGATION
C     CUMR3=CUMULATIVE RELEASE FOR ENERGY
C     CUMR4=CUMULATIVE RELEASE THROUGH SPILL
C     YMAX=MAXIMUM CAPACITY OF THE RESERVOIR
C     YMIN=MINIMUM CAPACITY OF THE RESERVOIR
C     DUMPE=DUMP ENERGY GENERATED
C     NMDUE=NO.OF MONTHS DUMP ENERGY GENERATED
C     REQA=ACTUAL WATER AVAILABLE FOR REQUIRED ENERGY GENERATION
C     ADNLV=ADDITIONAL VOL NEEDED FOR GENERATING REQUIRED ENERGY
C     PHMIN=MINIMUM POWER HEAD
C     EVAPO=EVAPORATION(DEPTH/VOLUME)
C     IFIRM=0,  IF NO HYDROPOWER
C     IFIRM=1,  IF FIRM ENERGY GENERATION IS REQUIRED IN SIMULATION
C     IFIRM=2,  IF TARGETED ENERGY GENERATION IS REQUIRED IN SIMULATIO
C     IFIRM=3,  IF MAXIMUM ENERGY GENERATION IS REQUIRED IN SIMULATION
C     IFIRM=4,  FOR MULTIPURPOSE RESERVOIR OPERATION
C     TODAM=TOP OF DAM
C     Y=GROSS CAPACITY
C     ADNLC=ADDITIONAL TURBINE CAPACITY AVAILABLE ABOVE REQV
C     REQV=ACTUAL WATER NEEDED FOR REQUIRED ENERGY GENERATION
C     REGEN=WATER FOR ENERGY GENERATION AVAILABLE FROM
C     RLS1 OR/AND RLS2
C     CASOC=CASES OF RESERVOIR OPERATION WITH CONVENTIONAL RULE
C     CASOR=CASES OF RESERVOIR OPERATION WITH RULE CURVE
C     CASOZ=CASES OF RESERVOIR OPERATION WITH ZONING
C     WAVFU=WATER AVAILABLE FOR UTILIZATION
C     CASO=CASES OF RESERVOIR SIMULATION/OPERATION
C     =0   (SIMULATION)
C     =1   (CONVENTIONAL RULE)
C     =2   (RULE CURVE)
C     =3   (ZONING)
```

```
C     ENER=MONTHLY ENERGY GENERATED AT SITE(I,T)
C     CCF=10**9 WHEN VOLUMETRIC UNITS ARE IN TMC M**3
C     =10**6 WHEN VOLUMETRIC UNITS ARE IN MILLION M**3
C     =10**4 WHEN VOLUMETRIC UNITS ARE IN HA.M
C     NREMT=NUMBER OF TIMES RESERVOIR IS EMPTY IN TIME T
C     NRFUT=NUMBER OF TIMES RESERVOIR IS FULL IN TIME T
C     AVQDS=AVERAGE MONTHLY DEFICIT FOR D/S USE
C     ACQI=AVERAGE MONTHLY DEFICIT FOR IRRIGATION
C     AADEI=AVERAGE MONTHLY DEFICIT FOR ENERGY
C     REQEF=FIRM REQUIREMENT FOR ENERGY
C     REQIF=FIRM REQUIREMENT FOR IRRIGATION
C     IEVPO=1(IF EVAPO IS IN DEPTH)
C     =0   (IF EVAPO IS IN VOLUME)
C    IOPTI=OPTION FOR IRRIGATION
C     =0,  IF NO IRRIGATION
C     =1,  IF IFIRM IRRIGATION IS REQUIRED IN SIMULATION
C     =2,  IF TARGETED IRRIGATION IS REQUIRED IN SIMULATION
C     =3,  FOR MULTIPURPOSE RESERVOIR OPERATION
C     AMDDS=AVERAGE MONTHLY DEFICIT IN DOWN STREAM
C     AMDI=AVERAGE MONTHLY DEFICIT IN IRRIGATION
C     AADDS=AVERAGE ANNUAL DEFICIT IN DOWN STREAM
C     ADNLD=ADDITIONAL VOLUME REQUIRED TO MEET THE REQUIRED ENERGY
C     REQVM=REQUIRED VOLUME FOR MAXIMUM POWER GENERATION
C     NADEI=NUMBER OF ANNUAL DEFICIT IN IRRIGATION
C     VALO2=UNIT VALUE OF RELEASE
C     IFLM=IDENTIFIER FOR A FLOOD MONTH
C     =1,  IF FLOOD MONTH ,OTHERWISE 0
C     REMWA=REMAINING WATER AVAILABLE DAILY
C     DEMND=DAILY DEMAND FOR IRRIGATION OR D/S OR POWER GENERATION
C     RLS1T=DAILY RELEASE FOR D/S
C     RLS2T=DAILY RELEASE FOR IRRIGATION
C     RLS3T=DAILY RELEASE FOR POWER GENERATION
C     RLS4T=DAILY RELEASE OF WATER THROUGH SPILL
C     MREMT=NUMBER OF TIMES RESERVOIR EMPTY IN TIME PERIOD
C     MRFUT=NUMBER OF TIMES RESERVOIR FULL IN TIME PERIOD
C     IRQDS=OPTION FOR DS WATER REQUIREMENTS(M &I USE)IS 1,OTHERWISE 0
C     AVSPL=AVERAGE ANNUAL SPILL
C     ARD=ANNUAL REQUIREMENT
C     IREQ=1  FOR HYDROPOWER AND  0  FOR NON HYDROPOWER
C     NDSRE= OPTIONS FOR DOWNSTREAM USES
C     1     IF ONLY IRRIGATION
C     1     IF ONLY HYDROPOWER
C     2     IF IRRIGATION AND WATER SUPPLY
C     3     IF IRRIGATION, WATER SUPPLY AND HYDROPOWER
```

```
C     PELEI=PERCENTAGE ALLOWANCE  IN IRRIGATION
C     PELEE=PERCENTAGE ALLOWANCE  IN HYDROPOWER
C     IPRTW= OPTION FOR RESERVOIR WORKING TABLE IF WORKING TABLE
C     REQUIRED 1 IF NOT REQUIRED 0
C     IPRTD= OPTIONS FOR DATA 1 IS REQUIRED AND 0 NOT REQUIRED
C     IPRTB= OPTIONS FOR BENEFITS 1 IS REQUIRED 0 NOT REQUIRED
C     IPRTC= OPTIONS FOR COMPUTATION I IS REQUIRED 0 NOT REQUIRED
C     IPRTR= OPTIONS FOR RATIO 1 IS REQUIRED 0 IS NOT REQUIRED
C     IPRTF= OPTIONS FOR FLOOD 1 IS REQUIRED 0 IS NOT REQUIRED
C     ISITE= OPTIONS FOR NUMBER SITE
C     1    BADANALA
C     2    KALLUVODDUHALLA
C     3    BODHGHT
C     4    SARAPADHIA
C     5    BARGI
C     IUSE= OPTIONS FOR NUMBER OF USES
C          BADANALA  =1
C          KALLUVODDUHALLA = 1
C          BODHGHT = 1
C          SARAPADHIA =1
C          BARGI  = 1 2 3 4
C*******************************************************************
C        AFBD =ANNUAL FULL BENEFIT (D/S USES) FOR USE II AT SITE I
C        APBD =ANNUAL PARTIAL BENEFIT (D/S USES)FOR USE II FOR
C     1  YEAR  J AT SITE I
C        ALBD =ANNUAL LOSS IN BENEFIT (D/S USES )FOR USE II FOR YEAR
C     1  J AT SITE I
C        ADBD =ANNUAL DUMP ENERGY BENEFIT (D/S USES )FOR
C     1  HYDROPOWER USE II FOR YEAR  J AT SITE I
C        ABFD =ANNUAL BENEFIT FUNCTION (D/S USES )FOR USE II AT SITE I
C        ALFD =ANNUAL LOSS IN BENEFIT FUNCTION (D/S USES )FOR
C     1  USE II AT SITE I
C        ADFD =ANNUAL DUMP ENERGY BENEFIT FUNCTION(D/S USES) FOR
C        HYDROPOWER USE II AT SITE I
C        CCRE = CAPITAL COST OF RESERVOIR AT SITE I
C        CCPP = CAPITAL COST OF HYDROPLANT AT SITE
C        CCWD = CAPITAL COST OF WATER USE (D/S USES )FOR
C     1  USE II AT SITE I
C        AORE = ANNUAL OM COST OF RESERVOIR AT SITE I
C        AOPP = ANNUAL OM COST OF HYDROPLANT AT SITE I
C        AODW = ANNUAL OM COST OF RESERVOIR AT SITE (D/S USES)
C     1  FOR USE II AT SITE I
C        CFRE = CAPITAL COST FUNCTION OF RESERVOIR AT SITE I
C        CFPP = CAPITAL COST FUNCTION OF HYDROPLANT AT SITE I
C        CFWD = CAPITAL COST FUNCTION OF WATER )(D/S USES )FOR
C     1  USE II AT SITE I
```

```
C        AOFR = ANNUAL OM COST FUNCTION OF RESERVOIR AT SITE I
C        AOFP = ANNUAL OM COST FUNCTION  HYDROPLANT AT SITE I
C        AOFD = ANNUAL OM COST FUNCTION OF WATER USE (D/S USES)
C     1  FOR USE II AT SITE I
C        VPBD = PRESENT VALUE OF PARTIAL BENEFITS (D/S USES)
C     1  FOR USE II AT SITE I
C        VDBD = PRESENT VALUE OF DUMP ENERGY BENEFITS (D/S USES)
C        FOR HYDROPOWER USE II AT SITE I
C        VORE = PRESENT VALUE OF OM COST OF RESERVOIR AT SITE I
C        VOPP = PRESENT VALUE OF OM COST OF HYDROPLANT AT SITE I
C        VOWD = PRESENT VALUE OF WATER USE (D/S USES )FOR
C     1  SE II AT SITE I
C        TVCC = TOTAL CAPITAL COST AT SITE I
C        TVBD = TOTAL PRESENT VALUE OF BENEFITS (D/S USES) AT SITE I
C        TVOD = TOTAL PRESENT VALUE OF OM COST (D/S USES) AT SITE I
C        TVC = TOTAL CAPITAL COST SYSTEM
C        TVB = TOTAL PRESENT VALUE OF BENEFITS OF SYSTEM
C        TVO = TOTAL PRESENT VALUE OF OM COST OF SYSTEM
C        PVNB= PRESENT VALUE OF NET BENEFITS FORM SYSTEM
```

```
C*************************************************************************
C                 ***********************************
C                     ***************************
C                          COMPUTER PROGRAMME FOR
C                       (LINEAR PROGRAMMING SIMPLEX)
C                     ***************************
C                 ***********************************
C*************************************************************************
C      LINEAR PROGRAMME SIMPLEX
C      M= NOS. OF CONSTRAINTS
C      K= NOS. OF VARIABLE
C      NLET=NOS. OF LT OR =CONSTRAINTS
C      NGET=NOS. OF GT OR= CONSTRAINTS
C      NET=NOS. OF  = CONSTRAINTS
C      NTYPE= TYPE OF PROBLEM, USE 0 IF MINIMIZATION, 1 IF MAXIMIZATION
C      NOPT= 0 IF ONLY OPTIMAL SOLUTIONS REQUIRED, =1 IF ALL SOLU.REQD.
C      CODE=0 FOR <OR=CONS.,1 FOR >OR=CONS.,2 FOR=CONS.
C      CONSTANT= NUMERICAL VALUE IN CONSTRAINTS
       COMMON KP1,MP1,N,K,M,NGET,NLET,NET,NTYPE,NP1,
      1 NC,NC1,INDEXG,INDEXL,INDEXE,NFLAG,BASICS,OPTSOL,SUM,NOPT
       INTEGER CODE,XB,BASICS,OPTSOL
       DIMENSION A(250,250),B(250),C(250),XB(250),CODE(250),ARTV(250)
       COMMON/BLK1/A
       COMMON/BLK2/B
       COMMON/BLK3/C
       COMMON/BLK4/CODE
       character*10 file1,file2
       write(*,*)'fileinput='
       read(*,'(a)')file1
       write(*,*)'fileoutput='
       read(*,'(a)')file2
       open(unit=1,file=file1)
       open(unit=2,file=file2)
       READ(1,*)IGEN
       IF(IPRNT1.NE.0.)WRITE(2,700)IGEN
       READ(1,*)IPRNT1
       WRITE (2,*)IPRNT1
700    FORMAT(5I5)
50     READ(1,*)NTYPE,NOPT
       IF(IPRNT1.NE.0.)WRITE(2,700)NTYPE,NOPT
       IF(IPRNT1.NE.0.)WRITE(*,777)
777    FORMAT(2X,'CALL MATRIX ')
       IF(IGEN.EQ.1)CALL MATRIX
```

```
      IF(IGEN.EQ.1)GO TO 701
      READ(1,*)M,K,NLET,NGET,NET
      DO 25 I=1,M
      READ(1,*)CODE(I),B(I)
      READ(1,*)(A(I,J),J=1,K)
 25   CONTINUE
      READ(1,*)(C(J),J=1,K)
 701  IF(IPRNT1.NE.0.)WRITE(2,700)M,K,NLET,NGET,NET
      IF(IPRNT1.NE.0.)WRITE(2,40)
 40   FORMAT(1X,'THE ORIGINAL COEFFICIENTS OF THE CONSTRAINTS',//
     1 15X,'CODE=0 LT OR= CONSTRAINTS',/15X,'CODE1=GT OR=
     2 CONSTRAINTS',/15X,'CODE 2=CONSTRAINTS',//)
      IF(IPRNT1.NE.0.)WRITE(2,55)
 55   FORMAT('I CODE CONSTANT A(I,1) A(I,2) A(I,3) A(I,4) A(I,5)
     1 A(I,6) A(I,7)',//16X,'A(I,8) A(I,9) A(I,10) A(I,11) A(I,12)
     2 A(I,13)',//16X,'A(I,14)', //)
      DO 45 I=1,M
      IF(IPRNT1.NE.0.)WRITE(2,51)I,CODE(I),B(I)
 51   FORMAT(I3,I4,F9.3)
      IF(IPRNT1.NE.0.)WRITE(2,52)(A(I,J),J=1,K)
 52   FORMAT(15X,7F8.2,/(15X,7F8.2))
 45   CONTINUE
      IF(NTYPE.NE.0)GO TO 35
      IF(IPRNT1.NE.0.)WRITE(2,36)
 36   FORMAT(//5X,'THE COEFFICIENT IN THE ORIGINAL OBJECTIVE FUNCTION
     1 TO BE MINIMIZED',/5X,'ARE:',/)
      GO TO 37
 35   IF(IPRNT1.NE.0.)WRITE(2,38)
 38   FORMAT(//5X,'THE COEFFICIENTS IN THE ORIGINAL OBJECTIVE'
     1 'FUNCTIONS ARE TO BE MINIMIZED',/5X,'ARE:',/)
 37   IF(IPRNT1.NE.0.)WRITE(2,39)(C(J),J=1,K)
 39   FORMAT(1X,7F10.2/1X,7F10.2)
C     READ(1,*)NOPT
      WRITE(*,778)
 778  FORMAT(2X,'CALL SSARTV')
      CALL SSARTV(XB)
      WRITE(*,779)
 779  FORMAT(2X,'RETURN')
C     IF(IFLAG.EQ.1) GO TO 50
      BASICS=0.0
      OPTSOL=0.0
      WRITE(2,160)
 160  FORMAT(//)
      WRITE(*,780)
 780  FORMAT(2X,'SIMPLX')
      CALL SIMPLX(XB)
```

```
      WRITE(2,*)NFLAG
      IF(NFLAG.EQ.1.OR.NFLAG.EQ.2)GO TO 333
      IF(NTYPE.EQ.1)GO TO 220
      SUM=-SUM
 220  WRITE(2,230)SUM
 230  FORMAT(4X,'OPTIMAL VALUE OF THE ORIGINAL',/
     1 4X,'OBJECTIVE FUNCTION IS',F12.2)
C     CLOSE(UNIT=1)
 333  STOP
      END
C     ****************************************************************
      SUBROUTINE  SSARTV(XB)
C     ****************************************************************
      COMMON KP1,MP1,N,K,M,NGET,NLET,NET,NTYPE,NP1,
     1 NC,NC1,INDEXG,INDEXL,INDEXE,NFLAG,BASICS,OPTSOL,SUM,NOPT
      INTEGER CODE,XB,BASICS,OPTSOL
      DIMENSION A(250,250),B(250),C(250),XB(250),CODE(250),ARTV(250)
      COMMON/BLK1/A
      COMMON/BLK2/B
      COMMON/BLK3/C
      COMMON/BLK4/CODE
C     INITIALIZE VARIABLE
      IFLAG=0
      IA=1
      KP1=K+1
      MP1=M+1
      N=K+2*NGET+NLET+NET
      NP1=N+1
      NC=K+NGET+1
      NC1=NC+NLET
      INDEXG=K+1
      INDEXL=K+NGET+1
      INDEXE=K+NGET+NLET+1
      DO 69 I=1,MP1
      DO 69 J=KP1,NP1
69    A(I,J)=0.
150   DO 5 I=1,M
5     A(I,NP1)=B(I)
      DO 4 I=1,M
      IF(CODE(I).EQ.0)GO TO 6
      IF(CODE(I).EQ.1)GO TO 8
      ARTV(IA)=I
      IA=IA+1
      XB(I)=INDEXE
      A(I,INDEXE)=1.
      INDEXE=INDEXE+1
```

```
      GO TO 4
8     XB(I)=INDEXE
      ARTV(IA)=I
      IA=IA+1
      INDEXE=INDEXE+1
      A(I,INDEXG)=-1
      INDEXG=INDEXG+1
      GO TO 4
6     XB(I)=INDEXL
      A(I,INDEXL)=1
      INDEXL=INDEXL+1
4     CONTINUE
      GO TO 151
C     CHECK FOR MAXIMIZATION
151   CONTINUE
      IF(NTYPE.EQ.0)GO TO 12
      DO 60 J=1,K
60    A(MP1,J)=-C(J)
      GO TO 50
12    DO 55 J=1,K
55    A(MP1,J)=C(J)
50    DO 61 J=KP1,NP1
      A(MP1,J)=0.
61    C(J)=0.
      DO 62 J=1,K
62    C(J)=-A(MP1,J)
      DO 63 J=NC1,N
63    C(J)=-10.E2
      IF(NGET+NET.EQ.0)RETURN
      IA=IA-1
      KPGTE=K+NGET
      DO 64 J=1,KPGTE
      SUM=0.0
      DO 65 I=1,IA
      IJL=ARTV(I)
65    SUM=SUM+A(IJL,J)
64    A(MP1,J)=A(MP1,J)-10.E2*SUM
      SUM=0.0
      DO 66 I=1,IA
      IJL1=ARTV(I)
66    SUM=SUM+A(IJL1,NP1)
      A(MP1,NP1)=A(MP1,NP1)-10.E2*SUM
      RETURN
      END
```

```
C      ****************************************************************
       SUBROUTINE SIMPLX(XB)
C      ****************************************************************
       COMMON KP1,MP1,N,K,M,NGET,NLET,NET,NTYPE,NP1,
      1 NC,NC1,INDEXG,INDEXL,INDEXE,NFLAG,BASICS,OPTSOL,SUM,NOPT
       INTEGER CODE,XB,BASICS,OPTSOL
       DIMENSION A(250,250),B(250),C(250),XB(250),CODE(250),ARTV(250)
       COMMON/BLK1/A
       COMMON/BLK2/B
       COMMON/BLK3/C
       COMMON/BLK4/CODE
       NFLAG=0
 100   BASICS=BASICS+1
       WRITE(*,*)BASICS
       IF(NOPT.EQ.0)GO TO 200
 105   WRITE(2,104)BASICS
 C     WRITE(*,*)BASICS
 104   FORMAT(5X,'BASICS SOLUTION',I4,/)
       DO 110 I=1,M
 110   WRITE(2,106)I,XB(I),A(I,NP1)
 106   FORMAT(7X,'XB(',I3,')=X(',I3,')=',F12.2)
       SUM=0.0
       DO 111 I=1,M
 111   SUM=SUM+C(XB(I))*A(I,NP1)
       WRITE(2,130)SUM
 130   FORMAT(/4X,'CURRENT VALUE OF OBJECTIVE',/
      1 4X,'FUNCTION IS',E14.8//)
       IF(OPTSOL.EQ.1)GO TO 920
 200   NEG=0
       GNEG=0
       DO 21 J=1,N
       IF(A(MP1,J).GE.GNEG)GO TO 21
       GNEG=A(MP1,J)
       NEG=J
 21    CONTINUE
       IF(NEG.EQ.0)GO TO 900
 400   SPR=10.E10
       DO 410 I=1,M
       IF(A(I,NEG).LE..000001)GO TO 410
       IF(A(I,NP1)/A(I,NEG).GE.SPR)GO TO 410
       SPR=A(I,NP1)/A(I,NEG)
       NSPR=I
 410   CONTINUE
       IF(SPR.LE.10.E8)GO TO 510
       WRITE(2,420)
 420   FORMAT(///'OBJECTIVE FUNCTION IS NOT BOUNDED BY CONSTRAINTS')
```

```
      NFLAG=1
      RETURN
510   PELE=A(NSPR,NEG)
      DO 500 J=1,NP1
500   A(NSPR,J)=A(NSPR,J)/PELE
      XB(NSPR)=NEG
600   DO 610 I=1,MP1
      IF(I.EQ.NSPR)GO TO 610
      HOLD=A(I,NEG)
      DO 620 J=1,NP1
620   A(I,J)=A(I,J)-HOLD*A(NSPR,J)
610   CONTINUE
      GO TO 100
900   OPTSOL=1
      IF(NOPT.EQ.1)GO TO 920
      GO TO 105
920   DO 930 I=1,M
      IF(XB(I).LT.NC1)GO TO 930
      IF(A(I,NP1).LE.0)GO TO 930
      WRITE(2,940)
940   FORMAT(///'A FEASIBLE SOLUTION DOES NOT EXIST')
      NFLAG=2
      RETURN
930   CONTINUE
      WRITE(2,950)
950   FORMAT(4X,'THE LAST BASIC FEASIBLE',/4X,'SOLUTION IS OPTIMAL')
      RETURN
      END
```

```
C***************************************************************************
C          ****************************************
C              *******************************
C                        COMPUTER PROGRAMME FOR
C                LINEAR PROGRAMMING MODEL-DEVELOPMENT OF
C                    SOFTWARE FOR INPUT DATA MATRIX
C                           (MATGEN PACKAGE)
C                 DEVELOPED BY : ASSADULLAH KOHISTANI
C                  SUPERVISOR  : Dr. D.K. SRIVASTAVA
C              *******************************
C          ****************************************
C***************************************************************************
      SUBROUTINE MATRIXC
      DIMENSION A(250,250),B(250),C(250),CODE(250),CC(100)
      DIMENSION FLOW(100),FLOW1(100),FLOW2(100),DELT(100)
      DIMENSION XK1(100),XK2(100),XK3(100),EV(100),WS(100),P(100)
      DIMENSION ICOLR(100),ICOLI(100),ICOLP(100),EQR(50)
      DIMENSION TIME(250),AT(100),POWPF(100),EQI(50),OUTF(100)
      DIMENSION ALPHA(100),HEAD(100),XNETA(100),EQP(50)
      DIMENSION IAL(100),IUP(100),ILO(100),IEQ(100),UL(100)
      DIMENSION LM(100),EQ(100),EQU(100),DS(1),NVAAL(100),BT(100)
      COMMON KP1,MP1,N,K,M,NGET,NLET,NET,NTYPE,NP1,
     1 NC,NC1,INDEXG,INDEXL,INDEXE,NFLAG,BASICS,OPTSOL,SUM,NOPT
      INTEGER CODE,XB,BASICS,OPTSOL
      COMMON/BLK1/A
      COMMON/BLK2/B
      COMMON/BLK3/C
      COMMON/BLK4/CODE
      REAL LM
      REAL IBNFT
      REAL I100
      READ(1,*)MM
      READ(1,*)NVAR
      READ(1,*)YD
      READ(1,*)OBJR,OBJI,OBJP,OBJF
      IF(OBJR.EQ.2.OR.OBJR.EQ.3)READ(1,*)Y
      READ(1,*)(FLOW(I),I=1,MM)
      READ(1,*)(WS(I),I=1,MM)
      READ(1,*)IEVAP
```

```
      IF(IEVAP.EQ.1)READ(1,*)(XK2(I),I=1,MM),(XK3(I),I=1,MM)
      IF(IEVAP.EQ.2)READ(1,*)(EV(I),I=1,MM)
      IF(IEVAP.EQ.2)READ(1,*)A0,AS
      IF(OBJR.EQ.-1)GO TO 300
      READ(1,*)NCOLR
      READ(1,*)(ICOLR(I),I=1,NCOLR)
      READ(1,*)NEQR
      READ(1,*)(EQR(I),I=1,NEQR)
      IF(OBJR.EQ.1)READ(1,*)C1,OM1
      IF(OBJR.EQ.2)READ(1,*)(DELT(I),I=1,MM)
      IF(OBJR.EQ.3)READ(1,*)(CC(I),I=1,MM)
      IF(OBJR.EQ.4)READ(1,*)(OUTF(I),I=1,MM)
300   IF(OBJI.EQ.-1)GO TO 301
      READ(1,*)NCOLI
      READ(1,*)(ICOLI(I),I=1,NCOLI)
      READ(1,*)NEQI
      READ(1,*)(EQI(I),I=1,NEQI)
      READ(1,*)A2,C2,OM2
      READ(1,*)(XK1(I),I=1,MM)
301   IF(OBJP.EQ.-1)GO TO 303
      READ(1,*)NCOLP
      READ(1,*)(ICOLP(I),I=1,NCOLP)
      READ(1,*)NEQP
      READ(1,*)(EQP(I),I=1,NEQP)
      IF(OBJR.EQ.2)GO TO 302
      READ(1,*)A3,C3,OM3
      READ(1,*)(XNETA(I),I=1,MM)
      READ(1,*)(ALPHA(I),I=1,MM)
      READ(1,*)PR1,PR2,I100
      READ(1,*)QAV,Q15,AHEAD,AVHR
302   READ(1,*)EFFCI,CV,CP
      READ(1,*)(HEAD(I),I=1,MM)
      READ(1,*)(TIME(I),I=1,MM)
      READ(1,*)(POWPF(I),I=1,MM)
303   IF(OBJF.EQ.-1)GO TO 304
      READ(1,*)A4
304   READ(1,*)IPRNT
      READ(1,*)IPRT1
      READ(1,*)ISAL
      IF(ISAL.EQ.-1)GO TO 82
      READ(1,*)(NVAAL(J1),J1=1,ISAL)
      DO  81 J1 =1,ISAL
      IAL(NVAAL(J1))=1
81    CONTINUE
      DO 13 J1=1,NVAR
      IF(IAL(J1).EQ.0)GO TO 13
```

```
      READ(1,*)IUP(J1),ILO(J1),IEQ(J1)
      READ(1,*)UL(J1),LM(J1),EQU(J1)
 13   CONTINUE
 82   READ(1,*)IFL,MMF
      READ(1,*)YF2
      IF(IPRT1.NE.0)WRITE(2,*)MM
      IF(IPRT1.NE.0)WRITE(2,*)NVAR
      IF(IPRT1.NE.0)WRITE(2,*)YD
      IF(IPRT1.NE.0)WRITE(2,*)OBJR,OBJI,OBJP,OBJF
      IF(OBJR.EQ.2.OR.OBJR.EQ.3.AND.IPRT1.NE.0)WRITE(2,*)Y
      IF(IPRT1.NE.0)WRITE(2,*)(FLOW(I),I=1,MM)
      IF(IPRT1.NE.0)WRITE(2,*)(WS(I),I=1,MM)
      IF(IPRT1.NE.0)WRITE(2,*)IEVAP
      IF(IEVAP.EQ.1.AND.IPRT1.NE.0)WRITE(2,*)(XK2(I),I=1,MM),
     1 (XK3(I),I=1,MM)
      IF(IEVAP.EQ.2.AND.IPRT1.NE.0)WRITE(2,*)(EV(I),I=1,MM)
      IF(IEVAP.EQ.2.AND.IPRT1.NE.0)WRITE(2,*)A0,AS
      IF(OBJR.EQ.-1)GO TO 305
      IF(IPRT1.NE.0)WRITE(2,*)NCOLR
      IF(IPRT1.NE.0)WRITE(2,*)(ICOLR(I),I=1,NCOLR)
      IF(IPRT1.NE.0)WRITE(2,*)NEQR
      IF(IPRT1.NE.0)WRITE(2,*)(EQR(I),I=1,NEQR)
      IF(OBJR.EQ.1.AND.IPRT1.NE.0)WRITE(2,*)C11,OM11
      IF(OBJR.EQ.2.AND.IPRT1.NE.0)WRITE(2,*)(DELT(I),I=1,MM)
      IF(OBJR.EQ.3.AND.IPRT1.NE.0)WRITE(2,*)(CC(I),I=1,MM)
      IF(OBJR.EQ.4.AND.IPRT1.NE.0)WRITE(2,*)(OUTF(I),I=1,MM)
305   IF(OBJI.EQ.-1)GO TO 306
      IF(IPRT1.NE.0)WRITE(2,*)NCOLI
      IF(IPRT1.NE.0)WRITE(2,*)(ICOLI(I),I=1,NCOLI)
      IF(IPRT1.NE.0)WRITE(2,*)NEQI
      IF(IPRT1.NE.0)WRITE(2,*)(EQI(I),I=1,NEQI)
      IF(IPRT1.NE.0)WRITE(2,*)A2,C21,OM21
      IF(IPRT1.NE.0)WRITE(2,*)(XK1(I),I=1,MM)
306   IF(OBJP.EQ.-1)GO TO 308
      IF(IPRT1.NE.0)WRITE(2,*)NCOLP
      IF(IPRT1.NE.0)WRITE(2,*)(ICOLP(I),I=1,NCOLP)
      IF(IPRT1.NE.0)WRITE(2,*)NEQP
      IF(IPRT1.NE.0)WRITE(2,*)(EQP(I),I=1,NEQP)
      IF(OBJR.EQ.2)GO TO 307
      IF(IPRT1.NE.0)WRITE(2,*)A3,C31,OM31
      IF(IPRT1.NE.0)WRITE(2,*)(XNETA(I),I=1,MM)
      IF(IPRT1.NE.0)WRITE(2,*)(ALPHA(I),I=1,MM)
      IF(IPRT1.NE.0)WRITE(2,*)PR1,PR2,I100
      IF(IPRT1.NE.0)WRITE(2,*)QAV,Q15,AHEAD,AVHR
307   IF(IPRT1.NE.0)WRITE(2,*)EFFCI,CV,CP
      IF(IPRT1.NE.0)WRITE(2,*)(HEAD(I),I=1,MM)
```

```
      IF(IPRT1.NE.0)WRITE(2,*)(TIME(I),I=1,MM)
      IF(IPRT1.NE.0)WRITE(2,*)(POWPF(I),I=1,MM)
 308  IF(OBJF.EQ.-1)GO TO 309
      IF(IPRT1.NE.0)WRITE(2,*)A4
 309  IF(IPRT1.NE.0)WRITE(2,*)IPRT1
      IF(IPRT1.NE.0)WRITE(2,*)IPRT1
      IF(IPRT1.NE.0)WRITE(2,*)ISAL
      IF(IPRT1.NE.0)WRITE(2,*)IUP(J1),ILO(J1),IEQ(J1)
      IF(IPRT1.NE.0)WRITE(2,*)UL(J1),LM(J1),EQU(J1)
      IF(IPRT1.NE.0)WRITE(2,*)IFL,MMF
      IF(IPRT1.NE.0)WRITE(2,*)YF2
      IF(EQR(1).NE.1)GO TO 32
C     ******************************************************************
C     Continuity equation
```

C $O_t - S_{t-1} + K_t'.S_t = I_t + P_t + \bar{I}_t - \left[O_t^d + O_t^m\right]$ for all t (3.2.1.1

```
C     ******************************************************************
      IROW=0
      JCOL=0
      JROW=0
1     IROW=IROW+1
      JROW=JROW+1
      B(IROW)=FLOW(JCOL+1)+P(JCOL+1)+FLOW2(JCOL+1)-WS(JCOL+1)
      CODE(IROW)=2
      XMULT=1.0
      IF(B(IROW).LT.0.0)XMULT=-1.0
      B(IROW)=B(IROW)*XMULT
      A(IROW,ICOLR(1)+JCOL)=1.0*XMULT
      A(IROW,ICOLR(2)+JCOL)=-1.0*XMULT
      IF(JCOL.LT.(MM-1))A(IROW,ICOLR(2)+JCOL+1)=XK2(JCOL+1)*
     1 XMULT
      IF(JCOL.EQ.(MM-1))A(IROW,ICOLR(2))=XK2(JCOL+1)*XMULT
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRNT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM) GO TO 1
32    IF(EQR(2).NE.1)GO TO 33
C     ******************************************************************
C     Continuity equation for annual safe yield from  a reservoir
```

C $-S_{t-1} + K_t'.S_t + \left[Sp_t + \delta_t.O^*\right] = I_t + P_t + \bar{I}_t - \left[O_t^d + O_t^m\right]$ for all t (3.3.

```
C     ******************************************************************
      JCOL=0
      JROW=0
2     IROW=IROW+1
      JROW=JROW+1
```

```
      B(IROW)=FLOW(JCOL+1)+P(JCOL+1)+FLOW2(JCOL+1)-WS(JCOL+1)
      CODE(IROW)=2
      XMULT=1.0
      IF(B(IROW).LT.0.0)XMULT=-1.0
      B(IROW)=B(IROW)*XMULT
      A(IROW,ICOLR(2)+JCOL)=-1.0*XMULT
      A(IROW,ICOLR(5)+JCOL)=1.0*XMULT
      A(IROW,ICOLR(6))=1.0*DELT(JCOL+1)*XMULT
      IF(JCOL.LT.(MM-1))A(IROW,ICOLR(2)+JCOL+1)=XK2(JCOL+1)*
     1 XMULT
      IF(JCOL.EQ.(MM-1))A(IROW,ICOLR(2))=XK2(JCOL+1)*XMULT
      IF(IPRINT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRINT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM) GO TO 2
33    IF(EQR(3).NE.1)GO TO 34
C     *******************************************************************
C     Continuity equation for  discontinuous  model for estimation of
C     over-year carry-over storage
C     O_t - S_t-1 + K'_t.S_t + Sp_t = I_t + P_t + Ī_t - El_t - (O^d_t + O^m_t)   for all t   (3.4.1)
C     *******************************************************************
      JCOL=0
      JROW=0
3     IROW=IROW+1
      JROW=JROW+1
      B(IROW)=FLOW(JCOL+1)+P(JCOL+1)+FLOW2(JCOL+1)-WS(JCOL+1)
      CODE(IROW)=2
      XMULT=1.0
      IF(B(IROW).LT.0.0)XMULT=-1.0
      B(IROW)=B(IROW)*XMULT
      A(IROW,ICOLR(1)+JCOL)=1.0*XMULT
      A(IROW,ICOLR(2)+JCOL)=-1.0*XMULT
      A(IROW,ICOLR(5)+JCOL)=1.0*XMULT
      A(IROW,ICOLR(2)+JCOL+1)=XK2(JCOL+1)*XMULT
C     IF(JCOL.LT.(MM-1))A(IROW,ICOLR(2)+JCOL+1)=XK2(JCOL+1)*XMULT
C     IF(JCOL.EQ.(MM-1))A(IROW,ICOLR(2))=XK2(JCOL+1)*XMULT
      IF(IPRINT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRINT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM) GO TO 3
34    IF(EQR(4).NE.1)GO TO 35
```

```
C     ******************************************************************
C     Continuity equation for over-year carry-over reservoir capacity
C     for a known annual targeted demand
C     -S_{j,t-1} + K'_t.S_{j,t} + Sp_{j,t} = I_{j,t} - δ'_t.Oy^g     for all j and t
C                                              (3.5.1.1), (3.5.2.1)
C     ******************************************************************
      JCOL=0
      JROW=0
4     IROW=IROW+1
      JROW=JROW+1
      B(IROW)=FLOW(JCOL+1)-OUTF(JCOL+1)
      CODE(IROW)=2
      XMULT=1.0
      IF(B(IROW).LT.0.0)XMULT=-1.0
      B(IROW)=B(IROW)*XMULT
      A(IROW,ICOLR(2)+JCOL)=-1.0*XMULT
      A(IROW,ICOLR(5)+JCOL)=1.0*XMULT
      IF(JCOL.LT.(MM-1))A(IROW,ICOLR(2)+JCOL+1)=XK2(JCOL+1)*XMULT
      IF(JCOL.EQ.(MM-1))A(IROW,ICOLR(2))=XK2(JCOL+1)*XMULT
      IF(IPRINT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRINT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM) GO TO 4
35    IF(EQR(5).NE.1)GO TO 36
C     ******************************************************************
C     Continuity equation for direct use of  reservoir storage surface
C     area curve
C     O_t-(1+a_t)S_t+(1-a_t)S_{t-1}=I_t+A_0e._t+P_t+Ī_t-(O^d_t+O^m_t) for all t (3.2.7.3)
C     ******************************************************************
      JCOL=0
      JROW=0
5     IROW=IROW+1
      JROW=JROW+1
      B(IROW)=FLOW(JCOL+1)-A0*EV(JCOL+1)+FLOW2(JCOL+1)-WS(JCOL+1)
      CODE(IROW)=2
      XMULT=1.0
      IF(B(IROW).LT.0.0)XMULT=-1.0
      B(IROW)=B(IROW)*XMULT
      A(IROW,ICOLR(1)+JCOL)=1.0*XMULT
      AT(JCOL+1)=0.5*AS*EV(JCOL+1)
      A(IROW,ICOLR(2)+JCOL)=-(1-AT(JCOL+1))*XMULT
      IF(JCOL.LT.(MM-1))A(IROW,ICOLR(2)+JCOL+1)=(1+AT(JCOL+1))*XMULT
```

```
      IF(JCOL.EQ.(MM-1))A(IROW,ICOLR(2))=(1+AT(JCOL+1))*XMULT
      IF(IPRINT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRINT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM)GO TO 5
36    IF(EQR(6).NE.1)GO TO 37
C     ******************************************************************
C     Continuity equation for use of evaporation loss adjustment
C     coefficients
C     O_t-b_t.S_t+ b'_t.S_t-1 = I_t+ P_t+ Ī_t - (O^d_t + O^m_t)  for all t  (3.2.7.4)
C     ******************************************************************
      JCOL=0
      JROW=0
6     IROW=IROW+1
      JROW=JROW+1
      B(IROW)=FLOW(JCOL+1)+P(JCOL+1)+FLOW2(JCOL+1)-WS(JCOL+1)
      CODE(IROW)=2
      XMULT=1.0
      IF(B(IROW).LT.0.0)XMULT=-1.0
      B(IROW)=B(IROW)*XMULT
      A(IROW,ICOLR(1)+JCOL)=1.0*XMULT
      BT(JCOL+1)=0.5*EV(JCOL+1)*XK3(JCOL+1)
      A(IROW,ICOLR(2)+JCOL)=-(1-BT(JCOL+1))*XMULT
      IF(JCOL.LT.(MM-1))A(IROW,ICOLR(2)+JCOL+1)=(1+BT(JCOL+1))*
     1 XMULT
      IF(JCOL.EQ.(MM-1))A(IROW,ICOLR(2))=(BT(JCOL+1))*XMULT
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRNT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM) GO TO 6
37    IF(EQR(7).NE.1)GO TO 38
C     ******************************************************************
C     Storage at any time more or equal to dead storage
C     S_t-1≥Yd  for all t (3.2.1.2),(3.3.2),(3.4.2),(3.5.1.2),(3.5.2.3)
C     ******************************************************************
      JCOL=0
      JROW=0
7     IROW=IROW+1
      JROW=JROW+1
      B(IROW)=YD
      CODE(IROW)=1
      A(IROW,ICOLR(2)+JCOL)=1.
      IF(IPRINT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
```

```
      IF(IPRINT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM) GO TO 7
 38   IF(EQR(8).NE.1)GO TO 39
C     ****************************************************************
C     The contents of the reservoir at  any  time  cannot  exceed  t
C     capacity of the reservoir
C     S t-1 - Y ≤ 0                        for all t       (3.2.1.3),(3.5.1.
C     ****************************************************************
      JCOL=0
      JROW=0
 8    IROW=IROW+1
      JROW=JROW+1
      B(IROW)=0
      CODE(IROW)=0
      A(IROW,ICOLR(2)+JCOL)=1
      A(IROW,ICOLR(3))=-1
      IF(IPRINT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRINT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM) GO TO  8
 39   IF(EQR(9).NE.1)GO TO 40
C     ****************************************************************
C     Limit on reservoir storage
C     S t-1 ≤ Y^g                  for all  t              (3.3.3),(3.5.2.
C     ****************************************************************
      JCOL=0
      JROW=0
 9    IROW=IROW+1
      JROW=JROW+1
      B(IROW)=Y
      CODE(IROW)=0
      A(IROW,ICOLR(2)+JCOL)=1
      IF(IPRINT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRINT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM)GO TO 9
 40   IF(IFL.NE.1)GO TO 41
C     ****************************************************************
C     Storage for flood conservation purpose
C     S t -Ymax t ≤ 0  for t=1,..,t 1 months of flood provision   (3.2.4.1
C     ****************************************************************
      JCOL=0
      JROW=0
```

```
10    IROW=IROW+1
      JROW=JROW+1
      B(IROW)=0
      CODE(IROW)=0
      A(IROW,ICOLR(2)+JCOL+1)=1
      A(IROW,ICOLR(4)+JCOL)=-1
      IF(IPRINT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRINT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MMF) GO TO 10
C     ****************************************************************
C     Flood conservation limited by reservoir capacity
C     -Y+Ymax_t ≤ 0  for t = 1, .,t_1 months of flood provision
C                                                          (3.2.4.2)
C     ****************************************************************
      JCOL=0
      JROW=0
11    IROW=IROW+1
      JROW=JROW+1
      B(IROW)=0
      CODE(IROW)=0
      A(IROW,ICOLR(4)+JCOL)=1
      A(IROW,ICOLR(3))=-1
      IF(IPRINT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRINT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MMF) GO TO 11
C     ****************************************************************
C     For reservoir storage at the end of August for Bargi
C     S_2 = Ya - Yf_2                                      (8.3.4.2)
C     ****************************************************************
      IROW=IROW+1
      B(IROW)=Yf2
      CODE(IROW)=1
      A(IROW,ICOLR(3))=1
      A(IROW,ICOLR(2)+MMF)=-1
C     ****************************************************************
C     For storage storage at the end of August for bargi
C     Ya - Ymax_t = Yf_2                                   (8.3.4.3)
C     ****************************************************************
      IROW=IROW+1
      B(IROW)=Yf2
      CODE(IROW)=2
```

```
      A(IROW,ICOLR(3))=1
      A(IROW,ICOLR(4)+MMF-1)=-1
41    IF(EQI(1).NE.1)GO TO 42
C     ******************************************************************
C     The value of release from the reservoir must  be  sufficient  to
C     meet irrigation demand in that period
C     -O  + Sp  + K .Ir = I"                          for all t      (3.2.2.1)
C       t     t    t       t
C     ******************************************************************
      JCOL=0
      JROW=0
101   IROW=IROW+1
      JROW=JROW+1
      B(IROW)=FLOW1(JCOL+1)
      CODE(IROW)=2
      A(IROW,ICOLR(1)+JCOL)=-1
      A(IROW,ICOLR(5)+JCOL)=1
      A(IROW,ICOLI(1))=XK1(JCOL+1)
      IF(IPRINT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRINT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM) GO TO 101
42    IF(EQP(1).NE.1)GO TO 43
C     ******************************************************************
C     Energy generation limited to turbine discharge
C     -C .O .Ha .e.h  + E  = 0                        for all t      (3.2.3.1)
C       f  t   t     t    t
C     ******************************************************************
      JCOL=0
      JROW=0
201   IROW=IROW+1
      JROW=JROW+1
      B(IROW)=0
      CODE(IROW)=2
      CT=1.0/(TIME(JCOL+1)*3600.0)
      CF=9.8*CT*CV/CP
      A(IROW,ICOLR(1)+JCOL)=-CF*HEAD(JCOL+1)*EFFCI*TIME(JCOL+1)
      A(IROW,ICOLP(3)+JCOL)=1.0
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRNT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM)GO TO 201
43    IF(EQP(2).NE.1)GO TO 44
```

```
C     ******************************************************************
C     Energy generation limited to turbine discharge for constant head
C     in case of run-of-river
C     -C .O .H̄a.e.h +E =0                            for all t (3.2.3.1')
C       f  t       t  t
C     ******************************************************************
      JCOL=0
      JROW=0
202   IROW=IROW+1
      JROW=JROW+1
      B(IROW)=0
      CODE(IROW)=2
      CT=1.0/(TIME(JCOL+1)*3600.0)
      CF=9.8*CT*CV/CP
      A(IROW,ICOLR(1)+JCOL)=-CF*AHEAD*EFFCI*TIME(JCOL+1)
      A(IROW,ICOLP(3)+JCOL)=1.0
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRNT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM)GO TO 202
44    IF(EQP(3).NE.1)GO TO 45
C     ******************************************************************
C     Total energy is defined by
C     -η .E + E  - Ē  = 0                        for all t      (3.2.3.2)
C       t      t    t
C     ******************************************************************
      JCOL=0
      JROW=0
203   IROW=IROW+1
      JROW=JROW+1
      B(IROW)=0
      CODE(IROW)=2
      A(IROW,ICOLP(2))=-XNETA(JCOL+1)
      A(IROW,ICOLP(3)+JCOL)=1.0
      A(IROW,ICOLP(4)+JCOL)=-1.0
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRNT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JROW.LT.MM) GO TO 203
45    IF(EQP(4).NE.1)GO TO 46
```

```
C      ***********************************************************************
C      Energy generation limited to load factor
C      -αt.H.ht + Et = 0                            for all t      (3.2.3.3)
C      ***********************************************************************
       JCOL=0
       JROW=0
 204   IROW=IROW+1
       JROW=JROW+1
       B(IROW)=0
       CODE(IROW)=2
       A(IROW,ICOLP(1))=-ALPHA(JCOL+1)*TIME(JCOL+1)
       A(IROW,ICOLP(3)+JCOL)=1.0
       IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
       IF(IPRNT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
       JCOL=JCOL+1
       IF(JROW.LT.MM)GO TO 204
 46    IF(EQP(5).NE.1)GO TO 47
C      ***********************************************************************
C      Total annual energy is governed by
C          ∑ Et  ≤  Cf.Iav  .H̄a.e.(8760.0)                      (3.2.3.4)
C      ***********************************************************************
       JCOL=0
       IROW=IROW+1
       CT=1.0/(MM*AVHR*3600.0)
       CF=9.8*CT*CV/CP
       B(IROW)=CF*QAV*AHEAD*EFFCI*MM*AVHR
       CODE(IROW)=0
 205   A(IROW,ICOLP(3)+JCOL)=1.0
       IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
       IF(IPRNT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
       JCOL=JCOL+1
       IF(JCOL.LT.MM) GO TO 205
 47    IF(EQP(6).NE.1)GO TO 48
C      ***********************************************************************
C      The power plant capacity is governed by
C      H ≤ Cf.I15. H̄a.e                                          (3.2.3.6)
C      ***********************************************************************
       IROW=IROW+1
       CT=1.0/(AVHR*3600.0)
       CF=9.8*CT*CV/CP
       B(IROW)=CF*Q15*AHEAD*EFFCI
       CODE(IROW)=0
       A(IROW,ICOLP(1))=1.0
```

```
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRNT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
48    IF(EQP(7).NE.1)GO TO 49
C     *****************************************************************
C     Total annual energy is governed by
C     ∑ E_t ≥ C_f.I_av.H̄a.e.8760                                (3.2.3.7)
C     *****************************************************************
      JCOL=0
      IROW=IROW+1
      CT=1.0/(MM*AVHR*3600.0)
      CF=9.8*CT*CV/CP
      B(IROW)=CF*QAV*AHEAD*EFFCI*MM*AVHR
      CODE(IROW)=1
206   A(IROW,ICOLP(3)+JCOL)=1.0
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRNT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JCOL.LT.MM) GO TO 206
49    IF(EQP(8).NE.1)GO TO 50
C     *****************************************************************
C     The power plant capacity is governed by
C     H ≥ C_f.I_15.H̄a.e                                          (3.2.3.8)
C     *****************************************************************
      IROW=IROW+1
      CT=1.0/(AVHR*3600.0)
      CF=9.8*CT*CV/CP
      B(IROW)=CF*Q15*AHEAD*EFFCI
      CODE(IROW)=1
      A(IROW,ICOLP(1))=1.0
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRNT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
50    IF(EQP(9).NE.1)GO TO 51
C     *****************************************************************
C     Total reservoir release is  governed by
C     O_t ≥ I_100                            for all t         (3.2.3.9)
C     *****************************************************************
      JCOL=0
      JROW=0
207   IROW=IROW+1
      JROW=JROW+1
      B(IROW)=I100
      CODE(IROW)=1
      A(IROW,ICOLR(1)+JCOL)=1.0
```

```
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRNT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JCOL.LT.MM) GO TO 207
 51   IF(EQP(10).NE.1)GO TO 52
C     *********************************************************************
C     For safe yield from the reservoir for hydropower
C     0.6H-O*.Cf.Hat.e ≤ 0                  for  all t             (3.2.3.10
C     *********************************************************************
      JCOL=0
      JROW=0
 208  IROW=IROW+1
      JROW=JROW+1
      B(IROW)=0
      CT=1.0/(TIME(JCOL+1)*3600.0)
      CF=9.8*CT*CV/CP
      CODE(IROW)=0
      A(IROW,ICOLP(1))=PR1
      A(IROW,ICOLR(1)+JCOL)=-CF*HEAD(JCOL+1)*EFFCI
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRNT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JCOL.LT.MM) GO TO 208
 52   IF(EQP(11).NE.1)GO TO 53
C     *********************************************************************
C     In case of a single turbine
C     0.3H-Ot.Cf.Hat.e ≤ 0                  for  all t             (8.3.3.1)
C     *********************************************************************
      JCOL=0
      JROW=0
 209  IROW=IROW+1
      JROW=JROW+1
      B(IROW)=0
      CODE(IROW)=0
      CT=1.0/(TIME(JCOL+1)*3600.0)
      CF=9.8*CT*CV/CP
      A(IROW,ICOLP(1))=PR2
      A(IROW,ICOLR(6))=-CF*HEAD(JCOL+1)*EFFCI
      IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRNT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
      JCOL=JCOL+1
      IF(JCOL.LT.MM) GO TO 209
 53   IF(EQP(12).NE.1)GO TO 54
```

```
C      ******************************************************************
C      Energy production governed by safe yield
C      -C_f.Ha_t.δ_t.h_t.e + E_t = 0             for all t          (8.3.3.2)
C      ******************************************************************
       JCOL=0
       JROW=0
210    IROW=IROW+1
       JROW=JROW+1
       B(IROW)=0
       CODE(IROW)=2
       CT=1.0/(TIME(JCOL+1)*3600.0)
       CF=9.8*CT*CV/CP
       A(IROW,ICOLR(6))=-CF*HEAD(JCOL+1)*DELT(JCOL+1)*EFFCI*
      1 TIME(JCOL+1)
       A(IROW,ICOLP(3)+JCOL)=1.0
       IF(IPRNT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
       IF(IPRNT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
       JCOL=JCOL+1
       IF(JROW.LT.MM)GO TO 210
54     CONTINUE
C      ******************************************************************
C      LIMIT ON O(T),S(T),Y,DS,Ir,ECT.
C      ******************************************************************
       I3=IROW+1
       DO 88 J1=1,NVAR
       IF(IAL(J1).EQ.0)GO TO 88
       IF(IUP(J1).NE.0)GO TO 14
       IROW=IROW+1
       A(IROW,J1)=1
       B(IROW)=UL(J1)
       CODE(IROW)=IUP(J1)
       IF(IPRINT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
       IF(IPRINT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
14     IF(ILO(J1).NE.1)GO TO 15
       IROW=IROW+1
       A(IROW,J1)=1
       B(IROW)=LM(J1)
       CODE(IROW)=ILO(J1)
       IF(IPRINT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
       IF(IPRINT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
15     IF(IEQ(J1).NE.2)GO TO 88
       IROW=IROW+1
       A(IROW,J1)=1
```

```
      B(IROW)=EQU(J1)
      CODE(IROW)=IEQ(J1)
      IF(IPRINT.NE.0)WRITE(2,*)(A(IROW,K),K=1,NVAR)
      IF(IPRINT.NE.0)WRITE(2,*)CODE(IROW),B(IROW)
 88   CONTINUE
      M=IROW
C     ****************************************************************
C     DEVELOPMENT OF OBJECTIVE FUNCTION
C     ****************************************************************
      IF(ICOLR(3).NE.0.AND.OBJR.EQ.1)C(ICOLR(3))=-(C1+OM1)
      IF(ICOLI(1).NE.0.AND.OBJI.EQ.1)C(ICOLI(1))=A2-(C2+OM2)
      IF(ICOLR(6).NE.0.AND.OBJR.EQ.2)C(ICOLR(6))=1
      IF(ICOLP(1).NE.0.AND.OBJP.EQ.4)C(ICOLP(1))=-(C3+OM3)
      IF(ICOLP(2).NE.0.AND.OBJP.EQ.4)C(ICOLP(2))=A3
      IF(ICOLR(3).NE.0.AND.OBJR.EQ.4)C(ICOLR(3))=1
      JCOL=0
      DO 1000 I=1,MM
      IF(ICOLR(1).NE.0.AND.OBJR.EQ.3)C(ICOLR(1)+JCOL)=CC(JCOL+1)
      JCOL=JCOL+1
1000  CONTINUE
      IF(IPRINT.NE.0)WRITE(2,*)(C(K),K=1,NVAR)
      JCOL=0
      DO 500 I=1,MMF
      IF(ICOLR(4).NE.0.AND.OBJF.EQ.5)C(ICOLR(4)+JCOL)=-A4
      JCOL=JCOL+1
500   CONTINUE
      IF(ICOLR(3).NE.0.AND.OBJF.EQ.5)C(ICOLR(3))=C(ICOLR(3))+A4*
     1 FLOAT(MMF)
      IF(IPRINT.NE.0)WRITE(2,*)(C(K),K=1,NVAR)
C     ****************************************************************
C     DEFINING M, K NLET, NGET, NET
C     ****************************************************************
      M=IROW
      K=NVAR
      NLET=0
      NGET=0
      NET=0
      DO 100 I1=1,M
      IF(CODE(I1).EQ.0)NLET=NLET+1
      IF(CODE(I1).EQ.1)NGET=NGET+1
      IF(CODE(I1).EQ.2)NET=NET+1
100   CONTINUE
      RETURN
      END
C     ****************************************************************
```

Appendix 4.I

Sample Input Data for MATGEN Package for Annual Safe Yields from a Reservoir of Known Size (Max.Z_{sy})

In order to explain the flexibility in the input data for MATGEN computer package on linear programming a sample input data for annual safe yield from a reservoir of known size, i.e., model Max.Z_{sy} is given below.

4.I.1 Matrices [A], [B] and [C] in Detached Coefficient Form:The modeled constraint equations (3.3.1), (3.3.2), and (3.3.3) and the objective function (3.3.0) of Chapter-3 can be rewritten by rearranging the unknown variables in the sequence, S_{t-1}, S_t, Sp_t, and O^*. These are shown below:

(i) Continuity equation:

$$-S_{t-1} + K'_t.S_t + \left(Sp_t + \delta_t.O^* \right) = I_t + P_t + \bar{I}_t - \left(O_t^d + O_t^m \right) \quad \text{for all } t \qquad (3.3.1)$$

We can also put

$$R_t = I_t + P_t + \bar{I}_t - \left(O_t^d + O_t^m \right)$$

(ii) Limits on reservoir storages:

$$S_{t-1} \geq Yd \qquad \text{for all } t \qquad (3.3.2)$$

$$S_{t-1} \leq Y^g \qquad \text{for all } t \qquad (3.3.3)$$

(iii) Objective function

$$\text{Maximize} \quad Z_{sy} = O^* \qquad (3.3.0)$$

The above constraint equations can be written for all time periods t, and a matrix in Detached Coefficient Form can be prepared. For explanation this has been shown for two time periods below:

$$-S_0 + K'_1.S_1 + \left(Sp_1 + \delta_1.O^* \right) = R_1 \qquad \text{for } t = 1 \qquad (6.3.1\text{-}1)$$

$$K'_2.S_0 - S_1 + \left(Sp_2 + \delta_2.O^* \right) = R_2 \qquad \text{for } t = 2 \qquad (6.3.1\text{-}2)$$

$$S_0 \geq Yd \qquad \text{for } t = 1 \qquad (6.3.2\text{-}1)$$

$$S_1 \geq Yd \qquad \text{for } t = 2 \qquad (6.3.2\text{-}2)$$

$$S_0 \leq Y^g \qquad \text{for } t = 1 \qquad (6.3.3\text{-}1)$$

$$S_1 \leq Y^g \qquad \text{for } t = 2 \qquad (6.3.3\text{-}2)$$

The Detached Coefficient of Matrices [A], [B] and [C] for annual safe yield from a reservoir are given in Table 4.I.1.

4.I.2 A Sample Input Data for MATGEN: The sample input data for the computer package, MATGEN, on linear programming for the problem in para 4.I.1 are given in Table 4.I.2.

Table 4.I.1 Coefficients of matrices [A], [B] and [C] for annual safe yield from a reservoir of known size for MATGEN.

COL. NO.	1	2	3	4	5		
VAR.	S_0	S_1	Sp_1	Sp_2	O^*	SIGN [CODE]	RHS [B]
	C_2^R		C_5^R		C_6^R		
VCIN	1		3		5		
Equation			Coefficient Matrix [A]				
6.3.1–1	–1	K_1'	1	0	δ_1	=	R_1
6.3.1–2	K_2'	–1	0	1	δ_2	=	R_2
6.3.2–1	1	0	0	0	0	≥	Yd
6.3.2–2	0	1	0	0	0	≥	Yd
6.3.3–1	1	0	0	0	0	≤	Y^g
6.3.3–2	0	1	0	0	0	≤	Y^g
			Coefficient Matrix [C]				
3.3.0	0	0	0	0	1		

CIN = Column Index Number,
VCIN = Value of CIN,

SIGN represents CODE,
M = Number of constraint equations in matrix [A], and
K = Total number of variables,
Here , M = 6 , & K = 5,

All parameters R_1 and R_2 in the Matrices [A], [B] and [C] are known quantities and are computed from the Basic Input Data by the computer programme, MATGEN.

Table 4.I.2 Sample input data file for annual safe yield from a reservoir of known size for MATGEN.

Input parameter/variable read statement	Input parameter/variable to be given
IGEN	1
IPRNT1	0
NTYPE NOPT	1 0
MM	2
NVAR	5
YD	0
OBJR OBJI OBJP OBJF	2 -1 -1 -1
Y	Ya^g
FLOW	I_1 I_2
WS	–
IEVAP	1
XK2 XK3	K'_1 K'_2 0 0
EV	–
A0 AS	–
NCOLR	6
ICOLR	0 1 0 0 3 5
NEQR	9
EQR	-1 1 -1 -1 -1 -1 1 -1 1
C11 OM11	–
DELT	δ_1 δ_2
CC	–
OUTF	–
NCOLI	–
ICOLI	–

Table 4.I.2 continued

NEQI	–
EQI	–
A2 C21 OM21	–
XK1	–
NCOLP	–
ICOLP	–
NEQP	–
EQP	–
A3 C31 OM31	–
XNETA	–
ALPHA	–
PR1 PR2 I100	–
QAV Q15 AHEAD AVHR	–
EFFCI CV CP	–
HEAD	–
TIME	–
POWPF	–
A4	–
IPRNT	0
IPRT1	0
ISAL	–
NVAAL	–
IUP ILO IEQ	–
UL LM EQU	–
IFL MMF	–
YF2	–

Appendix 4.II

Sample Input Data for MATGEN Package for DiscontinuousModel for Estimation of Over-year Carry-overStorages for a Known Reservoir Capacityand Annual Targeted Demand (Max.Z_{tr})

A sample input data for discontinuous model for over-year carry-over storages for a known reservoir capacity and annual targeted demand, i.e., model Max.Z_{tr} is given below.

4.II.1 Matrices [A], [B] and [C] in Detached Coefficient Form: The modeled constraint equations (3.4.1), (3.4.2), and (3.4.3), (3.4.4) and (3.4.5), and the objective function (3.4.0) of Chapter-3 can be rewritten by rearranging the unknown variables in the sequence, O_t, S_{t-1}, S_t, and Sp_t. These are shown below :

(i) Continuity equation:

$$O_t - S_{t-1} + K'_t.S_t + Sp_t = I_t + P_t + \bar{I}_t - El_t - \left[O_t^d + O_t^m \right] \text{ for all t} \qquad (3.4.1)$$

We can also put

$$Q'_t = I_t + P_t + \bar{I}_t - El_t - \left[O_t^d + O_t^m \right]$$

(ii) Limits on reservoir storages:

$$S_{t-1} \geq Yd \qquad \text{for all t} \qquad (3.4.2)$$

$$S_{t-1} \leq Y^g \qquad \text{for all t} \qquad (3.4.3)$$

(iii) Upper bounds on reservoir releases:

$$O_t \leq O_t^g \qquad \text{for all t} \qquad (3.4.4)$$

(iv) Reservoir full condition

$$S_t = Y^g \text{ for t at the end of the monsoon period} \qquad (3.4.5)$$

(v) Objective function

$$\text{Maximize } Z_{tr} = \sum_{t=1}^{12} Va_t.O_t \qquad (3.4.0)$$

For explanation the above constraint equations have been shown for two time periods (t = 1, monsoon , and t = 2 , non-monsoon) below :

$O_1 - S_0 + K'_1.S_1 + Sp_1 = Q_1$ for t = 1 (6.4.1-1)

$O_2 - S_1 + K'_2.S_2 + Sp_2 = Q_2$ for t = 1 (6.4.1-2)

$S_0 \geq Yd$ for t = 1 (6.4.2-1)

$S_1 \geq Yd$ for t = 2 (6.4.2-2)

$S_0 \leq Y^g$ for t = 2 (6.4.3-1)

$S_1 \leq Y^g$ for t = 1 (6.4.3-2)

$O_1 \leq O_1^g$ for t = 1 (6.4.4-1)

$O_2 \leq O_2^g$ for t = 2 (6.4.4-2)

Further, limits have been put on reservoir storages as given below:

Let,

$S_0 = S_0^m$ for t=1 the assumed storage at the beginning of monsoon period (6.ii.1)

$S_1 = Y^g$ for t=1 at the end of the monsoon period (6.4.5)

$S_2 = S_2^{nm}$ for t=2 the assumed final storage at the end of non-monsoon period (6.ii.2)

The Detached Coefficient of Matrices [A], [B] and [C] for this model are given in Table 4.II.1.

4.II.2 A Sample Input Data for MATGEN: The sample input data for the computer package, MATGEN, on linear programming for the problem in para 4.II.1 are given in Table 4.II.2.

Table 4.II.1 Coefficients of matrices [A], [B] and [C] for discontinuous model for, over-year carry-over storages for a known reservoir capacity and annual targeted demand for MATGEN:

COL. NO.	1	2	3	4	5	6	7		
VAR.	O_1	O_2	S_0	S_1	S_2	Sp_1	Sp_2	SIGN [CODE]	RHS [B]
CIN	C_1^R		C_2^R			C_5^R			
VCIN	1		3			6			
Equation			Coefficient Matrix [A]						
6.4.1–1	1	0	–1	K_1'	0	1	0	=	Q_1'
6.4.1–2	0	1	0	–1	K_2'	0	1	=	Q_2'
6.4.2–1	0	0	1	0	0	0	0	≥	Yd
6.4.2–2	0	0	0	1	0	0	0	≥	Yd
6.4.3–1	0	0	1	0	0	0	0	≤	Y^g
6.4.3.2	0	0	0	1	0	0	0	≤	Y^g
6.4.4–1	1	0	0	0	0	0	0	=	O_1^g
6.4.4–2	0	1	0	0	0	0	0	=	O_2^g
			Limits on Variables						
6.ii.1	0	0	1	0	0	0	0	=	S_0^m
6.4.5	0	0	0	1	0	0	0	=	Y^g
6.ii.2	0	0	0	0	1	0	0	=	S_2^{nm}
			Coefficient Matrix [C]						
3.4.0	1	1	0	0	0	0	0		

CIN = Column Index Number,

VCIN = Value of CIN, SIGN represents CODE,

M = Number of constraint equations in matrix [A], and

K = Total number of variables,

Here , M = 11, & K = 7,

All parameters Q_1 and Q_2 in the Matrices [A], [B] and [C] are known quantities and are computed from the Basic Input Data by the computer programme, MATGEN.

Table 4.II.2 Sample input data file for discontinuous model for over-year carry-over storages for a known reservoir capacity and annual targeted demand MATGEN.

Input parameter/variable read statement	Input parameter/variable to be given
IGEN	1
IPRNT1	0
NTYPE NOPT	1 0
MM	2
NVAR	8
YD	Yd
OBJR OBJI OBJP OBJF	3 -1 -1 -1
Y	Y^g
FLOW	I_1 I_2
WS	-
IEVAP	1
XK2 XK3	K'_1 K'_2 0 0
EV	-
A0 AS	-
NCOLR	6
ICOLR	1 3 0 0 6 0
NEQR	9
EQR	-1 -1 1 -1 -1 -1 1 -1 1
C11 OM11	-
DELT	-
CC	1 1
OUTF	-
NCOLI	-
ICOLI	-
NEQI	-
EQI	-
A2 C21 OM21	-
XK1	-

Table 4.II.2 continued

NCOLP	–
ICOLP	–
NEQP	–
EQP	–
A3 C31 OM31	–
XNETA	–
ALPHA	–
PR1 PR2 I100	–
QAV Q15 AHEAD AVHR	–
EFFCI CV CP	–
HEAD	–
TIME	–
POWPF	–
A4	–
IPRNT	0
IPRT1	0
ISAL	5
NVAAL	1 2 3 4 5
IUP ILO IEQ	0 -1 -1
UL LM EQU	O_1^g 0 0
IUP ILO IEQ	0 -1 -1
UL LM EQU	O_2^g 0 0
IUP ILO IEQ	-1 -1 2
UL LM EQU	0 0 S_0^m
IUP ILO IEQ	-1 -1 2
UL LM EQU	0 0 Y^g
IUP ILO IEQ	-1 -1 2
UL LM EQU	0 0 S_2^{nm}
IFL MMF	0 0
YF2	–

Appendix 4.III

Sample Input Data for MATGEN Package for Total Gross Reservoir Capacity for a Known Annual Targeted Demand (Min.Z_{gc})

A sample input data for total gross reservoir capacity for a known annual targeted demand, i.e., model Min.Z_{gc} is given below.

4.III.1 Matrices [A], [B] and [C] in Detached Coefficient Form : The modeled constraint equations (3.5.1.1), (3.5.1.2), and (3.5.1.3), and the objective function (3.5.1) of Chapter-3 can be rewritten by rearranging the unknown variables in the sequence, $S_{j,t-1}$, $S_{j,t}$, Y, and $Sp_{j,t}$. These are shown below:

(i) Continuity equation:

$$-S_{j,t-1} + K'_t.S_{j,t} + Sp_{j,t} = I_{j,t} - \delta'_t.Oy^g \text{ for all j and t} \qquad (3.5.1.1)$$

We can put also

$$n_{j,t} = I_{j,t} - \delta'_t.Oy^g$$

(ii) Limits on reservoir storages:

$$S_{j,t-1} \geq Yd \qquad \text{for all j and t} \qquad (3.5.1.2)$$

$$S_{j,t-1} - Y \leq 0 \qquad \text{for all j and t} \qquad (3.5.1.3)$$

(iii) Objective function

$$\text{Minimize } Z_{gc} = Y \qquad (3.5.1)$$

For explanation the above constraint equations have been shown for two years for two time periods in a year below:

$-S_{1,0} + K_1'.S_{1,1} + Sp_{1,1} = n_{1,1}$ for j = 1, and t = 1 (6.5.1.1-1)

$-S_{1,1} + K_2'.S_{2,0} + Sp_{1,2} = n_{1,2}$ for j = 1, and t = 2 (6.5.1.1-2)

$-S_{2,0} + K_1'.S_{2,1} + Sp_{2,1} = n_{2,1}$ for j = 2, and t = 1 (6.5.1.1-3)

$-S_{2,1} + K_2'.S_{1,0} + Sp_{2,2} = n_{2,2}$ for j = 2, and t = 2 (6.5.1.1-4)

$S_{1,0} \geq Yd$ for j = 1, and t = 1 (6.5.1.2-1)

$S_{1,1} \geq Yd$ for j = 1, and t = 2 (6.5.1.2-2)

$S_{2,0} \geq Yd$ for j = 2, and t = 1 (6.5.1.2-3)

$S_{2,1} \geq Yd$ for j = 2, and t = 2 (6.5.1.2-4)

$S_{1,0} - Y \leq 0$ for j = 1, and t = 1 (6.5.1.3-1)

$S_{1,1} - Y \leq 0$ for j = 1, and t = 2 (6.5.1.3-2)

$S_{2,0} - Y \leq 0$ for j = 2, and t = 1 (6.5.1.3-3)

$S_{2,1} - Y \leq 0$ for j = 2, and t = 2 (6.5.1.3-4)

The Detached Coefficient of Matrices [A], [B] and [C] for this model are given in Table 4.III.1.

4.III.2 A Sample Input Data for MATGEN: The sample input data for the computer package, MATGEN, on linear programming for the problem in para 4.III.1 are given in Table 4.III.2.

Table 4.III.1 Coefficients of matrices [A], [B] and [C] for total gross reservoir capacity for a known annual targeted demand for MATGEN.

COL. NO.	1	2	3	4	5	6	7	8	9		
VAR.	$S_{1,0}$	$S_{1,1}$	$S_{2,0}$	$S_{2,1}$	Y	$Sp_{1,1}$	$Sp_{1,2}$	$Sp_{2,1}$	$Sp_{2,2}$	SIGN [CODE]	RHS [B]
CIN	C_2^R				C_3^R	C_5^R					
VCIN	1				5	6					
Equation				Coefficient Matrix [A]							
6.5.1.1–1	–1	K_1'	0	0	0	1	0	0	0	=	$n_{1,1}$
6.5.1.1–2	0	–1	K_2'	0	0	0	1	0	0	=	$n_{1,2}$
6.5.1.1–3	0	0	–1	K_1'	0	0	0	1	0	=	$n_{2,1}$
6.5.1.1–4	K_2'	0	0	–1	0	0	0	0	1	=	$n_{2.2}$
6.5.1.2–1	1	0	0	0	0	0	0	0	0	≥	Yd
6.5.1.2–2	0	1	0	0	0	0	0	0	0	≥	Yd
6.5.1.2–3	0	0	1	0	0	0	0	0	0	≥	Yd
6.5.1.2–4	0	0	0	1	0	0	0	0	0	≥	Yd
6.5.1.3–1	1	0	0	0	–1	0	0	0	0	≤	0
6.5.1.3–2	0	1	0	0	–1	0	0	0	0	≤	0
6.5.1.3–3	0	0	1	0	–1	0	0	0	0	≤	0
6.5.1.3–4	0	0	0	1	–1	0	0	0	0	≤	0
				Coefficient Matrix [C]							
3.5.1	0	0	0	0	1	0	0	0	0		

CIN = Column Index Number,

VCIN = Value of CIN,

SIGN represents CODE,

M = Number of constraint equations in matrix [A], and

K = Total number of variables,

Here, M = 12, & K = 9,

All parameters $n_{1,1}$, $n_{1,2}$, $n_{2,1}$, and $n_{2,2}$ in the Matrices [A], [B] and [C] are known quantities and are computed from the Basic Input Data by the computer programme, MATGEN.

Table 4.III.2 Sample input data file for total gross reservoir capacity for a known annual targeted demand for MATGEN.

Input parameter/variable read statement	Input parameter/variable to be given
IGEN	1
IPRNT1	0
NTYPE NOPT	0 1
MM	4
NVAR	9
YD	Yd
OBJR OBJI OBJP OBJF	4 -1 -1 -1
Y	–
FLOW	$I_{1,1}$ $I_{1,2}$ $I_{2,1}$ $I_{2,2}$
WS	–
IEVAP	1
XK2 XK3	K'_1 K'_2 0 0
EV	–
A0 AS	–
NCOLR	6
ICOLR	0 1 5 0 6 0
NEQR	9
EQR	-1 -1 -1 1 -1 -1 1 1 -1
C11 OM11	–
DELT	–
CC	–
OUTF	$\delta'_1 * Oy^g$ $\delta'_2 * Oy^g$
NCOLI	–
ICOLI	–

Table 4.III.2 continued

NEQI	–
EQI	–
A2 C21 OM21	–
XK1	–
NCOLP	–
ICOLP	–
NEQP	–
EQP	–
A3 C31 OM31	–
XNETA	–
ALPHA	–
PR1 PR2 I100	–
QAV Q15 AHEAD AVHR	–
EFFCI CV CP	–
HEAD	–
TIME	–
POWPF	–
A4	–
IPRNT	0
IPRT1	0
ISAL	–
NVAAL	–
IUP ILO IEQ	–
UL LM EQU	–
IFL MMF	–
YF2	–

Appendix 4.IV

Sample Input Data for MATGEN Package for Over-yearCarry-over Reservoir Capacity for a Known Annual Targeted Demand (Min.Z_{OC})

A sample input data for over-year carry-over reservoir capacity for a known annual targeted demand, i.e., model Min.Z_{oc} is known below.

4.IV.1 Matrices [A], [B] and [C] in Detached Coefficient Form:The modeled constraint equations (3.5.2.1), (3.5.2.2), and (3.5.2.3), and the objective function (3.5.2) of Chapter-3 can be rewritten by rearranging the unknown variables in the sequence, S_{t-1}, S_t, Y^o, and Sp_t. These are shown below :

(i) Continuity equation:

$$-S_{j-1} + K'_j \cdot S_j + Sp_j = I_j + P_j + \bar{I}_j - Oy^g - \left(O_j^d + O_j^m \right) \quad \text{for all j} \qquad (3.5.2.1)$$

We can also put

$$L_j = I_j + P_j + \bar{I}_j - Oy^g - \left(O_j^d + O_j^m \right)$$

(ii) Limits on reservoir storages:

$$S_{j-1} - Y^o \leq 0 \qquad \text{for all j} \qquad (3.5.2.2)$$

$$S_{j-1} \geq Yd \qquad \text{for all j} \qquad (3.5.2.3)$$

(iii) Objective function

Minimize $Z_{oc} = Y^o$ (3.5.2)

For explanation the above constraint equations have been shown for two time periods below:

$-S_0 + K'_1.S_1 + Sp_1 = L_1$ for j = 1 (6.5.2.1-1)

$K'_2S_0 - S_1 + Sp_2 = L_2$ for j = 2 (6.5.2.1-2)

$S_0 - Y^o \leq 0$ for j = 1 (6.5.2.2-1)

$S_1 - Y^o \leq 0$ for j = 2 (6.5.2.2-2)

$S_0 \geq Yd$ for j = 1 (6.5.2.3-1)

$S_1 \geq Yd$ for j = 2 (6.5.2.3-2)

The Detached Coefficient of Matrices [A], [B] and [C] for over-year carry-over active reservoir capacity are given in Table 4.IV.1.

4.IV.2 A Sample Input Data for MATGEN : The sample input data for the computer package, MATGEN, on linear programming for the problem in para 4.IV.1 are given in Table 4.IV.2.

Table 4.IV.1 Coefficients of matrices [A],[B] and [C] for over-year carry-over reservoir capacity for a known annual targeted demand for MATGEN.

	COL. NO.	1	2	3	4	5		
	VAR.	S_0	S_1	Y^o	Sp_1	Sp_2	SIGN [CODE]	RHS [B]
	COLUMNS	S0	S1	YO	SP1	SP2		
		C_2^R		C_3^R	C_5^R			
	VCIN	1		3	4			
ROWS	Equation	Coefficient Matrix [A]						
RCO1	6.5.2.1-1	–1	K_1'	0	1	0	=	L_1
RCO2	6.5.2.1-2	K_2'	–1	0	0	1	=	L_2
RSU1	6.5.2.2-1	1	0	–1	0	0	≤	0
RSU2	6.5.2.2-2	0	1	–1	0	0	≤	0
RSL1	6.5.2.3-1	1	0	0	0	0	≥	Yd
RSL2	6.5.2.3-2	0	1	0	0	0	≥	Yd
		Coefficient Matrix [C]						
OB 3 52	3.5.2	0	0	1	0	0		

CIN = Column Index Number,
VCIN = Value of CIN,
SIGN represents CODE,
M = Number of constraint equations in matrix [A], and
K = Total number of variables,
Here , M = 6, & K = 5,

All parameters L_1 and L_2 in the Matrices [A], [B] and [C] are known quantities and are computed from the Basic Input Data by the computer programme, MATGEN.

Also put K1D = K_1', K2D = K_2', L1 = L_1, L2 = L_2, S0 = S_0, S1 = S_1, YO = Y^o, YD = Yd, SP1 = Sp_1, and SP2 = Sp_2.

Table 4.IV.2 Sample input data file for over - year carry-over reservoir capacity for a known annual targeted demand for MATGEN.

Input parameter/variable read statement	Input parameter/variable to be given
IGEN	1
IPRNT1	0
NTYPE NOPT	0 0
MM	2
NVAR	5
YD	Yd
OBJR OBJI OBJP OBJF	4 -1 -1 -1
Y	–
FLOW	I_1 I_2
WS	–
IEVAP	1
XK2 XK3	K'_1 K'_2 0 0
EV	–
A0 AS	–
NCOLR	6
ICOLR	0 1 3 0 4 0
NEQR	9
EQR	-1 -1 -1 1 -1 -1 1 1 -1
C11 OM11	–
DELT	–
CC	–
OUTF	Oy^g
NCOLI	–
ICOLI	–

Table 4.IV.2 continued

NEQI	–
EQI	–
A2 C21 OM21	–
XK1	–
NCOLP	–
ICOLP	–
NEQP	–
EQP	–
A3 C31 OM31	–
XNETA	–
ALPHA	–
PR1 PR2 I100	–
QAV Q15 AHEAD AVHR	–
EFFCI CV CP	–
HEAD	–
TIME	–
POWPF	–
A4	–
IPRNT	0
IPRT1	0
ISAL	–
NVAAL	–
IUP ILO IEQ	–
UL LM EQU	–
IFL MMF	–
YF2	–

Appendix 4.V

Sample Input Data File for MPS Computer Package on Linear Programming

The input data feeding for the linear programming model for over-year carry-over active reservoir capacity for a known targeted demand , using standard programme package called MPS (Mathematical Programming System) available with IMB 360 computer is described below:

Each data of the non-zero coefficients of the constraint equations should start from the columns specified for it. These columns fields specified are 1-2, 5-14, 15-24, 25-39, 40-49, and 50-64 on the computer terminal screen.

4.V.1 Input Data for Rows (Constraint Equation Row Name)

1-2	5-14
ROWS	
N	OB352
E	RCO1
E	RCO2
L	RSU1
L	RSU2
G	RSL1
G	RSL2

Note:

N is for objective function

E is for = sign constraint equation

L is for ≤ sign constraint equation

G is for ≥ sign constraint equation

The nature of the objective function, i.e., whether to minimize or maximize is defined separately in the execution commands.

4.V.2 Input Data for COLUMNS (Variable Name)

Only non-zero coefficients of matrices [A] & [C] are to be given as data as shown below:

1-2	15-24	25-39	40-49	50-64
COLUMNS				
S0	RCO1	-1	RCO2	K2D
S0	RSU1	1	RSL1	1
S1	RCO1	-K1D	RCO2	-1
S1	RSU2	1	RSL2	1
YO	RSU1	-1	RSU2	-1
YO	OB352	1		
SP1	RCO1	1		
SP2	RCO2	1		

4.V.3 Input Data for RHS

Only non-zero coefficients of matrix [B] are to be given as data as shown below:

1-2	5-14	15-24	25-39
RHS			
	RHS1	RCO1	L1
	RHS1	RCO2	L2
	RHS1	RSL1	YD
	RHS1	RSL2	YD
ENDATA			

Appendix 4.VI

Sample Input Data File for LINGO Computer Package on Linear Programming

The input data feeding for the linear programming model for over-year carry-over active reservoir capacity for a known targeted demand, using standard programme package called LINGO is given below.

```
MODEL :
1] MIN = YO
2] - S0 + K1D * S1 + SP1 = L1;
3] K2D * S0 - S1 + SP2 = L2;
4] S0 - YO ≤ 0 ;
5] S1 - YO ≤ 0 ;
6] S0 ≥ 0 ;
7] S1 ≥ 0 ;
END
```

Estimation of Economic Parameters for Bargi Multipurpose Project

5.1.0 OBJECTIVE FUNCTION

The objective function is to maximize the annual net benefits from irrigation, hydropower and flood control which a reservoir is going to serve.

(i) Reservoir Cost:

The annual cost of reservoir can be calculated as follows:

Annual cost of reservoir $= C_1 + Om_1 = \left[C_1' + Om_1' \right] Y$

Where,

C_1 = annual capital cost of reservoir,

C_1' = unit annual capital cost function for reservoir,

Om_1 = annual OM (operation and maintenance) cost for reservoir and,

Om_1' = unit annual OM (operation and maintenance) cost function for reservoir.

(ii) Irrigation Benefits and Cost:

Lumped Irrigation:

The benefits from irrigation are initially calculated at the farmers level and are then converted at the project level. The gross annual irrigation benefits are calculated below. Gross annual irrigation benefits $= B_2 = a_2.Ir$

The annual cost of irrigation can be calculated as follows:

Annual cost of irrigation $= C_2 + Om_2 = \left[C_2' + Om_2' \right] Ir$

Where,

B_2 = gross annual irrigation benefits,

C_2 = annual capital cost of irrigation,

C_2' = unit annual capital cost function for irrigation,

Om_2 = annual OM cost of irrigation,

Om'_2 = unit annual OM cost function for irrigation,

a_2 = benefit function for irrigation, and

Ir = annual irrigation water target.

(iii) Hydropower Benefits and cost:

The gross annual hydropower benefits are calculated as follows:

Gross annual hydropower benefits $B_3 = a_3.E$

The annual cost of hydropower can be calculated as follows:

Annual cost of hydropower $= C_3 + Om_3 = \left[C'_3 + Om'_3 \right] H$

Where,

B_3 = gross annual hydropower benefits,

a_3 = unit benefit for energy,

E = annual energy target,

C_3 = annual capital cost of hydropower,

C'_3 = unit annual capital cost function for hydropower,

Om_3 = annual OM cost for hydropower, and

Om'_3 = unit annual OM cost function for hydropower.

5.2.0 COMPUTATION OF UNIT ANNUAL COST OF RESERVOIR

Unit annual cost of reservoir = Unit annual interest on capital cost of reservoir + unit annual depreciation on capital cost of reservoir + unit annual operation & maintenance cost of reservoir.

$$= \left[i_1^i + \frac{i_1^d}{(1 + i_1^d)^n - 1} + i_1^o \right] * CC_1$$

Where,

i_1^i = annual interest rate on capital cost of reservoir,

i_1^d = annual rate of depreciation on capital cost of reservoir using sinking fund method,

i_1^o = annual operation and maintenance rate on the capital cost of reservoir, and

CC_1 = unit capital cost of reservoir.

Capital cost of the reservoir is Rs. $48.737*10^7$ (This figure was given as per the price level of 1986). These costs have been brought to 1994 price level by assuming constant inflation rate of 7 percent. The assumption of 7 percent inflation rate is just arbitrary as per present day norms.

So the capital cost of the reservoir as per present day norms for year 1994 is calculated as follows:

$$F = P\left(1 + i\right)^N = 48.737*10^7\left(1 + 0.07\right)^7 = \text{Rs. } 78.261*10^7$$

Where,

F = future worth,

P = present worth,

i = inflation rate, and

N = number of years.

Gross storage of reservoir (up to top of the dam) = 3.932 TMC.

$$\therefore CC_1 = \left(\frac{78.261}{3.932}\right)*10^7 = 19.904*10^7 \text{ Rs./TMC}$$

(a) unit annual interest on capital cost

$$= \left(i_1^i * CC_1\right) = (0.050 * 19.904*10^7) = 0.9952*10^7 \text{ Rs. /TMC}$$

(b) unit annual depreciation on capital cost = $\left[\dfrac{i_1^d}{(1 + i_1^d)^n - 1}\right] * CC_1$

Where,

n = the life of the project considering as 22 years length of river inflow.

$$\left[\frac{0.01}{(1+0.01)^{22}-1}\right] * 19.904*10^7 = 0.81335*10^7 \text{ Rs. /TMC}$$

(c) unit annual operation and maintenance cost

$$\left(i_1^o * CC_1\right) = \left(0.005 * 19.904*10^7\right)*10^7 = 0.09952*10^7 \text{ Rs. /TMC}$$

$\therefore$ Unit annual cost of reservoir = $\left[\text{(a)} + \text{(b)}\right] + \text{(c)} = C_1' + Om_1'$

$$= \left[0.9952 + 0.81335\right] + 0.09952*10^7 = 1.8085*10^7 + 0.0995*10^7$$

$$= 1.9080*10^7 \text{ Rs. /TMC}$$

5.3.0 COMPUTATION OF UNIT ANNUAL COST OF IRRIGATION

Unit annual cost of irrigation = Unit annual interest on capital cost of irrigation + unit annual depreciation on capital cost of irrigation + unit annual operation & maintenance cost of irrigation.

$$= \left[i_2^i + \frac{i_2^d}{(1 + i_2^d)^n - 1} + i_2^o\right] * CC_2$$

Where,

i_2^i = annual interest rate on capital cost of irrigation,

i_2^d = annual rate of depreciation on capital cost of irrigation using sinking fund method,

i_2^o = annual operation & maintenance rate on the capital cost of irrigation, and

CC_2 = unit capital cost of irrigation.

Capital cost of the irrigation canal net work is Rs. $122.98*10^7$. So the capital cost of the irrigation canal as per present day norms for year 1994 is calculated as follows:

$$F = P\left(1 + i\right)^N = 122.98*10^7\left(1 + 0.07\right)^7 = \text{Rs. } 197.481*10^7$$

Total annual water requirement for irrigation is 3.947 TMC.

$$\therefore CC_2 = \left(\frac{197.481}{3.947}\right)*10^7 = 50.033\ 10^7 \text{ Rs. /TMC}$$

(a) unit annual interest on capital cost

$$\left(i_2^i * CC_2\right) = \left(0.050*50.033*10^7\right) = 2.50165*10^7 \text{ Rs. /TMC}$$

(b) unit annual depreciation on capital cost

$$\left[\frac{i_2^d}{(1 + i_2^d)^n - 1}\right]*CC_2$$

$$= \left[\frac{0.01}{(1+0.01)^{22}-1}\right]*50.033*10^7 = 2.04435*10^7 \text{ Rs. /TMC}$$

(c) unit annual operation and maintenance cost

$$\left(i_2^o * CC_2\right) = \left(0.01*50.033*10^7\right) = 0.500*10^7 \text{ Rs. /TMC}$$

$\therefore$ Unit annual cost of irrigation $= \left[(a) + (b)\right] + (c) = C_2' + Om_2'$

$$= \left[2.50165 + 2.04435\right]*10^7 + 0.500*10^7 = 4.546*10^7 + 0.500*10^7$$

$$= 5.046*10^7 \text{ Rs. /TMC}$$

(d) computation of irrigation benefits

Gross annual irrigation benefits = B_2 = a_2* Ir

Where,

B_2 = gross annual irrigation benefits for project = Rs. $132.951*10^7$

The present gross annual irrigation benefit as per year 1994 is calculated as follows:

$$F = P\left(1 + i\right)^N = 132.951*10^7\left(1 + 0.07\right)^7 = \text{Rs. } 213.490*10^7$$

$$\therefore a_2 = \left[\frac{213.49}{3.947}\right]*10^7 = 54.0892*10^7 \text{ Rs. /TMC}$$

5.4.0 COMPUTATION OF UNIT ANNUAL COST OF HYDROPOWER

Unit annual cost of hydropower = Unit annual interest on capital cost of hydropower + unit annual depreciation on capital cost of hydropower + unit annual operation & maintenance cost of hydropower.

$$= \left[i_3^i + \frac{i_3^d}{(1 + i_3^d)^n - 1} + i_3^o \right]*CC_3$$

Where,

i_3^i = annual interest rate on capital cost of hydropower,

i_3^d = annual rate of depreciation on capital cost of hydropower using sinking fund method,

i_3^o = annual operation & maintenance rate on the capital cost of hydropower, and

CC_3 = unit capital cost of hydropower.

Capital cost of the hydropower is Rs. $5.382*10^7$.So the capital cost of the hydropower as per present day norms for year 1994 is calculated as follows:

$$F = P\left(1 + i\right)^N = 5.382*10^7\left(1 + 0.07\right)^7 = \text{Rs. } 8.642*10^7$$

Power plant capacity is 90 MW.

$$\therefore CC_3 = \left[\frac{8.642}{90} \right] * 10^7 = 0.09602*10^7 \text{ Rs. /MW}$$

(a) unit annual interest on capital cost

$$\left[i_3^i * CC_3 \right] = \left[0.050*0.09692*10^7 \right] \left[0.050* 0.09602*10^7 \right] = 0.00480*10^7 \text{ Rs. /MW}$$

(b) unit annual depreciation on capital cost

$$\left[\frac{i_3^d}{(1 + i_3^d)^n - 1} \right] * CC_3$$

$$= \left[\frac{0.01}{(1+0.01)^{22} - 1} \right] * 0.09602*10^7 = 0.003924*10^7 \text{ Rs. /MW}$$

(c) unit annual operation and maintenance cost

$$\left[i_3^o * CC_3 \right] = \left[0.005*0.09602 \right] * 10^7 = 0.000480*10^7 \text{ Rs. /MW}$$

$\therefore$ Unit annual cost of hydropower $= \left[(a) + (b) \right] + (c) = C_3' + Om_3'$

$$= \left[0.00480 + 0.003924 \right] + 0.000480 = 0.008724*10^7 + 0.000480*10^7$$
$$= 0.00920*10^7 \text{ Rs. /MW}$$

(d) computation of hydropower benefits

Gross annual hydropower benefits $= B_3 = a_3.E$

Where,

a_3 = Rs. 2/KWhr.

ANNEXURES

Annexure-1

Salient Features of Badanala Project

1.1 LOCATION

1.	State	Orissa
2.	District	Koraput
3.	Name of river	Badanala
4.	Purpose	Irrigation

1.2 HYDROLOGY

1.	Catchment area	352 Sq.Km.
2.	Mean annual rainfall	1223 mm

1.3 RESERVOIR

1.	Full reservoir level (F.R.L.)	176.00 m
2.	Maximum reservoir level (M.W.L.)	176.00 m
3.	Dead storage level	163.80 m
4.	Lowest river bed level	131 m
5.	Top of dam	179 m
6.	Height of dam	48 m
7.	Gross storage capacity	7564 ha-m
8.	Live storage capacity	6714 ha-m
9.	Dead storage capacity	850 ha-m
10.	Type of dam	Earthen cum masonry dam

1.4 DISTRIBUTION SYSTEM

1.	Gross command area	13065 ha
2.	Culturable command area	9800 ha
3.	Annual irrigation requirement	14569 ha-m

1.5 COST ESTIMATES (as per price level of 1994)

1.	Capital cost of dam	Rs. 3187 10^5
2.	Capital cost of irrigation	Rs. 1328 10^5
3.	Annual gross benefit for irrigation	Rs. 4553 10^5

Annexure-2

Salient Features of Kalluvodduhalla Project

2.1 LOCATION

1.	State	Karnataka
2.	District	Shimoga
3.	Name of river	Kalluvodduhalla
4.	Purpose	Irrigation

2.2 HYDROLOGY

1.	Catchment area	41 Sq.Km.
2.	Mean annual rainfall	1305 mm

2.3 RESERVOIR

1.	Full reservoir level (F.R.L.)	633.495 m
2.	Maximum reservoir level (M.W.L.)	633.495 m
3.	Dead storage level	621.760 m
4.	Lowest river bed level	614.170 m
5.	Top of dam	637.155 m
6.	Height of dam	22.985 m
7.	Gross storage capacity	12.176 MCM
8.	Live storage capacity	11.302 MCM
9.	Dead storage capacity	0.874 MCM
10.	Type of dam	Earthen cum masonry dam

2.4 DISTRIBUTION SYSTEM

1.	Gross command area	1882 ha
2.	Culturable command area	1450 ha
3.	Annual irrigation requirement	17.549 MCM

2.5 COST ESTIMATES (as per price level of 1994)

1.	Capital cost of dam	Rs. 620.44 10^5
2.	Capital cost of irrigation	Rs. 333.24 10^5
3.	Annual gross benefits for irrigation	Rs. 126.20 10^5

Annexure-3

Salient Features of Bodhghat Project

3.1 LOCATION

1.	State	Madhya Pradesh
2.	District	Bastar
3.	Name of river	Indravati
4.	Purpose	Hydropower

3.2 RESERVOIR

1.	Full reservoir level (F.R.L.)	466.54 m
2.	Maximum reservoir level (M.W.L.)	467.60 m
3.	Minimum drawdown (M.D.D.L.)	426.72 m
3.	Dead storage level	410.00 m
5.	Tail water level (T.W.L.)	351.54 m
6.	Gross storage capacity	4458 MCM
7.	Live storage capacity	3718 MCM
8.	Dead storage capacity	740 MCM

3.3 POWER HOUSE

1.	Installed capacity	500 MW (100 x 5)
2.	Maximum head	116.16 m
3.	Minimum head	74.70 m
4.	Average head	110.67 m
6.	Annual energy requirement	1139000 MWhr

3.4 COST ESTIMATES (as per price level of 1994)

1.	Capital cost of dam	Rs. 4538 10^6
2.	Capital cost of hydropower	Rs. 1564 10^6
3.	Annual gross benefit for hydropower	Rs. 1383 10^6

Annexure-4

Salient Features of Bargi Project

4.1 LOCATION

1.	State	Madhya Pradesh
2.	District	Jabalpur
4.	Name of river	Narmada
5.	Purpose	Multipurpose

4.2 HYDROLOGY

1.	Catchment area	14556 Sq.Km.
2.	Mean annual rainfall	1148 mm
3.	Observed flood	11876 cumecs
4.	Design flood	45296 cumecs

4.3 RESERVOIR

1.	Full reservoir level (F.R.L.)	423.06 m
2.	Maximum reservoir level (M.W.L.)	424.28 m
3.	Dead storage level	410.56 m
4.	Top of dam	426.90 m
5.	Tail water level (T.W.L.)	368.20 m
6.	Height of dam	22.985 m
7.	Gross storage capacity	3.932 TMC
8.	Live storage capacity	3.190 TMC
9.	Dead storage capacity	0.742 TMC
10.	Type of dam	Earthen dam

4.4 DISTRIBUTION SYSTEM

1.	Gross command area	
2.	Culturable command area	402000 ha
3.	Annual irrigation requirement	3.947 TMC
4.	Annual water supply requirement	0.200 TMC

4.5 POWER HOUSE

1.	Installed capacity	90 MW (45 x 2)
2.	Maximum head	58.25 m
3.	Minimum head	36.47 m
4.	Average head	45.50 m
5.	Annual energy requirement	329000 MWhr

4.6 COST ESTIMATES (as per price level of 1994)

1.	Capital cost of dam	Rs. 78.261 10^7
3.	Capital cost of irrigation	Rs. 197.480 10^7
4.	Capital cost of hydropower	Rs. 8.642 10^7
4.	Annual gross benefit for irrigation	Rs. 213.490 10^7

PUBLICATIONS

PUBLICATIONS

1. Srivastava D.K and Assadullah Kohistani, Development of software for data matrix generation for reservoir planning in linear programming model (MATGEN PACKAGE), under processing for publication in J. of Water Resources Planning and Management Division, ASCE, (U.S.A).

2. Integrated planning and operation of a multipurpose reservoir using Optimization-simulation techniques under processing for publication in J. of Water Resources Management, Kluwer Academic Publishers, Netherlands.